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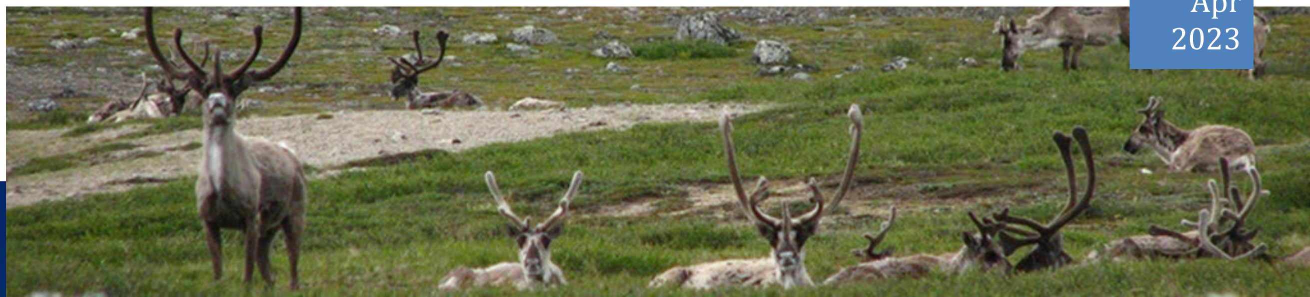

Cumulative Effects Assessment of Four Barren-ground Caribou Herds in the NWT

DRAFT Technical Methods for Barren-ground Caribou Scenario Analyses

Wildlife Management Advisory Council (NWT)

Gwich'in Renewable Resources Board

Wek'èezhìi Renewable Resources Board

Government of Northwest Territories / Gouvernement des Territoires du Nord-Ouest

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Table of Contents

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Acronyms

ACCWM	Advisory Committee for Cooperation on Wildlife Management
ALCES	A Landscape Cumulative Effects Simulator
CB	Cape Bathurst
BNE	Bluenose-East caribou
BNW	Bluenose-West caribou
CCP	Community Conservation Plan
DEWG	Délı̨nę ʔekwę́ Working Group
DGG	Délı̨nę Got'ı̨nę Government
ENR	Environment and Natural Resources, GNWT
GNWT	Government of the Northwest Territories
GRRB	Gwichin Renewable Resources Board
GSA	Gwich'in Settlement Area
HG	Headwater Group
HTC	Hunters and Trappers Committee
IK	Indigenous Knowledge
ISR	Inuvialuit Settlement Region
ITH	Inuvik-Tuktoyaktuk Highway
NU	Nunavut
NWT	Northwest Territories
NWT CIMP	Northwest Territories Cumulative Impact Monitoring Program
PopDyn	population dynamics
RRB	Renewable Resources Board
SARC	Species at Risk Committee
SRRB	Sahtú Renewable Resources Board; ʔehdzo Got'ı̨nę Gots'ę́ Nákedı
SSA	Sahtú Settlement Area
TAH	Total Allowable Harvest
TG	Tłı̨chǫ Government
TK	Traditional Knowledge
TP	Tuktoyaktuk Peninsula caribou
TRTI	Tłı̨chǫ Research and Training Institute
WMAC-NWT	Wildlife Management Advisory Council, NWT
WRRB	Wekèezhìı Renewable Resources Board

1. Introduction

As part of the ALCES Online[1] web application for cumulative effects assessment, the ALCES PopDyn model simulates wildlife 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 ALCES 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. Consequently, we customized ALCES PopDyn to address unique habitat and mortality risks associated within each of five seasons including 1) spring, 2) calving, 3) summer, 4) fall, and 5) winter. ALCES PopDyn includes five submodels that 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, the population output from the summer submodel is the population input for the fall submodel, and the fall submodel provides input into the winter submodel. The population output from the winter submodel is then the population input for the next year's spring submodel.

The computational steps that are used by ALCES PopDyn are summarized below to provide an overview of how the inputs are applied to simulate barren-ground caribou population dynamics. ALCES PopDyn's computation steps are:

1. The initial population dictates the starting point of the simulation in terms of the number of animals within each sex and age class. That population is distributed spatially based on spring migration habitat.
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 mortality.
3. The population migrates to the calving range and is distributed across cells based on habitat availability. 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.
4. 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.
5. The population remaining at the end of the calving season migrates to the summer range and is distributed across cells based on habitat availability.
6. 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.
7. The population remaining at the end of the summer season migrates to the fall range and is distributed across cells based on habitat availability.
8. 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.

[1] A training guide for ALCES Online is available at https://docs.google.com/document/d/11H3UJsEfG9DAtF45kgbyZ-Ak8nZDTuODJBmdnv59xoM/edit

9. The population remaining at the end of the fall season migrates to the winter range and is distributed across cells based on habitat availability.
10. 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.
11. 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.
12. 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.
13. Steps 2 through 12 are repeated for each year of the simulation. Habitat and vital rate relationships with land cover and climate are applied during the simulation to incorporate the effect of land use and climate change.

This document describes the rationale and initial assumptions that we used to populate the caribou model in ALCES PopDyn. The information required by ALCES PopDyn on each of these topics is first described and then the initial inputs we used for the Bluenose-East herd are presented. Key model inputs include seasonal ranges, initial population size and composition, habitat, fecundity, and mortality.

We emphasize that our initial focus on input assumptions was to establish a working simulation model in ALCES Online with plausible outputs; our goal in this initial stage of the project was not to generate "predictive" scenario results and outputs.

Thus, in lieu of a formal Results / Discussion section in this report, we provide two brief case studies to show: a) how ALCES Online simulates interactions and influences of changing landscape and climate conditions on caribou and habitat (Case Study 1.), and b) how ALCES PopDyn may be used to assess sensitivities to vital rate input assumptions and conduct comparative analyses that are based on scenarios for changing landscape and climate conditions (Case Study 2.).

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 herd-specific scenarios to explore and address specific issues and questions.

2. Seasonal Ranges

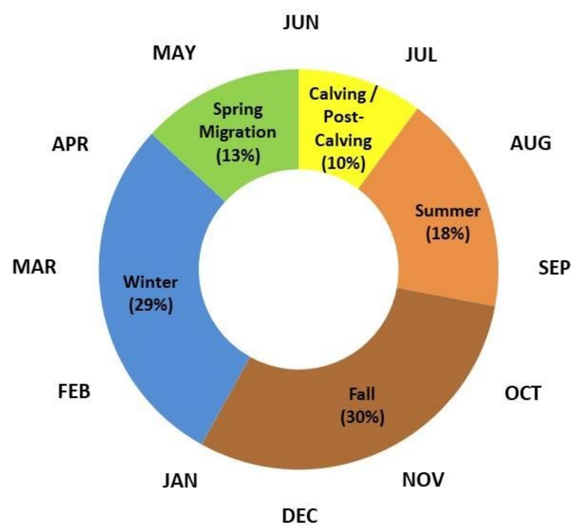
A year in the life of migratory barren-ground caribou may be broken into different activity periods that are based on seasonal environmental changes as well as the life-history strategies of caribou that reflect their seasonal reproductive biology, behavior, migratory and range use patterns (PCTC 1993, 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 (as highlighted above).

2.1. Seasonal Range Information Required by ALCES PopDyn

The Working Group recommended five (5) seasons for simulating barren-ground caribou dynamics within an annual cycle. These five seasons were established by aggregating 12 activity periods defined by Nagy (2011)[2] and are shown for the Bluenose-East herd in Figure 1. ALCES PopDyn requires spatial range maps identifying the location of each seasonal range.

2.2. Proposed Seasonal Range Inputs

Figure 2 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. 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 of the herd's seasonal ranges (see next section on Habitat).



a) Five caribou seasons within a year

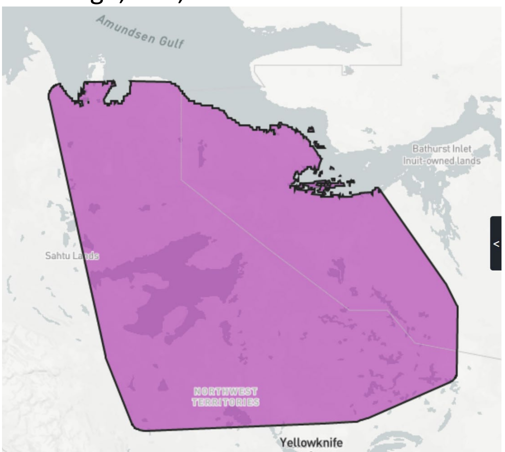
- Spring: 10 Apr – 27 May
- Calving (& post-calving): 28 May – 3 Jul
- Summer: 4 Jul – 6 Sep
- Fall: 7 Sep – 25 Dec
- Winter: 26 Dec – 9 Apr

b) Dates used to define caribou seasons

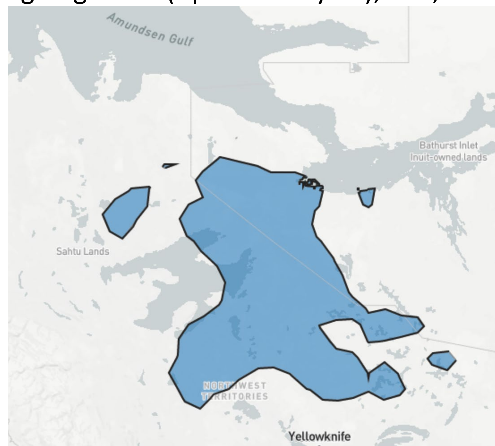
Figure 1. (a) Five caribou seasons to assess seasonal resource selection by Bluenose-East caribou with corresponding (b) dates used to define seasons (following Nagy 2011). The same approach was used to define five seasons and seasonal ranges for the other caribou herds – Bluenose West, Cape Bathurst, and Tuktoyaktuk Peninsula.

[2] Using geospatial data from collared female caribou, Nagy et al. (2005) grouped location data of the BNE herd (1993-2004) into 8 seasons and defined seasonal and cumulative ranges accordingly. In a subsequent analysis of collar data (1996-2008), Nagy (2011) identified 12 activity periods for seven migratory barren-ground caribou herds – including the BNE herd – and showed there were significant differences in daily movement rates by collared female caribou between activity periods.

Annual Range; 474,708 km^2

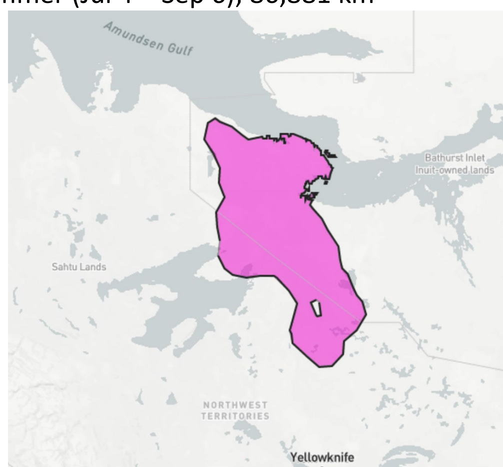


Spring Migration (Apr 10 - May 27); 178,413 km^2

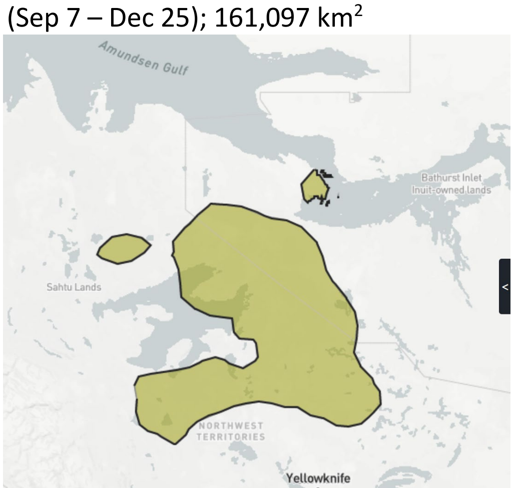


Calving (May 28 – Jul 3); 39,605 km^2

Summer (Jul 4 – Sep 6); 86,881 km^2



Fall (Sep 7 – Dec 25); 161,097 km^2



Winter (Dec 26 – Apr 9); 158,964 km^2

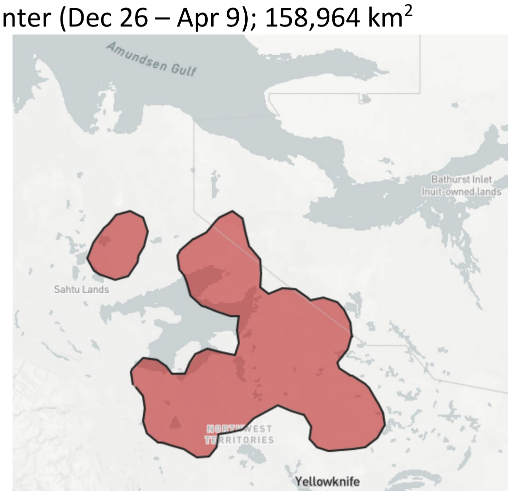


Figure 2. Annual (minimum convex polygon) and five seasonal ranges (utilization distributions) of the Bluenose East caribou herd derived from collared female caribou locations (1993-2009); range maps developed by Caslys Consulting Ltd., Saanichton, BC.

3. Habitat

3.1. Habitat Information Required by PopDyn

For each season, a habitat relationship is required 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 a cell's population (N) is low relative to its carrying capacity (i.e., N/K is low), the population is likely to increase based on elevated fecundity or immigration. When N/K is high (near or above 1) then the cell density is likely to decline because of reduced reproductive rates or dispersal loss of individuals to surrounding cells that have a lower N/K ratio. The user must specify whether yearlings should be included when calculating the N/K ratio. In the case of barren-ground caribou, yearlings were included when calculating N/K because maximum density estimates included yearlings.

The habitat relationship should produce values ranging from 0 to 1, with 1 indicating conditions that support maximum caribou density. The relationship should incorporate landscape variables that are available in ALCES Online or that can be imported. Ideally, at least some of the covariates should be affected by land use and climate scenarios (e.g., footprint, temperature, forest age). Maximum caribou density (#/km2) must also be provided for each range.

3.2. Proposed Habitat Inputs

Seasonal habitat indices were prepared using resource selection functions (RSFs) developed collaboratively with the Alberta Biodiversity Monitoring Institute (ABMI) (C. DeMars pers. comm.) across the annual range of the Bluenose-East herd. RSF coefficients were similarly developed for Bluenose-West, Cape-Bathurst, and Tuktoyaktuk-Peninsula caribou herds. The RSF analyses used a model step selection process to derive models using GNWT's comprehensive caribou collar telemetry dataset (2005 – 2020) and a comprehensive study area basemap in ALCES Online. The study area basemap included human footprint data[3] for the Northwest Territories[4] and Nunavut, natural land cover types (Land Cover Classification of Canada *circa* 2015[5]), and other key spatial attributes including forest age, topography (slope, aspect, and elevation), and climatic characteristics (temperature, precipitation, potential evaporation). Models were fit using a 1 km^2 resolution, with the exception of polygonal and linear footprints which were summarized using a 10 km moving window. The resulting RSF models achieved

[3] Winter road and exploration footprint overlapping with water was excluded when fitting models with the exception of winter road footprint for the winter seasonal RSF model.
[4] 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
[5] https://open.canada.ca/data/en/dataset/4e615eae-b90c-420b-adee-2ca35896caf6

high fit, with Spearman's correlation coefficients[6] of 0.99 or higher and k-fold cross-validation[7] statistics of 0.95 or higher. The resulting RSF coefficients (Table 1) were applied to land cover data in ALCES Online to calculate RSF values for each seasonal utilization distribution within the Bluenose East herd range at a 1 km^2 cell resolution. RSF values were transformed to a 0 to 1 habitat index by taking the exponential and performing linear stretch using minimum and maximum values based on current landscape and climate values. Minimum and maximum values were calculated for the overlapping portion of the seasonal utilization distribution and minimum convex polygon.

Each cell's carrying capacity equals its habitat index multiplied by seasonal maximum densities. Seasonal maximum densities were derived by dividing the maximum observed population (~120,000 in 2010[8]) by the size of the all season MCP-based range (475,652 km^2) and then by the average habitat index of the range according to current land cover and climate (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., selection probability equal to 1).

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[6] The Spearman's correlation coefficient measures the correlation between RSF predictions and caribou use (as represented by the caribou GPS locations). To do so, the predicted RSF values for the study area (as represented by the random points) are partitioned into 10 bins of equal area, with the 10th bin having the highest RSF values and therefore representing the areas showing the strongest selection by caribou. Predictive performance is then measured by assessing the correlation between bin rank and the proportion of caribou locations falling within each bin. A good performing model should show that as bin rank increases, the number of caribou locations within bins should progressively increase. The correlation is measured by Spearman's correlation coefficient and coefficients >0.90 indicate excellent model performance.

[7] k-fold cross-validation involves estimating the model with a subsample of caribou then testing the model's predictive performance on the withheld caribou).

[8] A maximum density of 120,000 is assumed based on a maximum historical population estimate of 121,702 ± 15,934 95% CI 1+ year-old caribou according to the 2010 post-calving photo-survey with Rivest estimator (Boulanger et al. 2018).

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

Variable[Φ]	Spring Migration			Calving			Summer			Fall			Winter		
	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 2. Maximum density of 1+ year-old Bluenose East caribou in best habitat as calculated by dividing the highest recorded population (120,000) by range area and average habitat index (i.e., selection probability).

Season	Population density (caribou/km^2)	Average selection probability	Max density in best habitat (caribou/km^2)
Spring Migration	0.2523	0.1102	2.2893
Calving	0.2523	0.0062	40.6912
Summer	0.2523	0.0341	7.3984
Fall	0.2523	0.0622	4.0560
Winter	0.2523	0.0498	5.0660

4. Initial Population Size and Composition

4.1. Initial Population Size and Composition Information Required by PopDyn

To initialize the model, the number of animals within each sex and age class must be provided. The initial population is then distributed spatially in the spring range based on the spring range habitat layer.

4.2. Proposed Initial Population Size and Composition Inputs

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 in to four age classes to reflect the types of empirical data that biologists regularly collect to monitor status and trend of caribou herds. With this structure in mind, we summarize initial input parameters needed for the simulation model including population size, sex and age class composition, and estimates of vital rates.

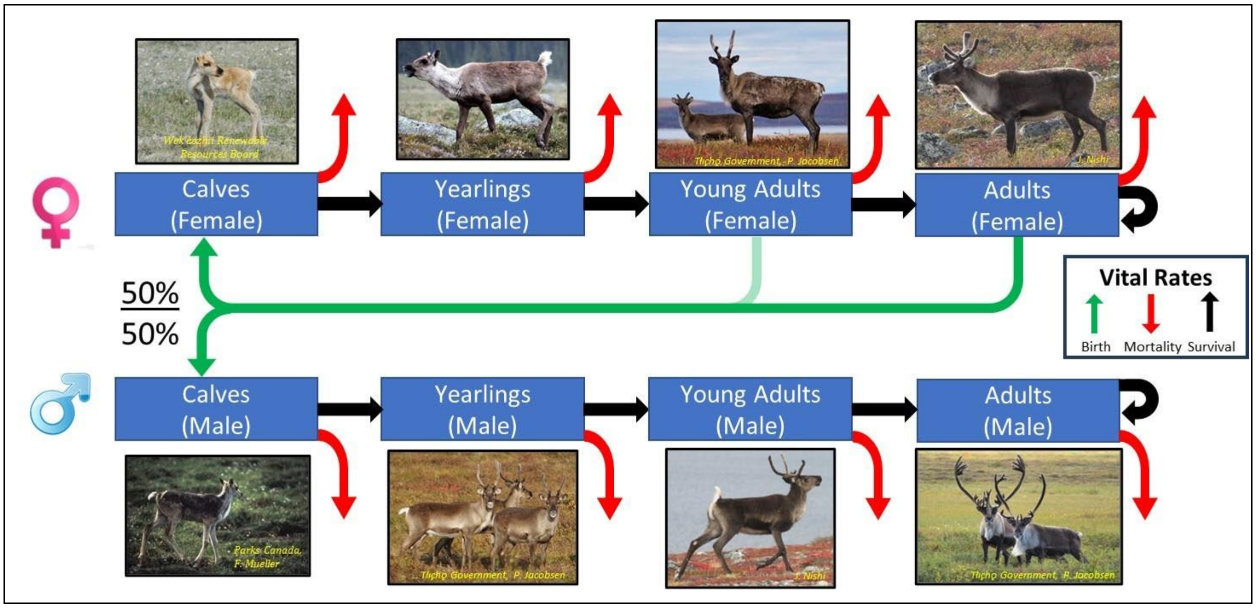


Figure 3. Basic structure of the wildlife population dynamics model

An initial non-calf population of 23,000 was used based on the 2021 calving photo-survey population estimate of 23,202 +/- 3,977 95% CI (Boulanger et al. 2022). We used Boulanger's (2017) initial model estimates to generate a stable age class distribution for Bluenose East that was applied to population estimates to derive the initial composition of female and male yearlings and adults (Table 3). The resulting adult sex ratio was 54 bulls per 100 cows, which is intermediate between that observed between 2009 and 2019 (35 - 43) and that observed in 2020 and 2021 (63.3 and 68.7 bulls per 100 cows; Adamczewski et al. 2022, and see Figure 4). The initial calf population was estimated based on 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. An even sex ratio for calves was applied, which is consistent with results from field studies of the Beverly herd[9].

[9] For barren-ground caribou in the Beverly herd (1980-1987, n=421), Thomas et al. (1989) found that sex ratio of calves varies with maternal age where young mothers (1.5 – 4 yr) produced more female fetuses than males (64 M : 100 F), and older (>10 yr) cows produced more males than females (207 M : 100 F). Although adult female age class structure may influence fetal sex ratio, Thomas et al. (1989) found that the overall fetal ratio was roughly equal across all four age groups of breeding females. In the absence of empirical data to suggest otherwise, we assumed a balanced sex ratio of caribou calves.

Table 3. Derived estimates for a stable age class distribution

Age Class	Proportion of Population		Sum
	Female	Male	
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.

5. Fecundity

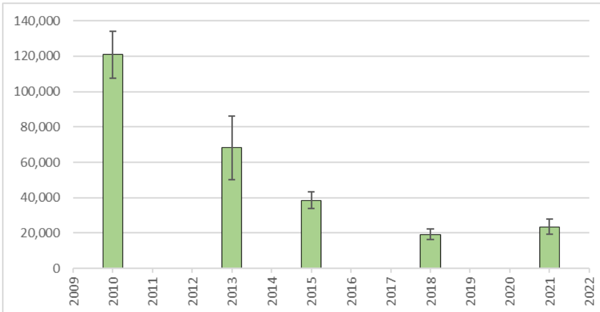
5.1. Fecundity Information Required by PopDyn

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). The fecundity rate can be entered as a constant or as a relationship such that it is a derivative of landscape conditions (e.g., anthropogenic footprint, climate). If a relationship is used, the relationship need not be tied to conditions within the calving range. For example, climate during the previous summer/fall and/or winter may be an important determinant of fecundity due to the effect of climate on body condition by way of processes such as forage availability and insect harassment.

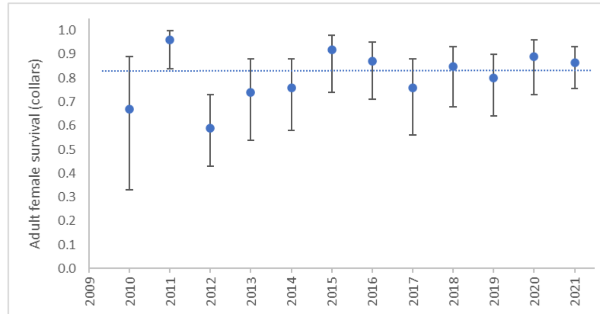
Although density dependent fecundity is available in PopDyn, it is not recommended when using seasonal models due to a limitation with how density dependent fecundity is modeled in that context. PopDyn currently requires that density dependent fecundity be calculated based solely on N/K occurring during the calving season, as opposed to integrating N/K across seasons. An implication of this limitation is that density dependent fecundity would be overly influenced by calving season habitat.

5.2. Proposed Fecundity Inputs

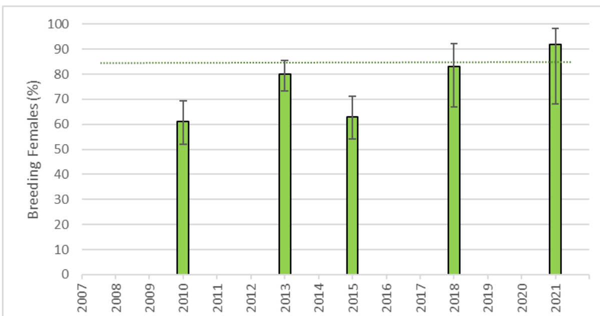
Figure 3 illustrates trends in data from March late winter and June calving composition surveys for the Bluenose East herd (2008-2021). Late-winter composition surveys provide an estimate of recruitment (i.e., survival) of calves to yearlings, with an upward trend in recent calf to cow ratios suggesting good recruitment in 2019-2022 (Adamczewski et al. 2023). June composition surveys are conducted on the calving grounds at the peak of calving (or shortly thereafter). The observed proportion of breeding cows to total cows in the survey area is likely a representative estimate of pregnancy rate assuming that breeding females are classified correctly and there has been sufficient survey coverage to sample all cows on the calving ground (Adamczewski et al. 2019).



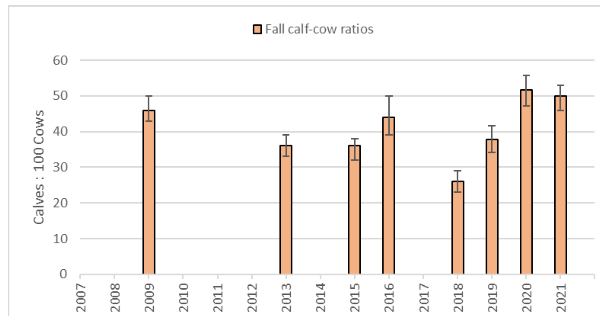
a) Herd estimates of Bluenose-East (2+ year old-caribou) from calving-ground photographic surveys



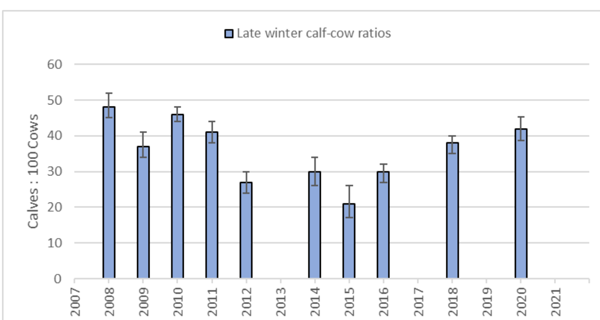
b) Annual survival estimates for collared adult female caribou (dashed line at 0.825)



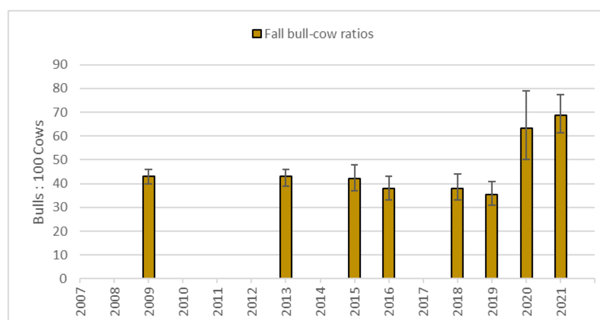
c) Percentage of adult cows that are breeding females in June on the calving grounds (dashed line at 0.85)



d) Calf to cow ratios in fall (October) composition surveys



e) Calf to cow ratios in late winter (March) composition surveys



f) Bull to cow ratios in fall (October) composition surveys

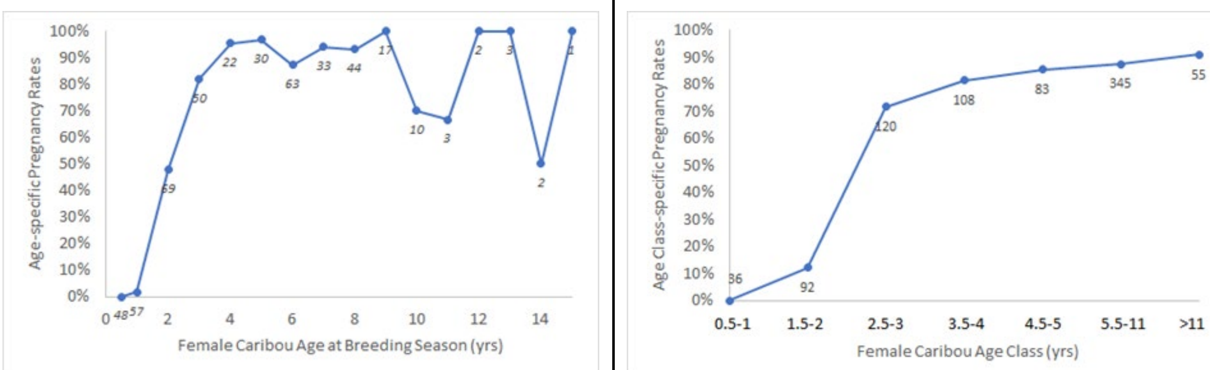
Figure 4. Trends in demographic indicators for Bluenose East caribou herd (2008-2021). Data provided by J. Adamczewski, Wildlife Division, GNWT; and see key references Adamczewski et al. 2014, 2022, 2023, and Boulanger et al. 2014, 2016, 2022.

We assumed a fecundity rate of 0.95 for mature adults (3 years and older) based on the average pregnancy rate used by Boulanger (2017) for Bluenose East (Table 4). We also explored sensitivity of simulation outcomes to the low pregnancy rate (0.83) from Boulanger (2017). A pregnancy rate of 0.15

was applied to young adults (2-year-old) based on fecundity rates for the Beverly herd and Qaminirjuaq population which were substantially lower for 2 year olds than for older age classes (Figure 4)

Table 4. 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



a) Age-specific pregnancy rates of females collected from the Qaminirjuaq population during or shortly after the 1966, 1967, and 1968 gestation periods (Source: Dauphine 1976; sample sizes shown as labels by data points)

b) Fecundity of age classes of female caribou sampled from the Beverly herd from 1979-80 through 1986-87 (Source: Thomas and Killian 1988; sample sizes shown as labels by data points)

Figure 5. Age related pregnancy (fecundity) rates for (a) Qaminirjuaq and (b) Beverly barren-ground caribou.

6. Mortality

6.1. Mortality Information Required by ALCES PopDyn

Mortality is defined as the proportion of animals that die each year. Multiple mortality types can be defined to incorporate the various sources of mortality that wildlife populations are subjected to such as predation, other sources of natural mortality (e.g., disease, old age), subsistence harvest, and recreational harvest. Mortality types are applied additively. For each type of mortality, rates can differ by sex and age class. A mortality rate can be set to be constant over space and time, or as a derivative of one or more other factors so that mortality changes over space and time in response to attributes such as roads and climate. Mortality types and rates can differ by season. When defining seasonal mortality rates, it is important to remember that mortality will be additive across seasons. For example, if a predation mortality rate of 0.1 (i.e., 10%) is set for each seasonal model, the annual predation mortality rate will be the sum of the seasonal rates which is 0.5 (i.e., 50%).

Mortality may 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). As with other mortality types, density dependent mortality is additive to other sources of mortality.

6.2. Proposed Mortality Inputs

As described above in our proposed approach for evaluating fecundity input values, we used input values for the Bluenose East herd outlined by Boulanger (2017) for survival (i.e., mortality rate = 1 - survival rate) to calibrate the population model (see Table 5 below). As per Boulanger (2017), a maximum age threshold (i.e., old age mortality) was not applied so that natural mortality did not exceed the rates described above.

Table 5. Initial input assumptions for survival and mortality (sensu Boulanger 2017)

Parameter	**Estimate**
Adult female survival (no old age mortality)	0.82 – 0.88 (basecase = 0.825)
Adult male survival (no old age mortality)	0.72
Yearling survival	0.86
Calf survival	0.22 – 0.60 (basecase = 0.40)

For additional context and based on an empirical relationship between adult cow mortality and population trend (Figure 5), we can infer that a cow mortality rate of ~17.5% (which equates to a survival rate of 82.5%) would 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).

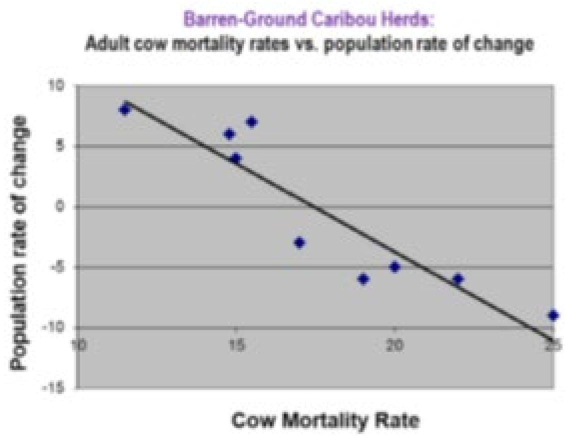


Figure 6. Empirical relationship between caribou adult cow survival rates and population rate of change (Figure 2 in Boulanger and Adamczewski 2016; p.4, courtesy of Don Russell, coordinator, CARMA Network, personal communication).

Total harvest is uncertain. In the absence of detailed information, we assumed that harvest is 50% of TAH and is limited to bulls. TAH for Bluenose East is 393. 50% TAH is therefore 197 bulls, which results in a harvest rate of 0.024 for bulls based on the estimated initial bull population. This harvest rate assumption is like that adopted by Boulanger (2022) for post-2018 (1 to 3%). We also explored the sensitivity of simulated population dynamics to a bull harvest rate of 0.048 (i.e., TAH), which is within the range adopted by Boulanger (2022) for pre-2018.

We do not know of empirical estimates of density dependent mortality. We followed Rempel et al.'s (2020) assumptions for density dependent mortality for boreal caribou initiating density dependent mortality at N/K=0.6 and reaching a maximum rate of 0.1 at carrying capacity. To avoid excessive density dependent mortality, the maximum rate of 0.1 was divided by 5 such that each season's maximum rate was 0.02. An implication is that density dependent mortality will not reach the maximum rate (0.1) if only some seasonal ranges are a carrying capacity.

7. Climatic Influences on Vital Rates

Following a Working Group sponsored 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 ALCES Online.

7.1. 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 7).

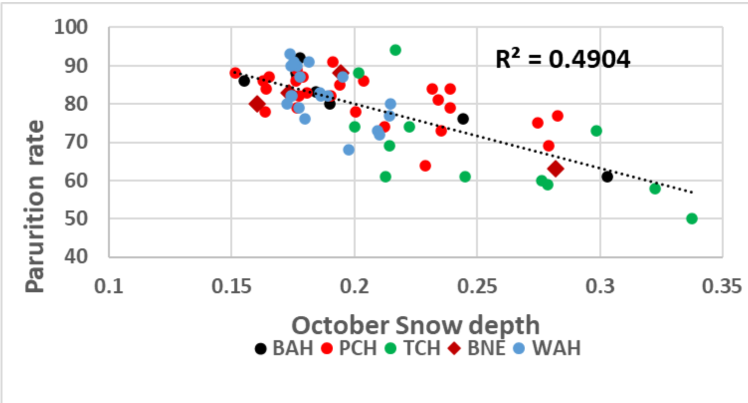


Figure 7. Relationship between spring parturition rate (%) in female caribou and average snow depth (m) during the preceding fall (October), where BAH = Bathurst herd; PCH = Porcupine herd; TCH = Teshukpuk herd; BNE = Bluenose East herd; and WAH = Western Arctic herd. Source: D. Russell, CircumArctic 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)*

To apply the parturition relationship, we used fall snow depth data instead of October snow depth because monthly data were not available[10]. We used the snow depth projection for RCP 8.5[11], 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.

7.2. 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 (Figure 8). *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).*

[10] 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.

[11] "The Representative Concentration Pathways (RCPs) describe four different 21st century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs are consistent with the wide range of scenarios in the mitigation literature assessed by WGIII (https://www.ipcc.ch/working-group/wg3). The scenarios are used to assess the costs associated with emission reductions consistent with particular concentration pathways. The RCPs represent the range of GHG emissions in the wider literature well; they include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0), and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5." [Source: Intergovernmental Panel on Climate Change (IPCC) – the United Nations body for assessing the science related to climate change; https://ar5-syr.ipcc.ch/topic_futurechanges.php].

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.

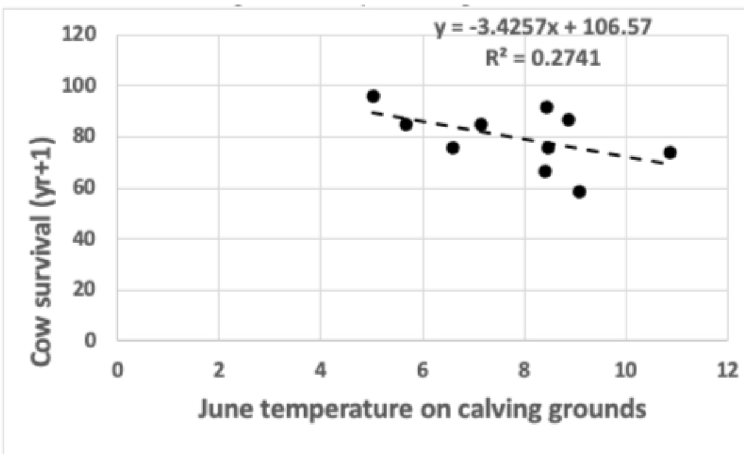


Figure 8. Relationship between cow survival rate and June temperature. Source: D. Russell, CircumArctic Rangifer Monitoring and Assessment (CARMA) Network, November 2021, Whitehorse, YK.

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

To apply this relationship in ALCES Online, 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.

Our approach of incorporating the relationships between fecundity and fall snow depth, and cow survival and June temperature was based on climate variables that are available in ALCES Online[12]. These relationships provide plausible ways of incorporating the influence of climate on caribou and are a starting point for exploring implications of changing climate conditions through scenario analyses. It is emphasized, however, that the validity of the climate and vital rate relationships for climates that are outside of the historically observed range is unknown. As such, the reliability of applying the relationships to long-term climate projections is uncertain. More research on the response of vital rates to climate is needed.

[12] Climate variables that are available in ALCES Online are average, minimum, and maximum temperature; precipitation; precipitation as snow; evaporation; and shortwave radiation. The climate variables are available annually and by month for three emission scenarios: RCP 2.6, RCP 4.5, and RCP 8.5. Historical data are also available for these variables.

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9. Appendices

9.1. Appendix 1. Summary of information on western NWT barren-ground caribou

Table 1. Herd estimates (+/- 95% CI) for Tuktoyaktuk Peninsula, Cape Bathurst and Bluenose-West (1+ year-old caribou from post-calving photographic surveys - Rivest estimator), and Bluenose-East (2+ year old-caribou from calving-ground photographic surveys) herds.

Year	Tuktoyaktuk Peninsula (TP)	TP (95% CI)	Cape Bathurst (CB)	CB (95% CI)	Bluenose-West (BNW)	BW (95% CI)	Bluenose-East (BNE)	BE (95% CI lower)	BE (95% CI upper)	References
1985										
1986			13,476		83,460					Nagy and Johnson 2006
1987			14,529	2,542	98,874	3,145				Nagy and Johnson 2006
1988										
1989										
1990										
1991										
1992			17,521	5,352	64,705	9,057				Nagy and Johnson 2006
1993										
1994										
1995										
1996										
1997										
1998										
1999										
2000			13,612	5,245	74,273	10,591	279,358	189,331	189,331	Boulanger et al. 2018; Nagy and Johnson 2006; Patterson et al. 2004 (104,000 ± 22,100)
2001										
2002										
2003										
2004										
2005			3,566	1,373	26,228	5,878				Boulanger et al. 2018
2006	3,320	623	2,039	319	28,461	7,431				Boulanger et al. 2019
2007										
2008										
2009	2,889	765	2,925	1,252	21,773	4,884				Boulanger et al. 2018
2010							120,880	13,398	13,398	Boulanger et al. 2018; Adamczewski et al. 2017
2011										
2012	2,237	358	2,447	344	32,326	15,482				Boulanger et al. 2018, Davison et al. 2016
2013							68,295	18,040	18,041	
2014										
2015	1,930	347	2,524	284	21,535	5,136	38,592	4,733	4,733	Boulanger et al. 2016, 2018
2016										
2017										
2018	1,499	626	4,521	875	21,011	4,602	19,294	2,767	3,230	Davison et al. 2020
2019										
2020										
2021	3,073	1,473	4,912	562	18,440	5,211	23,202	3,955	4,769	Boulanger et al. 2022; T. Davison pers comm. (2
2022										

Herd size (black text) of 1+ year-old caribou based on Lincoln-Petersen estimator of post-calving photo-surveys
Herd size (red text) of 1+ year-old caribou based on Rivest estimator of post-calving photo-surveys
Herd size (blue text) of 2+ year-old caribou from calving ground photo-surveys

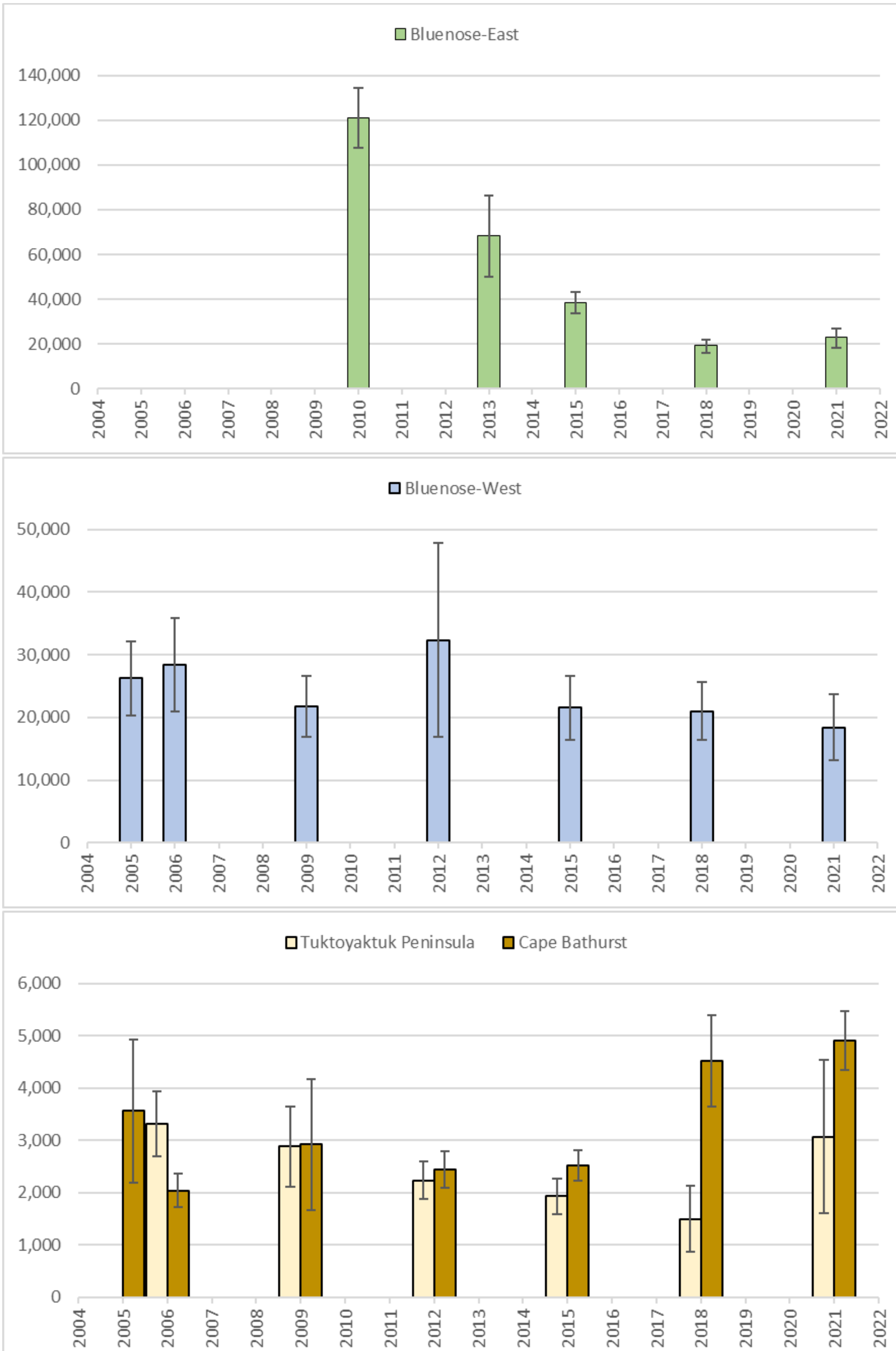

Figure 1. Caribou herd estimates (+/- 95% CI) for Tuktoyaktuk Peninsula, Cape Bathurst and Bluenose-West (1.5+ year-old caribou from post-calving photographic surveys - Rivest estimator) herds.

9.2. Case Study 1. Landscape and Climate Projections

Case Study on Landscape and Climate Projections for the Central Barren-Ground Caribou Project

M. Carlson, April 2023

Contents

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

Methods
Preparation of Land Cover and Climate Data

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 Online 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 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. 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)[13]. Climate data include monthly and annual temperature (min, max, mean), precipitation, precipitation as snow, shortwave radiation, and evaporation, downscaled to 1 km^2.

[13] 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 6. 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[14] are projected to transition to taiga ecoregions[15] were identified as being eligible for 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

[14] Ecoregions classified as tundra-dominated for the purpose of the simulation were those belonging to the Tundra level 1 ecoregion.
[15] Ecoregions classified as taiga or forest dominated were those belonging to the Taiga or Northern Forest level 1 ecoregions.

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[16].

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[17]. 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[18] under climate 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

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[16] 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.

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

[18] 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).

during simulations was random but guided by a relative likelihood layer that reflected the fire selection ratios and HFRZ burn rates[19]. The fire size class distribution used in the simulations was based on burned forest and shrub patch size[20] 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 7. 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 8. 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[21]	0.43	1.16	1.79
Deciduous	0.15	0.4	0.63

Table 9. Burned forest patch size class distribution occurring in the study area between 2010 – 2020.

Size Class (km2)	Simulated Size (km2)[22]	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

[19] 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.
[20] Nonforest cover types were excluded when calculating historical burned forest patch size to avoid exaggerating the size of burned forest patches.
[21] 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.
[22] 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.

Results

Current and projected future land cover and climate data can be viewed using ALCES Online[23]. For details on how to view data in ALCES Online, refer to 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 1. 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 5). 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 2) 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 3), which overlaps substantially with the spring migration, fall, and winter range of the Bluenose East herd.

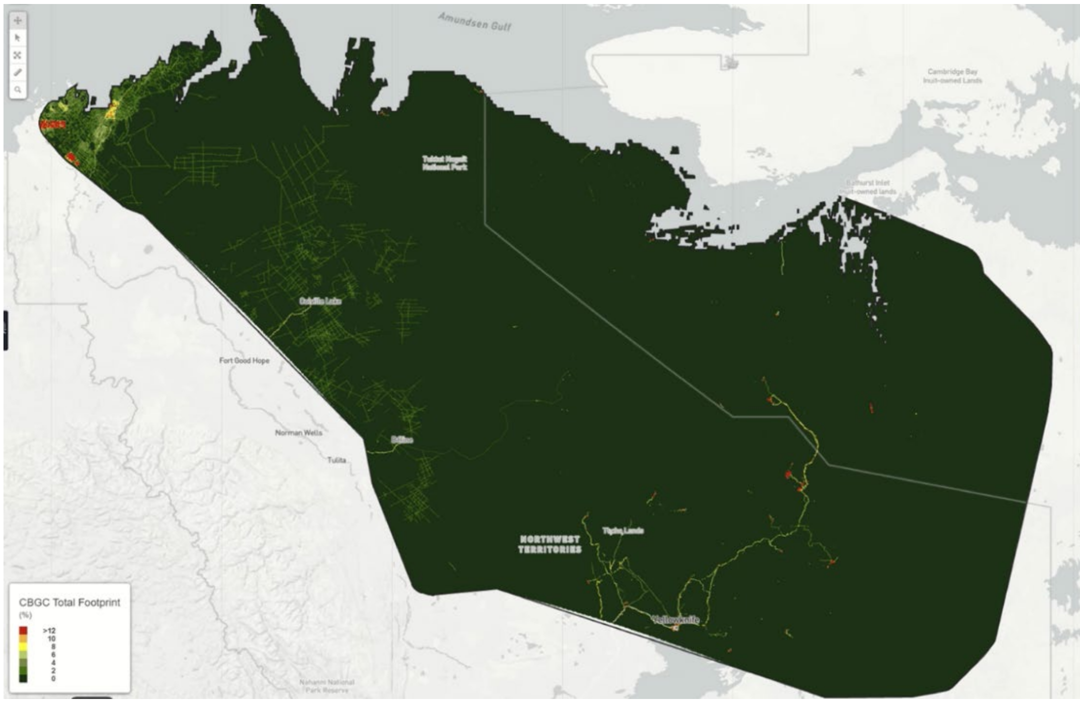
Annual average temperature rose during the RCP 8.5 climate scenario, increasing almost 3 C from 2020 to 2060 (Figure 4). In contrast, annual precipitation displayed substantial interannual variation but lacked directional trend (Figure 5).

Table 10. 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

[23] Guidance on how to view data in ALCES Online is provided at https://docs.google.com/document/d/11H3UJsEfG9DAtF45kgbyZ-Ak8nZDTuODJBmdnv59xoM/edit. A description of datasets is provided as table 1 of that document.

Figure 9. Development footprint at the start (top) and end (bottom) of the increasing development scenario.



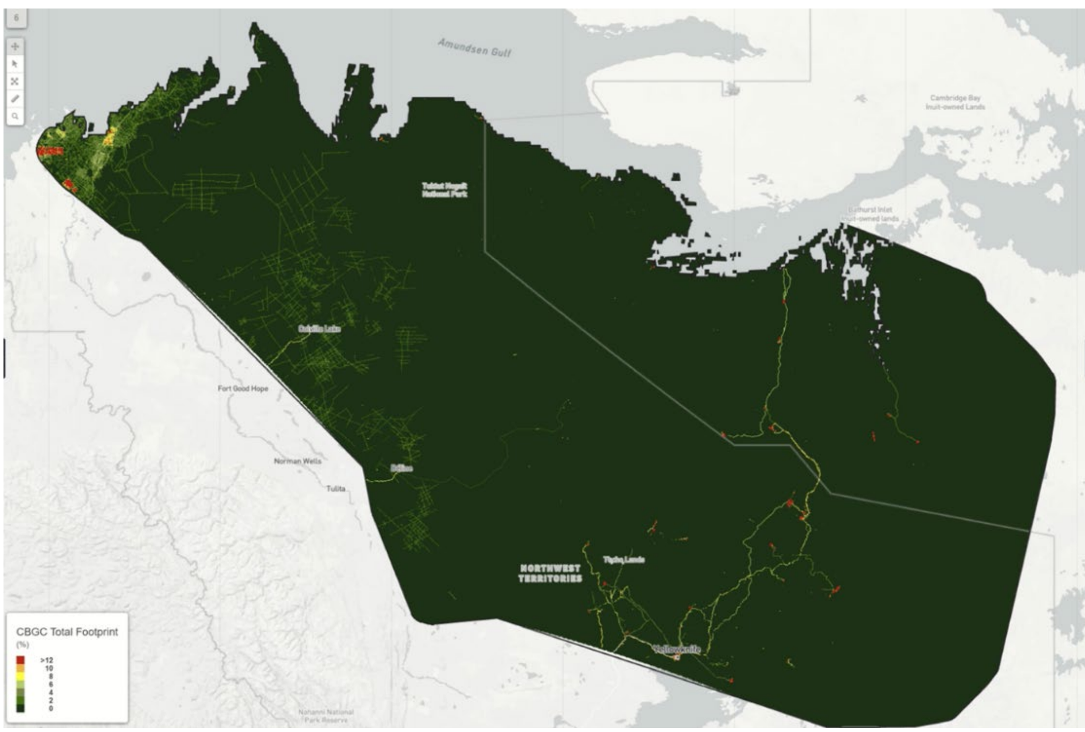
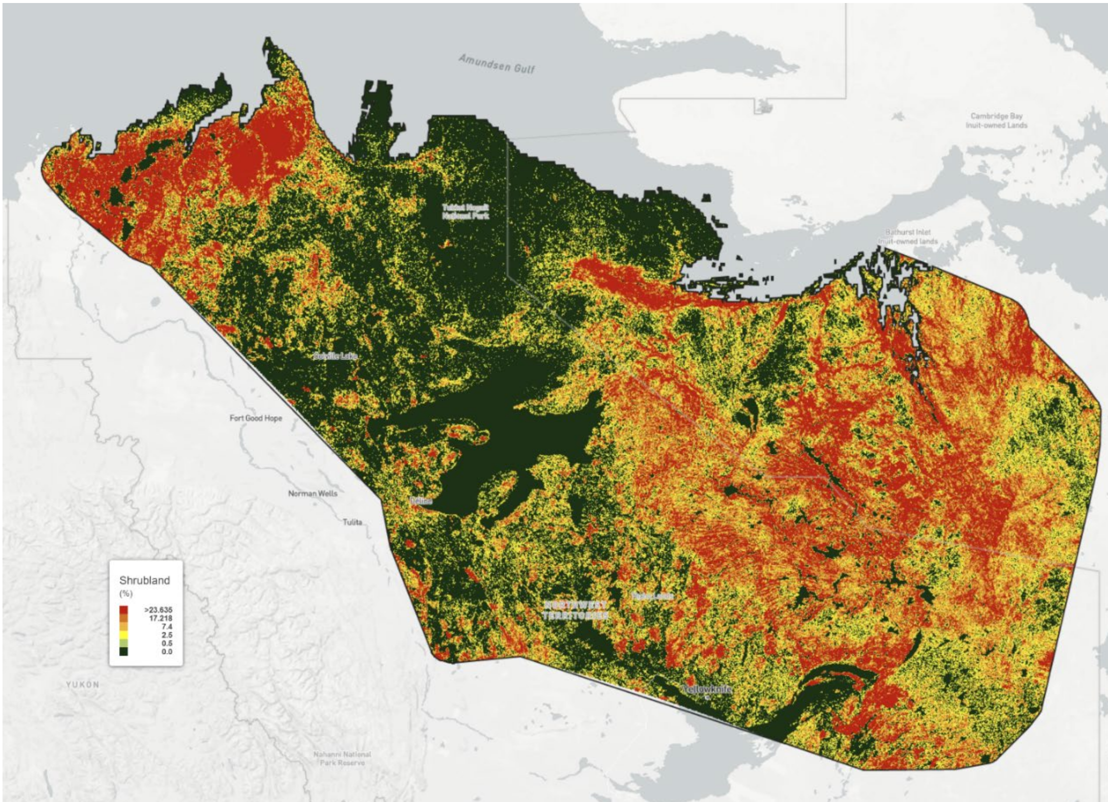


Figure 10. Shrubland coverage at the start (top) and end (bottom) of the RCP 8.5 climate scenario.



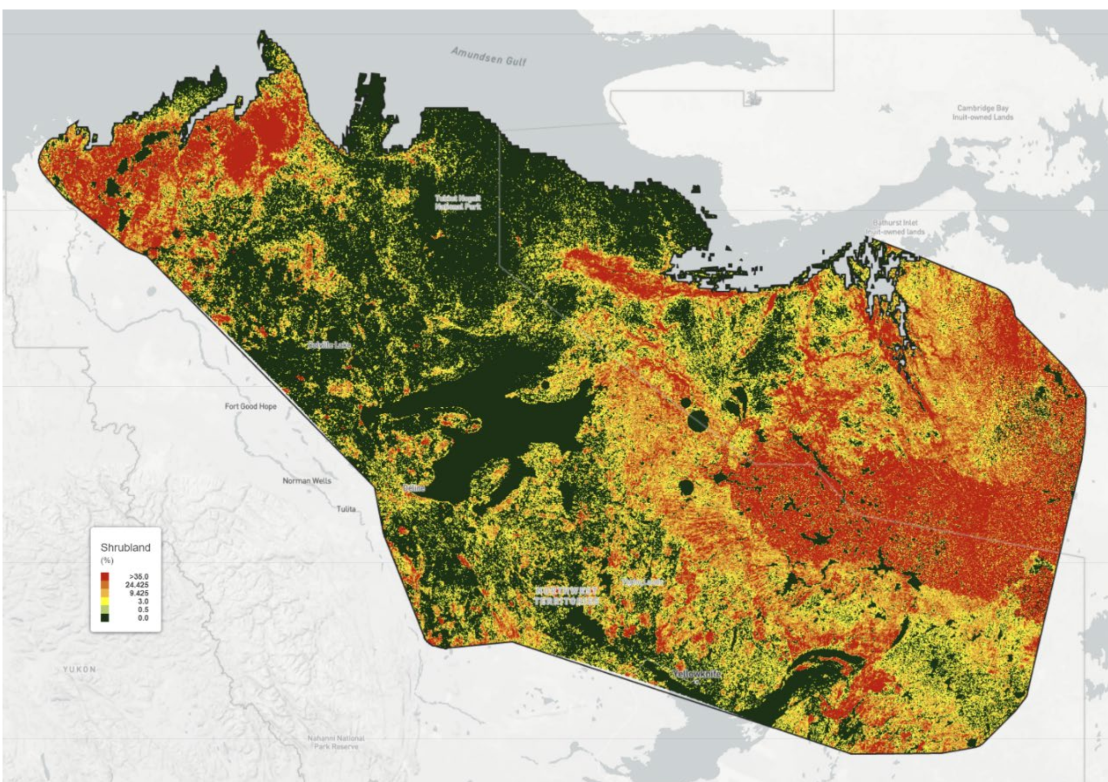


Figure 11. Forest older than 50 years at the start (top) and end (bottom) of the RCP 8.5 climate scenario.

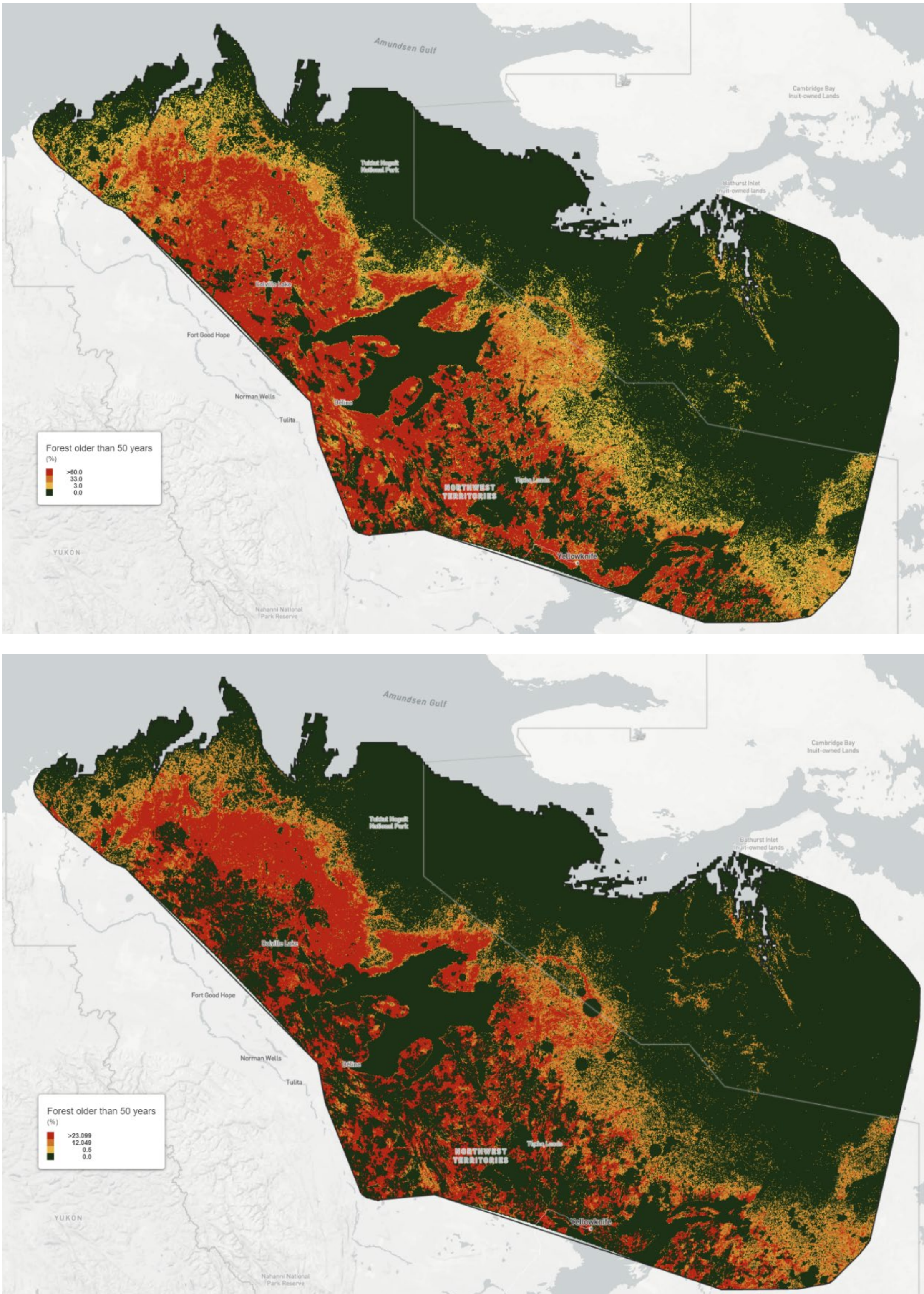


Figure 12. Map on the left is a snapshot of mean annual temperature in 2020 across the Minimum Convex Polygon (MCP) of the five herds of barren-ground caribou. Line graph on the right represents the directional change in mean annual temperature with climate change (RCP 8.5) from 2020 to 2060.

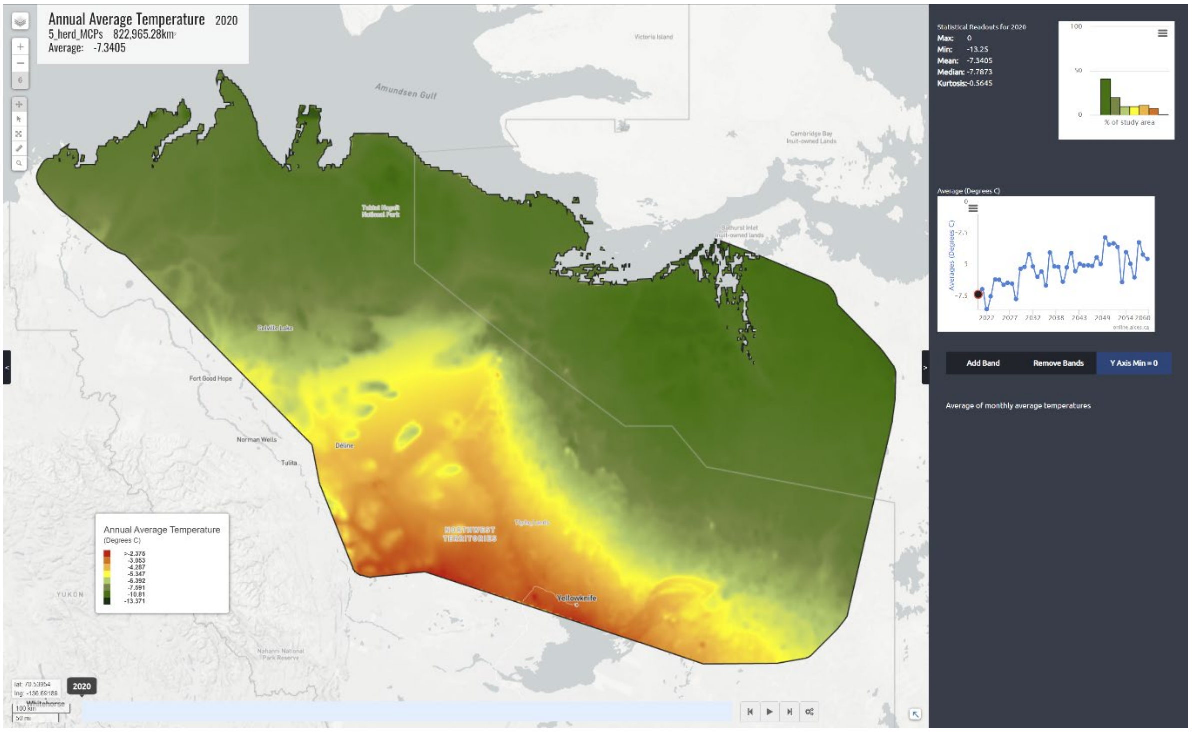
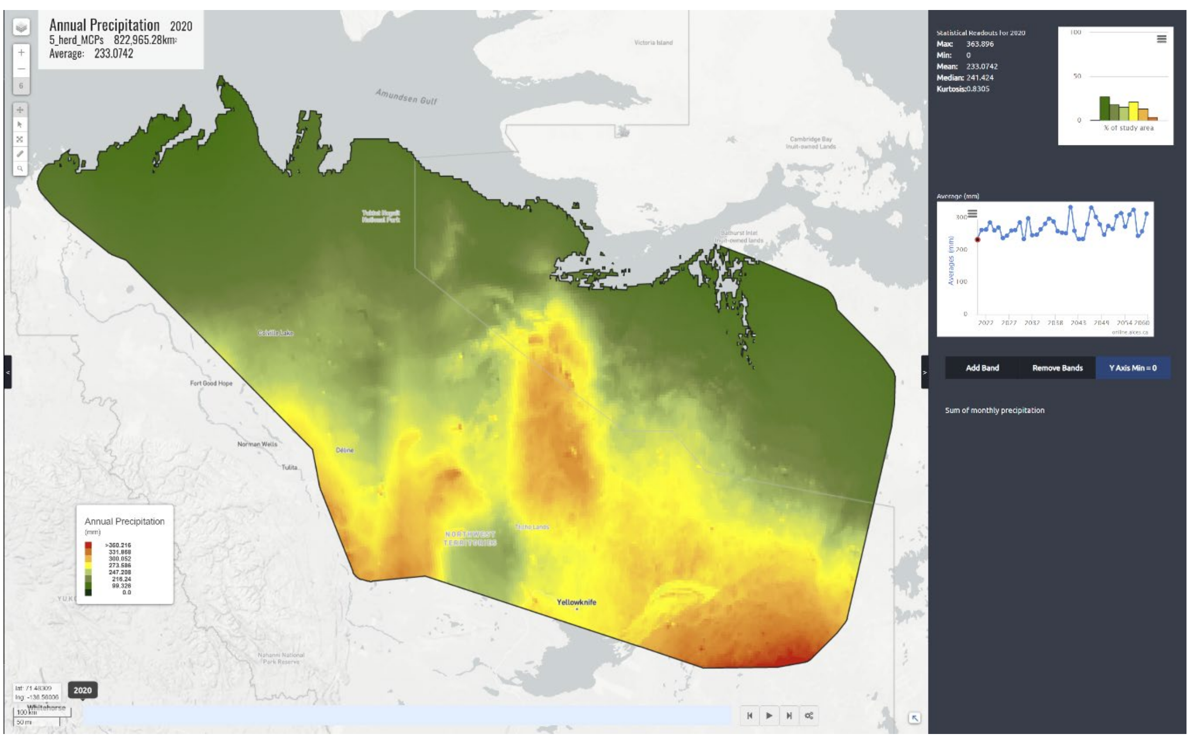


Figure 13. Map on the left is a snapshot of annual precipitation in 2020 across the Minimum Convex Polygon (MCP) of the five herds of barren-ground caribou. Line graph on the right represents the directional change in annual precipitation with climate change (RCP 8.5) from 2020 to 2060.



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9.3. Case Study 2. Barren-ground Caribou Population Dynamics

DRAFT Case Study on Barren-ground Caribou Population Dynamics Using ALCES PopDyn

M. Carlson, March 2023

Contents

Introduction

A case study was completed to assess the performance of the barren-ground caribou population dynamics models and illustrate their application. To assess the suitability of input parameters described in the population dynamics inputs report (and summarized in Table 1), a constant conditions scenario was simulated whereby land cover and climate remained at the current state. A set of scenarios were then simulated to explore sensitivity of Bluenose East population dynamics to the vital rate inputs. The implications of dynamic climate and landscape composition was also assessed by simulating population response to a scenario that incorporated climate change (as per the RCP 8.5 emission scenario) and development. The assumed relationship between climate variables and caribou habitat is described in the population dynamics model inputs document, as is the relationship between climate and vital rates (fecundity and cow mortality. Simulated landscape dynamics under the scenario are described in the land use scenario document. Landscape dynamics included project development as well as shifts in land cover in response to climate change.

The case study focused on the Bluenose East herd, which was used to calibrate model inputs and explore sensitivity to input parameters. The Bluenose East herd was selected as the focus because it had the most information available. Models were also prepared for Bluenose West, Tuktoyaktuk Peninsula, and Cape Bathurst, largely using the same inputs that were used for Bluenose East (with exception of the habitat models, range boundaries, and population estimates). Response of these three herds to the scenarios (constant conditions, climate change and development) is also presented in this report.

Before presenting population dynamic outcomes for the four herds, the response of habitat is presented. Habitat is an important input to the population dynamics models as it controls the spatial distribution of animals. Habitat is also a pathway through which development footprint and fluctuation in climate can influence the population trajectory; declines in habitat can trigger density dependent mortality thereby placing downward pressure on the population. Following the summary of habitat results, simulated population dynamic outcomes are presented, starting with the constant conditions scenario, followed by vital rate sensitivity analysis for Bluenose East, and concluding with the climate change and development scenario.

Table 11. Summary of inputs used in the constant conditions population dynamics models. Details are provided in the population dynamics inputs report.

	Bluenose East (BNE)	Bluenose West	Tuktoyaktuk Peninsula	Cape Bathurst
Initial Population	23,000 (adults)	18,440 (non-calf)	3,073 (non-calf)	4,912 (non-calf)
Fecundity	0.95 adults, 0.15 subadults	Same as BNE	Same as BNE	Same as BNE
Calf Survival	0.4	Same as BNE	Same as BNE	Same as BNE
Yearling Survival	0.86	Same as BNE	Same as BNE	Same as BNE
Cow Survival	0.825	Same as BNE	Same as BNE	Same as BNE
Bull Survival	0.72	Same as BNE	Same as BNE	Same as BNE
Bull Harvest	0.5 TAH	0.5 TAH	Same rate as BNE	0

Habitat Outcomes

Habitat within seasonal ranges was dictated by covariates (land cover, climate, forest age, topography), resulting in spatial variation in habitat value. The climate change and development forecast caused habitat to fluctuate over space and time in response to changes in climate and land cover. The effect of climate change was primarily to cause interannual variability in habitat. The most noticeable directional change in habitat was the Bluenose East winter range, which declined substantially at least in part due to a decline in older forest in the southern part of the range caused by a higher fire rate with climate change. In contrast to climate change, simulated future development had negligible effect on habitat because new development footprint occurring within the ranges was minimal. Seasonal habitat models that did not include climate variables (i.e., Bluenose West spring migration and summer) did not change during the forecast. Screenshots from ALCES Online illustrating seasonal habitat indices for the Bluenose East herd are presented in Figure 1. Screenshots for the other herds are in the appendix.

Figure 14. Screenshots from ALCES Online showing the seasonal (spring migration, calving, summer, fall, winter) habitat indices for the Bluenose East caribou herd. The maps are based on current landcover and climate. Habitat is set to 0 in cells outside of the seasonal range based on a kernel density function, and the study area is the seasonal range based on a minimum convex polygon (MCP). Legend values are from 0.05 (dark green) to >0.3 (red). The time series graphs to the right illustrate average response of the habitat index to the climate change and development forecast (2020 to 2060).

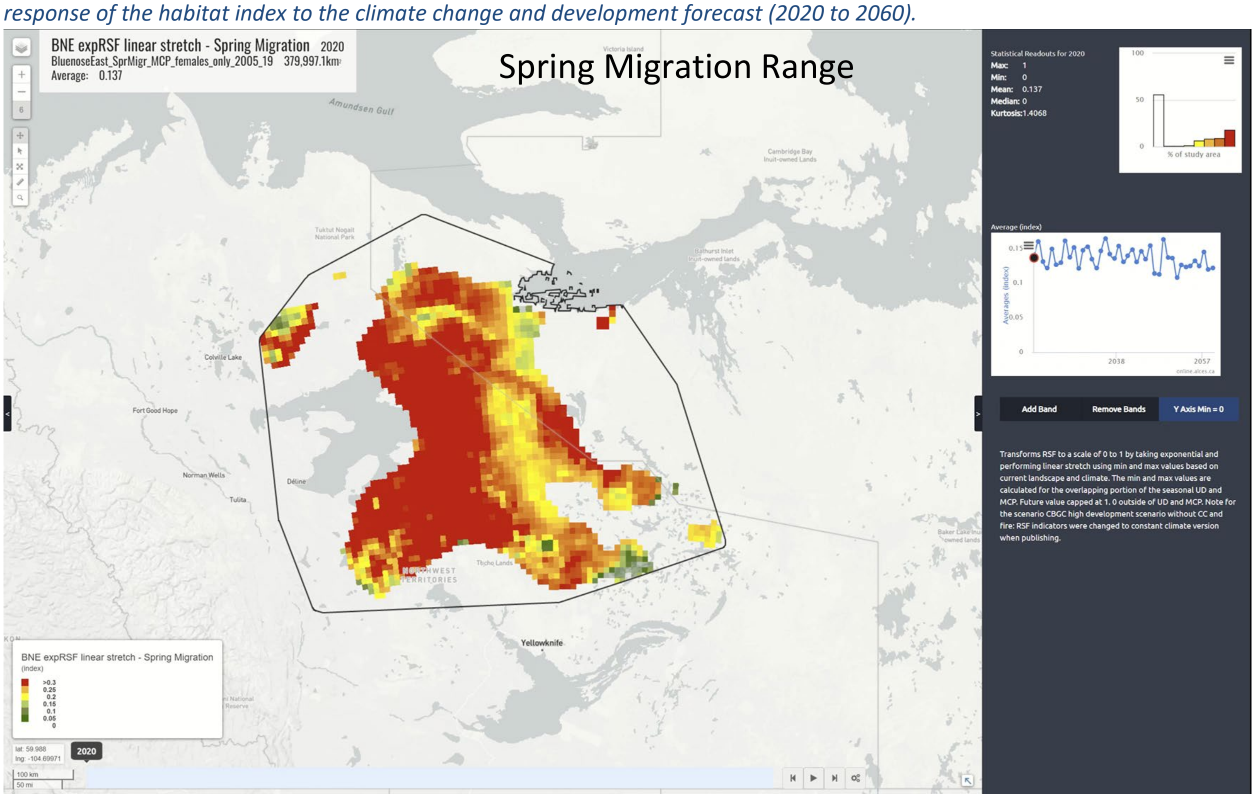
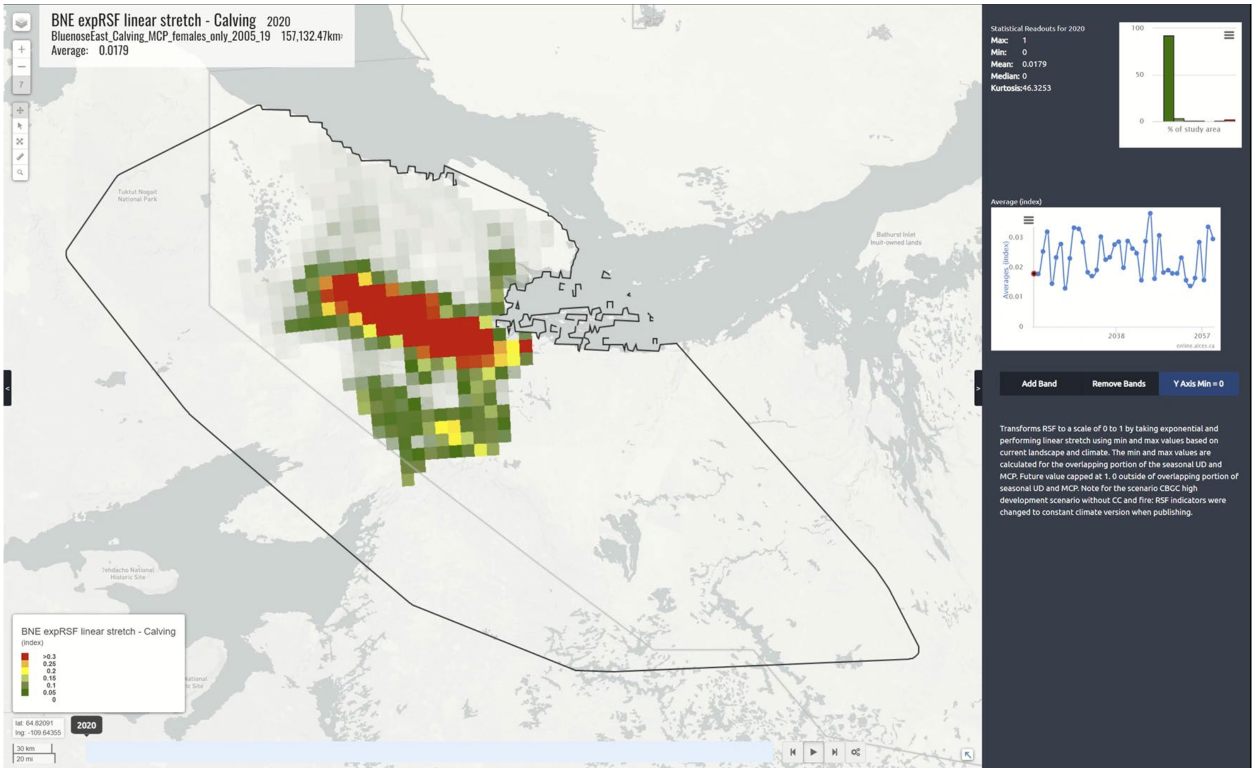


Figure 1 (continued)

Calving Range



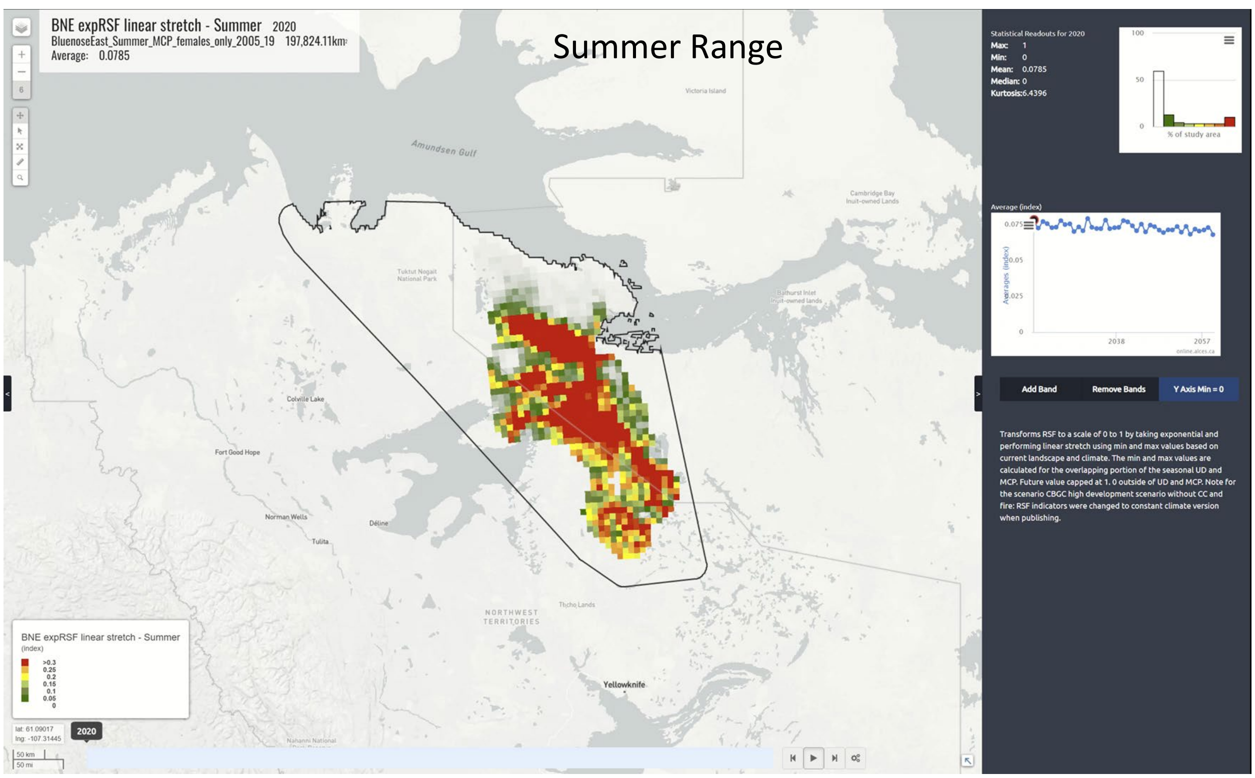
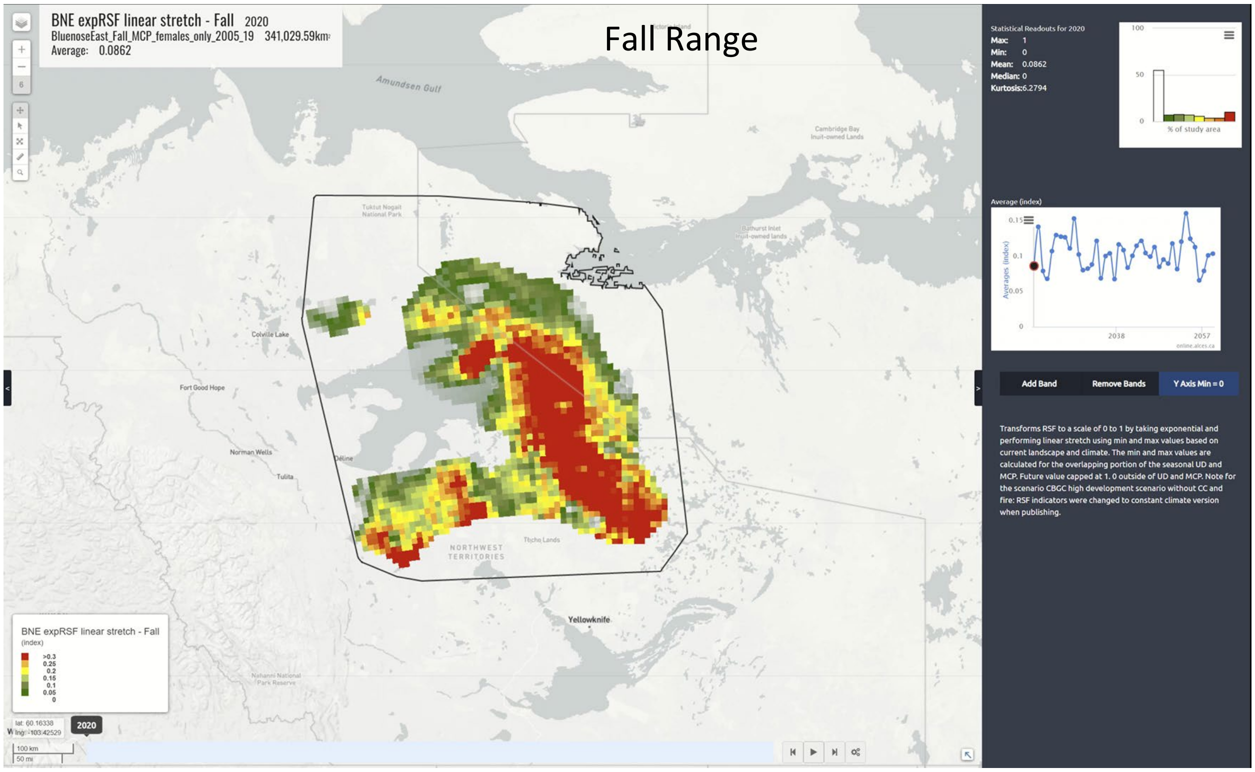
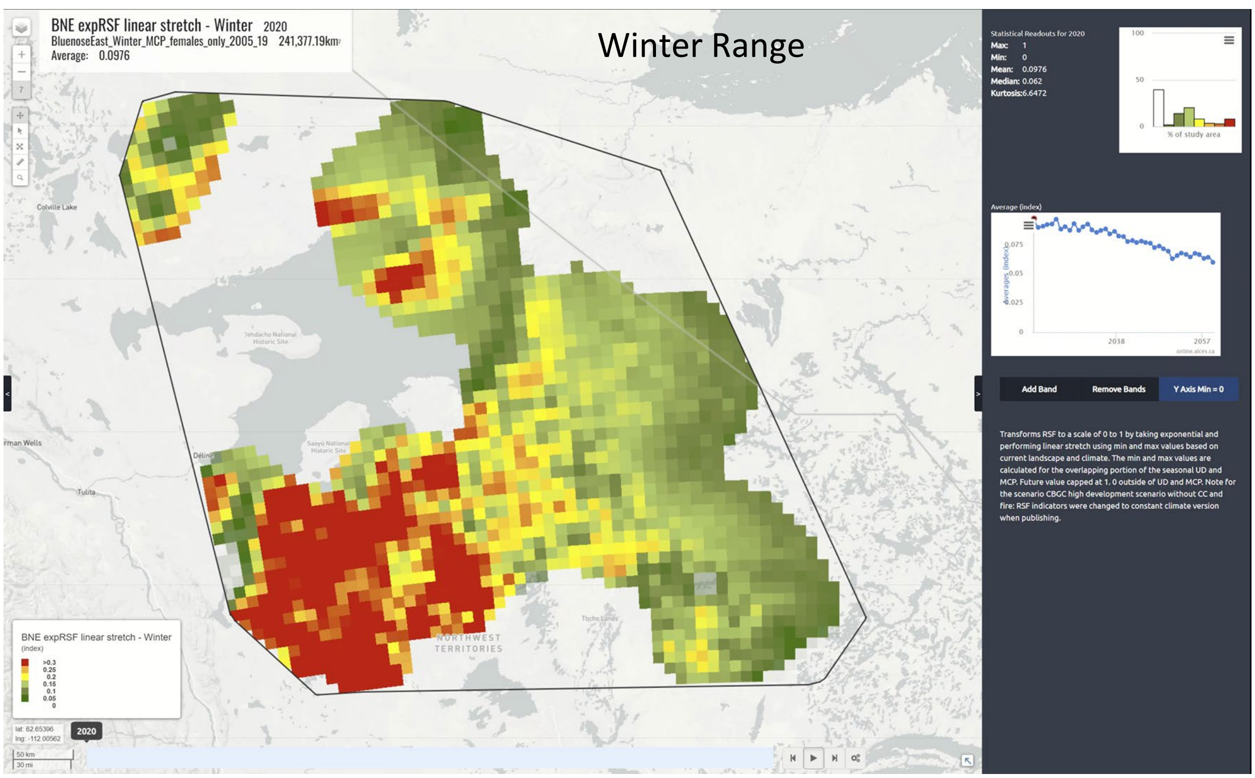


Figure 1 (continued)


Fall Range
BNE expRSF linear stretch - Fall 2020
BluenoseEast_Fall_MCP_females_only_2005_19 341,029.59km
Average: 0.0862
Amundsen Gulf
Colville Lake
Fort Good Hope
Norman Wells
Tulita
Déline
NORTHWEST TERRITORIES
Tlicho Lands
Yellowknife
BNE expRSF linear stretch - Fall
(index)
>0.3
0.25
0.2
0.15
0.1
0.05
0
2020
Statistical Readouts for 2020
Max: 1
Min: 0
Mean: 0.0862
Median: 0
Kurtosis:6.2794
% of study area
Average (index)
Averages (index)
2038
2057
online.alces.ca
Add Band
Remove Bands
Y Axis Min = 0
Transforms RSF to a scale of 0 to 1 by taking exponential and performing linear stretch using min and max values based on current landscape and climate. The min and max values are calculated for the overlapping portion of the seasonal UD and MCP. Future value capped at 1. 0 outside of UD and MCP. Note for the scenario CBGC high development scenario without CC and fire: RSF indicators were changed to constant climate version when publishing.


Winter Range
BNE expRSF linear stretch - Winter 2020
BluenoseEast_Winter_MCP_females_only_2005_19 241,377.19km
Average: 0.0976
Colville Lake
Déline
Tulita
NORTHWEST TERRITORIES
Tlicho Lands
BNE expRSF linear stretch - Winter
(index)
>0.3
0.25
0.2
0.15
0.1
0.05
0
2020
Statistical Readouts for 2020
Max: 1
Min: 0
Mean: 0.0976
Median: 0.062
Kurtosis:6.6472
% of study area
Average (index)
2038
2057
online.alces.ca
Add Band
Remove Bands
Y Axis Min = 0
Transforms RSF to a scale of 0 to 1 by taking exponential and performing linear stretch using min and max values based on current landscape and climate. The min and max values are calculated for the overlapping portion of the seasonal UD and MCP. Future value capped at 1. 0 outside of UD and MCP. Note for the scenario CBGC high development scenario without CC and fire: RSF indicators were changed to constant climate version when publishing.

Population Dynamics Outcomes

Constant Conditions Scenario

Simulation of Bluenose-East population dynamics in response to the constant conditions scenario (Table 1) resulted in intra-annual variation in population but a stable population across years (Figure 2). The oscillating pattern is driven by population growth each calving season in response to births, and population decline over the next four seasons in response to mortality. The population declined slightly during the initial 10-year calibration period before remaining stable over the next four decades. As such, the constant conditions scenario inputs are consistent with the current assessment of the Bluenose East population as stable.

Natural mortality is the primary source of mortality during the simulation (Figure 3), which occurs across all seasons, stages, and genders (albeit at varying amounts). In contrast, harvest occurred only in the winter season, was lower than natural mortality, and only affected bulls. No density dependent mortality was present in the simulations because the population was substantially below the assumed carrying capacity of 120,000 caribou, not including calves.

Constant conditions scenario outcomes for the other herds were similar to Bluenose East, with populations oscillating across seasons but remaining stable across years (Figure 4, Figure 5, Figure 6). An exception is the Tuktoyaktuk Peninsula herd which exhibited moderate population decline because the population experienced elevated mortality due to density dependence (Figure 7). Density dependent mortality affected the Tuktoyaktuk Peninsula herd because the initial non-calf population (3073) was close to the assumed carrying capacity (3250). In contrast, initial populations for the other herds were substantially below assumed carrying capacities such that density dependent mortality did not occur. It is important to note, however that substantial uncertainty surrounds the estimates of carrying capacity, especially for the Tuktoyaktuk Peninsula herd. Carrying capacity was estimated based on historical maximum recorded populations, and historical data is limited for the Tuktoyaktuk Peninsula herd because it was identified as a distinct herd only recently.

Figure 15. ALCES PopDyn output for population response of the Bluenose East herd to the constant conditions scenario. Calves are age 0, yearling are age 1, young adults are age 2, and adults are ages 3 and older. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.

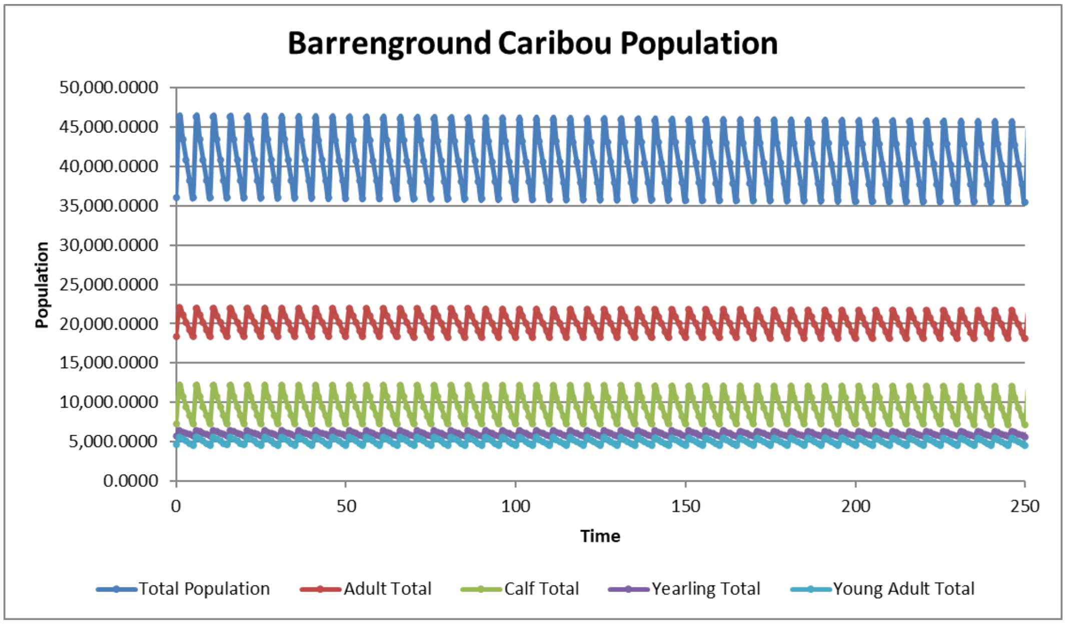


Figure 16. ALCES PopDyn output for Bluenose East herd mortality during the constant conditions scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.

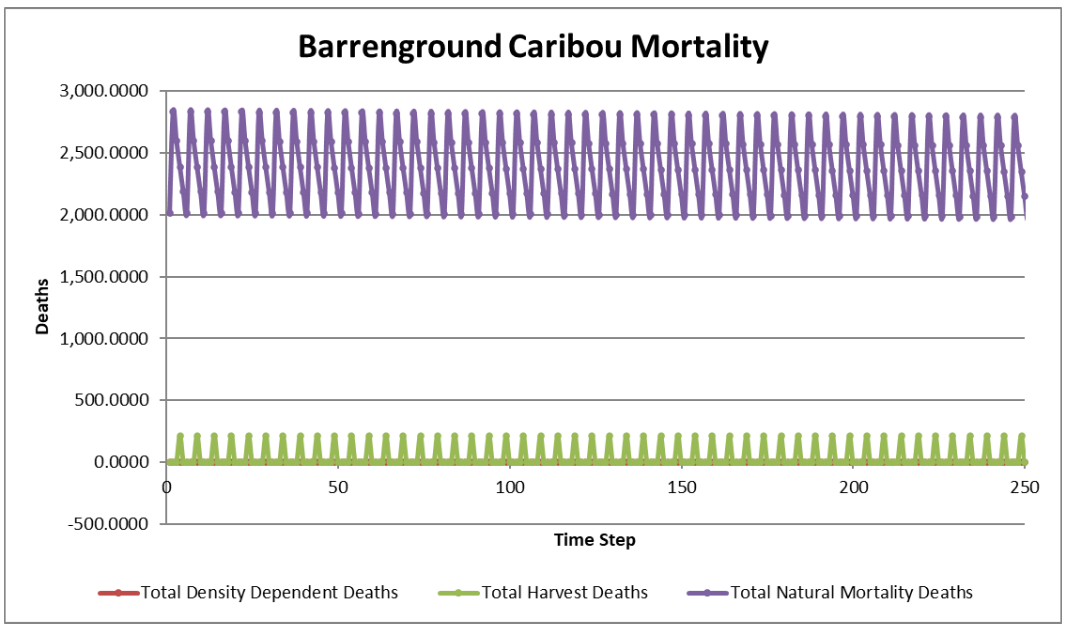


Figure 17. ALCES PopDyn output for population response of the Bluenose West herd to the constant conditions scenario. Calves are age 0, yearling are age 1, young adults are age 2, and adults are ages 3 and older. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.

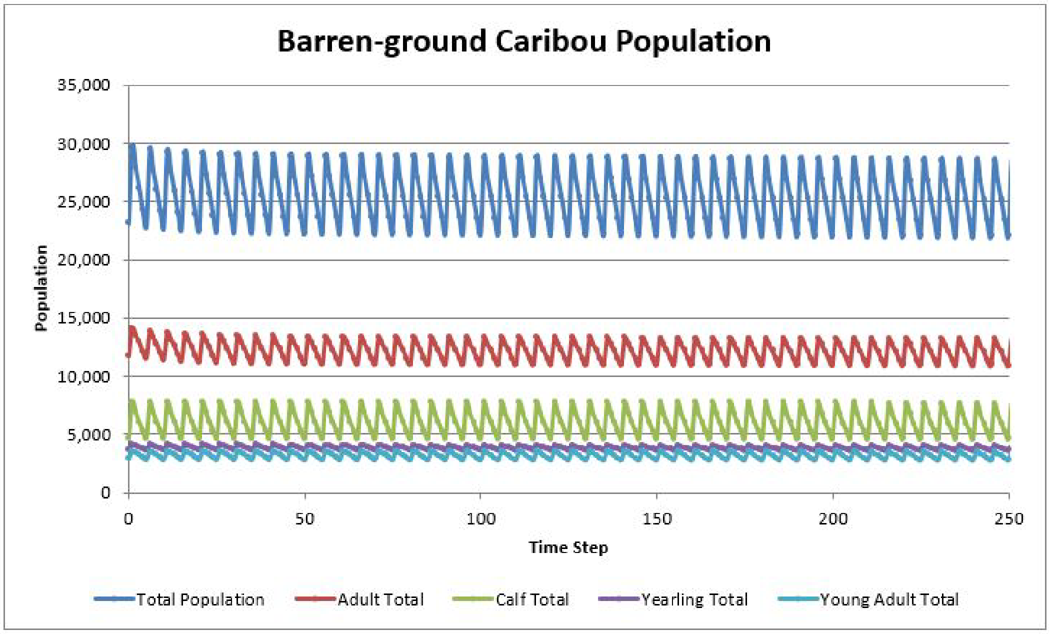


Figure 18. ALCES PopDyn output for population response of the Tuktoyaktuk Peninsula herd to the constant conditions scenario. Calves are age 0, yearling are age 1, young adults are age 2, and adults are ages 3 and older. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.

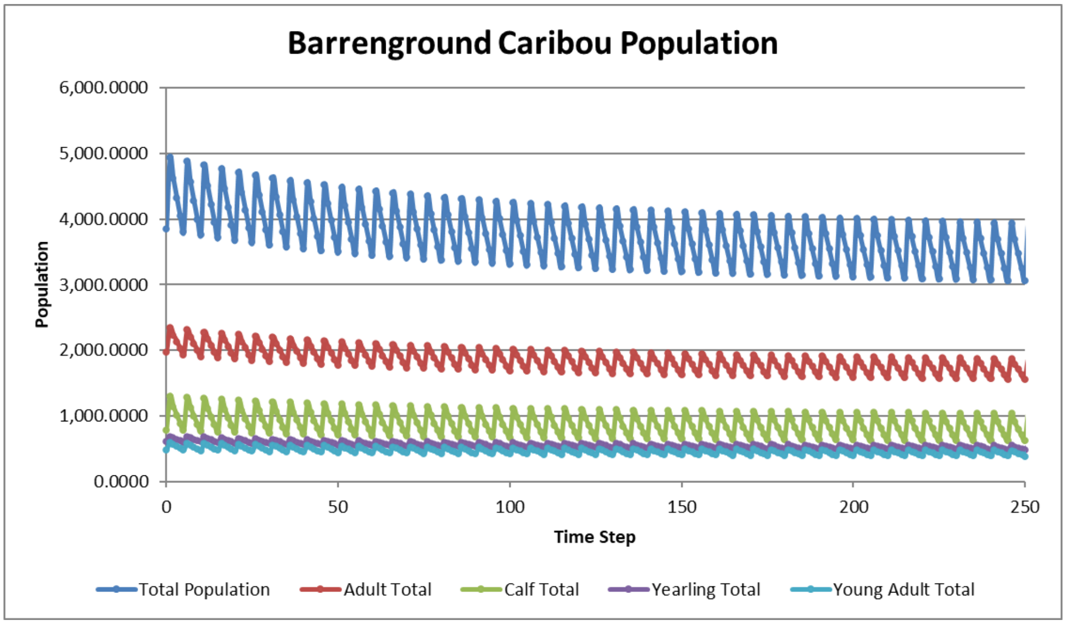


Figure 19. ALCES PopDyn output for population response of the Cape Bathurst herd to the constant conditions scenario. Calves are age 0, yearling are age 1, young adults are age 2, and adults are ages 3 and older. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.

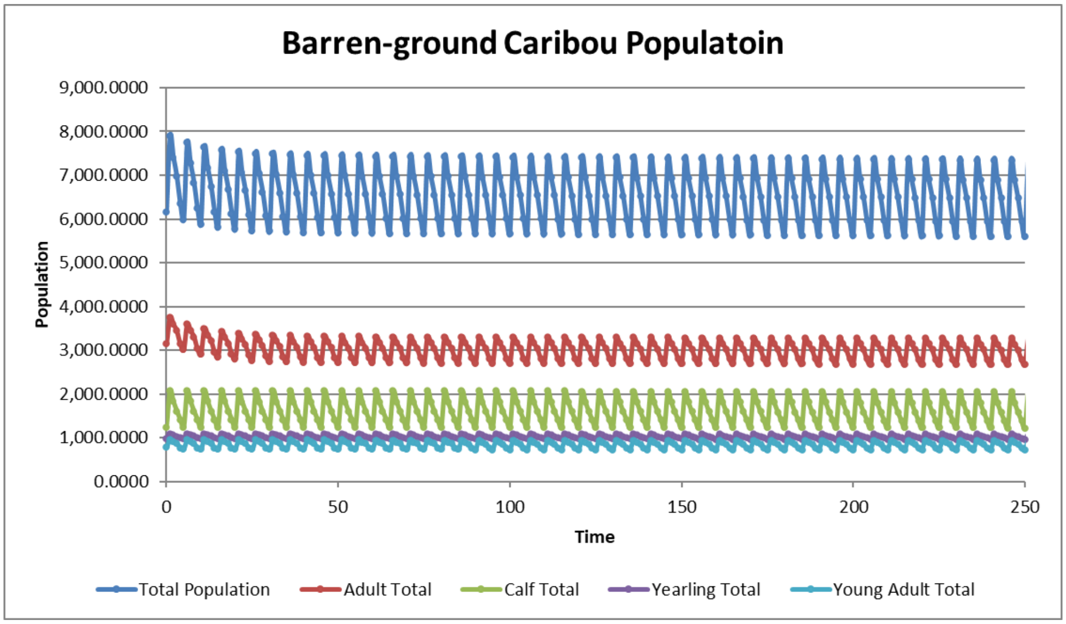
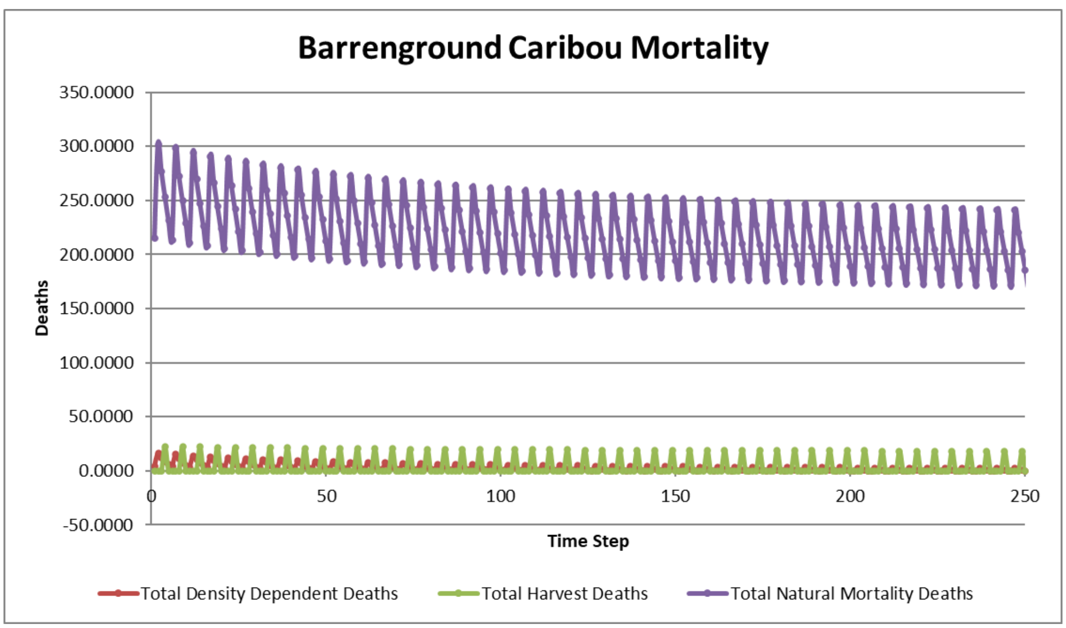


Figure 20. ALCES PopDyn output for Tuktoyaktuk Peninsula herd mortality during the constant conditions scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.



Bluenose East Vital Rate Sensitivity Analysis

Many of the vital rate assumptions applied in this project were based on those adopted for Boulanger's (2017) Bluenose East population simulations. Comparability with that previous analysis was explored by simulating the following scenario that was also assessed by Boulanger (2017): cow survival equal to 0.88, productivity equal to the average from 2010-12 (calf survival equal to 0.4, fecundity equal to 0.95), and no harvest. Although the absolute population differed between the simulations because Boulanger adopted a much higher initial population of more than 100,000, the resulting population growth rate was similar. Figure 6 from Boulanger (2017) indicates a median population growth rate slightly higher than 1, whereas applying the same vital rates to Bluenose East in ALCES PopDyn resulted in a population growth rate of 1.019 by the last decade of the forecast period.

To explore sensitivity of population dynamics to vital rate assumptions, a set of Bluenose East scenarios were simulated in which vital rates were modified within the range of estimates adopted by Boulanger (2017). As expected, reducing adult fecundity from the rate based on Boulanger's (2017) average and high productivity scenarios (0.95) to the rate based on their low productivity scenario (0.83) resulted in population decline due to fewer offspring (the low fecundity scenario in Figure 8). A similar but somewhat larger population decline was caused by reducing calf survival from the rate based on Boulanger's (2017) average productivity scenario (0.4) to their low productivity scenario (0.22) (the low calf survival scenario in Figure 8). On the other hand, increasing cow survival from 0.825 to Boulanger's (2017) cow survival estimate (0.88) triggered population growth that exceeded the rate of decline associated with the low fecundity and low calf survival scenarios (high cow survival scenario in Figure 8). Under the high cow survival scenario, the population grew more than three-fold. The higher sensitivity to cow survival is because more cows also results in more offspring (Figure 9), which creates a positive feedback loop as demonstrated by the increasing rate of population growth during the first 25 years of the forecast. Thereafter the rate of population growth began to decline due to the effect of density dependent mortality initiated when the population climbs above 60% of carrying capacity. In contrast to cow and calf survival and fecundity, the simulated population trajectory was insensitive to a doubling of bull harvest from 50% of 100% of total allowable harvest (high harvest scenario in Figure 8). This is to be expected, however, given that current total allowable harvest reflect severe harvest restrictions that were implemented in response to low barren-ground population abundance. Were harvest to be increased to historic rates and were cows to be included in the harvest, it is expected that the simulation would exhibit substantial population decline.

Figure 21. ALCES PopDyn output for spring migration season population response of the Bluenose East herd scenarios that explored sensitivity to vital rates. Scenarios are described in the text. The first 10 years are a calibration period with constant conditions.

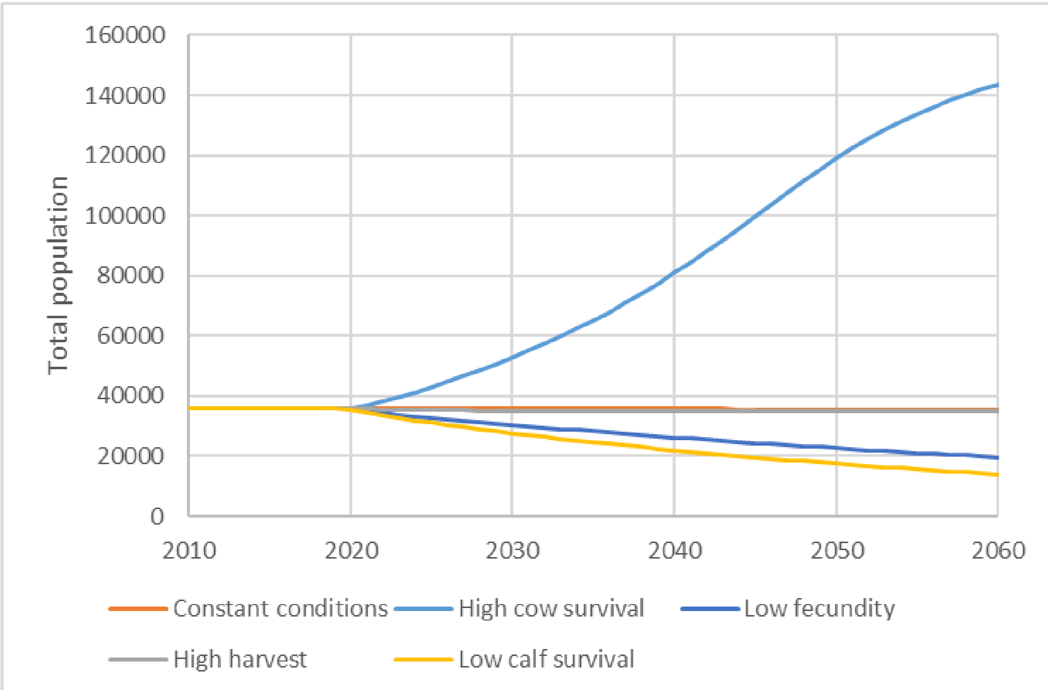
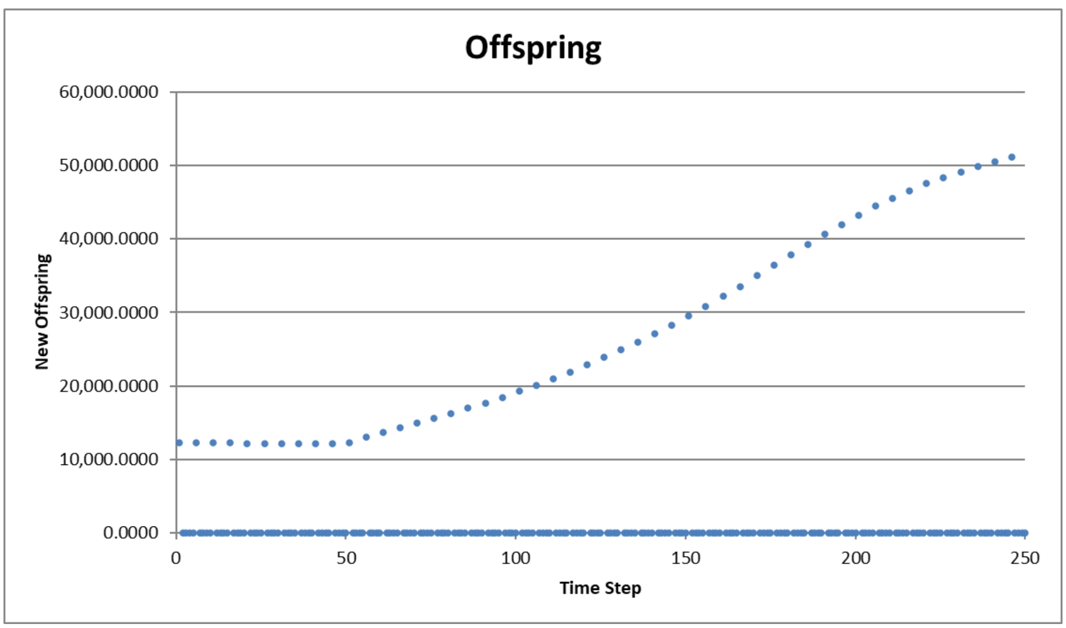


Figure 22. ALCES PopDyn output for Bluenose East offspring during the high cow survival scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps. The first 10 years (50 time steps) are a calibration period with constant conditions.



Climate Change and Development Scenario

In contrast to the stable population trajectory that resulted from the constant conditions scenario, the Bluenose East herd exhibited substantial population decline in response to a scenario that included climate change and development (Figure 10, Figure 11). Although the population initially increased in the forecast, it began to decline towards the end of the first decade and dropped to about a quarter of the current population by the end of the fourth decade. The climate change and development scenario incorporates multiple drivers, including the effect of development on habitat, the effect of climate change on habitat, and the effect of climate change on vital rates (fecundity and cow mortality). The relative importance of these drivers is illustrated by simulations that successively remove the drivers from the forecast. As expected due to the insensitivity of habitat to the development scenario, removing development from the forecast did not affect the population outcome. In other words, the Bluenose East population forecast was insensitive to the development scenario due to the absence of substantial new development footprint in the range. Bluenose East habitat did fluctuate in response to climate change but habitat fluctuations did not translate into population fluctuations because the Bluenose East population is assumed to be substantially below carrying capacity. In other words, the Bluenose East 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 Bluenose East 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, that fluctuation did cause the spatial distribution of the population to change from year to year in response to spatiotemporal variability in climate parameters.

Given the insensitivity of the Bluenose East population simulation to changes in habitat, it is apparent that the population decline is caused by the assumed effect of climate change on vital rates. The primary driver is the response of cow mortality to June temperature. June temperature exhibited a warming trend and, more importantly, occasional years with substantially elevated values (Figure 12). June temperature is assumed to have a negative effect on cow mortality, such that the cow mortality rate increases substantially during years exhibiting high June temperature (Figure 13). As illustrated by the sensitivity analysis, the population is sensitive to cow mortality such that occasional periods of elevated cow mortality triggers a negative feedback loop whereby cow mortality (i.e., fewer cows) results 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 (Figure 14). The low sensitivity of the climate change and fecundity relationship was because the project change in snow depth was relatively small (Figure 15).

Outcomes from the development and climate change scenario for the other herds were similar to Bluenose East with populations declining to very low levels (Figure 16, Figure 17, Figure 18, Figure 19, Figure 20, Figure 21),. As was the case with Bluenose East, the dominant cause of population decline was the relationship between cow mortality and climate. The occurrence of dry springs and/or warm falls resulted in elevated cow mortality, which caused populations to decline. Other drivers had limited impact. The relative stability of projected snow depth was such that changes in fecundity associated with climate change were minor. The population trajectory was insensitive to habitat loss associated with the land use forecast because new development footprint occurring in the ranges was minor. For the Cape Bathurst and Bluenose West herds, habitat fluctuation in response to climate change also had negligible impact on the population trajectory because the populations are substantially below carrying capacity and therefore not susceptible to density dependent mortality. The Tuktoyaktuk Peninsula herd was an exception this regard. In addition to population decline associated with the climate and cow mortality relationship, the Tuktoyaktuk population exhibited population decline associated with climate-change-related habitat fluctuation (Figure 22) which triggered elevated density dependent mortality (Figure 23). The sensitivity of the herd to habitat loss was because the population was assumed to be close to carrying capacity as estimated by the historical recorded maximum. As mentioned previously, however, the validity of this assumption is uncertain given that the Tuktoyaktuk Peninsula herd was only recently identified as a distinct herd.

Figure 23. ALCES PopDyn output for population response of the Bluenose East herd to the climate change and development scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps. The first 10 years (50 time steps) are a calibration period with constant conditions.

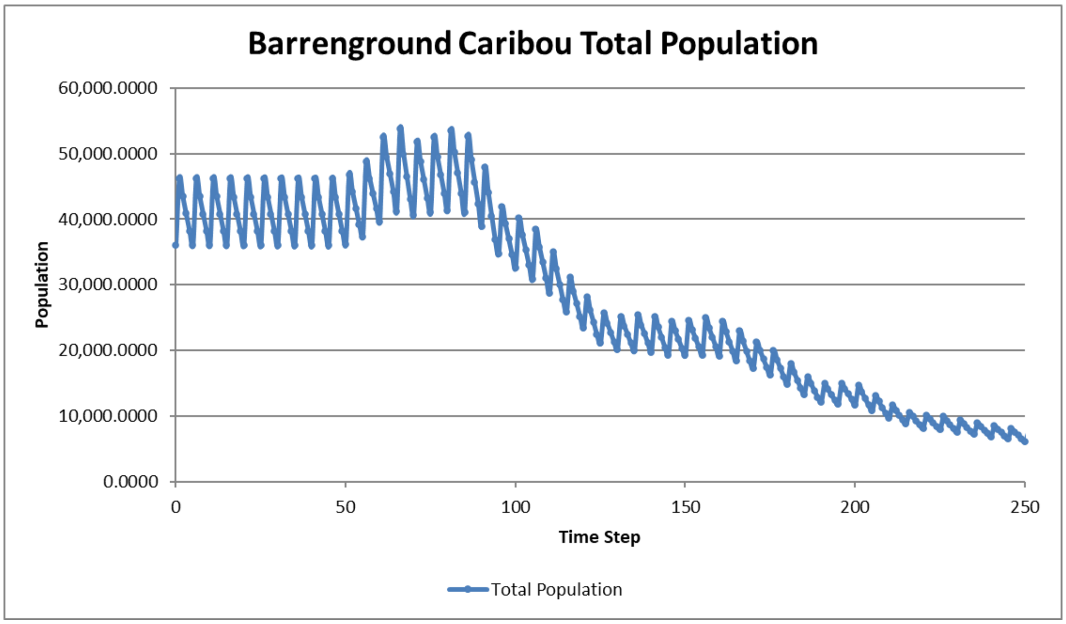


Figure 24. Screenshots from ALCES Online of Bluenose East total caribou population at the start and end of a 40 years simulation of the climate change and development scenario. Population maps are provided for each seasonal range.

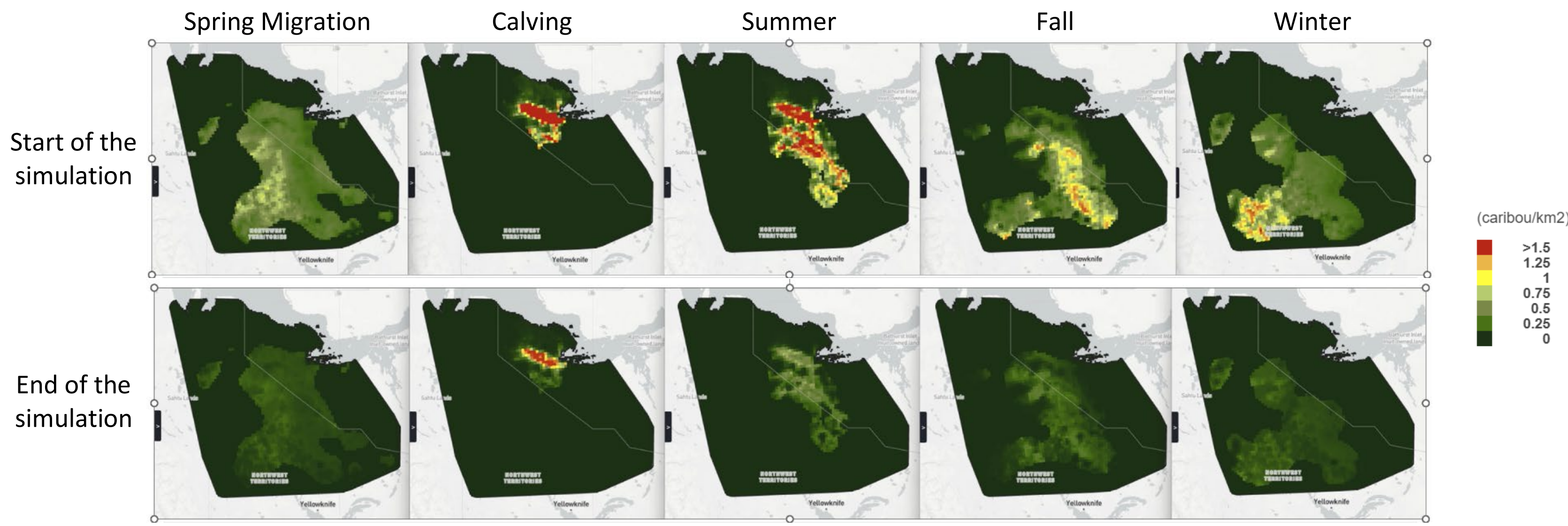


Figure 25. Screenshot from ALCES Online of June average temperature for the Bluenose East calving range. The map is of the current climate whereas the time series graph to the right illustrates projected (2020 to 2060) June average temperature for the range under climate change (RCP 8.5). Legend values are from 2 °C (dark blue) to >14 °C (red).

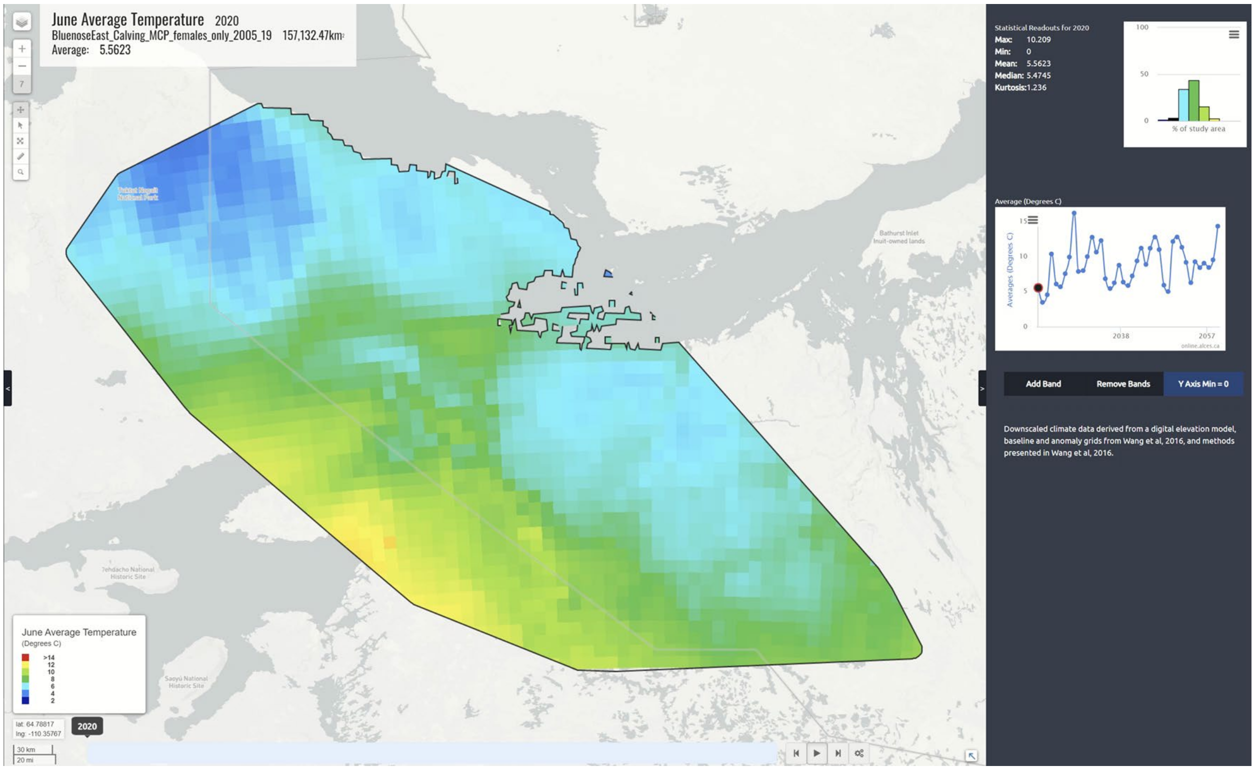


Figure 26. ALCES PopDyn output for Bluenose East female mortality during the climate change and development scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.

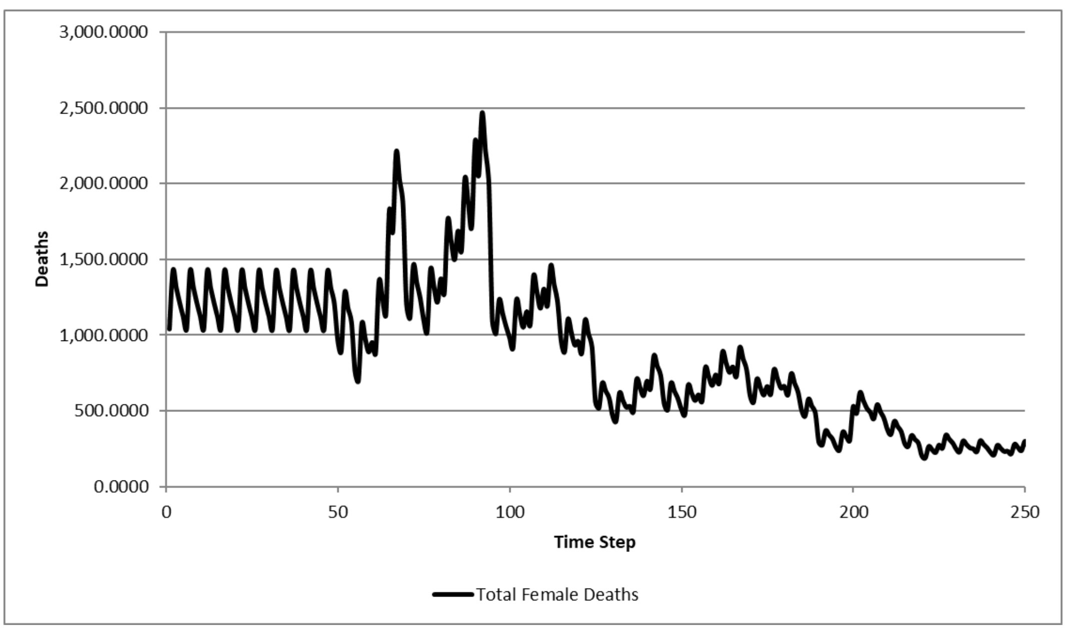


Figure 27. ALCES PopDyn output for Bluenose East fecundity during the climate change and development scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.

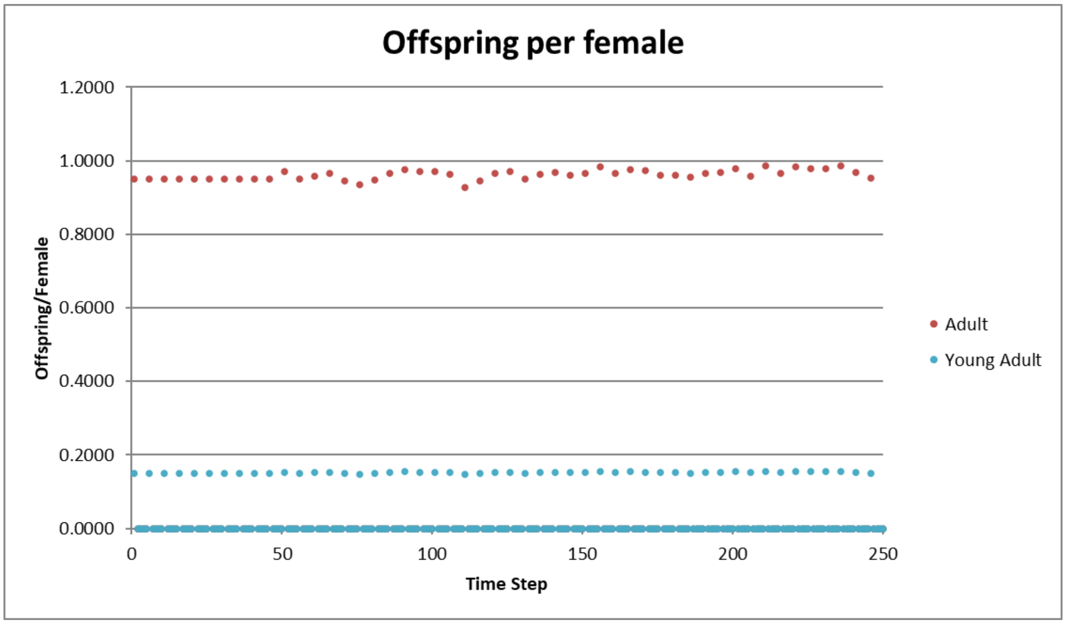


Figure 28. Screenshot from ALCES Online of fall snow depth for the Bluenose East fall range. The map is of the current climate whereas the time series graph to the right illustrates projected (2020 to 2060) fall snow depth for the range under climate change (RCP 8.5). Legend values are from 0.01 m (red) to >0.07 m (blue).

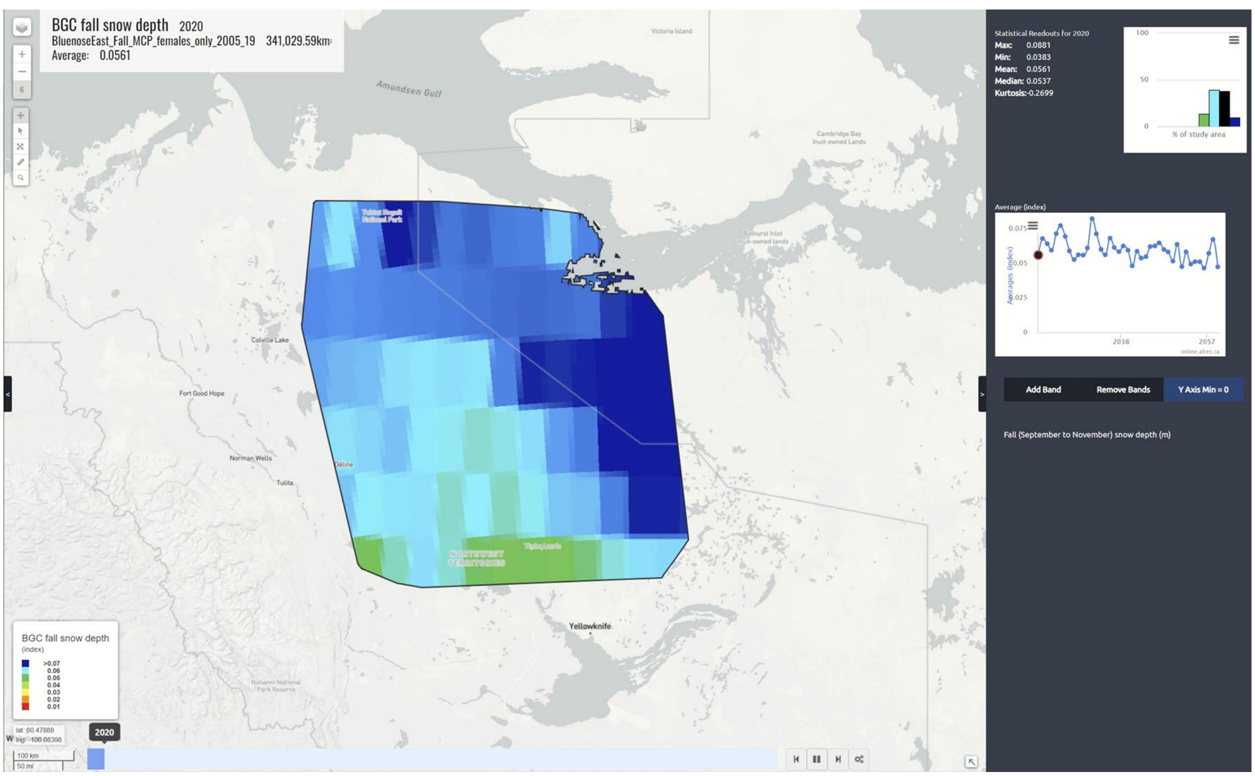


Figure 29. ALCES PopDyn output for population response of the Bluenose West herd to the climate change and development scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps. The first 10 years (50 time steps) are a calibration period with constant conditions.

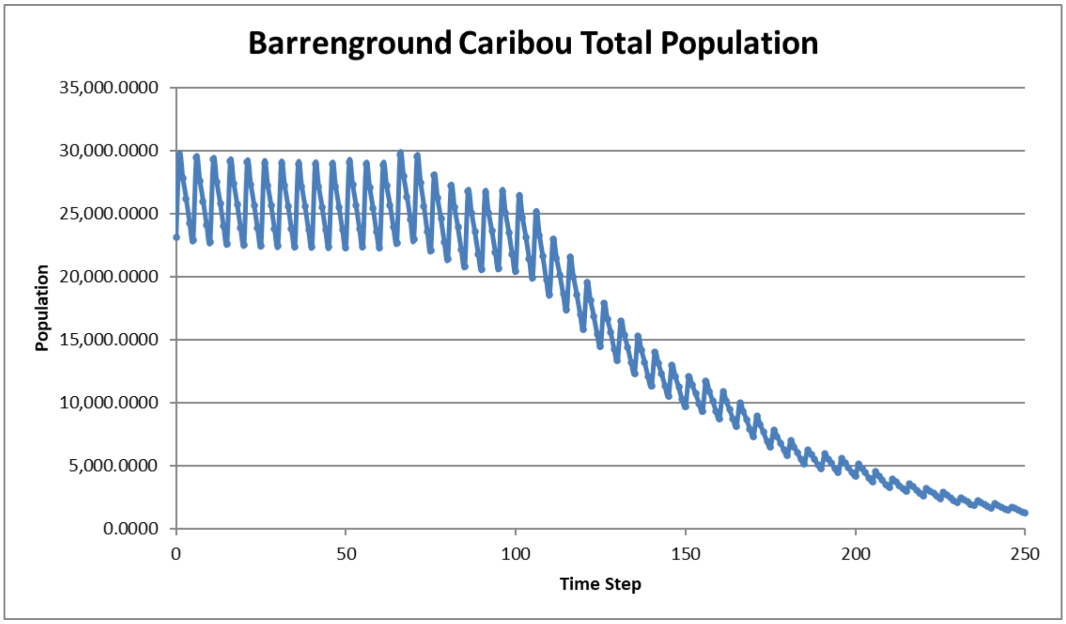


Figure 30. ALCES PopDyn output for population response of the Tuktoyaktuk Peninsula herd to the climate change and development scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps. The first 10 years (50 time steps) are a calibration period with constant conditions.

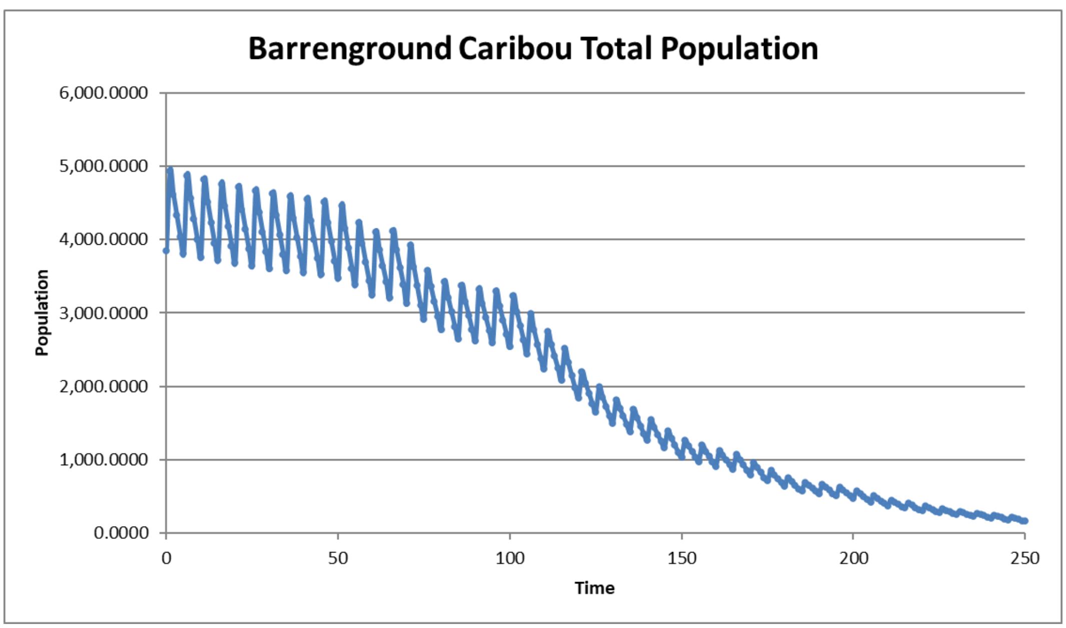


Figure 31. ALCES PopDyn output for population response of the Cape Bathurst herd to the climate change and development scenario. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps. The first 10 years (50 time steps) are a calibration period with constant conditions.

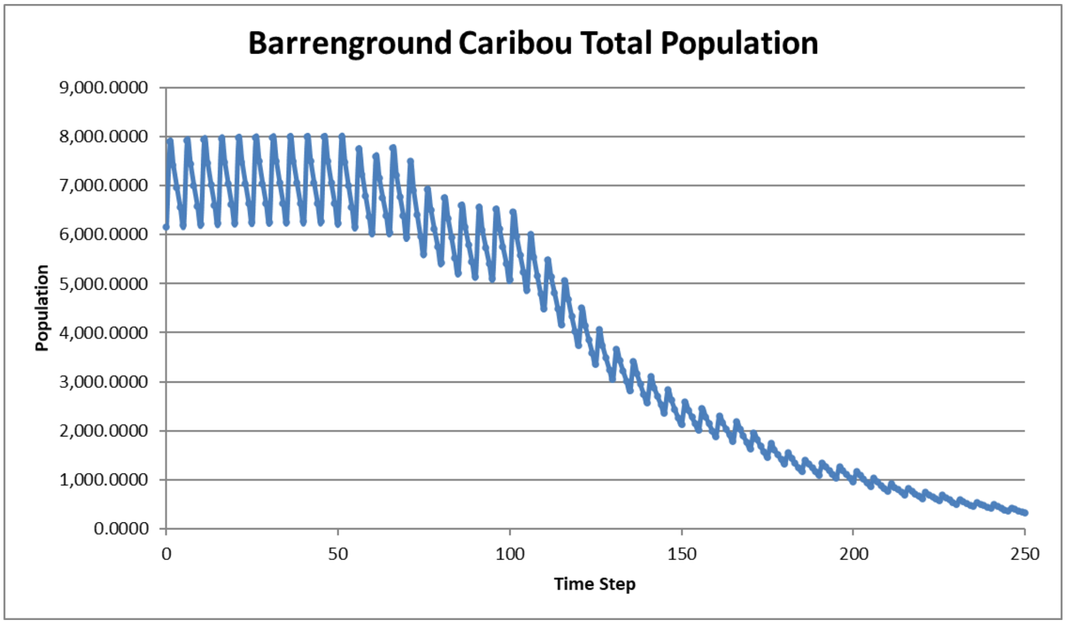


Figure 32. Screenshots from ALCES Online of Bluenose West total caribou population at the start and end of a 40 years simulation of the climate change and development scenario. Population maps are provided for each seasonal range.

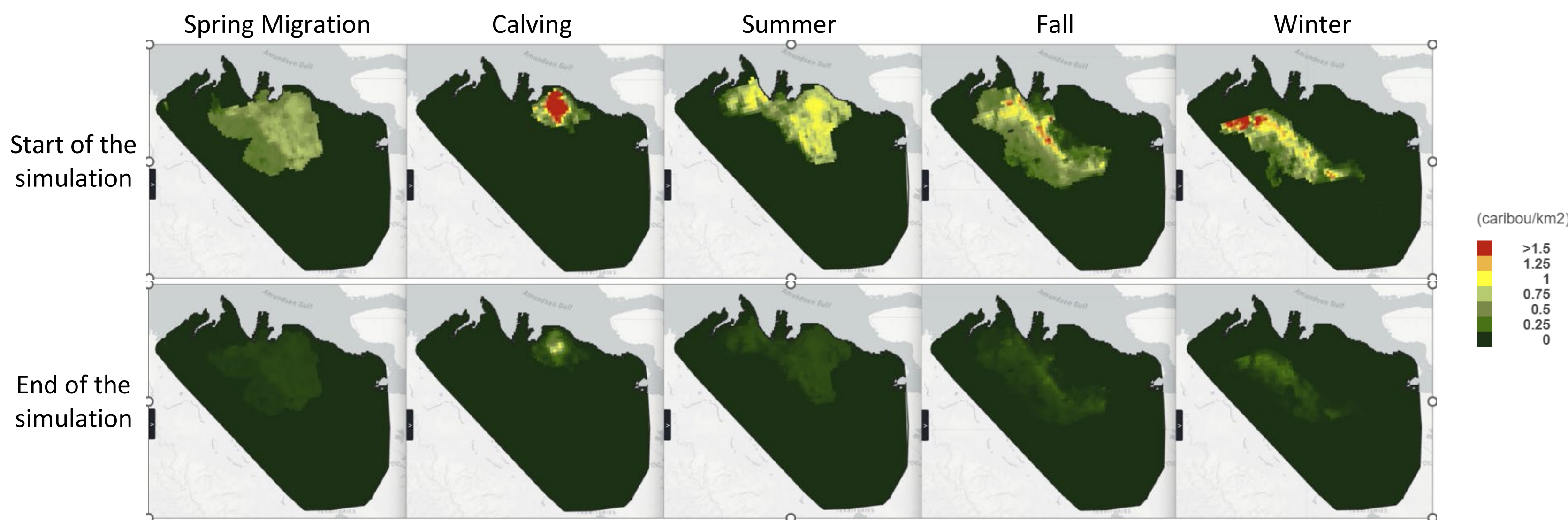


Figure 33. Screenshots from ALCES Online of Tuktoyaktuk Peninsula total caribou population at the start and end of a 40 years simulation of the climate change and development scenario. Population maps are provided for each seasonal range.

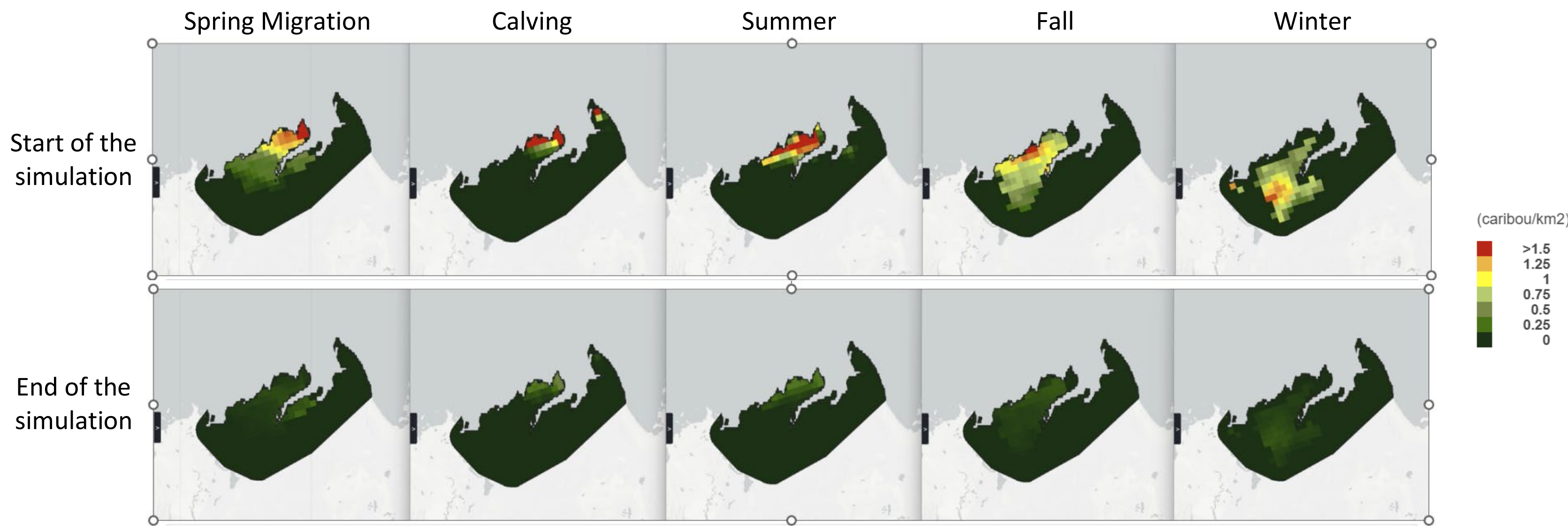


Figure 34. Screenshots from ALCES Online of Cape Bathurst total caribou population at the start and end of a 40 years simulation of the climate change and development scenario. Population maps are provided for each seasonal range.

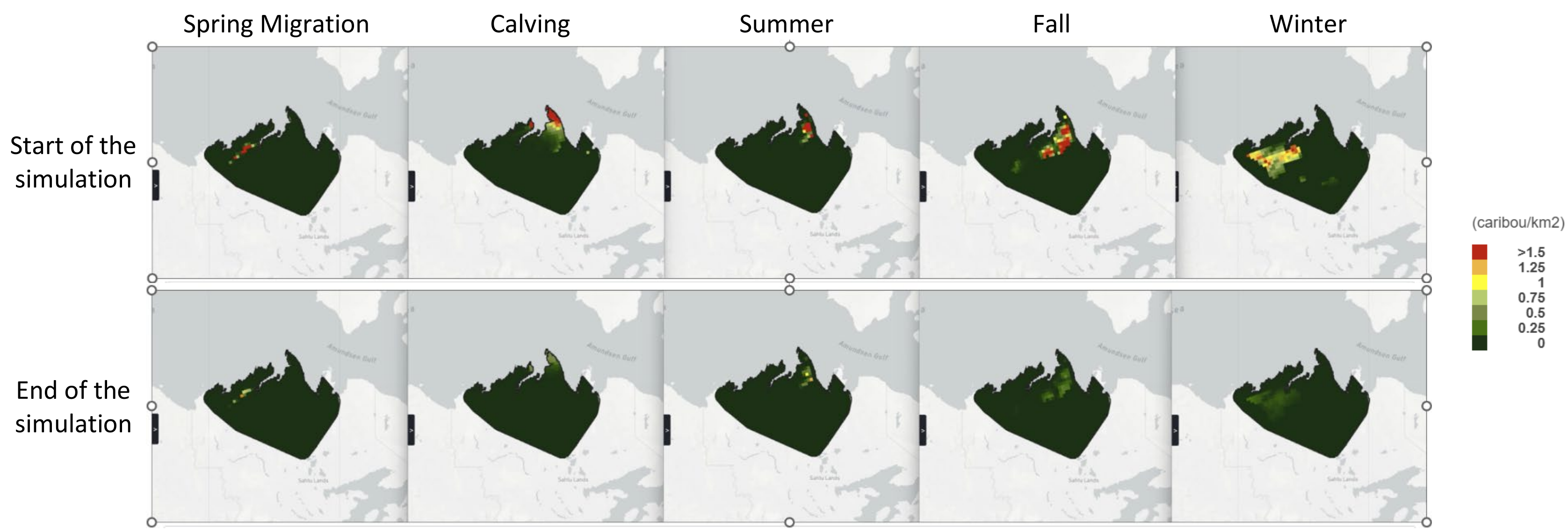


Figure 35. ALCES PopDyn output for the Tuktoyaktuk Peninsula herd population in the spring migration season under the constant conditions scenario and a scenario that modifies habitat in response to climate change (RCP 8.5 habitat). The difference between the scenarios illustrates the effect of climate-change-related habitat fluctuation on the simulated population trajectory. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps. The first 10 years (50 time steps) are a calibration period with constant conditions.

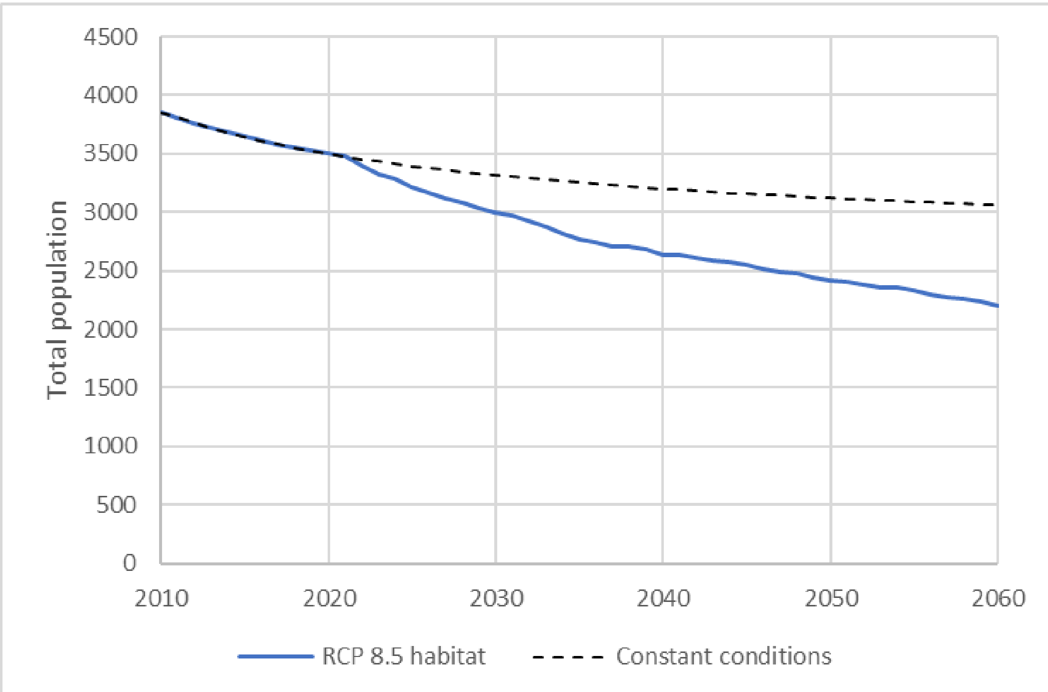
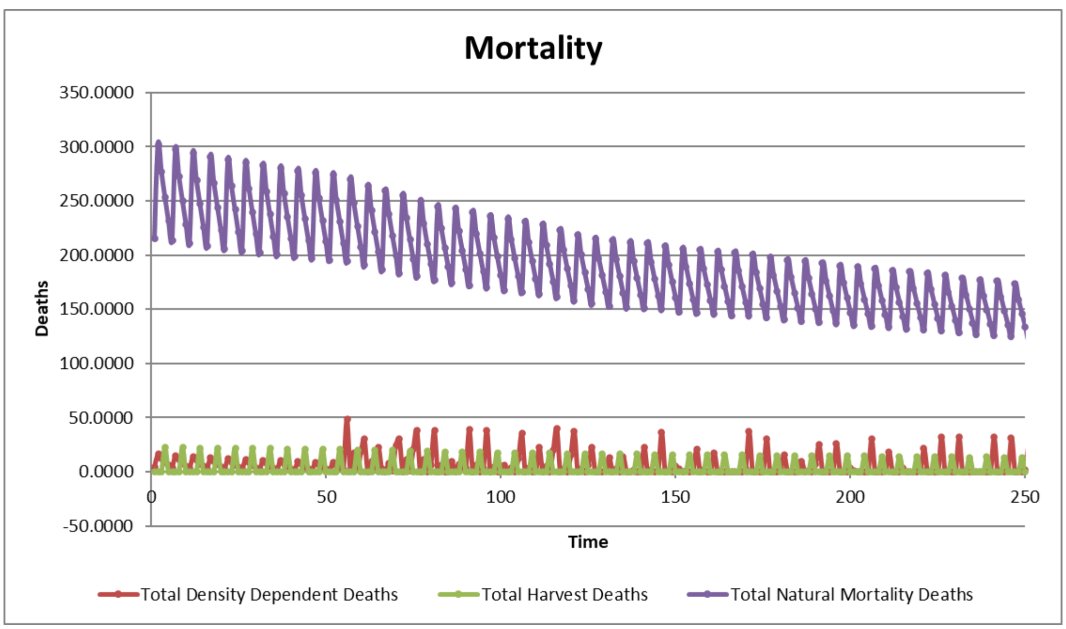


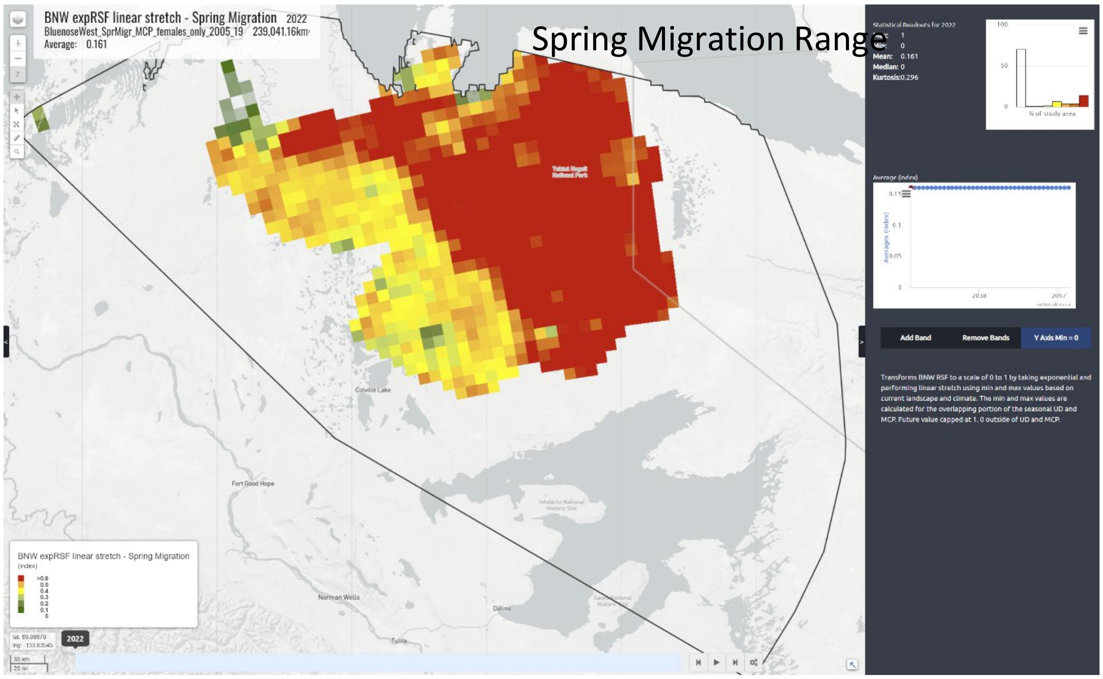
Figure 36. ALCES PopDyn output for Tuktoyaktuk Peninsula herd mortality during the constant conditions scenario. Density dependent deaths illustrate the effect of climate-change-related habitat fluctuations on mortality. The x-axis units (Time Step) refers to seasons (spring migration, calving, summer, fall winter), such that a 50-year simulation spans 250 time steps.



Appendix – Habitat Maps

The appendix presents habitat outcomes for the Bluenose West, Tuktoyaktuk Peninsula, and Cape Bathurst herds. Habitat outcomes for the Bluenose East herd are presented in the body of the report.

Figure 37. Screenshots from ALCES Online showing the seasonal (spring migration, calving, summer, fall, winter) habitat indices for the Bluenose West caribou herd. The maps are based on current landcover and climate. Habitat is set to 0 in cells outside of the seasonal range based on a kernel density function, and the study area is the seasonal range based on a minimum convex polygon (MCP). Legend values are from 0.1 (dark green) to >0.6 (red). The time series graphs to the right illustrate average response of the habitat index to the climate change and development forecast (2020 to 2060).



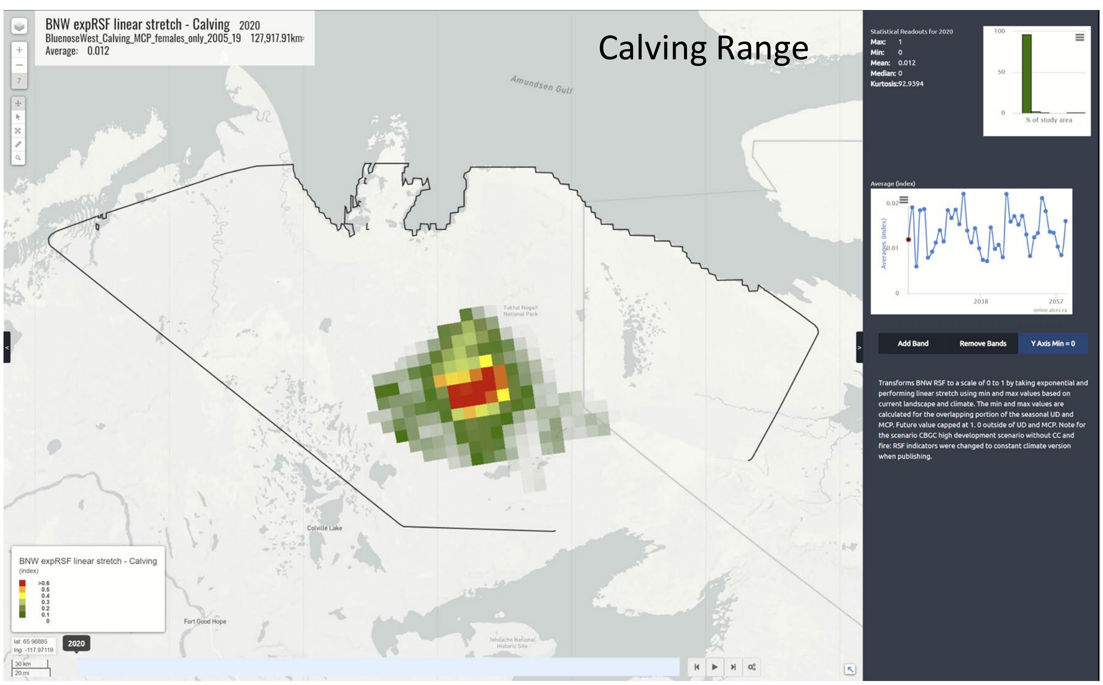
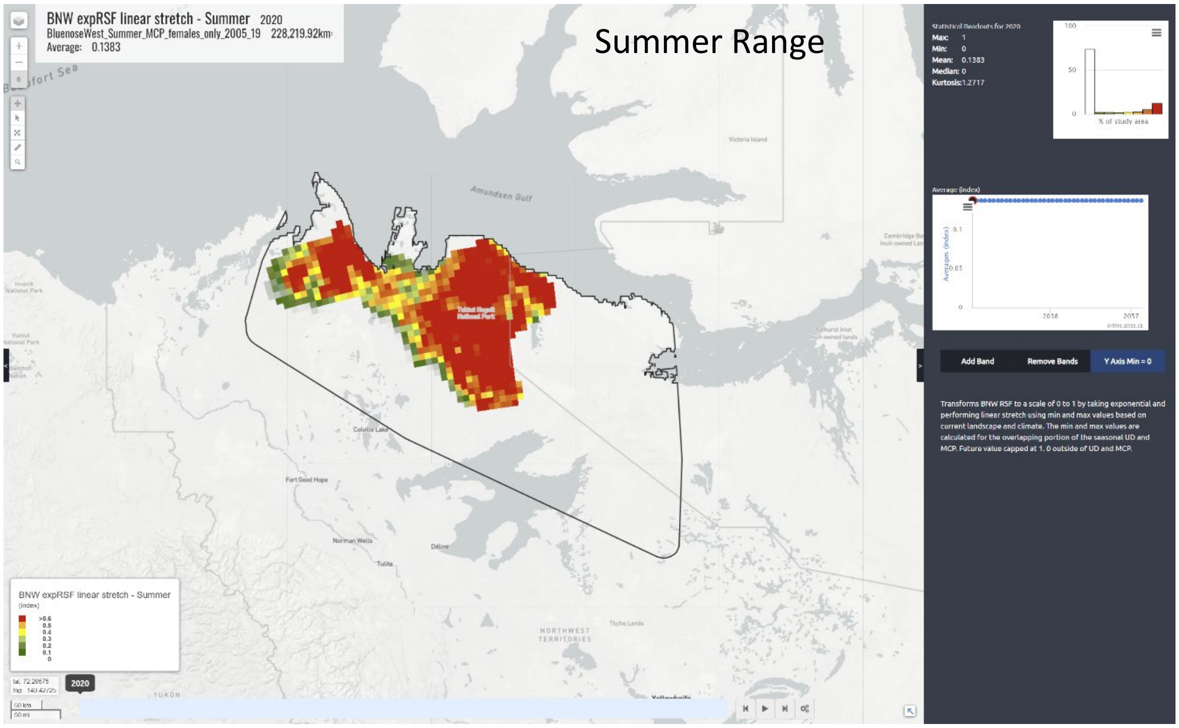
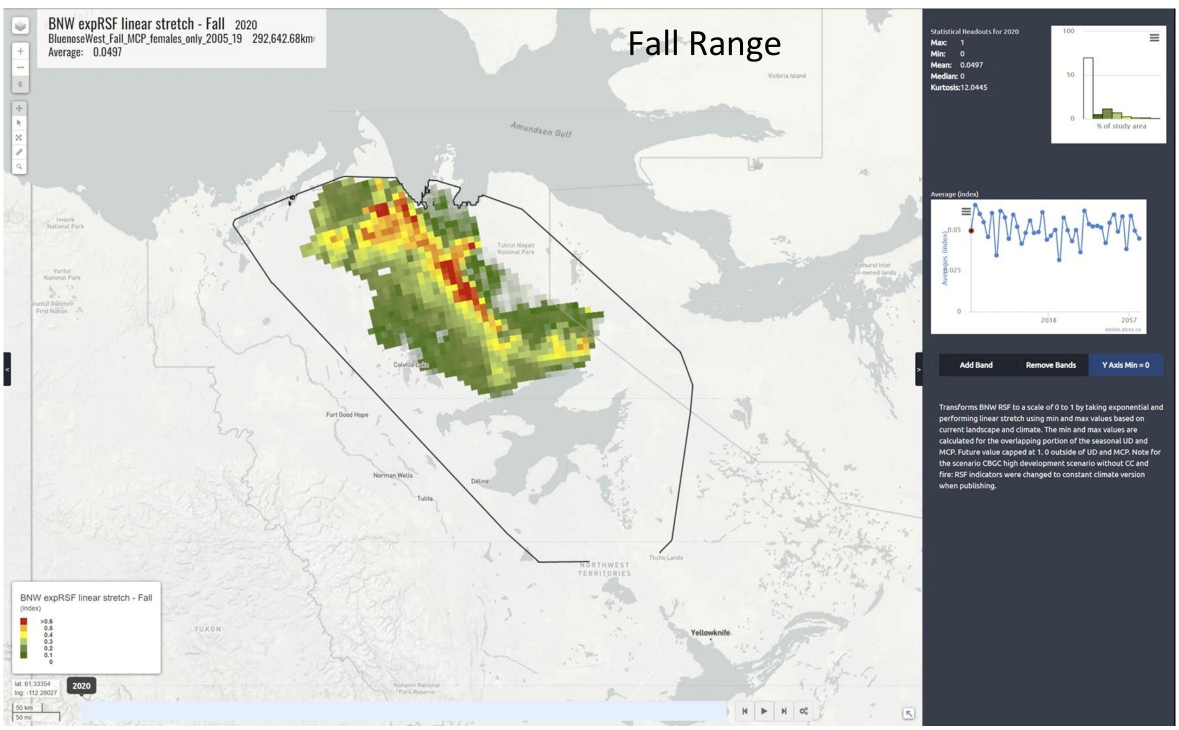


Figure 24 (continued)





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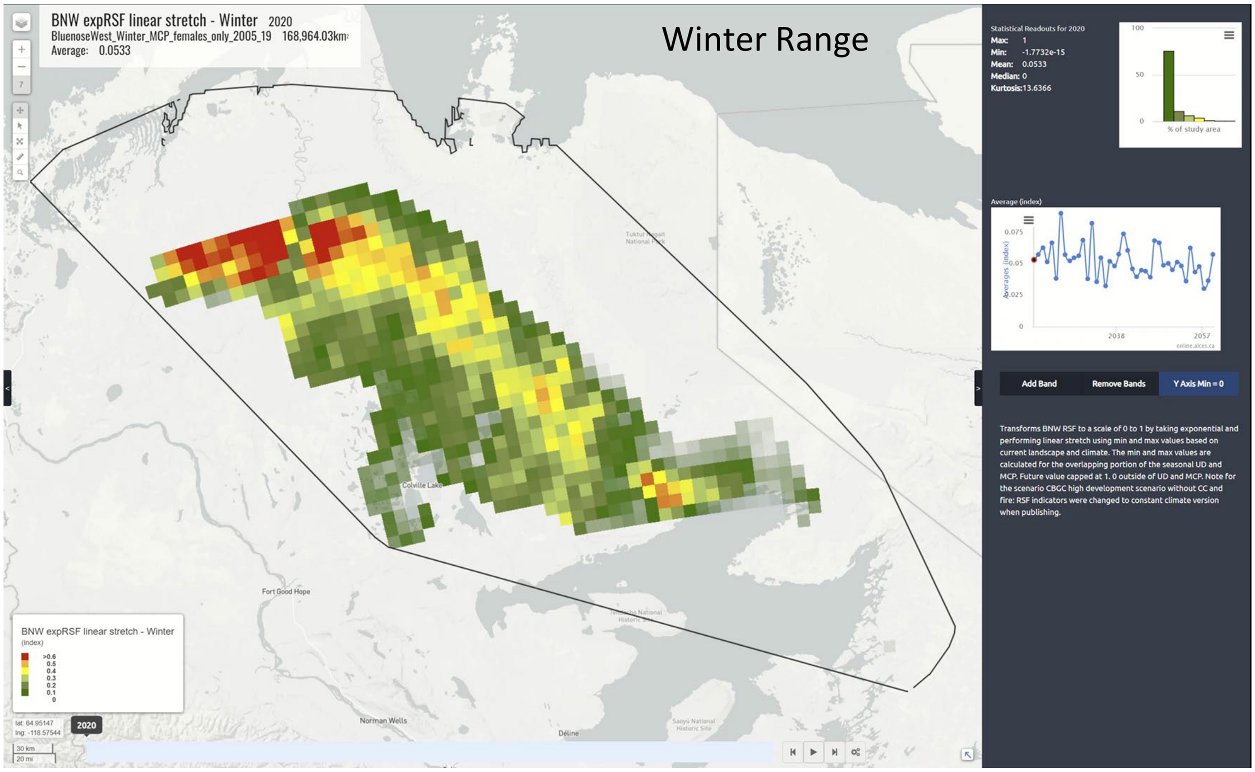
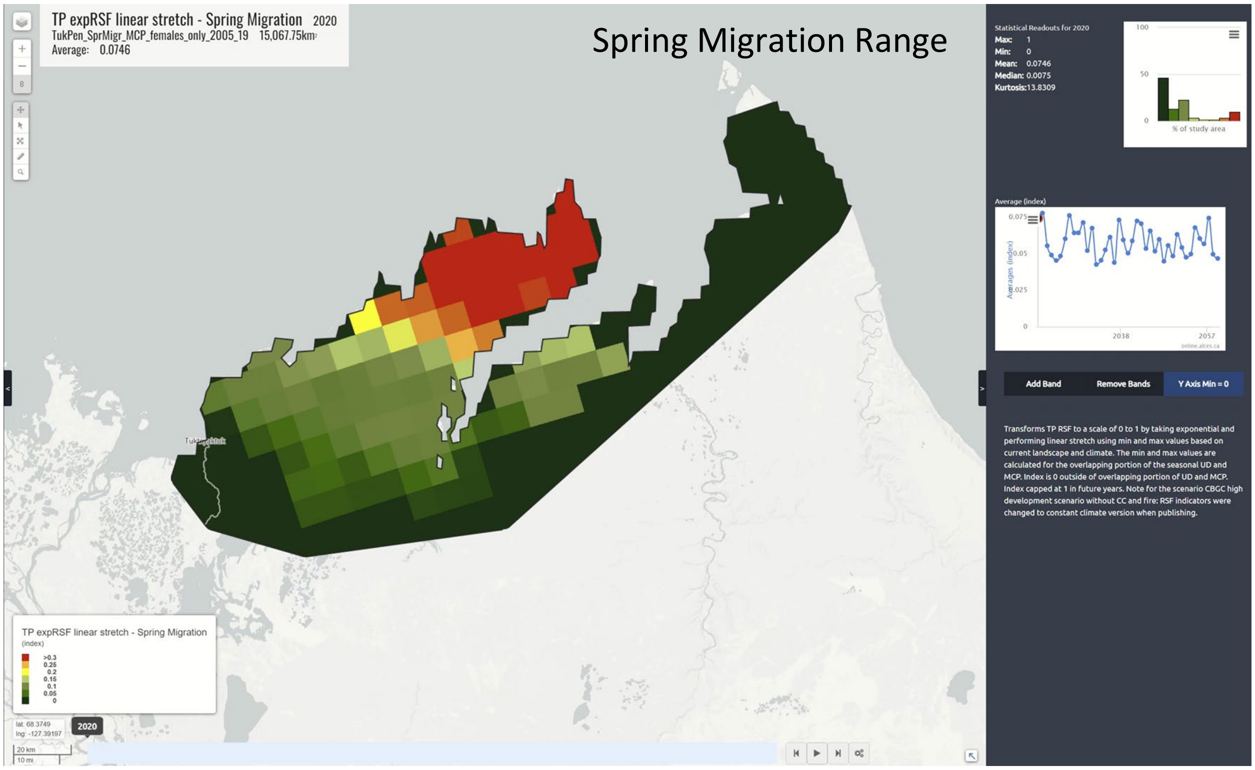


Figure 38. Screenshots from ALCES Online showing the seasonal (spring migration, calving, summer, fall, winter) habitat indices for the Tuktoyaktuk Peninsula caribou herd. The maps are based on current landcover and climate. Habitat is set to 0 in cells outside of the seasonal range based on a kernel density function, and the study area is the seasonal range based on a minimum convex polygon (MCP). Legend values are from 0.1 (dark green) to >0.6 (red). The time series graphs to the right illustrate average response of the habitat index to the climate change and development forecast (2020 to 2060).



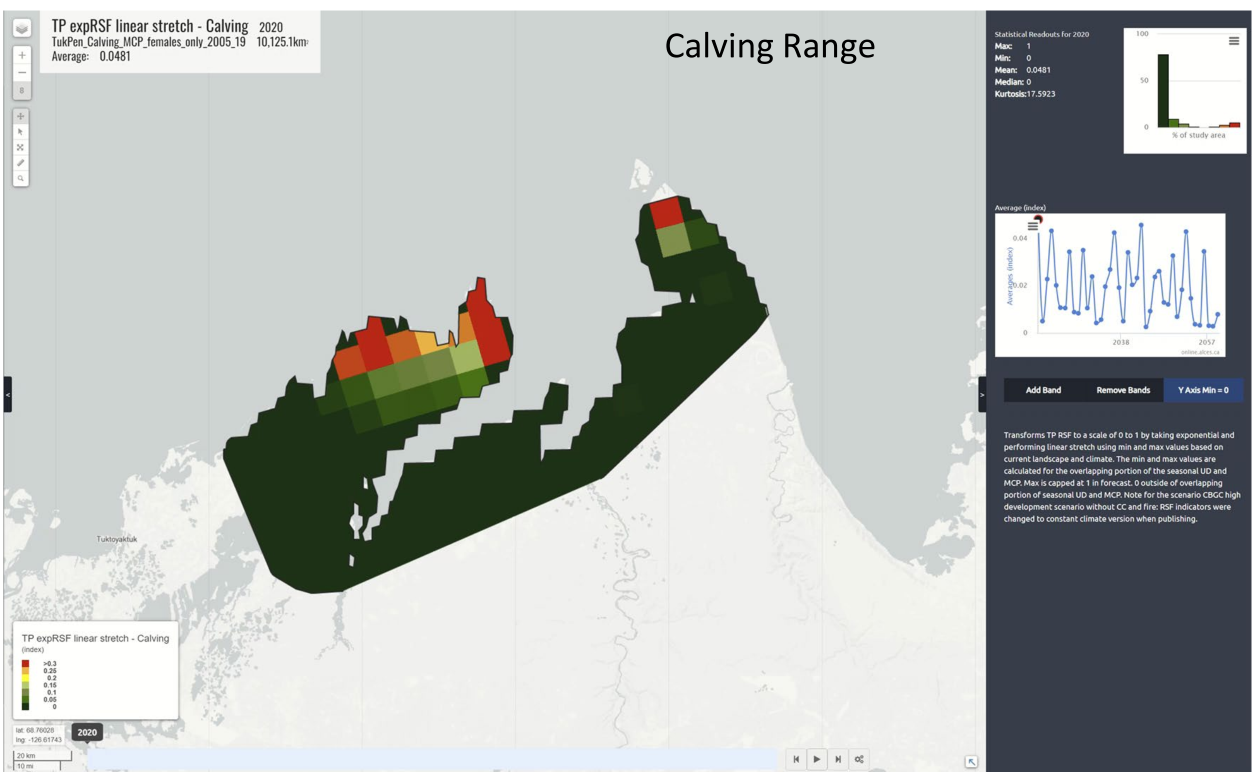
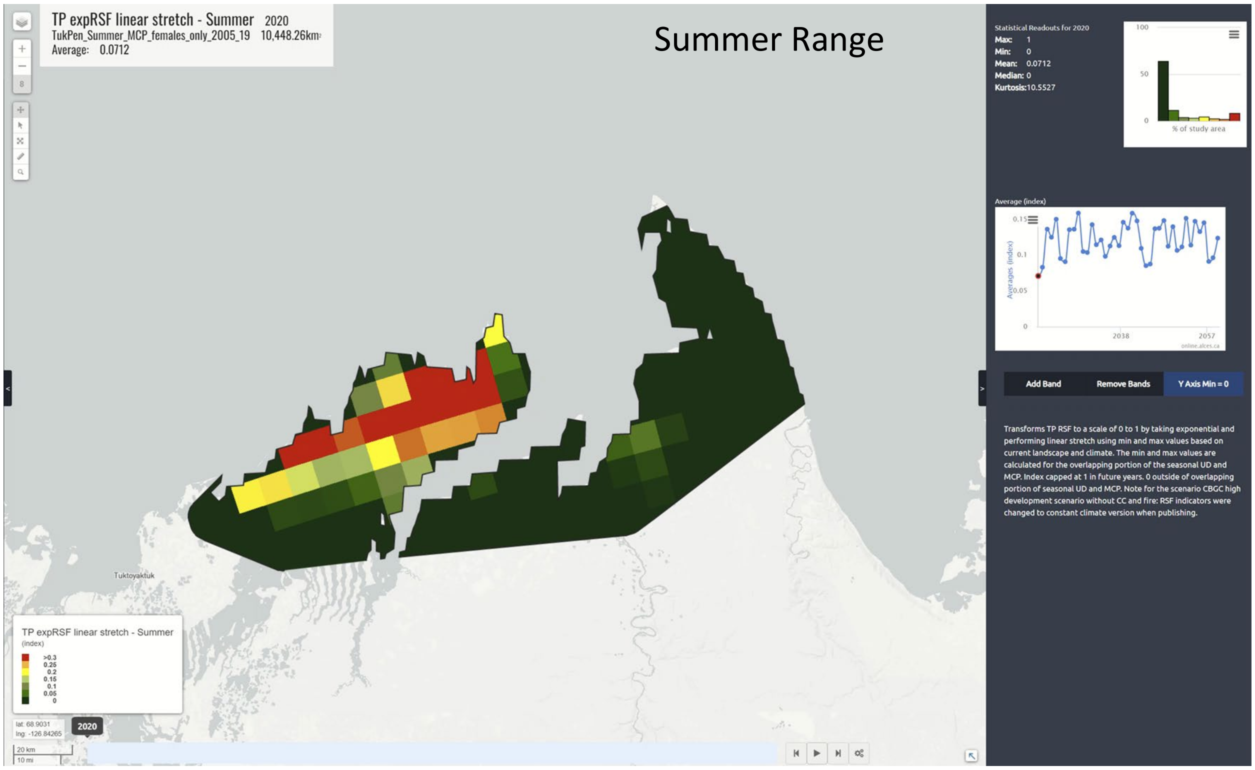


Figure 25 (continued)



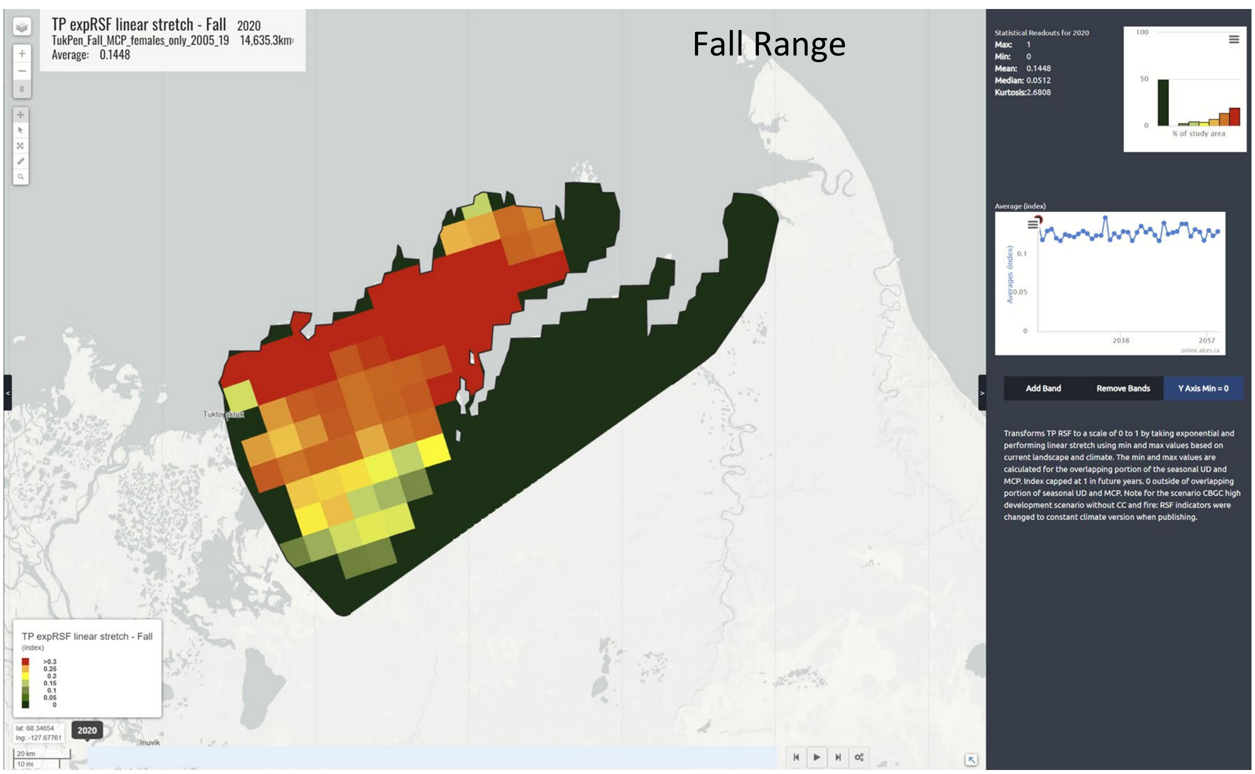


Figure 25 (continued)

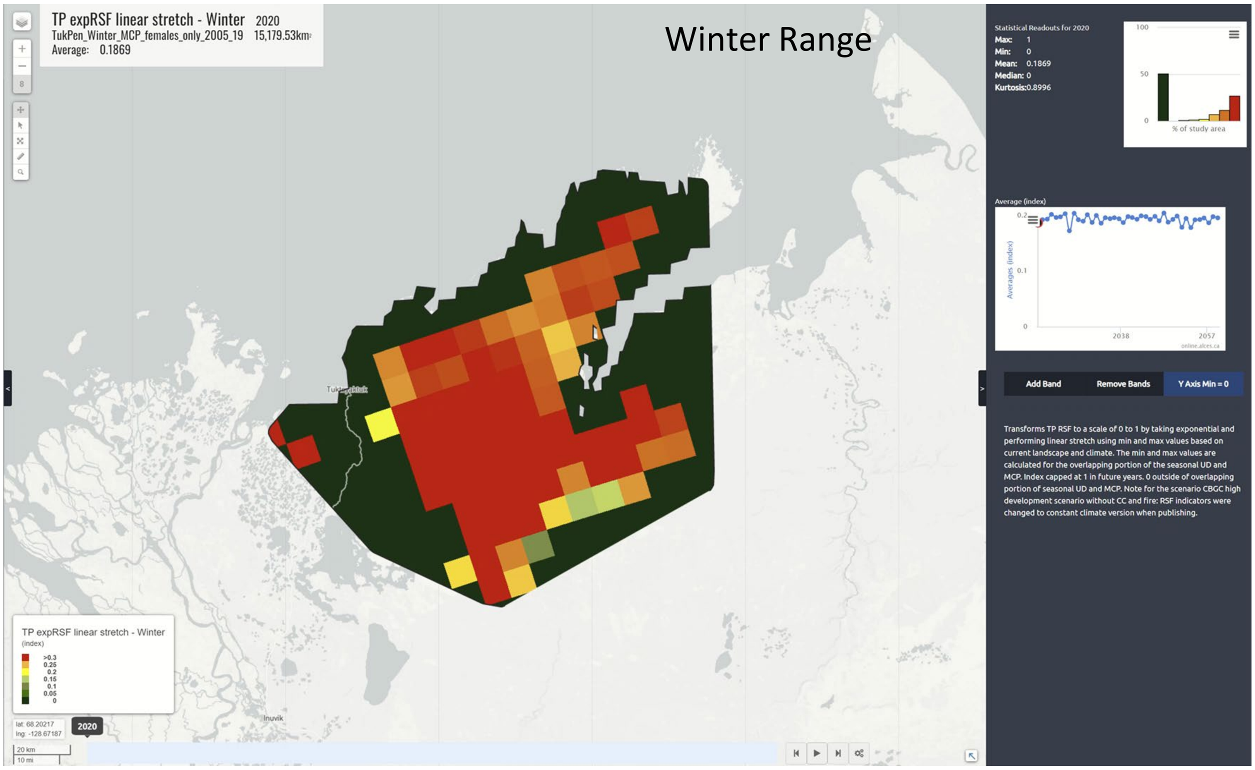
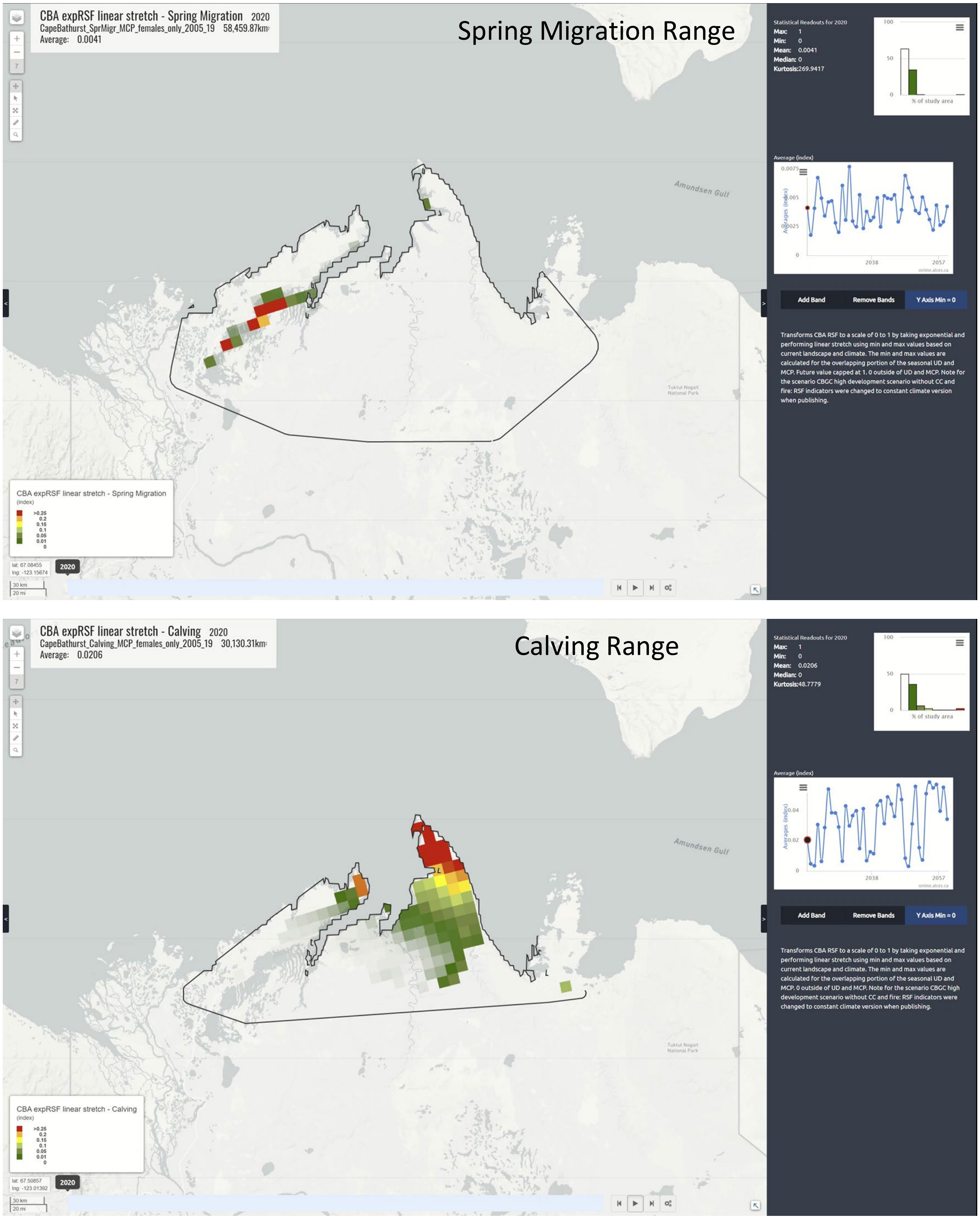


Figure 39. Screenshots from ALCES Online showing the seasonal (spring migration, calving, summer, fall, winter) habitat indices for the Cape Bathurst caribou herd. The maps are based on current landcover and climate. Habitat is set to 0 in cells outside of the seasonal range based on a kernel density function, and the study area is the seasonal range based on a minimum convex polygon (MCP). Legend values are from 0.1 (dark green) to >0.6 (red). The time series graphs to the right illustrate average response of the habitat index to the climate change and development forecast (2020 to 2060).



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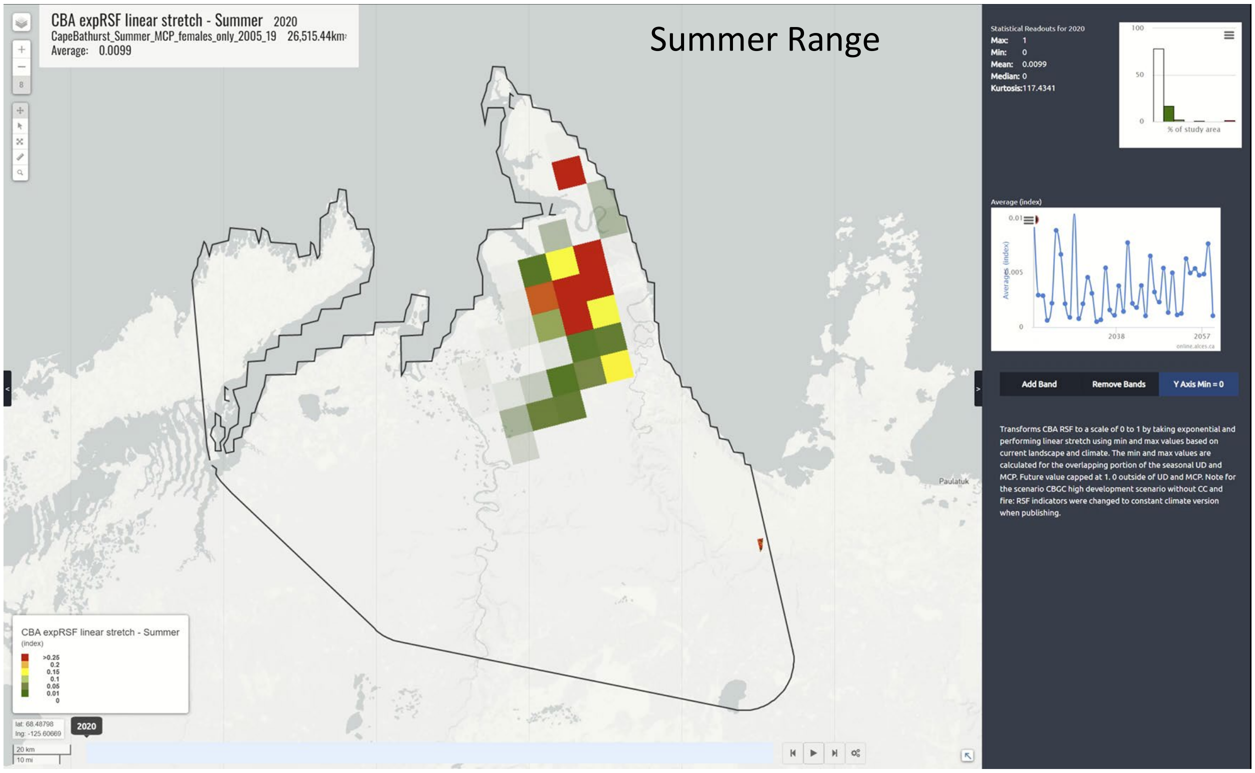

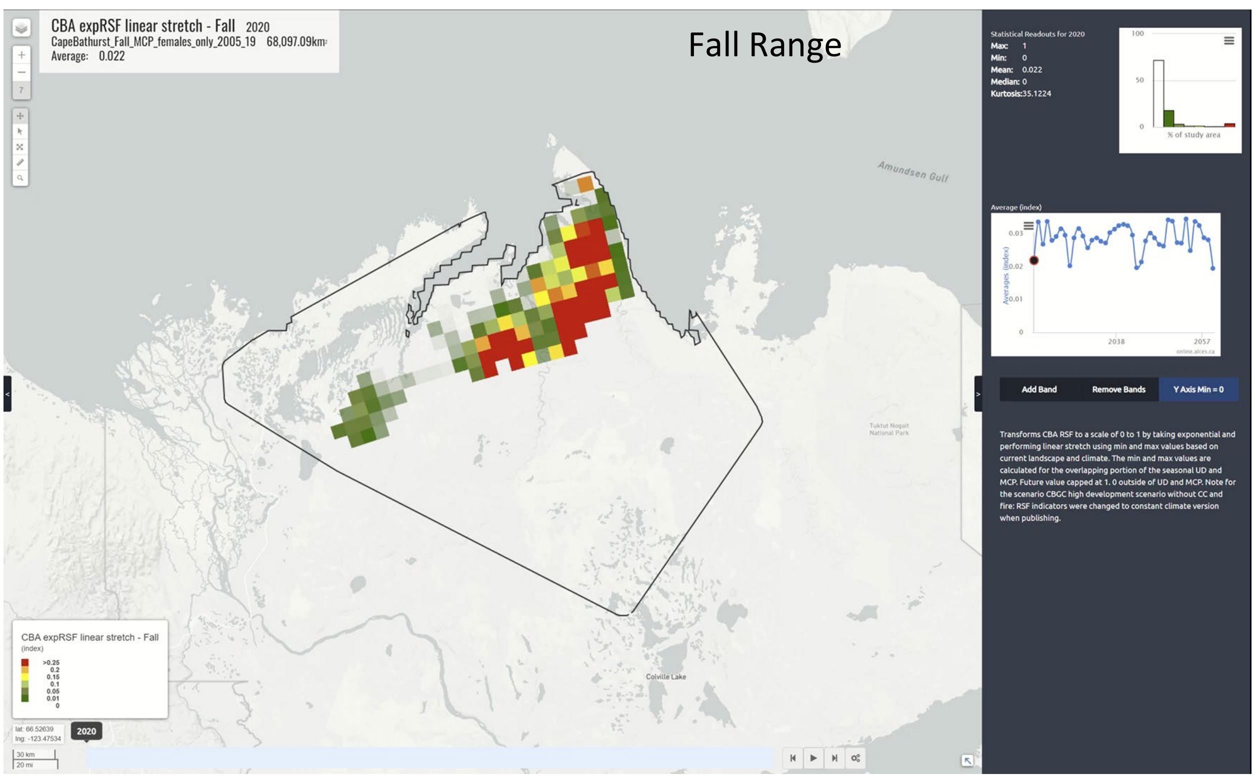

Figure 26 (continued)