Bathurst Caribou Population Dynamics Model Inputs and Example Outputs

CBGC ALCES User Guide

March 2025

Contents

Introduction 3
CBGC ALCES Model Structure 3
Population Dynamic Model Inputs 4
Seasonal Ranges 4
Habitat 5
Initial Population Size and Composition 10
Fecundity 11
Mortality 12
Natural Mortality 12
Climatic Influences on Vital Rates 14
Spring parturition and fall snow depth 14
Cow survival and June temperature 15
Population Dynamics Model Outputs 16
Basecase scenario 16
Climate change impacts to vital rates 19
Footprint zone of influence 20
Total annual harvest 21
Harvest risk near footprint 22
References 25
Appendices 27
Appendix 1. Developing a land cover dataset for ALCES 27
Appendix 2 – Key model inputs for other caribou herds 29
Habitat coefficients 29
Maximum density in best habitat 31
Initial Population Size and Composition 32

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 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 approach for deriving these inputs are now described in turn for the Bathurst herd. We emphasize that our focus of initial input assumptions was to establish a working simulation model with plausible outputs and results. We envision next steps as an iterative process with the Working Group 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] as follows.

- spring migration: Apr 10 to May 27
- calving: May 28 to July 3
- summer: July 4 to September 6
- fall: September 7 to December 25
- winter: December 26 to April 9

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 in order 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

[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).

[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.

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[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)	-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)[ϒ]		0.95			1.00			1.00			0.98			1.00	

[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

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.

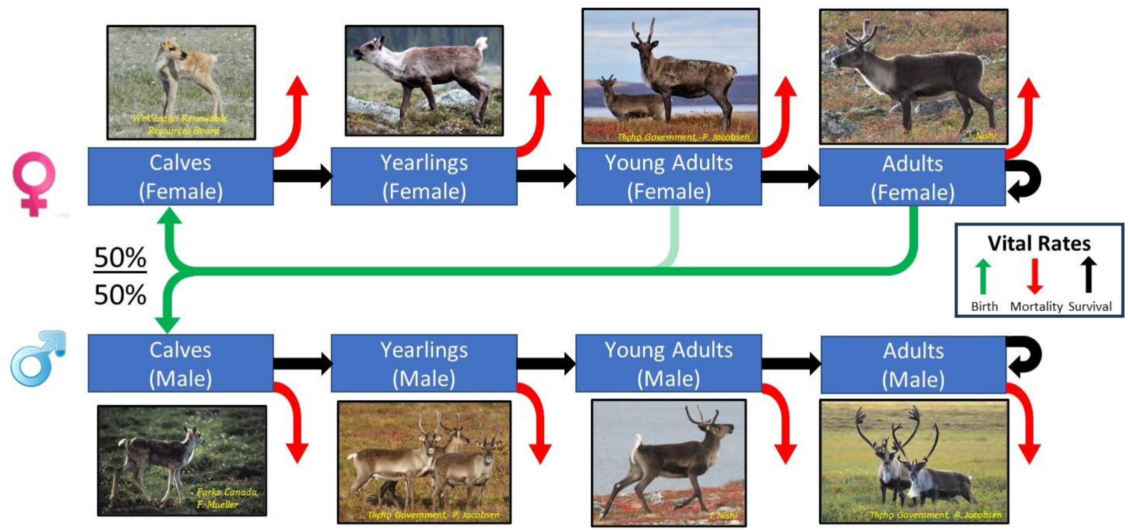

Figure 2. Basic structure of the wildlife population dynamics model.

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[vi]. A population simulation was completed to derive the initial age and sex composition expected given the assumed mortality and fecundity rates. In the simulation[vii], 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.

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

[vii] 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 CBGC ALCES model includes an option to adjust fecundity to represent the effect of projected fall snow depth. The relationship between fecundity and fall snow depth is described in the section Climatic Influences on Vital Rates.

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, whereas settings for density dependent mortality are fixed. 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[viii])	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

[viii] 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.

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[ix]. 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

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

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[x], 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.

Climatic Influences on Vital Rates

Following a workshop on “Climate and Barren-ground Caribou” in February 2021, D. Russell and A. Gunn (CircumArctic Rangifer Monitoring and Assessment – CARMA – Network) conducted additional analyses (*sensu* Russell and Gunn 2019) to identify potential key relationships between caribou vital rates and climate variables that may be simulated in CBGC ALCES.

Spring parturition and fall snow depth

Russell (pers. comm.) established a significant multi-herd correlation of spring parturition rate to preceding October snow depth. The strength of the relationship varied among herds, but if combined, it accounted for about 50% of the variability (Figure 3).

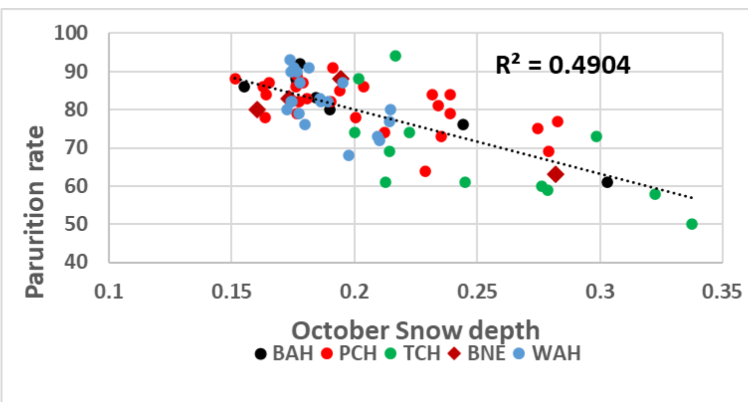

Figure 3. Relationship between spring parturition rate (%) in female caribou and average snow depth (m) during the preceding fall (October), where BAH = Bathurst herd; PCH = Porcupine herd; TCH = Teshukpuk herd; BNE = Bluenose East herd; and WAH = Western Arctic herd. Source: D. Russell, CircumArctic Rangifer Monitoring and Assessment (CARMA) Network, October 2021, Whitehorse, YK.

We applied the multi-herd parturition rate relationship with October snow depth based on the following formula:

*Parturition (%) = 113.37 – 166.93 * October snow depth (mean, m)*

[x] 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.

To apply the parturition relationship we used fall snow depth data instead of October snow depth because monthly data were not available[xi]. We used the snow depth projection for RCP 8.5, and converted it to change in fall snow depth by subtracting average fall snow depth in the 2010s from projected future fall snow depth. Change in fall snow depth was then multiplied by -166.93 (i.e., based on the parturition relationship) to determine the change in parturition in future years relative to the basecase assumption of 0.95.

Cow survival and June temperature

Russell (pers. comm.) suggested a relationship between cow survival and June temperature was informative based on Bathurst and Bluenose East datasets. *Calving and post-calving seasons are the most energetically demanding time for adult cows, especially for income breeders (low body reserves at calving and thus the need to rely on food intake to meet energy and protein demands). Favourable June climatic conditions thus would allow cows and their calves to enter the summer insect season in good condition.* Although the exact process of how June temperature affects cow survival is unclear, temperature is likely related to growing season and drought conditions, as well as insect harassment levels.

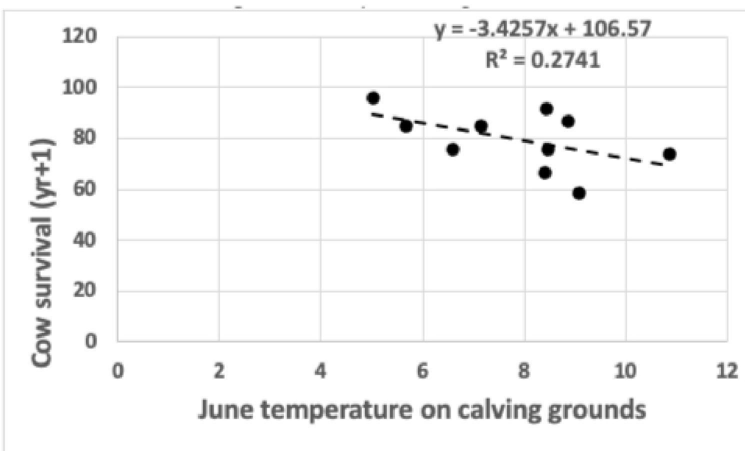

Figure 4. Relationship between cow survival rate and June temperature. Source: D. Russell, CircumArctic Rangifer Monitoring and Assessment (CARMA) Network, November 2021, Whitehorse, YK.

*Cow survival rate (%) = -3.4257 * June Temperature (°C) + 106.57*

To apply this relationship in CBGC ALCES, we used June temperature projection for RCP 8.5, and converted it to change in June temperature relative to current by subtracting average June temperature in the 2010s from the projected future June temperature. Change in June temperature was then multiplied by -3.4257 (i.e., based on the cow survival relationship) to determine the change in cow survival in future years relative to the basecase assumption of 0.825.

[xi] The source of the snow depth data was the Global climate model scenarios dataset available from Government of Canada (https://climate-change.canada.ca/climate-data/#/cmip5-data). That dataset is based on an ensemble of global climate model projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Its resolution is 1x1 lat/long degree.

Our approach of incorporating the relationships between fecundity and fall snow depth, and cow survival and June temperature was based on climate variables that were readily available. These relationships provide plausible ways of incorporating influence of climate on caribou and are a starting point for exploring implications of changing climate conditions through scenario analyses.

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.

Basecase scenario

The basecase scenario incorporates the effect of dynamic habitat in response to climate change and projected land use. 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[xii]. 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[xiii]. 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

[xii] 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.

[xiii] 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.

range, increase by 1.3% in the summer range, increase by 2.0% in the fall range, and increase by 1.7% in 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).

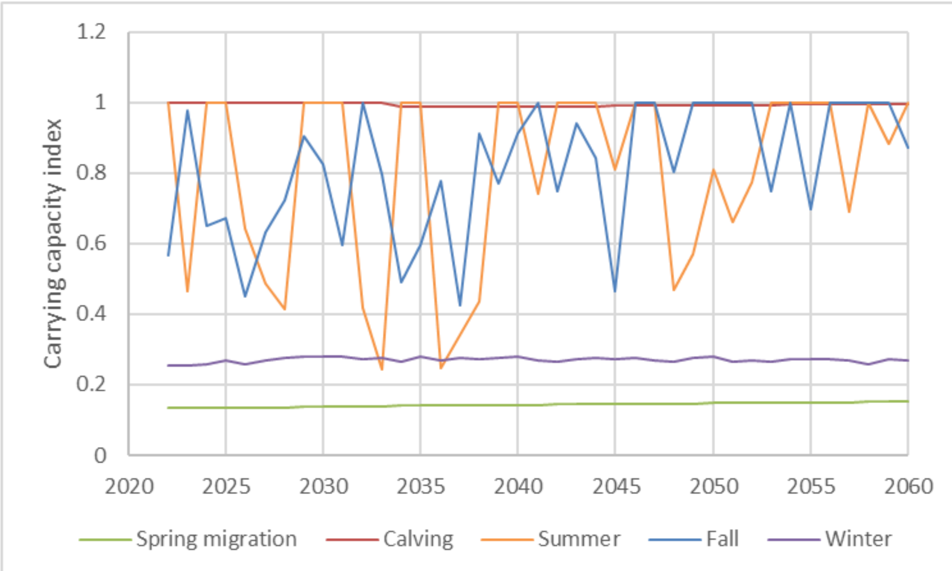

Figure 5. Response of a carrying capacity index to the basecase scenario. The carrying capacity index is calculated by dividing carrying capacity generated during the simulation by the maximum historical population (i.e., 128,000), such that value less than 1 indicates habitat below historical levels. 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.

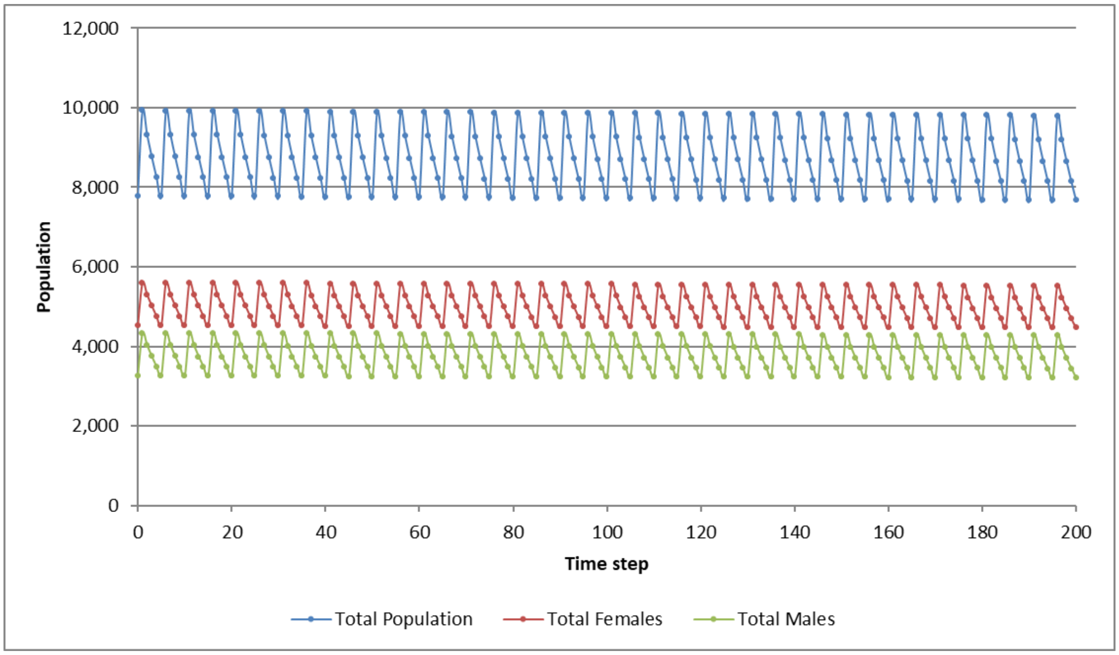

Figure 6. Response of Bathurst caribou population by sex to the basecase scenario. The x-axis refers to the seasonal time step. Each years consists of 5 seasons, such that a 40 year forecast has 200 time steps. The oscillations are caused by the population increasing in the calving season in response to births and then declining in the other seasons in response to deaths.

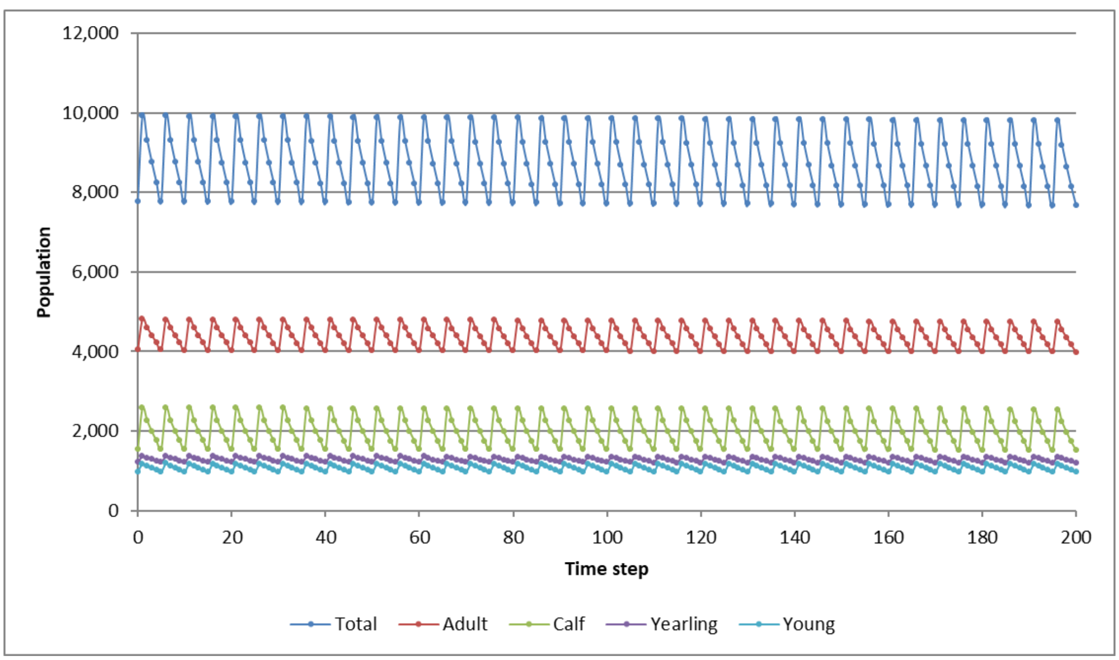

Figure 7. Response of Bathurst caribou population by age class to the basecase scenario. The x-axis refers to the seasonal time step. Each years consists of 5 seasons, such that a 40 year forecast has 200 time steps. The oscillations are caused by the population increasing in the calving season in response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

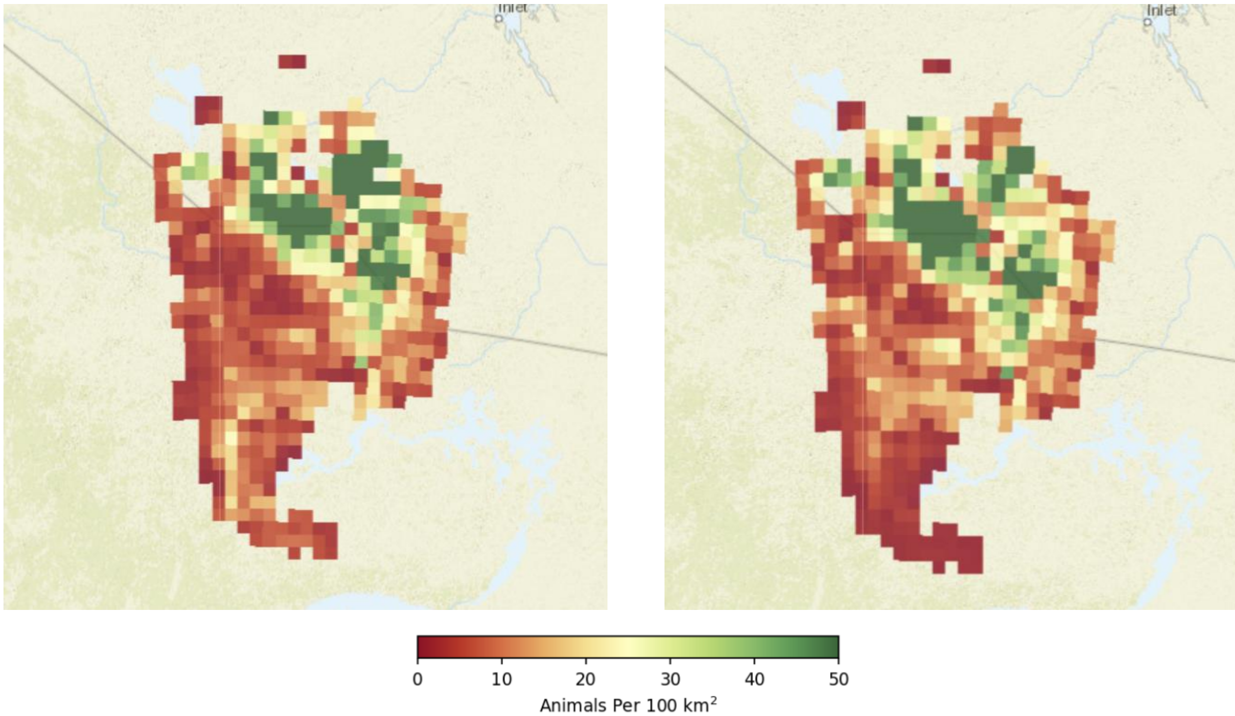

Figure 8. Modeled Bathurst caribou population density in the fall range in year 5 (left) and 15 (right) of the basecase scenario, to illustrate minor changes in the location of caribou in response to the effect of temporal climate variability on habitat.

Climate change impacts to vital rates

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 vital rates exhibited substantially higher sensitivity to climate change than was the case through habitat impacts alone. The primary driver was the response of cow mortality to June temperature, which exhibited a warming trend and, more importantly, occasional years with substantially elevated values. June temperature had a negative effect on cow mortality, such that the cow mortality rate increased substantially during years exhibiting high June temperature. Occasional periods of elevated cow mortality triggered a negative feedback loop whereby cow mortality (i.e., fewer cows) resulted in fewer offspring and rapid population decline. In comparison to the relationship between cow mortality and June temperature, fecundity was relatively insensitive to fall snow depth. The low sensitivity of the climate change and fecundity relationship was because the projected change in snow depth was relatively small.

Due to uncertainty associated with the underlying relationships, the effect of climate change on vital rates was not included in simulations assessing the effect of other drivers such as caribou harvest. However, 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.

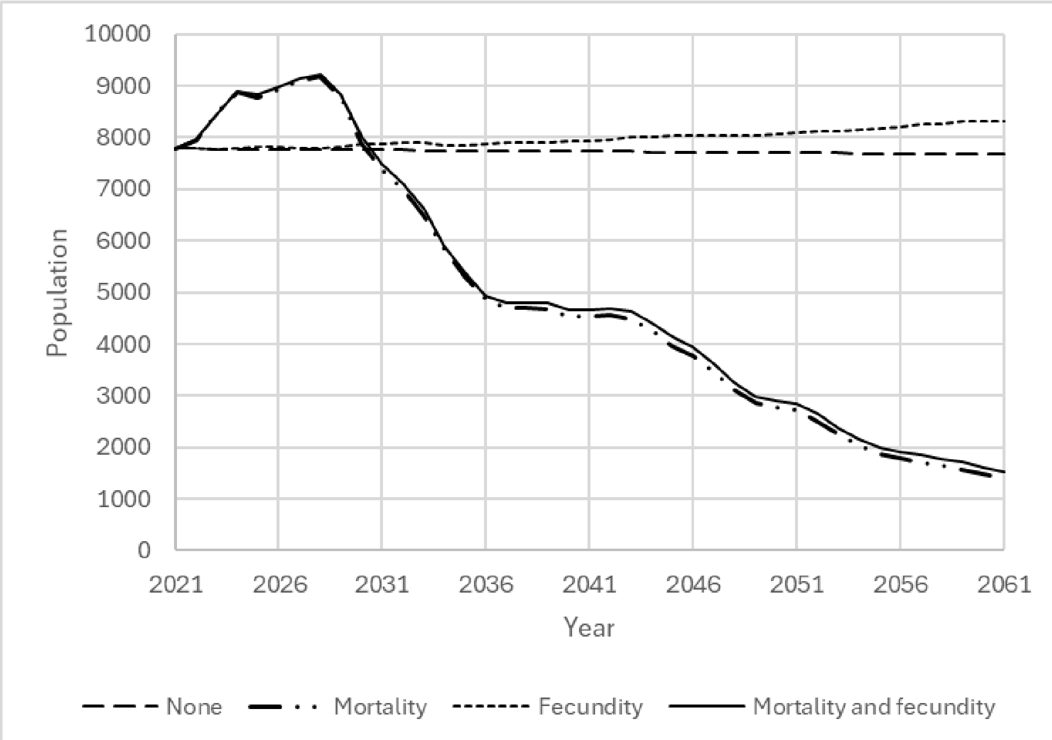

Figure 9. Response of the Bathurst caribou population to a scenarios that differ with respect to the effect of climate on vital rates. The scenarios are: no effect ('None'), effect on cow mortality ('Mortality'), effect on fecundity ('Fecundity'), and effect of both cow mortality and fecundity ('Mortality and fecundity').

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.

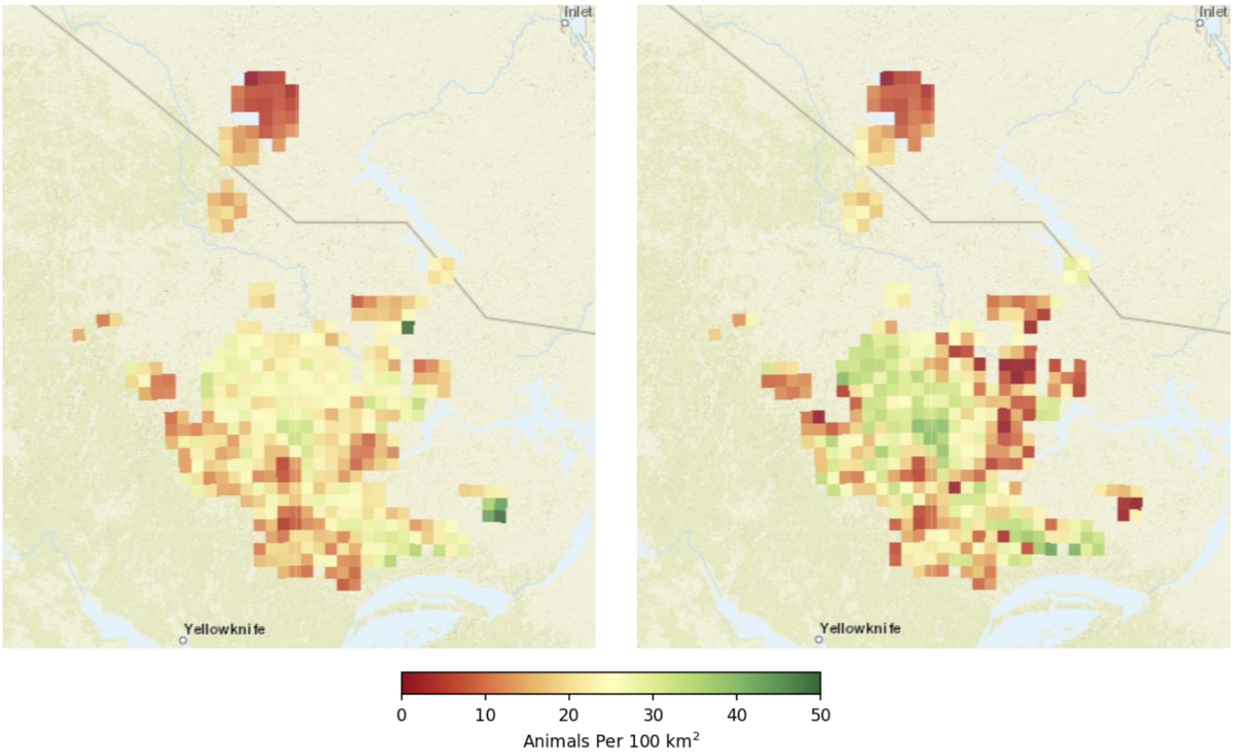

Figure 10. Modeled Bathurst caribou population density in the winter at the start of basecase scenario (left) and a scenario that assumed that habitat within the footprint zone of influence was not used (right). The zone of influence caused the location of caribou to shift to the west, away from footprint.

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[xiv]. When harvest was restricted to male caribou, the population declined over the first decade prior to stabilizing at around 6,500 animals. 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.

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

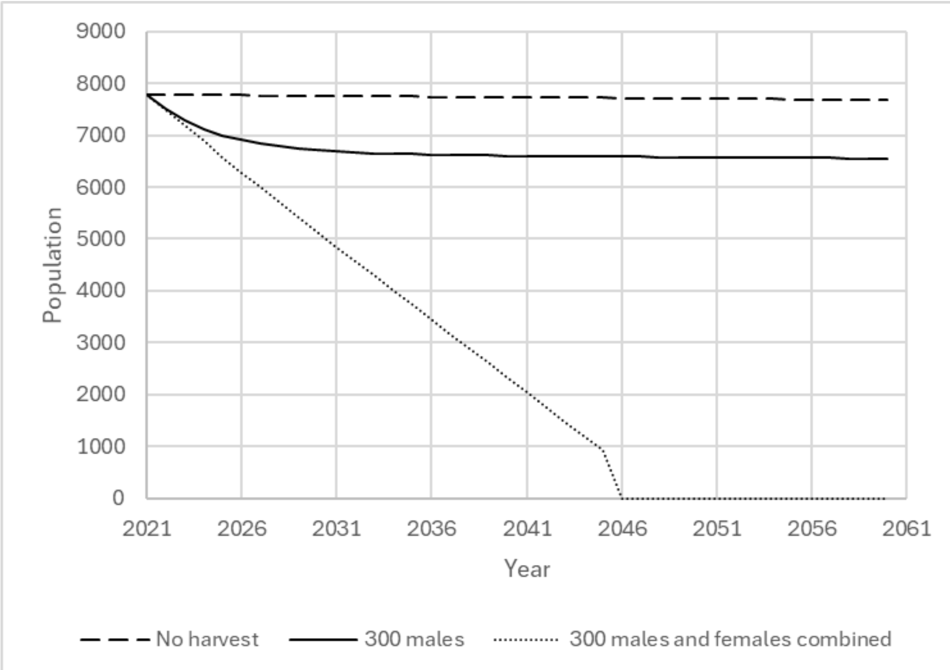

Figure 11. Response of the Bathurst caribou population to scenarios that differ with respect to the number of animals harvested.

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 in proximity to roads. In the case of winter roads[xv], harvest risk only occurred in the winter range. In the case of permanent roads, harvest risk occurred throughout the year. Due to the uncertainty associated with the magnitude of harvest risk and the distance from footprint within which harvest risk is elevated, a range of scenarios were simulated. The distance from footprints within which harvest risk was present was 25 km, 50 km, or 100 km, and the mortality rate in proximity to footprints was 2.5%, 5%, or 10%.

Harvest risk near roads caused mortality to increase, with negative consequences for the caribou population. When 5% harvest mortality of male and female adult caribou was applied within 50 km of roads, the population declined by 87% over 30 years to just over 1000 animals. 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 ranges accessible by road, especially in the non-winter seasons. With the

[xv] 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.

opening of the roads, the portion of range within 50 km of all season road increased from 0 to 81% in the spring season, 47% in the calving season, 94% in the summer season, and 87% in fall season.

Population outcomes were slightly more sensitive to the mortality rate in proximity to footprints than the distance from footprints within which harvest risk occurs (hereafter referred to the harvest buffer). This is the outcome of a complex temporal pattern in harvest mortality and its sensitivity to these parameters. During the first 15 years of the forecast, harvest only occurs in the winter season because the only type of roads present are winter roads. Winter roads are relatively abundant, such that the proportion of winter range within harvest buffers begins to plateau as the size of the buffer increases because the buffers begin to overlap. As a result, harvest during the 15 years is less sensitive to the size of the harvest buffer than it is to the harvest rate within the harvest buffer. In contrast, when the new roads are added (i.e., in 2035 and 2045), harvest in non-winter seasons is more sensitive to the size of the harvest buffers than it is to the harvest rate because overlap of buffers does not occur (i.e., because there is only a single all season road corridor). By 2035, however, the population has already declined by about 50% such that the absolute effect of harvest buffers in the later part of the scenario is diminished.

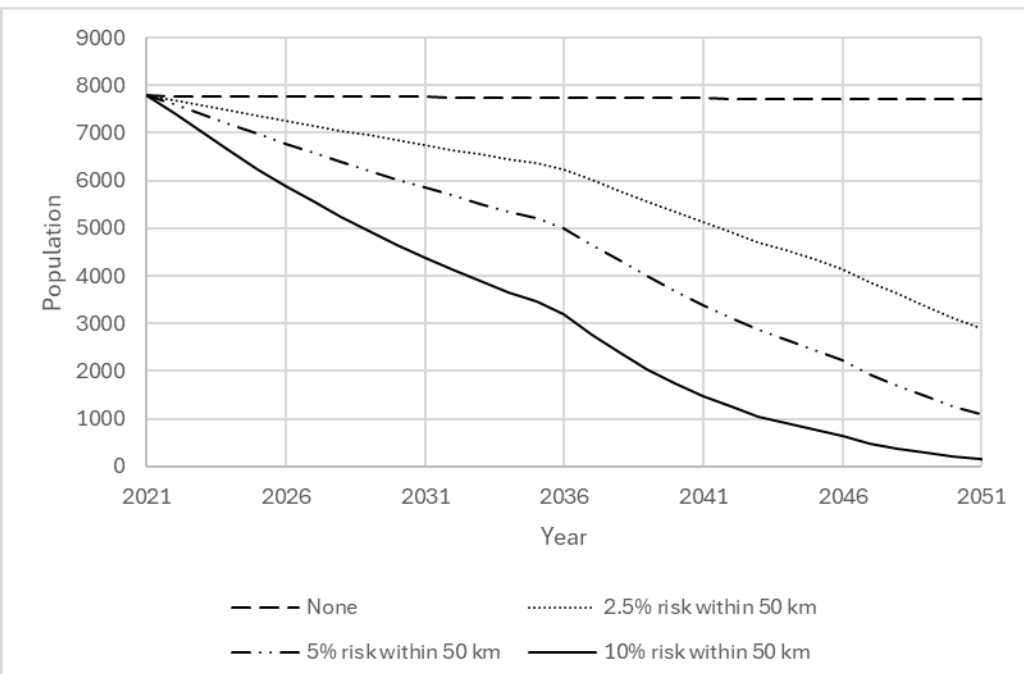

Figure 12. Response of the Bathurst caribou population to scenarios that differ with respect to the harvest rate within a 50 km buffer of roads. The harvest rate is only applied to winter roads in the winter range whereas the harvest rate if applied to permanent roads in all season.

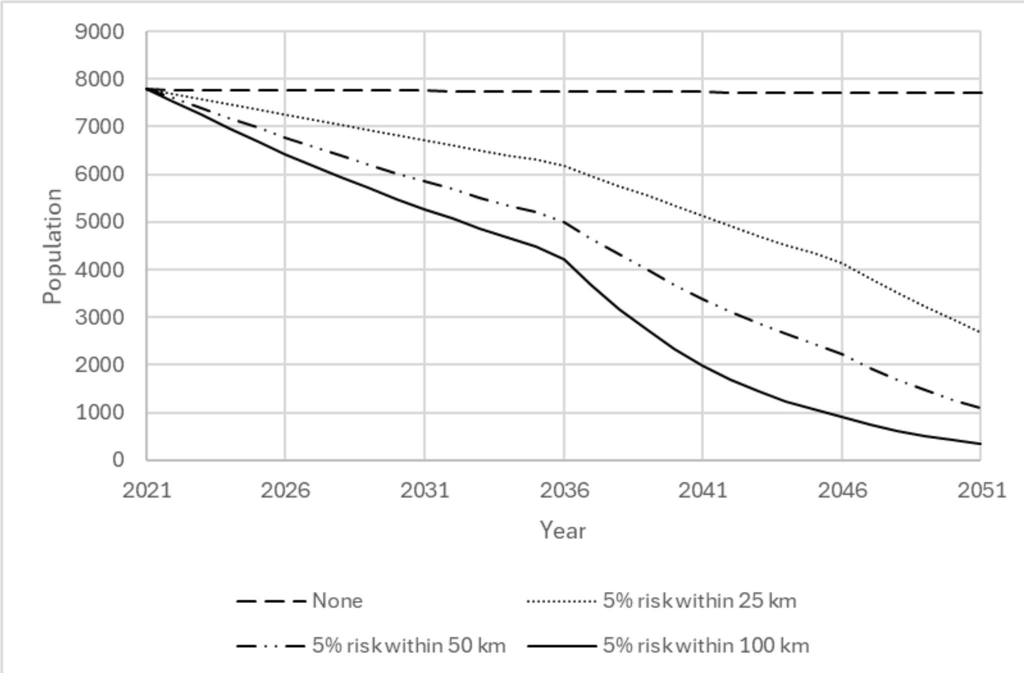

Figure 13. Response of the Bathurst caribou population to scenarios that differ with respect to distance from roads within which a 5% harvest mortality rate is applied.. The harvest rate is only applied to winter roads in the winter range whereas the harvest rate if applied to permanent roads in all season.

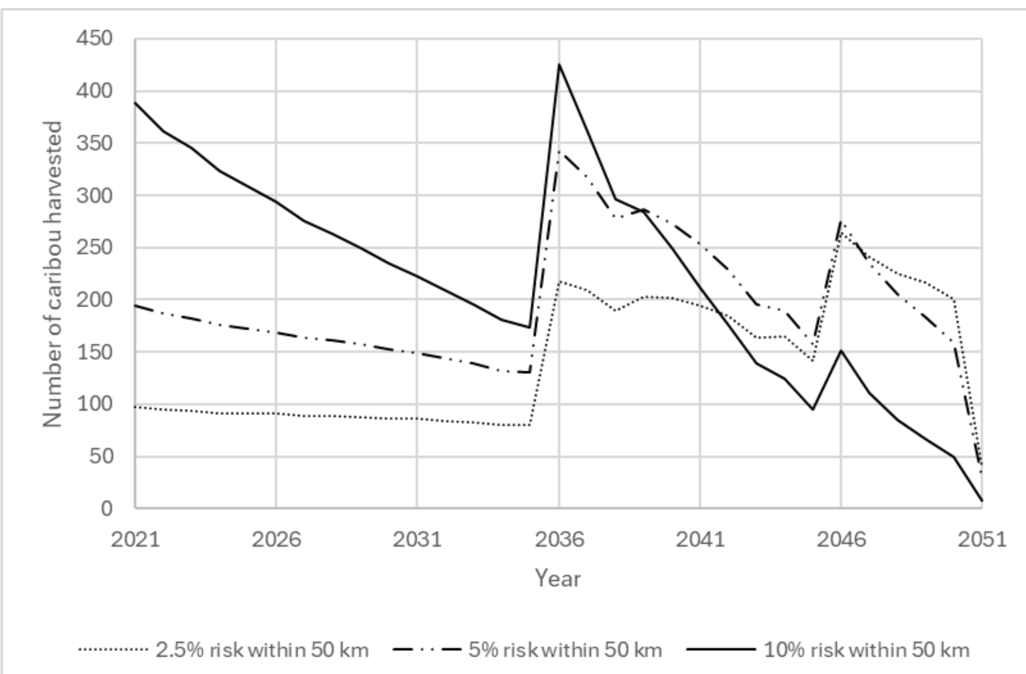

Figure 14. Response of the number of Bathurst caribou harvested to scenarios that differ with respect to the harvest rate within a 50 km buffer of roads. The harvest rate is only applied to winter roads in the winter range whereas the harvest rate if applied to permanent roads in all season.

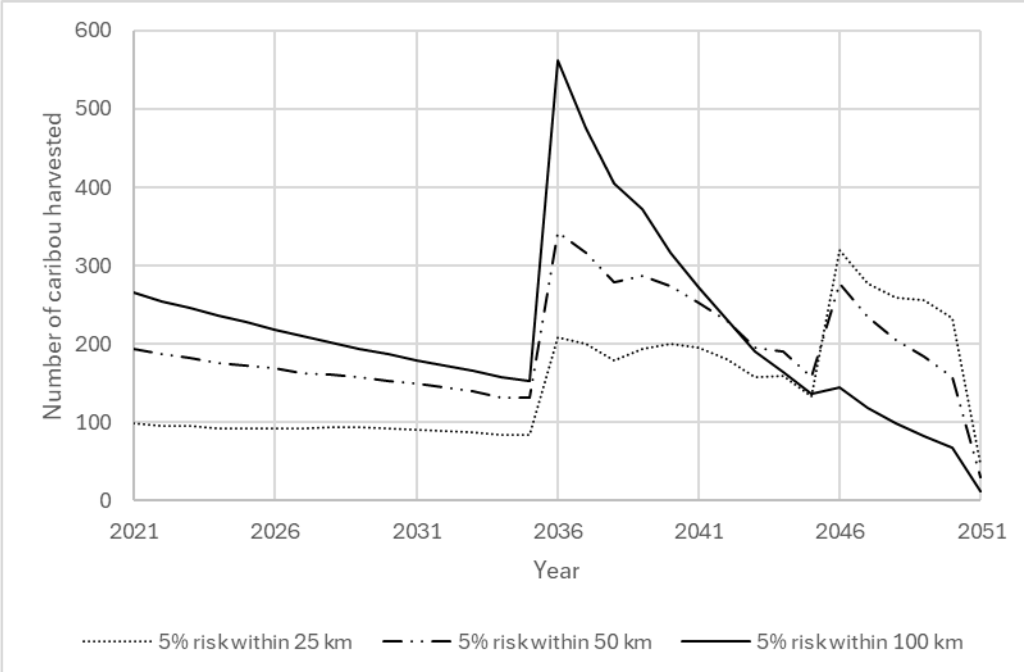

Figure 15. Response of the number of Bathurst caribou harvested to scenarios that differ with respect to distance from roads within which a 5% harvest mortality rate is applied. The harvest rate is only applied to winter roads in the winter range whereas the harvest rate if applied to permanent roads in all season.

References

Adamczewski, J. J. Williams, J. Boulanger, and C. Modeste-Burgin. 2024a. Fall 2023 composition surveys of Bathurst and Bluenose-east Barren-Ground Caribou Herds. Manuscript Report No. 328.

Adamczewski, J. J. Williams, and J. Boulanger. 2024b. March 2023 late-winter composition surveys of Bathurst, Bluenose-east and Beverly Barren-Ground Caribou Herds. Manuscript Report No. 318.

Beverly and Qamanirjuac Caribou Management Board (BQCMB). 1999. Protecting Beverly and Qamanirjuaq caribou and caribou range Part I: Background Information. Beverly and Qamanirjuaq Caribou Management Board, Ottawa, ON.

Boulanger, J. 2017. Exploration of harvest strategies for Bluenose-East caribou herd using post-calving based estimates of herd size in 2010. Manuscript Report No. 266, Government of the Northwest Territories, Yellowknife, NT.

DeCesare, N. J., M. Hebblewhite, M. Bradley, K. G. Smith, D. Hervieux, and L. Neufeld. 2012. Estimating ungulate recruitment and growth rates using age ratios. Journal of Wildlife Management 76:144-153.

Golder Associates Ltd. 2014. Jay Project – Developer's Assessment Report (DAR). Section 12. Barren-Ground Caribou. Prepared for Dominion Diamond Ekati Corporation. Submitted to Mackenzie Valley Environmental Impact Review Board, Nvember 2014.

Government of Northwest Territories (GNWT). 2018. Bathurst Caribou Range Plan, Supporting Report: Caribou Technical Information and Range Assessment. Department of Environment and Natural Resources, Government of the Northwest Territories. Yellowknife, NT.

Government of the Northwest Territories (GNWT). 2019. Bathurst Caribou Range Plan. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NT. Online [URL]: https://www.enr.gov.nt.ca/en/services/caribou-de-la-toundra/bathurst-caribou-range-plan

Mennell, R. 2021. Spatial and Temporal Trends in Range-use by the Bathurst Caribou During a Population Decline, 199-2019. MSc. Thesis. Queen's University.

Nagy, J. A. S. 2011. Use of space by caribou in northern Canada. Unpublished PhD Thesis. University of Alberta, Edmonton.

Porcupine Caribou Technical Committee (PCTC). 1993. Sensitive habitats of the Porcupine caribou herd. Report accepted by the International Porcupine Caribou Board from the Porcupine Caribou Technical Committee, Porcupine Caribou Management Board Whitehorse, YK.

Rempel, R.S., M. Carlson, A.R. Rodgers et al. 2021. Modeling cumulative effects of climate and development on moose, wolf, and caribou populations. Journal of Wildlife Management 85(7):1355-1376. Available online: https://wildlife.onlinelibrary.wiley.com/doi/full/10.1002/jwmg.22094.

Russell, D. E., and A. Gunn. 2019. Vulnerability analysis of the Porcupine Caribou Herd to potential development of the 1002 lands in the Arctic National Wildlife Refuge, Alaska. Report prepared for: Environment Yukon, Canadian Wildlife Service, and GNWT Department of Environment and Natural Resources, Whitehorse, Yukon.

Thomas, D. C., and H.P.L. Kiliaan. 1998. Fire-caribou relationships: (II) Fecundity and physical condition of the Beverly herd. Tech. Rep. Series No. 310. Canadian Wildlife Service, Prairie and Northern Region, Edmonton, Alberta. 96 pp.

Thomas, D. C., S. J. Barry, and H. P. Kiliaan. 1989. Fetal sex ratios in caribou: maternal age and condition effects. Journal of Wildlife Management 53:885-890.

Appendices

Appendix 1. Developing a land cover dataset for ALCES

We created a seamless and complete coverage for the large CEA Caribou study area in ALCES. Geospatial data sets were prepared as described below.

1. A unity data set was developed to provide proportional coverage of each cell in the study area by each land cover and human footprint type. Table A1-1 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.

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: National Burn Area Composite for fires between 1986 and 2019, the NWT fire history for fires prior to 1986 (1965 to 1985), and 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 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)[xvi]. Climate data include monthly and annual temperature (min, max, mean), precipitation, precipitation as snow, shortwave radiation, and evaporation, downscaled to 1 km^2.

The highest resolution 100 m x 100 m cell was the highest resolution available from ALCES Online. However, we used a coarser resolution during modeling, which was 1 km^2 for simulating landscape dynamics and 10 km^2 for simulating population dynamics.

[xvi] 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.

Table A1-1.

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

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. Input that did not differ from those used for the Bathurst herd include habitat zone of influence, fecundity, and 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$^{\Phi}$	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)	-3.582	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)$^{\Upsilon}$		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	

$^{\Phi}$ 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

† 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[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)	-3.216	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) [Υ]		0.93			0.88			0.90			1.00			1.00	

[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

Table A2-3. Seasonal resource selection function (RSF) model coefficients for the Cape Bathurst 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)	-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) [Υ]		0.87			0.72			0.92			0.99			0.89	

[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

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[17] and then by the average habitat index of the range (Table 2). 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).

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

[17] 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%.

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 4,912
- 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.