VULNERABILITY ASSESSMENT OF THE BATHURST CARIBOU HERD FOR THE PROPOSED SLAVE GEOLOGICAL PROVINCE ROAD, NWT

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ABSTRACT

The Slave Geological Province (SGP) road will replace the existing Tibbitt to Contwoyto Lake winter road and has the potential to complement Nunavut's proposed Grays Bay and Port Project. The SGP road is a planned 413 km two-lane gravel road starting from northeast of Yellowknife to the Northwest Territories (NWT)/Nunavut (NU) border. The road will potentially intersect not only with the seasonal movements of the Bathurst barren-ground caribou herd, but also by the Bluenose-East and other barren-ground caribou herds. In preparation for environmental input into the project, Government of the Northwest Territories (Environment and Natural Resources) contracted Shadow Lake Environmental Inc. to provide a vulnerability assessment of the NWT portion of the road on the Bathurst herd. This approach to vulnerability analysis describes potential impact as a function of exposure and sensitivity of the Bathurst herd to development. Reducing potential impacts of development depends in part on adaptive capacity which includes herd and habitat management as well as mitigation of the impacts of the roads. The outcome of adaptive capacity relative to potential impacts is the vulnerability of the Bathurst herd.

The caribou cumulative effects model was used, the model has (three linked sub-models: movement, energy-protein and population. The analysis was divided into two time periods (1996-2009 and 2010-2019) and examined changes in seasonal distribution for those time periods. Seasonal ranges except calving have contracted in size and shifted in location which affected the exposure of the Bathurst herd. The number of total encounters to existing infrastructure was higher pre-2009 based largely on more encounters in winter. Post-2009, total encounters dropped, with almost half in the fall. Before 2009, the highest encounters were in the three southern proposed road segments compared to the three northern segments after 2009. For both periods, the highest number of encounters was in fall and summer and lowest in calving. The NU border alternative would result in much higher potential encounters (43% higher density and 116% higher number of encounters/1,000 caribou).

The movement sub-model output identified if a caribou was in a zone of influence (ZOI) either associated with the infrastructure or the proposed SGP or potential Grays Bay Road. When caribou are close to the road (within 5 km) a penalty of reduced time spent feeding and increased walking and running, was assigned. The penalty was higher for calving, post-calving, and summer due to the documented sensitivity of caribou, especially cows and calves, in those seasons. To compare the energy-protein "cost" of each of the six road route combinations, the model was ran with only the existing development (the baseline scenario) and then compared to each of the runs representing the six route options.

The energy-protein model output fall body weight of the cow and her calf, relating to probability of pregnancy and overwinter calf survival. The highest cost was for routes that included Grays Bay Road with summed annual weight loss for Route 5 of 4.14 kg and Route

6 of 4.05 kg. The fall body weight of the cow was equated to a change in probability of pregnancy and the body weight of the calf to a change in overwinter survival.

All modelled routes were found to increase the rate of decline in the Bathurst herd. For all SGP-only routes the percent decline from baseline values were lowest if it included the Jolly Lake alternative and did not include the NU border alternative (Route 3) and highest if it did not include Jolly Lake but included the NU border (Route 2). The inclusion of the NU border alternative greatly increased the Bathurst herd's rate of decline. The percent reduction in productivity from the SGP-only road options (0.5-1.5% per year) and SGP road + Grays Bay Road options (1.2-2.6%) will be hard to measure given the natural variability in the system. Using the high (198,000 caribou) starting population, all-season road options resulted in 13,000-25,000 less caribou by 2030. In comparison from our low population (22,000 caribou) model runs, the all-season road options resulted in 900-6,000 less caribou by 2030.

Adaptive capacity considers the (a) effectiveness of mitigation, (b) monitoring to detect residual impacts and (c) landscape and herd management options to offset and/or trade-off residual impacts. The effectiveness of mitigation is mostly based on experience with mine roads. After mitigation of mine roads, residual impacts are that caribou within 3-5 km of a road and traffic may delay and parallel the road before crossing or may retreat and not cross. Most mine roads also serve public use, which includes hunting. Hunting increases responsiveness of caribou to vehicles and effectively increases the ZOI. Scenarios to project residual impacts using reduced traffic (compared to high traffic) were used and no hunting (compared to hunting) as mitigation. Encounter time within the ZOI was compared with the width of the ZOI based on current understanding of caribou responses to disturbance. The residual impacts for low traffic and no hunting were annual reductions in herd size of 3-5%. The impacts of no mitigation (hunting and high traffic) were projected to be 10-15% annual declines which were further increased if the two northern road routes (5 and 6) were included.

The Bathurst herd's decline has resulted in distributional shifts and contractions in seasonal range size which would result in a 78% increase in encounters and a 116% increase in impacts on herd productivity should the Grays Bay Road be built. Given the marked changes in distribution over this last decade, we will need to be able to determine if the concentration will continue with lower herdnumbers or, if portions of the herd are emigrating to the Beverly herd. Our analysis projected the potential costs of the proposed development. Three potential mitigation measures were identified: reduced traffic levels (reduce delays in the ZOI), eliminate hunting (reduce size of ZOI) and close road sections (reduce encounter days) during seasonally high ZOI encounters.

If relative impacts are considered, compared to current % herd decline, the effect of hunting on caribou responses along the proposed roads was predicted to have the highest impact, increasing the percent decline in the herd by 107%, followed by high traffic volume that increased the decline by 85% compared to low traffic volumes. Leaving the NU border alternative open in the fall season versus closing the road, increased the decline in the herd by 13%. Although, closing the NU border alternative only affects a small portion of the whole route and only in the fall season, thus it shouldn't be concluded that road closures are less effective than traffic management, as the scale of the mitigation is markedly different. Only the existing development and the addition of either an SGP road or both an SGP and Grays Bay Road has been considered. However, one of the rationales for constructing an all-season road is to provide a cheaper, reliable infrastructure for the existing and future exploration and development in the SGP's highly mineralized region. This assessment did not consider spin-off projects.

Although some climate trends and linkages between climate and vital rates were derived, the herd's vulnerability to future climate scenarios was not quantified. Depending on when the SGP road is constructed, the landscape could be changed, especially considering recent bad forest fire years because of extremes in fire weather index as summers are hotter and drier.

Further, our analysis only considered the Bathurst herd and we know that the assessment area is also frequented by the Bluenose-East herd to the west and the Beverly herd to the east, especially in winter. Thus, on a more regional basis, the road may have greater, unquantified, impacts on migratory caribou in general.

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INTRODUCTION

The Government of Northwest Territories (GNWT) is proposing to build an all-season road through the Slave Geological Province (SGP). It is intended to replace the Tibbitt to Contwoyto Lake winter road, a private supply road that services existing diamond mines in the SGP. As well, the proposed road has the potential to complement a similar initiative in Nunavut (NU), the Grays Bay Road and Port project (hereinafter the "Grays Bay Road"), that may eventually link Yellowknife to a deep seaport on the Arctic Ocean.

The current SGP road proposal has identified a 413 km two-lane gravel road from the end of the existing road about 70 km northeast of Yellowknife to the Northwest Territories (NWT)/NU border. The road will potentially intersect with seasonal movements of the Bathurst barren-ground caribou herd. In preparation for environmental input into the project, the GNWT Department of Environment and Natural Resources (ENR) contracted Shadow Lake Environmental Inc., to provide a vulnerability assessment of the NWT portion of the road on the Bathurst herd.

This approach to vulnerability analysis is similar to what is being used by the International Panel on Climate Change (IPCC) as IPCC (2007) described potential impact as a function of the sensitivity of a system to change and its exposure to those changes. This terminology has been adapted (Figure 1) to industrial developments on the Bathurst herd and its landscape. In this application, the capacity of the herd to adapt to potential impacts can be supported by herd and habitat level management actions as well as mitigation of the industrial activity. Monitoring provides feedback between impacts and mitigations (adaptive mitigation). The outcome of adaptive capacity relative to potential impacts is the vulnerability of the system to landscape changes.

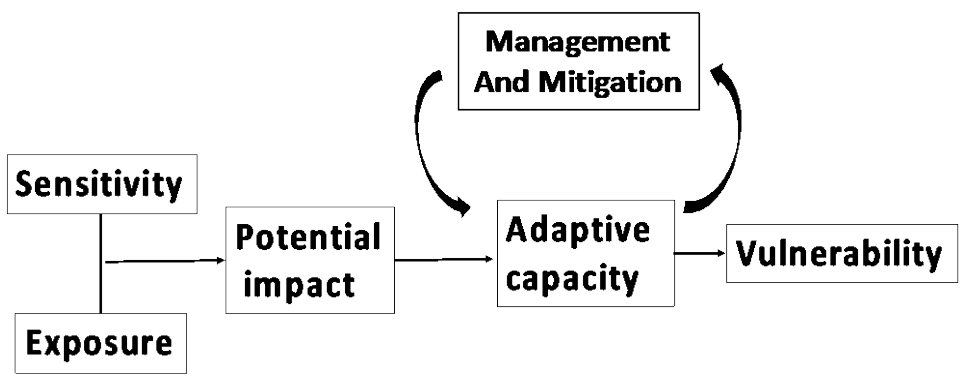

Figure 1. Components of a vulnerability analysis adapted from IPCC (2007).

This report is structured around the components of the vulnerability analysis to answer specific questions for the Bathurst herd.

Sensitivity

- What are the relevant highlights of the reproductive biology and ecology of the Bathurst herd?
- What is the current and possible future role of climate in Bathurst herd population dynamics?
- How has distribution and sizes of seasonal ranges shifted since 1996?
- Which portions of the annual range are most sensitive to impacts on herd productivity? Productivity is the rate of change in population size (often measured by extrinsic rate or exponential rate of change).

Exposure

- Can we quantify potential Bathurst herd encounters to the SGP road, and how has the number of encounters per caribou changed as the herd declined and distribution shifted?
- What would be the additive exposure of a future Grays Bay Road?

Potential Impact

- What are the quantitative effects of the proposed SGP road at the individual and herd scale?
- What are the potential additive impacts of a potential future Grays Bay Road link?

Adaptive Capacity

- Can landscape and herd management reduce the potential impact and minimize residual impacts?

Vulnerability

- What are the key residual (quantified and unquantified) impacts?

To quantify and assess the potential impacts of the SGP road and potential Grays Bay Road on the Bathurst herd, a caribou cumulative effects (CCE) model is used, which has evolved from a single energetics model into one for which protein dynamics were added (White et al 2014) and then, movement and population dynamics were subsequently added as sub-models (Russell et al 2021).

Currently the CCE model framework and the three linked sub-models allow caribou managers to undertake "what-if" analyses of the cumulative effects of development and climate change on caribou biology. The sub-models in the CCE model include:

- Movement: a model tracking movement patterns of a caribou herd with respect to past, present and future development;

- Energy-Protein: a model of how an individual caribou allocates protein and energy obtained from foraging to maintaining body reserves and milk for calf over time (White et al 2014); and
- Population: a model of the caribou herd's population dynamics (Figure 2).

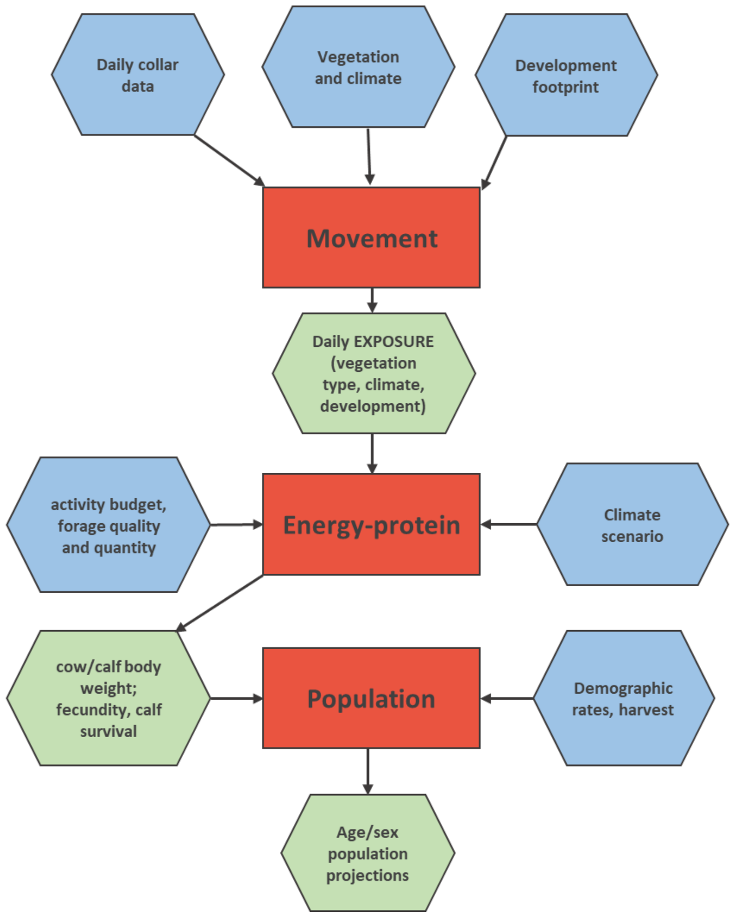

Figure 2. Schematic of the CCE model showing sub-model components (red), inputs (blue) and outputs (green).

The initial inputs for the movement sub-model are satellite or GPS collar location data, spatial layers for vegetation, climate, baseline development footprint, and scenario details about future development footprints. The movement sub-model, tracking individual movement paths from collared caribou across the herd's range, produces output on the caribou's daily environment. The energy-protein sub-model takes output from the movement sub-model and uses estimates of activity budgets, forage biomass, forage quality and climate indicators to simulate daily energy and nitrogen intake and allocation to project changes in body condition of an individual caribou (and, if applicable, her calf) over time (White et al 2014). The outputs of the energy-protein sub-model include the fall body weight of a cow and her calf which are equated to probability of a cow becoming pregnant and overwinter calf survival. Vital rates (for example, cow survival, pregnancy rates) fed into the population sub-model. Inputs to the population sub-model are initial population size, age/sex composition, adult and calf survival, fecundity, and harvest. The population sub-model then projects the future size and composition of the caribou herd.

Components of the model have been verified through applications that emphasize energy expenditure such as energy consequences of low flying fighter jet aircraft (Delta caribou herd: Luick et al. 1996), road and pipeline effects at Prudhoe Bay (Central Arctic herd [CAH]: Murphy et al. 2000), integration of nutritional components to determine responses to climate change (Porcupine caribou herd [PCH]): Griffith et al. 2002, Kruse et al. 2004, effects of climate change (PCH: Russell et al. 1996, CAH: Murphy et al. 2000), summer range assessment (George River Herd: Manseau 1996), and full integration of components for application to development assessment: North Baffin Herd (Russell 2012, 2014a), Qamanirjuaq Herd (Russell 2014b), Bathurst herd (Nishi 2017), Beverly-Ahiak and Dolphin and Union herds (Russell 2018). The models have recently been applied to assess the current impacts of development on the PCH (Russell and Gunn 2017) and impact on the PCH from potential hydrocarbon development on Alaska's north slope (Russell and Gunn 2019, Russell et al 2021).

SENSITIVITY

Trends in Herd Size and Vital Rates

The Bathurst herd has seen declines since 1986, from a high of 472,000 to the 2018 estimate of 8,200. Reporting on the latest population estimate, Adamczewski et al (2019) have provided up-to-date status, trends, and population vital rates for the Bathurst herd. Figure 3, based on Adamczewski et al (2019), indicates an 18% exponential rate of decline between 1996-2009, and a 15% decline from 2009-2018. Adult cow survival in Figure 3 was determined from the fate of radio collared cows (Figure 32 in Adamczewski et al 2019) combined with the estimated harvest rate on cows (Table 5, Appendix 3 in Adamczewski et al 2019). Annual survival (natural plus harvest) averaged 63% (73% natural survival minus 10% harvest) between 1996 and 2009. Between 2009 and 2018 survival rate, with an increasing trend, averaged 69%, all of which was attributed to natural mortality as maximum harvest was limited to 300, primarily bulls, from 2010-2015 and essentially 0 harvest from 2015-present.

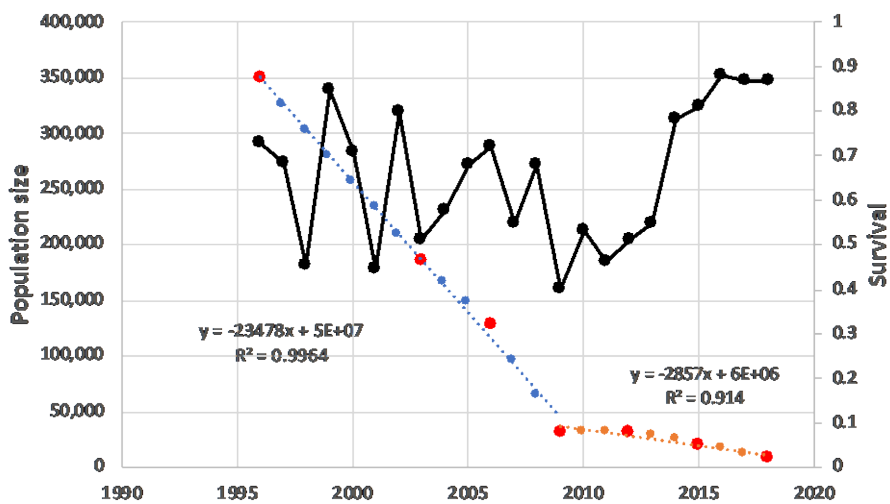

Figure 3. Population size and adult cow survival in the Bathurst caribou herd 1996-2018.

An index of annual pregnancy rate (% breeding females) has been monitored in the Bathurst herd during population survey years. The estimate is based on calving ground surveys when cows are classified as breeding or not breeding, depending on presence or absence of calves, udders and antlers. Based on nine surveys, the average percentage breeding females was 79.4%.

One of the linkages between the energy-protein sub-model and the population sub-model is the probability of pregnancy in relation to fall cow body weight (Cameron and Ver Hoef 1994, Cameron et al 2000). A body condition dataset since the 1960s across the circumpolar north (Russell unpublished data) includes four collections for the Bathurst herd (Table 1).

Table 1. List of Bathurst caribou body condition data sources and sample sizes.

Source	years	total	Eligible females*	pregnant	Barren	pregnancy rate
Croft	2007-11; 2013	289	102	80	22	78
Elkin	1995; 2000	32	27	23	4	85
Evans	2005	151	22	16	6	75
Heard	1990-92	176	59	35	24	59
Total		**648**	**210**	**154**	**56**	73

*** known 2+ years old; collected between Dec and May; known pregnancy status**

Of the 210 eligible females, 103 had body weight values. There was a significant difference between body weight of pregnant versus barren cows from December to April (85±7.0 kg versus 76±9.1 kg, respectively; p=<0.001). A significant logistic regression was calculated from the data (Figure 4; $p<0.01$; b_1=-1181., b_2=0.166), almost exactly to the equation determined for the adjacent Beverly herd (Russell, unpublished data from Don Thomas collections 1982-1987).

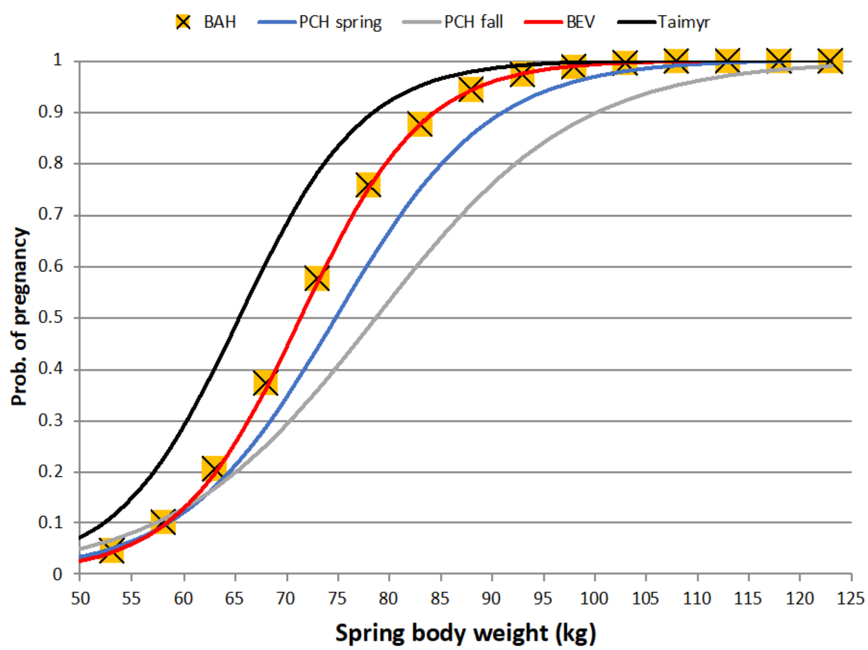

Figure 4. Probability of pregnancy in relation to spring body weight for migratory tundra rangifer.

The curves of body mass and the probability of pregnancy are interpreted in terms of resilience (steepness of the curve) and productivity (the lower the relative body weight to reach 0.5 probability of getting pregnant, the more productive is the herd). Thus, for the Bathurst herd it would be concluded that they are less resilient but more productive than the PCH, similar to the Beverly herd and less productive but similar resilience as the Taimyr herd in Russia.

Climate Linkages to Vital Rates

No long-term trends in the vital rates were found, assuming the 1988 value for spring calves: 100 cows (74) was an outlier and thus dropped from the analysis for the Bathurst herd (n=22; Table 2, Appendix A). For cow survival, the reported year (0.87 survival for 2018 for example) represents survival from June 2017 to June 2018. **Table 2.** Summary of Bathurst caribou herd vital rates 1987-2018. Data from Adamczewski et al 2019, Boulanger pers. comm. and Adamczewski pers. comm.).

Year	Pregnancy rate	Fall calves:100 cows	Spring calves:100 cows	Cow survival
1987			43	
1988			*	
1989			39	
1990	92		38	
1991			49	
1992			31	
1993			49	
1994			30	
1995			50	
1996	87			
1997				0.79
1998				0.75
1999				0.52
2000		38		0.92
2001		35	29	0.79
2002			21	0.5
2003	83		26	0.86
2004		14	22	0.58
2005				0.66
2006	76	38	9	0.78
2007		56		0.85
2008		32	49	0.71
2009	86		39	0.87
2010			48	0.61
2011		33	47	0.53
2012	80	24	25	0.46
2013				0.51
2014		25	27	0.55
2015	61		24	0.78
2016			19	0.81
2017		44		0.88
2018	70		37	0.87

Average	79.4	33.9	34.1	0.7
STDEV	10.08	11.56	11.87	0.15
cv	13	34	35	21
n	8	10	22	22
Pearson	0.35	0.01	-0.34	0.00
p-value	0.49	0.98	0.12	0.99

* 1988 spring calves:100 cows value (74) dropped from analysis

Pearson	-0.80826	0.00694	-0.34006	-0.00245
absolute	0.80826	0.00694	0.34006	0.00245
t-stat	2.74538	0.01964	1.61716	0.01095
p-value	0.041	0.985	0.122	0.991

Figure 5 provides a schematic of the linkages determined among vital rates and climate indicators (see Appendix A for detailed analysis).

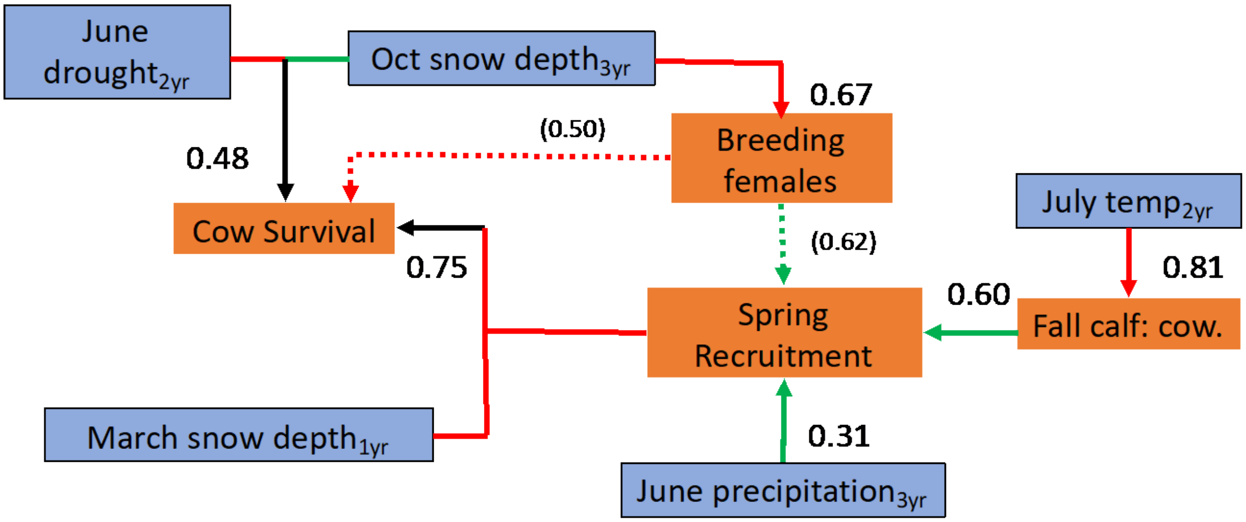

Figure 5. Schematic diagram showing the linkages derived to explain variability in the vital rates for the Bathurst caribou herd. Red arrows indicate a negative, and green arrows a positive relationship. The dotted lines indicate the linkage explained substantial variability, but sample sizes were too small for the relationship to be significant (Appendix A).

Spring recruitment (calves: 100 cows) is positively related to fall recruitment levels. Thus, high calf numbers in the fall generally translate into high calf numbers in the spring, suggesting that there isn't high among-year variability in winter survival of calves. The opposite situation occurs in the PCH (Russell and Gunn 2019), where fall calf numbers do not relate to subsequent spring calf numbers suggesting variable winter conditions can impact spring recruitment.

Adult cow mortality in the Bathurst herd is negatively related to spring recruitment in the previous year. For example, cow survival from June 2010 to June 2011 is related to spring recruitment in 2010. An explanation for the linkage is undoubtedly complex and related to the fall recruitment linkage to spring recruitment and the mix of climate indicators that relate to all three vital rates. Climate indicators alone only accounted for 48% of cow survival.

The role of early snow (October 31 snow depth) appears to negatively impact most vital rates (Table 9). In one sense, October snow depth is an index of overall winter snow (October snow correlated to March snow depth; r^2=0.30). However, as March snow depth does not play as significant a role in vital rates, overall winter snow depths do not appear as important as the timing of early snow. Although there is an energetic cost to early snow (walking and cratering), for the snow depths measured (maximum October 31 snow depth was 33 cm, 1983), the energetic costs would not be significant. Behaviourally, early snow may result in the Bathurst herd moving south earlier than normal which may have implications on forage conditions or, maybe more importantly, earlier access for harvesters and into ranges with higher wolf densities.

Seasonal Distribution

Appendix B presents the seasonal distribution of the Bathurst herd for the periods 1996-2009, 2010-2012, 2013-2015, and 2016-2019. These figures were used to characterize the trends in range sizes (Figure 6) and extent and direction of geographic shifts (Figure 7). The size of seasonal ranges is represented by the 90th percentile kernel density polygon. Kernel density is a GIS analysis of satellite collar data and the 90th percentile kernel represents the distribution that encompasses the densest configuration that contains 90% of the collar data. During this entire period, the Bathurst herd was declining from 349,000 in 1996 to 8,200 in 2018 (Adamczewski et al 2019). In all seasons, ranges were larger prior to 2010 when population levels were high but declining (average 198,000 between 1996 and 2009). During calving, winter, and spring the smallest ranges were in the 2013-2015 period, while after 2015 there were a number of caribou that drifted further east (based on radio collar data, Appendix B). Summer and fall ranges progressively declined in size as the population dropped. In summer, the range size between 2016-2019 was 24% of the size prior to 2010, while the fall range was only 15% of pre-2010 size (Figure 6).

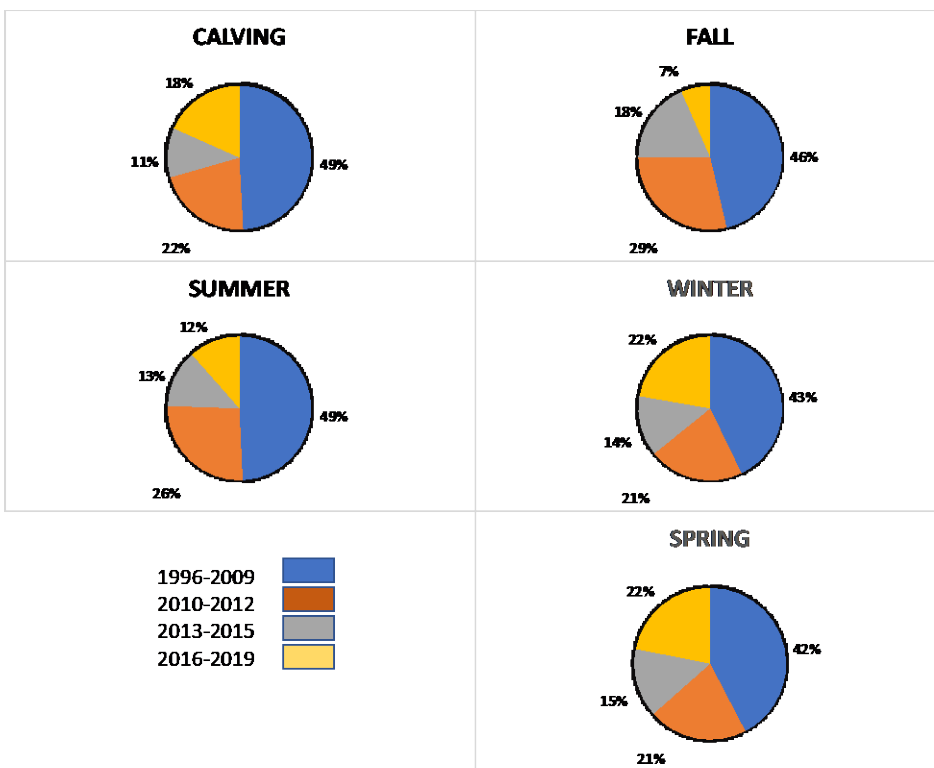

Figure 6. Relative area of seasonal ranges for four time periods (1996-2009, 2010-2012, 2013-2015 and 2016-2019) based on 90% kernel density.

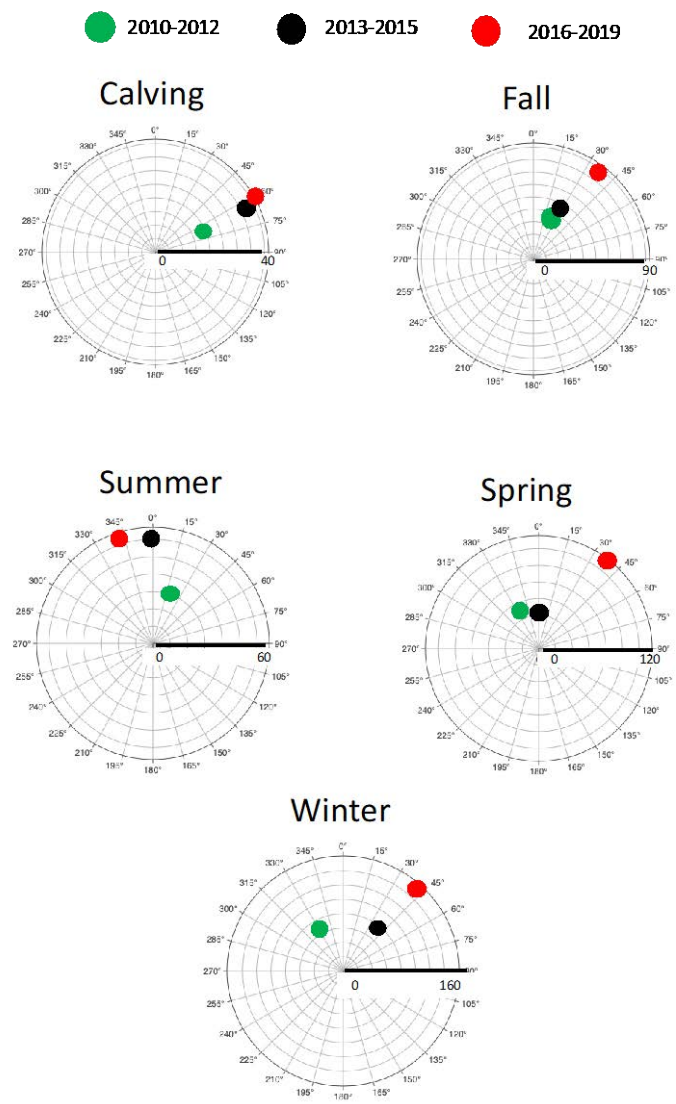

Figure 7. Polar plots of distance (in km) and direction of distribution shifts from 1996-2009 for three time periods (2010-2012, 2013-2015 and 2016-2019). Location of dots represent the centroids of 90% density kernels.

All seasonal ranges shifted north after 2010 and for all seasons, except summer, the shift was in the NNE direction (Figure 7). The extent of the shift from the 1996-2009 kernel centroid ranged from 40 km during calving to 160 km during winter.

Landscape Sensitivity

The annual movements of the Bathurst herd indicate seasonal high use areas. The objective of the landscape sensitivity analysis is to integrate habitat, climate, and use density across seasons into one metric: the cost, or sensitivity of each grid to herd productivity relative to a pristine landscape. To integrate these seasonal concentrations on an annual basis, we arbitrarily divided the herd range into 50 equal area grids (10,000 km^2). Although there is no “ideal” grid size, 50 cells were intended to show a range wide pattern of landscape sensitivity.

The caribou collar locations were divided into two eras (1996-2009 and 2010-2019) and all collars were ran through the CCE model using seasonally specific “penalties” (see Penalties section) for caribou entering the grid. For example, the penalty (reduction in foraging, increase in movement) for being in a grid during calving is greater than being in the grid in winter. The assumption is that if each grid in turn were “developed”, caribou would be subject to disturbance while in the grid. The CCE Population sub-model was ran 102 times (two “no development’ scenarios (for each time period) and one scenario for each grid in each time period). The results of the simulations were classified into five categories (1 = high sensitivity to 5 = low sensitivity) based on the potential impact on herd productivity (relative to “no development” scenario for that period; Figure 8).

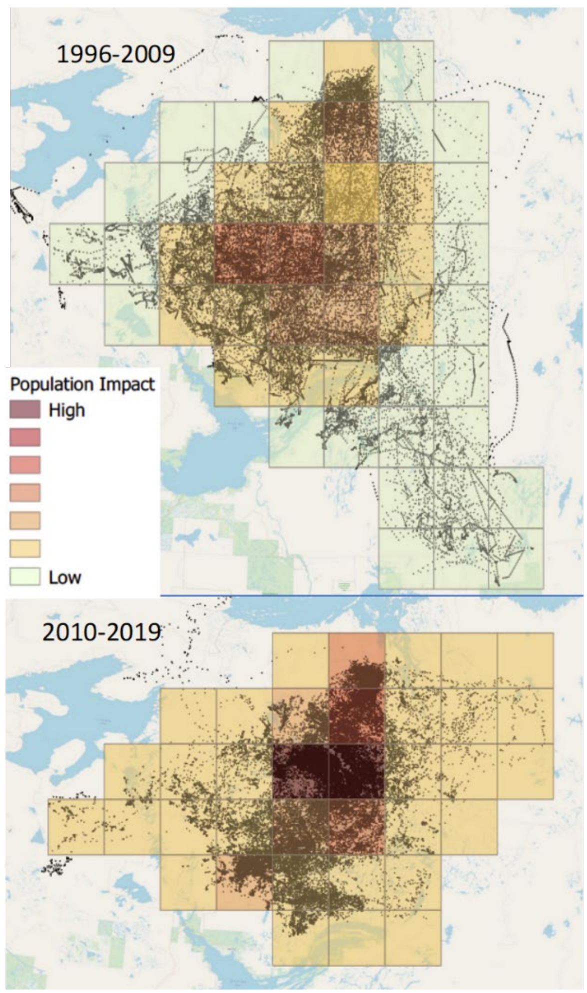

Figure 8. Results of landscape sensitivity analysis for two time periods. Each grid is coded to represent the relative impact on herd productivity assuming that all caribou that enter the grid are disturbed by human activity. Dots represent collar locations used in the model.

Differences between the two time periods can be seen. From 1996-2009, the highest grid sensitivity was Class 2 (two grids), and distribution was more widespread creating a number of lower sensitivity grids (Class 5) peripheral to the main core of the population, especially in the southeast (Figure 8). As the herd declined, general movement shifted north (2010-2019), and range sizes shrunk and no low sensitivity (Class 5) areas were identified. Two grids had the highest sensitivity rating (Class 1), just north and east of the highest grids in 1996-2009. Overall, of the 36 grids with caribou present in the latter period, only two had a lower sensitivity rating than the earlier period while 26 grids had a higher rating.

Sensitivity Discussion

The Bathurst herd has been declining throughout the analysis period (1996-2019) from an estimated 349,000 to 8,200 caribou. The assessment analysis was divided into two time periods (1996-2009 and 2010-2019) represented by a break in demographics (Figure 3) and management actions (significantly reduced harvest after 2009). Although cow survival has improved in the last five years, the herd continues to decline, partly due to emigration (Adamczewski et al 2019). The population is currently at an historic low.

Herd ranges have contracted for all seasons comparing pre- to post-2010 range sizes. Summer and fall ranges progressively declined in size as the population dropped and directionally shifted north and east, in some cases (winter) as far as 160 km. Spring and winter distributions shifted NNE after 2015 resulting in larger range sizes coincident with smaller population size. For calving the shift has been more gradual but in the same direction as winter and spring shifts.

The seasonal shifts and the concentration of use into smaller ranges has resulted in increased sensitivity of the overall range, based on this landscape sensitivity analysis. This analysis revealed a northeastern shift in landscape sensitivity after 2009 and a five-fold increase in overall sensitivity. The sensitivity analysis associates each cell with a percent decline in herd size compared to a pristine landscape. For the landscapes occupied in both time periods, the average herd productivity declined among all grids in the 1996-2009 period by 2%, compared to 10% decline in the 2010-2019 period. Thus, in planning for the long-term fluctuations of the Bathurst herd there should be focus on, as Skoog (1968) termed, the "center of habitation" of this large migratory herd.

EXPOSURE

Bathurst Caribou Road Encounters

To determine the potential exposure of caribou to the SGP and Grays Bay Roads, the movement sub-model was applied. All existing collar-years for the two time periods (185 caribou in 1996-2009; 240 caribou in 2010-2019) were modeled. The model requires a daily location so missing days in the dataset were interpolated to provide a daily value. It was assumed that an "encounter" was when a caribou location was within 5 km of the road footprint. The 5 km buffer, or Zone of Influence (ZOI), of the road was consistent with the distances used in the Bathurst Caribou Range Plan (see Zone of Influence section). It was assumed that if a caribou was in a ZOI, then the animal was in the ZOI for the day, thus one encounter was equivalent to one day of exposure. The road was divided into eight segments (Figure 9) and the movement sub-model was structured to note 1) whether a caribou was in a ZOI, and 2) if in the ZOI, which of the eight segments the caribou was located, 3) or if the caribou was associated with existing infrastructure (the baseline scenario). The encounters were then summarized into four different routes comprising all possible combination of road segments from Tibbitt Lake NWT to the NU border (Routes 1-4) and two additional routes extending from the border intersection to Coronation Gulf. Routes 5 and 6 included the potential Grays Bay Road which, of necessity, only considered the NU Border alternate instead of ending at the border to the east of the Grays Bay intersection.

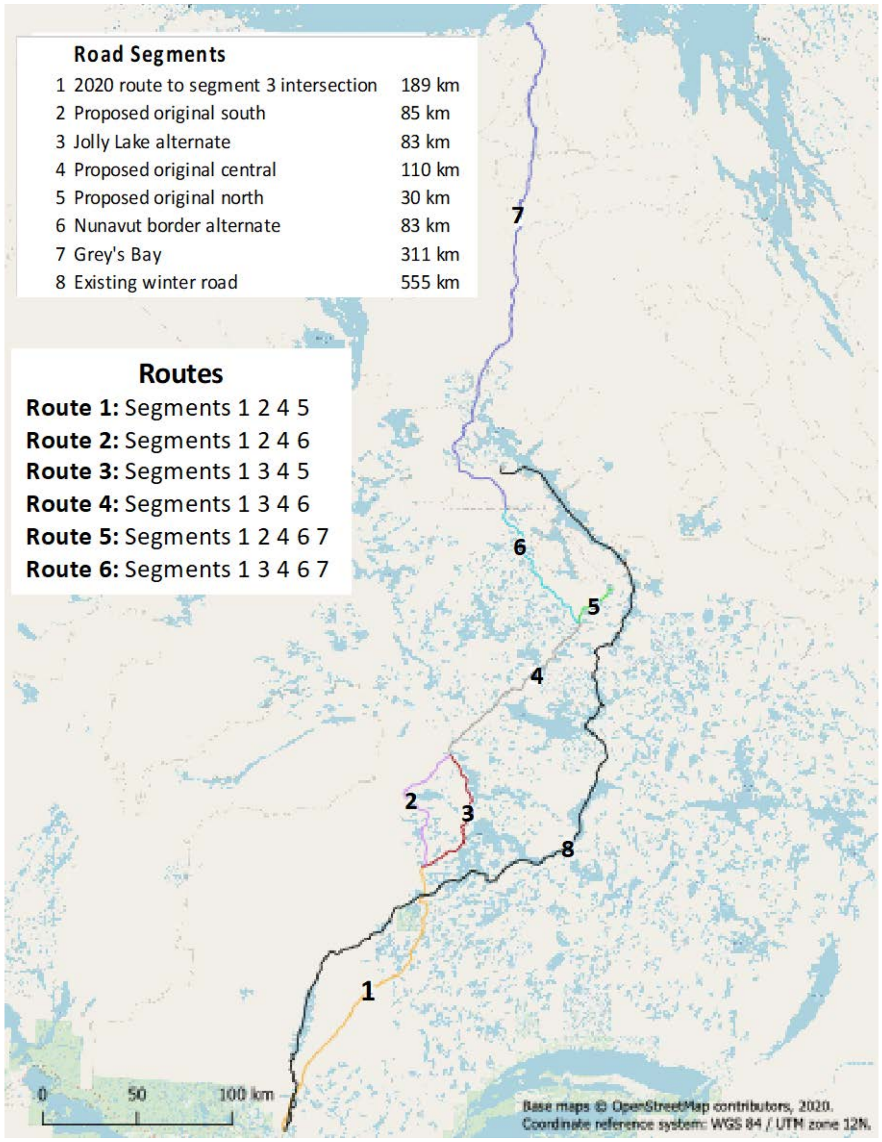

Figure 9. Proposed road segments and six route combinations modeled in the CCE Model.

Movement Sub-model Input

Only one run of the movement model was required for each time period 1996-2009 and 2010-2019) and the daily location of 185 and 240 collar-years was produced, respectively, over a one-year period. The movement sub-model output contained, for each collar, the daily location, vegetation type and whether it was in a ZOI or outside of a ZOI. If in a ZOI the model distinguished if the collar was in a "baseline" ZOI, or if within 5 km of the SGP or Grays Bay Road, which segment of the road was encountered (Figure 9).

A visual comparison indicates that during summer and fall, the concentrated areas of seasonal ranges (red tones) were more widespread in the early period compared to the later period. Summer and fall concentrations spanned the NU border alternative in the 2010-2019 period. Winter distribution was more dispersed in the south prior to 2009. In spring, concentrations are more dispersed prior to 2009, indicating a more gradual movement rate north. Since 2009 the pattern shows distinct southern and northern concentrations indicating the herd stayed late on their winter range and moved very quickly to their calving range. As a result, there were fewer locations near the road.

Using the results of polar plot directional shifts (Figure 7) the centroids were plotted in relation to the road segments (with the 5 km buffer applied; Figure 10). The map shows the NNE general directional shift and the potential increase in encounters near the NU border.

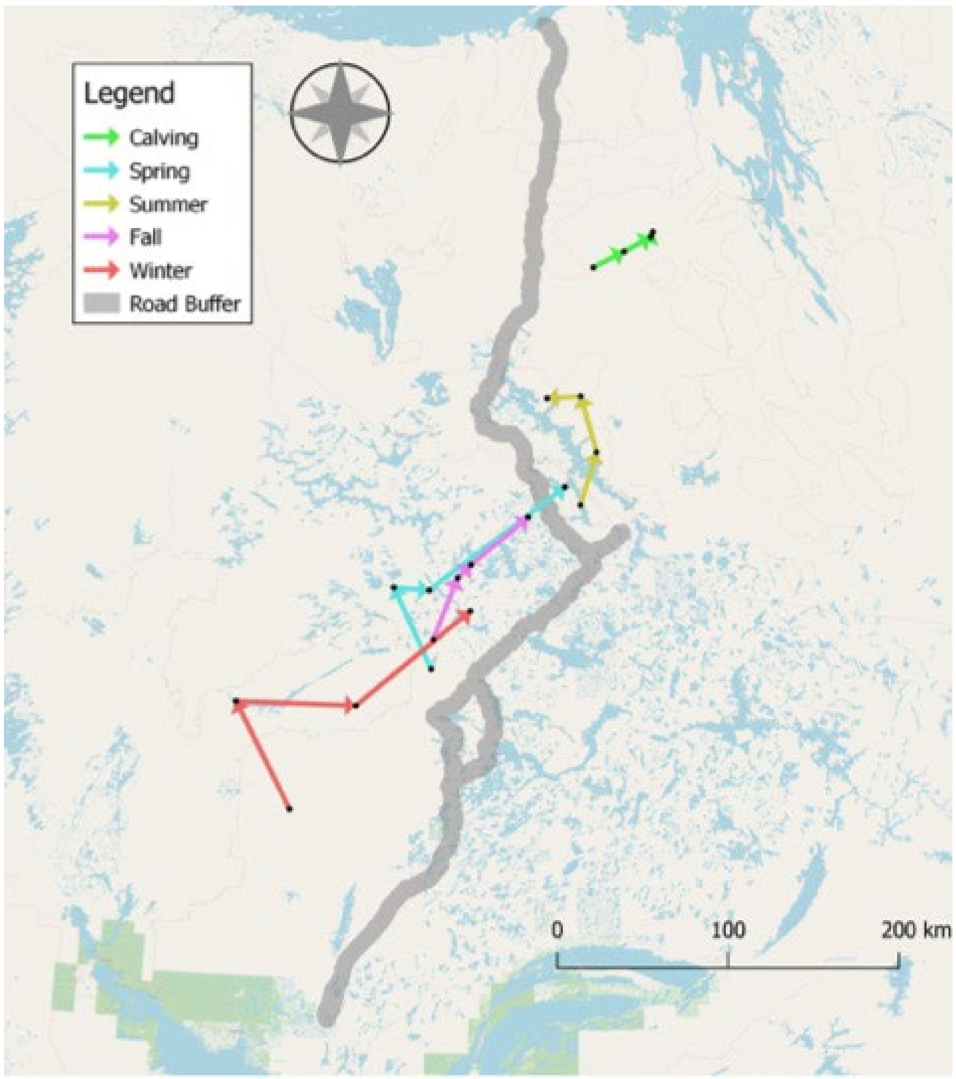

Figure 10. Directional shift in seasonal centroids (from Figure 7) in relation to the proposed SPG and potential Grays Bay Road. Road segments plotted with 5 km ZOI.

Vegetation

A habitat map for the Bathurst herd range was based on classification from Earth Observation for Sustainable Development of Forests (Canadian Forest Service 2005). For the

CCE modeling exercise, the vegetation classes were reduced to four types: taiga, shrub, herb and barren (Table 3).

Table 3. Vegetation Classes used in the CCE movement model.

NAME	Original CCRS map classes	CCE mapped
Needleleaf Forest	40, 38, 58, 37, 39, 47, 136	Taiga
Mixed Forest	41, 61, 49, 51, 103, 59	Taiga
Upland Shrub	69, 108, 87, 89, 77, 200	Shrub
Tall Shrub	13, 113	Shrub
Low Shrub Tundra	14	Shrub
Moist Sedge-Dryas Tundra	9, 15	Herb
Moist Sedge-Willow Tundra	7, 8	Herb
Tussock Tundra	4, 5, 6, 11	Herb
Alpine Tundra	10	Barren
Barren	3, 30	Barren

Existing Footprint

A number of future development scenarios were developed in the process of formulating a Bathurst Caribou Range Plan (2017). To depict existing conditions for this assessment the footprint for "Case 1.2" (BCRP 2017; Figure 11) was adopted.

Figure 11. The existing footprint and associated ZOI modeled as the baseline condition.

Zone of Influence

Table 4 lists the footprint types and the associated ZOI for the existing development scenario. Consistent with the Bathurst Caribou Range Plan (BCRP) buffer sizes, the ZOI values for mines, roads, transmission lines, etc. were used. For the proposed road a value of 5 km was used.

Table 4. Description of footprints and associated ZOI widths considered in the baseline scenario. Values from BCRP (BCRP 2017).

DESCRIPTION	ZOI (meters)
All-Season Access Road	5,000
Major Electrical Transmission Corridor	4,000
Public All-Season Paved Highway	5,000
Mainline All-Season Access (Haul) Road	5,000
Winter Road	1,000
Winter road Tibbitt to Contwoyto	4,000
Airstrip	5,000
Camp	5,000
Communications	1,000
General Industrial	1,000
Mineral Exploration	5,000
Minesite (Active)	14,000
Minesite (Past or Closed)	5,000
Power Generation Facility	5,000
Quarry	5,000
Settlement	15,000
Miscellaneous	1,000

Movement Sub-model Results

Existing Infrastructure – Baseline Scenario

Bathurst caribou annually encountered the current infrastructure on average 26 and 22 days (1996-2009, 2010-2019 respectively) with the majority in the fall and winter period (Figure 12). When the population was relatively large (1996-2009) the majority of encounters were in the winter, slightly higher than fall encounters. That condition reversed since 2009, where fall encounters were more than double the winter encounters (Figure 12).

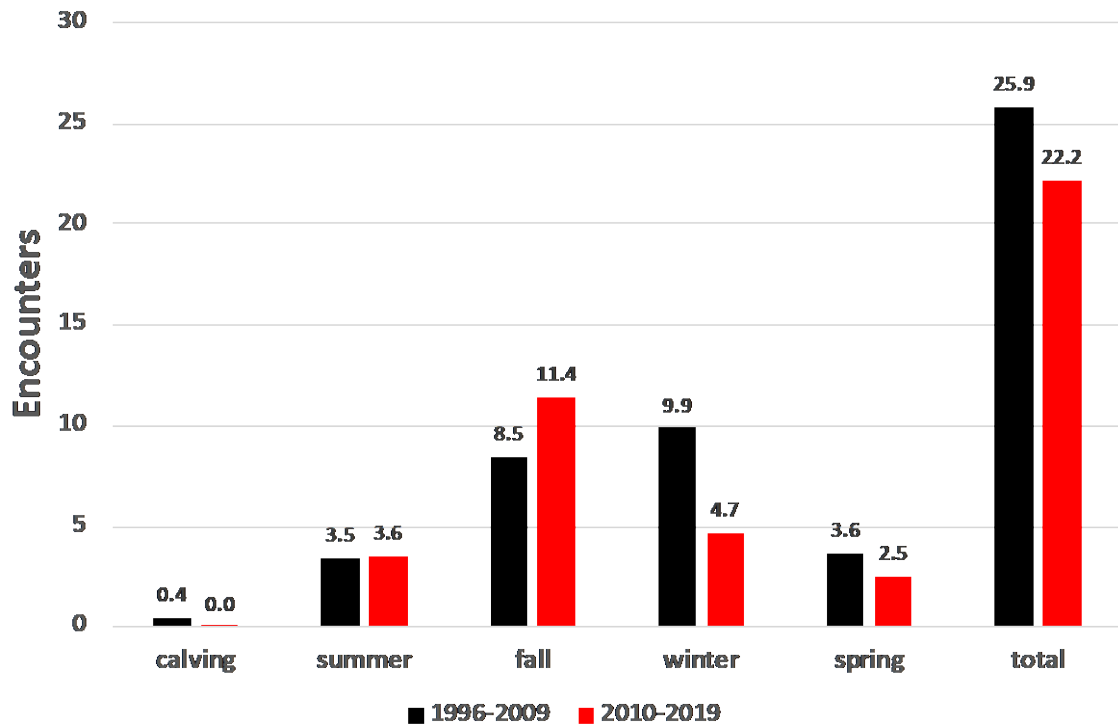

Figure 12. Average encounter per caribou with existing infrastructure (see Figure 11).

Road Segments and Alternatives

To assess the relative difference among alternative routes for the proposed SGP road, in the movement sub-model each caribou encounter was linked with specific road sections. Presenting the data as caribou/km of road length would be confusingly small so the results were summarized for encounters per 1,000 caribou per 10 km road section (Figure 13; 1996-2009 and Figure 14; 2010-2019). The results are also separated into five seasons: calving (June 1-21), summer (June 22 - August 15), fall (August 16 - November 30), winter (December 1 - March 31), and spring (April 1 – May 31).

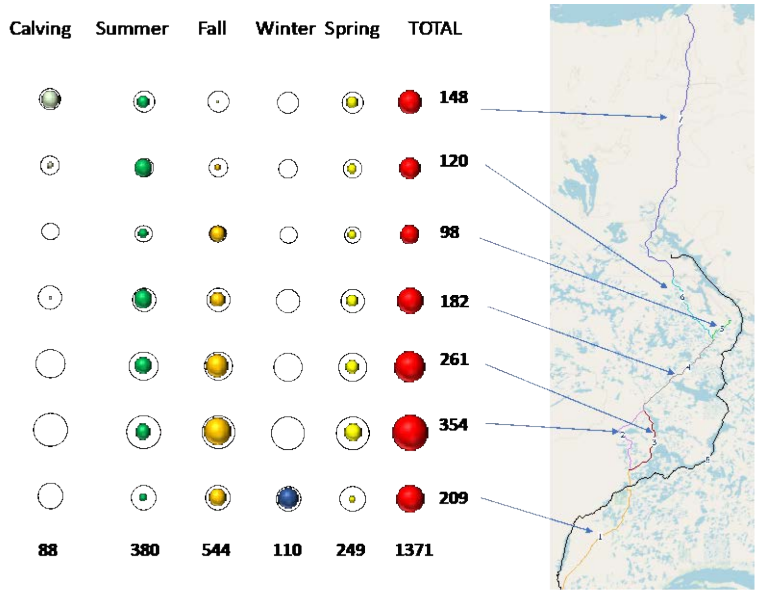

Figure 13. Average seasonal encounters/1,000 cows/10 km for seven segments (see Figure 9) of the SGP and Grays Bay Road between 1996-2009. The size of the red bubble is proportional to the total number of encounters per 10 km and the size of the coloured bubbles inside the circle is proportional for that season. Road segment encounters for each season are totaled (red bubbles), while total seasonal encounters across all road segments are totaled at the bottom of each column.

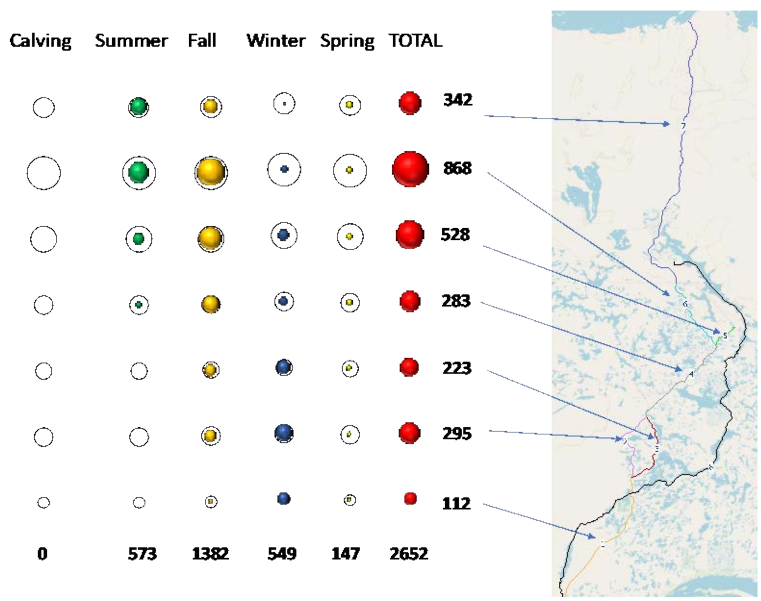

Figure 14. Average seasonal encounters/1,000 cows/10 km for seven segments (see Figure 9) of the SGP and Grays Bay Road between 2010-2019. The size of the red bubble is proportional to the total number of encounters per 10 km and the size of the coloured bubbles inside the circle is proportional for that season. Road segment encounters for each season are totaled (red bubbles), while total seasonal encounters across all road segments are totaled at the bottom of each column.

With respect to the two alternative routes, the Jolly Lake (segment #3, Figure 9) alternative resulted in 26% lower encounter density pre-2009 and 24% lower encounter density after 2009 compared to the proposed route (segment #2, Figure 9). Both these segments are of similar lengths (83 and 84 km for segments #2 and #3, respectively). The NU border alternative (segment #6, Figure 9) resulted in a 22% higher encounter density pre-2009 and 39% higher encounter density after 2009 compared to the proposed route (segment #5, Figure 9). However, the absolute number of encounters are even higher for the NU border alternative as the road length is 2.8 times longer than the proposed route (83 versus 30 km respectively).

Route Summaries

Figure 15 depicts potential encounters per caribou for the six route options (see Figure 9). For most routes, caribou would potentially encounter future roads more often when populations are low (8.7–25.6 days/year) compared to when populations are high (8.4–14.6 days/year). For all SGP-only routes, the number of encounters were lowest if it included the Jolly Lake alternative and did not include the NU border alternative (Routes 1 and 3, Figure 9). Encounters were highest if it did not include the Jolly Lake alternative but included the NU border alternative (Routes 2 and 4, Figure 9).

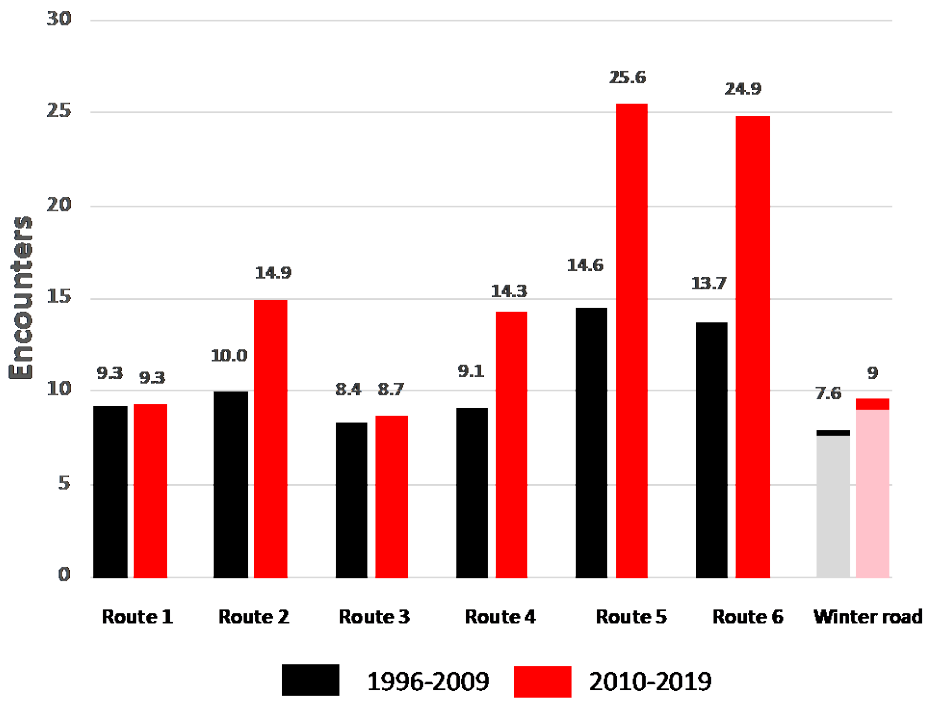

Figure 15. Number of days (encounters) per cow for the six route combinations and the existing Tibbitt to Contwoyto winter road for population highs (1996-2009) and population lows (2010-2019). For the winter road the solid red and black are encounters when road open, light red and black for periods when road not open.

One of the rationales for proposing an all-season road is to replace the Tibbitt-Contwoyto Lake winter road. Although season length varies, the winter road is only open about 8-10 weeks roughly from late January to late March. The number of encounters using the existing Tibbitt to Contwoyto winter road is low (7.6 and 9.0 for the 1996-2009 and 2010-2019 periods respectively, Figure 15). However, those are annual encounters whereas encounters when the road is normally open (end January – end of March) was less than a day (0.3 and 0.6 encounters, respectively, Figure 15).

Exposure Summary

Using the movement sub-model, the number and seasonal encounters associated with the existing development in the range of the Bathurst herd were determined. As well, the average number of seasonal encounters with segments of the proposed SGP and Grays Bay Road in each of the two time periods were determined. To examine encounters on a final road alignment, the proposed segments were combined into six possible routes and the segments were aggregated to reflect each final road alignment.

These CCE modeling results reflect distributional and range size shifts reported in the sensitivity section. The number of total encounters to existing infrastructure was higher pre-2009 (26 encounters per caribou) largely based on higher encounters in the winter (10). Post-2009 total encounters dropped to 22, with half in the fall (11). This is consistent with a northward shift and shrinkage of the winter range.

With respect to potential encounters with the proposed roads, potential encounters with different road segments in terms of encounters/1,000 caribou/10 km are reported. Seven segments based on four original proposed road segments were created from Tibbitt Lake in the south to the NU border in the north (#1, 2, 4 and 5) and two alternative segments, the Jolly Lake alternative (#3) and the NU border alternative (#6). The seventh segment was a potential Grays Bay Road. For comparison, encounters on an 8th segment were also tracked, the existing Tibbitt to Contwoyto Lake winter road. This segment will likely be made redundant if the all-season road is built.

The density of road segment encounters shifted from south to north consistent with the shift in distribution. Prior to 2009 the highest density of encounters was in the three southern proposed road segments. After 2009 the highest density of use was in the three northern segments. The overall density also increased by 63%, from 1,371 encounter density index (sum of seven segment densities) pre-2009 to 2,241 encounters after 2009.

Current planning indicates that two alternative options are given for the road alignment: the Jolly Lake alternative (segment #3) and the NU border alternative (segment # 6). Thus, the SGP Road would not connect to the Grays Bay Road (segment #5) unless segment #6 was chosen. Our analysis projects that the Jolly Lake alternative is preferred in terms of probability of encounters during both periods (25% less density and 25% lower absolute number of encounters) but the NU border alternative would result in much higher potential encounters (43% higher density and 116% higher number of encounters).

The total number of encounters increased for all seasons after 2009 except calving and spring which were higher in the 1996-2009 period. For both periods the highest number of encounters was in fall and summer and the lowest was in calving.

Six route combinations were analyzed with Route 1-4 representing only the SGP options and Routes 5 and 6 including the Grays Bay Road. For all SGP-only routes the number of encounters were lowest if it included the Jolly Lake alternative and did not include the NU border alternative (Route 3) and highest if it did not include the Jolly Lake but included the NU border (Route 2). The inclusion of the Grays Bay Road increased encounters, particularly in the 2010-2019 period.

POTENTIAL IMPACTS

To determine the potential impacts of the SGP and Grays Bay Road, the results of the movement sub-model runs were incorporated into the energy-protein model to produce fall body weights of the cow and her calf for all 185 (1996-2009) and 240 (2010-2019) caribou in the collar databases. Results for the energy-protein sub-model were then incorporated into the population sub-model and projected for 11-years (2019-2030) of population estimates.

Figure 16 indicates the number of runs of each sub-model: two time periods, eight segments, six routes. For this contract the number of encounters with both the SGP road and the Grays Bay Road (movement sub-model) was evaluated. Grays Bay routes were Route 5 (without Jolly Lake alternative) and Route 6 (with Jolly Lake alternative).

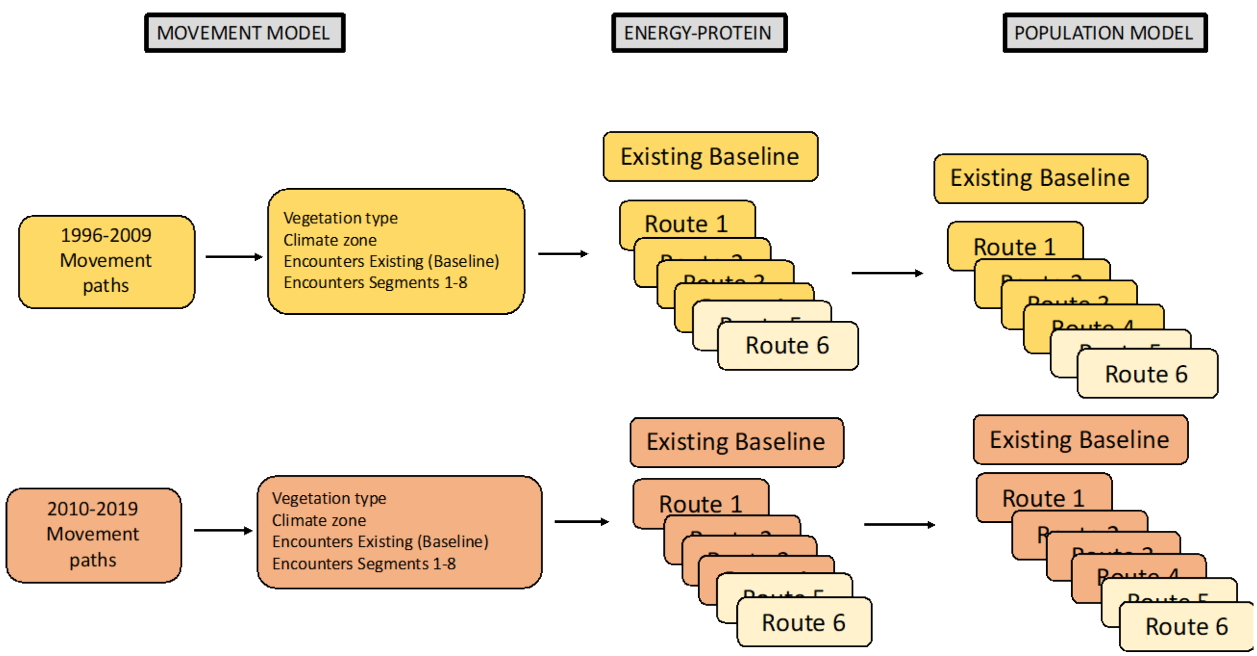

Figure 16. The process of assessing impacts of the SGP Road and Grays Bay Road by sub-models in the CCE model.

Energy-Protein Sub-model Input

Fourteen simulations of the energy-protein model were conducted – representing two time periods (1996-2009 and 2010-2019): baseline run (existing infrastructure) and six route combinations, all including existing development (see Figure 16).

The output of the energy-protein runs was fall cow and calf weight for the 185 (1996-2009) and 240 (2010-2019) individuals modeled. The baseline scenario (only existing footprints) was used for each period to calculate average cow and calf weight. In the Route 1-6 scenarios, departures from this baseline weight were calculated. To equate a drop in cow body weight with the probability of pregnancy, the established logistical regression derived for the Bathurst herd was used (Russell unpublished data); $b_1 = -11.4456$, $b_2 = 22.4123$; see Figure 4). For example, using an average body weight of 80 kg, a body weight drop of 1.0 kg equates to a decline in the probability of pregnancy of 2.6%.

A similar process was applied to calf body weight. Baseline fall body weight was the mean fall body weight of the baseline run. Baseline calf body weight was equated to average overwinter calf survival. Departures from calf body weight were converted to departures from baseline overwinter survival using a relationship developed from data presented in Arthur and Del Vecchio (2009; Figure 17). Arthur and Del Vecchio (2009) captured and weighed calves in the CAH in September and tracked survival with collared cows through March. They concluded that calves that were heavier in September were more likely to survive the following winter ($p < 0.0001$). Their results from Table 1 (mean calf weights by year and capture location) were combined with their Figure 5 results (overwinter survival by year and capture location) to produce Figure 17. Thus, using Arthur and Del Vecchio's (2009) data, a 1 kg change in baseline calf body weight to a 5% change in overwinter mortality was applied.

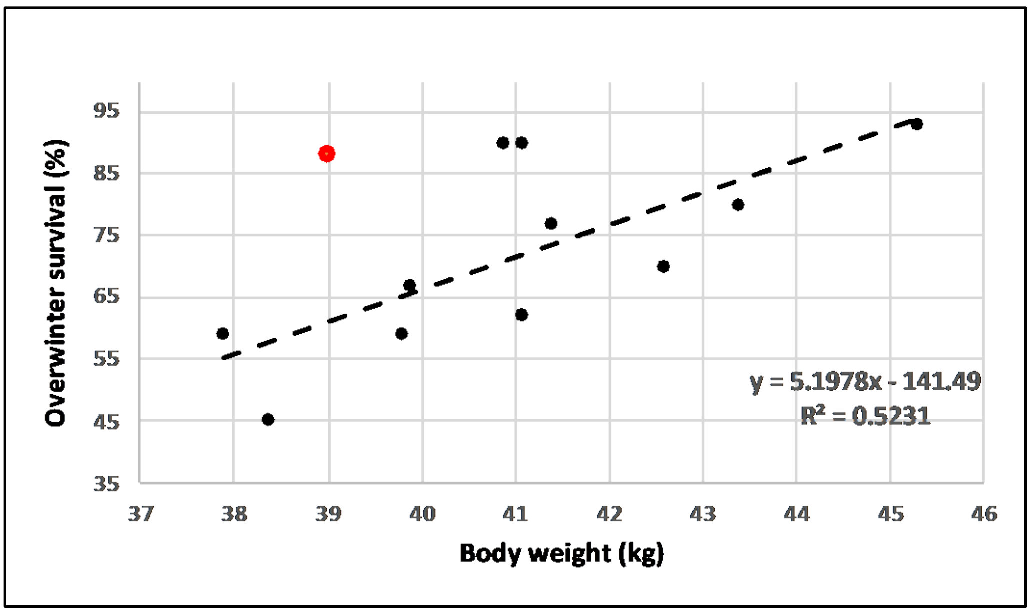

Figure 17. Correlation between fall body weight and overwinter survival calculated by combining data from Arthur and Del Vecchio (2009) Table 1, Figure 5. The red dot is considered an outlier in the formulation of this correlation.

Penalties

In the CCE model "penalties" were assigned to daily activity budgets when caribou are in the ZOI of development infrastructure and associated human activity. Many factors can affect the magnitude of those penalties including:

- Type of infrastructure
- Level of human activity
- Presence or absence of hunting activity
- Season of year
- Other associated disturbances (predation, insect harassment, hunting)

Caribou are integrating several factors on a daily and seasonal basis which means how caribou allocate their time feeding, standing, walking, running, and resting is significantly variable. Factors such as snow depth and snow melt, the timing of plant growth and the harassment of insects can alter activity budgets (Russell et al 1993). Daily, seasonal changes in the length of the active/rest cycles, often cued by sunrise and sunset, produce distinct patterns of activity and rest (Russell et al 1993). Thus, to account for these natural influences is essential, while documenting any added effects of disturbance from human activity.

There are few attempts to quantify disturbance impacts within and around a ZOI. For calving, post-calving and summer ranges, little data exists. Many studies about the effects of oilfield development on caribou are contradictory, and many older papers lack the scope of more recent works. Vistnes and Nellemann (2008) reviewed 85 disturbance studies and found that 83% of the regional studies concluded that the impacts of human activity were significant, while only 13% of the local studies did the same.

Murphy and Curatolo (1987) partially paired development study areas with control areas and determined that caribou close to development (roads, traffic, and pipelines) did not reduce feeding in the presence or absence of insects, but development resulted in an increase of up to 15% in running activity at the expense of lying down and, less so, standing. What is missing in their study was the activity of those groups after they passed through the development zone, as caribou require a fixed, but seasonally specific, alteration in active and rest cycle for proper rumination. Disturbed animals may have just delayed their rest cycle until out of sight. Fancy (1983), also in the Prudhoe Bay area, documented activity budgets near development infrastructure and traffic compared to control sites 4 km away. Although they did measure a 10% and 8% (in the absence and presence of insects, respectively) lower feeding times near development, sample sizes were low, coefficient of variation varied between 36-38%, and thus it was concluded there was no significant development effect. Further, these studies were conducted during times when no hunting was associated with the infrastructure. Hunting activity can exacerbate the impact of other human activity (Russell and Martell 1985, Johnson and Russell 2014, Plante et al 2018).

As part of monitoring requirements, diamond mines in the NWT are required to document disturbance effects of development on caribou. BHPB (2004) reported a 10-13% decline in feeding time for caribou closer than 5 km of a large open pit mine complex compared to caribou beyond 5 km. As with most scan surveys, sample sizes were too small to detect a significant difference. There is no hunting at the diamond mine site, but hunting does occur along an all-weather road for Meliadine gold mine, NU. The behavioural scans of caribou were at 3 minutes for 30-minute bouts and reported that following a disturbance such as a vehicle, the proportion of alerted, trotting or running caribou increased but returned to baseline behaviour within six minutes (AEM 2020b).

Data does exist with respect to movement rates through a ZOI. Figure 18 is derived from a number of path analyses of movement rates of different barren-ground herds that move into and out of a ZOI (Russell unpublished data). On average, movement rate increases by 65% when entering or leaving a ZOI between two subsequent days. At Meadowbank Mine, Boulanger et al. (2020) reported that caribou increased movement rates after crossing the road up to 2.6 km east of the road.

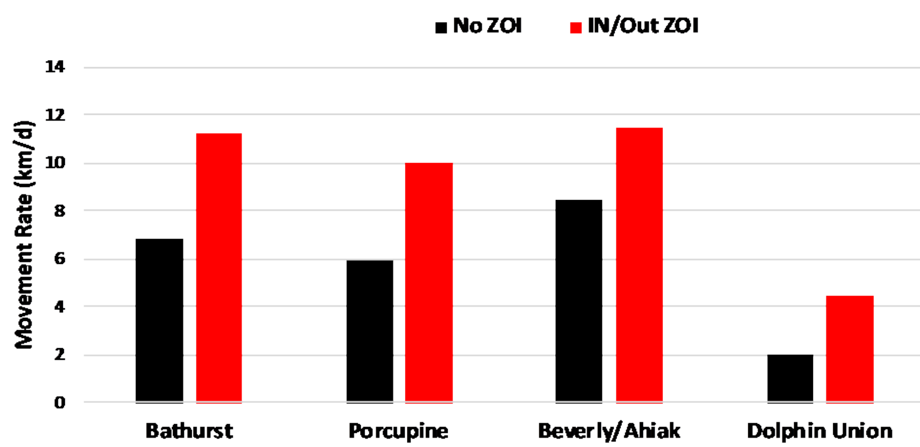

Figure 18. Daily movement rates for days when caribou either entered or left a ZOI (in/out ZOI) compared to days when caribou not associated with ZOI (no ZOI) for four North American herds.

In this modeling, for periods not including calving, post-calving, and summer, a penalty for being in the ZOI is assumed as:

- 6% decrease in foraging,
- 3% increase in walking,
- 3% increase in running and
- 3% decline in feeding intensity (the % of the foraging time spent ingesting food).

These values could be conservative in the presence of hunting, when both the degree of reaction and the distance from the human activity that caribou react increases. Given the equivocal results described above and uncertainty inherent (Harwood and Stokes 2003) in quantifying disturbance, these penalties are a logical compromise to objectively assess the cumulative effects of development.

However, these "base" penalties are not applied to the calving, post-calving, and summer period. There is a common thread through the literature to suggest that 1) cows and newborn calves are most sensitive to human disturbance during the calving (Cameron et al 1992, Wolfe et al 2000, Vistnes and Nellemann 2001, Reimers and Coleman 2006) and post-calving period; when cows give birth, calves become mobile and lactating cows' daily requirement for energy and protein doubles (Russell et al 1993) and 2) the larger the group the less likely they will be able to successfully cross through development zones (Smith and Cameron 1985). It is during the post-calving period that larger and larger aggregations begin to form, partially or wholly in response to insect harassment.

Due to the sensitivity of caribou during calving and the relationship between larger groups lack of success dealing with infrastructure, for calving, post-calving, and summer, the penalties in the ZOI of development were doubled; and a decrease of 12% feeding, 6% increase in walking, a 6% increase in running and a 6% decline in feeding intensity were applied.

Energy-Protein Sub-model Results

Cow (Figure 19) and calf (Figure 20) fall body weights are summarized for the six route options relative to the baseline scenario. In all scenarios body weights were lower than baseline (only existing infrastructure) values.

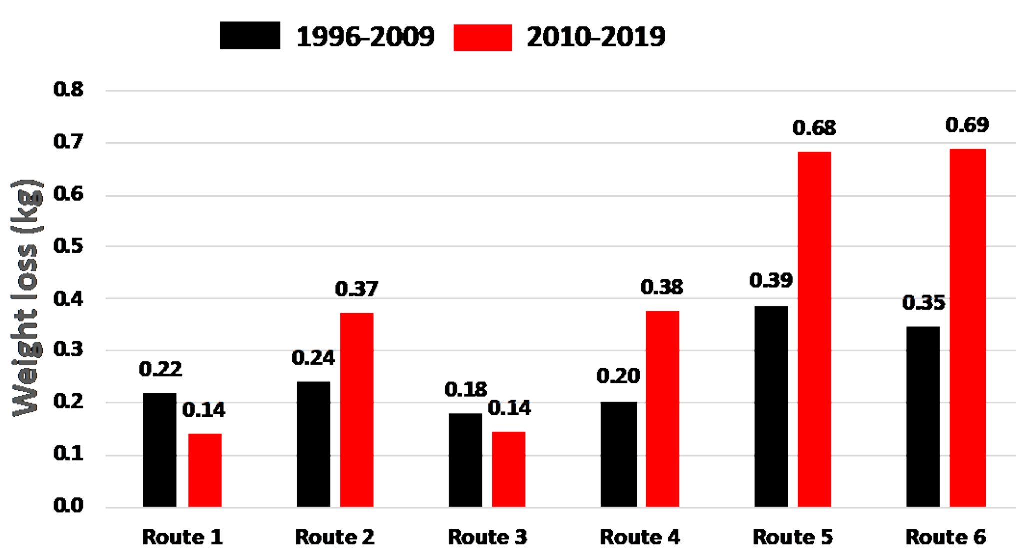

Figure 19. Weight loss of adult cows relative to "baseline" scenario for six route options for the proposed SGP road and the potential Grays Bay Road.

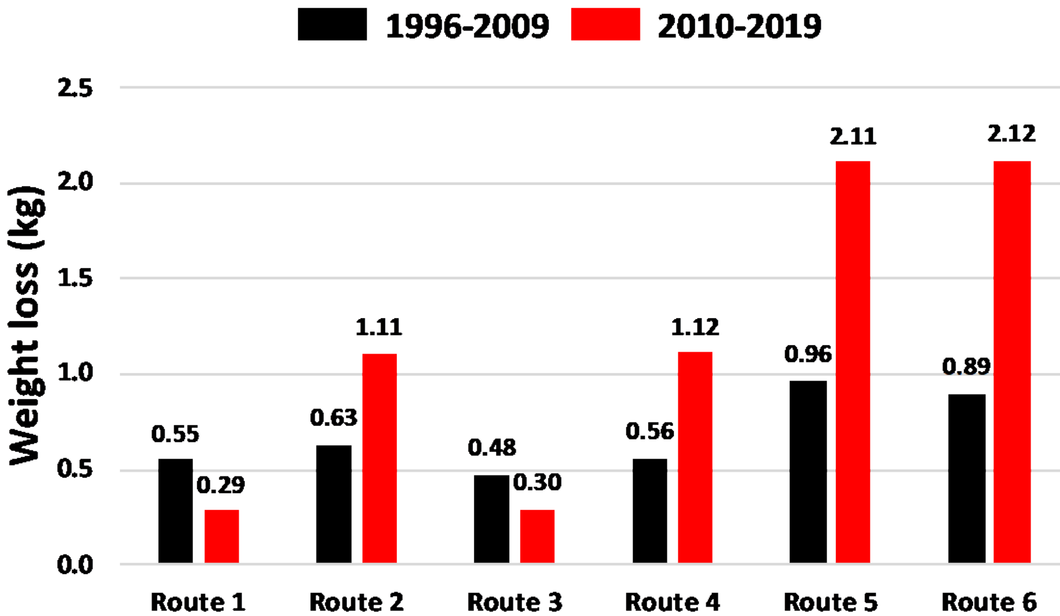

Figure 20. Weight loss of calves relative to "baseline" scenario for six route options for the proposed SGP road and the potential Grays Bay Road.

For all SGP-only routes the weight loss from baseline values were lowest if it included the Jolly Lake alternative and did not include the NU border alternative (Route 3) and highest if it did not include the Jolly Lake but included the NU border (Route 2). The only exception was that the weight difference between Route 1 (without Jolly Lake) and Route 3 (with Jolly Lake) for both cows and calves was negligible in the 2010-2019 period.

Population Sub-model Set-up

Departures from overwinter calf survival and cow probability of pregnancy for the energy-protein scenarios were linked to the population sub-model. As the potential impact of the SGP road throughout the cycle of herd abundance was desired, two scenarios were ran: 1) a high population starting at 198,000 (mean estimate from 1996-2009) and 2) a low population of 22,000 (mean estimate from 2010-2019). Using 100 Monte Carlo iterations varying adult cow survival and pregnancy rates were simulated over 11 years (2019-2030) within long term means and standard deviations for the Bathurst herd. For pregnancy rate, the long-term average was (80% $\pm$ 6.4), based on the collection from Elkin, Croft and Evans (see section on Sensitivity). Adult survival for both population sizes was set at 85%, indicative of a stable population. The estimated survival has been much lower during the current decline, however, given the objective of this study was not to model the current trend conditions, a stable trend for the baseline run was used to better isolate the impacts of the development scenarios.

Population Results

The population model was deliberately parameterized to result in a stable population size over the 11 years of the simulation. For the baseline scenario, the annual rate of decline for the 1996-2009 period was 0.22%/year and for the 2010-2019 period, 0.83%/year decline). Figure 21 summarizes the results of the population runs and are presented as the rate of decline relative to the baseline scenario.

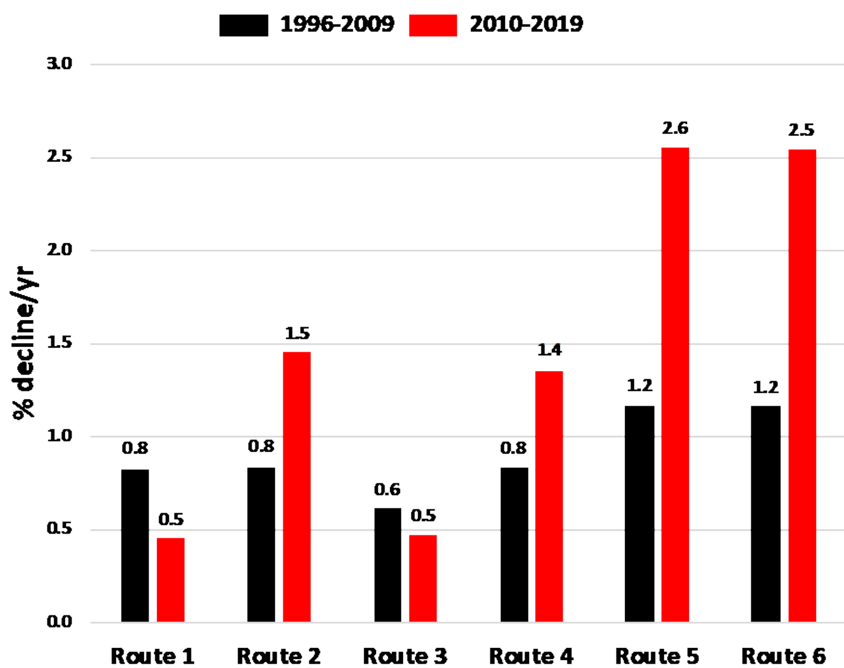

Figure 21. Percent annual decline in population projection relative to "baseline" scenario for six route options for the proposed SGP road and the potential Grays Bay Road.

These results showed that all routes will increase the rate of decline in the Bathurst herd. For all SGP-only routes the percent decline from baseline values were lowest if it included the Jolly Lake alternative and did not include the NU border alternative (Route 3) and highest if it did not include the Jolly Lake but included the NU border (Route 2). The only exception was that the percent difference between Route 1 (without Jolly Lake) and Route 3 (with Jolly Lake) was negligible in the 2010-2019 period. The inclusion of the NU border alternative greatly increased the rate of decline. To put these percentages in perspective, from the population high (198,000) starting population, all season road options resulted in 13,000-25,000 less caribou by 2030. In comparison from the low population (22,000) model runs, all season road options resulted in 1,800-2,500 less caribou by 2030.

Potential Impact Summary

The results of the movement sub-model, including the daily vegetation, climate and whether in or out of a ZOI for 185 (1996-2009) and 240 (2010-2019) caribou, were passed to the energy-protein sub-model. To compare the cost to caribou of each of the six road route combinations, the model was ran with only the existing development (the baseline scenario) and then compared to each of the runs representing the six route options. These scenarios were repeated for each period.

If a caribou was in a ZOI, a disturbance penalty was applied that reduced forage time and increased walking and running. Further, the penalty was higher for some periods (calving, post-calving, and summer, for example) due to the documented sensitivity of the herd, especially cows and calves, in those seasons.

For each model run the average cow and calf weight at the rut was calculated and the weight relative to the baseline scenario was determined for each road route option. Overall, among all routes, Route 3 which included the Jolly Lake alternate and did not include the NU border alternative had the least cost on fall body weights (1.1 kg weight difference by summing cow and calf relative weight loss from baseline for both time periods) while, for SGP-only road routes, Route 2 (not including the Jolly Lake alternative but including the NU border alternative) had the highest cost (2.35 kg total). The highest cost was for routes that included Grays Bay Road with summed weight loss for Route 5 of 4.14 kg and Route 6 of 4.05 kg (Figure 19, 20).

These weight loss values from the various energy-protein sub-model scenarios were passed to the population sub-model. To be precise, the fall body weight of the cow was equated to a change in probability of pregnancy and the body weight of the calf to a change in overwinter survival. For each scenario the population sub-model was run 100 times where adjusted survival and pregnancy rates were picked from a mean and standard deviation resulting in 100 future population estimates. In the simulation starting populations for the high population runs (representing 1996-2010) was 198,000 while the starting population for the low population runs (representing 2010-2019) was 22,000.

All routes will increase the rate of decline in the Bathurst herd. For all SGP-only routes the percent decline from baseline values were lowest if it included the Jolly Lake alternative and did not include the NU border alternative (Route 3) and highest if it did not include the Jolly Lake but included the NU border (Route 2). The only exception was that the percent difference between Route 1 (without Jolly Lake) and Route 3 (with Jolly Lake) was negligible in the 2010-2019 period. The inclusion of the NU border alternative greatly increased the rate of decline.

The percent reduction in productivity from the SGP-only route options (0.5 – 1.5% per year) and SGP + Grays Bay Road options (1.2 – 2.6%) will be hard to measure given monitoring precision. To put these percentages in perspective, from the population high (198,000) starting population, all road options resulted in a range of 13,000-25,000 less caribou by 2030. In comparison from the low population (22,000) model runs, all road options resulted in a range of 900-6,000 less caribou by 2030.

ADAPTIVE CAPACITY

The vulnerability approach for assessing impacts to caribou of development uses a pathway linking exposure, sensitivity, potential impacts, and adaptive capacity (Figure 1). Adaptive capacity is the capability to adapt to potential impacts and, for wildlife, including caribou, partially depends on their evolutionary and behavioural plasticity (Beever et al. 2017, Glick et al. 2011). As well, adaptive capacity depends on how impacts of infrastructure are mitigated and how the surrounding landscape is managed.

Adaptive capacity, in the context of vulnerability of the Bathurst herd to the SGP road, will depend on how caribou productivity responds to feedback between mitigation, residual impacts (the mitigation-monitoring feedback cycle) and herd and landscape management (Figure 35). Supporting the adaptive capacity of barren-ground caribou includes the application of multi-scale mitigation to allow free movement of caribou. Movement across seasonal ranges is how caribou adapt to annual and longer-term trends in climate and range condition.

Modeling is used to project residual impacts which depend on the effectiveness of mitigation. The residual impacts can be offset through landscape and caribou management. For example, landscape management such as an increase in the rate of reclamation or project delay would change caribou exposure, and thus offset residual impacts. Likewise, herd management may, through changes in age structure or survival rates, influence sensitivity and trends in herd size.

In this section, the (a) effectiveness of mitigation, (b) monitoring to detect residual impacts and (c) landscape and herd level management options to offset and/or trade-off residual impacts are considered. Specifically, information available from on-going mitigation and monitoring on the ranges of migratory tundra caribou, especially for roads, is used. Management options available for the Bathurst herd are then examined and the CCE model is used to project how these supports to adaptive capacity increase or decrease vulnerability.

Mitigation

Mitigation as applied to roads and traffic on the ranges of migratory tundra caribou and proposed during environmental assessments over the last ten years for mines with all-weather roads, ice roads and public highways is examined. Experience in northern Canada is emphasized although the usefulness of experience with roads and mines for wild and domestic reindeer is recognized (for example, Lawrence and Larsen 2019). Information on mitigation effectiveness and residual impacts, available through monitoring reports and independent studies, is applied to develop mitigation scenarios for the SGP road to project residual impacts (Figure 22). Lastly, model projections for how landscape or herd management can offset the residual impacts are compared.

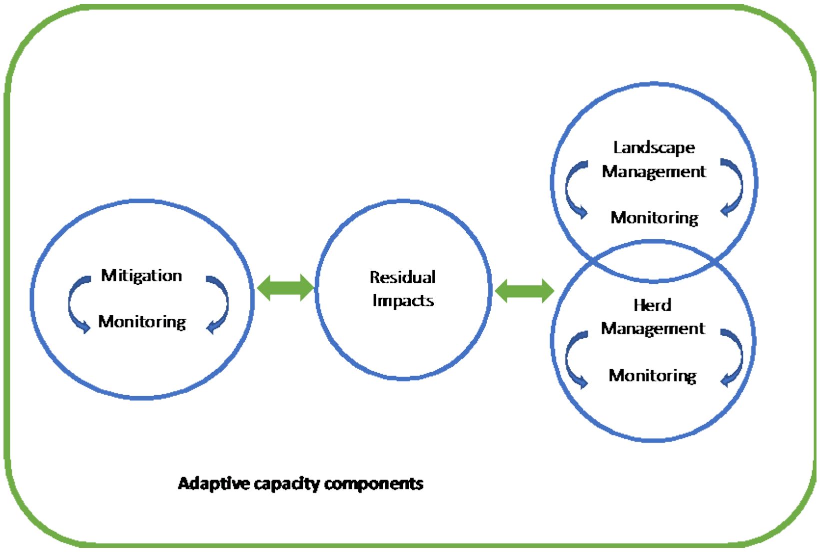

Figure 22. Elements to support building adaptive capacity in caribou.

For information, the public registries for environmental assessment boards, published literature and current studies are used. In the NWT and NU, monitoring and mitigation practices have increased in effort and type during the last decade through the Mackenzie Valley Environmental Impact Review Board's and NU Impact Review Board's environmental assessments. During an environmental assessment, while the proponent initially describes monitoring and mitigation, procedural steps (information requests, technical meetings, and commitments) allow intervening parties and the proponent to discuss the proposed monitoring and mitigations. The outcome in NU is a Terrestrial Environment Mitigation and Monitoring Plan (NU) or in the NWT, a Wildlife Management and Monitoring Plan. After project approval, the mining companies are responsible for annual monitoring reports which are reviewed by agencies with jurisdictional responsibility. An example of the process in reviewing types of mitigation plans is for caribou and roads at the Ekati mine (Appendix F, GNWT 2017).

Current monitoring and mitigation for roads and traffic, including if and how mitigation effectiveness can be assessed are summarized and reported on (Appendix B). It is surmised that if mitigation is effective, residual impacts will be reduced. What may seem like extraneous detail is included, but it is to build a case about the effectiveness of mitigation as a justification for the scenarios that were used to project residual impacts.

Scenarios to Project Residual Impacts

Scenarios for the SGP road were based on caribou responses and mitigation practices to project residual impacts. It is an exploratory approach to scenarios while it is recognized that other approaches to scenarios especially community perspectives (Falardeau et al. 2018) will also contribute to understanding possible effects of the road and the role of mitigation.

The present state of knowledge suggests that caribou are likely to respond to traffic on a road by delays for days and then either crossing the road or not (Poole et al. 2021, Boulanger et al. 2020). The only mitigation for which there is evidence as to its effectiveness is road closure (Boulanger et al. 2020) but the duration of closures, whether some traffic was excluded and the required gap between vehicle passages needed for caribou crossing a road are uncertain (Appendix C). Given that uncertainty, low and high traffic frequency are contrasted.

To model those residual impacts which reflect the effectiveness of mitigation, input for the model projections including the time spent in the ZOI and the extent of the ZOI itself are used. At this stage, the level of penalties for foraging time are not changed as the possible trade-offs between foraging and risk-aversive movement is unknown. Potentially, the trade-offs based on what is known about non-consumptive effects of predation as responses to disturbance are similar to responses to predation (Frid and Dill 2002).

To keep the number of scenarios manageable, the impacts of three mitigation actions were investigated: (i) reducing traffic, (ii) closing hunting access and (iii) seasonal road segment closure, resulting in eight scenarios (Table 5). Scenarios based on encounter rates determined in the 2010-2019 period when herd size was low and encounter rates with the potential road was the highest were also applied. The rationale was that given the current status of the herd and the high rate of encounters the results of the scenarios would be both the worst-case scenario and a more likely scenario for the next ten to 15-year horizon given the current trend in the Bathurst herd size.

Table 5. The three mitigation factors and profile of eight resultant scenarios (H=Hunting; T=Traffic).

Factor	Mitigation
Hunting	No or Yes
Traffic	Low or High
Road closure	Closed or Open
Scenarios	
NoH-LowT-Closed	
NoH-LowT-Open	
NoH-HighT-Closed	
NoH-HighT-open	
YesH-LowT-Closed	
YesH-LowT-Open	
YesH-HighT-Closed	
YesH-HighT-open	

Metrics for comparing the results of the scenarios are number of encounter days (Figure 15), fall cow weight (Figure 19), calf weight (Figure 20) and population trend (Figure 21). Further, the scenarios were applied to the six road routes identified in this report (Figure 9). By determining the mitigations separately for each road route, in effect, another mitigation is added at the scale of landscape, the choice of road segment alternatives presented in this report.

Hunting ZOI Scenarios

As hunting and road access are often the basis of concerns, the first scenarios are based on the behaviour disturbance effects from hunting (effect on increasing ZOI and mitigation is no hunting). The residual effect is indexed based on Plante et al. (2018; Table 6).

Table 6. Scaling factors applied to encounter rates to model hunting, traffic, and their mitigation. Note: low traffic crossing duration was not calculated for fall by Poole et al 2021) and thus the average for all other seasons (1.5 days) was applied.

Scenario	calving	fall	spring	summer	winter
Low traffic cross duration (days)	**0.24**	**1.50**	**0.24**	**0.83**	**2.25**
High traffic cross duration (days)	**0.63**	**4.54**	**0.63**	**8.08**	**3.08**
High traffic delay factor	2.6	3.0	2.6	9.7	1.4
Hunting scale factor	1	3	1	1	3

The reported ZOI was applied for hunting disturbance as a scenario by scaling the model's rate of encounters by a factor of three to account for the tripling of the ZOI from 5-15 km (Table 6; Plante et al 2018). No effect of hunting on survival rates was applied, as currently, hunting is not allowed for the Bathurst herd. It was assumed that fall and winter hunting was the most likely and the scaling factor of three was applied only to the fall and winter period. The mitigation applied was closure of the road to hunting.

Traffic Scenarios

The above studies report that delayed crossings or deflections are documented caribou responses to roads and traffic. For this scenario, then, seasonal delays (days) estimated for Ekati mine roads were used to scale the modeled encounter days (Table 6). The mitigation was low traffic meaning all the road was closed to almost all (except emergency or monitoring vehicles) traffic. Based on the number of ZOI encounter days determined from the movement-sub model (Figure 15), under the heavy traffic scenario the number of encounter days by season as high traffic delay (days)/low traffic delay (days) was increased. This assumes that the number of encounter days from the movement model were representative of low traffic conditions.

Road Segment Six Closure Scenarios

Although a road closure scenario could have been applied to several road segments (Figure 9), the closure to Segment 6, the NU border alternative, was applied due to the high frequency of exposures on that segment (Figure 15). As well the closure was only applied to the fall period when most encounters occur (Figure 14).

Scenario Results

Table 7 summarizes the results of the scenario runs and plots and encounters by the three defined metrics for residual impacts: calf weight loss (Figure 23), cow weight loss (Figure 24) and percent decline in the herd (Figure 25). Among the scenarios, calf weight loss varied from 1.87 kg for Routes 1 or 3 with low traffic, no hunting and either the Segment 6 open or closed. There was no effect of the road closure of the NU border alternative as this segment was not contained in Routes 1 and 3. The highest calf weight loss was 16.5 kg under the high traffic, hunting and no NU border alternative closure for Route 6. The same scenarios and routes also accounted for the range in cow weight loss (0.9 – 6.9 kg) and percent herd decline (2.6-22.0 %).

Figure 23. 2010-2019 modeled results of fall calf weight loss (relative to no SGP road) for eight mitigation scenarios incorporating hunting, traffic, and road closures for the Bathurst herd. For each mitigation scenario the six datapoints represent the six routes. The lowest

encounters for each scenario are Routes 1 and 3, higher encounters are Routes 2 and 4 and highest encounters are Routes 5 and 6.

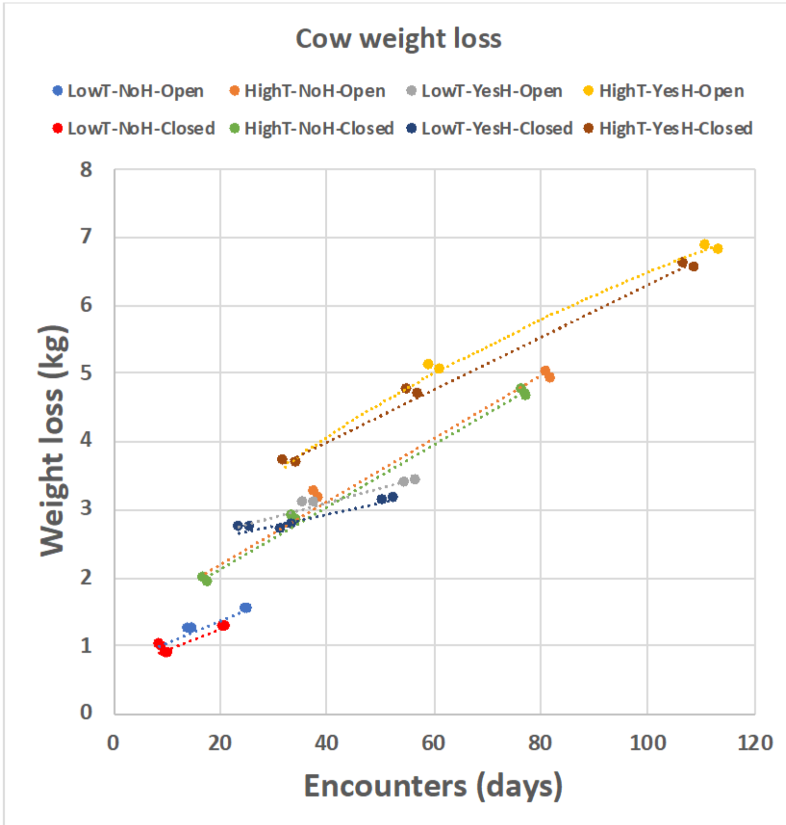

Figure 24. 2010-2019 modeled results of fall cow weight loss (relative to no SGP road) for eight mitigation scenarios incorporating hunting, traffic, and road closures for the Bathurst herd. For each mitigation scenario the six datapoints represent the six routes. The lowest encounters for each scenario are Routes 1 and 3, higher encounters are Routes 2 and 4 and highest encounters are Routes 5 and 6.

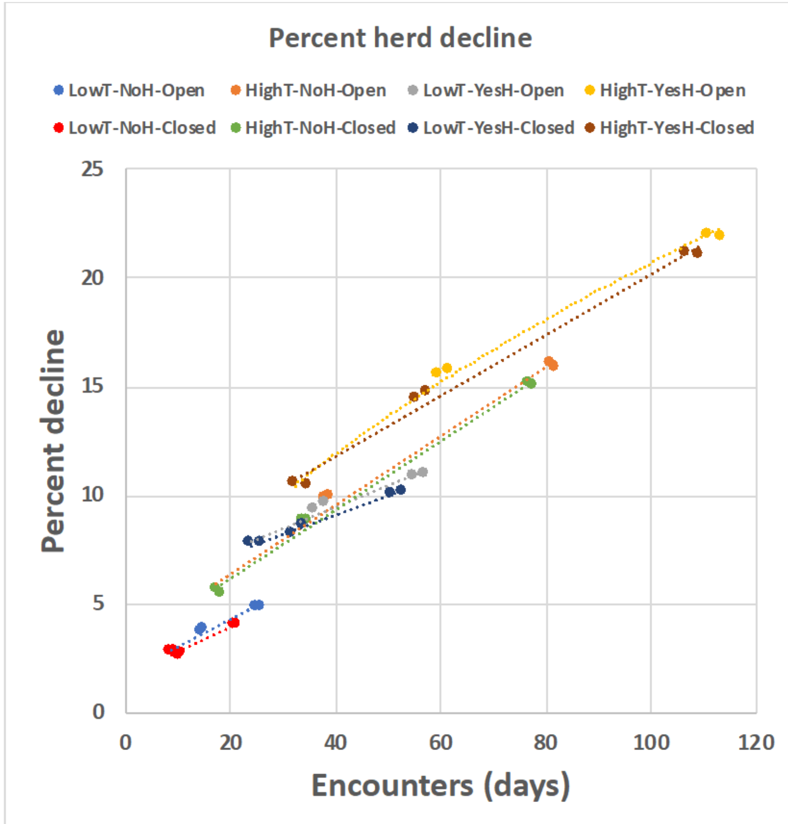

Figure 25. 2010-2019 modeled results of percent herd decline (relative to no SGP road) for eight mitigation scenarios incorporating hunting, traffic, and road closures for the Bathurst herd. For each mitigation scenario the six datapoints represent the six routes. The lowest encounters for each scenario are Routes 1 and 3, higher encounters are Routes 2 and 4 and highest encounters are Routes 5 and 6.

Table 7. Results of mitigation scenarios with respect to calf weight change, cow weight change and percent herd decline in the Bathurst caribou herd (High and Low = traffic; no and yes = hunting; open and closed = open vs. closed traffic in fall at the NU border alternative).

Scenario	route	encounters	Calf wt loss	Cow wt loss	% DECLINE
LowT-NoH-Open	Route 1	9	1.87	0.99	2.84
LowT-NoH-Open	Route 2	15	2.69	1.22	3.83
LowT-NoH-Open	Route 3	9	1.87	1.00	2.86
LowT-NoH-Open	Route 4	14	2.69	1.23	3.74
LowT-NoH-Open	Route 5	26	3.69	1.53	4.93
LowT-NoH-Open	Route 6	25	3.70	1.54	4.92
HighT-NoH-Open	Route 1	18	3.61	1.9	5.49
HighT-NoH-Open	Route 2	39	6.97	3.2	9.94
HighT-NoH-Open	Route 3	17	3.72	2.0	5.66
HighT-NoH-Open	Route 4	38	7.14	3.3	9.91
HighT-NoH-Open	Route 5	82	11.84	4.9	15.83
HighT-NoH-Open	Route 6	81	12.05	5.0	16.04
LowT-YesH-Open	Route 1	26	5.15	2.7	7.82
LowT-YesH-Open	Route 2	38	6.81	3.1	9.71
LowT-YesH-Open	Route 3	24	5.12	2.7	7.81
LowT-YesH-Open	Route 4	36	6.75	3.1	9.38
LowT-YesH-Open	Route 5	57	8.22	3.4	10.99
LowT-YesH-Open	Route 6	55	8.15	3.4	10.86
HighT-YesH-Open	Route 1	34	6.90	3.7	10.48
HighT-YesH-Open	Route 2	62	11.09	5.0	15.81
HighT-YesH-Open	Route 3	32	6.97	3.7	10.62
HighT-YesH-Open	Route 4	59	11.20	5.1	15.55
HighT-YesH-Open	Route 5	113	16.37	6.8	21.88
HighT-YesH-Open	Route 6	111	16.50	6.9	21.97
LowT-NoH-Closed	Route 1	9	1.87	1.0	2.84
LowT-NoH-Closed	Route 2	11	1.93	0.9	2.75
LowT-NoH-Closed	Route 3	9	1.87	1.0	2.86
LowT-NoH-Closed	Route 4	10	1.89	0.9	2.63
LowT-NoH-Closed	Route 5	21	3.08	1.3	4.12
LowT-NoH-Closed	Route 6	21	3.07	1.3	4.09
HighT-NoH-Closed	Route 1	18	3.61	1.9	5.49
HighT-NoH-Closed	Route 2	34	6.21	2.8	8.85
HighT-NoH-Closed	Route 3	17	3.72	2.0	5.66
HighT-NoH-Closed	Route 4	34	6.34	2.9	8.81
HighT-NoH-Closed	Route 5	78	11.23	4.7	15.01
HighT-NoH-Closed	Route 6	77	11.42	4.8	15.20
LowT-YesH-Closed	Route 1	26	5.15	2.7	7.82
LowT-YesH-Closed	Route 2	34	6.05	2.8	8.62
LowT-YesH-Closed	Route 3	24	5.12	2.7	7.81
LowT-YesH-Closed	Route 4	32	5.95	2.7	8.27
LowT-YesH-Closed	Route 5	53	7.61	3.2	10.17
LowT-YesH-Closed	Route 6	51	7.53	3.1	10.02
HighT-YesH-Closed	Route 1	34	6.90	3.7	10.48
HighT-YesH-Closed	Route 2	57	10.33	4.7	14.73
HighT-YesH-Closed	Route 3	32	6.97	3.7	10.62
HighT-YesH-Closed	Route 4	55	10.40	4.7	14.44
HighT-YesH-Closed	Route 5	109	15.76	6.6	21.07
HighT-YesH-Closed	Route 6	107	15.87	6.6	21.14

Table 8 focusses on the four routes within the NWT and not Routes 5 and 6 which include the Grays Bay Road. Route 2 and 4 both contain the NU border alternative while Routes 1 and 3 ends just southeast of Contwoyto Lake. From Table 8, the relative impact of the behavioural response to hunting (wider ZOI) had the highest impact increasing the percent decline in the herd by 107%. This is followed by High traffic which increased the decline by 85% compared to low traffic volumes. Leaving the NU border alternative open in the fall season versus closing the road increased the decline in the herd by 13%. We could conclude that closing segment 6, the NU border alternative results in less of a decline than the traffic management option (13% versus 85% decline respectively). However, the closure scenario presented is only for Segment 6 and only for the fall.

Table 8. Summary of model scenario results for GNWT only routes in respect to percent decline in the Bathurst herd.

Route	Segment 6 closure	Traffic	% decline: No hunting	% decline: Hunting
Routes 2&4	no close	HIGH	9.9	15.7
Routes 2&4	no close	LOW	3.8	9.5
Routes 2&4	close	HIGH	8.8	14.6
Routes 2&4	close	LOW	2.7	8.4
Routes 1&3	n/a	HIGH	5.6	10.5
Routes 1&3	n/a	LOW	2.8	7.8

Adaptive Capacity Summary

Mitigation for the impacts of roads and traffic typically follows a hierarchy from warning signs, reduced speed, giving caribou the right of way, convoying traffic, and closing a road. The effectiveness of those mitigations is uncertain as monitoring design and reporting are insufficient. Specific studies of caribou movements and behaviour during road mitigation (i.e., residual impacts) have documented that caribou within 3-5 km of a road and traffic may delay and parallel the road before crossing or may retreat and not cross. When a road is closed to traffic or there are few vehicles, caribou may cross but details about how long after a vehicle has passed, that caribou will then cross a road are lacking. Most mine roads also serve public use which includes hunting. Hunting increases the responsiveness of caribou to disturbance such as vehicles. Given the uncertainties about effectiveness of mitigations, scenarios to project residual impacts using mitigation-reduced traffic (compared to high traffic) and no hunting (compared to hunting) were used. Encounter time within the ZOI and the width of the ZOI were used based on current understanding of caribou responses to disturbance for the scenarios. The residual impacts for low traffic and no hunting were annual reductions in herd size of 3-5%. The impacts of no mitigation (hunting and high traffic) were projected to be severe, being 10-15% annual declines, which were further increased if the two northern road routes (5 and 6) were included.

CONCLUSIONS OF THE VULNERABILITY ANALYSIS

The Bathurst herd has been in decline for the period considered for this analysis. That decline has resulted in distributional shifts and changes in seasonal range size that has effectively concentrated the herd during most seasons in the vicinity of the proposed road alignments. Thus, in the latter period of low population size, the herd is more vulnerable to the proposed road. Not only has the shift resulted in high encounter days but the shift has necessitated a more cooperative approach to managing the herd as more and more potential conflict has shifted to NU. From this analysis, compared to the pre-2009 period, the distribution shift of the herd since 2009 would result in a 78% increase in encounters and a 116% increase in impacts on herd productivity should the Grays Bay Road be built.

The adaptive capacity modeling predicted the residual impacts would be annual reductions in herd size of 3-5% for mitigation scenarios looking at road closure, low traffic and no hunting. The residual impacts of no mitigation (hunting and high traffic) were projected to be 10-15% annual declines which were further increased with the inclusion of the two northern road routes (5 and 6). Those worst-case scenarios suggest that offsetting or compensatory mechanisms may be needed as the residual impacts of the SGP road are predicted to be severe. Although it seems unlikely that caribou would spend 113 days within 15 km of the road under the high traffic and hunting scenario, this does include the possibility that the caribou, for example, in a season such as winter, might be moving parallel to the road – a deflection within the 15 km ZOI.

Potentially, the predicted residual impacts could be offset through herd management by increasing adult survival. However, currently for the Bathurst herd, adult survival is high suggesting that offsetting options may be limited to landscape management. Landscape management can include such strategies as delaying or downsizing a proposed project and increase mitigation effectiveness at existing mines to reduce any costs to the caribou.

The scenarios applied to project the Bathurst herd's vulnerability did not include uncertainty from whether the extent of the decline increases the likelihood of ecological surprises and tipping points. First, ecological surprises: the herd's collapse to about 2% of its peak size despite reducing harvest, was unexpected - an ecological surprise. An ecological surprise is a situation where human expectations or predictions of ecosystem behaviour deviate from observed ecosystem behaviour. (Filbee-Dexter et al. 2017). The unexpected collapse of Atlantic cod despite conventional fisheries management and then the expected recovery, once fishing was halted, did not happen are two examples of ecological surprises (Filbee-Dexter et al. 2017).

Second is whether the herd's decline has taken the caribou-dominated ecosystem close to a critical threshold (tipping point). A tipping point is a non-linear response such that a "a relatively small perturbation can cause a large, qualitative change in the future state of a system” (Cumming and Peterson 2017). For example, the combined effects of a warmer climate, landscape changes including mining, roads and railways and increasing predation are driving reindeer herding in Finland toward tipping points when adaptive mechanisms reach their limits (Landauer et al. 2021). In this case of the domestic reindeer, it is more the social part of the reindeer social-ecological systems (e.g. Ostrom 2009) that is close to a tipping point.

An additional point to be learnt from the Finnish example is that what reindeer herders regarded as negative, still others saw economic opportunities (Landauer et al. 2021) which is similar to choices facing communities on the Bathurst caribou range. The SGP road is projected to have negative impacts which given the herd’s reduced size, may take the herd toward a tipping point while economic gains from the SGP’s access to potential mining accrue. Thus, exploring adaptive capacity should include both negative and positive scenarios and community input (Landauer et al. 2021, Falardeau et al. 2018). Only the existing development and the addition of either an SGP road or both an SGP and Grays Bay Road are considered. However, one of the rationales for constructing an all-season road is to provide a cheaper reliable infrastructure for the existing, and future, exploration and development in this highly mineralized region. This assessment of the road did not consider spin-off projects.

While this modeling projects that the SGP road will increase the herd’s vulnerability from negative residual impacts despite adaptive capacity, uncertainties are also acknowledged.

Although some climate trends and linkages between climate and vital rates are derived, the herd’s vulnerability to future climate scenarios has not been attempted to be quantified. Depending on when the project is constructed the landscape could be changed, especially considering recent bad forest fire years because of extremes in fire weather index as summers become hotter and drier. Further, this analysis only considered the Bathurst herd, it is known that the assessment area is also frequented by the Bluenose-East herd to the west and the Beverly and other herds to the east, especially in winter (Guraire et al. 2020). Thus, on a more regional basis, the road may likely have a greater, unquantified, impact on migratory caribou in general. And lastly, we conclude on a note of caution as it is recognized that in modeling the vulnerability of a caribou herd to an all-weather road, this is a complex, unpredictable and incompletely known system. Wasserman and Lenton (2012) have written about tipping points in Arctic systems which reinforces our caution.

> “Our clinging to simple, linear predictive models is bewildering because we all know that these models often fail to grasp reality correctly. Non-linearity and the potential for tipping points must thus become part of our thinking and management strategies.”

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APPENDIX A. RELATIONSHIP OF CLIMATE VARIABLES WITH VITAL RATES OF THE BATHURST CARIBOU HERD

A number of climate indicators were regressed to Bathurst herd vital rates. In preliminary analysis of a number of North American herds (Russell unpublished data), it was found that vital rates were often correlated with both single year climate indicators (described in Russell et al 2013), but more often two to three year running averages, suggesting that a series of either favourable or unfavourable years correlated with vital rates, especially measures of recruitment and survival. Table 9 lists those variables that were significant (p<0.05) with Bathurst herd vital rates.

Table 9. List of climate indicators that correlated with Bathurst caribou vital rates with associated Pearson r and p-value.

Vital rate	Indicator	year average	Pearson r	*p*-value
Spring calves:100/cows	June precipitation	3	0.53	0.009
	June drought	3	-0.42	0.044
	October snow	2	-0.48	0.019
Adult cow survival	June drought	1	-0.53	0.008
	Freezing rain	2	0.53	0.008
	October snow	3	0.55	0.008
	Sept temperature (minimum)	1	-0.45	0.036
Fall calves/100 cows	July precipitation	2	0.72	0.015
	Freezing rain	1	0.70	0.020
	July temperature	2	-0.87	0.000
	October snow	3	0.75	0.009
	October temperature (maximum)	1	-0.70	0.019
% Breeding females	October snow	1	-0.82	0.004
	May 15 snow	1	0.67	0.040

To provide a predictive regression between vital rate and climate the highest correlation from Table 9 was chosen using the calculated residuals and the best calculated 2-factor equation. In cases when vital rates were correlated, results using the vital rate and the climate indicator correlated with the residuals are presented as well as correlations using just climate indicators.

Correlation Among Vital Rates

Although there was a negative relationship (r^2=0.50) between percent breeding females and cow survival$_{(y+2)}$, and a positive relationship (r^2=0.67) between percent breeding females and spring calves: 100 cows $_{(y+1)}$, neither relationship was significant given the low sample size (6 and 5 respectively).

Cow survival rates were correlated with spring calves: 100 cows ratios in the previous spring (r^2=0.51, n=12, p=0.007; Figure26). To develop this relationship, the 2008 spring calves: 100 cows ratio (49) was considered to be an outlier.

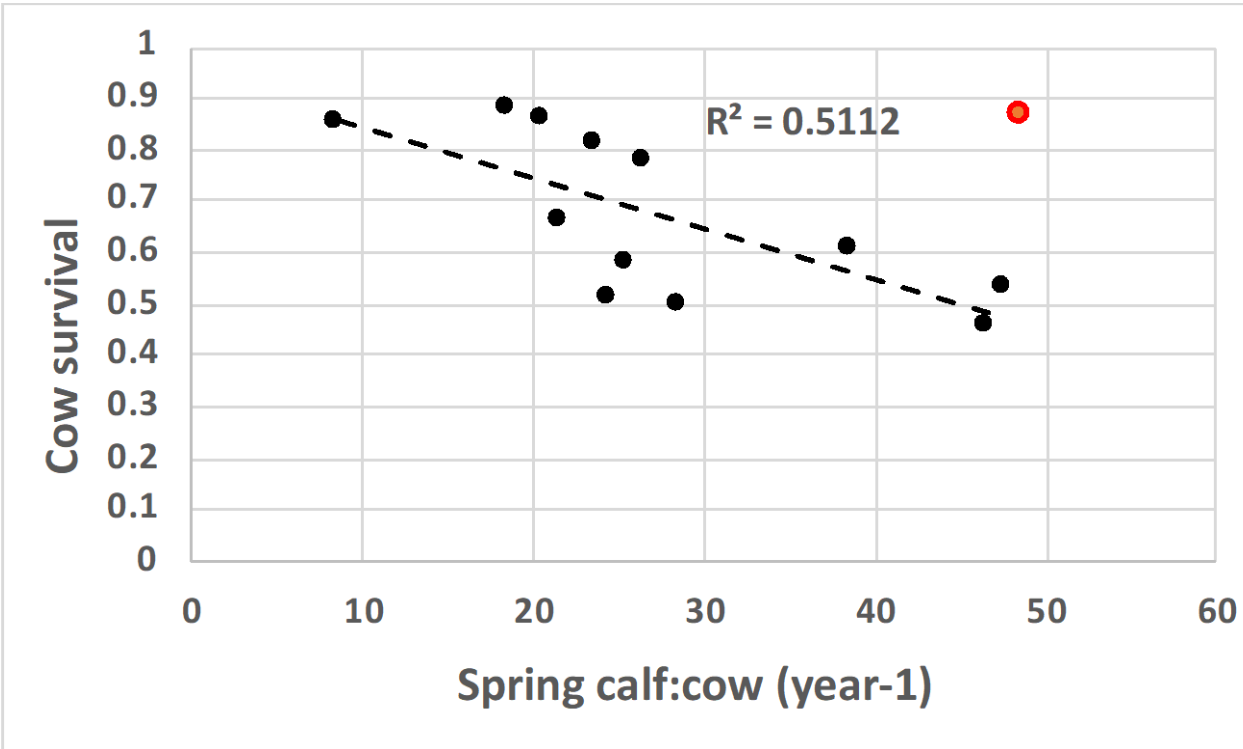

Figure 26. Relationship between previous spring calf: 100 cow ratio and cow survival. The red data point was considered an outlier.

The residual of this relationship was inversely correlated to March snow depth (Figure27).

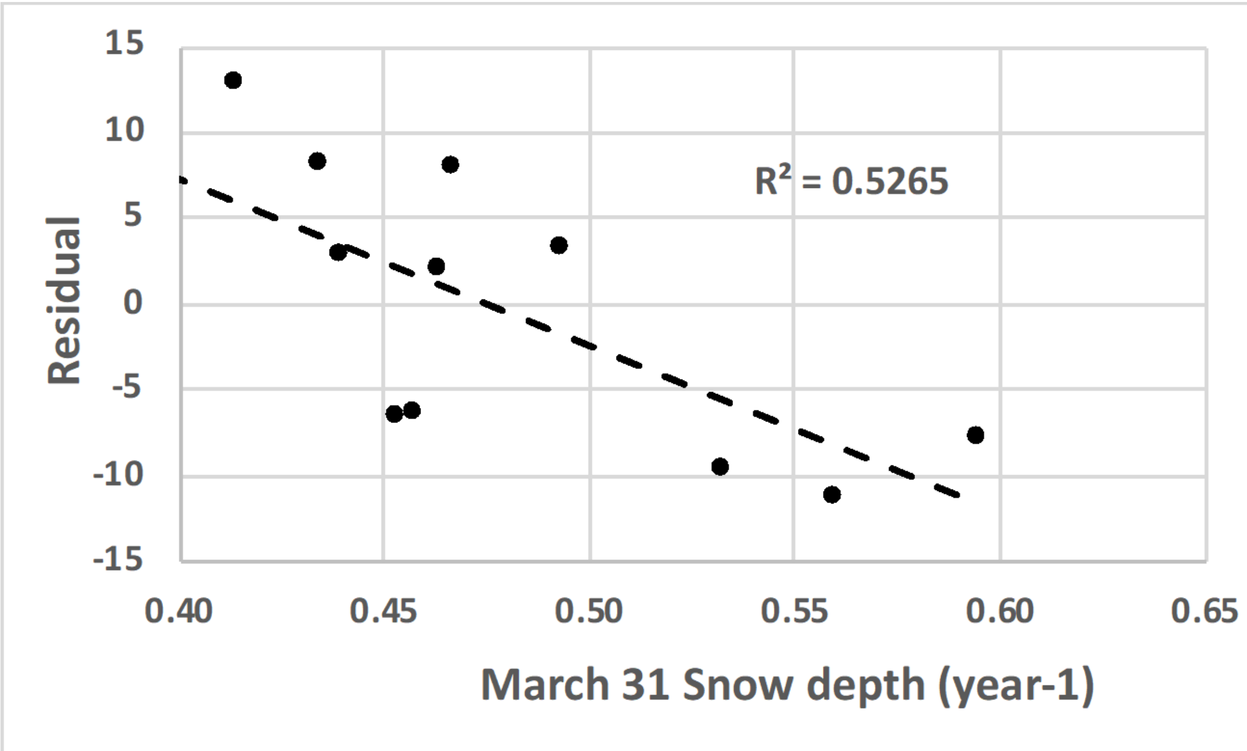

Figure 27. Relationship between March 31 snow depth and the residuals from the regression from Figure 26.

Together the multiple regression accounted for 75% of the variability in adult cow survival in the Bathurst caribou herd (F=13.4, p=0.002), according to the equation:

Survival = -0.0126 * spring calves: 100 cows - 1.397 * March snow depth + 1.687

Spring calves: 100 cows were correlated with the previous fall calves: 100 cows ratio (r^2=0.60, n=7, p=0.034; Figure). Given the small sample size (n=7), we did not seek a climate indicator to relate to the residuals.

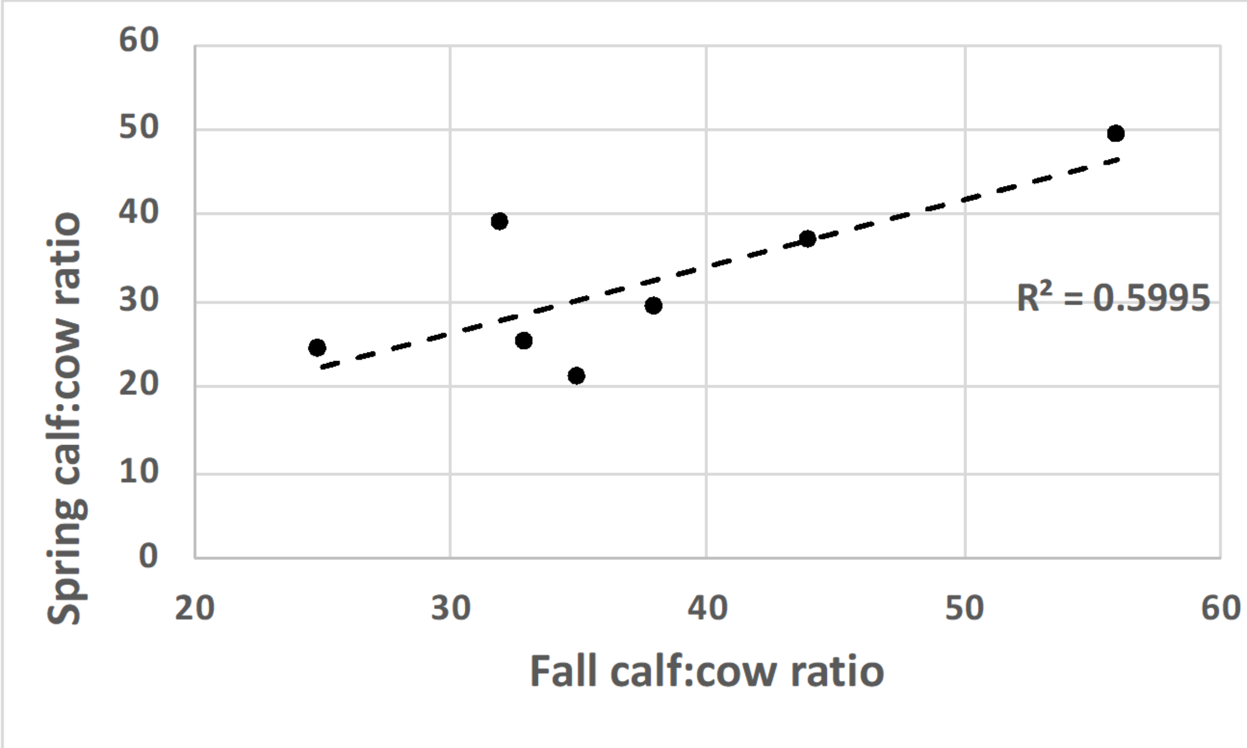

Figure 28. Relationship between fall calf:cow ratio and subsequent spring calf:cow ratio in the Bathurst caribou herd.

Percent Breeding Females

The strongest climate correlation was a negative relationship between percent breeding females in late spring and snow depth at the end of October in the previous fall (r2=0.67; p=0.007; Figure 9).

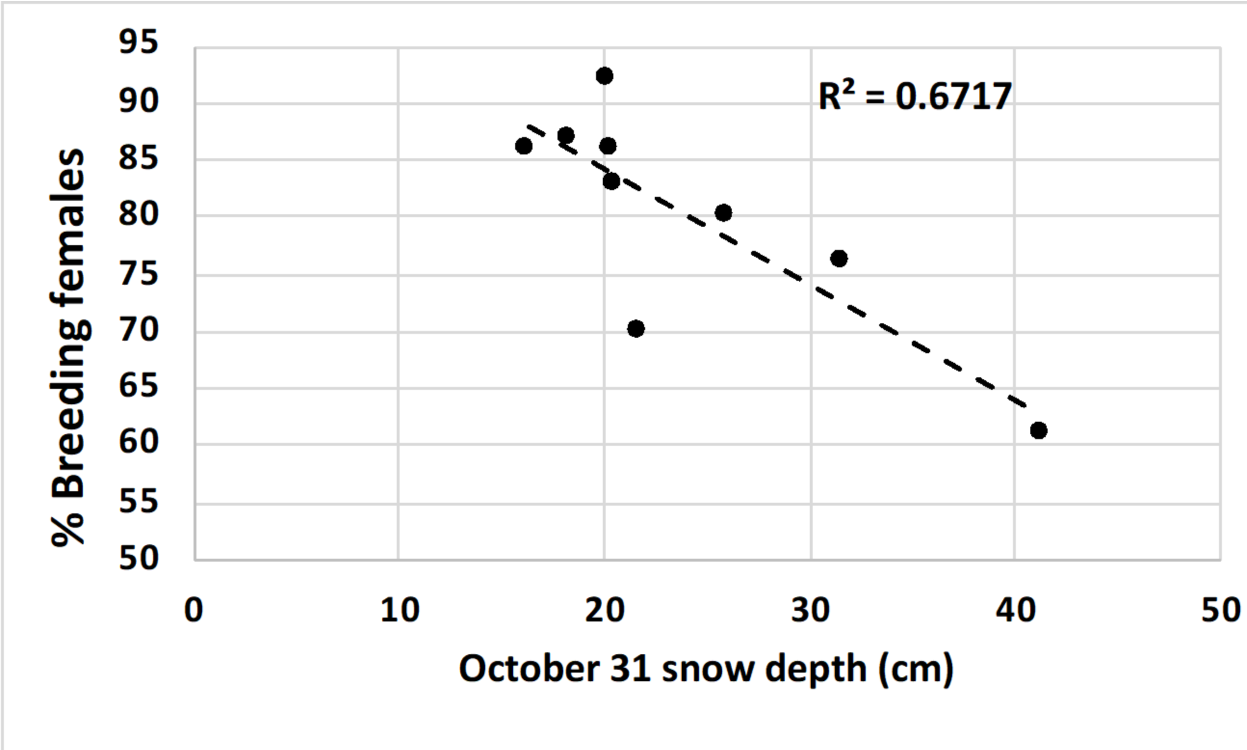

Figure 29. Relationship between percent breeding females in the spring and end of October snow depth in the previous fall.

Adult Cow Survival

The strongest climate correlation between adult cow survival in the Bathurst herd was the three-year running average of October 31 snow depth (r^2=0.26; p=0.01; Figure30). The climate indicator that most accounted for residuals from this correlation was the two-year running average of June drought index (r^2=0.30; p=0.02; Figure 31).

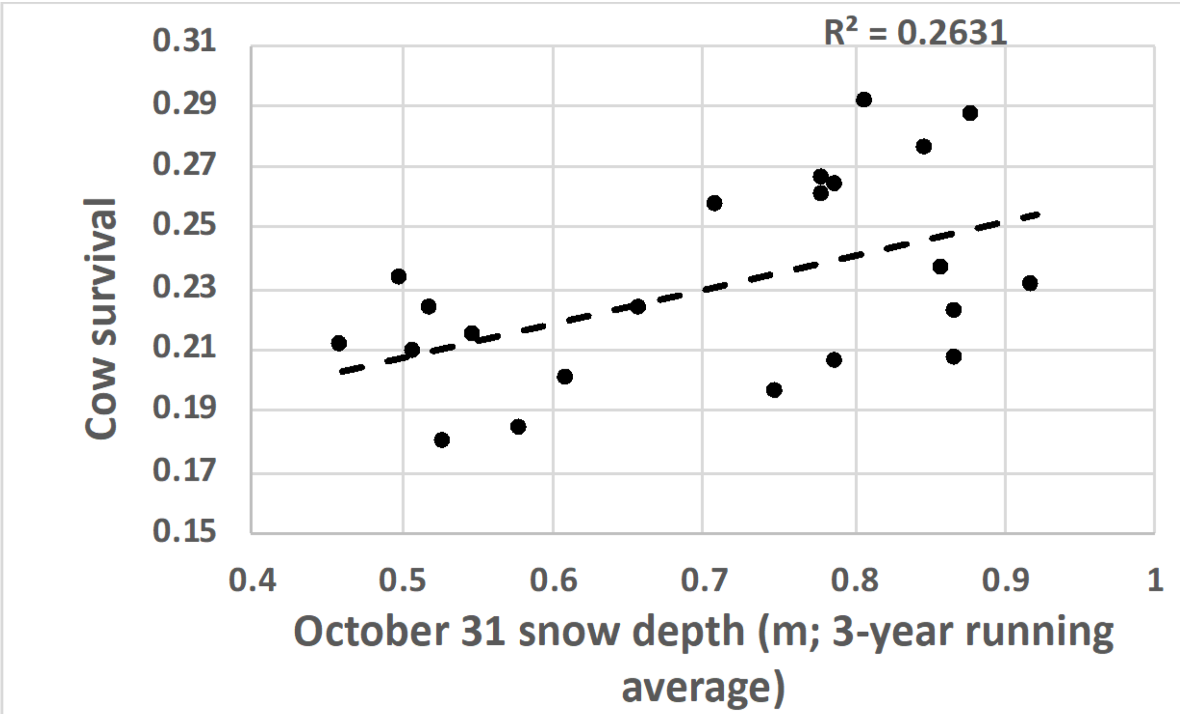

Figure 30. Relationship between October 31 snow depth and adult cow survival in the Bathurst caribou herd.

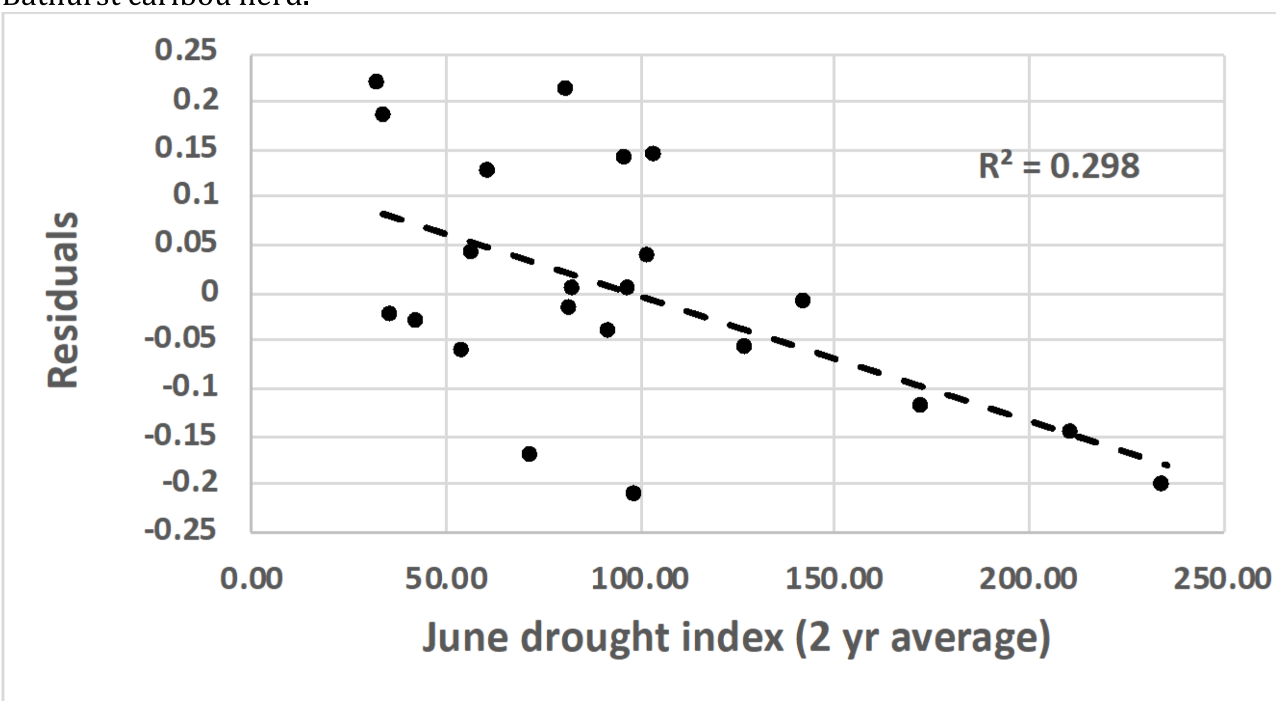

Figure 31. Relationship between the residuals from Figure30 and June drought index.

Together the multiple regression accounted for 48% of the variability in adult cow mortality in the Bathurst caribou herd ($F=8.9$, $p=0.002$), according to the equation:

$$\text{Survival} = 2.137 \times \text{October snow}_{3yr} - 0.0013 \times \text{June drought}_{2yr} + 0.3412$$

Fall Calves: 100 Cows

The strongest correlation with fall calves: 100 cows in the Bathurst herd was the two-year running average of July temperature in $year_{t-1}$ (r^2=0.76; p<0.001; Figure32). Given the small sample size (n=10), we did not seek a climate indicator to relate to the residuals.

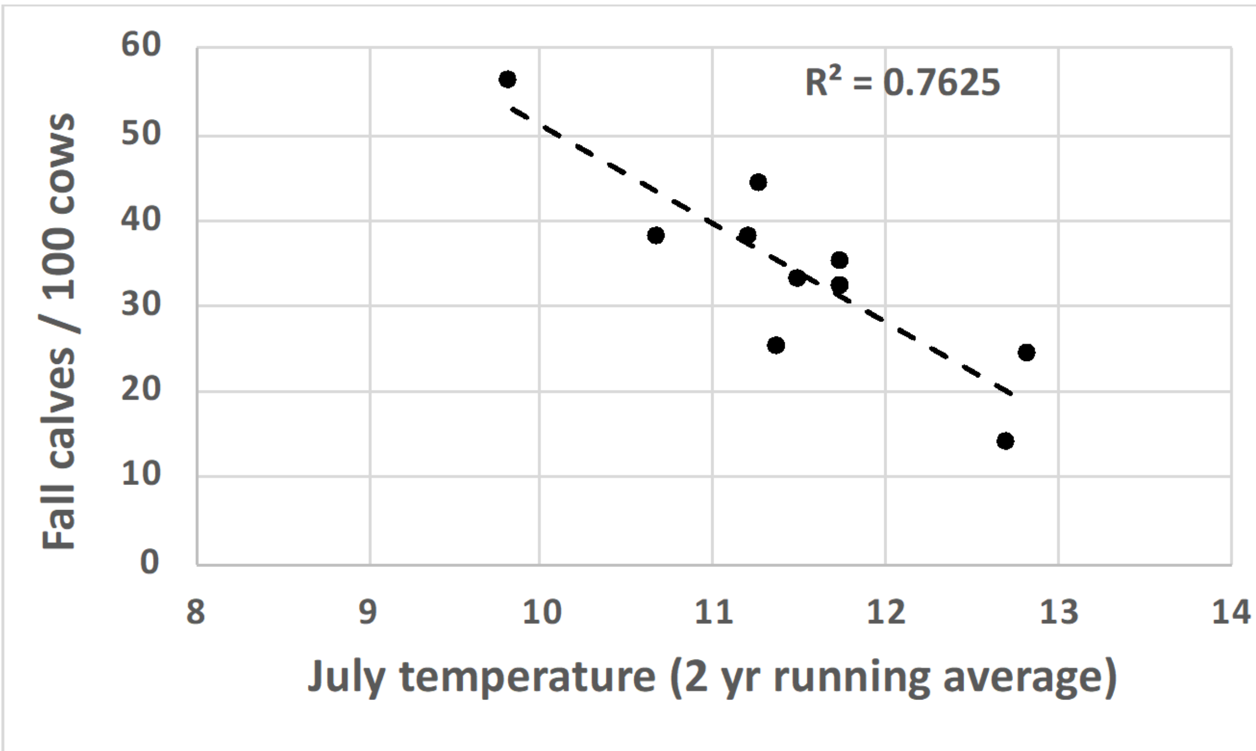

Figure 32. Relationship between fall calf:cow ratio and July temperature in the Bathurst caribou herd.

The predictive equation that explained 76% of fall calves: 100cows in the Bathurst herd was:

$$Fall\ calves: 100\ cows = 165.39 - 11.44 * July\ temperature$$

where, July temperature is the two-year running average of July temperature for $year_{t-1}$.

Spring Calves: 100 Cows

The strongest correlation between spring calves: 100 cows was the three-year running average for June precipitation in $year_{t-1}$ (r^2=0.31; p=0.001; Figure 33). No climate indicator accounted for residuals.

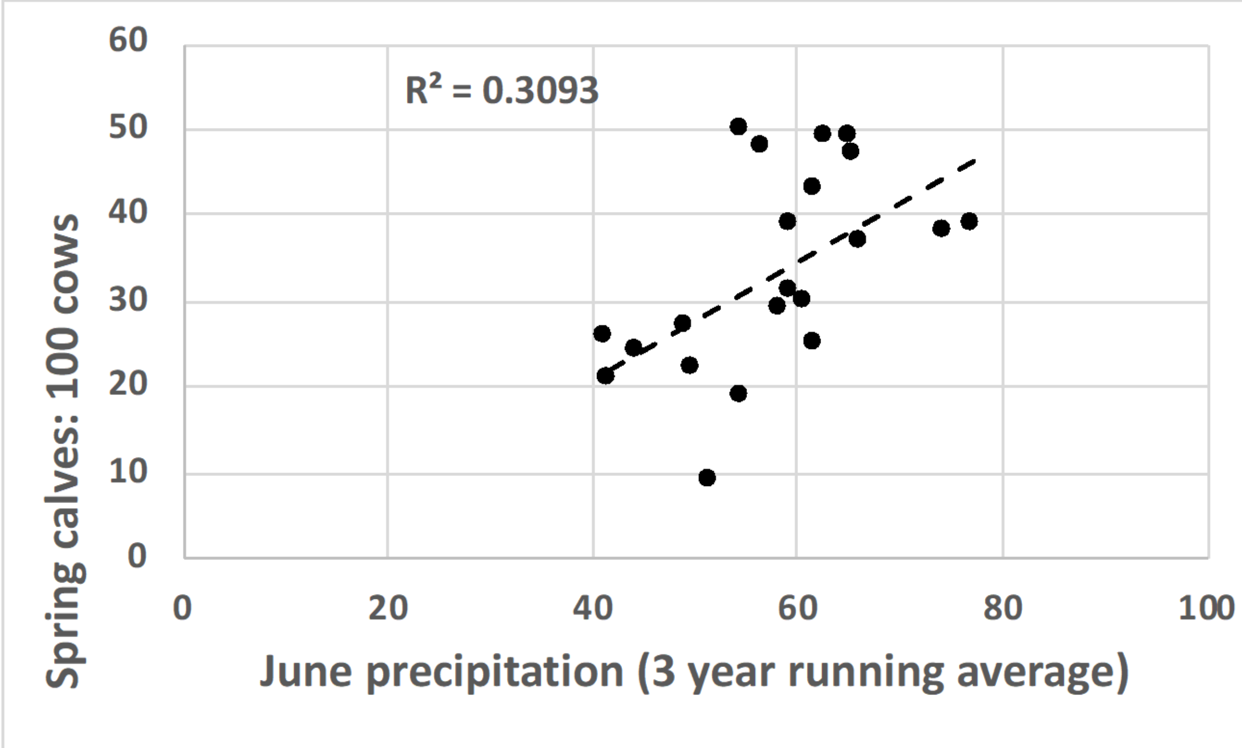

Figure 33. Relationship between June precipitation and spring calves: 100 cows in the Bathurst caribou herd.

The predictive equation that explained 31% of spring calves: 100 cows in the Bathurst herd was:

$$Spring\ calves{:}\ 100\ cows = -12.3 + 0.824 * June\ precipitation$$

Drought

Although drought conditions on the Bathurst herd summer range did not show a significant trend, or a significant independent variable related to vital rates, conditions in a single year could have longer term implications for herd productivity. Drought conditions on the Canadian shield can result in dramatic forage quality and quantity changes due to the bedrock-controlled substrate. Boulanger (in press) uses drought index as a measure of annual changes in the ZOI around mines sites on the Bathurst herd's range associated with diamond mining infrastructure. Recent high forest fire years on the Bathurst herd winter range was associated with very high drought index measures in 2014 and 2016 (Figure34). On the Bathurst herd summer range there is an inverse relationship between July temperature and July precipitation (Figure35). As a result, there is a tendency to get cool wet years and hot dry years resulting in high annual variability in calculated drought index. Between 2000 and 2019 the coefficient of variation for precipitation was 34%, temperature 14% and drought index 82%. The implications may be that drought conditions could produce cohort effects in bad years, that would carry through over the next years in respect to recruitment and survival. Further, as mentioned, extreme drought conditions in 2014 and

2016 coincided with bad forest fire years on the taiga range of the Bathurst herd, an example of a single year climate event resulting in long-term implications to range quality.

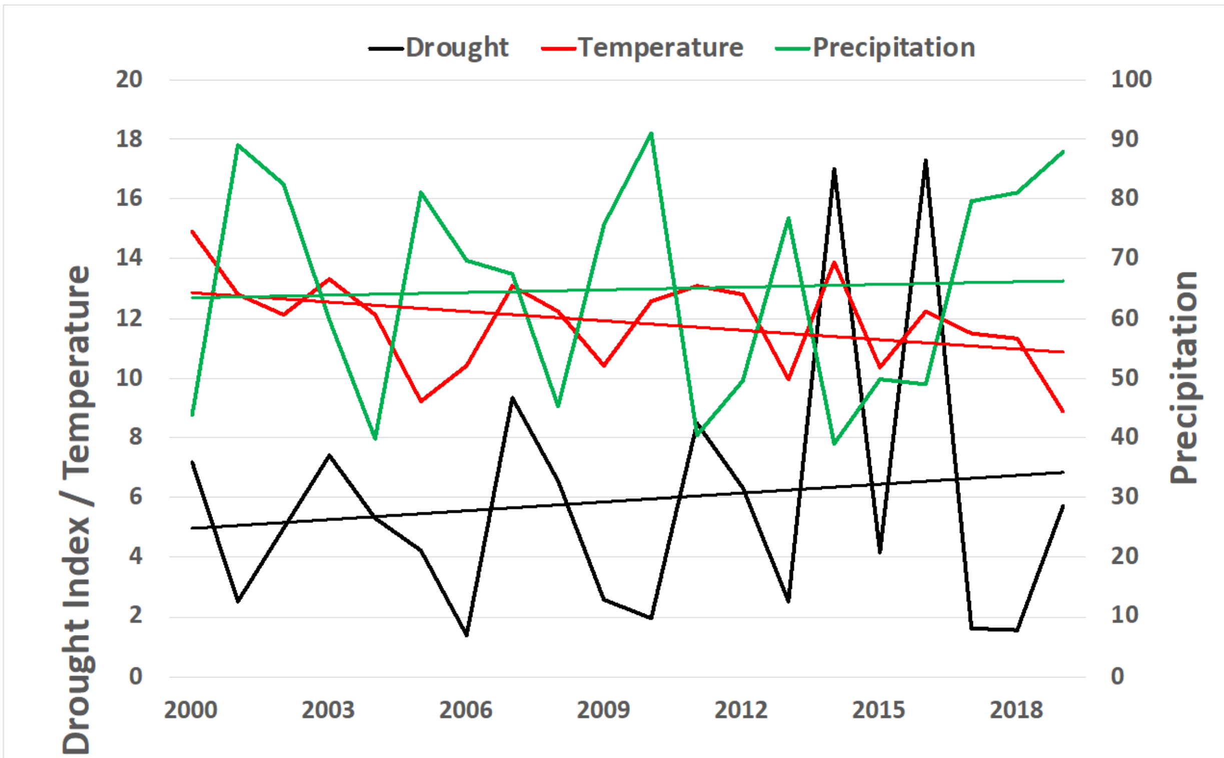

Figure 34. Annual July temperature, precipitation and derived drought index for the summer range of the Bathurst caribou herd.

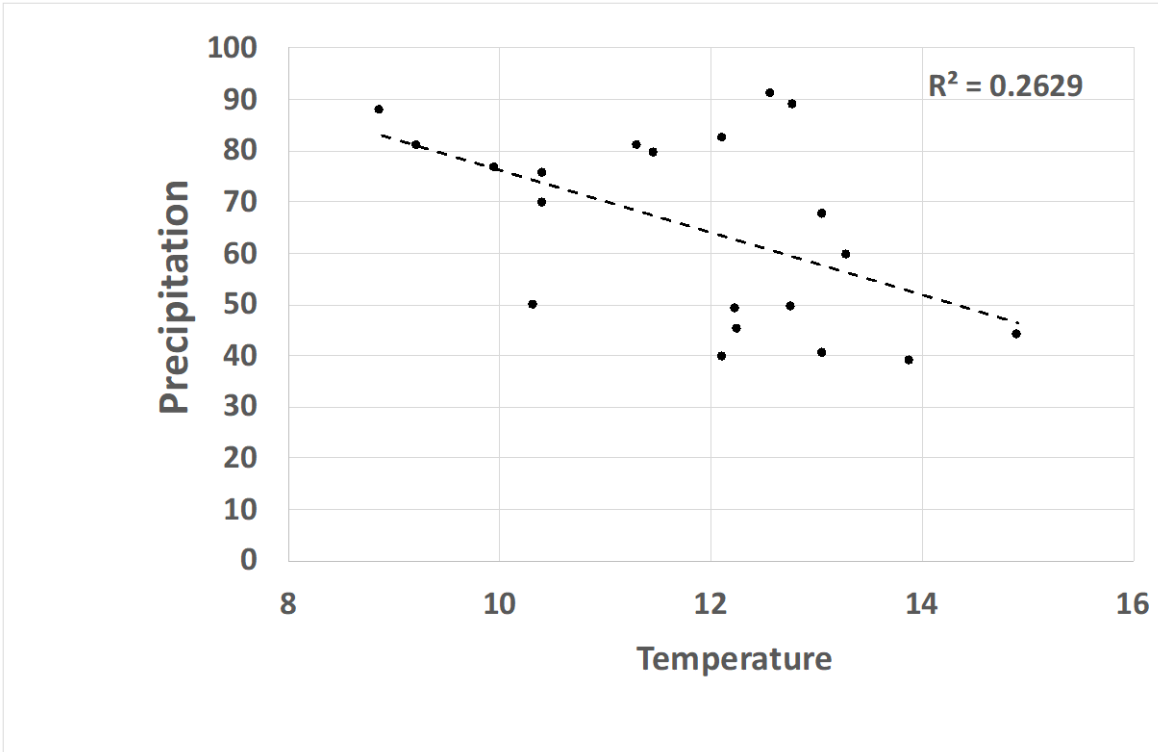

Figure 35. Relationship between July precipitation and temperature for the summer range of the Bathurst caribou herd.

APPENDIX B. BACKGROUND AND REVIEW OF MINE MONITORING AND MITIGATION EFFECTIVENESS

The Roads

The opportunities to learn about effective mitigation for caribou and roads are based on the four operational mine roads and one public highway on migratory tundra caribou ranges with monitoring and mitigation plans in NWT and NU. The application of potential mitigation to minimize or avoid effects (the mitigation hierarchy) is dynamic, and often intensified if thresholds such as caribou numbers within specific distances are met. Additional to the mine roads, there are two roads (Dempster and Tibbitt-Contwoyto winter road) which do not have formal monitoring and mitigation plans but where some information is available.

We used information available for:

- two public all-weather roads (Dempster and Inuvik-Tuktoyaktuk)
- three mine all-weather roads with public access (Mary River, Meadowbank/Whale Tail and Meliadine)
- a mine with all-weather ore-haul roads (Ekati)
- a mine ice road with public access (Tibbitt-Contwoyto winter road)
- a mine ice road without public access (Sabina Back River) in NU

Operational mines which have open pits distant from their main site use all-season roads to link the centrally located ore processing plants to the open pits and rely on a high frequency of haul trucks to move the ore (Whale Tail and Ekati). Three operational mines have all-season supply roads linking a barge landing with the mine site (Mary River, Meadowbank and Meliadine). Available annual or monthly traffic data was converted to daily totals and the number of minutes per vehicle to give an idea of potential gaps available for the caribou to cross.

The Mary River mine road is a 100 km road (the Tote Road) connecting an open pit iron ore mine to an ore shipping port on Milne Inlet, north Baffin Island across calving and summer ranges of North Baffin caribou. The road was constructed in 2007 following an existing trail and ore shipping started in 2014 to haul four then six million tons per year of ore to the port. In 2018, the passage rate is a haul truck every seven minutes which together with all other vehicles is a vehicle passage every six minutes (EDI 2019). In 2021, NIRB (NU Impact Review Board) is currently reviewing a third project certificate amendment request to triple ore shipping to 12 million tonnes, which requires constructing a railway to parallel the existing Tote Road.

The Meadowbank all-weather access road (AWAR) is a supply road to link Baker Lake barge landing site with the Meadowbank gold mine (mill, tailings storage, camp and airstrip) across the pre-calving and fall migration routes of the Lorillard and Wager Bay caribou herds. The deposit was mined 2010-2019 and mine life was extended with the discovery of further deposits. The development of those deposits required the Whale Tail all-weather road (WTR) which is an 80 km extension of AWAR north of the Meadowbank mill. The WTR was approved in 2016 (NIRB 2016) and production at the Whale Tail pit started in 2019. Subsequent to the 2016 approval, increasing WTR width so haul trucks could pass each other and increase in truck frequency was approved in 2020 (NIRB 2020). The haul truck frequency was predicted to average of 190 passages per day (a vehicle every 7.6 minutes) to 226 passages per day (every 6.4 minutes) with >75% as haul trucks (Kivalliq Inuit submission to NIRB 2020 proceedings).

The Meliadine AWAR is a 24 km road linking Rankin Inlet (supply barge landing point) to supply Agnico-Eagle's gold mine and crossed post-calving ranges of the Qamanirjuaq herd. The mine was constructed 2017-2018 and began production in 2019. The road is open to hunters with all-terrain vehicles and light trucks to cabins and traditional areas. The road has an unmanned gate at Rankin end of road to notify the public if road access is restricted during blizzards, caribou crossings or accidents. Saline water intrusion into the mine was higher than anticipated and has to be pumped out and trucked to discharge into the sea which contributed to an additional 1,620 brine trucks August-October 2019 (AEM 2020a App. J-1, AWAR Usage). Overall, traffic increased in 2019 compared to the predicted levels and averages 112 vehicle passages/day (every 12.5 minutes).

The Ekati diamond mine is an open pit mine which started producing in 1998. The mine has a total of 141 km of roads connecting the various open pits with the main site. The mine overlaps seasonal ranges of the Bathurst herd. The main roads are the 29 km Misery Road site and 26 km Sable haul road which began to be used in 2016. The proposed Jay Road northeast of Misery was constructed in 2017 but has limited subsequent traffic due to re-evaluation of the project. The 2017 Caribou Road Mitigation Plan for Ekati describes traffic frequency 1997-2015 to have an interval of 6-26 minutes between haul trucks on the Misery Road (ERM 2018). For the Jay Road the proposed interval would be an average of 56 round trips per day by long-haul trucks with an average of 12 minutes between trucks, not including seasonal traffic from the Tibbitt-Contwoyto Winter Road (TCWR). Light vehicle traffic in January to April with all other larger trucks and vehicles is 160-210 passes per day without the TCWR, and 290 to 340 passes per day with the TCWR, which is about one vehicle every four to five minutes.

The TCWR is a private partnership ice road which is open to the public and is used for both hunting and hauling supplies to mines since 1982. The 400 km road is 85% on lakes and annually open for about 67 days between February and April (JVWR 2021). In 2018, 8,209 trucks and in 2019 7,489 trucks which are dispatched as convoys of four trucks at 20-minute intervals. The road does not have a formal mitigation or monitoring plan although truck speed is regulated and one of the mine specific instructions lists giving wildlife right of way and reduced speed (JVWR 2021).

The Sabina Back River ice road is a 170 km winter ice road linking a barge supply site to a proposed inland mine site which is at a preconstruction stage. The ice road was constructed and used in 2018/2019 with a relatively low number of about 60 loads (ERM 2020).

The Inuvik-Tuktoyaktuk highway is a 138 km all season public highway from north of Inuvik to Tuktoyaktuk which was opened in fall 2017. The Cape Bathurst caribou herd seasonally crosses the road. The road links the Dempster Highway to the Arctic coast and is expected to attract tourism as there is a current moratorium on oil and gas drilling in the Beaufort Sea. The annual report notes that the road has, since 2017, had a traffic counter and in August 2018, monthly traffic peaked at 3,500 vehicles which is a vehicle every 13 minutes.

The Dempster Highway is a 737 km public highway from Dawson City in the Yukon to Inuvik in the NWT which crosses fall and winter ranges of the Porcupine herd. The Dempster was completed in 1979 and the road is used for supplies including for oil and gas exploration and tourism. Traffic frequency increased 1994-2008 and in 2007, average daily traffic was about 260 vehicles.

Dynamic Nature of Caribou Exposure

A herd's exposure depends on the orientation and extent of the road relative to seasonal distribution which is described as part of the baseline reported during environmental assessments. However, over the life of a road, the distribution of caribou may shift which then changes exposure. The season of exposure and subsequent rate of movements determines whether the caribou are more likely to pass through a site or spend time foraging such as in fall and winter. Variation in exposure means that corresponding monitoring and mitigation have to be nimble to accommodate annual changes from few to many caribou. For example, Ekati started construction in 1996 and Bathurst herd caribou distribution changed as abundance changed (see Figures 20, 21). Caribou exposure to Ekati mine is annually variable (Figure 38) and as distribution shifted, the season of exposure shifted. From 1998-2005, caribou exposure was highest in summer (Figure) while winter exposure was variable and increased after 2015 (Poole et al. 2021). Additionally, the neighbouring Beverly herd has shifted its distribution and now overlaps the vicinity of Ekati during winter 2017-2019, summer and fall 2016 and 2017, and fall 2018. In 2019, while the incidental sightings were about 10,000 caribou, the road surveys recorded almost 7,000 caribou which may suggest that a high proportion of caribou on site encounter the roads (Table 10) however, overlap between the incidental sightings and road surveys is possible.

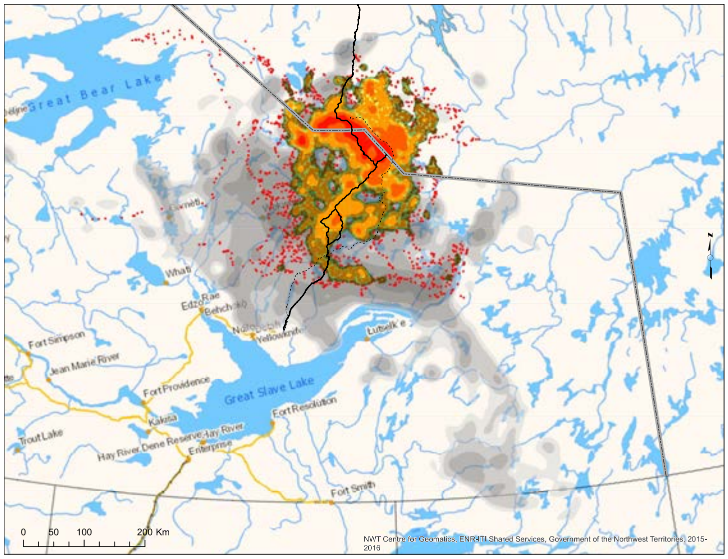

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Figure 36. Kernel density analysis for summer and fall seasons for the two time periods modeled in this report (1996-2009 – grey tones and 2010-2019 – colour tones). Red dots represent the collar-year data used in the CCE model. SGP and Grays Bay routes and existing winter road are shown.

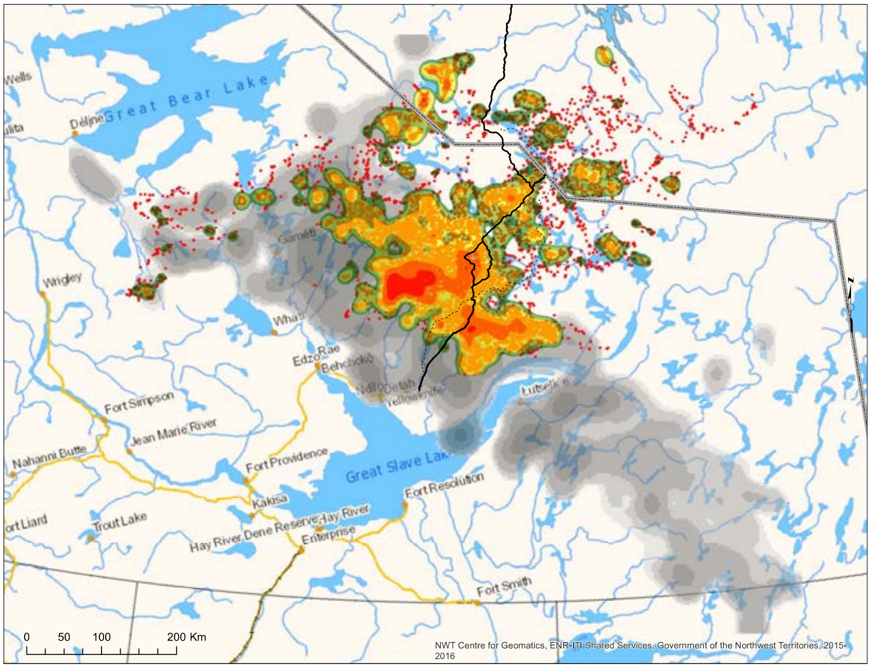

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Figure 37. Kernel density analysis for winter, spring and calving seasons for the two time periods modeled in this report (1996-2009 – grey tones and 2010-2019 - colour tones). Red dots represent the collar-year data used in the CCE model. SGP and Grays Bay routes and existing winter road are shown.

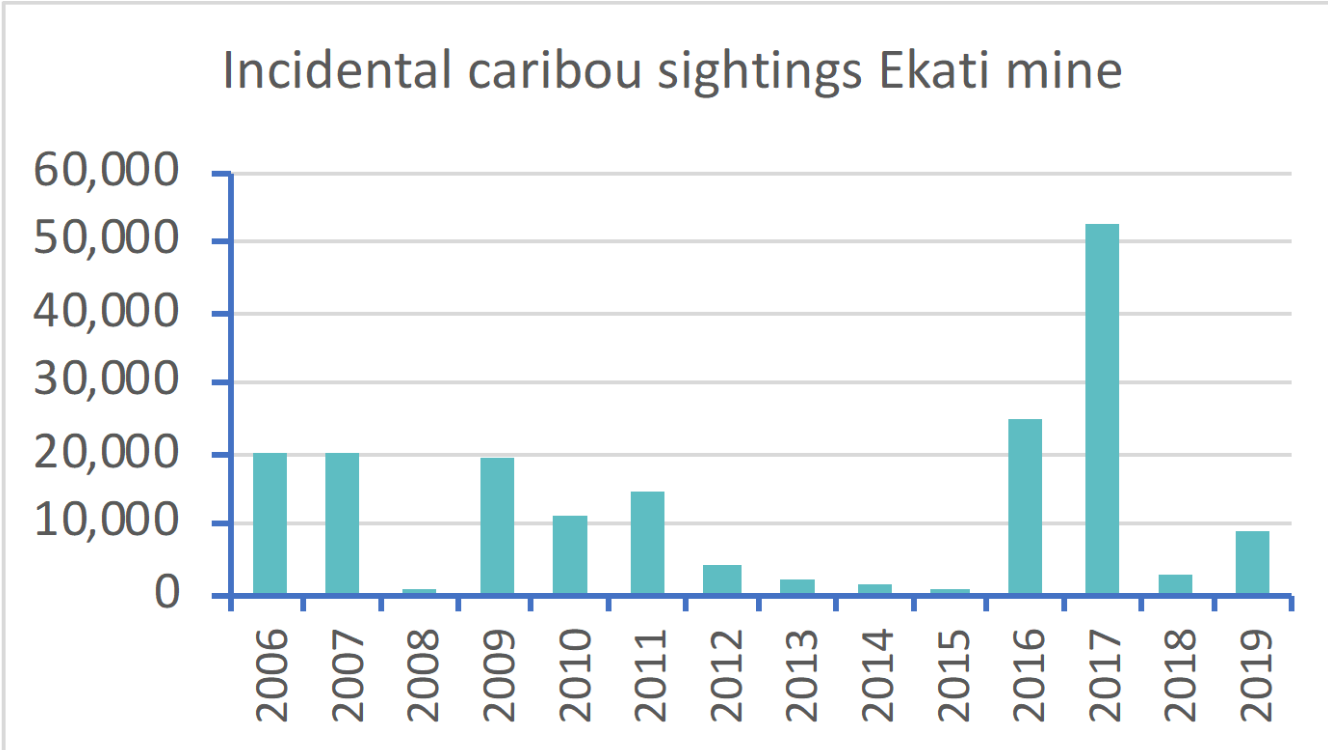


Figure 38. Annual incidental caribou sightings recorded at Ekati mine 2006-2019. The sightings likely include duplicate sightings (from data in DDMI 2020).

Table 10. Caribou numbers based on road surveys at Ekati mine (DDMI 2020) and truck frequency (based on monthly numbers provided by DDMI).

Roads	Misery	Sable	Lynx	Jay	Fox	Total
Total caribou	3,899	2,195	191	684		6,969
No. surveys	39	21	12	11		
Annual no. one-way truck passages	5,316	11,081			3,740	
Winter road trucks	2,220					

A similar pattern of high annual variability in the numbers of caribou exposed to the roads is apparent at Meadowbank mine's all-weather road. From 2007-2019, the average total count of caribou recorded during road surveys was 11,510±3,271 SE (range 920-41,840) (AEM 2020a).

Mines on post-calving and summer ranges can have large aggregations of caribou moving rapidly but their exact timing can be unpredictable. Within 1 km of the Meliadine AWAR road, Qamanirjuaq collared caribou have been present in only four years (winter and late winter) between 1993 and 2010. However, between 2011 and 2019 caribou started to annually migrate in large aggregations moving rapidly through the area in June and July. In 2019, for example on 26 and 27 June, behavioural observations were for groups of 3-27 caribou. Then on 28 and 29 June, the groups were in the 100s and 1,000s (AEM 2020b) and based on the number of collared caribou, can include all the cows in a herd in any one seasonal exposure. For example, in 2018, the Qamanirjuaq herd had 44 collared cows (AEM 2019): 40 collared cows were recorded within 5 km of the Meliadine mine all-weather road and 37 collared cows crossed the road during post-calving movements (AEM 2020b).

The least predictable timing and duration of exposure is during fall migration and winter (for the Bathurst herd, see Gunn et al. 2013). In contrast, pre-calving migration is relatively predictable in its timing in April-May depending on how far the calving ground is relative to a mine's location. The movement rates tend to be relatively high as the pregnant cows are strongly motivated to reach their calving grounds. Even though pre-calving migration is the most predictable in its time, it is still variable as for example, caribou reached the Meadowbank all-weather road seven days later in 2012 than 2011 (Boulanger et al. 2020). The importance of predictability of caribou exposure is to plan for the onset of mitigation such as road closures which can require the stockpiling of ore and fuel.

The exposure of caribou to mine roads is annually reported based on road surveys, incidental sightings and movements of collared caribou. The reporting of remote cameras is sporadic which is a limitation as camera data could be useful to evaluate effectiveness of mitigation. For example, remote cameras have been deployed at Ekati mine since 2011 but reporting has only been in 2014 and 2016. Monitoring of caribou movements relative to public highways or the TCWR is limited. Annual reports are produced on the Inuvik-Tuktoyaktuk highway which summarize wildlife accidents but more detailed information on the extent of exposure of caribou is not included.

Existing Mitigation Approaches

Given the extent of public concerns about roads and about the effectiveness of mitigation, recent recommendations or project conditions include mitigation for roads and caribou (Table 13).

Table 11. Summary of measures and recommendations during environmental assessments for industrial developments with roads after 2010, NWT and NU.

2013 Gahcho Kué Diamond Mine (MVEIRB 2013)
MEASURE 2 - De Beers will: Construct and operate the winter access road in a way that minimizes its adverse effects as a partial barrier to caribou movement and migration; Monitor to determine the presence and behaviour of caribou along the winter access road using different methods in addition to satellite collar data, such as track counts and visual observations; and Ensure that the caribou protection plan, the Wildlife Effects Monitoring Program and the Wildlife and Wildlife Habitat Protection Plan address the effects on caribou movement and behaviour along the winter access road.
Measure 3 - De Beers will:

Monitor project specific effects (e.g. size of the zone of influence, changes in habitat, effects of the winter access road on caribou movement and behaviour) and will report to the GNWT and make the results public on how project specific effects contribute to cumulative effects for the duration of the Project.
2016 Dominion Diamond Ekati Corp. Jay Project (MVEIRB 2016)
Measure 6-1: Road mitigations for caribou impacts a) In order to mitigate significant incremental and cumulative adverse impacts to caribou from roads used by the Jay Project, Dominion will: use convoys or other methods to manage traffic on the road in order to maximize interval between disturbances from vehicles; use real-time caribou collar satellite information and other detection systems to enable early detection of caribou in the vicinity of the road as a trigger for action levels for management responses; construct caribou crossing features along a minimum of 70% of the length of the Jay road. b) In addition, Dominion will update and revise the Wildlife Effects Monitoring Plan with the appended Caribou Road Mitigation Plan according to GNWT requirements under Section 95 of the *Wildlife Act* and any future Section 95 regulations. The plan(s) required under Section 95 will be in force for the duration of the Jay Project. c) The Caribou Road Mitigation Plan will detail the means to be employed to avoid and minimize habitat disturbance and include a response framework that links monitoring results to changes in mitigation. When developing monitoring and mitigation, Dominion will give special consideration to the esker crossing and specify contingency measures if caribou do not cross the Jay Road at the esker. d) Dominion will submit the Caribou Road Mitigation Plan to ENR for approval before constructing the Jay Road. As part of this approval process, the GNWT should provide the opportunity for public comment. Dominion will annually report monitoring results, success or failure of mitigation, and adaptive management to communities in person in a culturally appropriate manner.
Back River Sabina gold mine NIRB Project Certificate No.: 007 (NIRB 2017)
Term and Condition 39: The Proponent shall provide, within its Wildlife Mitigation and Monitoring Program Plan (WMMPP), measures for the staged reduction of project activities should caribou occur in proximity to the project site. The WMMPP will include a detailed description of all project activities, equipment, and components that would be managed during different phases of staged reduction mitigation events, including rapid and planned operational shutdowns should caribou calving or post-calving ranges overlap with the Project. Any planned activity restrictions/cessations should be of sufficient duration to take into account annual variation in the timing and distribution of calving and post-calving caribou interactions with the Project.
Whale Tail Pit Project Certificate No. 008 and NIRB Reconsideration Report and Recommendations for the Whale Tail Pit Expansion Project Proposal (NIRB 2019)
Term and Condition 30: work with both the Government of NU and Baker Lake Hunters and Trappers Organization through the Terrestrial Advisory Group to develop and update thresholds to trigger implementation of mitigation measures on both the AWAR and Whale Tail Haul Road, up to and including temporary road closures. The Proponent shall consider how these thresholds and mitigation measures reflect caribou life cycle

sensitivities as well as demonstrate how Inuit Qaujimajatuqangit was incorporated throughout the development of these criteria and procedures.
Term and Condition 65: To mitigate impacts to migrating caribou by constructing the Whale Tail haul road in a manner that facilitates caribou movement across the road.

Road Operation

Roads reviewed through environmental assessments have detailed mitigation plans. Additionally, in the NWT, under the *Wildlife Act*, wildlife plans are required for major developments including public highways and the plans include mitigation and monitoring. The Inuvik-Tuktoyaktuk Road's plan states that mitigation will be considered after discussions between ENR and management partners which may include guidelines for restriction of highway access and/or reduced speed limits during peak caribou migration periods (GNWT 2018).

Although the Back River Sabina gold mine (NIRB 2017) is at the pre-construction stage, its proposed mitigation is included (Table 12). The proposed gold mine is on the pre-calving migration and summer ranges of the Bathurst and Beverly herds and close enough to calving grounds, that a shift in calving would overlap with the proposed mine site. This possible shift is included as a contingency for a rapid and planned site shutdown (Sabina 2017). A 160 km long ice road links the marine laydown site to the mine site and monitoring and mitigation for the ice roads is summarized for the first year of operation in 2019.

Table 12. Comparison of mitigation levels for mine and public roads, NU and NWT.

	Meadowbank/Whale Tail	Ekati	Back River	Meliadine	Inuvik-Tuktoyaktuk
Decision Tree	Yes	Yes	Yes- no levels	No	No
Mitigation Plan	TEMMP	CRMP[1]	TEMMP[2]	TEMMP	WWHHP[3]
Level 1					
Daily site notification	X	X			
Yellow Alert signage					
Level 2					
Daily site notification	X	X			
updates to drivers every 3 hours	X				
Orange Alert signage		X			
Speed limits (20 km/h caribou <200 m or 40 km/h <500 m		X			
Level 3 (Migration)					
Daily site notification		X			
Suspend non-essential vehicles when caribou <500 m	X				
Red Alert signage		X			

Short-term or long-term road closures		X			
Road closed to non-essential vehicles	X				
Vehicles must stop and yield to caribou	X	X			
30 km/hr speed limit	X				
Hourly site-wide notification	X				
Road may be re-opened if Project tolerant caribou are grazing next to road and not migrating	X				
Level 3 non-migration					
Speeds reduced to 30 km/hr near caribou	X		<500 m road slow to 40 km/h		
Limit non-essential traffic	X				
Non-tree mitigation					
Site-wide notification of caribou presence	X		X	X	Signage
50 caribou at 5 km moving toward AWAR/mine				X	Potential speed limits
Year-round					
Suspend traffic when caribou <100 m road				X	
Vehicles must stop and yield to caribou			<50 m road with intent to cross Stop for 20 min	X	X
Caribou on site 30 km/h speed limit otherwise 50 km/h				X	
No hunting buffer	Voluntary	X		Voluntary	Possible

[1] Caribou Road Mitigation Plan (CRMP)
[2] Terrestrial Environmental Monitoring Plan
[3] Wildlife and Wildlife Habitat Protection Plan

Mine mitigation plans typically are applied as a hierarchy of increasing/decreasing levels of intensification (typically following a decision tree format). The use of decision trees goes back to at least 2008 (Mary River Project 2014) and since then, decision trees usually specify three levels and thresholds based on collared caribou, distance, and group size. Among mine projects, thresholds vary even for similar activities such as traffic and roads partly because the thresholds are a rule of thumb rather than tested. A weakness to the thresholds is that although they may be adjusted for season, they are not based on caribou behaviour. Caribou rely on leadership (and followship) during migration and tend to migrate in waves which are difficult to accommodate with thresholds based on relatively large group sizes.

The first and second levels of mitigation (Table 9) emphasize managing vehicle driver's behaviour including early warnings of caribou presence (central dispatch to alert traffic, daily briefings, signage). Speed restrictions increase vehicle stopping distance (avoid collisions) and the lower speeds may give caribou more time to assess the approaching vehicle as well as reduce dust creation from the road surface. The third mitigation level is managing traffic frequency. Traffic management relies on creating gaps in traffic through vehicles giving right of way to caribou, traffic convoys or temporary road closures. In the monitoring reports, terminology is imprecise as it is not always clear what is meant by partial closure vs closure and how convoys are used. The duration of closures is variable from minutes to days.

The Meliadine mine's 2019 Terrestrial Environment Management and Monitoring Plan's (TEMMP) lists thresholds for the AWAR as small to moderate aggregations of caribou (i.e., 1 to 50 animals) within 100 m of a road, trigger reduced vehicle speed to 30 km/h; large aggregations of caribou (i.e., 50 or more) within 100 m of a road, trigger traffic suspension, wildlife has the right of the way and vehicles must wait without disturbing their movements. Additionally, when large aggregations of caribou (>50 individuals) are detected within 5 km and moving toward the AWAR, the southern gate is closed to public cars and trucks although use of ATVs is allowed. AWAR use by hunters will be conditional on observing the 1 km no-shooting zone. In 2018 and 2019, 50 caribou were observed within 5 km of the Project footprint boundary during summer migration triggered work stoppage and closure and restrictions on AWAR. The work stoppage was for 191 hours in 2018 and 222 hours in 2019 which in 2019 was on ten days for periods varying from 6-24 hours (AEM 2020b). The height-of-land survey, behaviour and collared caribou reporting do not include an assessment of the effectiveness or responses to the work stoppage and the annual monitoring report did not analyze if and how the restrictions affected caribou movements or behaviour.

Snow clearing is part of mitigation undertaken to minimize barriers including limiting the height of snowbanks to approximately 1 m and snow plowing will be conducted in such a way as to limit the angle and vertical height of the snowbank edge which should be broken into sections with gaps, so caribou are not 'trapped' on the road. Managing traffic and drivers reduce the time that caribou are close to the road waiting to cross. This in turn, reduces the time during which the caribou are more alerted, foraging less and moving more.

The timing of mitigation may be the most important aspect of mitigation relative to caribou movements and migration. Indigenous elders have consistently identified the role of leadership to increase the likelihood that caribou will cross the road if that is their intent. 'Let the Leaders Pass' was the Porcupine Caribou Management Board's recommended mitigation for the Dempster Highway although in practice the policy struggled (Padilla 2010). For Meadowbank and Whale Tail roads, the importance of leadership and the observation that caribou migrate in waves, was raised during public hearings and testimony from Baker Lake.

The Independent Environmental Monitoring Agency (IEMA), while reviewing Ekati's Caribou Road Management Plant suggested that ensuring predictable breaks in traffic would allow or encourage those caribou adjacent the road, including the leaders, to cross (GNWT 2017). IEMA suggested when more than ten caribou are known to be present within 500 m of the road alignments, regularly scheduled breaks in all traffic for 20 minutes every two hours may be effective (Table 13). Similarly, when caribou are detected, stopping times should be considered to provide an opportunity for caribou to cross. If nothing else, the suggestions are appropriate objectives to test their effectiveness.

Table 13. IEMA proposal during Mackenzie Valley Environmental Impact Review Board Jay hearings 2016.

Table 1. Agency Proposal for caribou distance thresholds, criteria for resuming traffic speed limits and duration of the stop.

Distance of Caribou from the Road	Calving, Post-calving and Fall (<10 adults in a nursery group)	Calving, Post-calving and Fall (≥10 adults)	Northern (spring) migration (any group size)
Less than 200 m	Driver to remain stopped for 30 minutes, then may proceed at 20 km/hr if behaviour is unchanged and caribou are not moving towards the road	Driver to remain stopped until caribou are greater than 500 m from the road	Driver to remain stopped/short-term closure
200-500 m	Driver to remain stopped for 10 minutes, then may proceed at 20 km/hr if behaviour is unchanged	Driver to remain stopped until caribou are greater than 500 m from the road	Driver to remain stopped/short-term closure
In sight and greater than 500 m	Driver to proceed at 30 k m /hr	Driver to proceed at 30 k m /hr	Driver to proceed at 40 k m /hr

Hunting

Hunting likely increases caribou responsiveness to roads and especially traffic as seen for example, for elk (Proffitt et al. 2009, 2013) but for migratory tundra caribou direct evidence is rare. Plante et al. (2018) summarized how caribou response distance (ZOI) is greater when caribou are hunted. Plante et al. (2018) analyzed the spatial relationship between harvesting sites and caribou movements and the ZOI for Leaf River for three of five years was 12, 14 and 15 km. The authors noted that the road did not act as barrier to caribou movements although details were few. Movement rates were lower before road crossings than during or after the crossings suggesting caribou delayed before crossing. The study area is the transition between tundra and taiga and the road crosses the southern extremity of the Leaf River herd's winter range. The analysis was only for caribou exposed to the hunting and a high proportion (83%) of harvest sites were within 10 km of the nearest road although caribou were more likely to be harvested within meters from a road than at 10 km from it (Plante et al. 2016). Plante et al. (2016) did not include harvest levels and effort.

Hunting occurs along the Meadowbank and Meliadine all-weather roads while the Whale Tail haul road which extends north from the Meadowbank all-weather road is closed to public access. The TCWR is open to the public. For the Back River ice road, the trigger is if five or more groups of hunters are observed, "enhanced' management will be applied to limit use of the ice road through discussing possible options with the Hunters and Trappers Organization leaving a level of uncertainty about the mitigation options. In the first year of operation (2019), daily monitoring reported that hunters did not use the road. Both Meadowbank and Meliadine have a check station or gate where notices for the public can be posted to close the road when caribou are present, but effectiveness is not reported.

Effectiveness of Mitigation

The need to assess whether mitigation is effective is partly because it relates to the level of residual impacts of roads and traffic for caribou. Industry's approach to assessing mitigation effectiveness is to compare monitoring results with the effects monitoring thresholds and if the thresholds were not exceeded, mitigation is considered effective. Relying on the thresholds is logical if the threshold definitions are appropriate and comprehensive. In practice, we find shortfalls. At Meadowbank mine, the thresholds for sensory disturbance along the road were not defined while other thresholds describe the number of caribou directly killed by mine-related activities (Table 14).

Table 14. Accuracy of impact predictions – sensory disturbance and mortality thresholds along the AWAR, Vault Haul Road and Whale Tail Haul Road in 2019 (summarized from Table 11.2 AEM 2020a).

Potential Effect	Threshold
Sensory disturbance (Satellite-collaring data daily and weekly pit and mine-site ground surveys AWAR and haul road surveys, height of land surveys motion sensing cameras)	No threshold but decision trees followed when caribou are seen near mine facilities
Project-related Mortality (roads)	Caribou or muskoxen will not be killed or injured by vehicle collisions. Threshold level of mortality is two individuals per year.
Project-related Mortality (mine site)	Two caribou or muskoxen mortality per year because of mine-related activities (e.g. falling into pits, tailing, sludge or other means)

How to define thresholds can be problematic: for Meliadine mine all-weather road, the sensory disturbance threshold is 10% deflections based on the collared caribou pathways (AEM 2020b). Deflection was defined as "*if their path moved toward the AWAR but exhibited an approximately 90 degree turn or larger and did not move closer to the AWAR again*" (Golder 2021). However, the definition does not take into account paralleling behaviour by the caribou.

Annual monitoring reports vary in describing how mitigation is triggered and whether it was effective. Limitations include not integrating data reported at different timescales. For example, the Meadowbank Road closures and convoys and caribou road crossings were listed at the daily time scale while the average number of caribou seen during the road surveys and traffic frequency were tabled at the monthly scale (AEM 2020a). Other limitations include how objectives are worded and whether data were analyzed relative to conclusions about effectiveness. The report concluded:

> "The number and frequency of road surveys in 2019 demonstrate Agnico Eagle's commitment to avoiding impacts to caribou from the AWAR, Vault Haul Road and Whale Tail Haul Road. Mitigation measures such as reduced speeds and multiple road closures appear to be minimizing road-related effects including mortality and restricted caribou passage." (AEM 2020a) [our underlining].

There is insufficient testing to determine whether signage and speed reduction are effective for caribou sensory behaviour and road crossing rates in the absence of road closures. However, speed reduction may influence sensory disturbance and reduce the probability of collisions, but this has not yet been targeted in behavioural studies.

At Ekati mine, 2019 was the third year that the CRMP was in operation (DDMI 2020). Level 2 and Level 3 require caribou to have the right-of-way, and for traffic to keep distances of at least 100 m away from caribou, and slow vehicle speed to 20 km/h. The red level requires road closures, but the report only briefly stated that closures ranged between 0.02 h to 7.5 h but the number of closures, the type and frequency of traffic was not given nor the caribou responses – whether they crossed or not. Exposure of caribou to the Ekati roads is high at least in 2019 as road surveys observed 2,554 caribou walking on or within 500 m the mine roads. Golder (2020) acknowledged that "*Information regarding speed limit reductions and road closures related to the CRMP was not recorded, i.e., specific action, date, time, location (road), frequency, duration, and length of road segments*." Additionally, the report noted that *"Documenting the mitigation and monitoring efforts associated with the CRMP will enable ongoing evaluation of the program to determine its effectiveness in mitigating and reducing incidents at and along roads…"*,

The 2019 Ekati annual monitoring report suggested that the roads do not impede caribou movement. But it is difficult to substantiate the apparent lack of a barrier effect given missing analyses (i.e., more than summaries) on caribou crossings or deflections and delays from collars, road surveys, behaviour studies or the remote cameras. The different monitoring approaches raise questions about their effectiveness in detecting deflections from the roads. Previously, at the Ekati open pit mine on the Misery haul road, 55-60% of the barren-ground caribou tracks deflected from the road based on snow tracking (2002-2011) but based on remote cameras, the deflection rate was 1-2%. However, the cameras field of view was different from the area sampled along the road by the track surveys. Further if caribou are typically deflected from crossing a road, they likely would have deflected further out than remote cameras positioned along the road surface. Behavioural studies at Meadowbank and Meliadine (AEM 2020a and b) reported that caribou were more likely to be >300 m than closer to the road.

The 2020 annual report on Meliadine mine reveals the difficulties of assessing mitigation effectiveness despite considerable monitoring effort. The Meliadine Mine TEMMP (AEM 2020b) objectives include determining mitigation effectiveness. The TEMMP specifies that locations of the collared caribou cows and a threshold of 50 caribou within 5 km of the road trigger mitigation actions (advisory notices, speed restrictions and work suspension). Although the collars and numbers of caribou (from weekly sighting surveys) approaching the AWAR triggered whether the road was partially or completely closed for a total of 165 hours over ten days in July 2020, details are lacking about the timing of the crossings relative to vehicle passage, numbers of vehicles and their timing. The track/sighting surveys recorded a total of 14,637 caribou during 17 surveys in 2020 but the annual report does not have the data to allow estimating a daily sighting rate (Section 9.1, AEM 2021). The report does mention groups of 2,000 and 3,000 seen on the all-weather road on 6 and 16 July when the road was closed and open, respectively (AEM 2021: Table 12.3). Only annual traffic frequency by vehicle type is reported (AEM 2021).

The monitoring at Meliadine also includes a behaviour study and remote cameras during the July caribou post-calving migration. The behavioural scans were to measure caribou behaviour changes in response to passing vehicles and predators or blasting. About half the 56 30-minute behaviour scans between 1 and 17 July 2020 included responses to convoys, haul trucks, light trucks, ATV and audible rifle shots (from hunting) despite partial and total road closures. Scans which recorded caribou crossing the road were few (6/56) and were mostly the caribou close to the road (within 50 m) but sample size was small as most caribou groups were further than 300 m from the road (AEM 2021 Appendix D). The objectives for the remote cameras were whether caribou selected certain road construction features (height and slope, esker or rock coverings) and whether there were high use crossing sites consistent with the sites identified by elders or by collared caribou. The 41 remote cameras recorded a total of 6,001 caribou which included a large number of caribou crossing the road but those data were not examined relative to traffic frequency and the timing of the road closures.

An analysis of caribou crossing the Back River ice road during pre-calving migration did not find that caribou slowed down or deflected from the road (ERM 2020 Appendix 5C). Traffic frequency was extremely low (only 60 haul loads and additional monitoring vehicles). Recently, the route of pre-calving migration of the Bathurst herd after 2017 changed the herd's exposure to the Back River winter road (ERM 2020 Appendix 5B). ERM (2020) reported that in 2017, 2018, and 2019, 26% of collared Bathurst cows crossed to the east side of Bathurst Inlet which was unexpected. The winter ice road construction and hauling were delayed in 2019 and the road season was extended after 15 April into May which should have triggered intensified mitigation after April 15 (ERM 2020). But the mitigation had not been specified, leading the company to acknowledge a need for a formal procedure to record how a caribou observation leads to a road closure so that this data can be better reported. The delayed road closure led to a requirement for an analysis of the collared caribou movements.

To date, while annual mine monitoring could measure mitigation effectiveness, the criteria for assessing effectiveness, analyses and reporting are limited. Three of the four mines with roads used for hauling ore do close the road when caribou are in the vicinity and caribou do cross when the roads are closed. The problem is that prolonged closures affect mine operation, but the timing and duration of closures needed for caribou to cross remain uncertain partly through lack of analyses and traffic frequency. The needed scale is daily or even hourly to measure the gaps in traffic: 360 vehicles/day is a vehicle every 4 minutes which given the effect of sight, sound and dust train may not be enough of a gap for a caribou to cross especially as the caribou avoid the close vicinity of the roads. Typically, haul trucks are managed through a central dispatcher which together with GPS technology means truck positions are monitored (for example, www.ae.ca/projects/details/tibbit-to-contwoyto-winter-road-dispatch-software). However, currently only the annual monitoring for the Mary River mine reports daily frequency (EDI 2019).

Lack of monitoring hampers understanding the impacts of the public highways (Dempster and Tuktoyaktuk-Inuvik) on caribou and those roads do not have the same standard of mitigation as required for private (mine) roads. The TCWR does not have a formal monitoring-mitigation plan although one mine stipulated that drivers give right of way to caribou, there is no closure of the road for caribou (JVWR 2021).

Besides the mine monitoring, a few specific studies were designed to describe caribou responses (residual impacts) after or during mitigation. The studies used collared caribou (Table **15**) but the collar data have limitations as low sample sizes restrict inferences. We did not include published road crossing studies (Panzacchi et al. 2013, Johnson and Russell 2014, Plante et al. 2016, Johnson et al. 2019) as the extent of mitigation actions, if any, are unknown.

Table 15. Studies that measure residual impacts (after mitigation actions) for caribou and roads in the NWT and NU.

	Impact	**Hunting**	**Mitigation actions**	**Reference**
Tibbitt Contwoyto winter road	Reduced crossing rate	Yes	Speed restriction and convoyed trucks	A. Smith in Prep.
Back River ice road	No measured impact	No	Speed restrictions, caribou have right of way	ERM 2020
Ekati Misery/Sable	Delays and reduced crossing rate	No	Speed restrictions, caribou have right of	Poole et al. In Prep.

			way, vehicles halt for caribou	
Meadowbank AWAR	Delays spring migration crossing with possible deflections	Yes	Speed restrictions, caribou have right of way, vehicles halt for caribou and road closures	Boulanger et al. 2020

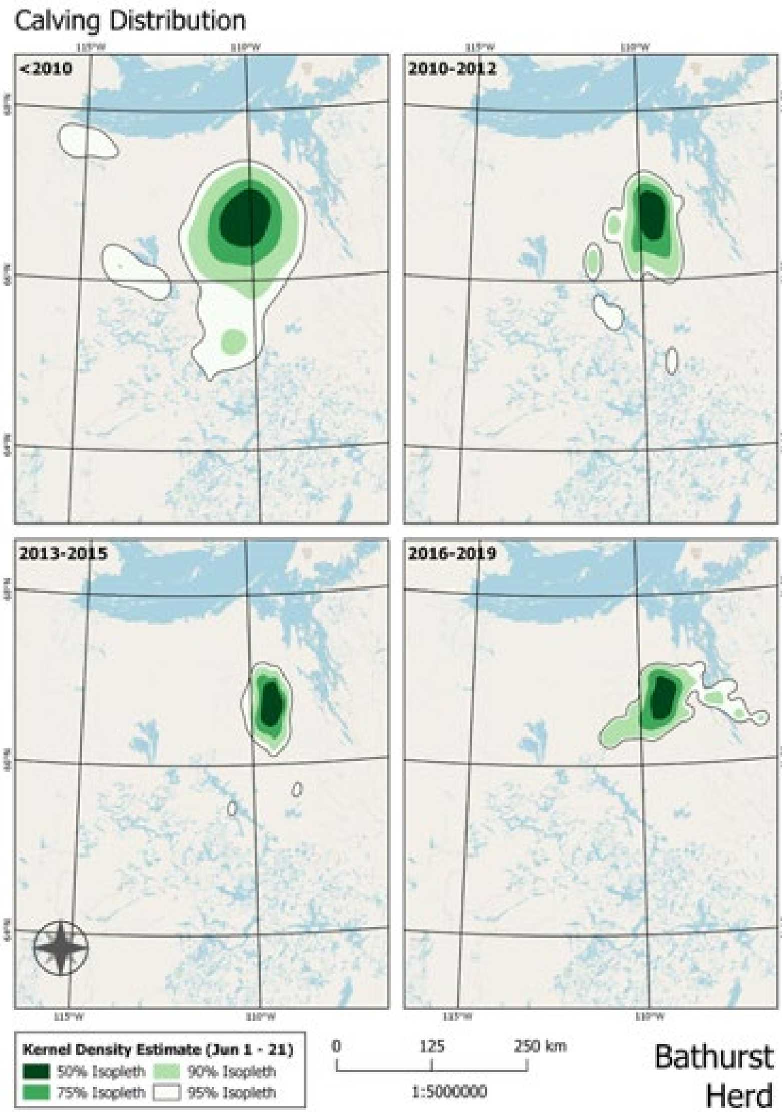
Findings for caribou responses to the 575 km TCWR are preliminary as the research is on-going (Angus Smith pers. comm. 2021). The road is open to the public and is used for both hunting and hauling supplies to mines typically. The loaded trucks are dispatched in convoys of four vehicles every 20 minutes and their speed limit is 10-25 km/hr while returning empty trucks are limited to 60 km/hr on the ice. During late winter and the start of pre-calving migration in 2018 and 2019, caribou deflected from the road and did not cross (Angus Smith pers. comm.). In 2018 and 2019, the number of loaded trucks was 8,209 and 7, 489 respectively. Public access is not managed, and the road does not have a mitigation or monitoring plan (Wikipedia 2021).

For Ekati mine, Poole et al. (2021) summarized collared caribou encounters relative to landscape features including lakes and the Ekati mine and its major roads. The roads have on-going mitigation and monitoring including traffic alerts, speed restrictions and brief closures (DDMI 2020) but details and analyses of effectiveness are unavailable. Thus Poole et al. (2021) examined the sequences of movement from 280 individual pathways to estimate residual impacts. Within 30 km of the mine: 27% (76/280) passed straight through the 30 km zone, primarily (60%) during pre-calving migration. Within 3 km of the mine, 35% (98/280) changed direction at a lake or other natural landscape feature and 38% were within 3 km of the mine and its two major haul roads (106/280). As some pathways entered, left and re-entered the 3 km zone, there were 155 encounters of which 57% (88/155) delayed within the 3 km zone and 43% (67/155) did not delay. Of the delays, 83% (73/88) did not cross the mine and its roads. Encounters that did not have delays, 66% (44/67) did not cross. Overall, delays with no crossings averaged 108±15 h SE (range 3-648 hr) based on 72 encounters. Delays were shorter when the 14 encounters included crossings: 36±10 SE (range 6-144). Delays in fall and summer were twice and three times as long as in winter, respectively. The analyses did not include traffic frequency as the data were unavailable at the daily scale.

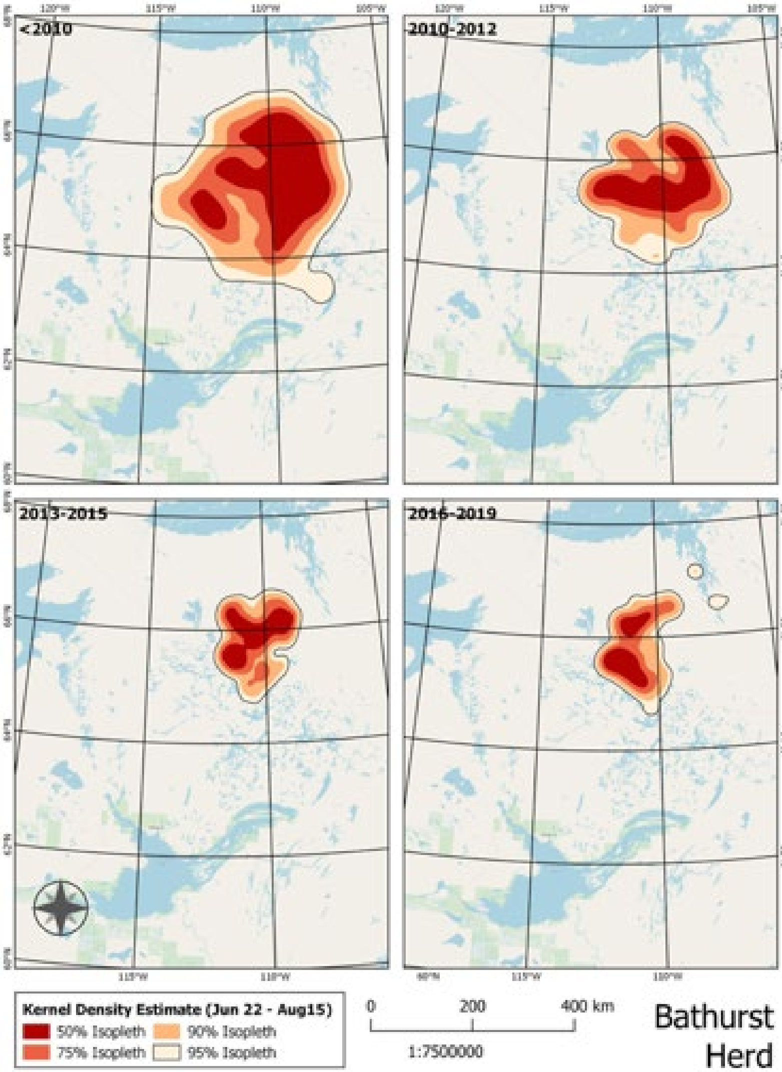
For the Whale Tail haul road (no public access) and the Meadowbank all-weather road (mine supply and public access) during pre-calving migration in 2018 and 2019, analyses of collared caribou demonstrated reduced caribou crossing frequency and delays (Kite et al. 2017, Boulanger et al. 2020). Estimated delays were 4.3 and 2.5 days for 2018 and 2019 respectively. In 2011-2016, before Whale Tail Road was built in 2017-2018, 55% (12 of 22) of collared caribou deflected north around the Meadowbank mine but when Whale Tail Road north of Meadowbank mine was built, the rate of deflections dropped to 14% deflections (three of 23 caribou). During pre-calving migration, mitigation includes speed restrictions and road closures although road closures reduced but did not halt all traffic as essential traffic and observers used the road (AEM 2020a). For the collared caribou analyses, traffic frequency was unavailable. Seventy-four percent (17 of 23) of collared caribou crossings were when the roads were closed to non-essential traffic (Boulanger et al. 2020).

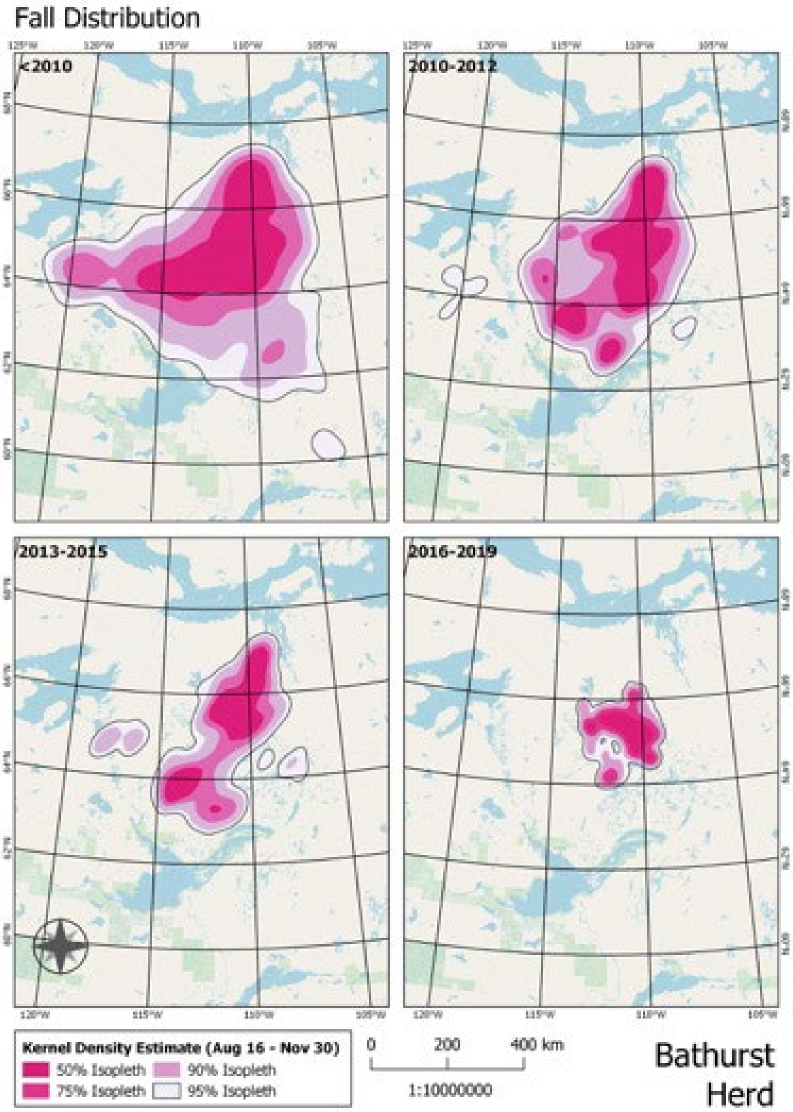
The importance of traffic frequency is clear from published literature. In Norway, pregnant wild reindeer migrating to their calving ground had to cross a highway with a vehicle/3 minute (500 vehicles/day). The cows deflected (changed direction and paralleled the road) for about five days before crossing when traffic frequency was lowest after midnight. During fall migration, traffic frequency was lower (300 vehicles/day) and the reindeer crossed the road directly (Panzacchi et al. 2013). The surrounding terrain is mountainous, and the caribou migration corridor is narrow where the wild reindeer have to cross the road. Although cabin development is restricted in the area, road traffic is not subject to mitigation (Olav Strand pers. comm. 2021). In summer at the Prudhoe Bay oilfield, Murphy and Curatolo (1987) reported that when the traffic frequency was 15-32 vehicles/hr, caribou crossing success of a road was low (the road was paralleled by an elevated pipeline). Plante et al. (2018) reported from analysis of collared caribou that a mine haul road on the summer range of the Leaf River herd had a barrier effect as habitat selectivity indicated lower crossing rate although low sample size prevented measuring movement rates. Concentrate ore is hauled along an all-weather 150-kilometre road from the Raglan nickel mine complex to a shipping point on Hudson Strait. Although these results support a residual effect of haul roads, the extent of monitoring and mitigation and traffic frequency is unknown.

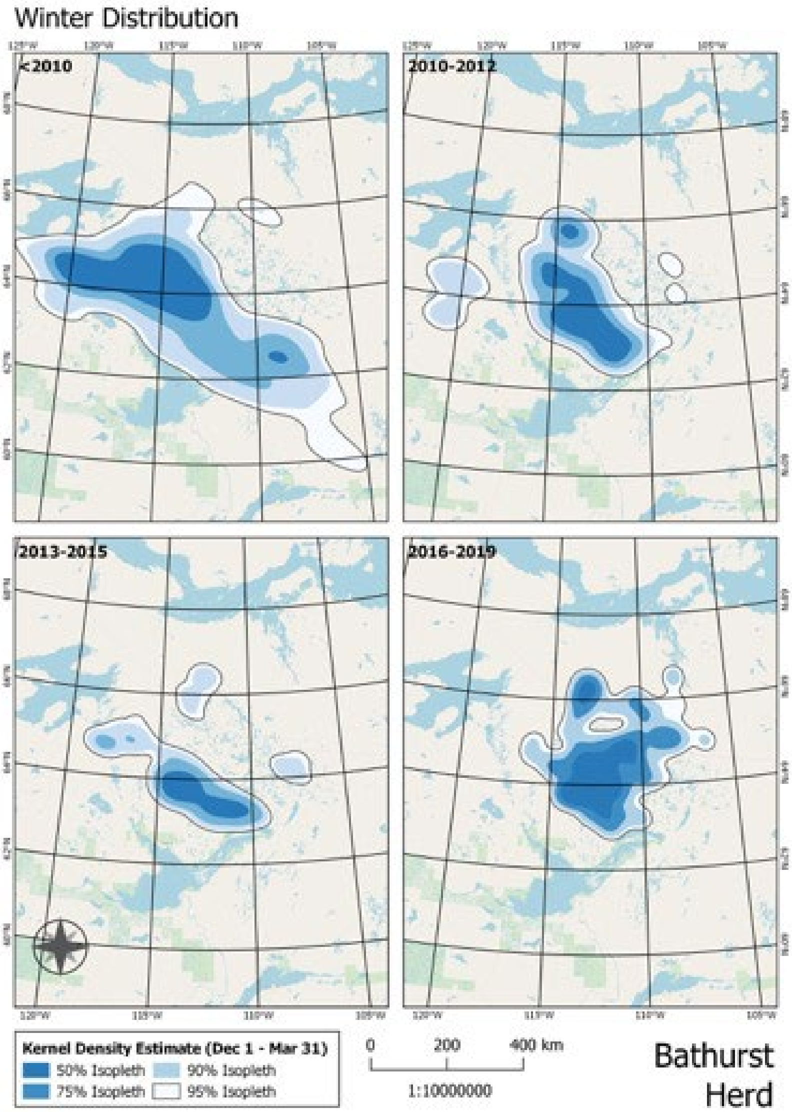
APPENDIX C. SEASONAL DISTRIBUTIONS 1996-2019

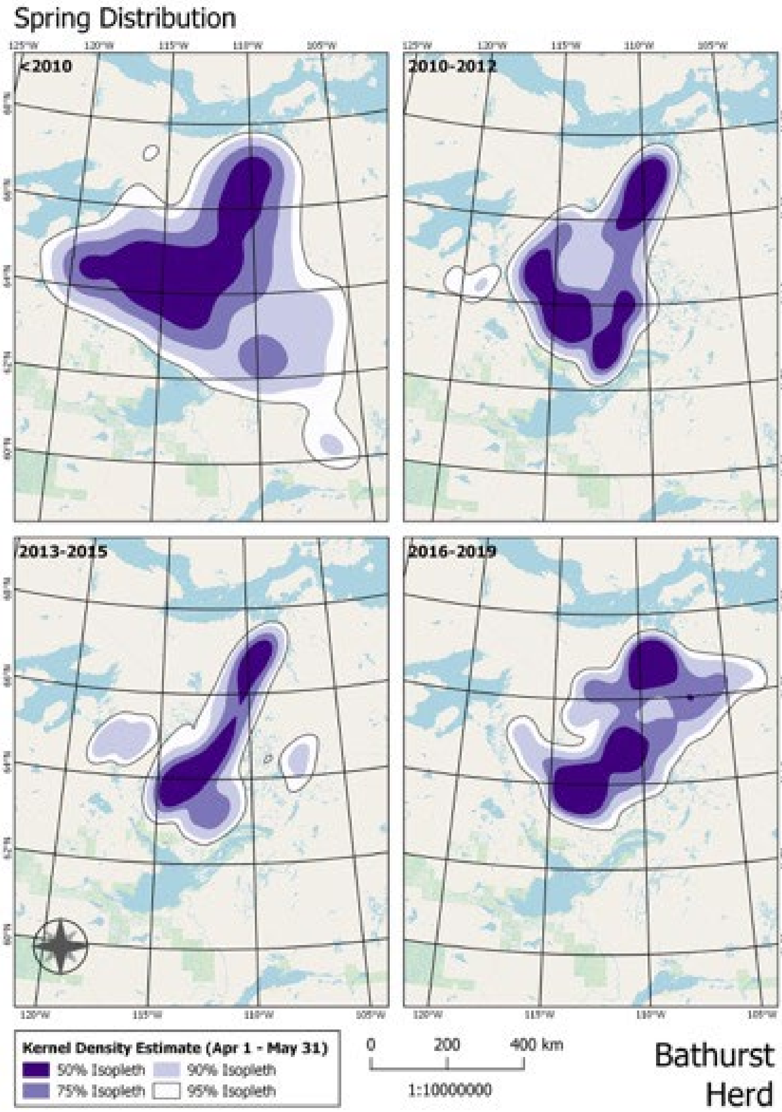


Summer Distribution




Fall Distribution
<2010
2010-2012
2013-2015
2016-2019
Kernel Density Estimate (Aug 16 - Nov 30)
50% Isopleth
75% Isopleth
90% Isopleth
95% Isopleth
0
200
400 km
1:10000000
Bathurst
Herd


Winter Distribution
<2010
2010-2012
2013-2015
2016-2019
Kernel Density Estimate (Dec 1 - Mar 31)
50% Isopleth
75% Isopleth
90% Isopleth
95% Isopleth
0
200
400 km
1:10000000
Bathurst
Herd


Spring Distribution
<2010
2010-2012
2013-2015
2016-2019
Kernel Density Estimate (Apr 1 - May 31)
50% Isopleth
75% Isopleth
90% Isopleth
95% Isopleth
0
200
400 km
1:10000000
Bathurst
Herd