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Appendix 16B

Vulnerability Assessment of the Bathurst, Beverly/Ahiak, and Dolphin and Union Caribou Herds to the Proposed Grays Bay Road and Port Project

Vulnerability assessment of the Bathurst, Beverly/Ahiak, and Dolphin and Union caribou herds to the proposed Grays Bay Road and Port project

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Executive Summary

In 2025, we used our Caribou Cumulative Effects model to project the vulnerability of three migratory tundra caribou herds—the Bathurst, Beverly/Ahiak, and Dolphin and Union herds—to the potential effects of the proposed Grays Bay Road and Port (GBRP) Project. The Project, proposed by West Kitikmeot Resources Corp., is a 230-kilometre (km) all-season access road linking a deep-water port on the Arctic coast to the former Jericho Mine site. Future phases could connect to the proposed Slave Geological Province (SGP) Corridor, an all-season road that may replace the Tibbitt-Contwoyto ("Tibbitt") Winter Road, an ice road currently used to service northern mines.

We combined satellite and GPS collar movement data to assess the vulnerability of caribou within 5 km of the Grays Bay Road. In simulations using 100 randomly selected Bathurst cow-years from 2010–2024, average annual exposure under the combined GBRP and SGP scenario was 26.7 days. Under the GBRP-only scenario, exposure averaged 9.4 days per year. Most encounters were during the calving-to-rut period, when lactation and fat storage are critical. When the collared caribou were within 5 km of the road, we assumed their movements were delayed by a day and that, for the baseline scenario (low traffic and no hunting), this reduced foraging time by 6% with 3% increases in walking and running time, and reduced feeding intensity by 3%. These penalties were supported by monitoring at the Meadowbank and Meliadine mines. The reduced forage intake was modelled to project a change in body weight by the fall which in turn influences pregnancy rates and overwinter calf survival.

Climate exposure was assessed using updated indicators from the CARMA climate database, including growing degree days, drought index, insect harassment indices, snow depth, rain-on-snow events, and freeze-thaw cycles. Among the three herds, the Bathurst herd range had the warmest summers. Projected climate for 2050, under an optimistic warming scenario, indicated that mean summer temperatures across the Bathurst herd range will exceed current mean maximum temperatures. We used the climate projections to adjust forage quality, insect activity, and growing season timing in the Energy-Protein sub-model.

Under the current climate, GBRP and SGP roads could reduce cow and calf weight 1.28 kg and 1.99 kg, respectively, compared to the no development baseline, which correspond to a small decrease in pregnancy from 87.3% to 84.9% and an increase in calf mortality from 45% to 55%. However, under a warmer climate scenario, the impact of the GBRP and SGP roads increased to 3.48 kg for cows and 5.64 kg for calves. These weight increases corresponded to pregnancy being reduced to 79.5% and calf mortality increased to 73%.

Under current climate and no development, the population remained stable over 10 years. With the addition of GBRP and SGP infrastructure, the model projected a 3.6% annual decline in population. Under future climate alone, a 7.5% annual decline was projected, and when combined with development, the annual rate of population decline reached 12%.

Mitigation scenarios were assessed by varying traffic volume and hunting activity. Under high traffic and active hunting, foraging penalties were tripled. Road closure windows and convoying strategies were modelled based on existing mitigation approaches used at other Arctic development sites. Under the most stringent mitigation (low traffic, no hunting), the population decline rate for the GBRP and SGP scenario improved from 10.1% to 5.3%.

The Beverly/Ahiak herd's seasonal range, by contrast, showed minimal overlap with the GBRP corridor, particularly after 2010. As a result, we did not model the BVA herd further. The Dolphin and Union herd has little overlap with the GBRP route, with its calving and summer range centered on Victoria Island. Seasonal migrations across sea ice are critical for this herd's life cycle. However, movement data revealed increasing variability in the timing and location of sea-ice crossings, likely due to shifting ice conditions.

For the Dolphin and Union herd, the simulated effects of GBRP were minimal. The observed reductions in body weight—56 grams for cows and 308 grams for calves—resulted in negligible changes to pregnancy and calf survival. As a result, population modeling was not conducted for the Dolphin and Union herd under the parameters of this study.

This technical assessment, based on empirical data and validated models, concludes that development-related exposure from the GBRP and associated roads results in measurable impacts on caribou energetics and demographics, particularly for the Bathurst herd. Climate change introduces additional strain, and the combination of both factors significantly accelerates projected population decline. However, mitigation measures targeting traffic and hunting pressure have the potential to reduce those effects when applied consistently.

Table of Contents

List of Figures

List of Tables

Introduction

The West Kitikmeot Resources Corp. (WKR) has applied to the Nunavut Impact Review Board (NIRB) to build the Grays Bay Road and Port (GBRP) Project in Nunavut (NT) (https://www.westkit.ca/gbrp). The Project is a deep-water port, a small craft harbour, landside' port infrastructure, and a 230-kilometre (km) all-season access road to connect the Grays Bay Port to the site of the former Jericho Mine, close to Contwoyto Lake, and the former Lupin mine. The road will be open to commercial and public vehicles, with controlled access radio communications protocols to ensure safe operation. WKR will monitor and manage use of the port and road to keep the public safe and to reduce effects on wildlife and the environment. WKR expects that construction of the Project will take approximately five years.

In some years, the Tibbitt to Contwoyto ("Tibbitt") Winter Road may be extended north to Jericho Station allowing seasonal access to Yellowknife, Northwest Territories (NWT). In Phase 2, the Grays Bays all-season road will be extended to the end of the NWT's proposed Slave Geological Province (SGP) Corridor, an all-season road that the NWT government is pursuing but that is not yet funded. The NWT's proposed SGP Corridor (GNWT 2019) is a likely replacement for the Tibbitt Winter Road that has been annually constructed since 1982 to supply mines from Yellowknife. However, the increasingly warmer winters have shortened the ice road season and the NWT government is looking to build an all-weather replacement.

In 2024, we assessed the vulnerability of the Bathurst (BAH) caribou herd (Russell et al. 2024a) to proposed NWT SGP Corridor including an extension to Grays Bay. We used our Caribou Cumulative Effects (CCE) model (Russell et al. 2019), and we considered (a) the effectiveness of mitigation, (b) monitoring to detect residual effects, and (c) landscape and herd level management options to offset and/or trade-off residual effects. Specifically, our scenarios quantified mitigation effectiveness with respect to hunting, traffic management, and road closures. Previously, we have also applied the CCE model to assess the potential impact of the Hope Bay mine project on the Dolphin and Union (DU) and Beverly/Ahiak (BVA) herds (Russell 2018).

We updated information since our assessment for the SGP road (Russell et al. 2023):

> (1) As more information has been reported since 2024 about how caribou respond to roads both with and without mitigation, we have included updated monitoring and mitigation sections.
>
> (2) We have used updated collar data for the BAH herd (2020–2024) and 1996–2024 collar data for the BVA and DU herds.
>
> (3) Recognizing the rapid changes from a warmer climate, we have integrated a warmer climate into our assessment based on a global assessment of climate change for the three herds (Russell and Gunn 2025).

For the Grays Bay Road,, we use a four-step pathway to assess caribou vulnerability to the road and a warmer climate based on IPCC (2007)'s approach to describe vulnerability. The four steps are to assess potential effects as a function of the sensitivity of a system to change, its exposure to those changes, and how management and mitigation can support the adaptive capacity to minimize potential effects (Figure 1). The outcome of adaptive capacity relative to potential effects is the vulnerability of the caribou–people system.

The importance of climate for migratory tundra caribou has attracted attention and climate indicators have been linked to range quality (Heggberget et al. 2002, Fauchald et al. 2017), *Rangifer* body condition (Weladji et al. 2003, Albon et al. 2017, Mallory and Boyce 2017), and overall herd responses for individual herds or geographic regions (Post and Forchhammer 2008, Joly et al. 2011, Tyler 2010). However, attempts to extrapolate findings from one study to *Rangifer* as a whole is simplistic (cf Post and Forchhammer 2008 with Tveraa et al. 2013, Veiberg et al. 2016, and Gustine et al. 2017). The difficulty of generalizing is partly because migratory tundra caribou have annual ranges that widely vary in landscapes and climate.

Recognizing the different geographies of individual herds, Russell and Gunn (2025) applied the CCE model to assess the impact of climate warming on three representative migratory tundra herds. This effort was part of the initiative of the World Wildlife Fund (WWF) to project effects of climate change on biodiversity into the future. WWF's Global Arctic Programme initiated the Arctic Conservation Forecast Project[1] (ARCON4) using climate forecasts and interdisciplinary expert deliberations to describe Arctic ecological changes across the 21st century under different warming scenarios. In that WWF study, we examined climate warming and the BAH herd, Central Arctic herd (Alaska) and Taimyr herd (Russia) as representative herds to provide a global picture of potential impacts under climate scenarios of "optimistic" (low warming) and "pessimistic" (high warming) and considered 2050- and 2100-time frames.

Our goal is to assess the vulnerability of the BAH caribou to landscape changes from the Grays Bay Road and a warmer climate and the vulnerability of the DU and BVA herds with respect to the Grays Bay Road.

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[1] https://www.arcticwwf.org/our-priorities/biodiversity-and-nature/arctic-conservation-forecast-initiative/. For further information on this initiative, please contact info@arcticwwf.org.

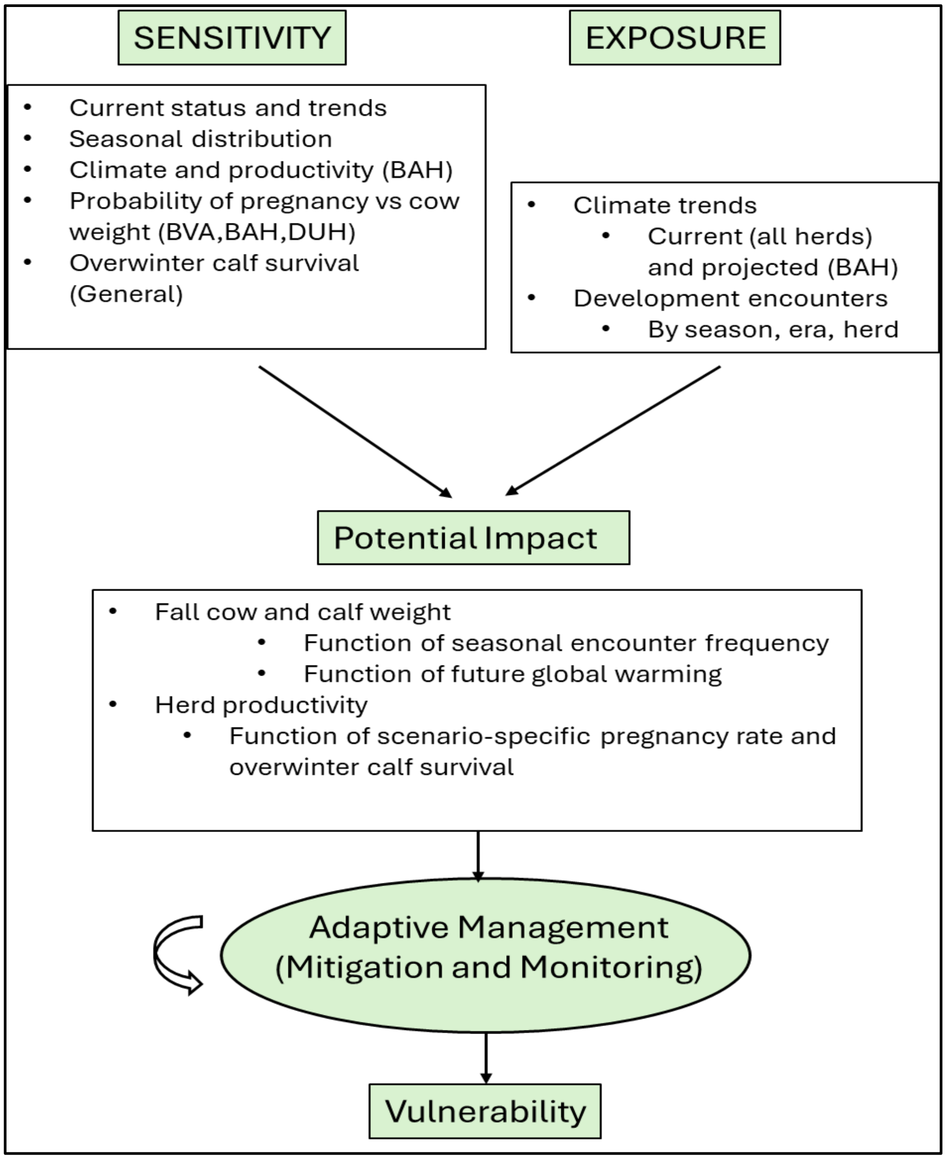


Figure 1 Flow diagram of pathway components incorporated into the vulnerability analysis

Caribou Cumulative Effects Model

The CCE model is based on previously published Energy-Protein which has been developed and improved since the 1980s (White et al. 2014). The current CCE model framework is three linked sub-models; the first sub-model is the Movement sub-model (Figure 2).

For the present application, the Movement sub-model requires the following inputs to be configured:

1. The stratification and spatial layer of the landscape based on vegetation, climate and development

2. The simulation period including the start Julian date, the number of years the model will run and the number of collar/years to analyze
3. Input spatial distribution of proposed development
4. Zone of Influence (ZOI) buffer width for development polygons (metre [m])
5. ZOI buffer width for roads (m)
6. A csv file with the satellite or global positioning system (GPS) collar data

Thesub-model algorithm has the following steps:

1. *Allocating development and the ZOI on the landscape:* Thesub-model begins with the proposed development polygon and road layers. All combined developments and roads (initial and projected) are buffered according to the user specified inputs to generate the final ZOI risk layers.
2. *Sampling from the caribou collar data:* The input collar data consists of multiple caribou each with data for multiple days. For the start timestep and Julian day, thesub-model randomly samples the collar data to pick an individual caribou. In this way a random sample of movement trajectories can be obtained for each year and iteration of thesub-model run. Wherever possible thesub-model will use daily locations from the collar data but if there are missing days, thesub-model interpolates the location on those days assuming a uniform travel speed between dates bounding a period with missing locations. At the end of this step the algorithm produces a set of location coordinates for each iteration and day of the simulation.
3. *Overlaying the collar data with vegetation, climate and development layers:* The final step in the algorithm is to overlay the location of a caribou on each iteration and day with the corresponding layers for vegetation, climate, and development ZOI. At the end of this step thesub-model produces a "Location" table identifying the stratum that an individual caribou experiences on each iteration and day of the simulation. This table summarizes exposure and is used as a direct input for the Energy-Protein sub-model.

The second sub-model, 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). Based on the spatial location of an individual caribou on a given day (from the Movement sub-model), natural environmental conditions (e.g., snow, food, insect harassment) dictate the proportion of the day that caribou will feed, rest, and move. Much of the data used to link environmental factors came from group scans and focal animal data (White et al. 1975; Russell et al. 1993; Witter et al. 2011). As new studies become available the algorithms can be easily updated.

Aside from the Movement sub-model output, a number of climate indicators are required to set up any Energy-Protein sub-model run. Herd-specific climate was obtained from a climate database developed within the CircumArctic Rangifer Monitoring and Assessment (CARMA) Network (Russell et al. 2013). In the Energy-Protein sub-model:

1. Snow depth impacts energy expenditure during winter, both in travelling through the snow and in digging feeding craters to access forage (Russell et al. 1993).
2. Energy balance is also impacted due to less time spent foraging and ingesting food, if snow is deep (Russell et al. 1993).
3. Early spring snowmelt provides early green forage in late spring, coinciding with calving and post-calving (Finstad 2008).
4. Warmer summer conditions affect the phenological changes in forage, higher biomass but lower quality (digestibility and nitrogen; Finstad 2008).
5. Warmer summers mean higher insect harassment (Russell et al. 1993). Higher insect activity reduces foraging time and feeding intensity and increases standing, walking and running.
6. Warmer summers (days >19^{o}C) also impacts foraging time.

The outputs include the fall body weight of a cow and her calf which equate to the probability of a cow becoming pregnant and overwinter calf survival.

The third sub-model, the Population sub-model (Figure 2), uses the pregnancy rates and calf survival as well as 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.

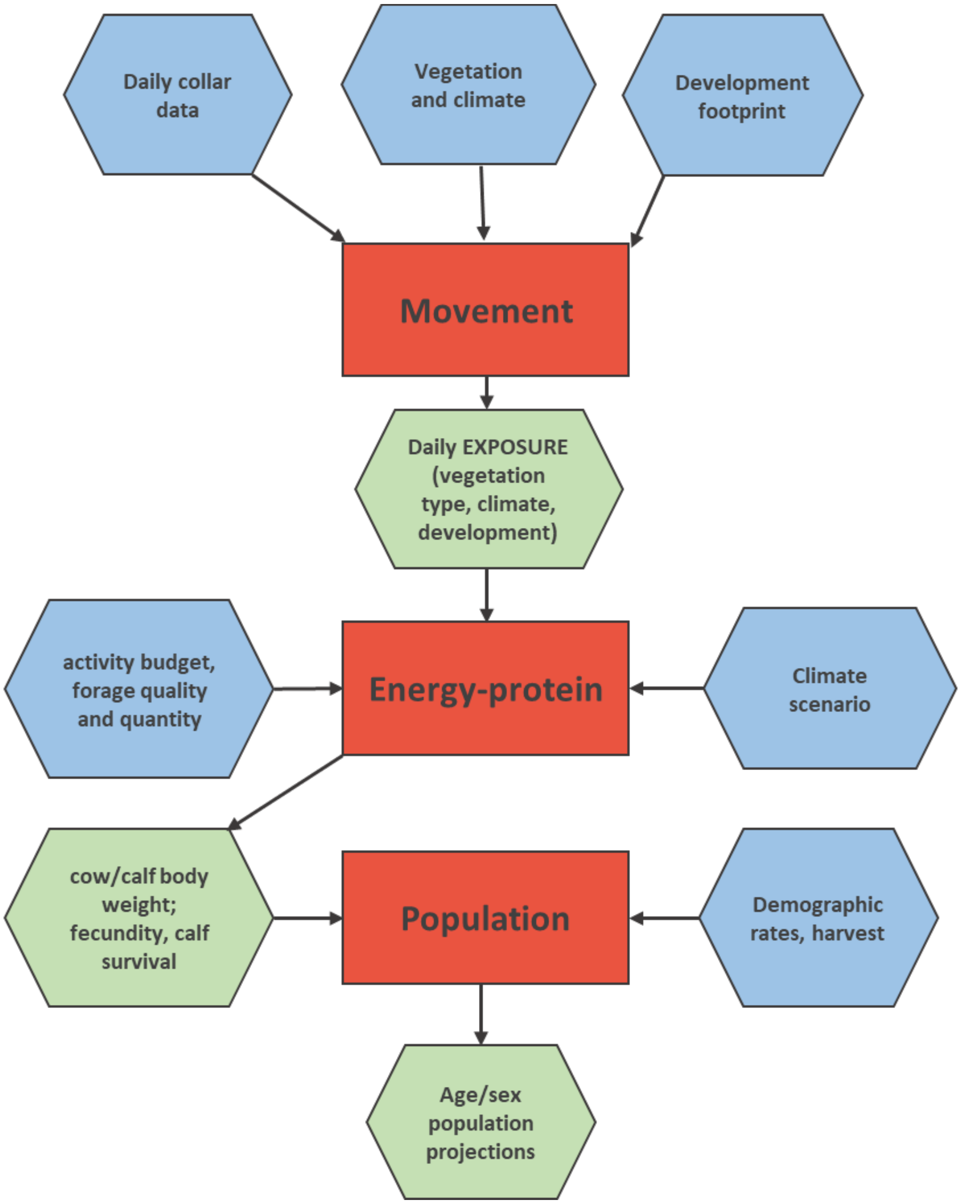


Figure 2 Schematic of the CCE model showing sub-model components (red), inputs (blue) and outputs (green)

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), BAH herd (Nishi 2017), BVA and DU herds (Russell 2018). The model have recently been applied to assess the current impacts of development on the PCH (Russell and Gunn 2017), impact on the PCH from potential hydrocarbon development on Alaska's north slope (Russell and Gunn 2019, Russell et al. 2021), assessment of impacts on the BAH herd from the SGP Road, and future fate of migratory tundra caribou based on climate scenarios (Russell et al. 2025).

Vulnerability Analysis Components

1. Sensitivity

Sensitivity is the degree to which a climate variability or change (Glick et al. 2011) affects a natural system such as caribou ecology. It is the internal attributes of a system such as herd distribution and herd productivity. Productivity in turn reflects the key relationship of cow body weight and the probability of pregnancy or calf body weight and calf overwinter survival. Sensitivity reflects the responsiveness of a system to climatic influences and disturbance.

Productivity and Herd Trend

Recent herd estimates (Figure 3) indicate the declining numbers in the region, with herd numbers declining by 98 percent (%) for the BAH, 89% for the DU herd, and 63% for the BVA herd, although recently the declining trend for the BVA herd has reversed. The history of the "Beverly" and "Ahiak" herds has been controversial (Adamczewski et al. 2015).

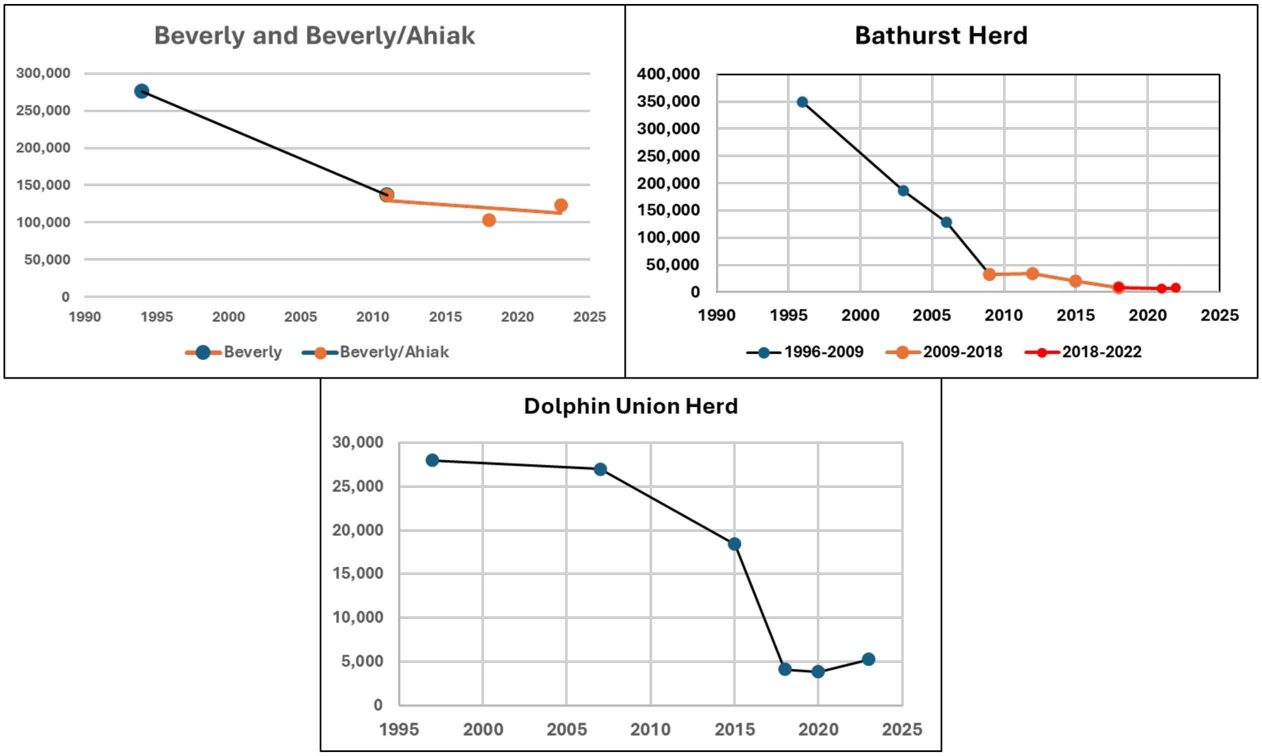


Figure 3 Population estimates of the BVA, BAH, and DU herds from mid 1990s to 2023

Bathurst

The Bathurst herd has been in decline since a high of 472,000 in 1986 to the current estimate of 6,851 in 2022. Reporting on the latest population estimate, Adamczewski et al. (2019) and Boulanger et al. (2024) 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 and 2009, a 15% decline from 2009 to 2018 and a stable population from 2019 to 2022 (Boulanger et al. 2024). The population has remained stable since 2018 at an average estimate of 6,880 animals. Adult cow survival 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 demonstrated an increasing trend, with an average survival rate of 69%; this survival rate was attributed to natural mortality because the maximum harvest was limited to 300 (primarily bulls) from 2010 to 2015 in the NWT and then further reduced to 0 in the NWT, and a limited harvest of 10 bulls in NT.

Beverly/Ahiak

In 1994, the Beverly herd size was estimated at 276,000 ± 106,600 (standard error [SE]) adult caribou, but monitoring was minimal from 1994 to 2007. The next calving ground survey in 2002 revealed that caribou densities had dropped by more than half since 1994; subsequent annual surveys from 2007 to 2009 demonstrated an extreme decline in numbers of calving cows, and by 2011, no newborn calves were seen (Adamczewski et al. 2015). One explanation is that the herd declined to low numbers and migrated north with the Ahiak herd (Adamczewski et al. 2015). The BVA herd was last counted in 2023 with an estimated population of 153,000, which is a significant increase since the years of decline (Campbell et al. 2025).

Dolphin and Union

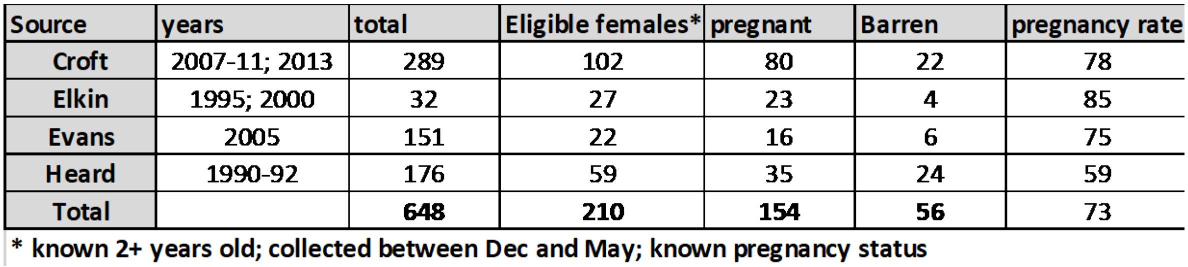
The DU herd is recognized as Endangered under the NWT *Species at Risk Act* (2023); Special Concern under the federal *Species at Risk Act* (2004) although the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) re-assessed the DU caribou as Endangered (2017). The status is based on a sharp decline over a 26-year period; from 28000 in 1997; 5,226 ± 635 SE in 2023 (Leclerc et al. 2023). The herd depends on seasonal migrations between Victoria Island and the mainland; when the ice melts earlier and freezes up later, this poses a risk to the migrating caribou (Poole et al. 2010, Ekaluktutiak Hunters and Trappers Organization 2019).

Probability of Pregnancy and Fall Cow Weight

An index of annual pregnancy rate (% breeding females) has been monitored in the BAH herd during census 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 of breeding females was 80.1 ± 3.2 SE%.

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, collected since the 1960s across the circumpolar north (Russell, unpublished data), includes four collections for the BAH 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 kilogram [kg] versus 76 ± 9.1 kg, respectively; p=<0.001). We calculated a significant logistic regression 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).

Similarly, Gunn (unpublished data) shared data on collections of female caribou for the DUH from 1987 to 1992. Based on the 72 eligible females (both pregnancy status and weight available), data also showed a very similar logistic curve between relative body weight and probability of pregnancy (Figure 4).

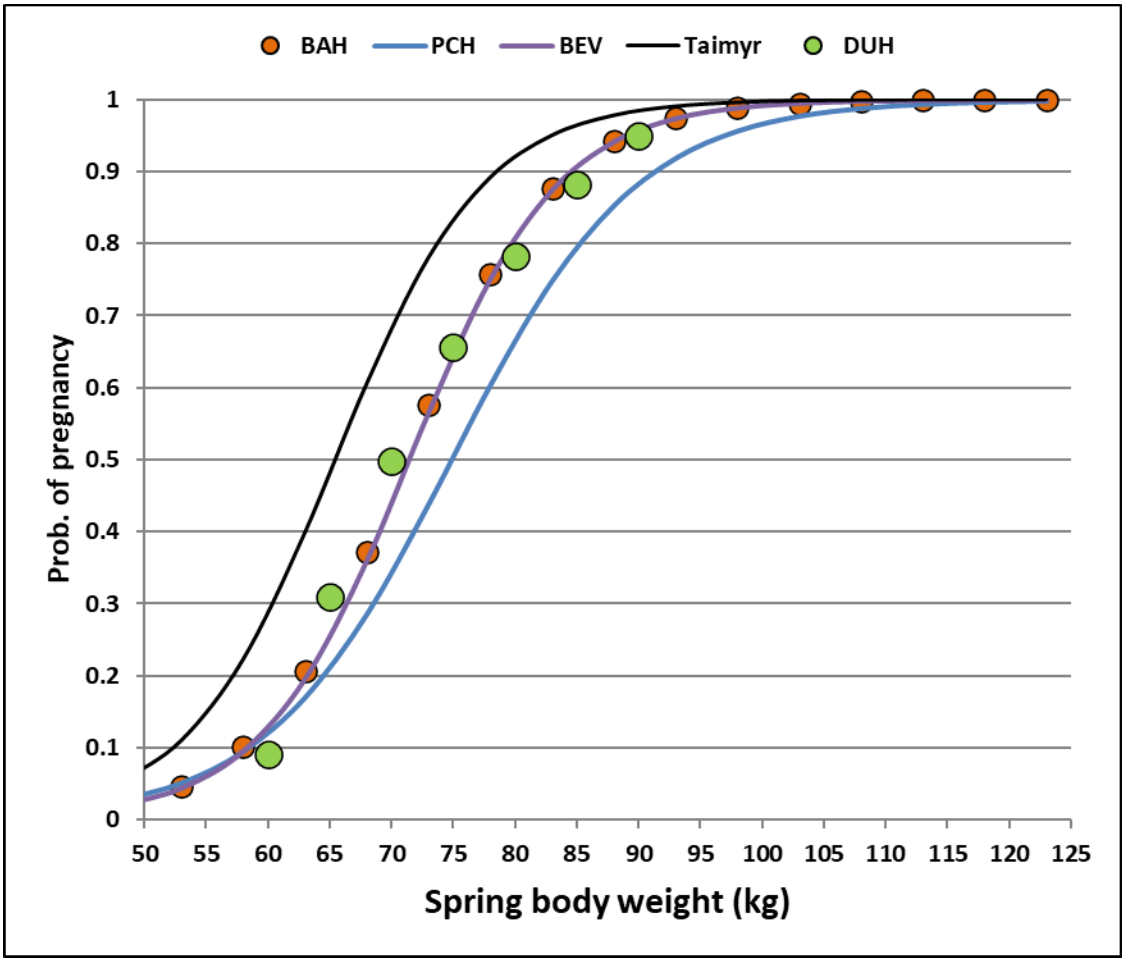


Figure 4 Probability of pregnancy in relation to spring body weight for migratory tundra *Rangifer*

We interpret the curves of body mass and the probability of pregnancy 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 BAH and DU herds, we would conclude that they are less resilient but more productive than the PCH, similar to the Beverly herd and less productive but with similar resilience as the Taimyr herd in Russia (Figure 4). The significance of the resilience is their capability to recover after difficult environmental conditions.

Overwinter Calf Survival and Fall Calf Weight

In the CCE model, we use the fall body weight of the calf to estimate overwinter calf survival. Baseline calf body weight was equated to average overwinter calf survival. Departures from calf body weight was converted to changes from baseline overwinter survival using a relationship we developed from data presented in Figure 17 of Arthur and Del Vecchio (2009). Arthur and Del Vecchio (2009) captured and weighed calves in the Central Arctic Herd in September and tracked survival with collared cows through March. Calves that were heavier in September were more likely to survive through the following winter ($p < 0.0001$). We combined their Table 1 (mean calf weights by year and capture location) with their Figure 5 (overwinter survival by year and capture location) to produce our Figure 5. Thus, using Arthur and Del Vecchio's (2009) data, we applied a 1 kg change in baseline calf body weight to a 5% change in overwinter mortality. Being underweight likely increases the susceptibility of the calf to predation, the energetic costs of foraging and movements, and accidents.

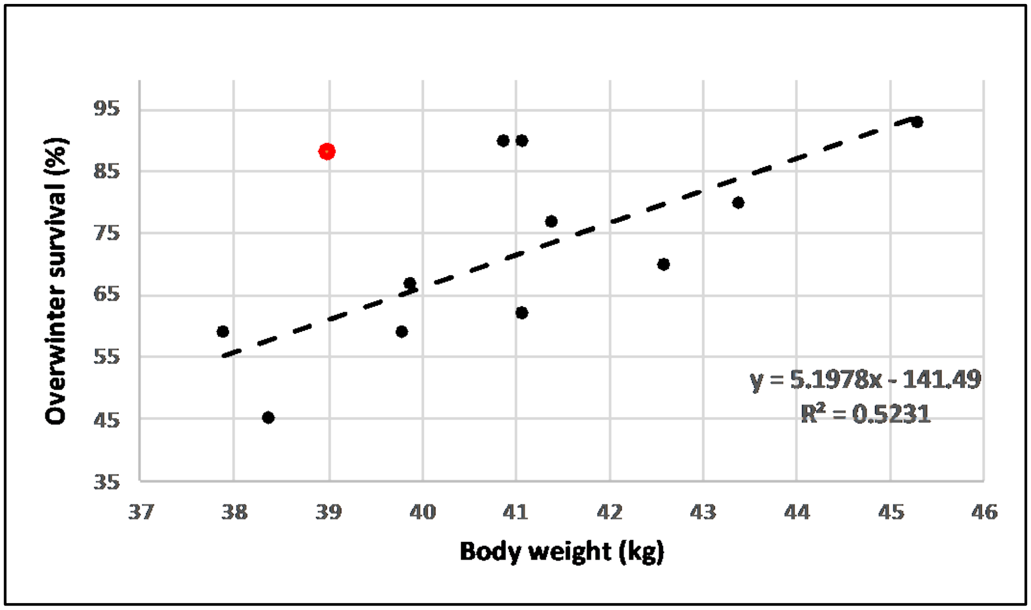


Figure 5 Correlation between fall body weight and overwinter survival calculated by combining data from Arthur and Del Vecchio (2009) Table 1 and Figure 5. The red dot is considered an outlier in the formulation of this correlation.

Seasonal Distribution

Distribution is a key component of assessing the Grays Bay Road. As herds contract and expand in size, their seasonal ranges also contract and expand which changes their exposure to the Grays Bay proposed route and regionally variable climate. The distribution is based on kernel density analyses. In Figure 6 through to Figure 13, the central red zone is the 50% kernel density while the yellow (left map) and the green (right map) is the 95% kernel density.

Bathurst

The BAH herd's range, especially the winter and summer range, contracted and shifted (Russell et al. 2024a, Mennell 2021) when the herd declined rapidly (1996–2009); the herd then stabilized (Figure 6) but at relatively low numbers (2010–2022). For our assessment of the GBRP project, we updated the collar dataset to compare distribution of the herd between 2010–2019 and 2020–2024. Therefore, from Figure 8 to Figure 12, we can compare if there have been any obvious distributional shifts, especially from the 2010 to 2019 period.

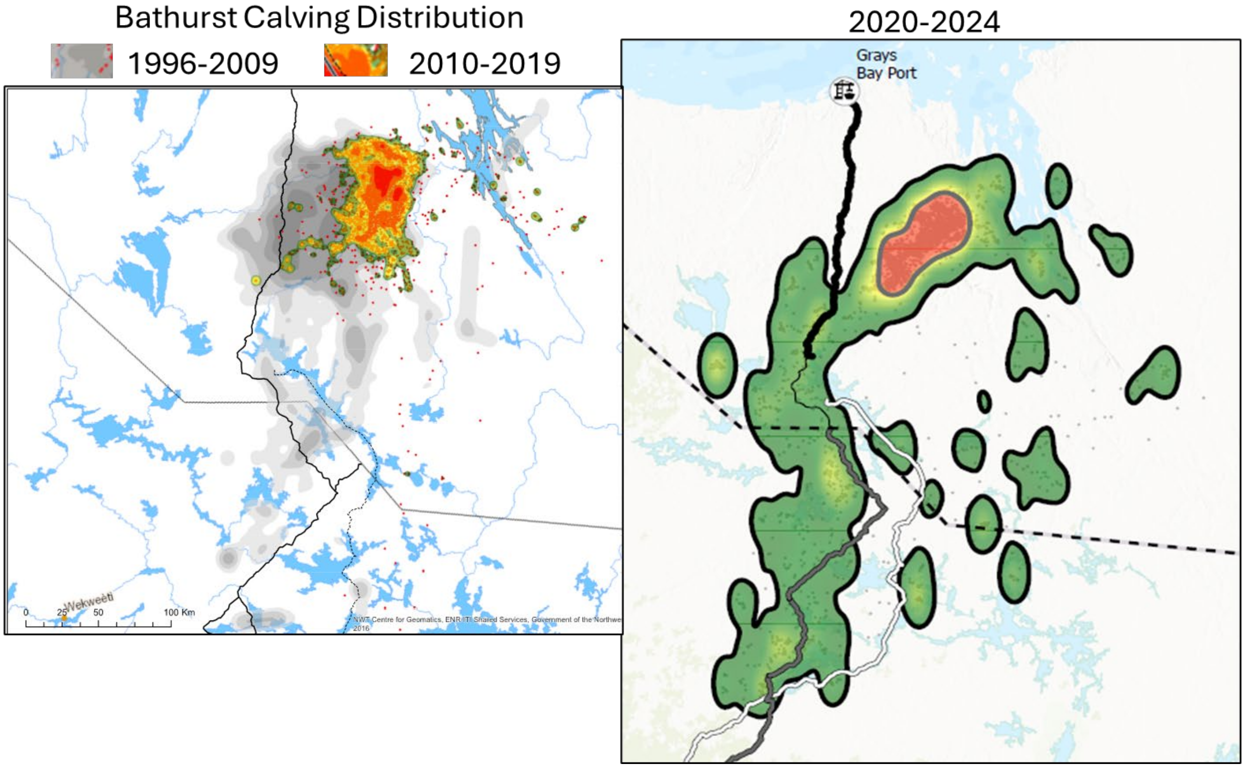


Figure 6 Bathurst caribou kernel density analysis for three time periods during the calving season: 1996–2009 (grey tones) and 2010–2019 (colour tones) on the left and 2020–2024 on the right. The SGP and Grays Bay routes (black line) and existing Tibbitt Winter Road (white line) are shown. Distribution includes parturient and non-parturient cows as we do not have the data to plot only parturient.

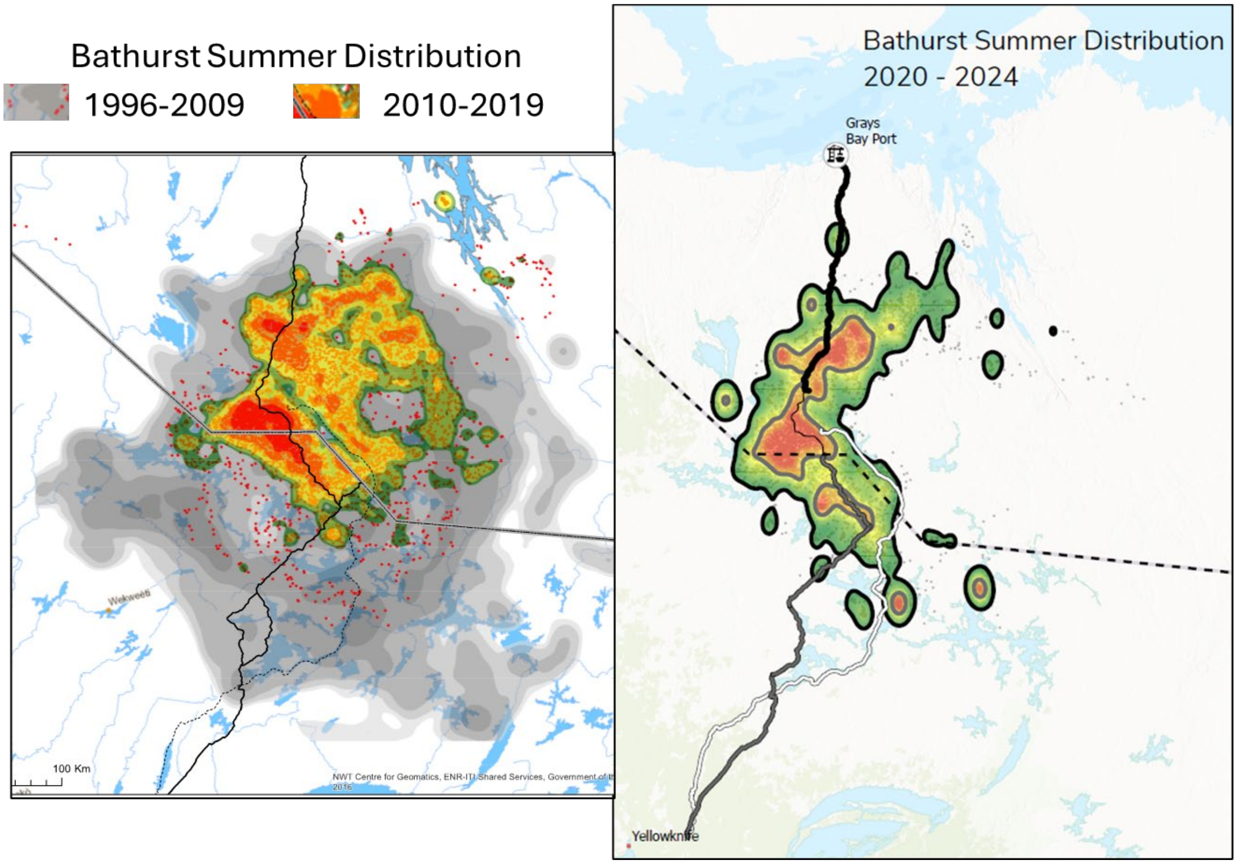


Figure 7 Bathurst caribou kernel density analysis for three time periods during the summer season: 1996–2009 (grey tones) and 2010–2019 (colour tones) on the left and 2020–2024 on the right. The SGP and Grays Bay routes (black line) and existing Tibbitt Winter Road (white line) are shown.

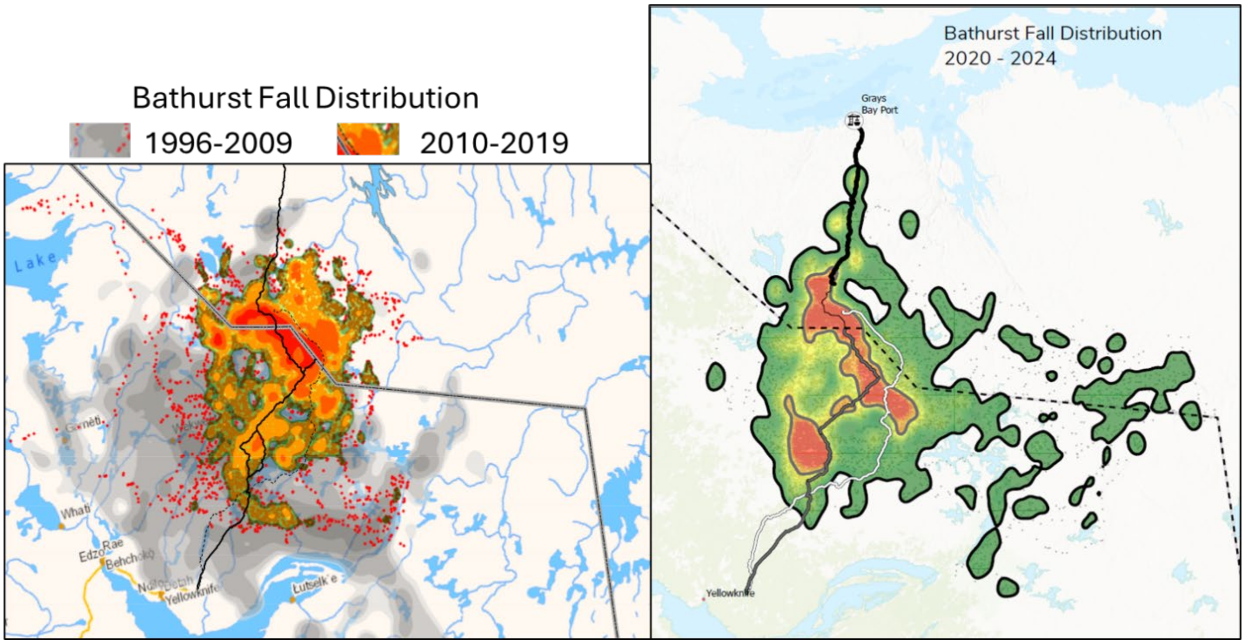


Figure 8 Bathurst caribou kernel density analysis for three time periods during the fall season: 1996–2009 (grey tones) and 2010–2019 (colour tones) on the left and 2020–2024 on the right. The SGP and Grays Bay routes (black line) and existing Tibbitt Winter Road (white line) are shown.

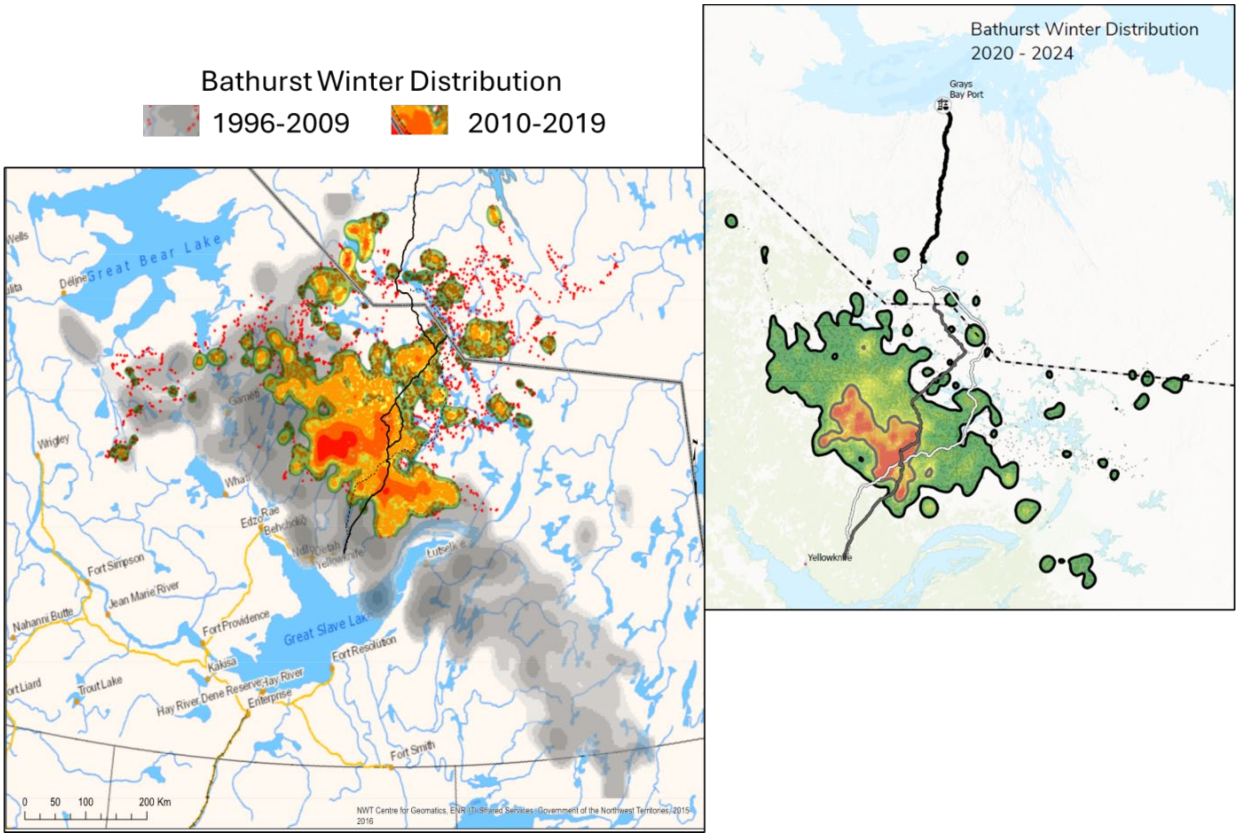


Figure 9 Bathurst caribou kernel density analysis for three time periods during the winter season: 1996–2009 (grey tones) and 2010–2019 (colour tones) on the left and 2020–2024 on the right. The SGP and Grays Bay routes (black line) and existing Tibbit Winter Road (white line) are shown.

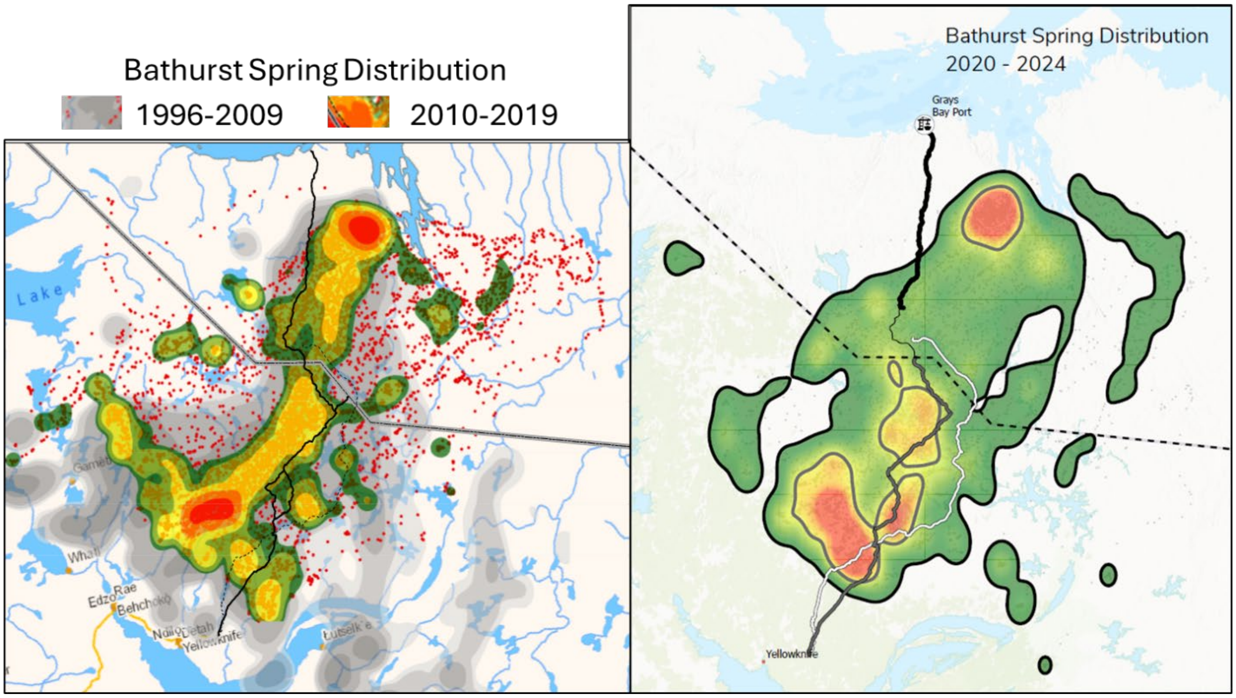


Figure 10 Bathurst caribou kernel density analysis for three time periods during the spring season: 1996–2009 (grey tones) and 2010–2019 (colour tones) on the left and 2020–2024 on the right. The SGP and Grays Bay routes (black line) and existing Tibbitt Winter Road (white line) are shown.

Based on the small changes, especially in areas of seasonal concentrations, between 2010–2019 and 2020–2024, there is no support to treat time periods 2010–2019 and 2020–2024 separately. Furthermore, as the herd has contracted significantly since 2010 into a region more likely to be impacted by the GBRP and SGP projects, we confined our analyses to the herd distribution since 2010.

Beverly/Ahiak

Figure 11 presents our seasonal distribution analysis for the BVA herd from 2010–2024. Seasonally, the BVA herd has little interaction with the Grays Bay Road; therefore, we did not consider this herd further. But we do note that in fall, winter, and spring seasons, the herd has significant potential for encounters with the SGP road where there is considerable overlap with the BAH herd in northern sections of the SGP. Russell (2018) projected very few encounters by the BVA with the GBRP project in his analysis of the Hope Bay project east of Bathurst Inlet.

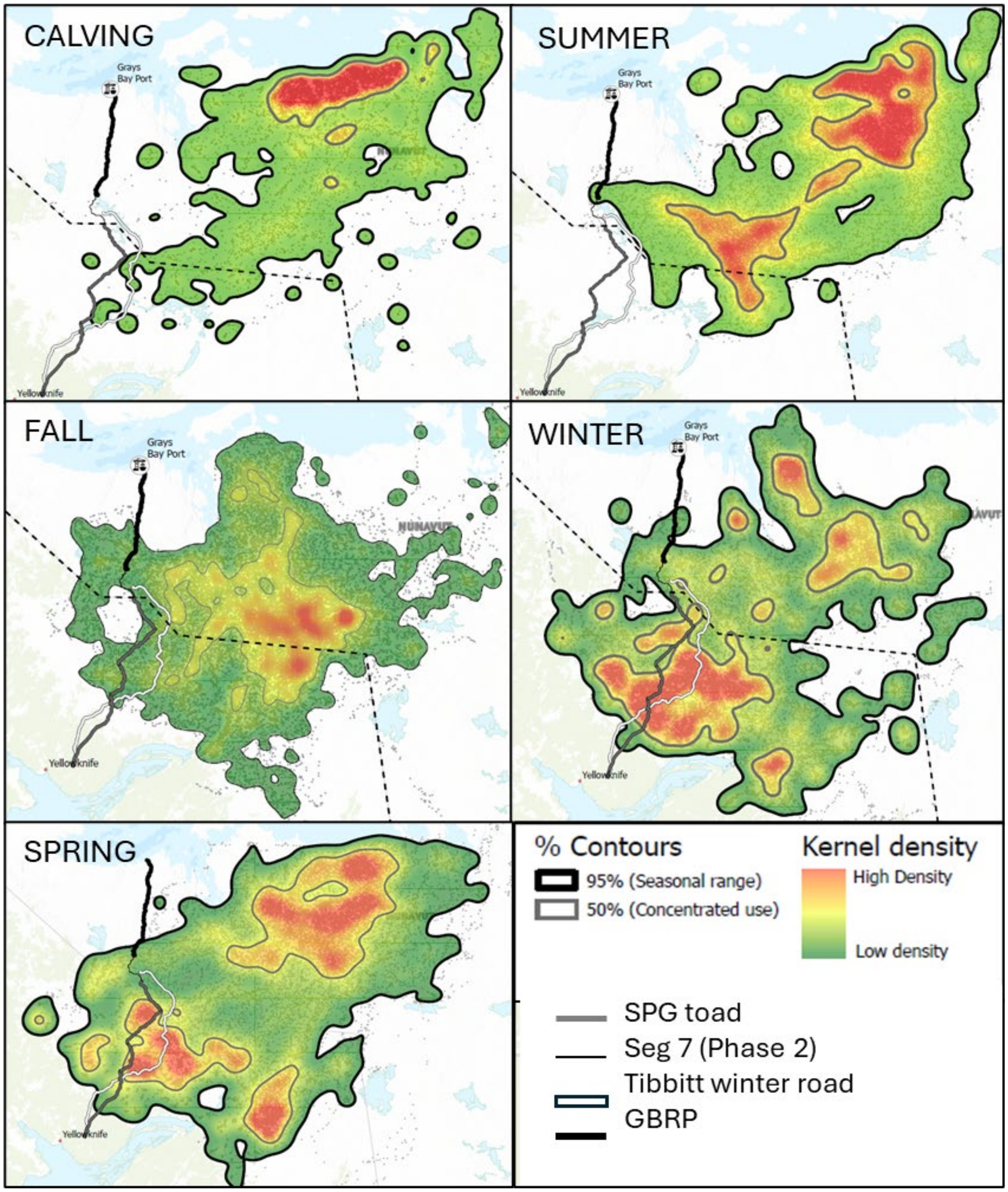


Figure 11 Beverly/Ahiak caribou kernel density analysis for 2010–2024 during calving, summer, fall, winter, and spring. The SGP and Grays Bay routes (black line) and existing Tibbitt Winter Road (white line) are shown.

Dolphin and Union

The seasonal distribution of the DU herd currently reveals minimal overlap with the Grays Bay Road. Previously, Russell (2018) modelled the encounter rates with and without the GBRP project. Here, we confined our analysis to two scenarios presented in Russell (2018): 1) Current infrastructure with no Hope Bay development and 2) foreseeable future scenarios which included the GBRP project.

A characteristic of the DU herd is its seasonal migrations across the sea ice in spring and fall. Winter distribution on the mainland and calving to fall distribution on Victoria Island have changed as the herd has increased and decreased in abundance (SARC 2023). Additionally, trends in the timing of freeze-up and break-up influence the timing and location of the crossings (Poole et al. 2010, Ekaluktutiak Hunters and Trappers Organization 2019). Based on remote cameras at the Hope Bay mine site (east of Bathurst Inlet), DU caribou sightings were identified in June and July of 2023 and 2024, which may suggest that some caribou may not be migrating to Victoria Island, given the annual timing of sea-ice melt (AEM 2025d).

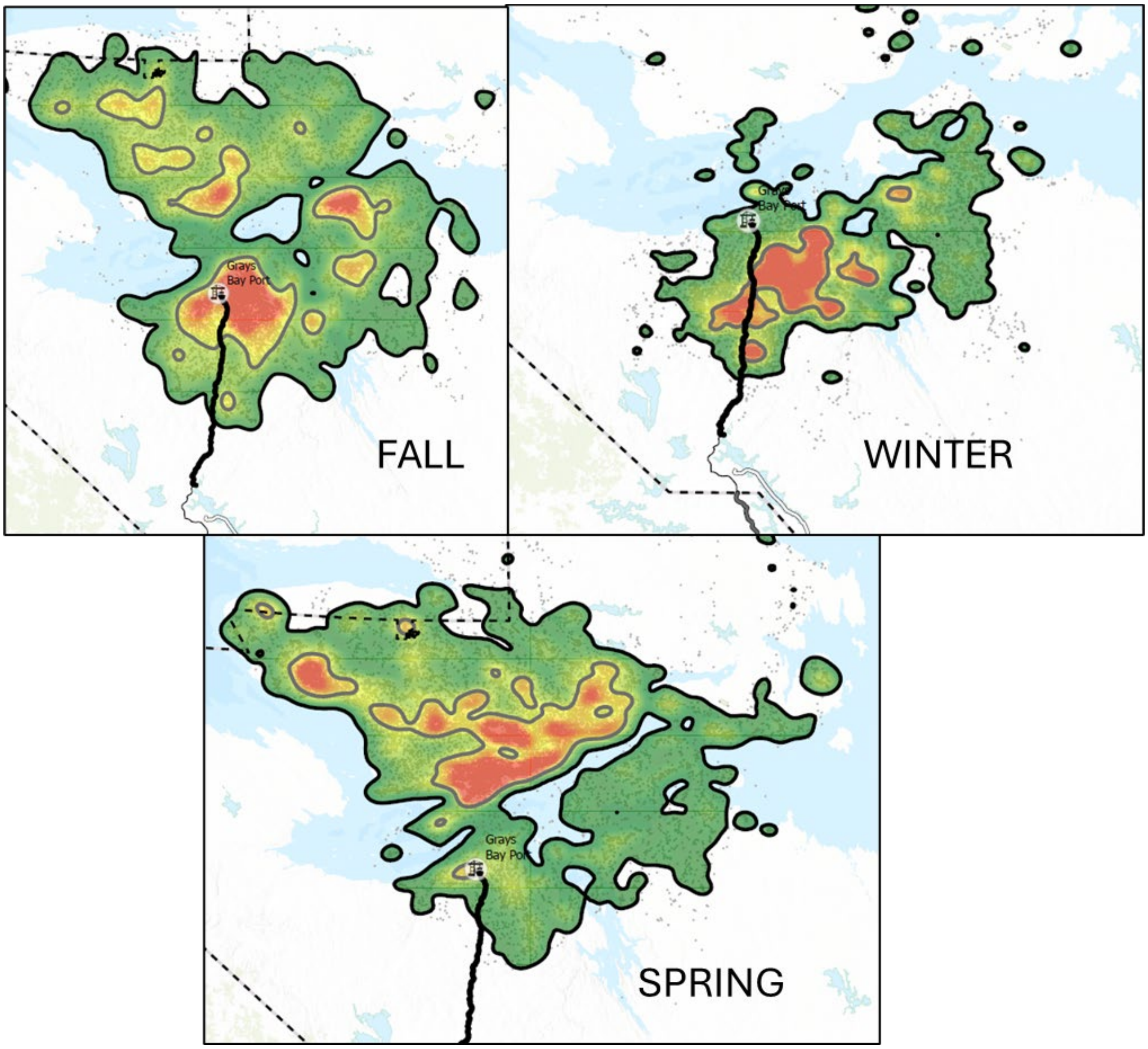


Figure 12 Dolphin and Union caribou kernel density analysis for 2010–2024 during the fall, winter, and spring seasons. The northern SGP and Grays Bay routes (black line) and existing Tibbitt Winter Road (white line) are shown.

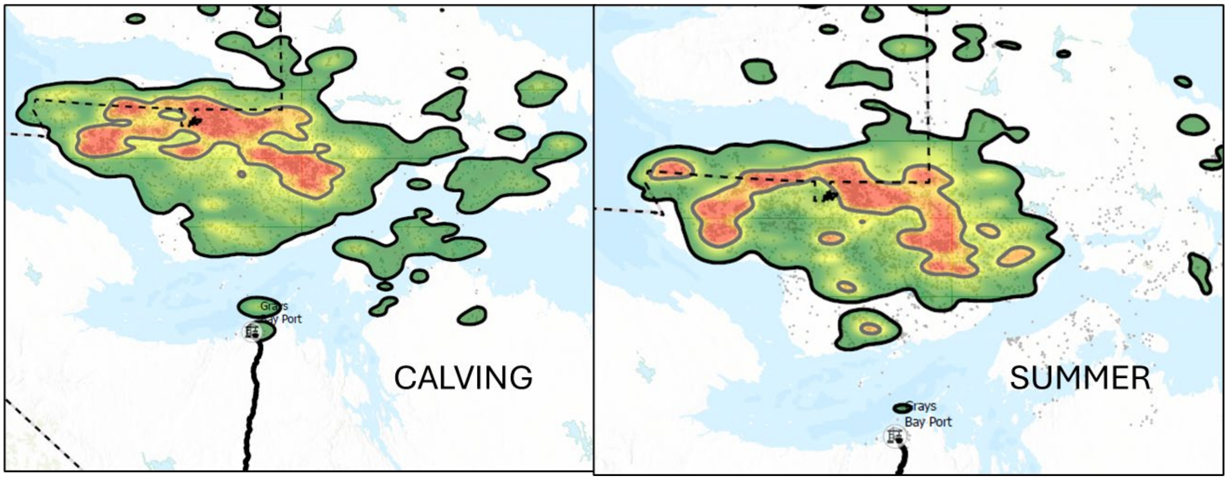


Figure 13 Dolphin and Union caribou kernel density analysis for 2010–2024 during calving and summer seasons. The northern SGP and Grays Bay route (black line) road and existing Tibbitt Winter Road (white line) are shown.

2. Exposure

Exposure is the projected changes within the range of the herds that will impact the herd. In the context of this analysis, we considered climate, and the Grays Bay Road caribou encounter rates with roads as the drivers of change. In addressing those drivers, we relied on Russell and Gunn (2025) reporting the impacts of future climate on the BAH and Russell et al. (2024a) reporting the impact of the proposed SGP road in the NWT and the Grays Bay Road in NT.

Current Climate Indicators

We compared the climate within the ranges of BAH and, for regional context, the climate within the ranges of the DU and BVA herds. We recognize that the summer ranges of the three herds are geographically separate as the DU herd summers on Victoria Island and the BVA herd is found along the cooler (ice covered) Queen Maud Gulf coast in early summer. Data are derived from the CARMA climate database (Russell et al. 2013) and updated to 2023. Indicators considered are:

For summer range (Figure 14):

- Temperature (monthly average May–August)
- Cumulative growing degree days at end of month (May–August)
- Cumulative mosquito and oestrid index at end of month (May–August)
- Drought (monthly average May–August)

For winter range (Figure 15):

- Average snow depth at end of month (October, December, March, May)
- Cumulative rain-on snow (# days and total rainfall to December 31)
- Freezing rain (# days and total rainfall December 31)
- Freeze/thaw (# days December 31)

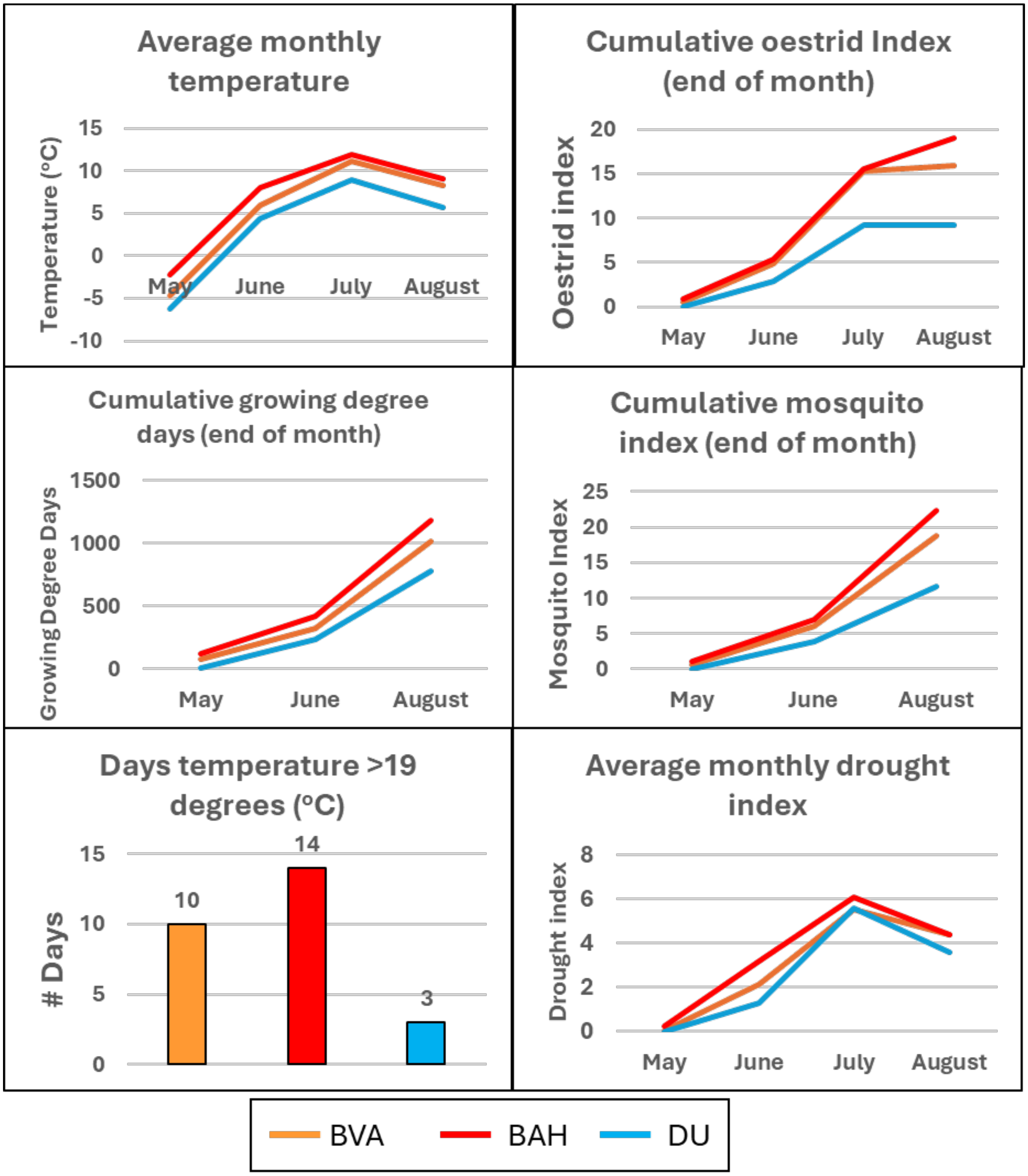


Figure 14 Summer climate indicators for the BAH, BVA, and DU herds

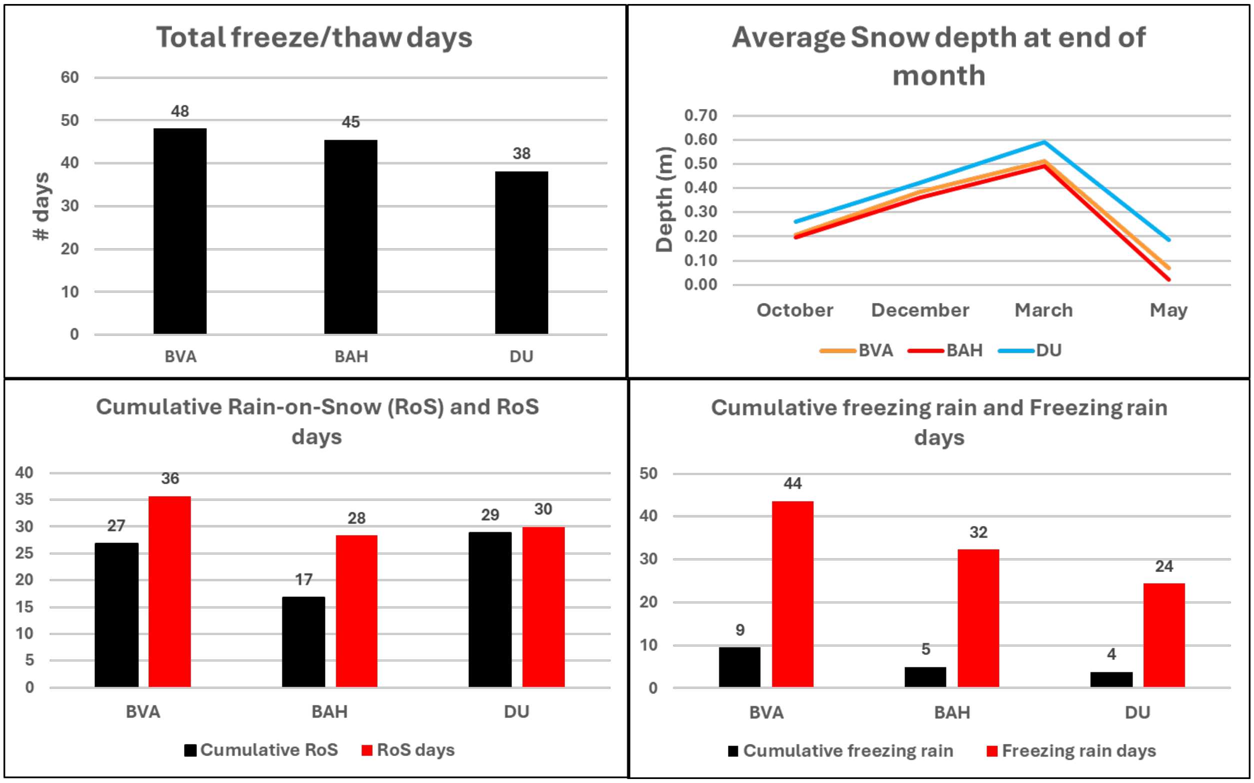


Figure 15 Winter climate indicators for the BAH, BVA, and DU herds

BAH Temperature Projections

Based on Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate model scenarios, BAH summer range temperatures will continue to increase from current levels into the mid century under the optimistic scenario, showing a stable temperature from 2050 through to 2100 (Russell and Gunn 2025). Under the pessimistic scenario, temperature will continue to increase through to 2100. Therefore, for the application of the GBRP project, we will restrict our assessment of climate change on the BAH herd under optimistic scenario in 2050.

The BAH herd has the warmest summer range compared to the DU and BVA herds (Figure 14). By 2050, summers on the BAH herd's range are projected to be hotter, with mean temperatures equalling current mean maximum temperatures.

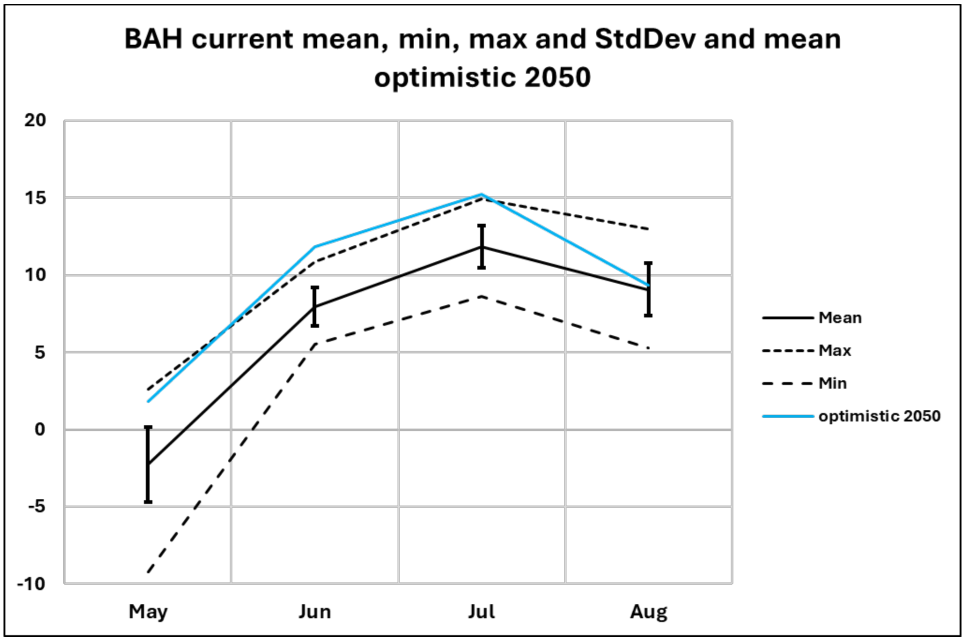


Figure 16 Mean May to August temperature from CMIP6 Global Climate Model projections on the Bathurst (BAH) herd summer range

Figure 16 indicates that by 2050, mean May, June, and July summer temperature will be similar to the current mean maximum temperatures, while the mean projected August temperatures will be similar to current August mean temperatures.

Applying Climate Indicators to the Caribou Cumulative Effects Model

Based on these projections, we converted future temperatures into caribou-relevant indicators (Russell et al. 2013) that could be used in the CCE.

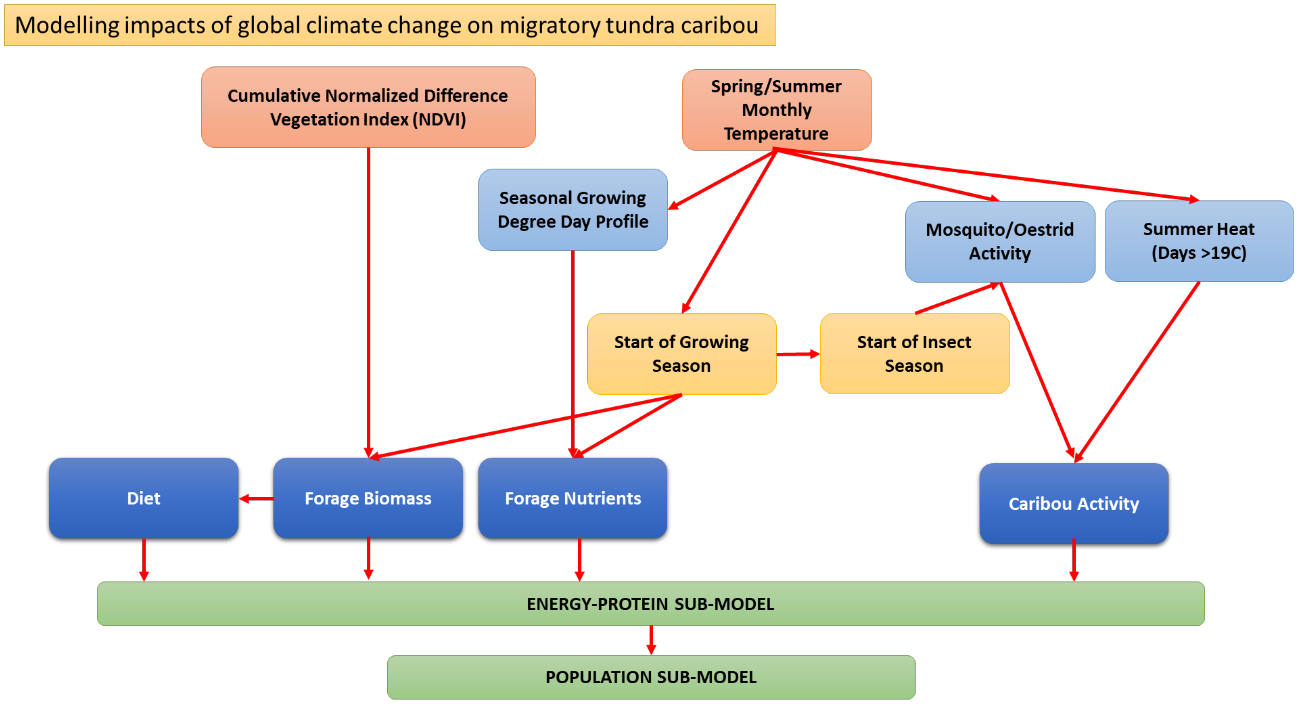


Figure 17 Process of quantifying linkages to create caribou-relevant indicators used in the CCE model (see Appendix 1 for details)

Based on the linkages identified in Figure 17, we developed algorithms to project four spinoff, caribou-relevant indicators from projected temperature (Linkages 1-4 in Figure S2-1, Appendix 1).

- Temperature to growing degree day spring and summer profiles
- Temperature to start of growing season
- Temperature to summer oestrid and mosquito harassment indices
- Temperature to the monthly number of hot days (days greater than 20°C)

These four indicators were used to populate the Energy-Protein sub-model with respect to plant biomass, forage nutrient quality of plants, and activity budgets. A quantitative assessment of these linkages is presented in Appendix 1 and summarized below (Table 2).

Table 2 Summary of caribou-relevant indicators derived from 2050 temperature projections for the BAH herd

Climate Indicator	Current	Future
Average summer temperature	6.8	10.3
Growing degree days (to July 27)	595	769
Start of season (days before present	0	8
Oestrid harrassment index	2	7.2
Mosquitoe harrassment index	11	19.3
# days >19°C	9	36

Encounters and Penalties

We quantified exposure through the output of the Movement sub-model which is a GIS-based sub-model that accepts a data layers for the range of the herd being analyzed: vegetation, climate zone (Tundra/Taiga), infrastructure (with separately assigned 5 km buffer to represent the ZOI; Boulanger et al. 2021), harvest zones, management zones, etc. When satellite or GPS-collar data are provided, the sub-model will select a given number of random collar years and create location data for 365 days of the year. If there are missing days, locations are interpolated.

Output from the Movement sub-model is the daily attributes for each selected collar/year day including whether in or out of the ZOI, what section of infrastructure is encountered, distance moved from previous day, and what vegetation/climate zone is occupied. If a caribou is located within the ZOI, it is assigned a day duration within the ZOI. The rationale is that if the location is logged at 12 noon each day, then the caribou was outside the ZOI at 12 noon on day 1, inside the ZOI 24 hours later (day 2), and outside the ZOI 48 hours later (noon on day 3). The caribou could have been in the ZOI for just under an hour to just under 48 hours. Therefore, 24 hours is the average amount of time the caribou could have been in the ZOI. The same rationale applies when we impose a 48-hour penalty if a collared caribou is in the ZOI on two consecutive days (average of 24 hours minimum and 72 hours maximum) and a 72-hour penalty if a caribou is in the ZOI on three consecutive days (average of 48 hours minimum and 96 hours maximum).

We considered this approach an underestimate of actual herd exposure as the Movement sub-model has no way to impose a penalty if the caribou was outside the ZOI on two consecutive days, when in fact it could have entered the ZOI after noon on day 1 and left just under 24 hours later, either by deflecting back out or passing straight through the ZOI.

The 24-hour duration of being within the ZOI is conservative and is supported by published studies (for example, see GNWT 2019). At Meadowbank mine, Boulanger et al. (2025) reported that caribou reduced their movement rates approaching the road and delayed crossing the road in part due to caribou paralleling the road before crossing (Boulanger et al. 2024, Poole et al. 2021, Fullman et al. 2025). However, when the road was closed to most traffic, the caribou were more likely to cross, and the delay was reduced from about 2.5 to 4.3 days (28–68%; Boulanger et al. 2025). At the Ekati diamond mine, Poole et al. (2021) also described delays of 36 ± 10 hours SE (range: 6–144 hours) if caribou crossed the road and 108 ± 15 hours SE (range: 3–648 hours) if caribou did not cross the road.

The assumed 5-km ZOI is also conservative: elsewhere estimates of the ZOI along roads vary from 17.21 ± 5.47 SE km before crossing a road to 2.97± 1.13 km after crossing a road (Boulanger et al. 2025). As the ZOI is a behavioural response to habitat (including disturbance) (Boulanger et al. 2021), it is not surprising that it varies extensively but there will also be added variation from the analyses to estimate the ZOI (Wagenmakers et al. 2022). The distances at which a caribou can detect mine structures and activities vary: coarse dust particles on leaves and changes in lichen cover extend about 1 km from a road, a haul truck is visible at 2 km, and mine structures such as waste rock piles are visible at 5 km (Chen et al. 2017a and b).

In the CCE model (Section 3), we assigned “penalties” to daily activity budgets when caribou were 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)

Caribou are integrating several factors on a daily and seasonal basis which means how caribou allocate their time feeding, standing, walking, running, and resting varies. Snow depth and snow melt, the timing of plant growth, and the harassment of insects can alter activity budgets (Russell et al. 1993). Daily and 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). To account for these natural influences is essential while documenting any added effects of disturbance from human activity (Russell et al. 2024a).

There are few attempts to quantify disturbance impacts within and around a ZOI. For calving, post-calving and summer ranges, little data exist. BHPB (2004) reported a 10% to 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. At Meadowbank mine, although responses increased closer to a road during the behaviour scans, this was also confounded with group size. Responses were stronger in small groups which were also more likely to be within 300 m of the road (AEM 2025a). Additionally, at Meadowbank, the behaviour analyses combined seasons and years. The behavioural scans at Meliadine mine also combined years but were mostly during early summer before the insect season (AEM 2025 a and b).

There is no hunting at the Ekati, Diavik and Gahcho Kue diamond mine sites, but hunting does occur along an all-weather road for both Meadowbank and Meliadine gold mines in NT. The behavioural scans of caribou were every 3 minutes for 30-minute bouts and following a disturbance such as a vehicle; immediately after the disturbance the proportion of alerted, trotting, or running caribou increased but 89% (95% CI = 80–94%) of caribou returned to baseline behaviour within 9 minutes (AEM 2025b). The responses were also measured between 2 and 11 sequential disturbances; the probability of a caribou returning to baseline behaviour 15 minutes after 3 disturbances was 75% (AEM 2025b).

In our modelling (Russell et al. 2024a), we have assumed a penalty for being within the ZOI when traffic is low and there is no hunting:

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

The 6% foraging penalty was applied to the entire 24-hour period, which represents the average amount of time the caribou could be in the ZOI (as explained at the beginning of this section). 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 to both increase (Plante et al. 2016, 2018). Given the equivocal results described above and uncertainty inherent in quantifying disturbance (Harwood and Stokes 2003), we feel these penalties are a logical compromise to allow us to objectively assess the cumulative effects of development.

Figure 18 summarizes the output from the Movement sub-model for a random sample of 100 pregnant and lactating cows for each of three seasons. The seasons were chosen to cover the dynamics of lactation and its costs to the cow.

- Day 1–162 (from the start of the calendar year to calving: January 1 to June 11)
- Day 163–283 (post-calving to the rut: June 12 [begins lactating] to October 10)
- Day 284–365 (post-rut to end of calendar year: October 11 to December 31)

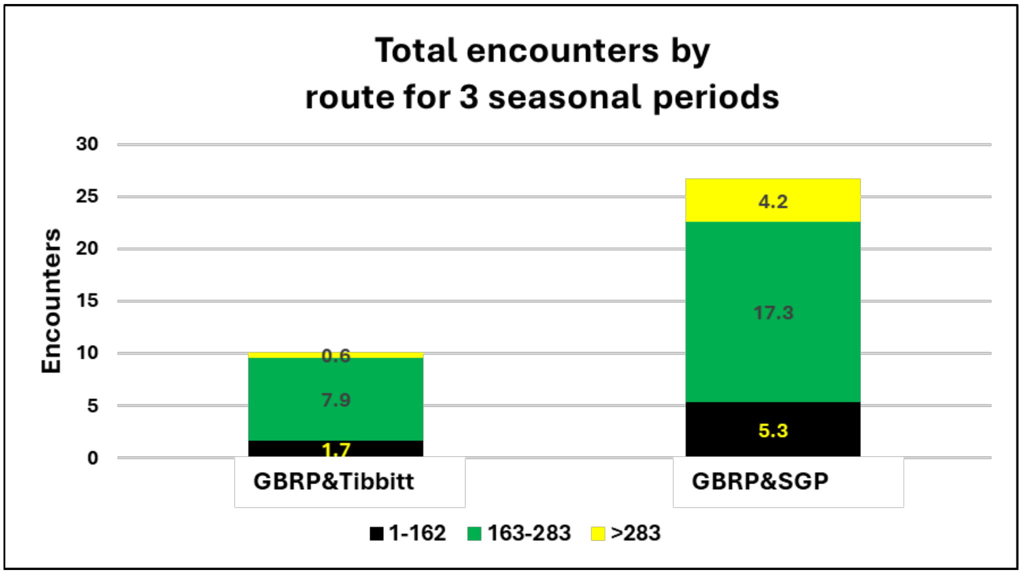


Figure 18 Seasonal distribution of encounters by route for three seasonal periods (Day 1–162: start of calendar year to calving; Day 163–283: calving to rut; Day 283–365: rut to end of calendar year)

We used three scenarios: (1) No development – this assumes that Grays Bay Road and Port project, Tibbitt Winter Road and the proposed SGP Road are not built. (2) Grays Bay Road and Tibbitt Winter Road (GBRP&Tibbitt). We only counted Tibbitt Road encounters if they occurred from the end of January to the end of March, the typical time period the road is open to vehicle traffic and (3) Grays Bay Road and the proposed all-weather SGP Road (GB&SGP). For this scenario we used the route with the lower number of encounters (i.e., Route 6 from Russell et al. 2024a).

The two scenarios where encounters were a factor were the combined GBRP and SGP scenario and the GBRP and Tibbitt Winter Road. The highest encounters were the GBRP project and the SGP road link to Yellowknife. On average, caribou had encounters with roads for 26.7 days (Figure 19) within the disturbance ZOI. For the GBRP Road alone, animals encountered the road an average of 9.4 days (Figure 19). The Tibbitt Winter Road did not contribute significantly to the total encounters. It is important to note that the animals did encounter the Tibbitt alignment more often than the GBRP road; however, we restricted our data from the end of January to the end of March, the normal opening and closing dates for the winter road, which explains the low number of encounters with Tibbitt Winter Road in our modelling scenario.

For both route options, the calving to rut period was the most represented season for encounters (Figure 19). This is the most critical period: calves are born, and cows are both lactating and trying to replenish fat and protein reserves before winter. Cows encountered routes in late winter to spring less often, while encounters were least frequent after the rut, through early winter.

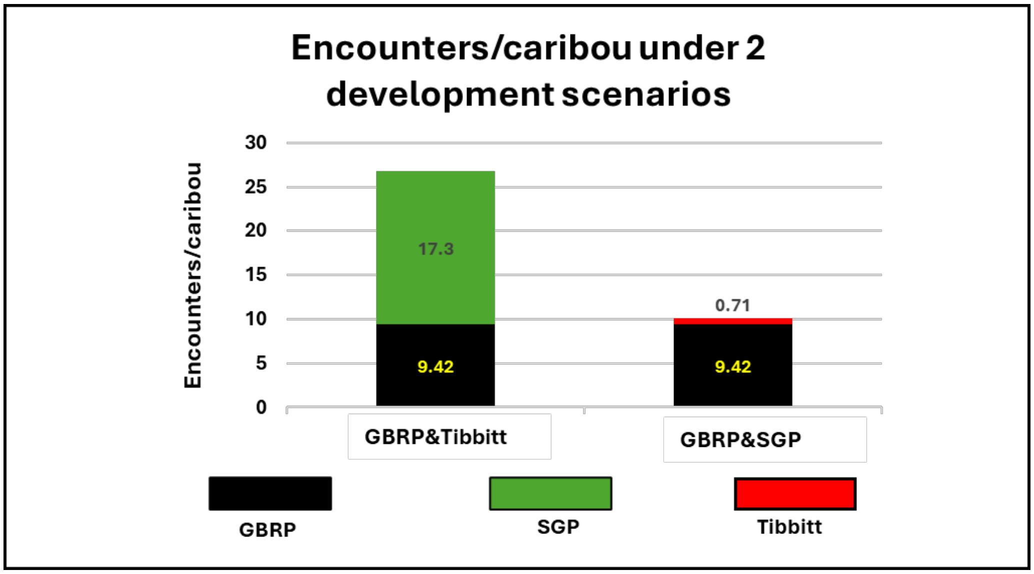


Figure 19 Average number of encounters for two development scenarios based on the movements of 100 random BAH cows since 2010

There was a near linear cumulative frequency of total encounters (Figure 20, Panel A) for the GBRP and SGP road route with 60% of animals encountering the route 27 times or less compared to 10 encounters or less for the GBRP and Tibbitt route. Similarly, during the critical post-calving to rut period (Figure 20, Panel B), 60% of caribou encountered the routes 18 and 7 times or less, respectively.

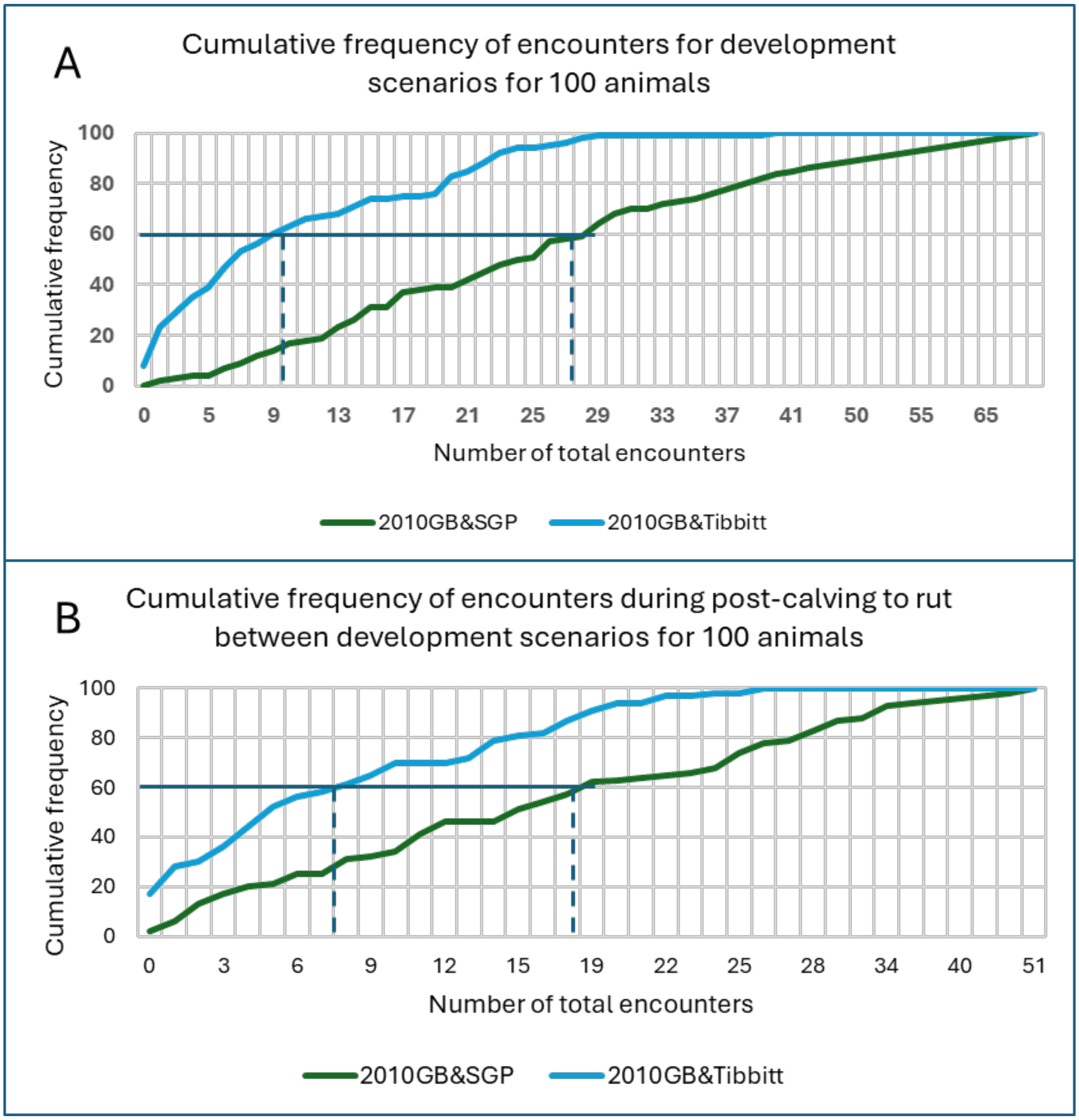


Figure 20 Frequency of caribou encounters overall (A) and during the post-calving to rut period (B)

3. Potential Impacts

Development Scenarios

We defined exposure as when a caribou entered a road's ZOI (i.e., within 5 km of the road). We determined the 5 km ZOI encounters for three development scenarios:

1. No development – this assumes that Grays Bay Road and Port project, Tibbitt Winter Road and the proposed SGP Road are not built.
2. Grays Bay Road and Tibbitt Winter Road (GBRP&Tibbitt). We only counted Tibbitt Road encounters if they occurred from the end of January to the end of March, the typical time period the road is open to vehicle traffic.
3. Grays Bay Road and the proposed all-weather SGP Road (GB&SGP). For this scenario we used the route with the lower number of encounters (i.e., Route 6 from Russell et al. 2024a).

Cow and Calf Body Weights

Bathurst Caribou

We modelled the energy/protein dynamics of 100 random BAH cow caribou under the six scenarios:

- Three developments – no developments, Grays Bay Road and Tibbitt ice road, and Grays Bay Road and SGP all-season road.
- Two climates – Current and Optimistic Future (2050 temperature projection for BAH summer range)

We used fall body weights of cows and calves as our indicators of animal performance and the link to the population sub-model through probability of pregnancy (fall cow body weight) and overwinter survival (fall calf weight). Because we chose random starting body weights for the cows on January 1 to compare differences in fall body weights of cows among our development/climate scenarios, we needed to correct for starting body weight. There was a strong relationship between starting body weight and fall body weight (fall body wt = 0.7477*Jan 1 body wt +13.133; r^2= 0.813). There was no relationship between starting body weight of the cow and the fall body weight of the calf. Because the only difference among the 100 random animals among the scenarios was encounter rate, we considered the residuals of average fall cow body weight to be the result of average encounter rate. Therefore, we determined the "cost" to fall body weight of the cow to be the differences in the average residuals of predicted–observed from the equation above, while the actual fall calf weight differences among scenarios as the "cost" to fall calf weight. These costs are summarized in Figure 21.

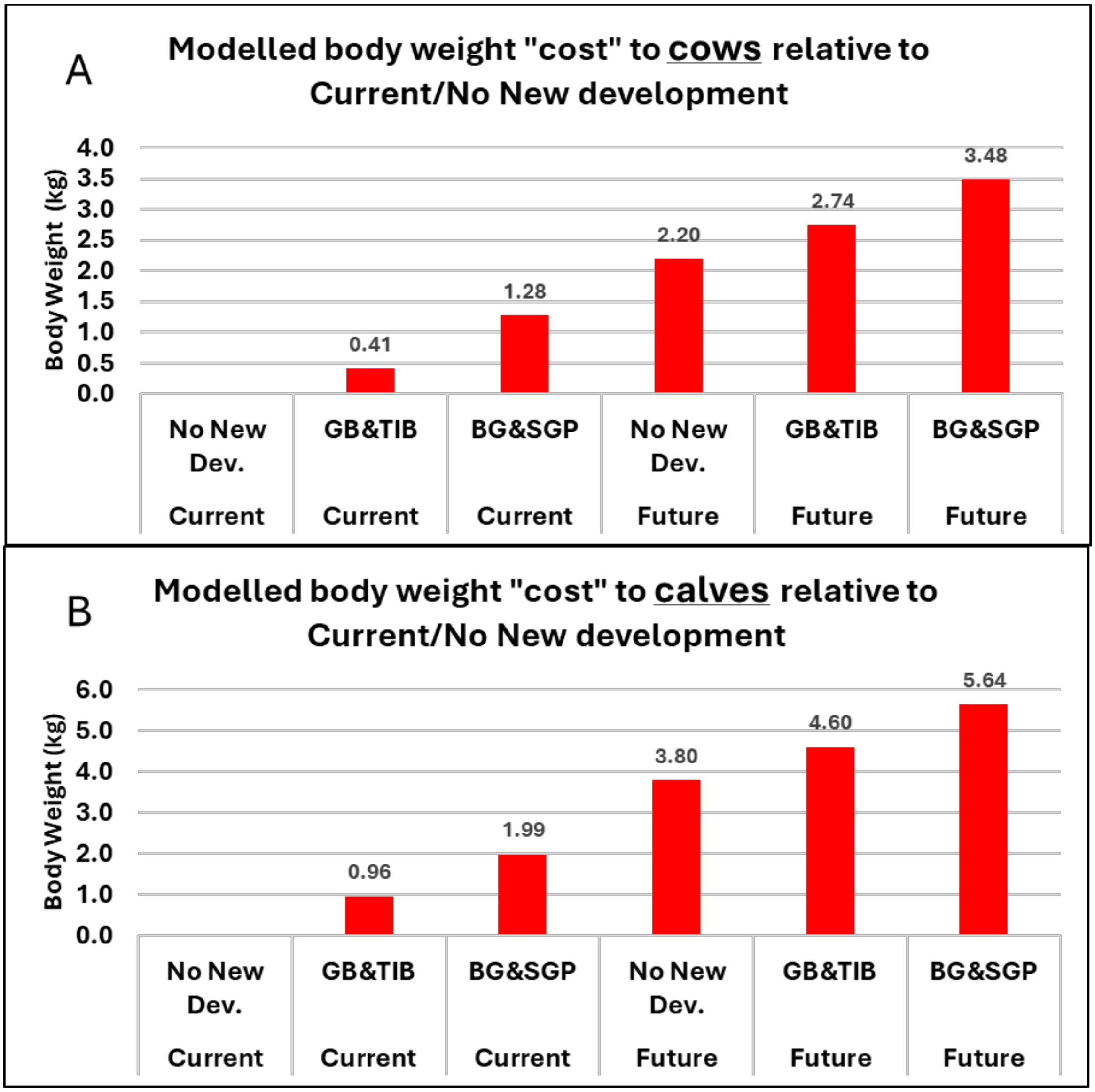


Figure 21 Body weight cost to cows (A) and calves (B) for development scenarios relative to no development scenario under current and future climate scenarios

The cost to fall cow weight from the two route scenarios varied from 0.41 kg for the GB&Tibbitt route to 1.28 kg for the GB&SGP route. Similarly, cost to calf weight varied from 0.96 kg to 1.99 kg for the same scenarios, respectively. Further, our analysis shows that future climate will have a much higher impact than encounters under current climate conditions.

Dolphin and Union Herd

The DU herd is potentially exposed to the GBRP route primarily from late fall to early spring. We ran the Movement sub-model for 75 caribou using a 5 km buffer around the GBRP infrastructure and determined average annual encounters for the DU herd with the GBRP project and existing infrastructure (Table 3). From Table 1, we divided the annual encounters into three seasonal periods, both from a chronological rationale as well as relevance to our modelling output. In the Energy-Protein sub-model, we started the simulation on January 1 and, although we ran through the entire year, the output linked to the Population sub-model was the fall body weights of the cow and her calf in the rut season. Therefore, the January 1 – parturition period represents mid-winter and spring encounters, when animals are in mid to late gestation and from when animals that cross to the mainland are already on the mainland to when the vast majority have returned to Victoria Island. The parturition to rut period is the lactation period as caribou weaning normally coincides with the rut. This period also covers the period when most if not all of the herd is on Victoria Island. The third period covers the time when animals begin returning to the mainland after the rut and as ice formation allows. We linked the output of the Energy-Protein sub-model (cow and calf body weight) to the Population sub-model (via pregnancy rate and overwinter calf mortality) at the rut. In the Movement sub-model, we track encounter days between the rut and end of calendar year (Table 3); however, this value is not reflected in our Population sub-model results.

Table 3 Number of annual encounters of the DU herd with mainland infrastructure, both existing and with the GBRP project

Season	Existing	GBRP	GBRP + existing
Jan 1-Parturition	2.4	9.9	12.3
Parturition - Rut	0.3	0.2	0.5
Rut - Dec 31	4	6.6	10.6
Total	6.7	16.7	23.4

The DU caribou will, on average, encounter the GBRP project for 23.4 days, which according to Table 3 will be primarily from the post-rut to spring parturition; only 0.5 days will be associated with calving and summer. Of the 75 animals we tracked in the Movement sub-model, very few animals stayed on the mainland near the proposed GBRP project. Relevant to our modelling protocols, the GBRP project would affect caribou for 12.8 days between Jan 1 and the rut with all but 0.5 days before calves are born.

Based on this location analysis, we ran the 75 animals through our Energy-Protein sub-model to derive fall body weights. Our analysis, not surprisingly, showed only small differences in body weight among cows and calves: correcting for Jan 1 body weights of cows at the start of the simulation, the cost of the GBRP project was only 56 g for cows and 308 g calves which translates into an average reduction in probability of pregnancy of 0.15% and an increase in overwinter calf mortality of less than 1%.

Given such low impact we felt it unnecessary to run the Population sub-model as the differences would be insignificant.

Relationship Between Encounters and Cow and Calf Weights

There is an opportunity to generalize the results of the CCE model output which can be used to develop an assessment tool for application to future changes in route locations, in assessing spinoff projects, and in assessing mitigation strategies. To that end, we summarized relationships between number of encounters (from the start of year to the rut) and fall cow weights (observed-predicted) and fall calf weights but only for the BAH herd (Figure 22) as we found no relationships between calf weight and encounters given the few encounters, especially in the parturition to rut period for the DU herd.

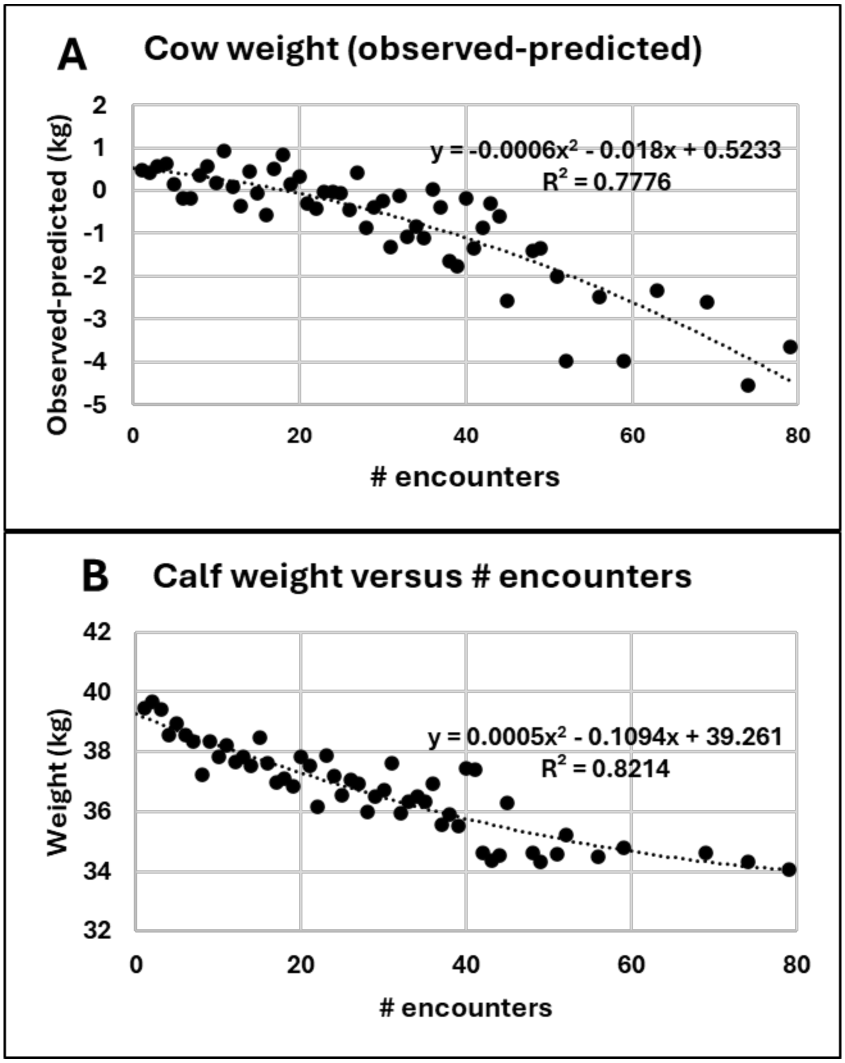


Figure 22 Relationships between number of encounters and "cost" to (A) fall body weight of BAH cows and (B) BAH calves. NOTE: for cows we report on the residuals after regressing January 1 weight and weight at rut.

Population sub-model

The BAH herd has been relatively stable at low numbers since 2010. Our approach to assessing impacts of climate and roads therefore was to ask the question: “What would the population impact over a 10-year period be on those stable low numbers if either roads were in place and/or if climate change, projected for 2050?”. As well, we asked, “What would be the population impacts if the herd was distributed based on 2010–2024 collar movements?”

As a starting point, we modelled a relatively stable population over 10 years with a starting population of 10,000 animals, which was characterized by a 0.872 pregnancy rate and a 45% female calf mortality. We also assumed no harvest even though we know there is a limited amount of harvest on the herd. We then assigned these parameters to the 2010–2024 no development/current climate scenario. Body weight differences were then used to calculate scenario-specific impacts in pregnancy rate and calf mortality (Table 4 and Table 5).

Table 4 Probability of pregnancy derived from fall body weights of cows

Climate	Development	Cow weight (kg)	Weight difference (kg)	Probability of pregnancy
Current	No Dev.	82.88	0	0.873
Current	GB&TIB	82.47	-0.41	0.865
Current	GB&SGP	81.60	-1.28	0.849
Future	No Dev.	80.68	-2.20	0.826
Future	GB&TIB	80.14	-2.74	0.812
Future	GB&SGP	79.39	-3.48	0.795

Table 5 Calf mortality projected based on fall body weight differences among scenarios

Climate	Development	Calf weight (kg)	Weight Difference (kg)	Calf mortality
Current	No Dev.	36.33	0	0.450
Current	GB&TIB	35.37	-0.96	0.498
Current	GB&SGP	34.34	-1.99	0.549
Future	No Dev.	32.53	-3.80	0.640
Future	GB&TIB	31.73	-4.60	0.680
Future	GB&SGP	30.69	-5.64	0.732

Under the no development scenario, the cost of a warmer climate scenario is projected to reduce pregnancy rates by 4.7% and increase calf mortality by 19% (Table 4 and Table 5). In comparison, the cost of Grays Bay Road and Tibbit ice road is lower, with only about 1% pregnancy and 5% increase in calf mortality, assuming no change in current climate. But combining the costs of Grays Bay and Tibbitt roads in a warmer climate projects a high cost of 23% increase in calf mortality and 6.1% reduction in pregnancy (Table 4 and Table 5).

Based on scenario-specific values in Table 4 and Table 5, we ran the sub-model over 10 years and calculated the exponential rate of change (i.e., population change in direct proportion to population size as an exponential function of time) among the scenarios (Figure 23).

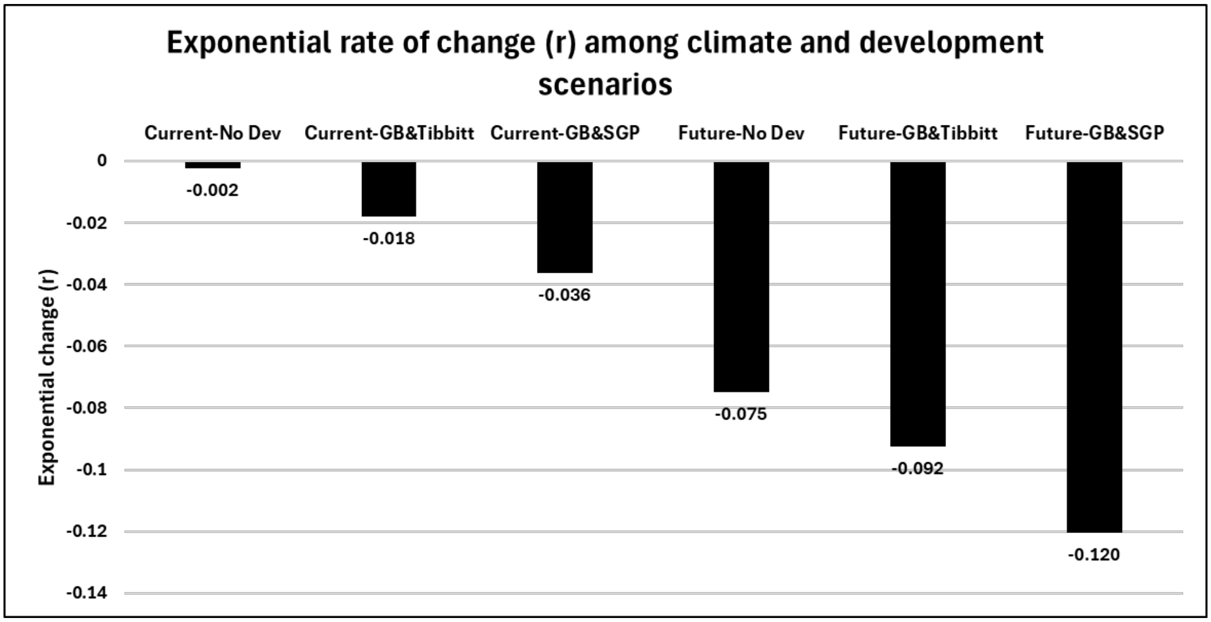


Figure 23 Exponential rate of change among the two route options, two eras, and two climate scenarios based on a 10-year simulation varying pregnancy rate and calf overwinter mortality rate as listed in Table 4 and Table 5

Figure 23 suggests that the impact of the two route options under current climate conditions are less than the impact of future climate. However, under current climate conditions, we project a 1.6% (2010–2024) exponential decline compared to no development for the GB/Tibbit scenario compared to a 3.4% decline for the GB/SGP scenario. Thus, with a starting stable population of 10,000 BAH caribou, this translates into 2,800 fewer caribou in 10 years with the GB/SGP scenario compared to the no development scenario. In comparison, under the future scenarios, there will be 6,766 fewer caribou for the GB&SGP scenario compared to the current no development scenario.

It is important to note that our application of a 6% reduction in foraging time is predicated on light traffic and no hunting. In the next section we will present a more realistic projection that represents high impact involving heavy traffic and hunting in the fall, winter, and spring seasons.

4. Adaptive Capacity

Adaptive capacity is the capability to adapt to potential impacts and, for caribou, it includes both mitigation (management actions to reduce or avoid impacts) and the caribou themselves, i.e., their evolutionary and behavioural plasticity (Beever et al. 2017, Glick et al. 2011).

Mitigation Scenarios

We evaluated five mitigation scenarios for the Grays Bay Road/SGP route, assuming that the road management will be limited to either relatively high or low traffic levels. We classified high traffic and hunting as the worst-case scenario (no mitigation) and no hunting and low traffic as the most stringent mitigation (Figure 24).

AEM (2025a) reported that caribou will return to normal activity 6 to 9 minutes after a disturbance. We have previously used a 6% reduction in foraging time if caribou encounter road infrastructure (Russell et al. 2024a). A 6% reduction in foraging would thus be equivalent to approximately 7 disturbances in a day; we classified a disturbance as a vehicle on the road. We used this as our low traffic scenario. In the presence of high traffic volume, we doubled the penalty for being within the ZOI, i.e., 12% (equivalent to about 12 vehicle disturbances). In this Grays Bay model, a decrease in foraging is compensated for by an increase in walking and running (3% each under baseline scenario) as well as spending 3% less time in the foraging period ingesting food (i.e., eating intensity).

We assessed road closure at relatively low traffic frequencies which is conservative and was in line with Severson et al. (2023) who reported that caribou responded at lower frequencies (<5 vehicles/hour) than expected. Relying on reduced foraging intake as the response rather than whether the caribou crossed the road or not is also conservative and based on the behavioural monitoring at Meadowbank and Meliadine mines (AEM 2025 a and b).

Hunting and tourism using the road likely exacerbate disturbance to animals. Caribou behaviour is complex; for example, caribou make trade-off decisions to modify their responses to predation and forage availability (Basille et al. 2015). Caribou have a similar behavioural plasticity to human activities (e.g., hunting and industrial disturbance) as they do to predation (Lima and Dill 1990), and their learnt experience can both increase and diminish a behavioural response. For example, Russell and Gunn (2017) and Plante et al. (2018) summarized how caribou response distance (i.e., ZOI) is greater when caribou are hunted. Hunting associated with roads increased the road ZOI from 0–3 km to 15 km (Plante et al. 2018).

For our mitigation scenarios, in the presence of hunting, we tripled the penalty in terms of foraging time if the caribou was in the smaller (5 km) ZOI, rather than capturing more daily encounters in a wider 15 km ZOI. In these scenarios, we only assumed hunting from fall to spring, with no hunting during calving and summer, although we recognize that the road itself will possibly change ease of access. We applied the mitigation scenarios for the combined GBRP/SGP route although the concentrated winter distribution falls along the SGP portion of the route. Although hunting is restricted for the BAH herd, there is hunting of other herds and wildlife.

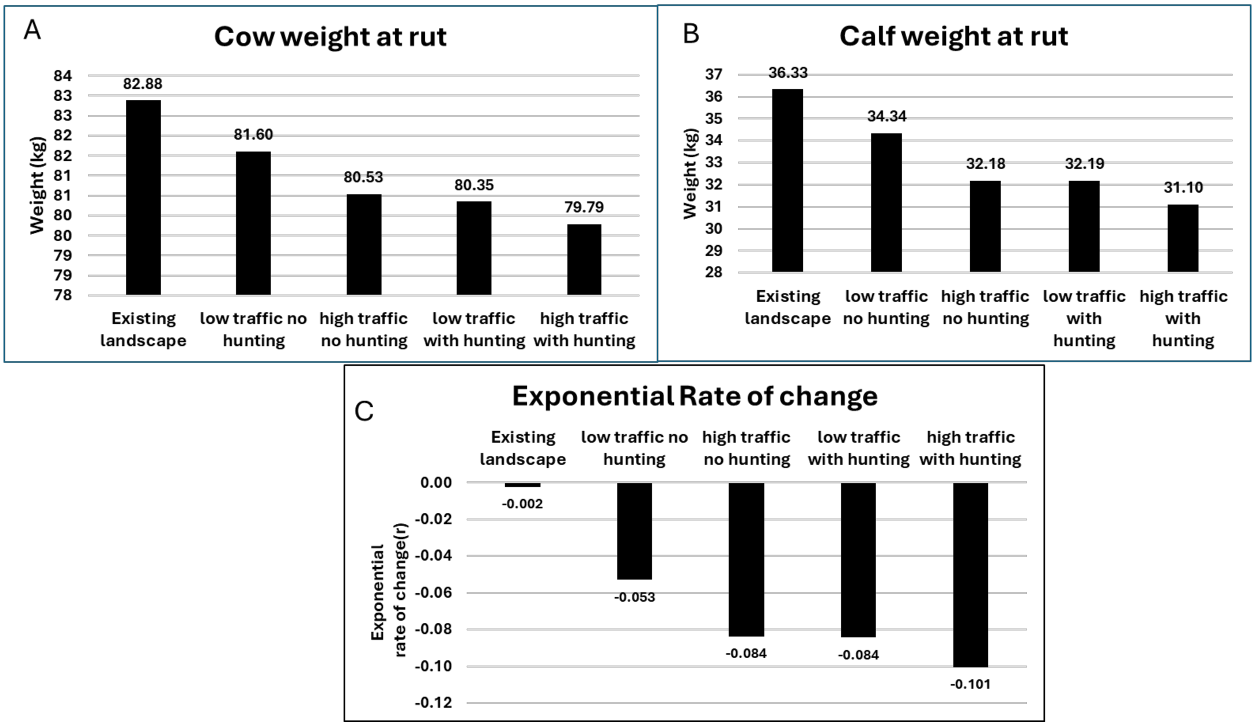


Figure 24 Mitigation analysis for the combined GBRP and SGP roads. The scenarios show decreasing mitigation from left to right; from the current existing landscape without the GB and SGP road through to both roads under high traffic and hunting conditions. Panels A and B represent outputs from the Energy-Protein sub-model for fall weight of cows and calves. These data were linked to probability of pregnancy and overwinter calf mortality and used in the Population sub-model (Panel C).

We modelled the existing landscape to reflect relatively stable conditions currently experienced by the BAH (low rate of decline; -0.002). With the construction of the GBRP and SGP roads, we projected future declines from a -0.101 exponential rate of decline under an unmitigated management policy, improving to a –0.053 rate of decline under mitigation with respect to hunting and traffic volume control. The proportionally greatest improvement was through restriction of heavy traffic for both cows and calves and for the herd rate of change (Figure 24).

We recognize that the extent of restrictive mitigation is uncertain even though WKR will control access. The road will be open to commercial and public vehicles while WKR will monitor and manage use of the port and road to reduce effects on wildlife and the environment. However, public access roads are typically not subject to the type of mitigation and monitoring experienced for mine roads. The Inuvik-Tuktoyaktuk Highway is a 138 km all-season public highway which opened in fall 2017. The Cape Bathurst caribou herd seasonally crosses the road and their reduced crossing success has changed habitat use west of the highway in the absence of mitigation (Boulanger and d’Eon-Eggertson 2024). The Dempster Highway is a 737 km public highway which crosses fall and winter ranges of the Porcupine caribou herd. Community concerns about the road were high and '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). The Dempster Highway was completed in 1979 and the road is used for supplies including for oil and gas exploration and tourism. Average daily traffic from 1994 to 2008 increased to about 260 vehicles (one-way passages).

We also suggest that in practice mitigation for the Grays Bay Road could be more nuanced than blanket closures through collaboration and innovation based on recent updates to mitigation. We know that without mitigation, caribou crossing rates in response to traffic are decreased (Severson et al. 2023, Smith and Johnson 2023, Boulanger et al. 2024, Fullman et al. 2025). However, an analysis of mid-summer caribou movements at the Meliadine mine did not find caribou consistently deflecting from or paralleling the all-season road although individual variability was high and the study was mostly during the insect harassment season (AEM 2025a). Reported differences on caribou responses are partly because caribou responses to mines and roads are complicated by including the caribou's learnt behaviour and memory. We are increasingly realizing the complexity of the decisions that wildlife use to cross roads (e.g., elk; Poulin et al. 2023).

At the Meadowbank mine, the scale of caribou exposure can be high and prolonged; in 2024, a total of 56,168 caribou sightings were recorded during spring and fall migrations. Consequently, the roads were closed for spring and fall migrations for 40 days and 22 days, respectively. The impact on the mine operation and concerns from Inuit elders about whether the road closures were protective of lead caribou during the spring migration led to a pilot project in 2024. For 10 days after the lead caribou were identified, minimal traffic used the road only on alternating days to have 40-hour windows with no traffic disturbances (AEM 2025c). After 10 days, the mitigation reverted to daily convoys (e.g., fuel, freight) to pulse the traffic flow and leave gaps in vehicle passage. A three-year trial of more adaptive mitigation for the fall was initiated in 2024. The mitigation was daily calls with the operational government and Inuit organizations to get their input on a convoy for fuel, freight, crew changes, and food transportation—the key innovation was that the convoy would be followed by a gap of at least 24 hours (no non-essential traffic). Assessment of the effectiveness of the innovative approaches is underway as they are pilot projects and continue to be monitored.

We did not assess mitigation for tourism as we assumed that tourism would elicit similar responses to hunting as vehicles stop and the caribou may perceive a direct approach as a threat. We examined mitigating hunting by assuming no hunting; however, in practice, this may not be necessary. Although the impact of a 1-km buffer along the Meliadine all-weather road is unknown, a buffer zone is an option but the most effective mitigation could be a gatehouse supported by education. About 30% of the Tibbitt ice road is within the Mobile Protection Zone for Bathurst caribou and Cluff et al. (In press) conclude it is mostly effective in restricting hunting. The Tibbitt ice road does not yet have a formal monitoring and mitigation plan;

although one mine stipulated that drivers give right-of-way to caribou, there is no closure of the road for caribou. Reliance on collared caribou is the proposed monitoring to understand the impacts of the existing public highways (Dempster and Tuktoyaktuk-Inuvik) on caribou. Actions to mitigate impacts of traffic on caribou have not yet been proposed.

In general, the effectiveness of mitigation has been weakly demonstrated. For example, the duration of a gap between vehicles to allow a caribou to cross or the timing of the gap is still unknown but if measured could refine the timing of road closures. Likewise, analyses of caribou movement rates could contribute to improving the timing of road closures. In contrast to spring migration, average movement speeds during fall migration tended to be highest during the day and dusk and lowest during the dawn movement (AEM 2025b). Again, this type of information could help refine the timing of closures and does suggest that collaborative studies could increase understanding of caribou behaviour relative to fine-tuning mitigation and monitoring for roads.

5. Vulnerability

The BAH herd's vulnerability is already high as the herd's 98% decline has not been followed by recovery. The herd is currently stable and has been stable or slowly declining for uncertain reasons since 2018 (Figure 3). A second reason for the herd's vulnerability is the impacts of the warming climate which are likely to become more severe (Russell and Gunn 2025). Our CCE modelling suggests that low rate of encounters of the Grays Bay Road with individual caribou means the cost of the road to caribou is low. The corollary of this is that if distribution changed and encounters with the road increased, then so would the costs to the herd. We should not lose sight of the role of mitigation to reduce those costs—traffic management would be a key mitigation. If, for example, the calving ground shifted westward, then specific mitigation such as road closure would protect the cows during calving.

We have modelled a baseline (no development) scenario that would track the current low stable population size. We then assessed the impact of the two route options (GB&Tibbitt and GB&SGP) under current and future climate regimes. We reduced adult cow pregnancy rate and calf survival rates by the "cost" of development and future climate as projected from our Energy-Protein sub-model. Presently, we assume that a realistic, although worst-case scenario, is the unmitigated GB&SGP route under future climate, which would result in an exponential rate of decline of r=0.12 (a halving rate of 6 years).

If the management goal is to offset development and climate change and try to maintain the BAH at stable low population levels, and assuming that the current 16% adult cow mortality remains the same then we would need to: 1) reduce calf mortality by 28%, from 45% to 17%, and 2) increase average pregnancy rates by 7.8%, from 87.2% to 95% (Russell and Gunn unpubl. data).

If, however, the management goal is to generate a herd growth rate of r=0.10 (a doubling rate of 7 years), indicative of historical rates of increase of central Canadian migratory tundra herds, then not only would we have to generate these improvements in pregnancy rates and calf mortality but we would also have to halve the current adult cow mortality, from 16% to 8% and reduce harvest (including inadvertent harvesting on the herd) to zero. In other words, enhanced herd co-management is needed for herd recovery, which would increase the herd's resilience to the costs of the Grays Bay Road.

Our modelling assumes that the costs of the Grays Bay Road are a consequence of reduced forage intake for a day when the caribou are within a 5 km ZOI. This assumption is supported by the findings of monitoring at existing mines. We then used well-established ecological relationships to link how forage reduction drives caribou productivity. We did not include costs of any deflection from the Grays Bay Road including the energetic costs of extra travel. The modelling also does not reflect encounters after the rut because we relied on estimating body weight in fall. Potentially, a cow could lose more weight and start the following year at a lower body weight; although cows buffer environmental change at the expense of calves, there will be a point where lower body weight reduces cow survival. An additional limitation of our model is that although we applied hunting as likely increasing responses to traffic, we did not include hunting as a direct cost (reduce survival rates).

We recognize that the Grays Bay Road is intended to support a corridor to southern Canada and to support further mining but we have not projected those landscape scale changes relative to the vulnerability of the caribou herds. Further costs to the caribou are likely but through collaboration and innovation, progress in mitigating those costs could reduce increases in vulnerability and support the caribou to increase their tolerance through their learning and our adaptive mitigation.

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Appendix 1 Assessing Future Climates (Methodology)

With respect to the ARCON4 project, our challenge was to create CCE model input based solely on mean monthly temperature data obtained from the CMIP6 global climate initiative. We have identified 15 linkages (Figure S2-1) required to apply in the CCE model to assess the potential impact of a warmer future climate on migratory tundra caribou.

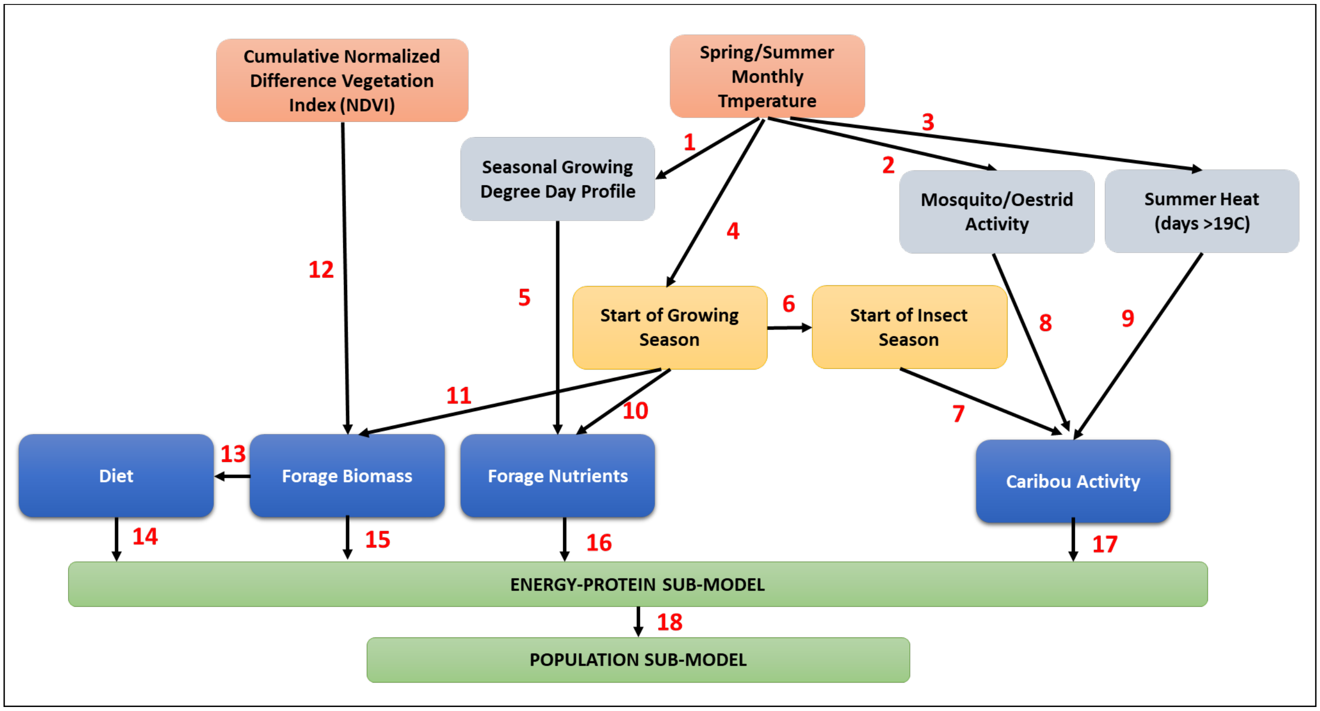

Figure S2-1 Based on spring/summer monthly temperature derived from CMIP6 projections, linkages used to derive caribou relevant indicators and input into CCE Energy-Protein and Population sub-models

Linkage 1: Monthly temperature to growing degree days

Using CARMA's Modern-Era Retrospective analysis for Research and Applications (MERRA) based dataset, we generated multiple regression equations predicting Growing Degree Days (GDD) in late spring and summer from mean monthly temperatures (Table S2-1). As our MERRA database contains daily cumulative GDD, we generated unique equations for each herd at date intervals (between May 26 and July 27, approximately every 10 days; Table S2-2) and, interpolating between these intervals, we produced a daily profile of GDD for each herd, scenario, and time period.

Table S2-1 Multiple regression equations to predict growing degree days from mean monthly average temperatures at roughly 10-day intervals during the spring and summer. Data based on MERRA database (Russell et al. 2013).

Date	Equation
26-May	1.3233*MayT^2+13.08*MayT+34.689
05-Jun	1.0289*MayT^2+16.208*MayT+79.032
16-Jun	1.1178*MyJnT^2+17.672*MyJnT+74.996
26-Jun	2.1062*MyJnT^2+18.011*MyJnT+155.39
09-Jul	54.991*MyJn0.5Jy+163.65
27-Jul	58.649*MyJn0.5Jy+353.15

Table S2-2 Based on multiple regression equations (Table S2-1), projected growing degree days for our three representative herds under current, optimistic, and pessimistic scenarios in 2050 and 2100

Scenario	**ERA**	**Herd**	**26-May**	**05-Jun**	**16-Jun**	**26-Jun**	**09-Jul**	**27-Jul**
Current		BAH	19	57	134	227	376	595
Optimistic	**2050**	BAH	62	111	248	376	554	769
Optimistic	2100	BAH	47	93	233	355	539	754
Pessimistic	**2050**	BAH	100	152	298	449	615	834
Pessimistic	2100	BAH	252	301	499	753	832	1066
Current		CAH	27	68	145	237	374	560
Optimistic	**2050**	CAH	38	83	180	283	438	645
Optimistic	2100	CAH	37	82	178	280	438	646
Pessimistic	**2050**	CAH	64	113	227	347	504	716
Pessimistic	2100	CAH	187	239	396	595	716	942
Current		TAI	0	2	22	76	176	344
Optimistic	**2050**	TAI	4	31	95	176	301	500
Optimistic	2100	TAI	3	29	86	167	279	476
Pessimistic	**2050**	TAI	9	43	128	215	375	579
Pessimistic	2100	TAI	70	120	274	415	607	826

Linkage 2: Monthly temperature to start of growing season

Warmer temperatures result in an earlier growing season. In the CCE model, the 10 plant groups contain unique seasonal biomass profiles through the growing season (Russell et al. 1993). Based on projected temperature profiles unique to each herd/scenario, we adjusted the start of the growing season as shown in Figure S2-2 (A and B).

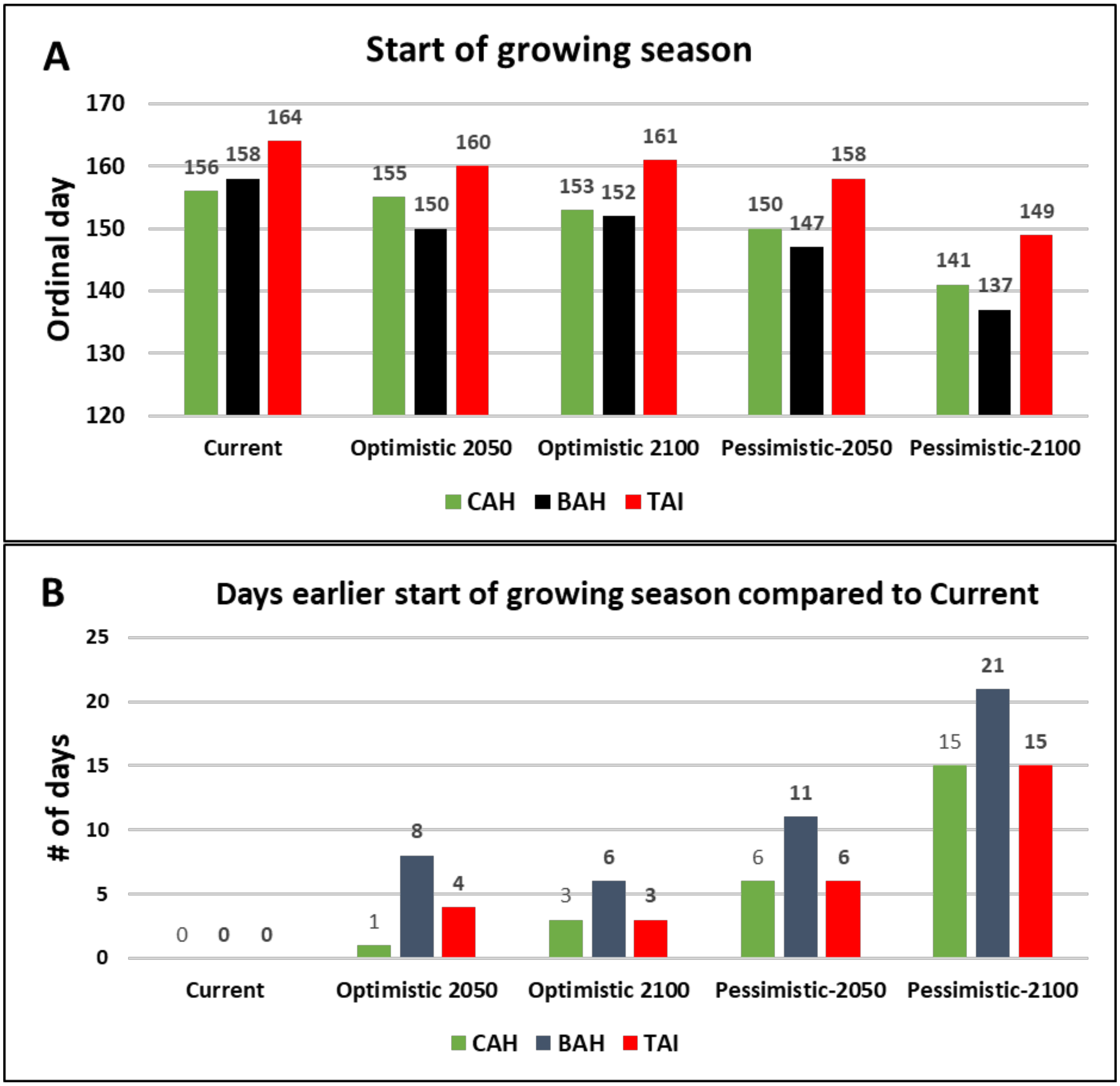

Figure S2-2 Projected ordinal days (A) and days earlier than current (B) for start of growing season based on future scenarios

Linkage 3: Monthly temperature to mosquito/oestrid activity

CARMA's MERRA climate database contains an annual cumulative insect index from 1980–2019 (Russell et al. 2013) for our three representative herds. Using a similar analysis of converting mean monthly temperatures to growing degree days, we converted mean monthly temperature to insect harassment indices, separately for mosquitoes and oestrids (Figure S2-3; Table S2-3).

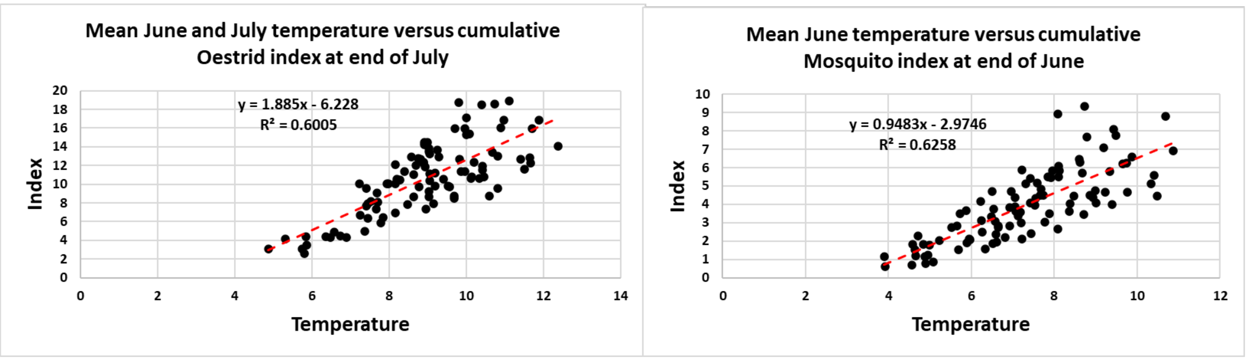

Figure S2-3 Regressions relating cumulative oestrid and mosquito harassment indices based on mean June/July temperature on the summer ranges of the Central Arctic (CAH), Bathurst (BAH), and Taimyr (TAI) herds

Table S2-3 Projected June and July mosquito and oestrid harassment indices for the three herds under future scenarios

Scenario	ERA	Herd	June Mos	July Mosq	June Oestrid	Jluy Oestrid
Current		BAH	4.0	11.0	2.0	8.0
Optimistic	**2050**	BAH	8.3	19.3	7.2	15.5
Optimistic	2100	BAH	8.3	19.6	7.3	16.3
Pessimistic	**2050**	BAH	9.3	21.1	9.4	18.1
Pessimistic	2100	BAH	13.6	29.5	22.5	34.4
Current		CAH	5.0	13.0	2.0	4.0
Optimistic	**2050**	CAH	5.5	13.1	2.8	6.6
Optimistic	2100	CAH	5.4	13.3	2.7	7.1
Pessimistic	**2050**	CAH	6.9	15.4	4.8	8.5
Pessimistic	2100	CAH	11.0	23.8	13.9	21.4
Current		TAI	1.0	5.0	1.0	2.0
Optimistic	**2050**	TAI	2.7	9.6	0.7	5.4
Optimistic	2100	TAI	2.1	8.4	0.5	4.4
Pessimistic	**2050**	TAI	4.4	13.3	1.7	9.4
Pessimistic	2100	TAI	9.4	23.0	9.7	24.4

Linkage 4: Monthly temperature to summer heat

Due to problems with thermal regulation (overheating), we incorporated a modifier on caribou foraging based on work by Trondrud et al. (2023) who documented that at 20ºC reindeer spent 9% less time foraging compared to cooler days. We used our MERRA data to regress mean monthly temperature with number of days ≥20°C for each herd and future scenario and applied the relationships to projected temperature changes associated with our future scenarios (Figure S2-4). The likely impact of heat stress on caribou based on the number of days >20ºC is notable for the Bathurst herd. The number of days jumps fourfold from current to the 2050 optimistic and pessimistic scenarios before almost doubling again for the 2100 pessimistic scenario.

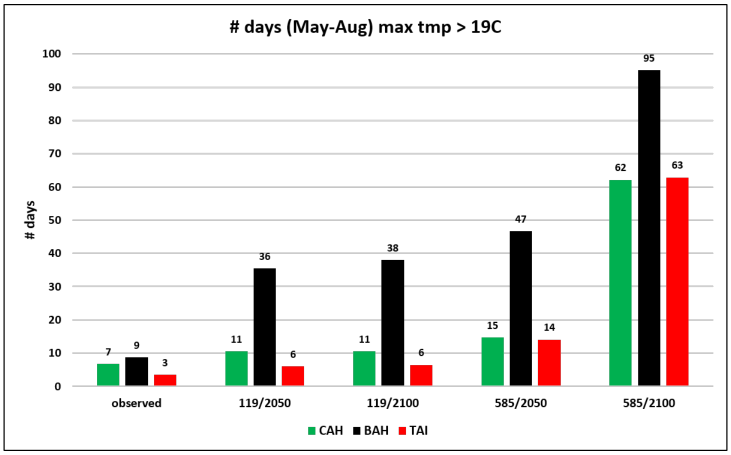

Figure S2-4 The number of days > 20ºC in each scenario

Linkage 5: Cumulative NDVI to forage biomass

Our approach to providing biomass to the CCE model was to develop four representative vegetation types within the range of the Central Arctic Herd (CAH; coastal, tussock tundra, non-tussock graminoids, and shrub herb) by collapsing types mapped from Raynolds et al. (2019). Species composition and biomass among the four vegetation types were approximated from representative sites presented in Epstein et al. (2004) and Walker et al. (2003). These authors worked on the Circumpolar Arctic Vegetation map (CAVM) and types can be generalized across the Arctic. After developing the biomass dataset for the CAH, we applied the same vegetation types and adjusted among herds based on analysis done by Qin Yu (2016) who showed that the Bathurst (BAH) and Taimyr (TAI) herds had lower green biomass compared to the CAH (Figure S2-5). The relative difference was applied to all green vegetation, while non-vascular plants remained the same (although lichen biomass was elevated in the summer range of the BAH, reflecting its unique location on the Canadian Shield).

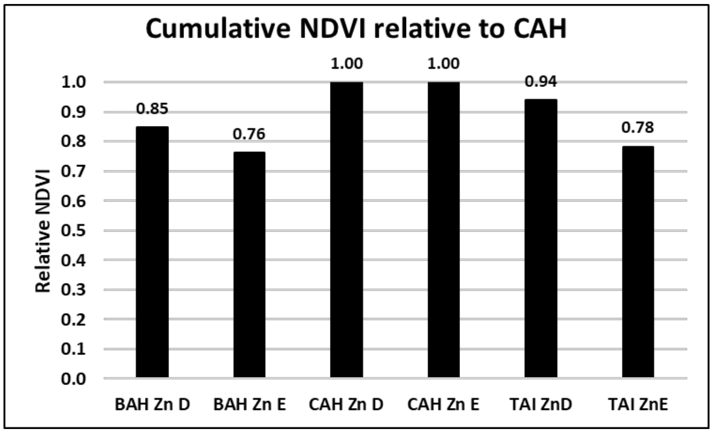

Figure S2-5 Biomass modifier based on cumulative Normalized Difference Vegetation Index (NDVI) relative to the CAH in coastal (Zn D) and interior (Zn E) ranges (Qin et al. 2016)

Linkage 6: Growing degree days to plant biomass

The seasonal profile of plant biomass changed among scenarios based on the timing of growing degree days (Linkage 2). However, we decided not to increase peak biomass in response to warmer climates, as our review of recent literature was equivocal in respect to greater biomass under warmer climates for most plant groups). Figure S2-6 is an example of seasonal plant biomass for the 10 plant types contained in the CCE model under current conditions in the four vegetation types modelled for the CAH.

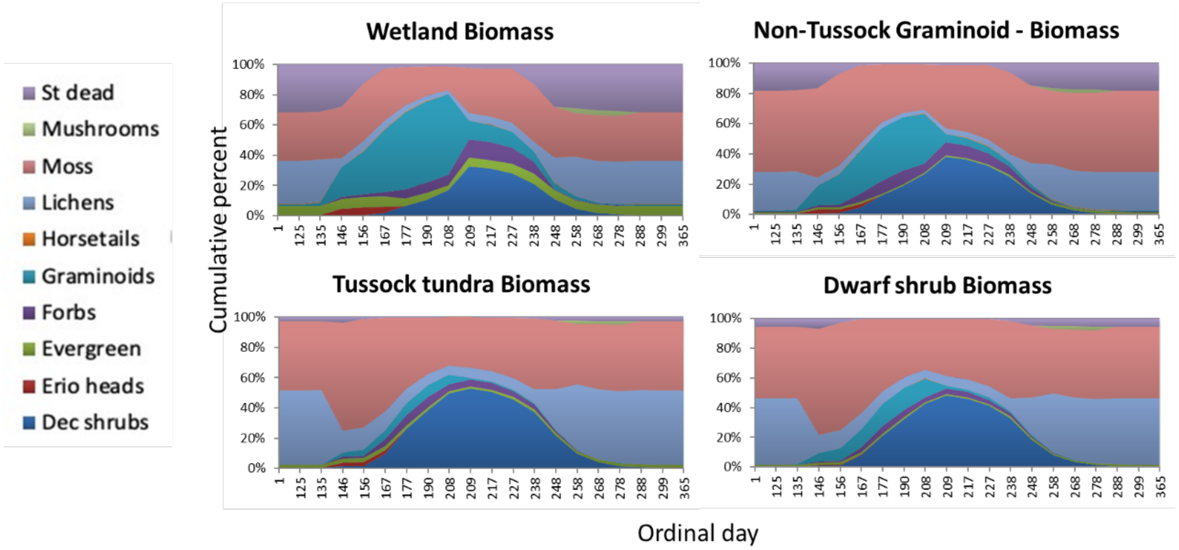

Figure S2-6 Cumulative biomass associated with four vegetation communities on the summer range of the CAH for the 10 plant groups modelled in the CCE model. Actual biomasses were derived from data provided in Epstein et al. (2004) and Walker et al. (2003).

Linkage 7: Growing degree days to forage nutrients

Warmer temperatures will impact the quality and timing nutrient availability. To link growing degree days to nutrient quality, we used three plant nutrient datasets from northern Alaska that sampled plant species throughout the late spring, summer, and early fall period. Finstad (1998) sampled on the Seward peninsula from 1996–1998, Adams et al. (2018) sampled the summer range of the CAH from 2011–2014, and Leffler et al. (2022) sampled the summer range of the CAH from 2016–2018.

Integrating our MERRA climate database with the plant nutrient collections, we are able to link GDD with changes in plant nutrient contents. Predictive equations were developed from the datasets to generate nutrient input into the model in relation to GDD. For key plant groups in the diet of caribou we generated:

1. Percent nitrogen and Bovine Serum Albumen (BSA) by applying polynomial regression equation between GDD and percent nitrogen and BSA.
2. Neutral detergent fibre (NDF) from relationship between estimated percent nitrogen (from Step 1) and NDF.
3. Acid detergent fibre (ADF) generated from relationship between ADF and NDF (from Step 3).

All components updated automatically from GDD profile for any climate scenario. Predictive equations were attempted on all 10 plant groups tracked in the model; however, where relationships were not significant (p>0.05), mean values were substituted (Table S2-4).

Table S2-4 Predictive equations used to construct a profile of seasonal phenological change in plant nutrients among plant groups

PLANT GROUP	Y=X	EQUATION	MEAN (x)	R-sq
Deciduous shrub: *Salix*	N=GDD	y = 4.158e-0.001x		0.63
Deciduous shrub: *Salix*	NDF=N	y = 0.601e-0.324x		0.48
Deciduous shrub: *Salix*	NDF=ADF	y = 0.0615e3.547x		0.91
Deciduous shrub: *Salix*	BAS=GDD	y = -1E-07x2 + 0.0002x + 0.151		0.12
Deciduous shrub: *Betula*	N=GDD	y = 2E-06x2 - 0.0037x + 3.5384		0.66
Deciduous shrub: *Betula*	NDF=N	y = -0.0429x + 0.5004		0.08
Deciduous shrub: *Betula*	NDF=ADF	y = 0.5662x + 0.0193		0.73
Deciduous shrub: *Betula*	BAS=GDD	y = -4E-07x2 + 0.0003x + 0.124		0.21
Eriophorum flower	N=GDD	y = -0.0022x + 2.7056		0.7
Eriophorum flower	NDF=N	ns	0.63	0.05
Eriophorum flower	NDF=ADF	y = -0.0667x + 0.3783		0.78
Evergreen shrub	N=GDD	ns	0.98	
Evergreen shrub	NDF=N	ns	0.46	
Evergreen shrub	NDF=ADF	ns	0.32	
Evergreen shrub	BAS=GDD	ns	0.21	
Forb	N=GDD	y=-0.0027x+4.0518		0.67
Forb	NDF=N	y = -0.0322x + 0.265		0.36
Forb	NDF=ADF	y = 0.6686x - 0.0005		0.91
Graminoid	N=GDD	y = -0.0014x + 2.7012		0.48
Graminoid	NDF=N	y = -0.0419x + 0.7464		0.31
Graminoid	NDF=ADF	y = 0.9292x - 0.3074		0.7
Horsetail	N=GDD	y = 5.3663e-0.001x		0.79
Horsetail	NDF=N	ns	0.315	
Horsetail	NDF=ADF	ns	0.176	
Lichen	N=GDD	ns	0.5	
Lichen	NDF=N	ns	0.55	
Lichen	NDF=ADF	ns	0.02	
Moss	N=GDD	ns	0.8	
Moss	NDF=N	ns	0.76	
Moss	NDF=ADF	ns	0.6	
Mushroom	N=GDD	ns	5.6	
Mushroom	NDF=N	ns	0.35	
Mushroom	NDF=ADF	ns	0.143	
Standing Dead Graminoid	N=GDD	ns	0.5	
Standing Dead Graminoid	NDF=N	ns	0.75	
Standing Dead Graminoid	NDF=ADF	ns	0.42	

Linkage 8: Mosquito/oestrid activity to caribou activity

Caribou reduce their exposure to mosquitos at the expense of foraging as the caribou move to windier, less vegetated areas to escape the insect impacts of irritation, blood loss, and parasite transmission (Russell et al. 1993 for PCH; Witter et al. 2011 for BAH). Mosquito harassment leads to reduced body reserves, reproduction, and overwinter survival for adult caribou females (Johnson et al. 2018). The trend to early springs as well as changing the peak of plant nitrogen will also advance peak mosquito harassment (Gustine et al. 2017).

The potential exposure of caribou to biting and parasitic insects as indexed for mosquitos shows a relatively modest change in magnitude from current for the optimistic 2050 scenarios (Figure S2-7) for the CAH (28%) and TAI (20%), while the BAH is projected to have a 62% increase in insect harassment. The index for all three herds remains unchanged by 2100. However, for the pessimistic scenario, the three herds have an index 45–75% higher by 2050 and 220–300% higher by 2100.

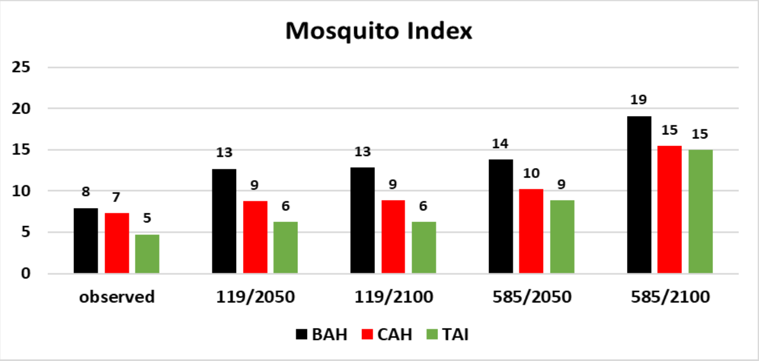

Figure S2-7 Current and projected mosquito harassment index

The insect activity reduces the percentage of the day spent foraging based on the level of insect harassment; this is the input into the CCE model (Figure S2-8). The pattern is similar to the insect index but the importance is emphasized as the reduction in the percentage of the day spent foraging. The daily reduction in foraging time is 5–10% compared to current foraging time.

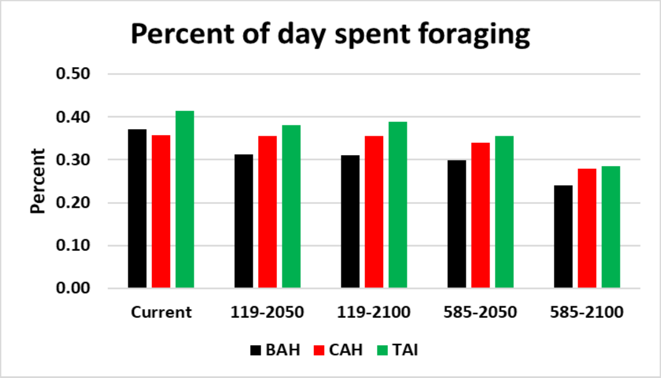

Figure S2-8 The percentage of the day spent foraging based on level of insect harassment for the three herds and four scenarios

Linkage 9: Summer heat to caribou activity

To reflect impact of hot days on caribou activity, we reduced the proportion of foraging time actually spent ingesting food. By doing so, we assume that the hot conditions do not change the activity costs (e.g., walking, running) but impacts the time spent ingesting food while foraging. In our CCE model, this is referred to as eating intensity which has been also documented to be impacted by increased insect harassment and deeper snow when cratering for food in the winter. Figure S2-9 shows the reduction in eating intensity due to the combined effect of hot days and increased insect harassment during the month of July.

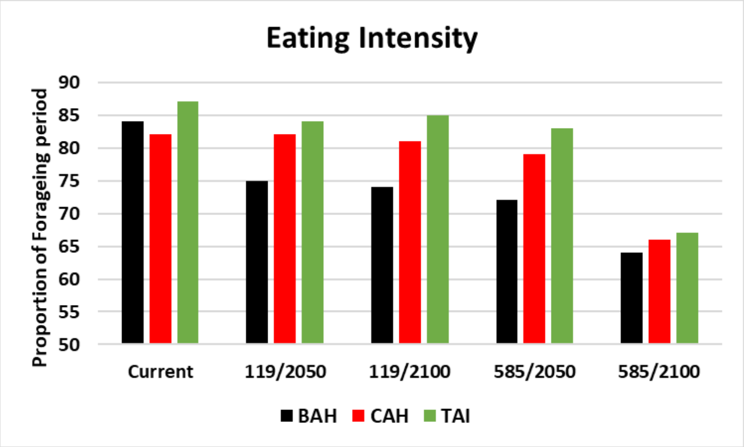

Figure S2-9 July reduction on eating intensity due to insect harassment and the number of days ≥20°C for each scenario

Linkage 10: Forage biomass to diet

Diet can be either empirically-derived or generated from seasonally available plant biomass using an algorithm (White et al. 1999). Although there is empirical data on diets in the CAH (White et al. 1975), we applied the diet algorithm so that diet is sensitive to changes in timing and magnitude of plant biomass in the climate-mediated scenarios. Our diet algorithm is based on seasonal selectivity indices for major plant groups, constrained by plant group biomass. Figure S2-10 is an example of a diet generated from biomass (see Russell and Gunn (2025) in the herb/shrub vegetation type in the CAH.

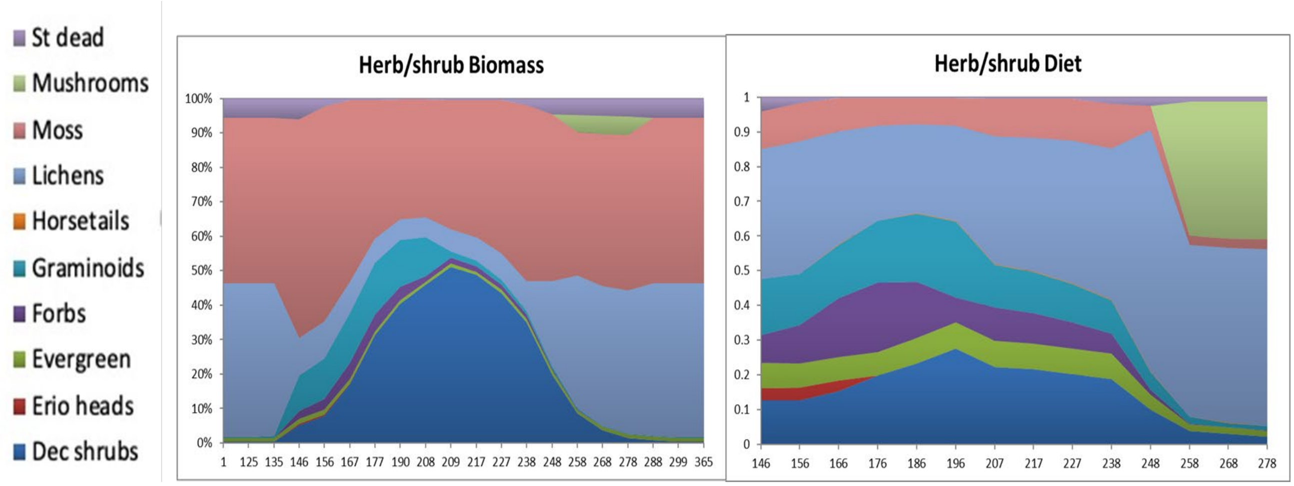

Figure S2-10 An example of the conversion of plant biomass to diet selection for herd/shrub community in the CAH using algorithm derived from White et al. 1999

Linkages 11-13:

- Diet to Energy-Protein sub-model
- Forage biomass to Energy-Protein sub-model
- Forage nutrients to Energy-Protein sub-model

A major component of our CCE model is the rumen sub-model (Figure S2-11) which simulates food intake and digestion producing daily metabolizable energy and nitrogen to be allocated to the caribou for growth, reproduction, and mounting an immune response. From Figure S2-11, we see where nutrient quality indicators derived in Table S2-4 (ADF, NDF, BSA, N), biomass (Linkage 12) and diet (Linkage 11) were used to generate daily metabolizable energy (Figure S2-11A) and protein (Figure S2-11B). These two nutrients are allocated in the Allocation sub-model to grow the cow and calf (see detailed description in White et al. [2014]).

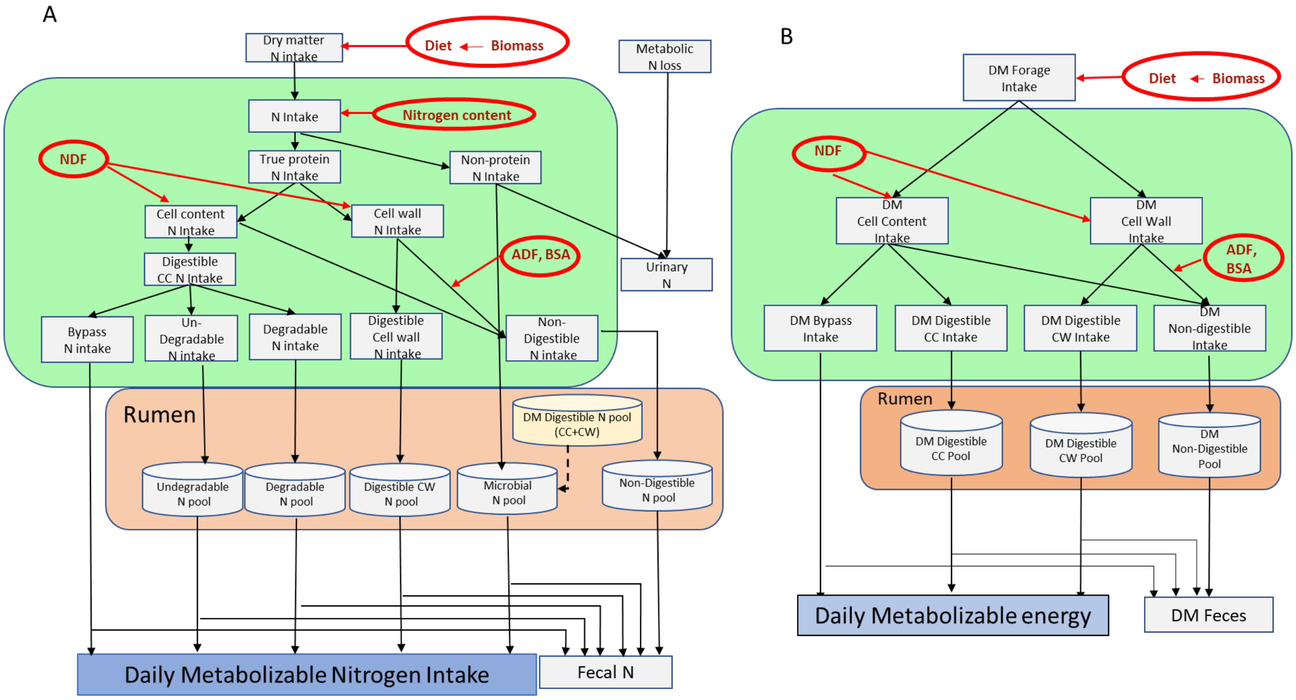

Figure S2-11 Nutrient pathways for energy (A) and nitrogen (B) in the rumen sub-model. Acronyms in red depict where nutrient components entered the pathways.

Linkage 14: Caribou activity to Energy-Protein model

The default seasonal activity budgets were developed over the years based on previous group and focal animal scan data (Russell et al. 1993, Witter 2010) and datalogger data (van Oort et al. 2005). For our application, activity budgets for all three herds were identical except as impacted by summer inset harassment (reduction in foraging and lying, increase in standing, walking and running (see Russell et al. 1993 and Witter 2010). Both hot days and insect harassment also reduced eating intensity, defined by the proportion of the foraging time spent ingesting food (Russell et al. 1993, Witter 2010, Trondrud et al. 2023). The herd-specific changes to percent of day foraging and eating intensity were derived in Linkages 8 and 9, respectively.

Linkage 15: Energy-Protein sub-model to Population sub-model

Explained in main report.