The ALCES Population Dynamics Model User Guide for the Bathurst, Bluenose-East, Bluenose-West, Cape Bathurst, and Tuktoyatuk Peninsula Central Barren-Ground Caribou Herds in the Northwest Territories and Nunavut

Prepared by the CBGC ALCES Project Team – Matt Carlson, Thom Stubbs, John Nishi, and Mélanie Routh

April 2026

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Introduction

CBGC (Central Barren-Ground Caribou) ALCES is a population dynamics model for the Bathurst, Bluenose-East, Bluenose-West, Cape Bathurst, and Tuktoyatuk Peninsula central barren-ground caribou herds in the Northwest Territories and Nunavut. The model is a customized version of the ALCES landscape and population dynamics (PopDyn) models. CBGC ALCES integrates a range of data and model logic, including a spatial representation of current landscape composition, a 40-year forecast of landscape and climate dynamics, a default future development scenario, and a seasonal barren-ground population dynamics model. This document describes the population dynamics model using the inputs and outputs for the Bathurst caribou range as an example. Descriptions of current land cover, the landscape and climate forecast, and the development forecast are available at https://cbgc.alces-flow.com/public/web/docs/index.html. CBGC ALCES is designed to make barren-ground population dynamics simulations accessible to analysts from partner organizations. This report forms a component of the user guide for CBGC ALCES that is available at https://cbgc.alces-flow.com/public/web/docs/index.html. Access to the full user guide and to the tool to run simulations requires a login and password. Analysts from partner organizations should contact Melanie Routh (Melanie_Routh@gov.nt.ca) to request access to CBGC ALCES.

CBGC ALCES is an exploratory tool for considering the consequences of development footprint, harvest, and climate change on barren-ground caribou habitat and population. Use of the tool can help understand the relative importance of risks and effectiveness of management options. It is important to note, however, that the tool should not be considered predictive due to limitations in caribou knowledge and model scope, as well as inherent uncertainty associated with drivers such as climate change.

CBGC ALCES Model Structure

The CBGC ALCES model simulates caribou population dynamics in response to habitat, fecundity, and mortality. It is a cell-based spatial model, with each cell defined as a Leslie-matrix population model with a carrying capacity dictated by the cell's habitat. The model is linked to landscape simulations so that habitat and mortality risk respond to landscape and climate dynamics. Seasonality is a key characteristic of the annual life cycle for barren-ground caribou, and CBGC ALCES includes five seasonal submodels: 1) spring, 2) calving, 3) summer, 4) fall, and 5) winter. The five submodels are linked such that the population output from the spring submodel is the population input for the calving submodel, the calving submodel provides input to the summer submodel, and so on. CBGC ALCES's computation steps are:

1. The initial population dictates the starting point of the simulation in terms of the spatial distribution of animals within each sex and age class. The initial population is distributed across the spring migration range based on habitat availability.
2. Habitat layers for each season are prepared using landscape covariates, and each cell's carrying capacity by season is calculated for subsequent use when applying density dependence relationships for fecundity and mortality.
3. The population migrates to the calving range and is distributed across cells based on habitat availability.

4. Fecundity rates for each cell are calculated, adjusting for density dependence if necessary. Fecundity rates are applied to the number of females within relevant age classes to calculate the number of births per cell. Each cell's population is adjusted accordingly.
5. Mortality rates for each cell are calculated for the calving season, adjusting for density dependence if necessary. Mortality rates are applied to the number of animals by sex and age class to calculate the number of deaths per cell. Each cell's population is adjusted accordingly.
6. The population remaining at the end of the calving season migrates to the summer range and is distributed across cells based on habitat availability.
7. Mortality rates for each cell are calculated for the summer season, adjusting for density dependence if necessary, and applied to the number of animals by sex and age class to calculate the number of deaths per cell. Each cell's population is adjusted accordingly.
8. The population remaining at the end of the summer season migrates to the fall range and is distributed across cells based on habitat availability.
9. Mortality rates for each cell are calculated for the fall season, adjusting for density dependence if necessary, and applied to the number of animals by sex and age class to calculate the number of deaths per cell. Each cell's population is adjusted accordingly.
10. The population remaining at the end of the fall season migrates to the winter range and is distributed across cells based on habitat availability.
11. Mortality rates for each cell are calculated for the winter season, adjusting for density dependence if necessary, and applied to the number of animals by sex and age class to calculate the number of deaths per cell. Each cell's population is adjusted accordingly.
12. The population remaining at the end of the winter season migrates to the spring migration range and is distributed across cells based on habitat availability.
13. Mortality rates for each cell are calculated for the spring migration season, adjusting for density dependence if necessary, and applied to the number of animals by sex and age class to calculate the number of deaths per cell. Each cell's population is adjusted accordingly. This provides the starting point for the next simulation year.
14. Steps 3 through 13 are repeated for each year of the simulation.

Population Dynamic Model Inputs

Key inputs to the CBGC ALCES population dynamics model include seasonal ranges, initial population size and composition, habitat, fecundity, and mortality. The approaches for deriving these inputs are now described in turn for the Bathurst herd. Inputs for other herds are presented in Appendix 2. We emphasize that our focus of initial input assumptions was to establish a working simulation model with plausible outputs and results. We envision use of CBGC ALCES as an iterative process to improve inputs as better information and functional relationships are identified, and through co-development of specific scenarios to explore specific issues and questions.

Seasonal Ranges

A year in the life of migratory barren-ground caribou may be broken into different activity periods that are based on seasonal environmental changes as well as the life-history strategies of caribou that reflect their seasonal reproductive biology, behavior, migratory and range use patterns (PCTC 1993, BQCMB 1999, GNWT 2019). Defining caribou activity periods is useful because it provides a way to describe and understand the inter-related seasonality of environmental conditions, caribou biology and distribution, and it provides a logical basis for developing and informing submodels.

Following the approach adopted when simulating population dynamics for Bluenose East, Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula caribou herds, five (5) seasons were used when simulating barren-ground caribou dynamics within an annual cycle. These five seasons were established by aggregating 12 activity periods defined by Nagy (2011)[1] into the following: spring migration, calving, summer, fall, and winter.

Figure 1 illustrates the corresponding five seasonal ranges, which provide spatial extents in the model to simulate seasonal range use by caribou within the herd's annual range. The size of the Bathurst range has declined dramatically over the past two decades in response to the herd's large population decline. Mennell (2021) estimates that the annual range declined by 90% between 1997 and 2019 in response to the population declining from 350,000 to 8,200. Seasonal ranges are estimated to have declined between 35.2% and 90.2% during this period. To avoid exaggerating range sizes, seasonal range boundaries were based on caribou location data from the past 10 years (2014 to 2023). The seasonal ranges were based on kernel-density estimates instead of minimum convex polygons to constrain ranges to those areas where caribou are most likely to occur. When applying kernel-density estimates, a utilization distribution threshold of 95% was applied. Finer-grained input assumptions for habitat use are nested within each of the five seasonal ranges and are based on resource selection function (RSF) coefficients that were derived for each seasonal range (see next section on Habitat).

Habitat

For each season, the model requires a habitat relationship as well as the maximum density that can be supported in ideal habitat. The habitat relationship is applied to spatially distribute the population existing at the start of each season. The habitat layer is also used when applying density dependent relationships for fecundity and mortality. Because PopDyn knows the maximum density (i.e., K) in best habitat, and knows the habitat value (0.00-1.00) of each cell in the study area, it can compute the carrying capacity (K) for each cell, using the following equation:

Cell K (#/km2) = Max K (#/km2) * Cell Habitat Value (0.00-1.00)

When N/K is high (near or above 1) then the cell density is likely to decline because of reduced reproductive rates or increased mortality. Of note is that calves are not included when calculating a cell's population for the N/K ratio because calves have minimal forage demands.

Seasonal habitat indices were prepared using resource selection functions (RSFs) developed collaboratively with the Alberta Biodiversity Monitoring Institute (ABMI) (C. DeMars pers. comm.). The RSF analyses included the GNWT's comprehensive caribou collar telemetry dataset (2005 – 2020), and a comprehensive study area basemap comprised of landscape layers from ALCES. As summarized in

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[1] In an analysis of collar data (1996-2008), Nagy (2011) identified 12 activity periods for seven migratory barren-ground caribou herds – including the Bathurst herd – and showed there were significant differences in daily movement rates by collared female caribou between activity periods.

Appendix 1, the study area basemap included human footprint data for the Northwest Territories[2] and Nunavut, natural land cover types (Land Cover Classification of Canada *circa* 2015[3]), and other key spatial attributes including forest age, topography (slope, aspect, and elevation), and climatic characteristics (temperature, precipitation, potential evaporation). The resulting RSF coefficients (Table 1) were transformed to a normalized scale of 0 to 1 and applied to land cover data in ALCES to derive habitat index values for each season within the Bathurst herd range at a 1 ha cell resolution. Transformation of RSF coefficients was done by taking the exponential and performing a linear stretch using minimum and maximum values based on current landscape and climate values. Minimum and maximum values were calculated for the more recent seasonal ranges (2014-2023 for Bathurst, 2005-2020 for the other herds).

Each cell's carrying capacity will then equal its habitat index multiplied by seasonal maximum densities. Calculation of maximum seasonal population densities is complicated by the range contraction that has occurred over the past two decades. In addition to the seasonal ranges used in the modeling based on 2014 to 2023 data, kernel density based estimates of seasonal ranges were available for the 2005 to 2019 period. The older seasonal range estimates were used when calculating maximum population density because the Bathurst population was higher during that period. The highest population recorded between 2005 and 2019 was 128,000 caribou in the year 2006[4]. Seasonal maximum densities were derived by dividing that maximum population (128,000) by the size of the 2005-2019 seasonal range and then dividing by the average habitat index of the range[5] (Table 2). Dividing by the average habitat for a range was done in order to scale maximum density to what it would be if all cells were at maximum habitat (i.e., habitat index equal to 1).

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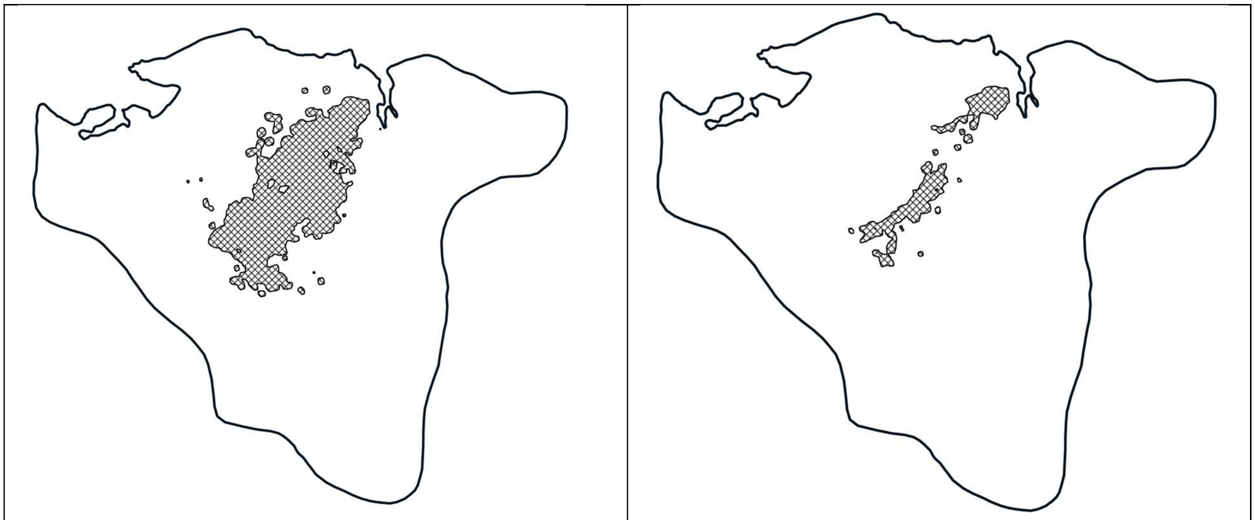
[2] Government of the Northwest Territories Centre for Geomatics, Inventory of Landscape Change, https://www.maps.geomatics.gov.nt.ca/Html5Viewer/Index.html?viewer=CIMP_ILC_Webmap.ILC_Viewer

[3] https://open.canada.ca/data/en/dataset/4e615eae-b90c-420b-adee-2ca35896caf6

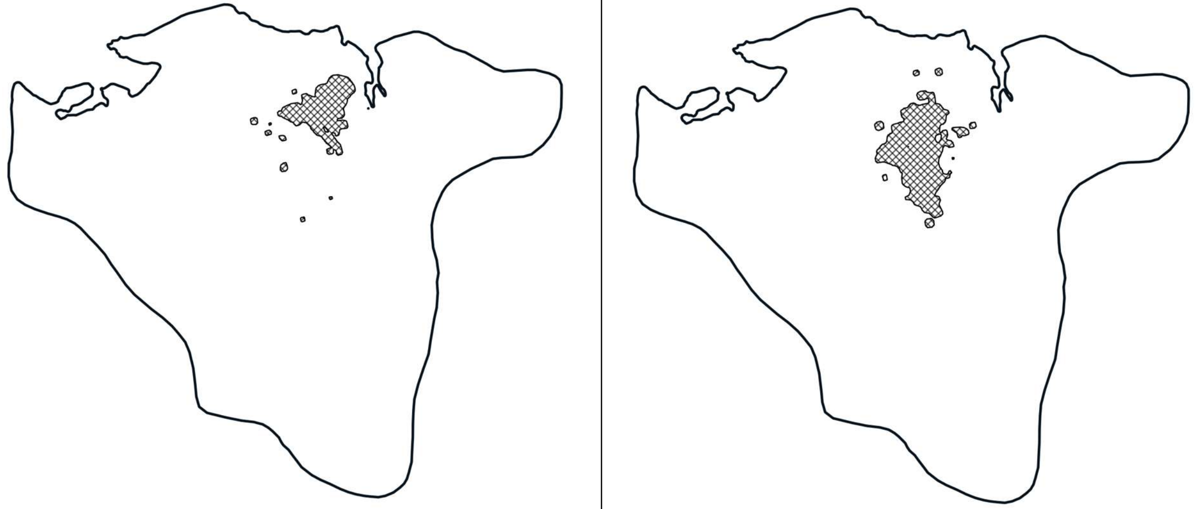
[4] https://www.cclmportal.ca/sites/default/files/2022-10/fact_sheet_bathurst_caribou_en_1.pdf

[5] The average habitat index of a seasonal range was calculated by first calculating the habitat index within each raster using the seasonal RSF model coefficients and current land cover and climate, and then calculating the average habitat index value across rasters occurring within the seasonal range.



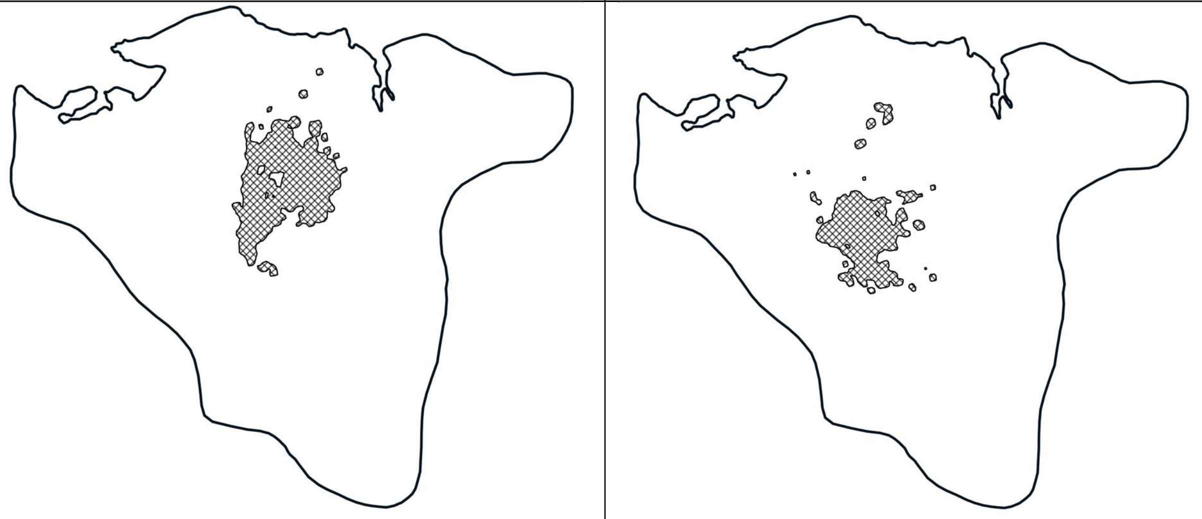
Annual Range

Spring Migration (Apr 10 - May 27)



Calving (May 28 – Jul 3)

Summer (Jul 4 – Sep 6)



Fall (Sep 7 – Dec 25)

Winter (Dec 26 – Apr 9)

Figure 1. Annual range and five seasonal ranges of the Bathurst caribou herd derived from collared female caribou locations (2014-2023). Each range is placed within the historical annual range for context.

Table 1. Seasonal resource selection function (RSF) model coefficients for the Bathurst herd (ABMI 2021).

	Spring Migration			**Calving**			**Summer**			**Fall**			**Winter**		
Variable$^{\Phi}$	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**
(Intercept)	-4.148	0.066	<0.001	-3.688	0.096	<0.001	-7.791	0.301	<0.001	-7.192	0.154	<0.001	-4.055	0.083	<0.001
Barren Lands	-0.019	0.001	<0.001	-0.006	0.001	<0.001	-0.073	0.002	<0.001	-0.108	0.003	<0.001	-0.030	0.001	<0.001
Shrublands	0.009	0.001	<0.001	0.008	0.001	<0.001	0.033	0.001	<0.001	0.023	0.000	<0.001	0.013	0.000	<0.001
Forested	-0.009	0.000	<0.001	-0.294	0.014	<0.001	-0.306	0.076	<0.001	-0.020	0.005	<0.001	-0.014	0.001	<0.001
Forest Age Indicator (> 50 yr old)	—	—	—	—	—	—	1.545	0.261	<0.001	2.293	0.132	<0.001	0.784	0.041	<0.001
Linear Features (10-km radius)	0.344	0.055	<0.001	-5.748	0.695	<0.001	1.713	0.092	<0.001	2.103	0.063	<0.001	-0.882	0.078	<0.001
Polygonal Disturbances (10-km radius)	0.283	0.011	<0.001	-0.350	0.127	0.006	-0.010	0.013	0.418	-0.092	0.011	<0.001	0.193	0.013	<0.001
Waterbody (Lakes)	-0.003	0.000	<0.001	-0.056	0.001	<0.001	-0.009	0.001	<0.001	-0.010	0.000	<0.001	-0.006	0.000	<0.001
Watercourse (Rivers)	0.020	0.035	0.569	0.636	0.044	<0.001	-0.001	0.051	0.977	-0.097	0.042	0.020	-0.286	0.032	<0.001
Wetlands	-0.132	0.006	<0.001	-0.174	0.012	<0.001	-0.034	0.006	<0.001	-0.018	0.004	<0.001	-0.034	0.002	<0.001
Minimum Elevation *	—	—	—	—	—	—	1.667	0.020	<0.001	1.794	0.016	<0.001	—	—	—
Maximum Elevation *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mean Elevation*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Slope*	—	—	—	0.256	0.009	<0.001	-0.026	0.015	0.082	-0.236	0.013	<0.001	-0.240	0.009	<0.001
Aspect*	—	—	—	-0.161	0.013	<0.001	0.020	0.010	0.054	0.054	0.008	<0.001	0.023	0.006	<0.001
Minimum Temperature *	—	—	—	—	—	—	-2.230	0.037	<0.001	—	—	—	—	—	—
Maximum Temperature*	—	—	—	—	—	—	—	—	—	—	—	—	0.337	0.011	<0.001
Mean Temperature *	—	—	—	—	—	—	—	—	—	-0.367	0.020	<0.001	—	—	—
Evaporation*	—	—	—	—	—	—	1.413	0.051	<0.001	0.179	0.022	<0.001	—	—	—
Precipitation*	—	—	—	—	—	—	0.371	0.016	<0.001	-0.371	0.018	<0.001	—	—	—
Forested * Forest Age Indicator	—	—	—	—	—	—	0.174	0.076	0.021	-0.015	0.005	0.004	0.015	0.001	<0.001
Spearman's correlation coefficient (r_S) $^{\Upsilon}$		0.95			1.00			1.00			0.98			1.00	

$^{\Phi}$ Grassland is the reference category for local land-cover variables

* standardized coefficients

$^{\Upsilon}$ correlation between RSF bin rank (1-10 bins with bin 10 being strongest selection) and proportion of all caribou locations falling within each bin

There is the option in the CBGC ALCES model to apply a zone of influence (ZOI) to footprints to reflect an avoidance response triggered by sensory disturbances such as noise, dust, odors, and visual stimuli. Reduced habitat use within the ZOI will have the effect of increasing caribou density elsewhere in the range (i.e., because caribou are forced to use only a portion of the range). Limiting caribou to a portion of the range through a ZOI effect can impact caribou population dynamics if population density outside of the ZOI is high enough to trigger density dependent mortality and fecundity. Two types of inputs are required to define footprint ZOIs: the scale factor and footprint buffers.

- The scale factor represents the proportional habitat value within the ZOI. The scale factor is assumed to be the same across all footprint types. Simulations completed to date for the Bathurst herd have explored the consequences of scale factors: 0 (total caribou avoidance of the ZOI), 0.5 (50% habitat use within the ZOI), and 1 (no avoidance of the ZOI). Most simulations assumed a scale factor of 0.5, which is within the range of scale factors that have been used elsewhere (e.g., Golder Associates 2014). The scale factor can be modified by the user.
- Footprint buffers identify the distance (in km) of the ZOI as measured from the outer edge of a footprint. For example, a footprint buffer of 5 km applied to permanent roads results in a ZOI that is 10 km wide. Buffer distances can differ between footprint types. The default buffer distances in the CBGC model are those identified in GNWT 2018 (table 3). Buffer distances can be modified by the user.

Table 2. Maximum density of 1+ year-old Bathurst caribou in best habitat as calculated by dividing the highest recorded population between 2005 and 2019 (128,000 in 2006) by the seasonal 2005-2019 range area and average habitat index.

Season	2005-2019 Range Area (km^2)	Average habitat index	Max density in best habitat (#/km^2)
Spring Migration	152,288	0.0566	14.85
Calving	24,447	0.2976	17.59
Summer	101,581	0.0297	42.43
Fall	89,729	0.0885	16.12
Winter	172,213	0.2414	3.08

Table 3. Default footprint zone of influence (ZOI) buffers adopted by the CBGC ALCES model.

Footprint Zone of Influence Buffers (km)			
Winter road, general industrial, miscellaneous	Transmission line	Permanent road, airstrip, camp, mineral exploration, mine, power generation, quarry	Settlement
1	4	5	15

Initial Population Size and Composition

The basic structure of the population dynamics model (Figure 3) reflects female and male caribou organized across four age classes and linked through vital rates of reproduction and mortality. Although the reproductive life of caribou is about 12 years – with females living to 12–16 years, and males a few years less (Thomas and Killiaan 1998) – the model aggregates their lifespan into four age classes to reflect the types of empirical data that biologists regularly collect to monitor status and trend of caribou herds.

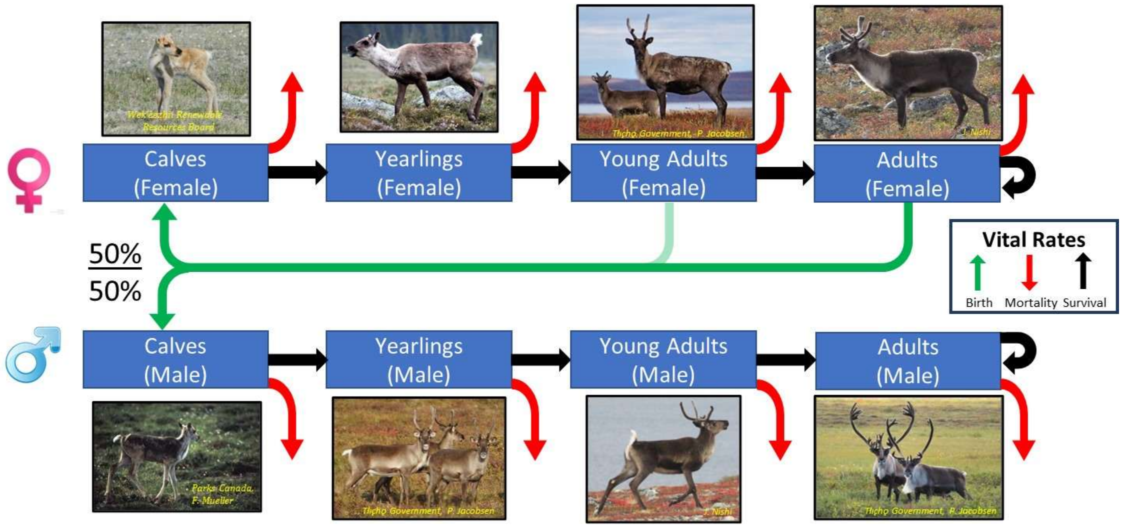


Figure 2. Basic structure of the wildlife population dynamics model.

A population dynamics simulation is initialized by distributing the current age and sex stratified population spatially in the spring range based on the spring range habitat layer. Current population size is 6,240 non-calves[6]. A population simulation was completed to derive the initial age and sex composition expected given the assumed mortality and fecundity rates. In the simulation[7], habitat was kept constant at current levels (i.e., no new development or climate change), which resulted in a steady total population and allowed the population composition to stabilize over four decades to values consistent with vital rate assumptions. Table 4 summarizes the resulting values for population size and composition that are adopted in the Bathurst population model. Although the bull to cow ratio (0.60) is substantially lower than was observed during 2022 and 2023 fall composition surveys (1.10 and 1.06), those surveys may in part reflect differential rates of movement of bulls and cows between the Bathurst and Beverly herds (Adamczewski et al. 2024a). The bull to cow ratio in 2020 (0.64) was more consistent with the ratio assumed in the simulations.

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[6] https://www.gov.nt.ca/ecc/en/services/barren-ground-caribou/bathurst-herd#:~:text=de%20la%20page-,Population,low%20of%20about%206%2C240%20today.

[7] For the simulation used to derive population composition, proportional composition was initialized at values used in previously completed Bluenose East population simulations that used similar vital rate inputs to those adopted for the Bathurst.

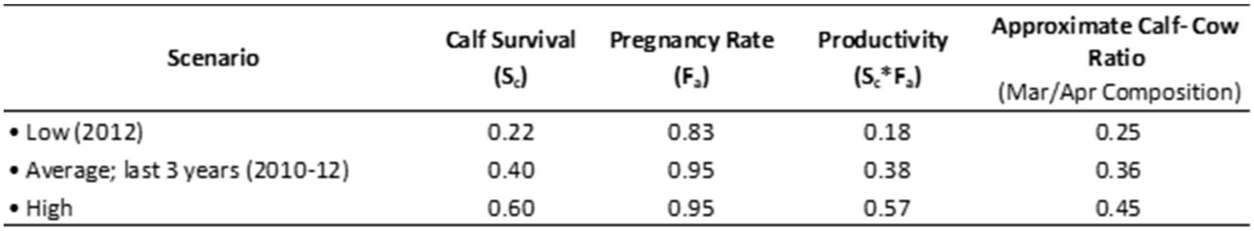
Table 4. Derived estimates for a stable age class distribution.

Age class	Female population (and proportion)	Male population (and proportion)
Calf (0 year)	774 (0.099)	774 (0.099)
Yearling (1 year)	605 (0.078)	605 (0.078)
Young adult (2 year)	512 (0.066)	468 (0.06)
Adult (3 to 14 years)	2,633 (0.388)	1,410 (0.181)
Total	4,524	3,257
Total Population Size	7,781	

Fecundity

Fecundity is defined as the average number of offspring born per female in units of offspring/female/year. A fecundity rate is needed for each age class; the fecundity rate can be 0 for one or more age classes (e.g., young of year). We adopted average productivity assumptions that were identified by Boulanger (2017) for the Bluenose East herd. According to Boulanger's (2017) average productivity scenario, the fecundity rate is 0.95. When combined with a calf survival rate of 0.4, the resulting productivity rate is 0.38. This productivity rate compares well with the 0.384 calf cow ratio derived in fall 2022 and the 0.368 calf cow ratio derived in the fall of 2024 (Adamczewski 2024a) . Although a higher calf-cow ratio of 0.484 was derived more recently in winter 2023, the estimate was associated with substantial uncertainty such that the fall 2022 calf-cow ratio should be treated with higher confidence (Adamczewski et al. 2024b). We applied a fecundity rate of 0.95 to adult cows (3 years and older). A lower fecundity rate of 0.15 was applied to young adults cows (2 years old) based data from the Beverly herd which indicated a sharp decline in pregnancy rate in two year olds (~10%) compared to 3 year olds (>70%) (Thomas and Killian 1988).

Table 5. Initial model input assumptions for fecundity and calf survival (sensu Boulanger 2017); basecase fecundity rate = 0.95



Scenario	Calf Survival (S_c)	Pregnancy Rate (F_a)	Productivity (S_c*F_a)	Approximate Calf-Cow Ratio (Mar/Apr Composition)
• Low (2012)	0.22	0.83	0.18	0.25
• Average; last 3 years (2010-12)	0.40	0.95	0.38	0.36
• High	0.60	0.95	0.57	0.45

Reproductive performance is typically affected by population density. As populations approach K (carrying capacity) the body condition of females may decline and this lowered body condition may reflect itself in lower fecundity rates. Two inputs are required to implement density dependent fecundity. The first input is the N/K value (N/K threshold) where density begins to affect reproductive performance. The second input is the maximum proportional reduction in the fecundity rate due to density dependence. PopDyn assumes a linear change in fecundity from 0 at the N/K threshold to the maximum proportional reduction at carrying capacity (N/K=1).

We do not know of empirical estimates of density dependent fecundity for barren-ground caribou. Rempel et al. (2021) assumed density dependent fecundity for boreal caribou to be initiated at N/K=0.5 and to reach a maximum reduction in the fecundity rate of 0.25 at carrying capacity. These values are used in the CBGC ALCES model.

The Effect of Footprint Encounters on Recruitment

Exposure of caribou to development footprints such as roads has been found to cause increase vigilance and decreased feeding activity (e.g., Smith et al. 2023). Increased movement and decreased feeding has the potential to reduce cow and calf weight, which in turn can cause probability of pregnancy and calf survival to decline (Russell et al. 2024). Using an energetics model, Russell et al. (2024) estimated the effect of footprint encounter scenarios on cow and calf weight loss, where a footprint encounter is defined as a day that a caribou spends within the footprint zone of influence. Russell et al. (2024) also refer to relationships between cow weight loss and probability of pregnancy, and between calf weight loss and calf survival.

Incorporating the effect footprint encounters recruitment into CBGC ALCES required three steps:

1. Estimate the number of footprint encounters based on the overlap between caribou habitat and the footprint ZOI. The footprint ZOI was defined using buffers from GNWT (2018) that were identified previously in this report (Table 3). The proportion of time that an average caribou spends within the ZOI was then estimated based on the proportion of caribou habitat (according to the seasonal RSFs) occurring within the ZOI. The proportion was calculated separately for each seasonal range, and the number of encounters (i.e., number of days spent within the ZOI) per season was estimated by multiplying the proportion of habitat occurring within the ZOI by the length of the season (in days).
2. Estimate cow and calf weight loss caused by footprint encounters. The results from Russell et al.’s (2024) energetic model simulations provide a set of data points that associate calf and cow weight loss with the number of encounters. Linear regression was applied to the data points to derive relationships between the number of encounters and cow and calf weight. The regression for number of encounters and cow weight loss achieved a R2 of 0.98 and estimated a weight loss of 0.1571 lb per footprint encounter. The regression for number of encounters and calf weight loss achieved a R2 of 0.96 and estimated a weight loss of 0.0683 lb per footprint encounter. These weight loss rates are applied in CBGC ALCES to estimate cow and calf weight loss caused by footprint encounters.
3. Estimate the reduction in pregnancy caused by cow and calf weight loss. Russell et al. (2024) presented a relationship between spring cow body weight and probability of pregnancy defined by a logistic regression. According to the relationship and assuming an initial cow weight of 80 kg, a weight loss of 1 kg is associated with a 2.6% reduction in the probability of pregnancy. In CBGC ALCES, a 2.6% reduction in the probability of pregnancy is assumed per kg of cow weight that is lost due to footprint encounters.
4. Estimate the reduction in calf survival caused by calf weight loss. Russell et al. (2024) refer to a correlation between fall calf body weight and overwinter survival derived using data from Arthur and Del Vecchio (2009). The relationship estimates at 5.1978% reduction in calf survival per kg of calf weight loss. In CBGC ALCES, a 5.20% reduction in the probability of winter survival is assumed per kg of calf weight that is lost due to footprint encounters.

The approach described above for modeling the effect of footprint encounters on recruitment (i.e., probability of pregnancy and calf survival) should be seen as a first attempt that requires future improvements to address uncertainties and simplifications. Key uncertainties and simplifications include:

- The effect of seasonality. The default setting in CBGC ALCES is for encounters to have the same effect on recruitment in all seasons. The user can use an input device in CBGC ALCES to have the effect differ by season, but information on seasonal differences in the effect of encounters on recruitment was not available.
- Differences among herds. The default setting in CBGC ALCES is for encounters to have the same effect on recruitment across herds. The user can use an input device in CBGC ALCES to have the effect differ by herd, but information on differences in the effect of encounters on recruitment among herds was not available.
- Nonlinear relationship between encounters and recruitment. Nonlinearities undoubtedly exist, as illustrated by the logistic model representing the relationship between cow body weight and probability of pregnancy. Additional model development and caribou research is needed to identify and represent nonlinear relationships in the model.
- Incorporating the effect of climate. There are likely interactions between the effects of footprint encounters and climate on vital rates. More research is needed to understand potential interactions.

Mortality

Three types of mortality are simulated by CBGC ALCES: natural mortality, density dependent mortality, and harvest. These mortality types are applied additively, such that total mortality equals the sum of natural mortality, density dependent mortality, and harvest. For natural and density dependent mortality, mortality is also additive across seasons. For example, if a natural mortality rate of 0.1 (i.e., 10%) is set for each seasonal model, the annual mortality rate will be the sum of the seasonal rates which is 0.5 (i.e., 50%). Natural mortality and harvest mortality can be controlled through the CBGC ALCES user interface, including selecting whether natural mortality should be influenced by climate change and whether harvest mortality should be influenced by roads that provide access for hunters. Each mortality type is now described in greater detail.

Natural Mortality

The ALCES CBGC user interface can be used to set natural mortality rates by season, age class, and sex. We used natural mortality rates based on survival rates (i.e., mortality rate = 1 - survival rate) adopted by Boulanger (2017). Although Boulanger (2017) used the survival rates in the context of the Bluenose East herd, the survival rates were calculated from Bathurst herd data.

The CBGC ALCES model includes an option to adjust natural mortality to represent the effect of projected changes in June temperature. The relationship between fecundity and June temperature is described in the section Climatic Influences on Vital Rates.

Table 6. Initial input assumptions for seasonal mortality as derived from Boulanger's (2017) estimates of natural survival rates.

Parameter	Annual Survival Rate	Seasonal Mortality Rate
Adult female survival (no old age mortality)	0.82 – 0.88 (basecase = 0.825[8])	0.035
Adult male survival (no old age mortality)	0.72	0.056
Yearling survival	0.86	0.028
Calf survival	0.22 – 0.60 (basecase = 0.40)	0.12

Climatic Influences on Cow Mortality

The effect of climate on caribou survival is modeled in CBGC ALCES using outcomes of research by Chloe Beaupre. Through statistical analysis of caribou mortality and climate data, a set of hazard curves were derived relating the relative risk of cow mortality to three climate variables: winter temperature, summer temperature, and snow depth (Figure 3, Figure 4, Figure 5). In CBGC ALCES, the user has the option of turning on one or more of the climate relationships. Doing so causes cow mortality to adjust each year in response to changes in the climate variables. The adjustment is implemented by multiplying the cow mortality rate by the hazard ratio. The hazard ratios refer to relative survival during one of two time periods (referred to here as hazard periods): the winter/spring period (December 1 to June 1) or the summer/fall period (June 2 to November 30). Application of the hazard ratios in CBGC ALCES required translating the hazard periods to the caribou seasons used by the population dynamics model (spring migration, calving, summer, fall, winter). The translation was implemented by calculating the proportional overlap between the timing of a season and the hazard periods (Table 7, Table 8) and then discounting the hazard ratio accordingly. The formula for discounting the effect of the hazard ratio in the case of partial overlap between the timing of a season and hazard period was *HR_seasonal_adjust = (HR-1)*overlap + 1*, where *HR_seasonal_adjust* refers to the HR for a herd's season after adjusting for overlap between the season and the HR period, *HR* refers to the hazard ratio calculated from climate, and *overlap* refers to proportional overlap between the HR period and each herd season.

Winter and summer temperature projections that are needed for the hazard curves were based on the ensemble mean from the CMIP6[9] statistically downscaled[10] climate projection for the SSP5-8.5 scenario (Government of Canada 2025a). The CMIP6 projections for snow depth were not available in a downscaled format. Instead, the CMIP6 snow depth projection uses the original 1x1 degree grid

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[8] For additional context and based on an empirical relationship between adult cow survival and population trend, we can infer that a cow mortality rate of ~17.5% (which equates to a survival rate of 82.5%) should result in a stable population. Based on an annual adult female survival rate of 0.825, calf:100 cow recruitment ratios of 37.5 and 42.5 would be needed to derive population rates of change (r) of -0.02 and 0 respectively (DeCesare et al. 2012). As described previously, we have adopted a productivity rate of 0.38, which is consistent with the calf:cow recruitment ratio required for a stable population under a cow mortality rate of 0.175.

[9] Coupled Model Intercomparison Project phase 6.

[10] Downscaling is required to increase the resolution of coarse general circulation model projections to a ~ 10 km grid. Two versions of the statistically downscaled data were available, one which was downscaled using the univariate BCCAQv2 method and the other which was downscaled using the multivariate MBCn method. The version that was produced using the multivariate MBCn method was used to preserve statistical properties between climate variables.

(Government of Canada 2025b). In both cases, the climate projections were available as monthly values. Mean monthly temperature of snow depth projections were converted to winter temperature, summer temperature, and winter snow depth projections based on the overlap between months and each herd's winter and summer season. This was implemented as a weighted average across months, with the weights being the proportion of a season occurring within each month. For example, winter temperature for the Bathurst herd was based on the average temperature between December 1 and April 19; i.e., (31/140)**Dec_t* + (31/140)**Jan_t* + (28/140)**Feb_t* + (31/140)**Mar_t* + (19/140)*Apr_t, where *Dec_t* refers to the average temperature for December (and so on). During the statistical modeling to derive the hazard curves, the Cape Bathurst and Tuktoyaktuk Peninsula herds needed to be combined into a single group. Accordingly, the timing of the winter and summer seasons for these herds is based on the average between the herds: summer is from July 4 to September 15 and winter is from December 1 to April 9.

When applying the climate adjustment, it is recommended that female adult mortality rates be set to those estimated by Chloe Beaupre from mortality data for the herds (Table 9). Doing so requires revising the default cow mortality rates using the CBGC ALCES user interface.

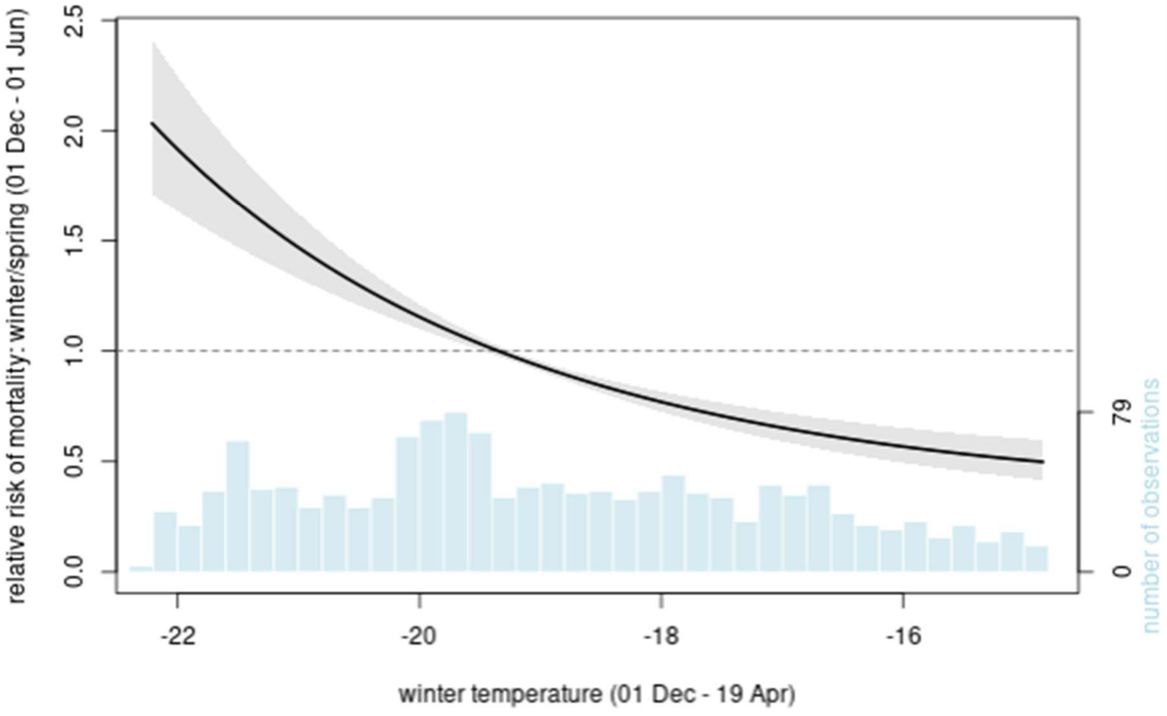

Figure 3. A hazard curve relating the relative risk of cow mortality to winter temperature. Prepared by Chloe Beaupre.

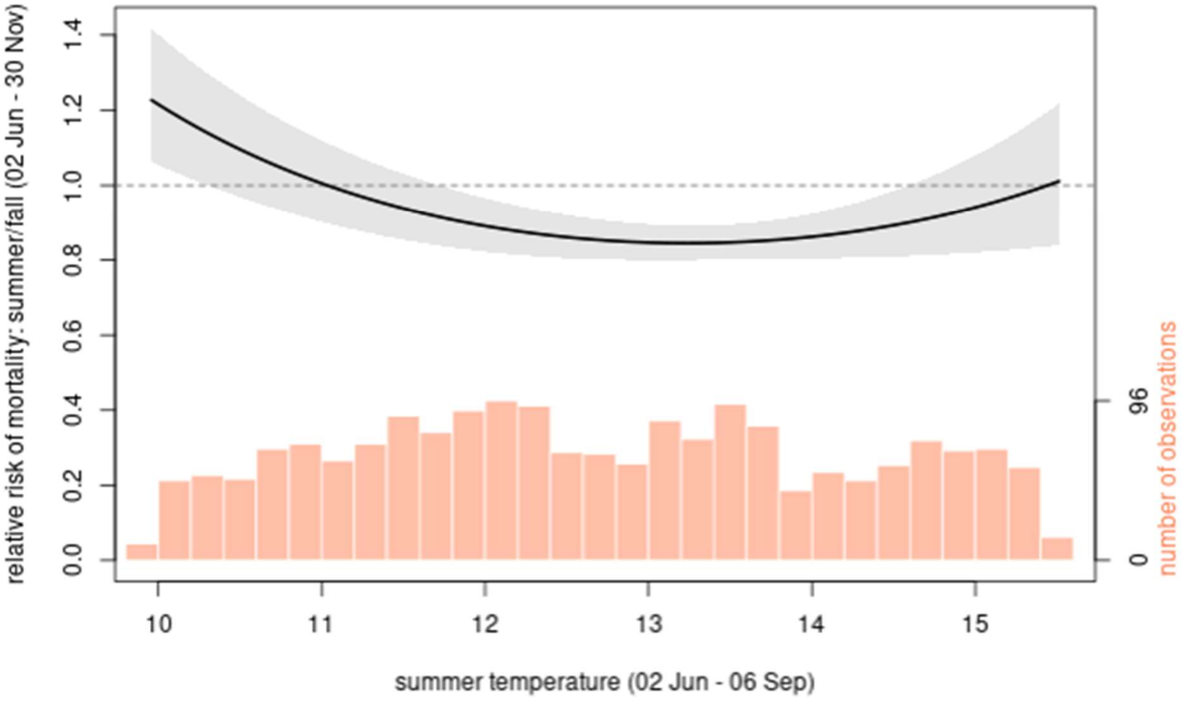

Figure 4. A hazard curve relating the relative risk of cow mortality to summer temperature. Prepared by Chloe Beaupre.

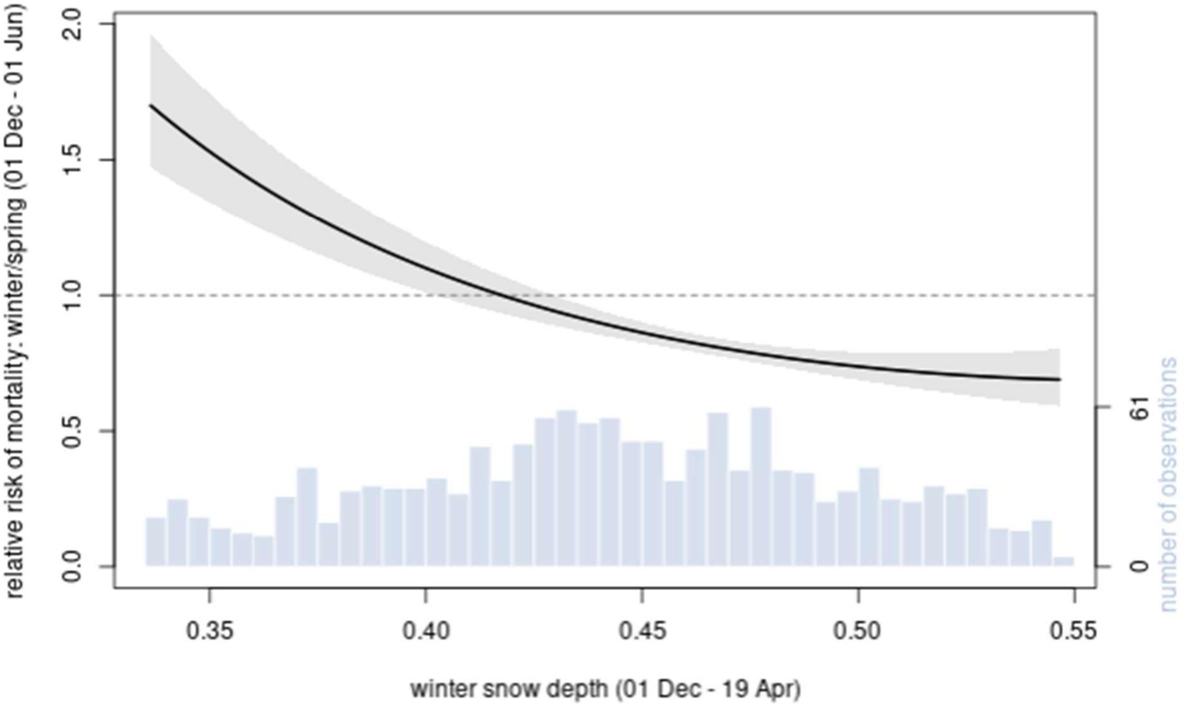

Figure 5. A hazard curve relating the relative risk of cow mortality to winter snow depth. Prepared by Chloe Beaupre.

Table 7. The percent of each caribou herd season time period occurring within the winter/spring hazard period (December 1 to June 1).

	Spring migration	Calving	Summer	Fall	Winter
Bathurst	100%	0%	0%	0%	100%
Bluenose East	100%	13.5%	0%	22.7%	100%
Bluenose West	100%	11.1%	0%	0%	100%
Cape Bathurst and Tuktoyaktuk Peninsula	100%	20%	0%	0%	100%

Table 8. The percent of each caribou herd season time period occurring within the summer/fall hazard period (June 2 to November 30).

	Spring migration	Calving	Summer	Fall	Winter
Bathurst	0%	100%	100%	100%	0%
Bluenose East	0%	86.5%	100%	77.3%	0%
Bluenose West	0%	88.9%	100%	100%	0%
Cape Bathurst and Tuktoyaktuk Peninsula	0%	80%	100%	100%	0%

Table 9. Adult female natural mortality (i.e., death) rates for each caribou herd season as estimated by Chloe Beaupre from mortality data for the herds. It is recommended that these death rates be used when applying the effect of climate on adult female mortality.

	Spring migration	Calving	Summer	Fall	Winter
Bathurst	0.019	0.006	0.056	0.045	0.044
Bluenose East	0.021	0	0.029	0.022	0.014
Bluenose West	0.011	0.008	0.029	0.055	0.055
Cape Bathurst and Tuktoyaktuk Peninsula	0.013	0.007	0.026	0.045	0.047

Density Dependent Mortality

As is the case with reproductive performance, mortality can be affected by population density. As populations approach K (carrying capacity) the availability of resources may decline and the prevalence of threats such as disease and predation may increase, resulting in higher mortality rates. Two inputs are required to implement density dependent mortality. The first input is the N/K value (N/K threshold) where density begins to cause additional mortality. The second input is the maximum proportion of the population that can die due to density dependence. PopDyn assumes a linear increase in the density dependent mortality rate from 0 at the N/K threshold to the maximum mortality rate at carrying capacity (N/K=1). The N/K threshold and density dependent mortality rate are not available as inputs in the CBGC ALCES user interface. We do not know of empirical estimates of density dependent mortality. Instead, density dependent mortality inputs are based on those used by Rempel et al. (2021) for boreal caribou. Rempel et al. (2021) assumed density dependent mortality for boreal caribou to be initiated at

N/K=0.6 and to reach a maximum rate of 0.1 at carrying capacity. For the CBGC ALCES model, the seasonal maximum density dependent mortality rate is 0.02 such that the maximum annual density dependent mortality rate is 0.1.

Harvest Mortality

Two methods are available in the tool for applying harvest mortality: Total Annual Harvest and Harvest Risk Near Footprint.

For the Total Annual Harvest option, the absolute number of caribou harvested each year is specified. When setting the harvest annual harvest, the number of caribou to be harvested needs to be specified for young (i.e., 2 year olds) and adult (i.e., 3 years and older) caribou for each sex. The model implements the harvest by removing the requested number of caribou from the population each winter. The location of the caribou removed from the population is proportional to the population's distribution across the winter range (i.e., proportional to winter range habitat). The Total Annual Harvest option is useful when the number of caribou to be harvested is thought to be relatively unaffected by the size of the population and the availability of footprints that can be used by hunters for access (e.g., roads). Although harvest of Bathurst caribou is not currently permitted, simulations have been run to assess the consequences of harvesting 300 animals, which was the recommended harvest target prior to closure in 2015[11]. Two scenarios were assessed: harvesting 300 bulls per year; or distributing the harvest mortality across bulls and cows based on their relative abundance.

The Harvest Risk Near Footprint option applies harvest mortality as a rate within a user-specified distance of footprints, based on the rationale that footprints such as roads are used to access areas for hunting. In contrast to the Total Annual Harvest option, the seasonality of Harvest Risk Near Footprint can be controlled by the user. This makes it possible to define scenarios where some footprints affect harvest in every season (e.g., permanent road) and some footprints only affect harvest in some season. In the Bathurst harvest scenarios, permanent roads caused harvest risk in all seasons whereas winter roads only caused harvest risk in the winter. In addition to seasonality, the inputs for Harvest Risk Near Footprint are the distance from each footprint type within which harvest mortality occurs, and the harvest mortality rates that should be applied to caribou occurring within that buffer. The harvest mortality rates are specified separately for young (2 year old) and adult (3 years and older) female and male caribou. If a footprint type does not facilitate harvest, the mortality rates should be set to 0. CBGC ALCES implements Harvest Risk Near Footprint by calculating the number of male/female young and adult caribou occurring within the user-defined distance of each footprint type[12], and removing animals from that subpopulation based on the user-defined mortality rates. If a location occurs within the footprint buffer for more than one footprint type, the largest mortality rate is applied. It is important to note that harvest rate is applied seasonally, such that the annual harvest rate is the sum of the seasonal harvest rates.

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[11] https://www.cclmportal.ca/sites/default/files/2022-10/fact_sheet_bathurst_caribou_en_1.pdf

[12] Caribou are distributed proportionally to habitat such that the number of caribou occurring within a ZOI is an outcome of the size of the population and the distribution of habitat relative to footprint.

Population Dynamics Model Outputs

The behaviour of the Bathurst population dynamics model is presented by first presenting outcomes of a basecase scenario in greater detail and then comparing outcomes of additional scenarios to the basecase to explore the potential effect of climate change, footprint zone of influence, and harvest. Outputs for other herds are summarized in Appendix 3. The names of scenarios that have been simulated in CBGC ALCES to prepare the report are provided in Appendix 4.

Basecase scenario

The basecase scenario incorporates the effect of dynamic habitat in response to climate change and projected land use (Appendix 1). Although development footprint affects habitat through the habitat index, an additional impact from a footprint zone of influence is not applied. Default assumptions for natural mortality and fecundity are applied without incorporating climate change impacts on vital rates. Caribou harvest does not occur.

Caribou habitat availability under the basecase scenario is below the assumed historical habitat availability for most seasons, as indicated by a carrying capacity index that is less than 1[13]. The carrying capacity index is lowest for spring migration (average value of 0.13 during the forecast) and winter (average value of 0.25 during the forecast) due to the contraction of these seasonal ranges in recent years. Despite the reduction, habitat availability is still high enough to avoid density dependent reductions in vital rates because the current Bathurst population is only 5% of historical[14]. Seasonal ranges for calving, summer, and fall seasons have exhibited substantially less contraction, resulting in lower declines in habitat availability from historical levels (i.e., carrying capacity indices that are closer to 1).

The effect of climate on habitat is evident in the carrying capacity index's temporal variability for the summer and fall ranges, which is caused by variability in projected summer climate (minimum temperature, evaporation, precipitation) and fall climate (mean temperature, evaporation, precipitation). The lower variability in habitat availability for the other ranges is not due to a more stable climate per se, but rather due to lower sensitivity of the habitat models to climate variables. To assess the effect of projected development on habitat availability, a simulation was run in which new development did not occur. When assessed at the scale of seasonal ranges, projected development had a negligible impact on habitat availability. Including projected development in the forecast caused habitat availability to increase by 1.3% in the spring migration range, decrease by 3.2% in the calving range, increase by 1.3% in the summer range, increase by 2.0% in the fall range, and increase by 1.7% in

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[13] The carrying capacity index is calculated by dividing carrying capacity generated during the simulation by the maximum historical population (i.e., 128,000), such that value less than 1 indicates habitat below historical levels. The carrying capacity index is truncated at a maximum value of 1. Carrying capacity during a simulation can exceed the maximum historical population due to changes in climate variables relative to current that cause a positive habitat response. The carrying capacity index shown in the graph is truncated at 1 because values greater than 1 do not imply a positive population response but rather that density dependent impacts are unlikely.

[14] Density dependent effects are assumed to begin when the population is at 50% of carrying capacity. This threshold is not reached during the simulation because the reduction in population relative to the historical maximum is substantially larger than the reduction in habitat relative to historical.

the winter range. The reason for the minor increases in habitat in some ranges when projected development was included is positive RSF coefficients for linear and/or polygonal footprint (table 1).

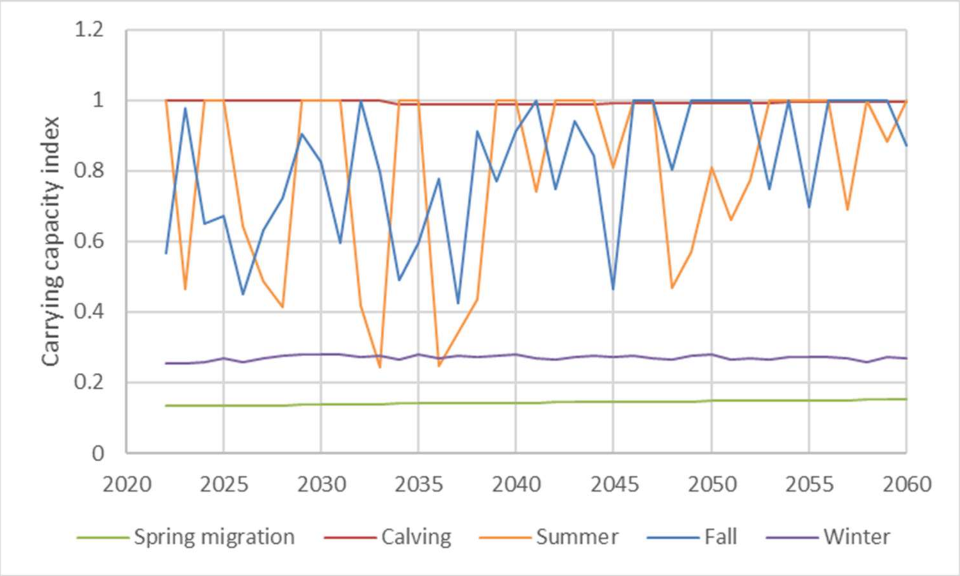

Figure 6. Response of a carrying capacity index to the basecase scenario. The carrying capacity index is calculated by dividing carrying capacity generated during the simulation by the maximum historical population (i.e., 128,000), such that value less than 1 indicates habitat below historical levels. The index is truncated to a maximum value of 1.

During the basecase forecast, the caribou population changed from season to season but was stable from year to year. The age composition of the population was also stable from year to year. The stable population from year to year was due to an annual number of births (2,560) that was roughly equivalent to the annual number of deaths (2,563). The change in caribou population from season to season was due to the positive effect of births during the calving season and the negative effect of mortality in the remaining seasons.

The stability of the population despite substantial fluctuations in habitat was because the Bathurst population is assumed to be substantially below carrying capacity, such that a large reduction in habitat would be needed to trigger density dependent effects. The current non-calf population is 6,240 animals compared to a maximum historical non-calf population of 128,000. In other words, the Bathurst population forecast was insensitive to the effect of climate change on habitat because it is assumed that there is currently a surplus of habitat relative to the Bathurst population. As such, modifying habitat, at least within the range exhibit during the climate change scenario, was inconsequential. Although the population trajectory was insensitive to habitat fluctuation associated with climate change, it did cause the spatial distribution of the population to change somewhat from year to year in the spring migration and fall ranges in response to spatiotemporal variability in climate parameters.

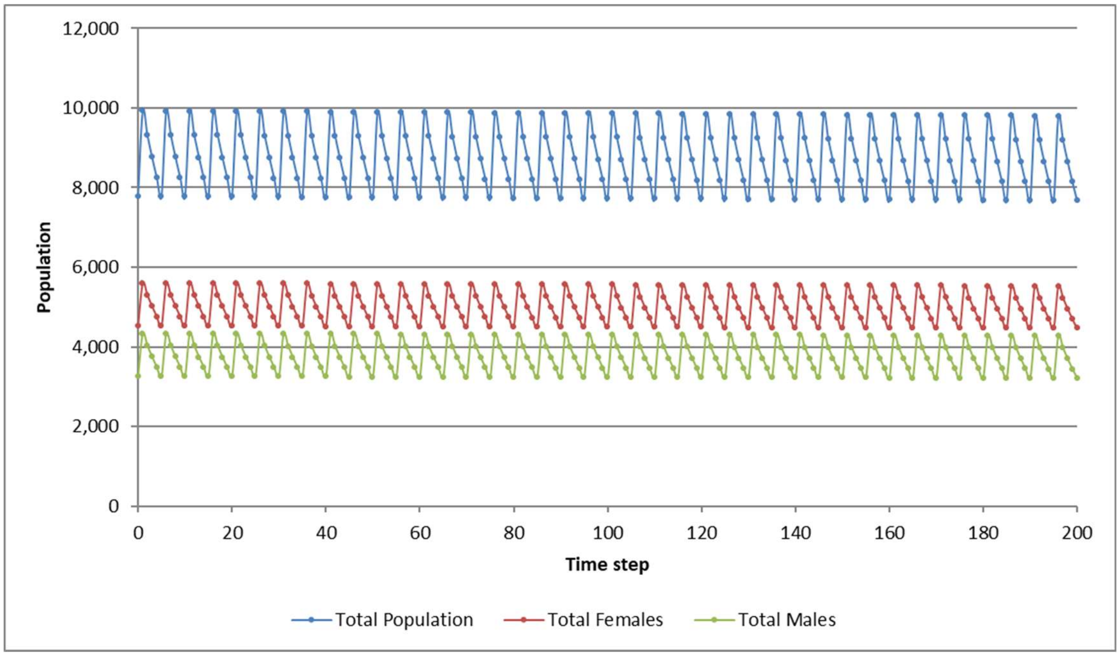

Figure 7. Response of Bathurst caribou population by sex to the basecase scenario. The x-axis refers to the seasonal time step. Each years consists of 5 seasons, such that a 40 year forecast has 200 time steps. The oscillations are caused by the population increasing in the calving season in response to births and then declining in the other seasons in response to deaths.

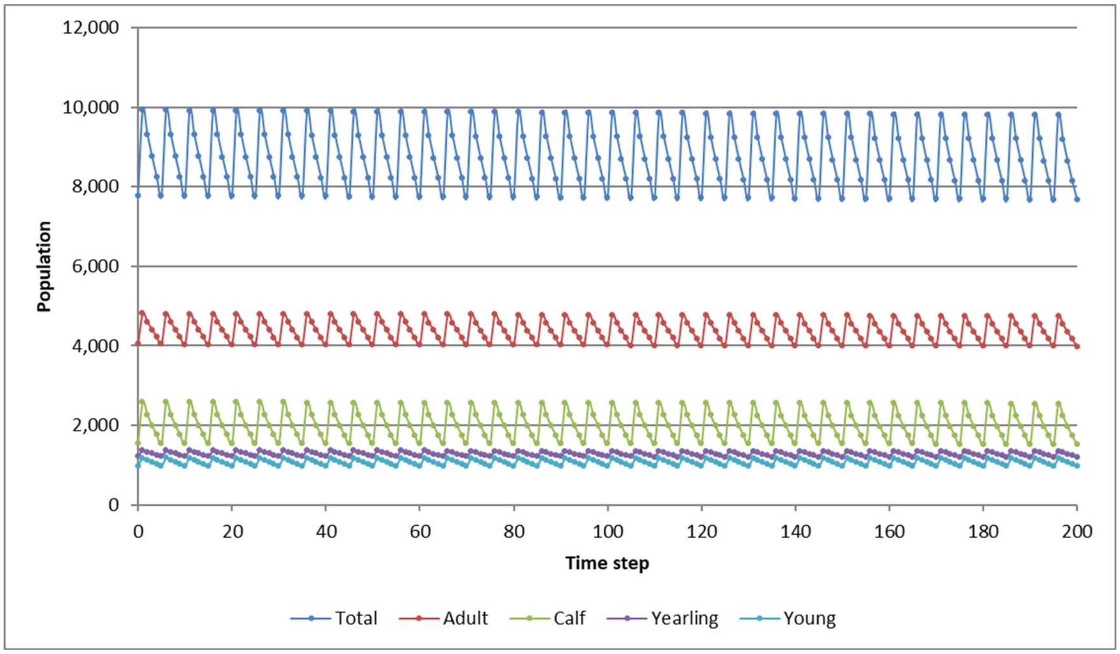

Figure 8. Response of Bathurst caribou population by age class to the basecase scenario. The x-axis refers to the seasonal time step. Each years consists of 5 seasons, such that a 40 year forecast has 200 time steps. The oscillations are caused by the population increasing in the calving season in response to births and then declining in the other seasons in response to deaths.

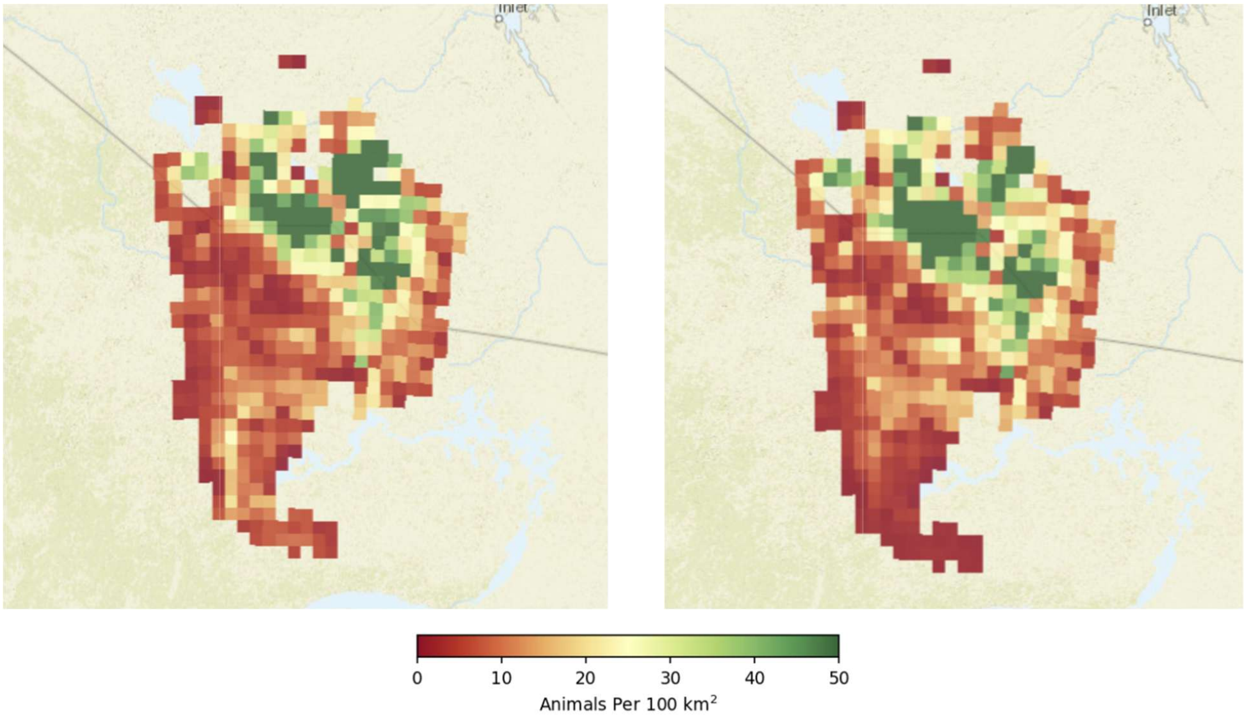

Figure 9. Modeled Bathurst caribou population density in the fall range in year 5 (left) and 15 (right) of the basecase scenario, to illustrate minor changes in the location of caribou in response to the effect of temporal climate variability on habitat.

Climate change impacts

An alternative pathway through which climate change could impact caribou population dynamics is through direct changes in vital rates (as opposed to indirect changes in vital rates through density dependence). Simulations applying climate change effects on cow mortality exhibited substantially higher sensitivity to climate change than was the case through habitat impacts alone. Increased cow mortality associated with the combined effect of projected changes in winter temperature, snow depth, and summer temperature caused population to decline more than 60% relative to the base case scenario after 20 years. The majority of the population decline was caused by the effect of winter temperature on cow mortality (Figure 10). The sensitivity of the caribou population to the relationship between cow mortality and climate illustrates that climate change is likely to reduce the resilience of the Bathurst population to harvest and other impacts.

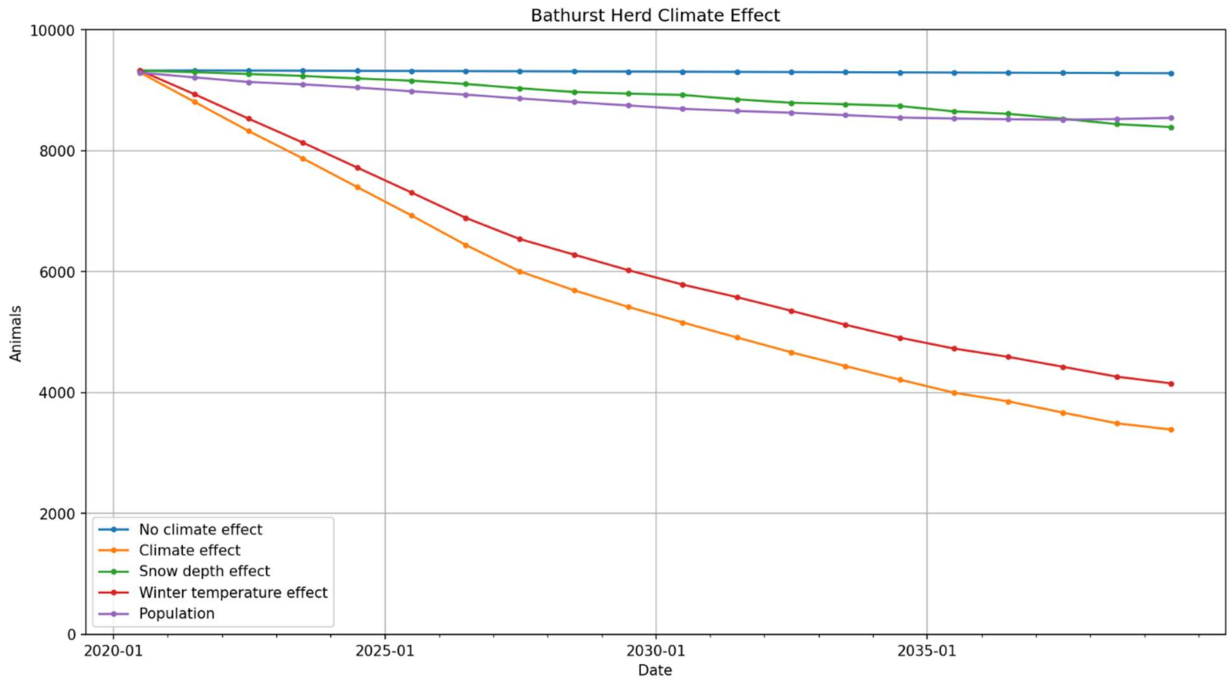

Figure 10. Response of the Bathurst caribou population to scenarios that differ with respect to the effect of climate on cow mortality. "No climate effect" does not incorporate climate impacts to cow mortality whereas "Climate effect" incorporates all three climate relationships with cow mortality (snow depth, winter temperature, summer temperature). The remaining scenarios apply each climate relationship separately.

Footprint zone of influence

To assess the impact of reduced habitat use in proximity of footprints, habitat value was set to 0 within the footprint buffers. This scenario likely exaggerates the potential impact of footprint zones of influence on habitat because caribou are unlikely to completely avoid them. For example, Golder Associates (2014) assumed habitat use of footprint zones of influence that ranged from 5% to 90% depending on the footprint type and proximity, with an average use of 53%. The rationale for simulating a scenario with 0% use was to explore population sensitivity to the lowest possible level of footprint zone of influence use.

By the end of the forecast, the reduction in habitat availability compared to the basecase scenario was 33% for the spring migration range, 4% for the calving range, 17% for the summer range, 21% for the fall range, and 27% for the winter range. The higher loss of habitat in spring migration range and winter range was due to a greater abundance of footprint. Despite the relatively high loss of habitat, the scenario did not trigger a population response because the population is already low relative to habitat availability. In other words, despite the decline in carrying capacity, the population was assessed as remaining substantial below the 0.5 N/K threshold that is required by the model to trigger density dependent mortality and fecundity. Although the footprint zone of influence did not cause population decline, it did cause changes in the spatial distribution of the population as animals shifted away from footprints. For example, the road corridor crossing the eastern portion of the winter range caused the population to shift westward when a zone of influence with 0% use was applied.

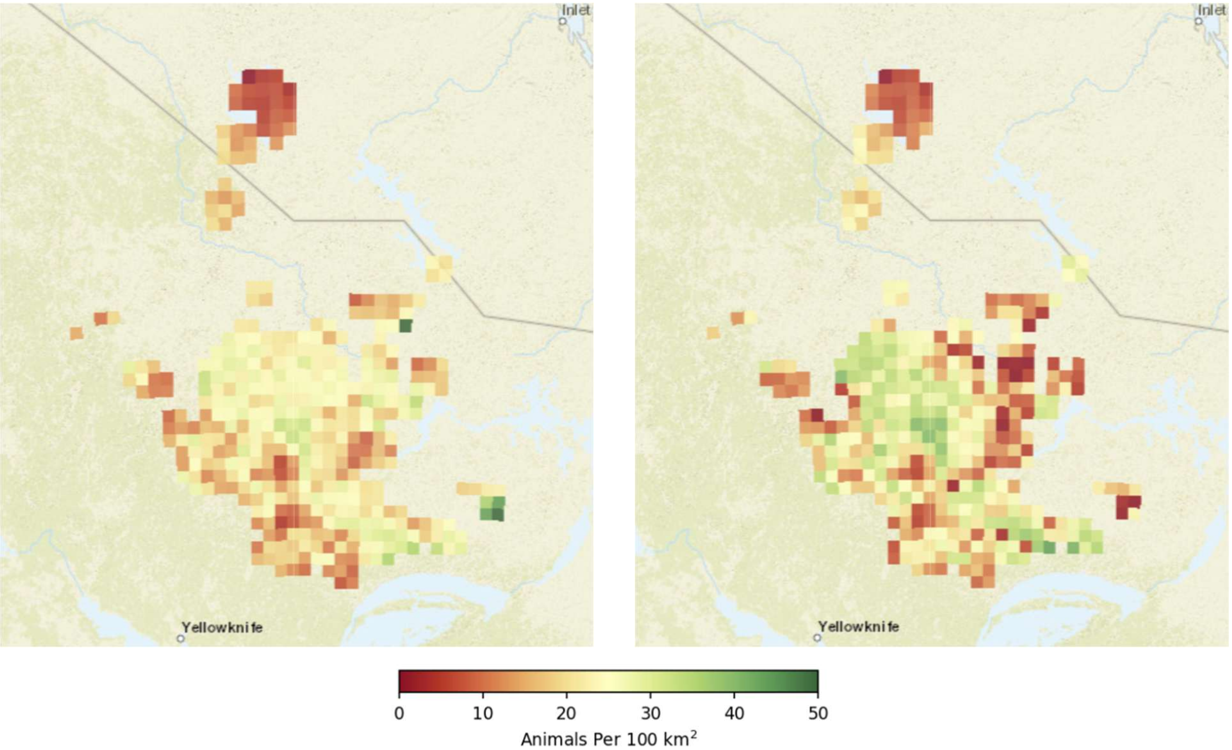

Figure 11. Modeled Bathurst caribou population density in the winter at the start of basecase scenario (left) and a scenario that assumed that habitat within the footprint zone of influence was not used (right). The zone of influence caused the location of caribou to shift to the west, away from footprint.

Footprint encounters

A 10-year forecast was completed to explore the frequency of footprint encounters for the Bathurst herd and the potential effect on caribou abundance due to impacts to recruitment. Two scenarios were completed: with and without the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments. A conservative approach was taken whereby only encounters with permanent road footprint were considered to affect energetics. Encounters were substantially higher when the proposed road was included, increasing from 11 to 34 encounters per year per caribou (Figure 12, Figure 13). A reduction in birth rate and calf survival caused by the energetic impact of encounters with existing road caused a 13% decline in the population relative to the basecase after 10 years. The decline increased to 37% when encounters with the proposed road was also considered (Figure 14).

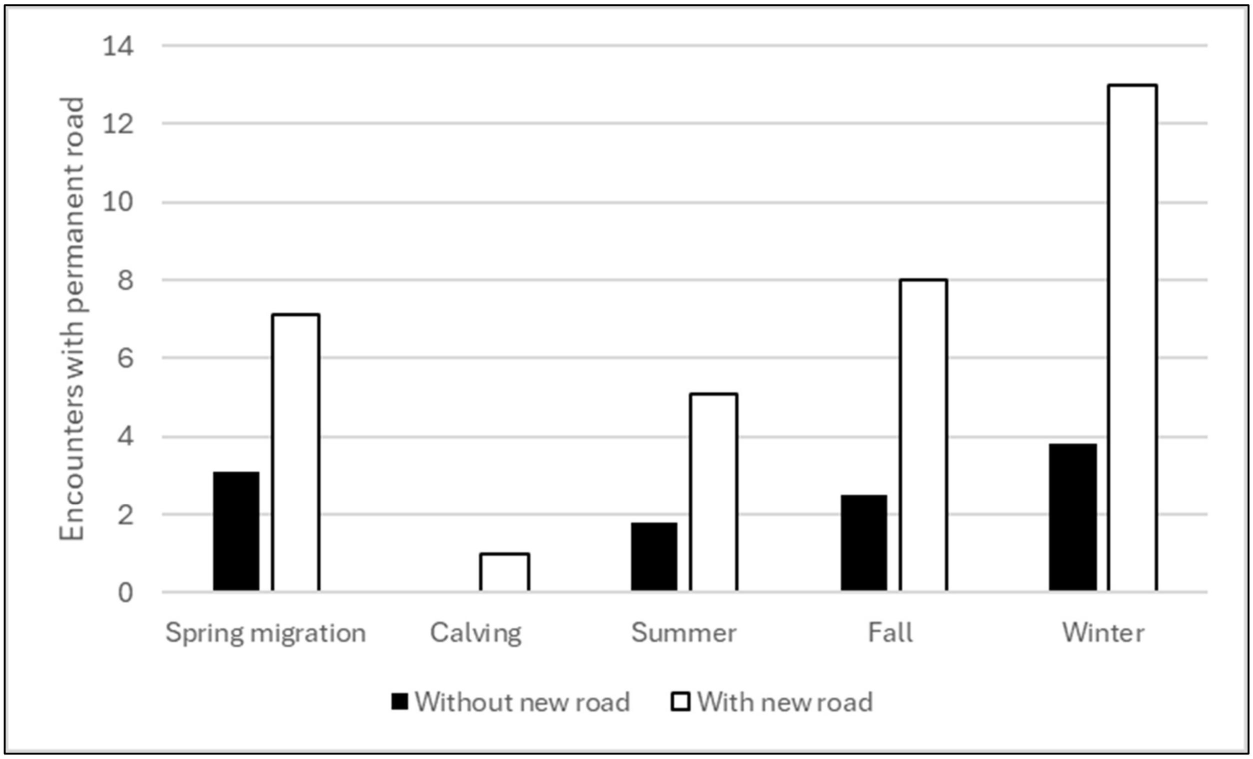

Figure 12. The estimated number of encounters with permanent road per caribou per season for the Bathurst herd. Encounters are presented for scenarios with and without the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments.

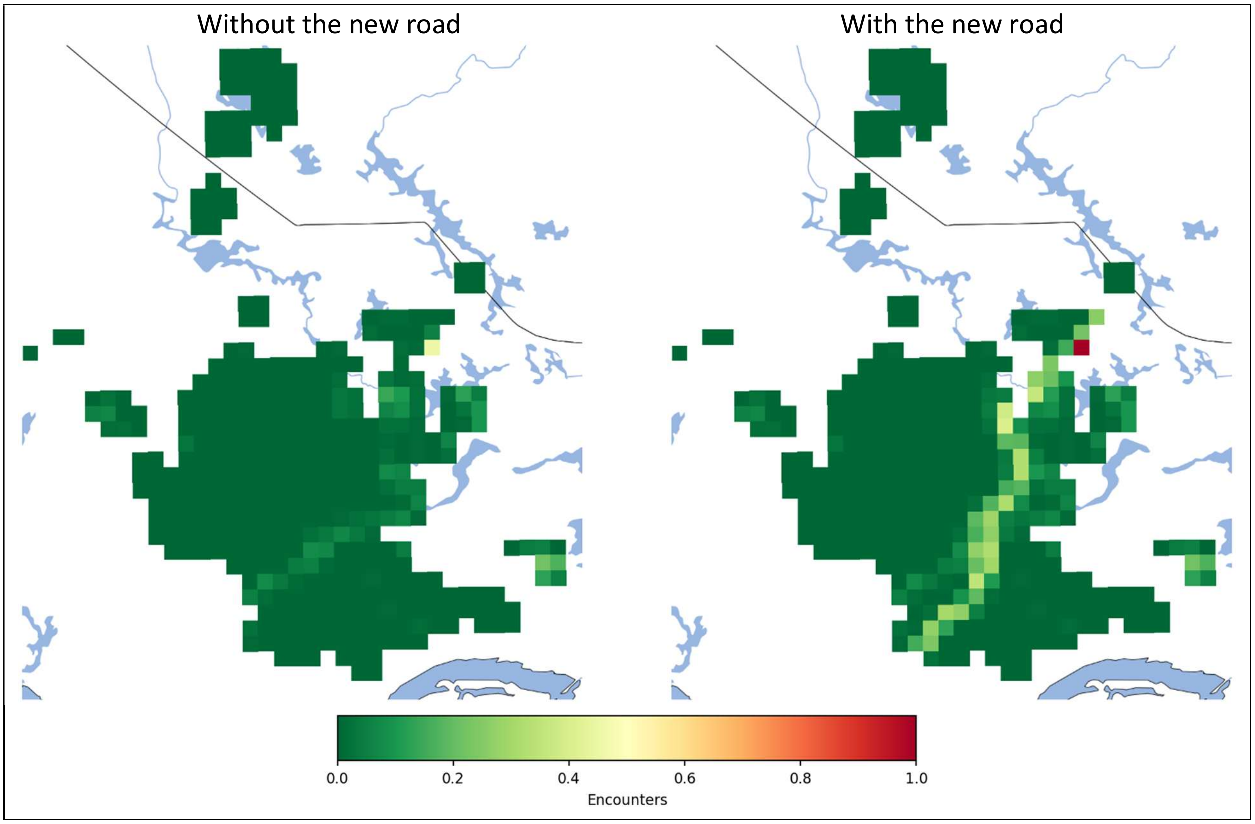

Figure 13. Modeled caribou encounters with permanent road in the winter Bathurst range under scenarios with and without the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments.

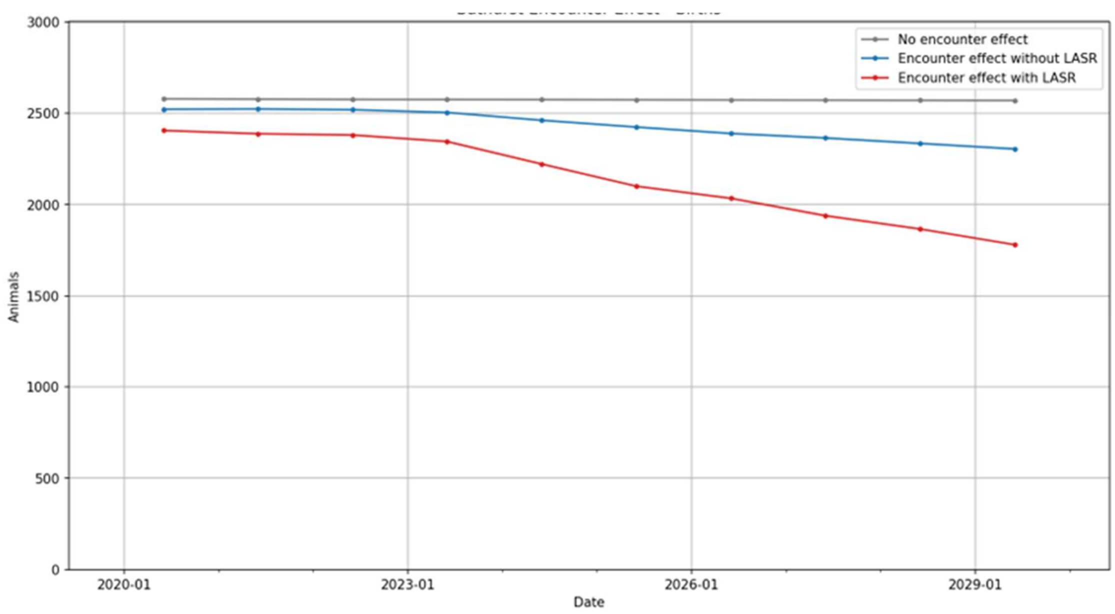

Figure 14. Forecasted Bathurst caribou population under scenarios that either do not incorporate an effect of permanent road encounters on recruitment or do incorporate the effect with and without the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments.

Total annual harvest

Although harvest of Bathurst caribou has not been allowed since 2015, sensitivity of the population to harvest was assessed by simulating an annual harvest target of 300 animals based on the recommended harvest target from 2010 to 2015[15]. When harvest was restricted to male caribou, the population declined over the first decade prior to stabilizing at around 6,500 animals (Figure 15). When harvest was distributed across females as well as males, however, the population declined steadily and was extirpated part way through the 3rd decade. Harvesting both females and males was more detrimental than harvesting only males because it affected the reproductive potential of the herd. Whereas the number of offspring per year remained at about 2,500 throughout the simulation when harvest was limited to males, the number of offspring declined steadily when females were also eligible for harvest.

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[15] https://www.cclmportal.ca/sites/default/files/2022-10/fact_sheet_bathurst_caribou_en_1.pdf

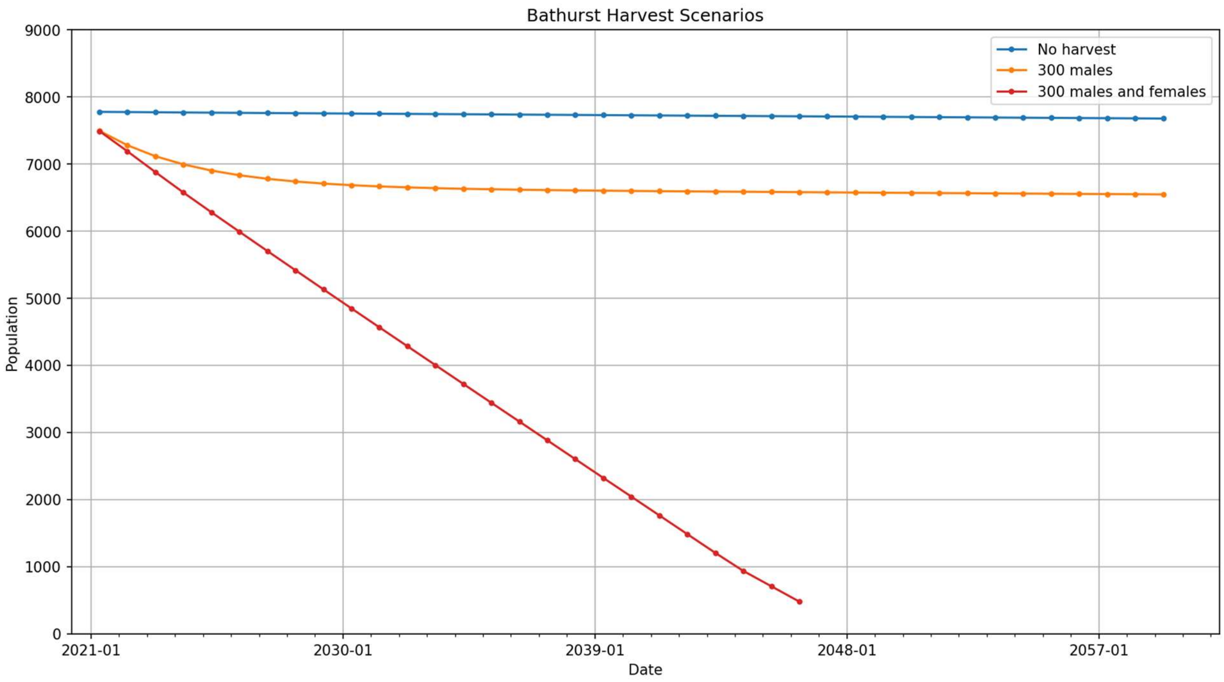

Figure 15. Response of the Bathurst caribou population to scenarios that differ with respect to the number of animals harvested. The scenario in which females and males were harvested resulted in extirpation by 2048.

Harvest risk near footprint

Although regulated harvest of Bathurst caribou is 0, realized harvest may be greater than 0 due to a combination of poaching and harvest of animals that are mistakenly believed to belong to another herd. The risk of harvest is likely greater in proximity to linear footprints that can facilitate motorized access. The sensitivity of the Bathurst herd to harvest risk facilitated by motorized access was assessed by elevating mortality within 10 km of roads. The 10 km buffer was based on the James Bay Region of northern Quebec, where 83% of caribou harvest sites were found to occur within 10 km of the nearest road (Plante et al. 2017). In the case of winter roads[16], harvest risk only occurred in the winter range. In the case of permanent roads, harvest risk occurred throughout the year.

Harvest risk near roads caused mortality to increase, with negative consequences for the caribou population. Due to the uncertainty associated with the magnitude of harvest risk, multiple levels of harvest risk in proximity to roads was simulated: 1%, 5%, and 10%. When 5% harvest mortality of male and female adult caribou was applied within 10 km of roads, the population declined by 56% over 40 years to just under 3400 animals (Figure 16). The rate of population decline increased in 2035 and again in 2045 in response to opening of the Lockhart All-Season and Gray Bay Port roads in 2035, and the Slave Geological Province Corridor in 2045. These roads increased the portion of the seasonal caribou

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[16] When categorizing roads for the purpose of applying harvest mortality, the winter road category included not only ice roads but also roads categorized as minor such as the road, road private, and road public categories in the Human Disturbance dataset. The reason for doing so is that inspection of road data in the Bathurst range indicated that these minor roads are likely only used in winter. The permanent road category was limited to major roads, an example of which is the Yellowknife highway. Major roads do not currently occur within the Bathurst range but will in the future if the Lockhart all-season road is constructed.

ranges accessible by road, especially in the non-winter seasons. With the opening of the roads, the portion of caribou habitat occurring within 10 km of all season road increased to 39% in the spring migration range, 10% in the calving range, 42% in the summer range, 38% in fall range, and 32% in the winter range.

Simulation outcomes were sensitive to assumptions for the rate of harvest mortality within the road buffer (Figure 16) and the size of the road buffer (Figure 17), emphasizing the importance of understanding the degree to which roads facilitate caribou harvest. The harvest near road simulations assumed that both male and female caribou were equally affected by hunting. When harvest mortality was limited to males, the effect of harvest declined dramatically (Figure 18).

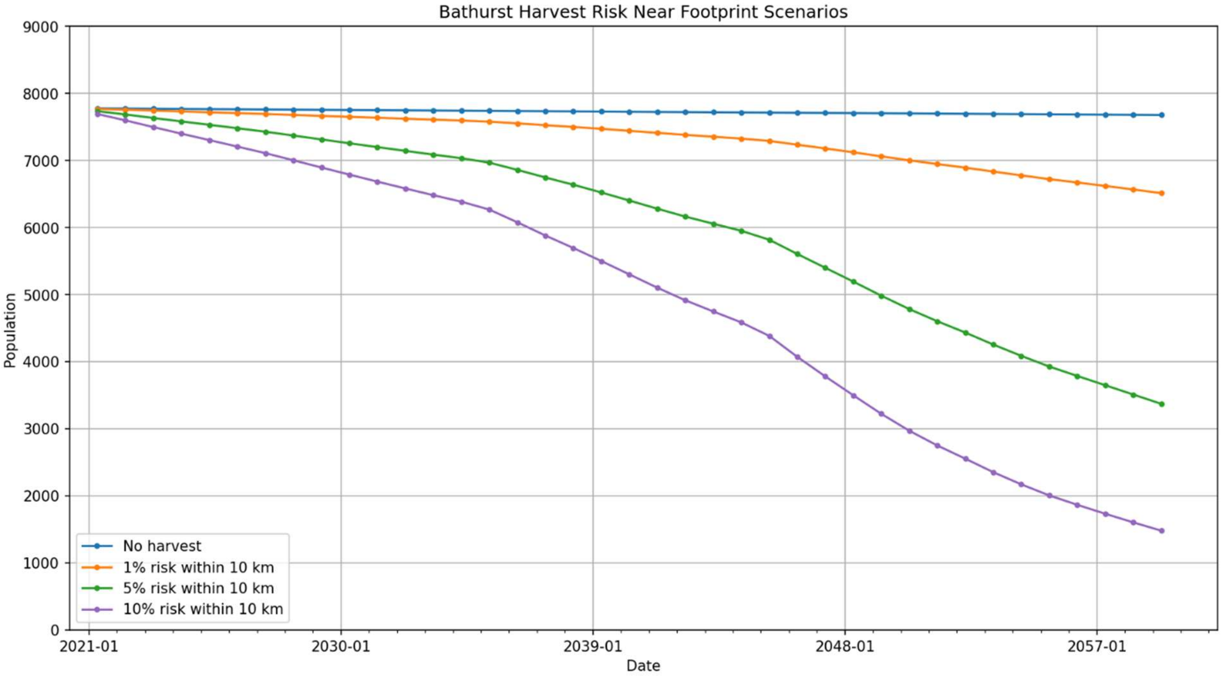

Figure 16. Response of the Bathurst caribou population to scenarios that differ with respect to the harvest rate within a 10 km buffer of roads. The harvest rate is only applied to winter roads in the winter range whereas the harvest rate if applied to permanent roads in all seasons.

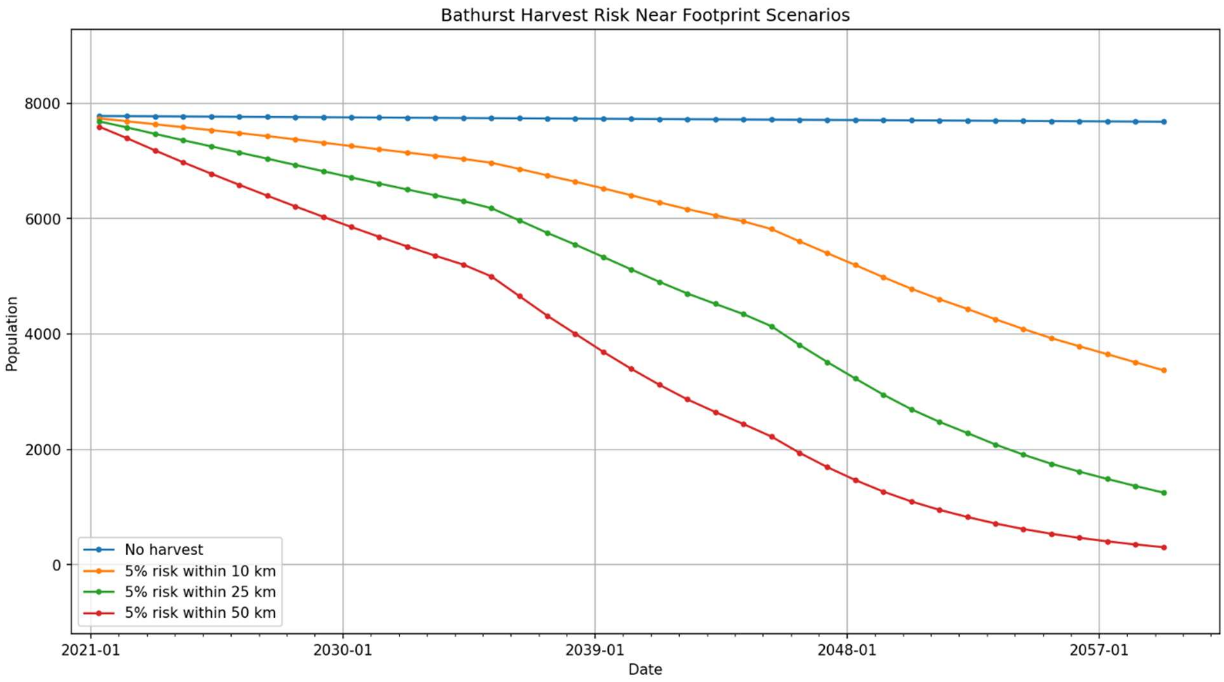

Figure 17. Response of the Bathurst caribou population to scenarios that differ with respect to distance from roads within which a 5% harvest mortality rate is applied. The harvest rate is only applied to winter roads in the winter range whereas the harvest rate if applied to permanent roads in all seasons.

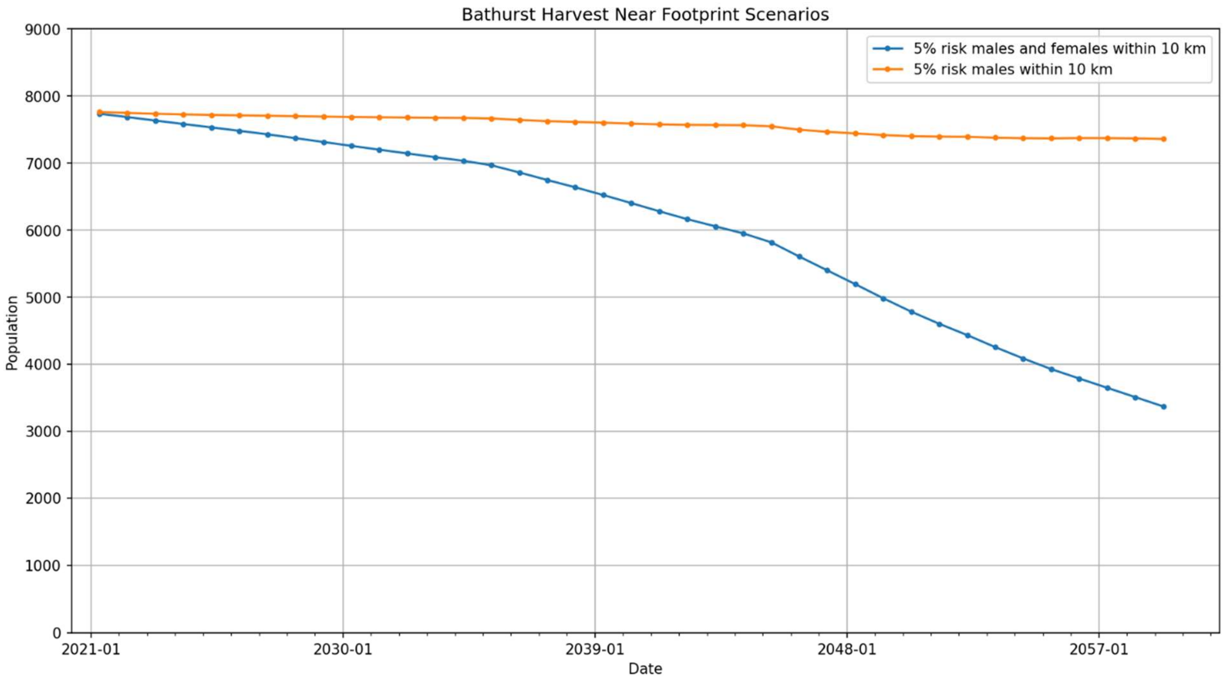

Figure 18. Response of the Bathurst caribou population to scenarios that apply a 5% risk of harvest within 10 km of road to all caribou or only male caribou.

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Appendices

Appendix 1. Landscape and Climate Projections for CBGC ALCES

Introduction

Simulating barren-ground caribou population dynamics required assessment of current and potential future landscape composition and climate. This document describes how ALCES was applied for this purpose and summarizes the resulting landscape and climate dynamics.

Methods

<u>Preparation of Land Cover and Climate Data</u>

We created a coverage of land cover and climate data for the full extent of NWT as well as the western portion of Nunavut occurring above (to the north of) NWT. This dataset captures the extent of the four caribou herds studied in this project (Bluenose East, Bluenose West, Cape Bathurst, Tuktoyatuk Peninsula) as well as the Bathurst herd which is expected to be studies in a subsequent phase. Geospatial data sets were prepared in ALCES as described below.

1. A landscape composition data set was developed to provide proportional coverage of each cell in the study area by each land cover and human footprint type. Table A1-10 provides a prioritized list of the cover types and a summary of the source data sets. The unity data set was prepared by intersecting the datasets with the 100 m x 100 m (1 ha) cell grid, and assigning priorities to source data sets during the intersection so that unity (i.e., no more or less than 100% coverage) is respected. The source data sets were selected based on input from experts within the Government of the Northwest Territories. Land Cover of Canada was selected as the primary natural land cover datasets because it was the most up-to-date inventory with complete coverage. The Human Disturbance dataset was the primary development footprint dataset. A 2020 version of the human disturbance dataset provided to the project included an expanded extent to include the Nunavut portion of the study area. The Human Disturbance dataset was augmented by CanVec datasets to achieve more comprehensive representation of footprint.
2. Digital elevation model (DEM) characteristics – aspect, slope, mean elevation, minimum elevation, and maximum elevation – were assigned for each 1 ha spatial unit within the study area (100 m x 100 m cell).
3. Forest age was assigned to forested spatial units based on estimated time since disturbance, which was derived from information on time since the most recent fire or timber harvest event. Forest age was estimated from three data sources: the NWT fire history dataset (1965 to 2020), the National Burn Area Composite for fires in Nunavut between 1986 and 2019, Canada Landsat Disturbance 2017 for timber harvest between 1984 and 2015. Where harvest and fire disturbance did not occur, forest age was established based on a national stand age data layer (*circa* 2011 and adjusted to 2019). Where harvest and fire disturbance overlapped, the most recent disturbance type and age was applied.
4. Climate data were downscaled from CanESM2 (https://climate-scenarios.canada.ca/?page=pred-canesm2) using DEM, baseline and anomaly grids based on methods presented in Wang et al.

(2016)[17]. Climate data include monthly and annual temperature (min, max, mean), precipitation, precipitation as snow, shortwave radiation, and evaporation, downscaled to 1 km^2.

Table A1-10. Cover types used in the landscape composition data set and associated source data. Higher priority cover types were given precedence in cases of overlap between source data sets.

Priority	Cover Type	Human Footprint / Natural Cover	Source data sets
1	Railway	Footprint	CanVec Transport Features (National Railway Network), Human Development Footprint, Human Disturbance Dataset 2020 Update*
2	Road Major	Footprint	CanVec Transport Features (National Road Network), Human Disturbance Dataset 2020 Update
3	Road Minor	Footprint	CanVec Transport Features (National Road Network), Human Disturbance Dataset 2020 Update
4	Road All Terrain	Footprint	CanVec Transport Features (National Road Network), Human Disturbance Dataset 2020 Update
5	Pipeline	Footprint	CanVec Resource Management Features, Human Disturbance Dataset 2020 Update
6	Transmission Line	Footprint	CanVec Resource Management Features, Human Disturbance Dataset 2020 Update
7	Power Station	Footprint	CanVec Resource Management Features, Human Disturbance Dataset 2020 Update
8	Settlement	Footprint	CanVec Manmade Features, Human Disturbance Dataset 2020 Update
9	Recreation	Footprint	CanVec Manmade Features, Human Disturbance Dataset 2020 Update
10	Runway	Footprint	CanVec Transport Features, Human Disturbance Dataset 2020 Update
11	Mining	Footprint	CanVec Resource Management Features
12	Mining and Exploration	Footprint	Human Disturbance Dataset 2020 Update
13	Aggregate	Footprint	CanVec Resource Management Features, Human Disturbance Dataset 2020 Update
14	Petroleum Well	Footprint	CanVec Resource Management Features, Human Disturbance Dataset 2020 Update
15	Road Winter	Footprint	CanVec Transport Features (National Road Network), Human Disturbance Dataset 2020 Update
16	Trail	Footprint	CanVec Land Features, Human Disturbance Dataset 2020 Update
17	Cutline	Footprint	NEB Seismic Lines, Human Disturbance Dataset 2020 Update
18	Camp	Footprint	CanVec Manmade Features, Human Disturbance Dataset 2020 Update
19	Industrial - Other	Footprint	CanVec Resource Management Features, Human Disturbance Dataset 2020 Update
20	Industrial - Oil and Gas	Footprint	CanVec Resource Management Features, Human Disturbance Dataset 2020 Update
21	Other Footprint	Footprint	Human Disturbance Dataset 2020 Update
22	Remediation	Footprint	Human Disturbance Dataset 2020 Update
23	Waterbody	Natural	CanVec Hydrographic Features (1:1M), 2015 Land Cover of Canada
24	Watercourse	Natural	2015 Land Cover of Canada
25	Wetland	Natural	2015 Land Cover of Canada
26	Barren lands	Natural	2015 Land Cover of Canada
27	Snow and Ice	Natural	2015 Land Cover of Canada
28	Sub-polar or polar barren-lichen-moss	Natural	2015 Land Cover of Canada
29	Sub-polar or polar grassland-lichen-moss	Natural	2015 Land Cover of Canada
30	Sub-polar or polar shrubland-lichen-moss	Natural	2015 Land Cover of Canada
31	Sub-polar taiga needleleaf forest	Natural	2015 Land Cover of Canada
32	Temperate or sub-polar broadleaf deciduous forest	Natural	2015 Land Cover of Canada
33	Temperate or sub-polar shrubland	Natural	2015 Land Cover of Canada
34	Temperate or sub-polar needleleaf forest	Natural	2015 Land Cover of Canada
35	Temperate or sub-polar grassland	Natural	2015 Land Cover of Canada
36	Mixed forest	Natural	2015 Land Cover of Canada

* Constructions and Land Use in Canada - CanVec Series - Manmade Features: Online [URL] https://open.canada.ca/data/en/dataset/fd4369a4-21fe-4070-914a-067474da0fd6
NWT Inventory of Landsape Change: Online [URL] https://www.maps.geomatics.gov.nt.ca/Html5Viewer/Index.html?viewer=CIMP_ILC_Webmap.ILC_Viewer

Landscape Projection

Simulations were completed to explore potential shifts in land cover and forest disturbance in response to anticipated development and climate change. The study area for the simulations was 822,965 km2 region defined by the combined extent of the minimum convex polygon of five herds: Bluenose East, Bluenose West, Cape Bathurst, Tuk Peninsula, and Bathurst. The simulations used annual time steps five decades into the future. Cell size for the simulations was 1 km2. Assumptions for the high/increasing development scenario are described in Land-use Scenarios Workbook document that is available as another of the report appendices. Assumptions for landscape response to the RCP 8.5 climate change projection focused on potential shifts in vegetation communities and fire, as described below.

Simulated expansion and contraction of taiga and tundra cover types was informed by climate-projected distributional shifts for North American ecoregions under RCP8.5 (Stralberg 2018). Areas where tundra ecoregions[18] are projected to transition to taiga ecoregions[19] were identified as being eligible for

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[17] Wang, T., A. Hamann, D. Spittlehouse, and C. Carroll. 2016. Locally downscaled and spatially customizable climate data for historical and future periods for North America. PloS One 11:e0156720.

[18] Ecoregions classified as tundra-dominated for the purpose of the simulation were those belonging to the Tundra level 1 ecoregion.

[19] Ecoregions classified as taiga or forest dominated were those belonging to the Taiga or Northern Forest level 1 ecoregions.

shrubification (e.g., Mod and Luoto 2016), simulated here as conversion of grassland to shrub land cover. The rate at shrubification is uncertain. Two scenarios were simulated: 1) conversion of 0.5% of eligible land cover (as opposed to total land cover) per year over the next 40 years; and 2) conversion of 1.0% of eligible land cover per year over the next 40 years. Because only a portion of the study area is eligible for shrubification, the area affected by these scenarios is substantially lower than 0.5% and 1.0% of the total study area per year. For example, 1% of eligible grassland equals about 0.11% (891 km2) of the study area. The 1% eligible grassland conversion scenario was applied in the landscape projection used in the population dynamics simulations.

Spatial distribution of shrubification was random with the following constraints:

1. Shrubification was limited to within areas that are projected to shift from a tundra ecoregion to a taiga ecoregion.
2. The likelihood of shrubification was inversely proportional to distance (km) to forest and shrub land cover. In other words, likelihood of conversion increased in closer proximity to forest and shrub.
3. The likelihood of shrubification was inversely proportional to the tundra refugia value (Stralberg 2019). In other words likelihood of conversion decreased with increasing tundra refugia value. Tundra refugia is a 0 to 1 index, with higher values indicating greater climate persistence and therefore tundra ecoregion resilience to change. The highest tundra refugia value occurring within the study area is 0.5.
4. Shrubification occurred within cells at levels of 0.1, 0.3, 0.5, 0.7, and 0.9 km2 based on the current distribution of cell coverage by shrubland in the study area[20].

Expansion of tundra was assumed to be catalyzed by fires occurring in areas where taiga ecoregions are projected to transition to tundra ecoregions. In the simulations, fire within the area of tundra ecoregion expansion caused coniferous and mixed forest to convert to deciduous forest, and caused deciduous forest and shrubland to convert to grassland. As such, conversion of coniferous forest to grassland required two fires during a simulation: the first burn to convert coniferous forest to deciduous forest and the second burn to convert deciduous forest to grassland. Locations with a tundra refugia value (Stralberg 2019) greater than 0.5 were excluded from the conversions.

Fire was simulated by applying projected changes in fire area by homogeneous fire regime zone (Boulanger et al. 2014). Baseline annual fire area for each homogeneous fire regime zone (HFRZ) was calculated as the average annual area of forest and shrub burned from historical (1965-1990) fire data for the study area[21]. Simulated future fire area was obtained by multiplying each HFRZ's baseline fire area by the area-weighted average projected annual area burned ratio across HFRZs[22] under climate

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[20] The frequency of different levels of 1 km2 cell coverage by shrubland in the study area is: cells with 0-20% shrubland coverage accounts for 5% of shrubland area; 20-40% coverage accounts for 11% of shrubland area; 40-60% accounts for 16% of shrubland area; 60-80% accounts for 24% of shrubland area; and >80% accounts for 44% of shrubland area.

[21] The NWT Fire History data layer was provided by Matthew Coyle, Government of the Northwest Territories.

[22] A projected annual area burned ratio was not available for the Western Subarctic HFRZ. As a result, the average projected annual area burned ratios were calculated as the area-weighted average across the remaining HFRZs (Great Slave Lake, Lake Athabasca, and Great Bear Lake).

scenario A2 for time periods 2011-2040 and 2041-2070. The average burn ratio for the 2011-2040 period was 2.1 and for the 2041-2070 period was 4.2.

In addition to differences in fire rate by HFRZ, local scale (1 km2) differences in fire rate were incorporated in simulations using fire selection ratios that differ by forest type and age class (Bernier et al. 2016). Cover types other than forest and shrub were assumed to be nonflammable. Fire location during simulations was random but guided by a relative likelihood layer that reflected the fire selection ratios and HFRZ burn rates[23]. The fire size class distribution used in the simulations was based on burned forest and shrub patch size[24] distribution occurring in the study area between 2010 and 2020.

Although annual burn area tends to vary substantially from year to year, simulations excluded interannual variation so that random differences in burn area from year to year did not obscure differences between scenarios. The effect of this simplification on caribou modelling outcomes is likely small given that forest age (i.e., time since disturbance) is incorporated in caribou habitat models at a coarse level of temporal detail (i.e., forest younger than 50 years).

Table A1-11. Baseline and future annual area burned and burn rate by homogeneous fire regime zone (HFRZ) in the study area. Baseline area burned was calculated as the average annual burn area from 1965 to 1990. Future area burned was calculated by multiplying the baseline annual burn area by the annual area burned ratio for a given time period averaged across HFRZs. Burn rate is expressed as percent of burnable land cover (i.e., forest and shrub).

HFRZ	Baseline annual burn area (and rate)	2011-2040 annual burn area (and rate)	2041-2070 annual burn area (and rate)
Great Slave Lake	314.3 km2 (0.6%)	663.0 km2 (1.3%)	1310.5 km2 (2.5%)
Lake Athabasca	100.7 km2 (0.9%)	212.4 km2 (1.8%)	419.8 km2 (3.6%)
Great Bear Lake	327.0 km2 (0.4%)	689.7 km2 (0.9%)	1363.2 km2 (1.7%)
Western Subarctic	12.1 km2 (0.06%)	25.5 km2 (0.12%)	50.3 km2 (0.23%)

Table A1-12. Fire selection ratios (Bernier et al. 2016) by cover type and age.

Forest Type	**Young (<30 years)**	**Mature (30-89 years)**	**Old (>89 years)**
Conifer	0.8	2	2.9
Mixed[25]	0.43	1.16	1.79
Deciduous	0.15	0.4	0.63

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[23] The fire selection ratios and the HFRZ burn rates were each normalized such that the area-weighted average value across the study area equaled one. Area-weighting was based on forest and shrub area. The normalizing was done so that the relative magnitude of local scale (i.e., fire selection ratios) and landscape scale (HFRZ burn rates) drivers of fire spatial distribution were approximately equal.

[24] Nonforest cover types were excluded when calculating historical burned forest patch size to avoid exaggerating the size of burned forest patches.

[25] Bernier et al. (2016) provide fire selection ratios for two types of mixedwood forest: coniferous leading and deciduous leading. Coniferous leading was used due to the prevalence of coniferous forest in the region.

Table A1-13. Burned forest patch size class distribution occurring in the study area between 2010 – 2020.

Size Class (km2)	Simulated Size (km2)[26]	Proportion of total burn area
<= 1	0.5	0.008
1.1 – 10	5.5	0.08
10.1 – 100	55	0.324
>100	307.4	0.588

Results

The results presented here focus on simulated changes in land cover and climate because these dynamics are helpful to understand when reviewing the outcomes of caribou population simulations.

Current and simulated future development footprint is presented in Figure 19. Footprint increased from 530 km2 to 689 km2. The primary contributor of footprint growth was mines (134.5 km2), followed by all season road (15.7 km2), transmission corridor (7.1 km2), and winter road (1.7 km2). The majority of footprint growth occurred outside of the caribou ranges that were the focus of the project (Table 14). The caribou herd's range receiving the most footprint during the simulation was Bluenose East, which experienced 0 to 36.76 km2 of footprint growth depending on the season. Ranges of the other herds received negligible footprint growth during the forecast.

Projected ecoregional shifts resulted in a 44% increase in the extent of shrubland from 79,178 km2 to 114,348 km2. Shrubland expansion, and associated decline in grassland, was focused in the eastern portion of the study area (Figure 20) such that its overlap with caribou range was limited with the exception of the Bathurst herd. Fire during the forecast resulted in a 43 % decline in forest older than 50 years, from 134,900 km2 to 77,499 km2. Loss of older forest was focused in the southwestern portion of the study area (Figure 21), which overlaps substantially with the spring migration, fall, and winter range of the Bluenose East herd.

Annual average temperature rose during the RCP 8.5 climate scenario, increasing almost 3 C from 2020 to 2060 (Figure 22). In contrast, annual precipitation displayed substantial interannual variation but lacked directional trend (Figure 23).

Table 14. Growth in development footprint during the high development scenario in seasonal ranges of the caribou herds. Seasonal ranges are kernel density based.

	Development footprint growth during the forecast (km2)			
	BNE	BNW	Cape Bathurst	Tuk Pen
Spring migration	36.76	0	0.03	0
Calving	0	0	0	0
Summer	15.9	0	0	0
Fall	27.85	0	0.03	0
Winter	12.7	0	0.03	0

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[26] Simulated fire size equaled the mid-point of each fire size class, with the exception of the largest class (>100 km2) for which the simulated size equaled the average size of burns between 2010 and 2020 that were >100 km2 in size.

Figure 19. Development footprint at the start (top) and end (bottom) of the increasing development scenario.

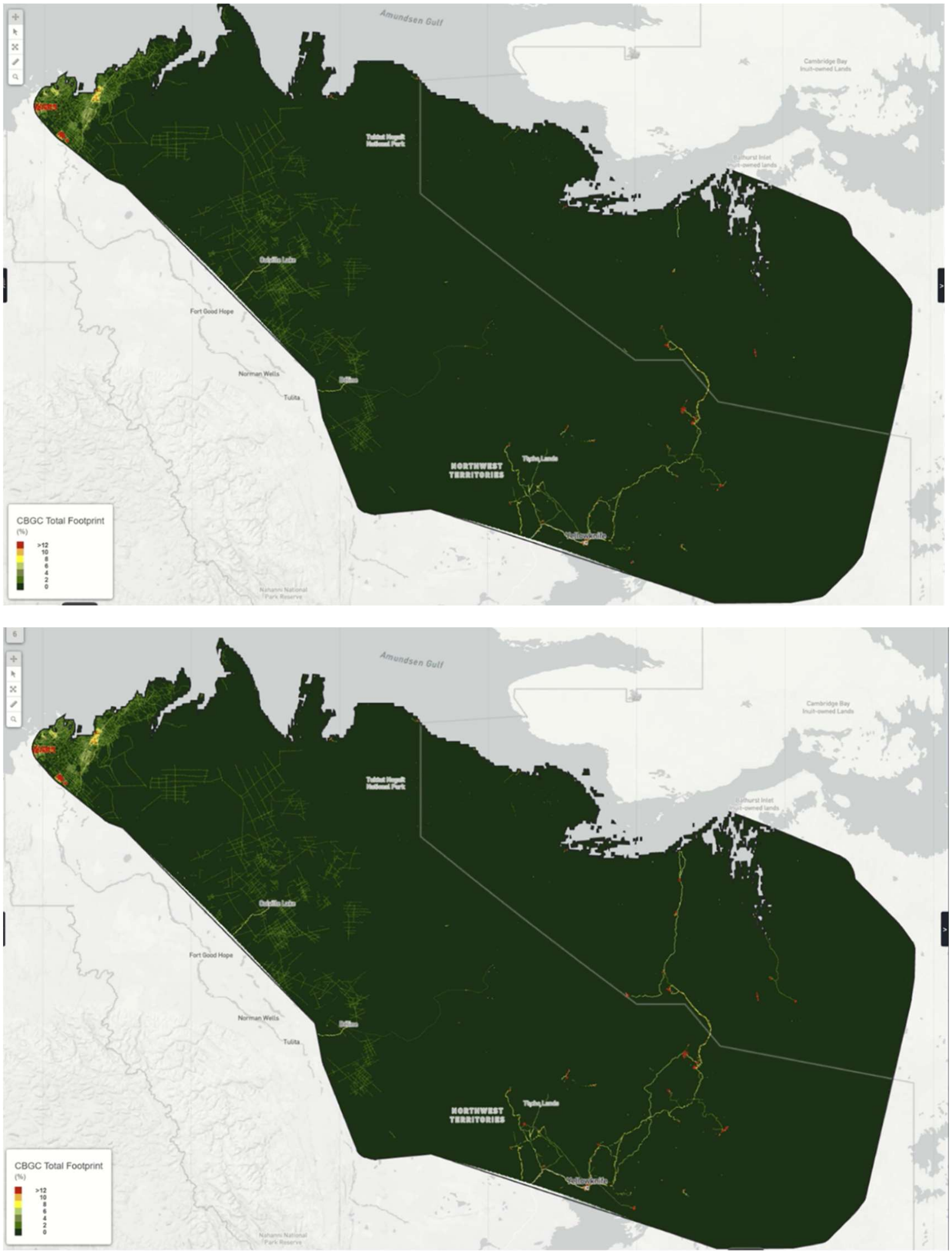


Figure 20. Shrubland coverage at the start (top) and end (bottom) of the RCP 8.5 climate scenario.

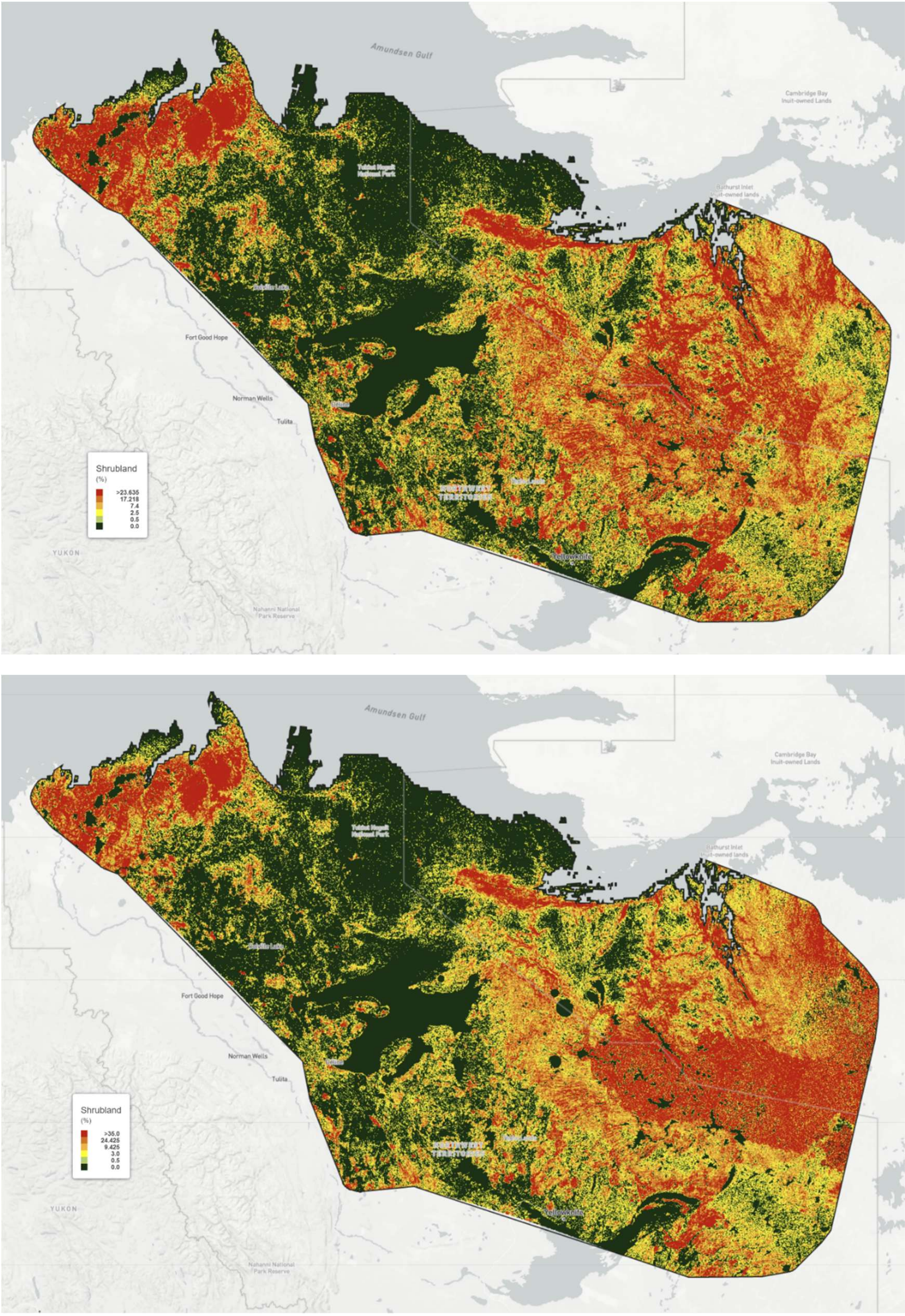


Figure 21. Forest older than 50 years at the start (top) and end (bottom) of the RCP 8.5 climate scenario.

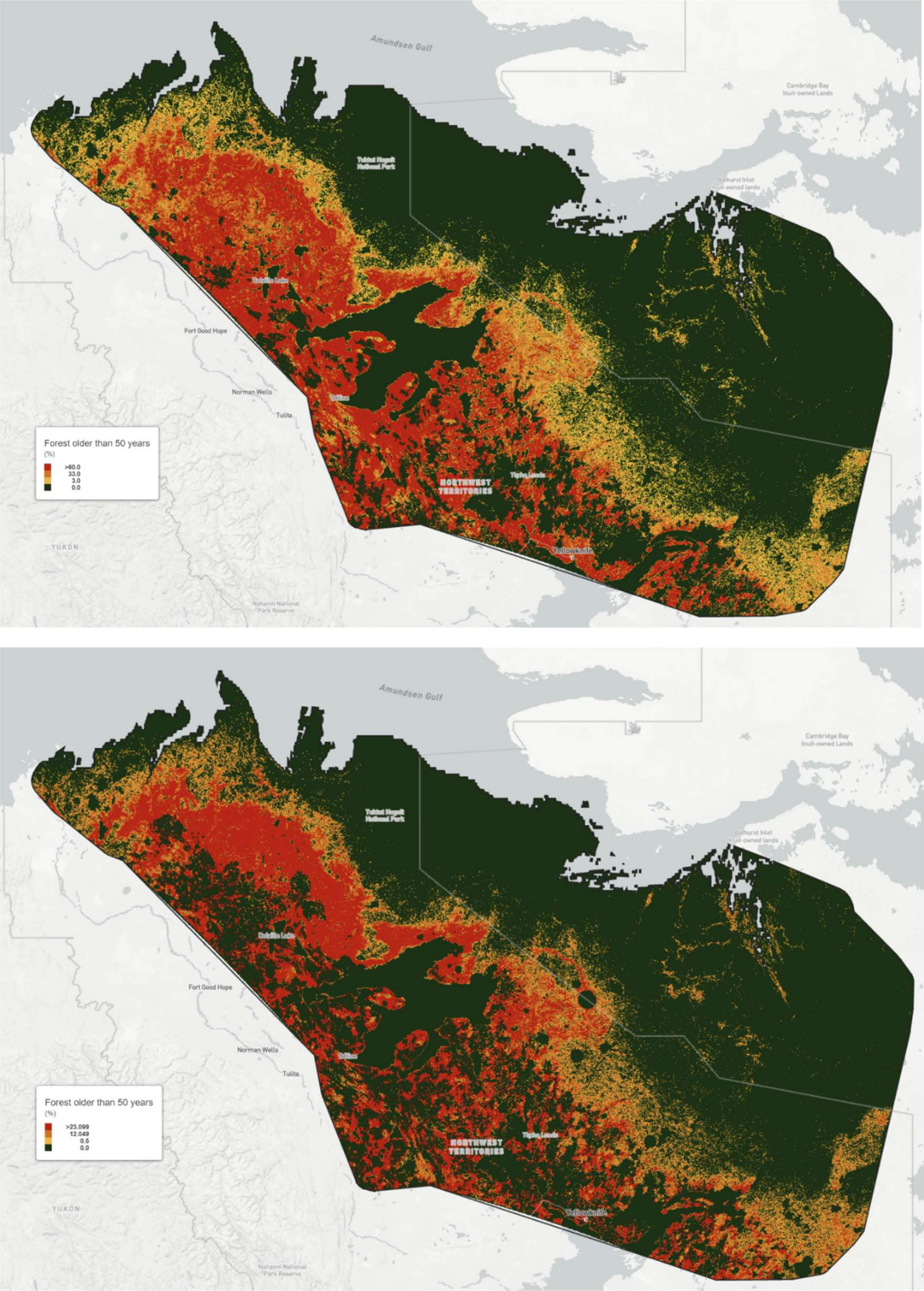
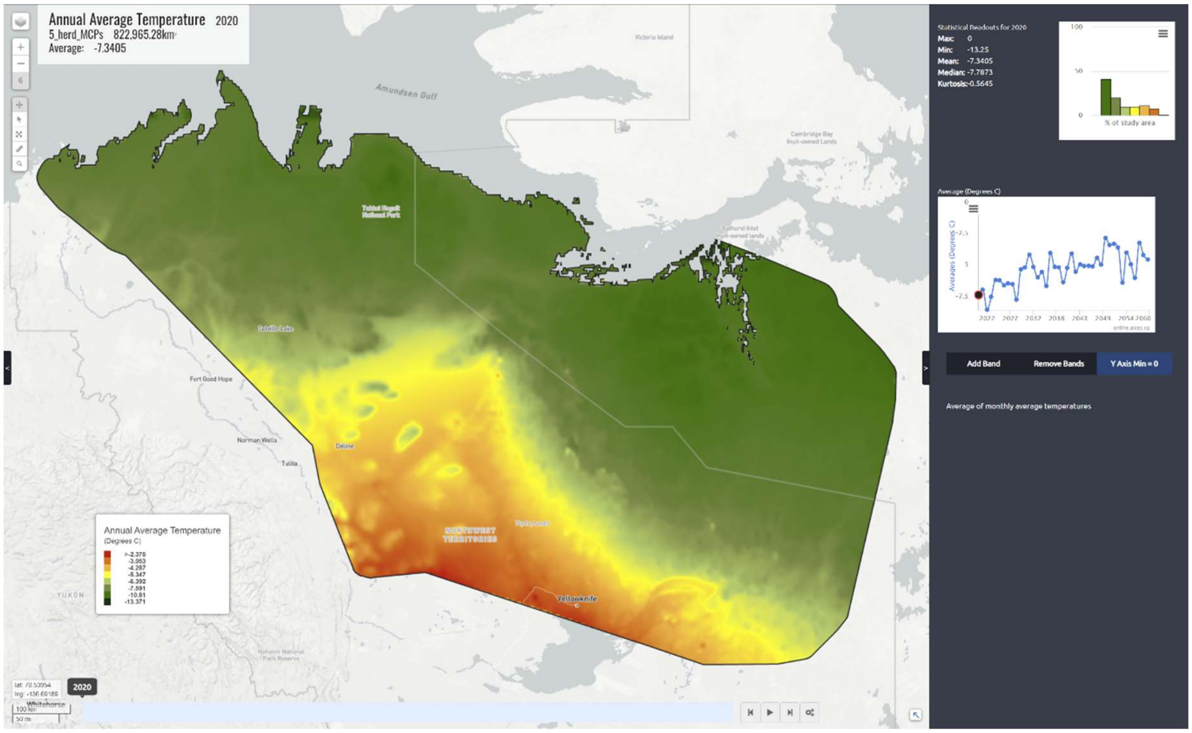


Figure 22. Map on the left is a snapshot of mean annual temperature in 2020 across the Minimum Convex Polygon (MCP) of the five herds of barren-ground caribou. Line graph on the right represents the directional change in mean annual temperature with climate change (RCP 8.5) from 2020 to 2060.

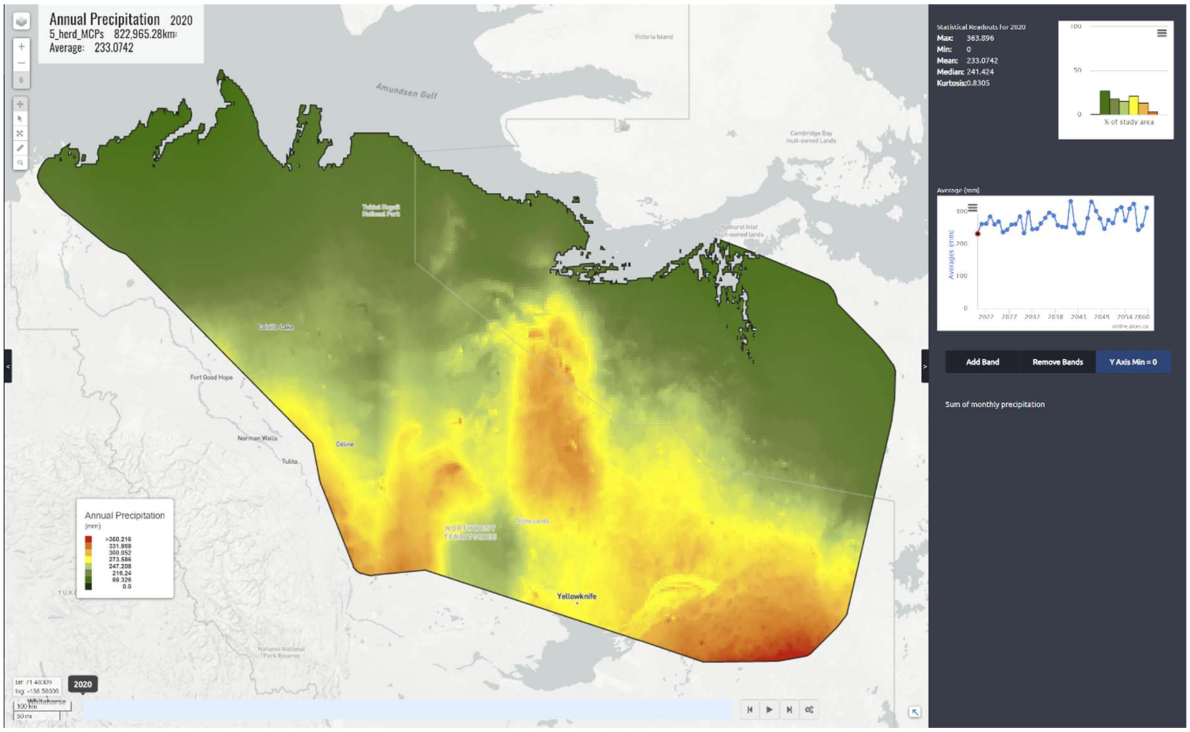


Annual Average Temperature 2020
5_herd_MCPs 822,965.28km²
Average: -7.3405

Statistical Readouts for 2020
Max: 0
Min: -13.25
Mean: -7.3405
Median: -7.7873
Kurtosis: -0.5645

Average of monthly average temperatures

Figure 23. Map on the left is a snapshot of annual precipitation in 2020 across the Minimum Convex Polygon (MCP) of the five herds of barren-ground caribou. Line graph on the right represents the directional change in annual precipitation with climate change (RCP 8.5) from 2020 to 2060.



Annual Precipitation 2020
5_herd_MCPs 822,965.28km²
Average: 233.0742

Statistical Readouts for 2020
Max: 363.896
Min: 0
Mean: 233.0742
Median: 241.424
Kurtosis: 0.8305

Sum of monthly precipitation

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Appendix 2 – Key model inputs for other caribou herds

CBGC ALCES default model inputs for the Bluenose East, Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula herds are presented below when they differ from those used for the Bathurst herd. Inputs that differ from those used for the Bathurst herd include habitat coefficients, maximum density in best habitat, and initial population size and composition. Inputs that did not differ from those used for the Bathurst herd include habitat zone of influence, fecundity, and mortality. The exception is that fecundity and mortality rates used for the Cape Bathurst herd were based on estimates from the Porcupine herd. Also, as described in Climatic Influence on Cow Mortality section of the Methods in the main body of the report, a different set of cow mortality rates were used when assessing climate impacts to cow mortality.

Habitat coefficients

Habitat coefficients were derived using the same approach used for the Bathurst herd, whereby seasonal habitat indices were prepared using resource selection functions (RSFs) developed collaboratively with the Alberta Biodiversity Monitoring Institute (ABMI).

Table A2-1. Seasonal resource selection function (RSF) model coefficients for the Bluenose East herd (ABMI 2021).

	Spring Migration			Calving			Summer			Fall			Winter		
Variable[Φ]	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**
(Intercept)	-3.582	0.072	<0.001	-8.995	1.086	<0.001	-8.712	1.281	<0.001	-4.946	0.116	<0.001	-3.701	0.096	<0.001
Barren Lands	-0.020	0.001	<0.001	-0.021	0.000	<0.001	-0.024	0.000	<0.001	-0.045	0.001	<0.001	-0.022	0.001	<0.001
Shrublands	-0.004	0.001	<0.001	0.010	0.000	<0.001	-0.018	0.001	<0.001	0.001	0.000	0.001	0.013	0.001	<0.001
Forested	-0.022	0.001	<0.001	-0.009	0.027	0.724	-0.062	0.066	0.351	-0.008	0.001	<0.001	-0.011	0.001	<0.001
Forest Age Indicator (> 50 yr old)	-0.130	0.043	0.003	5.103	1.086	<0.001	6.297	1.279	<0.001	2.607	0.062	<0.001	-0.003	0.043	0.952
Linear Features (10-km radius)	-16.817	0.434	<0.001	-5.460	0.445	<0.001	-72.732	3.442	<0.001	-21.208	0.689	<0.001	-20.689	0.451	<0.001
Polygonal Disturbances (10-km radius)	0.289	0.043	<0.001	-1.944	0.401	<0.001	-5.620	0.799	<0.001	-3.168	0.344	<0.001	0.168	0.059	0.004
Waterbody (Lakes)	-0.008	0.000	<0.001	-0.045	0.001	<0.001	-0.033	0.000	<0.001	-0.025	0.000	<0.001	-0.006	0.000	<0.001
Watercourse (Rivers)	-0.164	0.028	<0.001	0.120	0.025	<0.001	-0.214	0.029	<0.001	-0.109	0.025	<0.001	-0.233	0.027	<0.001
Wetlands	-0.029	0.001	<0.001	0.038	0.001	<0.001	0.001	0.001	0.223	-0.007	0.001	<0.001	-0.003	0.001	<0.001
Minimum Elevation *	0.013	0.008	0.108	-0.508	0.007	<0.001	—	—	—	0.641	0.008	<0.001	—	—	—
Maximum Elevation *	—	—	—	—	—	—	-0.075	0.008	<0.001	—	—	—	—	—	—
Mean Elevation*	—	—	—	—	—	—	—	—	—	—	—	—	0.210	0.009	<0.001
Slope*	0.097	0.005	<0.001	-0.181	0.008	<0.001	0.144	0.006	<0.001	-0.085	0.006	<0.001	-0.373	0.009	<0.001
Aspect*	0.043	0.006	<0.001	-0.164	0.008	<0.001	-0.004	0.007	0.558	0.041	0.005	<0.001	0.034	0.006	<0.001
Minimum Temperature *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Temperature*	—	—	—	-0.686	0.020	<0.001	-0.257	0.017	<0.001	—	—	—	—	—	—
Mean Temperature *	0.497	0.016	<0.001	—	—	—	—	—	—	1.194	0.011	<0.001	0.483	0.011	<0.001
Evaporation*	-0.340	0.013	<0.001	-0.372	0.018	<0.001	-0.100	0.029	<0.001	-0.331	0.012	<0.001	—	—	—
Precipitation*	-0.358	0.011	<0.001	-0.982	0.020	<0.001	0.035	0.010	<0.001	0.585	0.009	<0.001	-0.169	0.010	<0.001
Forested * Forest Age Indicator	0.028	0.001	<0.001	-0.249	0.028	<0.001	-0.008	0.066	0.899	-0.016	0.001	<0.001	0.026	0.001	<0.001
Spearman's correlation coefficient (r_S)[ϒ]		0.99			0.96			1.00			1.00			1.00	
k-fold cross-validation (mean (r_S))[†]		0.97			0.95			0.99			0.96			0.95	

[Φ] Grassland is the reference category for local land-cover variables

* standardized coefficients

[ϒ] correlation between RSF bin rank (1-10 bins with bin 10 being strongest selection) and proportion of all caribou locations falling within each bin

[†] mean r_S from 10 iterations of 5-fold cross-validation

Table A2-2. Seasonal resource selection function (RSF) model coefficients for the Bluenose West herd (ABMI 2021).

	Spring Migration			Calving			Summer			Fall			Winter		
Variable$^{\Phi}$	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**
(Intercept)	-3.216	0.060	<0.001	-6.439	0.098	<0.001	-2.377	0.064	<0.001	-5.045	0.225	<0.001	-5.809	0.207	<0.001
Barren Lands	-0.005	0.000	<0.001	-0.012	0.000	<0.001	-0.002	0.000	<0.001	-0.056	0.000	<0.001	-0.083	0.001	<0.001
Shrublands	-0.039	0.001	<0.001	-0.036	0.001	<0.001	-0.001	0.000	0.001	-0.027	0.000	<0.001	-0.024	0.000	<0.001
Forested	-0.009	0.000	0.183	-0.029	0.002	<0.001	-0.081	0.001	<0.001	-0.010	0.004	0.013	0.006	0.003	0.039
Forest Age Indicator (> 50 yr old)	—	—	—	—	—	—	—	—	—	2.730	0.213	<0.001	2.272	0.188	<0.001
Linear Features (10-km radius)	0.732	0.050	<0.001	-19.743	0.889	<0.001	-11.334	0.508	<0.001	-0.599	0.066	<0.001	0.216	0.028	<0.001
Polygonal Disturbances (10-km radius)	-12.164	1.070	<0.001	13.081	0.374	<0.001	3.946	0.392	<0.001	-11.185	1.302	<0.001	-36.521	1.656	<0.001
Waterbody (Lakes)	-0.021	0.000	<0.001	-0.058	0.001	<0.001	-0.044	0.000	<0.001	-0.022	0.000	<0.001	-0.004	0.000	<0.001
Watercourse (Rivers)	0.310	0.021	<0.001	0.354	0.022	<0.001	0.153	0.020	<0.001	-0.016	0.017	0.360	-0.130	0.017	<0.001
Wetlands	-0.032	0.001	0.002	-0.025	0.002	<0.001	-0.060	0.002	<0.001	-0.026	0.001	<0.001	-0.039	0.001	<0.001
Minimum Elevation *	—	—	—	—	—	—	—	—	—	0.249	0.006	<0.001	—	—	—
Maximum Elevation *	—	—	—	—	—	—	—	—	—	—	—	—	0.697	0.008	<0.001
Mean Elevation*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Slope*	—	—	—	—	—	—	—	—	—	-0.268	0.006	<0.001	-0.607	0.007	<0.001
Aspect*	—	—	—	—	—	—	—	—	—	0.067	0.004	<0.001	0.030	0.004	<0.001
Minimum Temperature *	—	—	—	—	—	—	—	—	—	—	—	—	0.549	0.007	<0.001
Maximum Temperature*	—	—	—	-4.030	0.025	<0.001	—	—	—	-0.957	0.013	<0.001	—	—	—
Mean Temperature *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Evaporation*	—	—	—	0.209	0.016	<0.001	—	—	—	-0.068	0.012	<0.001	—	—	—
Precipitation*	—	—	—	0.288	0.019	<0.001	—	—	—	-0.309	0.008	<0.001	-1.294	0.008	<0.001
Forested * Forest Age Indicator	—	—	—	—	—	—	—	—	—	0.000	0.004	0.987	0.017	0.003	<0.001
Spearman's correlation coefficient (r_S)$^{\Upsilon}$		0.93			0.88			0.90			1.00			1.00	

$^{\Phi}$ Grassland is the reference category for local land-cover variables

* standardized coefficients

$^{\Upsilon}$ correlation between RSF bin rank (1-10 bins with bin 10 being strongest selection) and proportion of all caribou locations falling within each bin

Table A2-3. Seasonal resource selection function (RSF) model coefficients for the Cape Bathurst herd (ABMI 2021).

	Spring Migration			Calving			Summer			Fall			Winter		
Variable$^{\Phi}$	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**
(Intercept)	-4.122	0.224	<0.001	-5.733	0.104	<0.001	-4.416	0.108	<0.001	-3.768	0.201	<0.001	-5.134	0.349	<0.001
Barren Lands	-0.070	0.002	<0.001	-0.104	0.001	<0.001	-0.081	0.001	<0.001	-0.098	0.003	<0.001	-0.086	0.003	<0.001
Shrublands	0.013	0.000	<0.001	0.001	0.000	0.047	0.025	0.000	<0.001	0.013	0.000	<0.001	0.015	0.000	<0.001
Forested	-1.774	0.955	0.063	-0.101	0.005	<0.001	-0.141	0.003	<0.001	-0.198	0.051	<0.001	-0.044	0.015	0.003
Forest Age Indicator (> 50 yr old)	0.530	0.209	0.011	—	—	—	—	—	—	1.327	0.184	<0.001	2.753	0.291	<0.001
Linear Features (10-km radius)	-0.002	0.000	<0.001	-0.037	0.000	<0.001	-0.025	0.000	<0.001	-0.020	0.000	<0.001	-0.012	0.000	<0.001
Polygonal Disturbances (10-km radius)	0.016	0.002	<0.002	0.065	0.002	<0.002	0.054	0.002	<0.001	-0.011	0.002	<0.001	-0.226	0.004	
Waterbody (Lakes)	0.304	0.049	<0.001	0.003	0.052	0.959	-0.702	0.045	<0.001	-0.322	0.046	<0.001	-0.009	0.040	0.829
Watercourse (Rivers)	0.100	0.032	0.002	0.016	0.034	0.638	-0.113	0.030	<0.001	-0.211	0.032	<0.001	-0.290	0.027	<0.001
Wetlands	0.002	0.001	0.204	-0.003	0.001	0.012	0.001	0.001	0.386	-0.004	0.002	0.034	-0.009	0.003	0.003
Minimum Elevation *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Elevation *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mean Elevation*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Slope*	-0.253	0.010	<0.001	—	—	—	—	—	—	-0.405	0.010	<0.001	-0.678	0.010	<0.001
Aspect*	-0.046	0.007	<0.001	—	—	—	—	—	—	0.084	0.006	<0.001	-0.116	0.005	<0.001
Minimum Temperature *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Temperature*	-1.101	0.014	<0.001	—	—	—	-2.550	0.017	<0.001	-0.407	0.019	<0.001	—	—	—
Mean Temperature *	—	—	—	-3.894	0.026	<0.001	—	—	—	—	—	—	2.288	0.014	<0.001
Evaporation*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Precipitation*	—	—	—	—	—	—	—	—	—	-0.677	0.012	<0.001	-0.650	0.010	<0.001
Forested * Forest Age Indicator	1.740	0.955	0.068	—	—	—	—	—	—	0.144	0.051	0.005	0.032	0.015	0.036
Spearman's correlation coefficient (r_S)$^{\Upsilon}$		0.87			0.72			0.92			0.99			0.89	

$^{\Phi}$ Grassland is the reference category for local land-cover variables

* standardized coefficients

$^{\Upsilon}$ correlation between RSF bin rank (1-10 bins with bin 10 being strongest selection) and proportion of all caribou locations falling within each bin

Table A2-4. Seasonal resource selection function (RSF) model coefficients for the Tuktoyaktuk Peninsula herd (ABMI 2021).

	Spring Migration			**Calving**			**Summer**			**Fall**			**Winter**		
Variable[Φ]	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**	**Estimate**	**Std. Error**	**Pr(>|z|)**
(Intercept)	-2.625	0.166	<0.001	-3.326	0.086	<0.001	-2.834	0.173	<0.001	-2.080	0.156	<0.001	-1.923	0.184	<0.001
Barren Lands	0.006	0.002	0.011	0.029	0.002	<0.001	0.008	0.002	<0.001	-0.025	0.003	<0.001	-0.043	0.005	<0.001
Shrublands	-0.028	0.001	<0.001	-0.096	0.003	<0.001	-0.050	0.001	<0.001	-0.026	0.001	<0.001	0.001	0.000	0.017
Forested	-0.131	0.005	<0.001	-0.454	0.046	<0.001	-0.415	0.028	<0.001	-0.193	0.007	<0.001	-0.050	0.001	<0.001
Forest Age Indicator (> 50 yr old)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Linear Features (10-km radius)	0.073	0.033	0.028	-3.891	0.092	<0.001	0.170	0.038	0.053	0.450	0.023	<0.001	-1.020	0.033	<0.001
Polygonal Disturbances (10-km radius)	-5.991	1.200	<0.001	-58.947	3.887	<0.001	-1.850	0.262	<0.001	-2.436	0.248	<0.001	1.379	0.107	<0.001
Waterbody (Lakes)	-0.009	0.000	<0.001	-0.031	0.000	<0.001	-0.026	0.000	<0.001	-0.014	0.000	<0.001	-0.011	0.000	<0.001
Watercourse (Rivers)	-0.185	0.053	0.001	0.047	0.055	0.398	0.048	0.049	0.324	0.038	0.048	0.430	-0.487	0.040	<0.001
Wetlands	0.011	0.001	0.519	-0.012	0.001	<0.001	0.000	0.001	0.892	0.020	0.001	<0.001	-0.013	0.001	<0.001
Minimum Elevation *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Elevation *	—	—	—	-2.692	0.062	<0.001	-1.491	0.047	<0.001	—	—	—	—	—	—
Mean Elevation*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Slope*	—	—	—	-1.037	0.038	<0.001	-1.341	0.036	<0.001	—	—	—	-0.684	0.015	<0.001
Aspect*	—	—	—	-0.168	0.011	<0.001	-0.091	0.011	<0.001	—	—	—	0.029	0.009	0.001
Minimum Temperature *	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Maximum Temperature*	0.270	0.024	<0.001	—	—	—	-0.064	0.027	0.020	0.323	0.038	<0.001	—	—	—
Mean Temperature *	—	—	—	-0.365	0.026	<0.001	—	—	—	—	—	—	—	—	—
Evaporation*	-0.017	0.021	0.417	0.455	0.015	<0.001	0.248	0.015	<0.001	-0.252	0.017	<0.001	—	—	—
Precipitation*	-1.220	0.025	<0.001	-0.969	0.042	<0.001	-1.124	0.036	<0.001	-0.050	0.018	0.006	0.608	0.014	<0.001
Forested * Forest Age Indicator	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Spearman's correlation coefficient (r_S)[ϒ]	0.95			0.92			1.00			1.00			0.81		

[Φ] Grassland is the reference category for local land-cover variables

* standardized coefficients

[ϒ] correlation between RSF bin rank (1-10 bins with bin 10 being strongest selection) and proportion of all caribou locations falling within each bin

Maximum density in best habitat

Seasonal maximum densities were derived by dividing the maximum observed population by the size of the seasonal range[27] and then by the average habitat index of the range (Table A2-5). Dividing by the average habitat index for a range is to scale max density to what it would be if all cells were at maximum habitat (i.e., habitat index equal to 1).

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[27] Seasonal range sizes were based on kernel density based estimates of seasonal range derived using 2005 to 2019 caribou location data and a utilization distribution threshold of 95%.

Table A2-5. Maximum density of 1+ year-old caribou in best habitat as calculated by dividing the highest recorded population by the seasonal 2005-2019 range area and current average habitat index.

Herd	Maximum population	Season	2005-2019 Range Area (km^2)	Average habitat index	Max density in best habitat (#/km^2)
Bluenose East	120,000	Spring Migration	178,413	0.2663	2.5257
		Calving	39,605	0.0686	44.1682
		Summer	86,881	0.1723	8.0162
		Fall	161,097	0.1717	4.3383
		Winter	158,964	0.1373	5.4981
Bluenose West	112,360	Spring Migration	77,138	0.4858	2.9984
		Calving	17,817	0.0763	82.6539
		Summer	65,395	0.4624	3.7158
		Fall	92,116	0.1504	8.1101
		Winter	62,157	0.1321	13.6843
Cape Bathurst	19,278	Spring Migration	24,645	0.0089	87.8903
		Calving	19,316	0.0287	34.7743
		Summer	7,122	0.0311	87.0374
		Fall	21,327	0.0621	14.5561
		Winter	14,429	0.2101	6.3593
Tuktoyaktuk Peninsula	3,250	Spring Migration	8,650	0.0978	3.8417
		Calving	2,533	0.126	10.1823
		Summer	4,096	0.1133	7.0025
		Fall	8,161	0.2044	1.9484
		Winter	10,314	0.2094	1.5048

Initial Population Size and Composition

Initial populations for the herds are as follows:

- Bluenose East initial adult population of 23,000
- Bluenose West initial non-calf population of 18,440
- Cape Bathurst initial non-calf population of 8,533
- Tuktoyaktuk Peninsula initial non-calf population of 3,073

Distribution of the population across age and sex classes is provided in the table below. We used Boulanger's (2017) initial model estimates to generate a stable age class distribution that was applied to population estimates to derive initial composition of female and male yearlings and adults (Table 4).

Table A2-6. Derived estimates for a stable age class distribution

Age Class	Proportion of Population		
	Female	Male	Sum
Calf (0 year)[#]	0.1015	0.1015	0.2030
Yearling (1 year)*	0.0800	0.0800	0.1600
Young Adult (2 year)†	0.0670	0.0600	0.1270
Adult (3 to 14 year) ‡	0.3460	0.1640	0.5100
Sum	0.5945	0.4055	1.0000

[#] Calculated by applying a calf:100 cow ratio of 42.5, which is the ratio estimated by DeCesare et al. (2012) as needed to derive a stable population (i.e., λ rate of change = 0). The ratio was applied to estimated female adult population (young adult and mature adult).

*Calculated based on BNE age-class composition estimate whereby 6% of population that is 1 year or older are female yearlings and 6% are male yearlings (Boulanger 2017).

†Calculated by applying a survival rate of 0.86 to the yearling population (Boulanger 2017).

‡The adult population was estimated based on BNE age-class composition estimate whereby 59% of population that is 1 year or older are female adults and 30% are male adults (Boulanger 2017). The mature adult population was then estimated by subtracting the sub adult population from the adult population.

Cape Bathurst Fecundity and Mortality Rates

In response to feedback provided by WMAC that Bluenose East vital rate estimates were unsuitable for the Cape Bathurst herd, fecundity and mortality rates were instead based on 5-year average estimates for the Porcupine herd (Porcupine Caribou Technical Committee 2025).

Table A2-7. Vital rate estimates used for the Cape Bathurst herd, based on 5-year averages calculated for the Porcupine herd in 2025.

Parameter	Estimate
Birth rate	0.78
Annual calf survival	0.86
Annual yearling survival	0.78
Annual cow survival	0.87
Annual bull survival	0.67

Appendix 3 – Simulation Outputs for other caribou herds

A core set of scenarios were simulated for each of the other herds (Bluenose East, Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula) to demonstrate response to key drivers. Model inputs were as described in Appendix 2. Outcomes are presented in the sections that follow for scenarios related to habitat dynamics and harvest near roads, a footprint encounter effect on recruitment, and climate effects on cow mortality.

Habitat and Harvest Drivers

Scenarios related to habitat dynamics and harvest near roads are:

- Basecase: habitat changes in response to fire, climate change induced changes in land cover, and future land use;
- ZOI: same as the basecase scenario except that habitat is set to 0 within the footprint zones of influence identified in the report;
- Low road harvest risk: same as the basecase scenario except that a harvest mortality rate of 5% is applied to young adult and adult caribou within 10 km of roads[28];
- High road harvest risk: same as the basecase scenario except that a harvest mortality rate of 50% is applied to young adult and adult caribou within 10 km of roads

Scenario outcomes are summarized in the figures below. The Bluenose East and Bluenose West herds were relatively stable in response to the basecase scenario, the Cape Bathurst herd population increased, and the Tuktoyaktuk Peninsula declined. The declining population of the Tuktoyaktuk Peninsula herd was due higher death rates and the population being closer to carrying capacity, such that habitat loss resulted in density dependent mortality. The differing responses of the Cape Bathurst and Tuktoyaktuk Peninsula simulations illustrate the influence of assumptions for natural death rates and the birth rate. The Cape Bathurst simulations used rates estimated for the Porcupine herd whereas the Tuktoyaktuk Peninsula simulations used rates estimated for the Bathurst and Bluenose East herds. Research is needed to better understand birth and death rates for these herds.

All herds were insensitive to the ZOI scenario because the ZOI buffers accounted for a small portion of caribou range and therefore had only a small effect on carrying capacity. Sensitivity to harvest risk along roads differed among herds depending on the abundance of roads. The Bluenose West, Cape Bathurst and Tuktoyaktuk Peninsula ranges contain very little road and as a result were insensitive to harvest risk. The Bluenose East herd displayed greater sensitivity to harvest risk but still required a high level of harvest mortality (i.e., 50% as opposed to 5%) within 10 km of roads to cause substantial population decline.

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[28] Harvest mortality is only applied to winter roads in the winter range whereas harvest mortality is applied to permanent roads in all seasons.

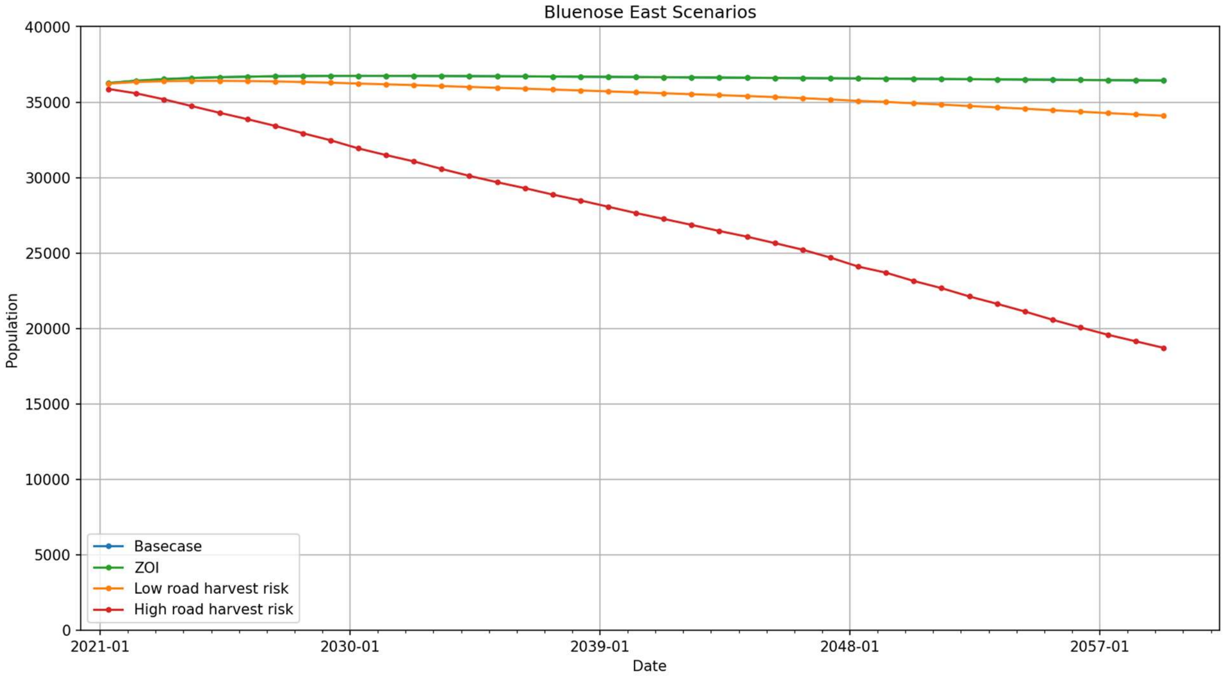

Figure A3-1. Simulated population trajectories for the Bluenose East caribou population to illustrate response to drivers related to habitat and harvest: habitat dynamics caused by climate change and development (Basecase); habitat avoidance within footprint zones of influence (ZOI); and two levels of harvest risk in proximity to roads (Low road risk, High road risk).

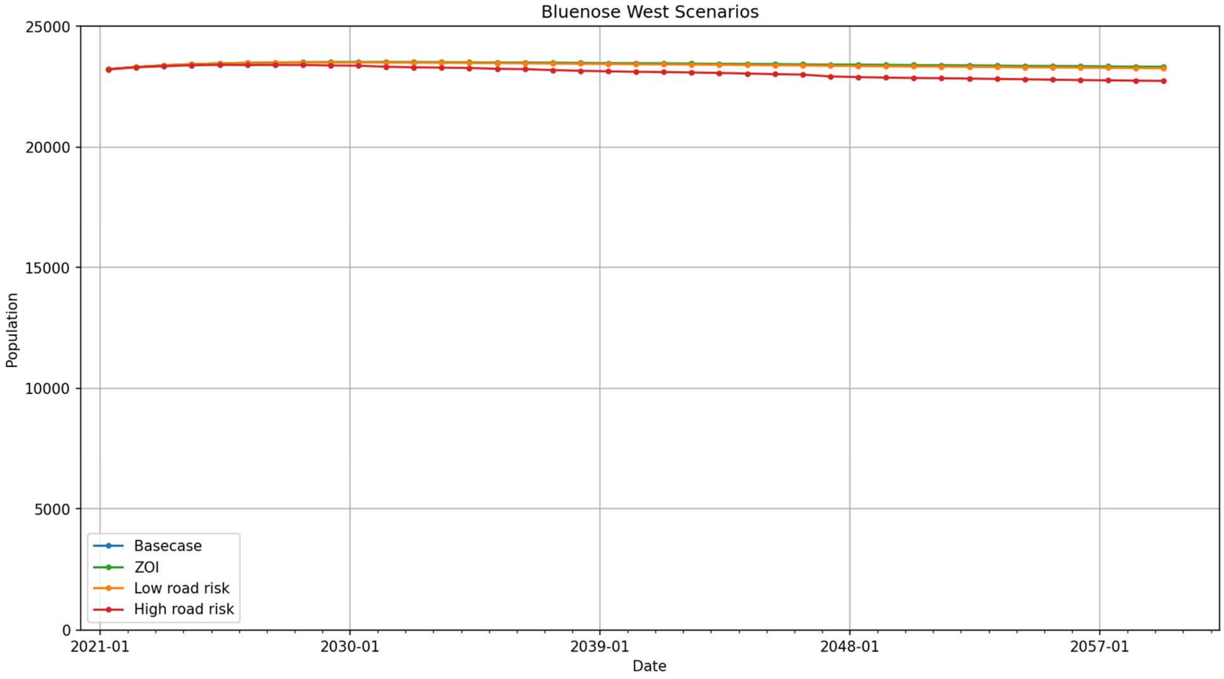

Figure A3-2. Simulated population trajectories for the Bluenose West caribou population to illustrate response to drivers related to habitat and harvest: habitat dynamics caused by climate change and development (Basecase); habitat avoidance within footprint zones of influence (ZOI); and two levels of harvest risk in proximity to roads (Low road harvest risk, High road harvest risk).

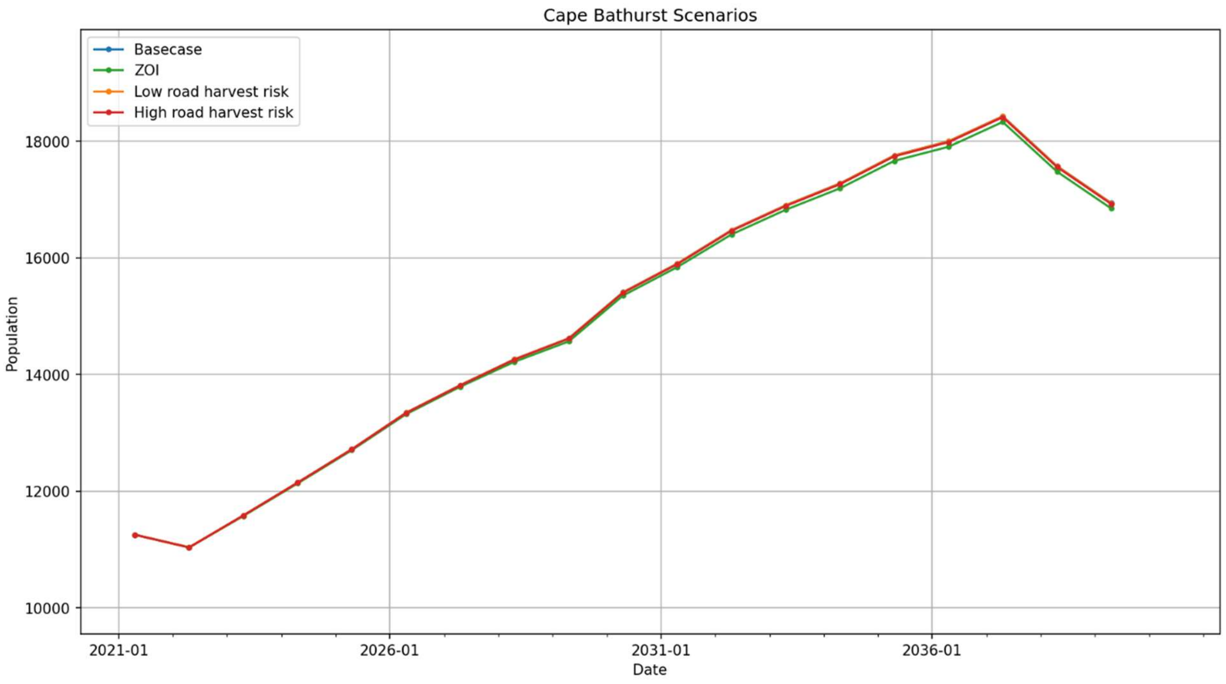

Figure A3-3. Simulated population trajectories for the Cape Bathurst caribou population to illustrate response to a core set of drivers: habitat dynamics caused by climate change and development (Basecase); potential changes in vital rates due to climate change (CC vital rates); habitat avoidance within footprint zones of influence (ZOI); and two levels of harvest risk in proximity to roads (Low road harvest risk, High road harvest risk).

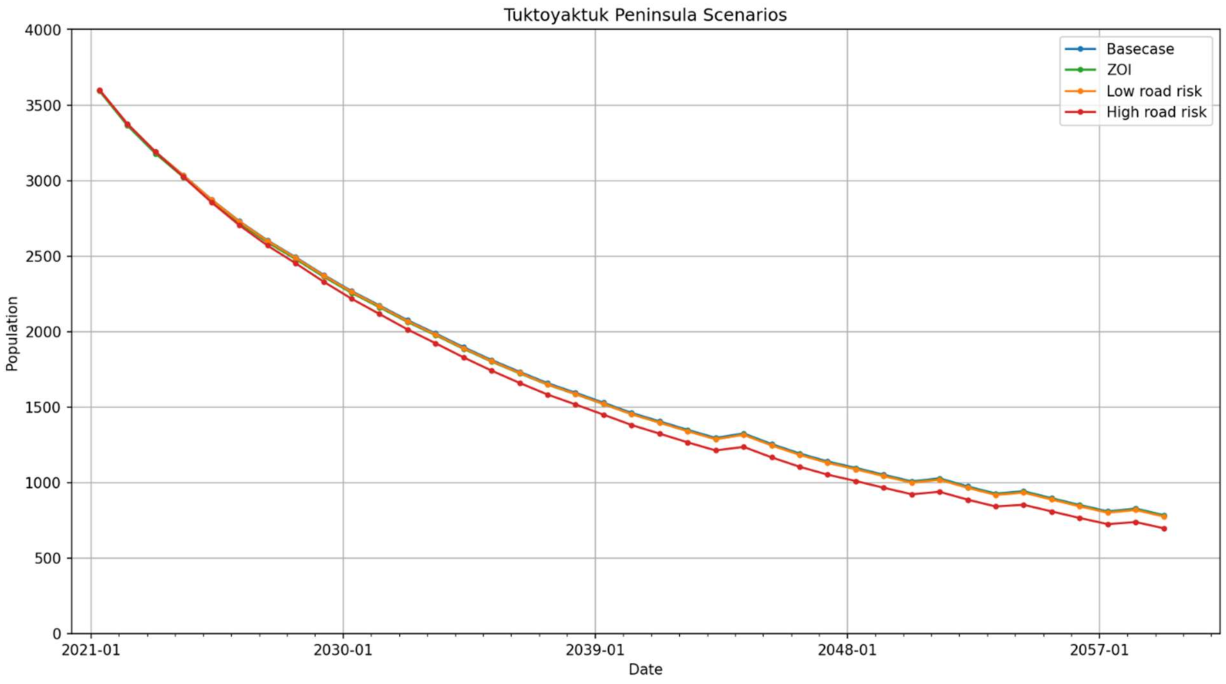

Figure A3-4. Simulated population trajectories for the Tuktoyaktuk Peninsula caribou population to illustrate response to drivers related to habitat and harvest: habitat dynamics caused by climate change and development (Basecase); habitat avoidance within footprint zones of influence (ZOI); and two levels of harvest risk in proximity to roads (Low road harvest risk, High road harvest risk).

Footprint Encounter Effects to Recruitment

A 10-year forecast was completed to explore the frequency of footprint encounters. A conservative approach was taken whereby only encounters with permanent road footprint were considered to impact birth rate and calf mortality; the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments was included although it only intersected with the Bluenose East range. The encounter effect was negligible for all herds due to the low abundance of permanent road. Additional scenarios could be simulated to explore the encounter effect if encounters with all footprint types are assumed to impact birth rate and calf mortality.

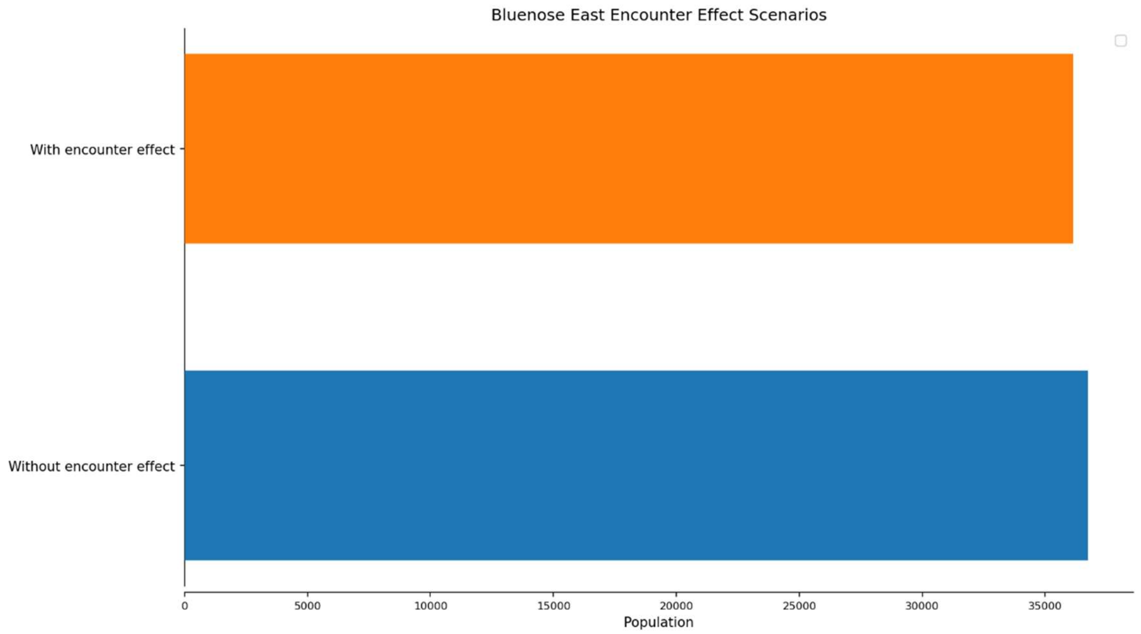

Figure A3-5. Simulated Bluenose East caribou population after 10 years with and without an encounter effect on birth rate and calf survival. Footprint encounters based on overlap of habitat with a 5 km buffer applied to permanent road, including the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments.

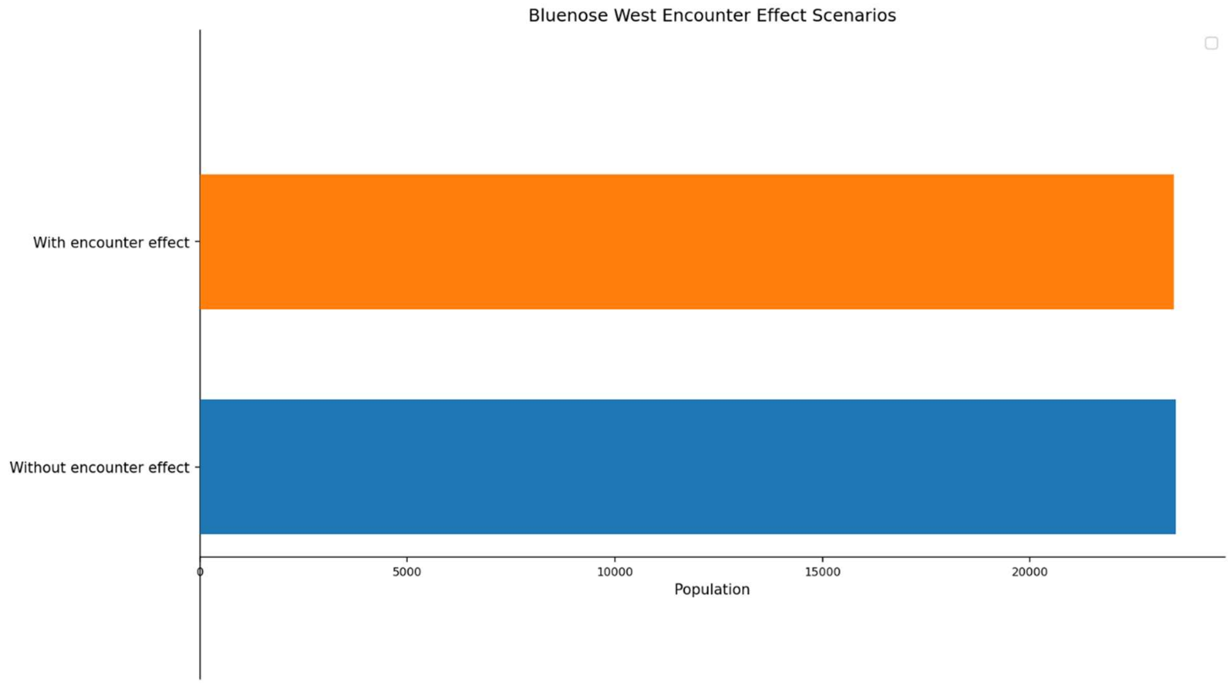

Figure A3-6. Simulated Bluenose West caribou population after 10 years with and without an encounter effect on birth rate and calf survival. Footprint encounters based on overlap of habitat with a 5 km buffer applied to permanent road, including the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments.

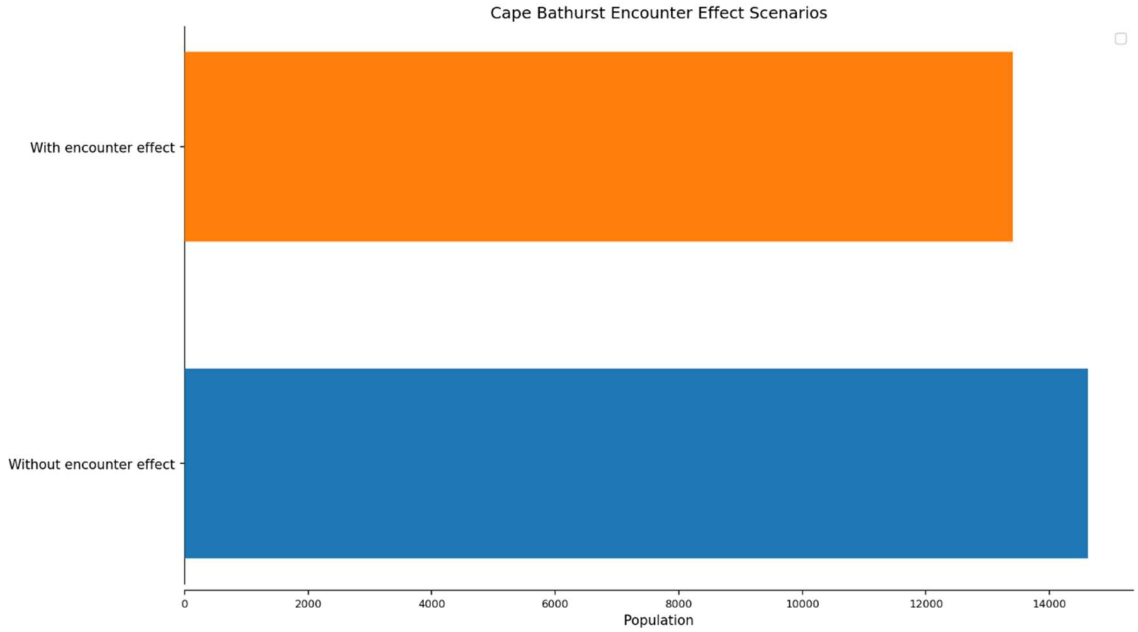

Figure A3-7. Simulated Cape Bathurst caribou population after 10 years with and without an encounter effect on birth rate and calf survival. Footprint encounters based on overlap of habitat with a 5 km buffer applied to permanent road.

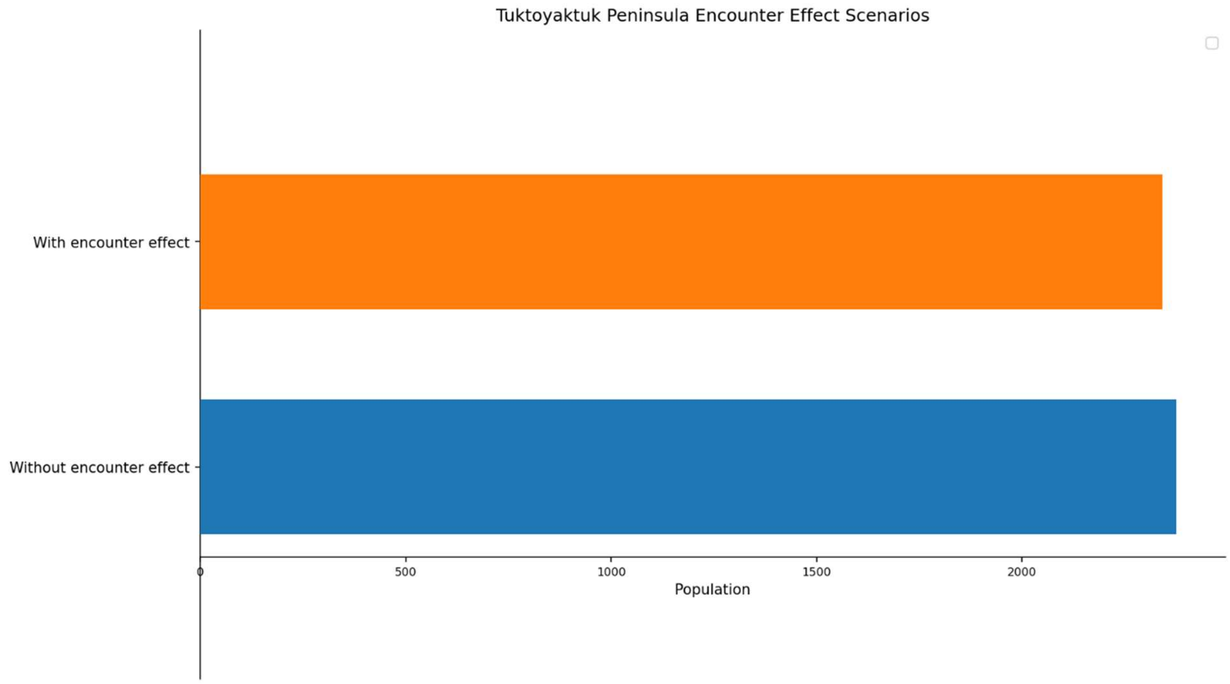

Figure A3-8. Simulated Tuktoyaktuk caribou population after 10 years with and without an encounter effect on birth rate and calf survival. Footprint encounters based on overlap of habitat with a 5 km buffer applied to permanent road, including the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments.

Climate Change Effects to Cow Mortality

Simulation outcomes were sensitive to climate change effects on cow mortality. Population declines after 20 years relative to the basecase scenario were 39% for the Bluenose East herd (Figure A3-9), 58% for the Bluenose West herd (Figure A3-10), 75% for the Cape Bathurst herd (Figure A3-11), and 80% for the Tuktoyaktuk Peninsula herd (Figure A3-12). The combined effect of projected changes in winter temperature, snow depth, and summer temperature caused population to decline by 50% or more relative to the base case scenario after 20 years. Of the three climate variables (snow depth, winter temperature, summer temperature), winter temperature had the largest effect on population outcomes for all four herds.

The simulations applied different cow mortality rates than were used for the scenarios presented earlier in this appendix. The cow mortality rates were provided by Chloe Beaupre and are based on the same analysis that was completed to derive the climate and cow mortality hazard relationships. Because different cow mortality rates were used, outcomes of the simulations differed from scenarios presented earlier in the appendix even when the climate relationships were not applied (i.e., the “No climate effect” scenario presented in the graphs below). The difference was largest for the Bluenose East herd, for which lower cow mortality rates resulted in substantial population growth during the forecast (Figure A3-9). The difference between the scenario and the scenarios presented previously (Figure A3-1) demonstrate the importance of research and monitoring targeted at improving understanding of caribou vital rates.

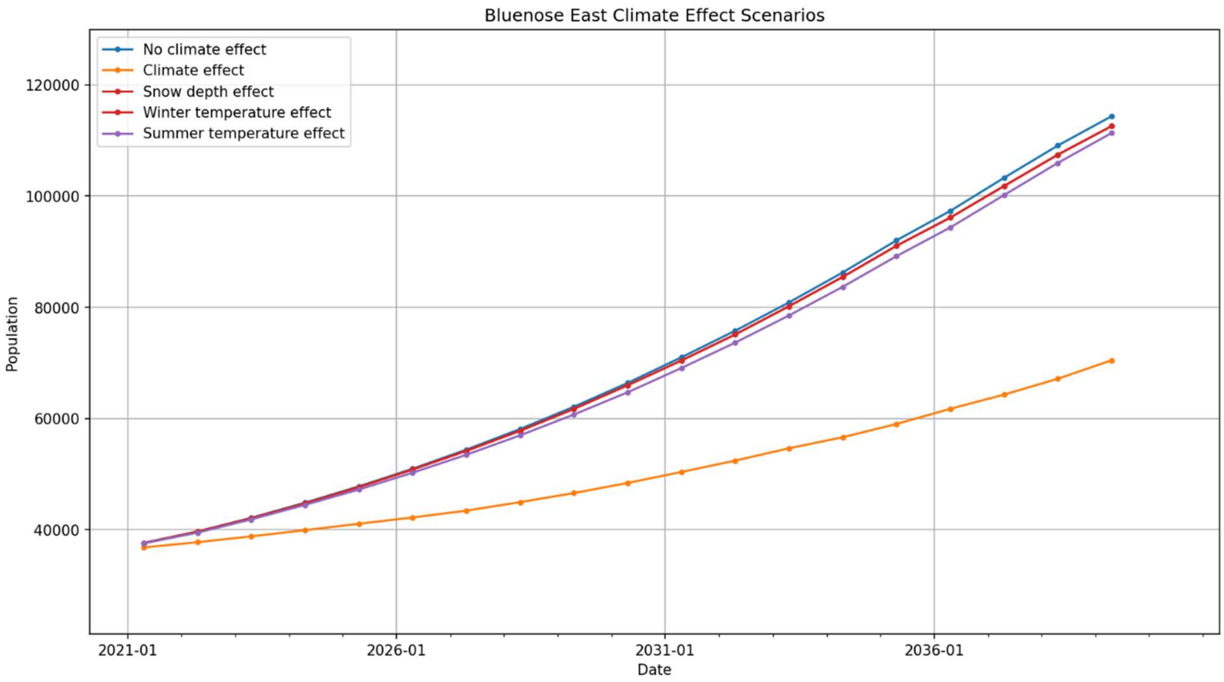

Figure A3-9. Response of the Bluenose East caribou population to scenarios that differ with respect to the effect of climate on cow mortality. “No climate effect” does not incorporate climate impacts to cow mortality whereas “Climate effect” incorporates all three climate relationships with cow mortality (snow depth, winter temperature, summer temperature). The remaining scenarios apply each climate relationship separately.

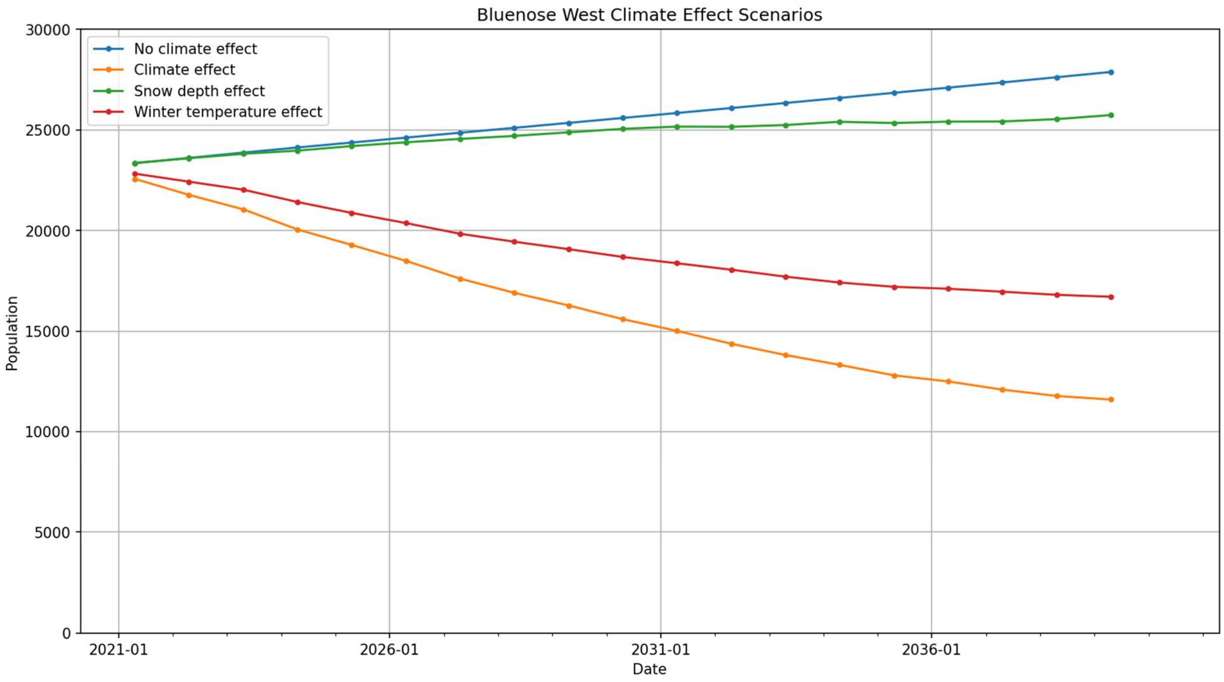

Figure A3-10. Response of the Bluenose West caribou population to scenarios that differ with respect to the effect of climate on cow mortality. “No climate effect” does not incorporate climate impacts to cow mortality whereas “Climate effect” incorporates *all three climate relationships with cow mortality (snow depth, winter temperature, summer temperature). The remaining scenarios apply each climate relationship separately.*

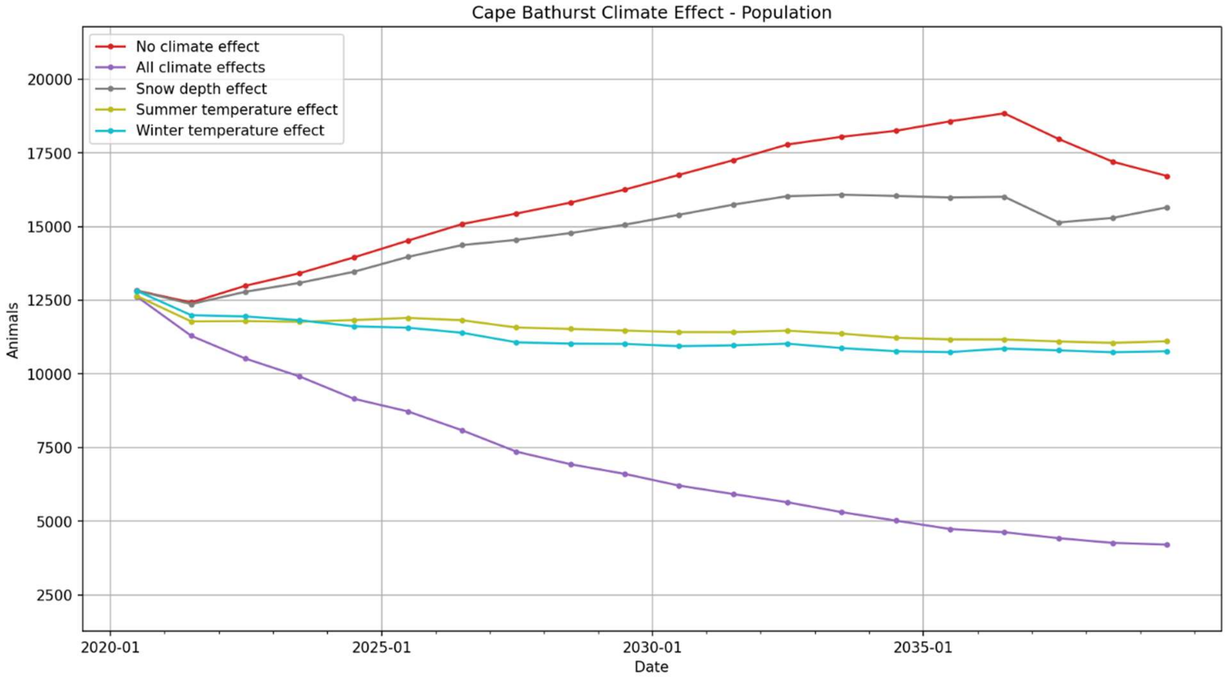

Figure A3-11. Response of the Cape Bathurst caribou population to scenarios that differ with respect to the effect of climate on cow mortality. “No climate effect” does not incorporate climate impacts to cow mortality whereas “Climate effect” incorporates all three climate relationships with cow mortality (snow depth, winter temperature, summer temperature). The remaining scenarios apply each climate relationship separately.

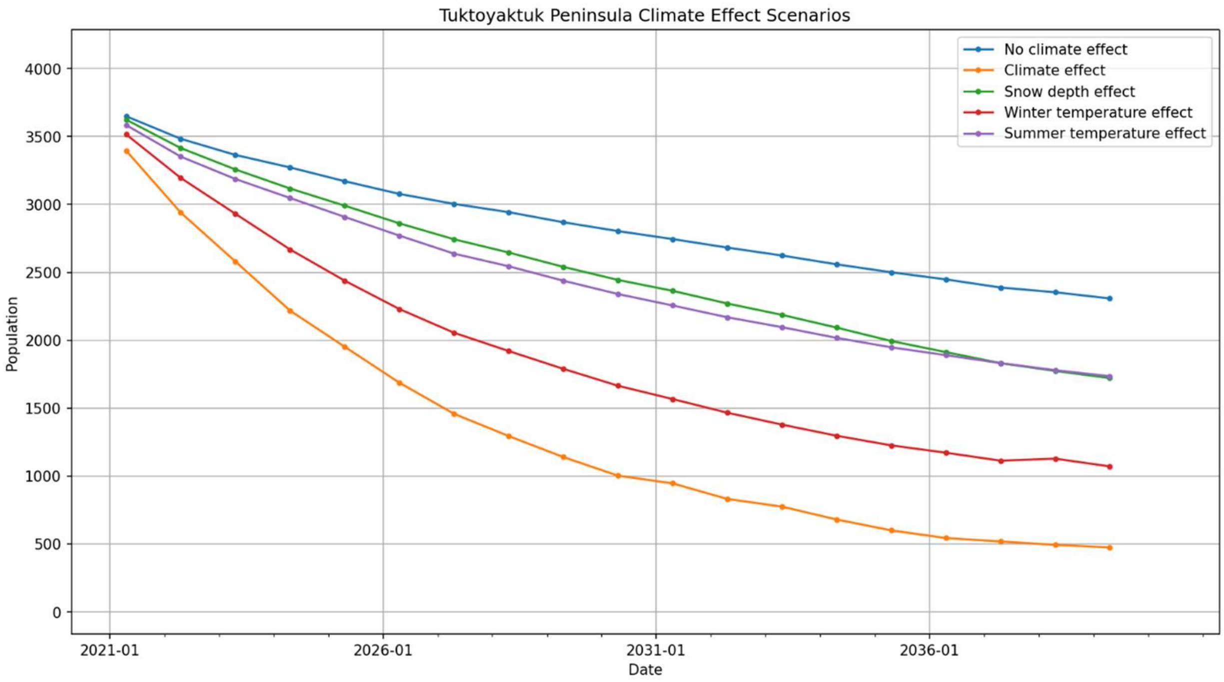

Figure A3-12. Response of the Tuktoyaktuk Peninsula caribou population to scenarios that differ with respect to the effect of climate on cow mortality. "No climate effect" does not incorporate climate impacts to cow mortality whereas "Climate effect" incorporates all three climate relationships with cow mortality (snow depth, winter temperature, summer temperature). The remaining scenarios apply each climate relationship separately.

Appendix 4 – CBGC ALCES Scenarios

The first table below identifies the names of Bathurst scenarios simulated using cbgc.alces-flow.com (i.e., as it appears in cbgc.alces-flow.com), the report figures within which each scenario appears, and a brief description of the scenario. All scenarios use the assumptions regarding initial population, fecundity rate, and mortality rates that are described in the report.

The second, third, and fourth tables identifies the names of scenarios simulated for other herds (Bluenose East, Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula) to explore impacts from habitat dynamics and harvest (Table A4-2), caribou encounters with permanent roads (Table A4-3), and climate effects to cow mortality (Table A4-4). Outcomes from the scenarios are summarised in Appendix 3.

Table A4- 1. Bathurst scenarios simulated using cbgc.alces-flow.com to generate outputs for the report.

Scenario name	Report figures	Description
Bathurst basecase 40yr	6, 7, 8, 9, 16, 17	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest.
Bathurst Beaupre no climate mortality	10	Same as basecase except natural cow mortality rates are those provided by Chloe Beaupre.
Bathurst Beaupre climate mortality	10	Same as basecase except climate change relationships (snow depth, winter temperature, summer temperature) with cow mortality are applied. Natural cow mortality rates are those provided by Chloe Beaupre.
Bathurst Beaupre snow effect	10	Same as basecase except snow depth relationship with cow mortality is applied. Natural cow mortality rates are those provided by Chloe Beaupre.
Bathurst Beaupre winter temp effect	10	Same as basecase except winter temperature relationship with cow mortality is applied. Natural cow mortality rates are those provided by Chloe Beaupre.
Bathurst Beaupre summer temp effect	10	Same as basecase except summer temperature relationship with cow mortality is applied. Natural cow mortality rates are those provided by Chloe Beaupre.
Bathurst ZOI 0 40yr	11	Same as basecase except habitat use within footprint zone of influence is 0%.
BA perm road encounter effect	12, 13, 14	Same as basecase except encounters with existing permanent roads affect birth rate and calf mortality.
BA LASR now perm road encounter effect	12, 13, 14	Same as basecase except birth rate and calf mortality is affected by encounters with existing permanent road and the proposed road consisting of the Lockhart, Slave Geological Province, and Gray Bay Port segments.
Bathurst harvest 300 male	15	Same as basecase except 300 males are harvested per year distributed between young adults and adults proportional to population distribution between the age classes.
Bathurst harvest 300 male femaile	15	Same as basecase except 300 males and females are harvested per year distributed between male and female young adults and adults proportional to population distribution between the sex and age classes.
Bathurst hr 10 0.05 40yr	16, 17	Same as basecase except a harvest rate of 5% is applied to young adults and adults within 10 km of roads.
Bathurst hr 10 0.01 40yr	16	Same as basecase except a harvest rate of 1% is applied to young adults and adults within 10 km of roads.
Bathurst hr 10 0.1 40yr	16	Same as basecase except a harvest rate of 10% is applied to young adults and adults within 10 km of roads.
Bathurst hr 25 0.05 40yr	17	Same as basecase except a harvest rate of 5% is applied to young adults and adults within 25 km of roads.
Bathurst hr 50 0.05 40yr	17	Same as basecase except a harvest rate of 5% is applied to young adults and adults within 50 km of roads.

Table A4- 2. Habitat and harvest scenarios for other herds (Bluenose East, Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula) simulated using cbgc.alces-flow.com.

Figure	Herd	Scenario name	Description
A3-1	Bluenose East	BNE basecase 40yr	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest.
		BNE ZOI 0 40yr	Same as basecase except habitat use within footprint zone of influence is 0%.
		BNE hr 10 0.05 40yr	Same as basecase except a harvest rate of 5% is applied to young adults and adults within 10 km of roads.
		BNE 10 0.5 40yr	Same as basecase except a harvest rate of 50% is applied to young adults and adults within 10 km of roads.
A3-2	Bluenose West	BNW basecase 40yr	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest.
		BNW ZOI 0 40yr	Same as basecase except habitat use within footprint zone of influence is 0%.
		BNW hr 10 0.05 40yr	Same as basecase except a harvest rate of 5% is applied to young adults and adults within 10 km of roads.
		BNW 10 0.5 40yr	Same as basecase except a harvest rate of 50% is applied to young adults and adults within 10 km of roads.
A3-3	Cape Bathurst	CBA dynamic habitat PCH rates	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest. Uses vital rate estimates for the Porcupine herd
		CBA ZOI 0 PCH rates	Same as basecase except habitat use within footprint zone of influence is 0%.
		CBA hr 10 0.05 PCH rates	Same as basecase except a harvest rate of 5% is applied to young adults and adults within 10 km of roads.
		CBA hr 10 0.5 PCH rates	Same as basecase except a harvest rate of 50% is applied to young adults and adults within 10 km of roads.
A3-4	Tuktoyaktuk Peninsula	Tuk Pen basecase 40yr	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest.
		Tuk Pen ZOI 0 40yr	Same as basecase except habitat use within footprint zone of influence is 0%.
		Tuk Pen hr 10 0.05 40yr	Same as basecase except a harvest rate of 5% is applied to young adults and adults within 10 km of roads.
		Tuk Pen 10 0.5 40yr	Same as basecase except a harvest rate of 50% is applied to young adults and adults within 10 km of roads.

Table A4- 3. Encounter effect scenarios for other herds (Bluenose East, Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula) simulated using cbgc.alces-flow.com.

Figure	Herd	Scenario name	Description
A3-5	Bluenose East	BNE basecase 40yr	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest.
		BNE LASR now perm road encounter effect	Same as basecase except birth rate and calf mortality rate is impact by caribou encounters with permanent road.
A3-6	Bluenose West	BNW basecase 40yr	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest.
		BNW perm road encounter effect	Same as basecase except birth rate and calf mortality rate is impact by caribou encounters with permanent road.
A3-7	Cape Bathurst	CBA dynamic habitat PCH rates	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest. Uses vital rate estimates from the Porcupine herd.
		CBA perm road encounter effect PCH rates	Same as basecase except birth rate and calf mortality rate is impact by caribou encounters with permanent road.
A3-8	Tuktoyaktuk Peninsula	Tuk Pen basecase 40yr	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No climate change effect on vital rates. No harvest.
		Tuk perm road encounter effect	Same as basecase except birth rate and calf mortality rate is impact by caribou encounters with permanent road.

Table A4- 4. Climate effect scenarios for other herds (Bluenose East, Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula) simulated using cbgc.alces-flow.com.

Figure	Herd	Scenario name	Description
A3-9	Bluenose East	BNE Beaupre no climate mortality	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No harvest. Uses cow mortality rates provided by Chloe Beaupre. No climate effect on cow mortality.
		BNE Beaupre climate mortality	Same as “BNE Beaupre no climate mortality” except cow mortality is impacted by snow depth, winter temperature, and summer temperature.
		BNE Beaupre snow depth mortality	Same as “BNE Beaupre no climate mortality” except cow mortality is impacted by snow depth.
		BNE Beaupre winter temp mortality	Same as “BNE Beaupre no climate mortality” except cow mortality is impacted by winter temperature.
		BNE Beaupre summer temp mortality	Same as “BNE Beaupre no climate mortality” except cow mortality is impacted by summer temperature.
A3-10	Bluenose West	BNW Beaupre no climate mortality	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No harvest. Uses cow mortality rates provided by Chloe Beaupre. No climate effect on cow mortality.
		BNW Beaupre climate mortality	Same as “BNW Beaupre no climate mortality” except cow mortality is impacted by snow depth, winter temperature, and summer temperature.
		BNW Beaupre snow depth mortality	Same as “BNW Beaupre no climate mortality” except cow mortality is impacted by snow depth.
		BNW Beaupre winter temp mortality	Same as “BNW Beaupre no climate mortality” except cow mortality is impacted by winter temperature.
		BNW Beaupre summer temp mortality	Same as “BNW Beaupre no climate mortality” except cow mortality is impacted by summer temperature.
A3-11	Cape Bathurst	CBA PCH & Beaupre rates no climate effect	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence effect on habitat use. No harvest. Vital rate estimates are from the Porcupine herd except uses cow mortality rates provided by Chloe Beaupre. No climate effect on cow mortality.
		CBA PCH & Beaupre rates no climate mortality	Same as “CBA PCH & Beaupre rates no climate effect” except cow mortality is impacted by snow depth, winter temperature, and summer temperature.
		CBA PCH & Beaupre rates snow depth mortality	Same as “CBA PCH & Beaupre rates no climate effect” except cow mortality is impacted by snow depth.
		CBA PCH & Beaupre rates winter temp mortality	Same as “CBA PCH & Beaupre rates no climate effect” except cow mortality is impacted by winter temperature.
		CBA PCH & Beaupre rates summer temp mortality	Same as “CBA PCH & Beaupre rates no climate effect” except cow mortality is impacted by summer temperature.
A3-12	Tuktoyaktuk Peninsula	Tuk Beaupre no climate mortality	Habitat changes in response to fire, climate change induced changes in land cover, and future land use. No zone of influence

			effect on habitat use. No harvest. Uses cow mortality rates provided by Chloe Beaupre. No climate effect on cow mortality.
		Tuk Beaupre climate mortality	Same as “Tuk Beaupre no climate mortality” except cow mortality is impacted by snow depth, winter temperature, and summer temperature.
		Tuk Beaupre snow depth mortality	Same as “Tuk Beaupre no climate mortality” except cow mortality is impacted by snow depth.
		Tuk Beaupre winter temp mortality	Same as “Tuk Beaupre no climate mortality” except cow mortality is impacted by winter temperature.
		Tuk Beaupre summer temp mortality	Same as “Tuk Beaupre no climate mortality” except cow mortality is impacted by summer temperature.