Government of Northwest Territories Gouvernement des Territoires du Nord-Ouest

ESTIMATES OF BREEDING FEMALES & ADULT HERD SIZE AND ANALYSES OF DEMOGRAPHICS FOR THE BLUENOSE-EAST HERD OF BARREN-GROUND CARIBOU: 2021 CALVING GROUND PHOTOGRAPHIC SURVEY

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ABSTRACT

This report describes the results of a calving ground photo survey of the Bluenose-East barren-ground caribou herd conducted June 1-15, 2021 west of Kugluktuk, Nunavut. The main objectives were to estimate the numbers of breeding females, adult females, and adults in the herd, and to compare with results of previous calving ground surveys of this herd, the last in 2018. A calving ground survey of the Bathurst herd was carried out simultaneously, and results from that survey are reported separately.

Survey blocks flown by the photo planes were designed around the main concentrations of collared female caribou (25 known Bluenose-East, 30 newly collared in March 2021). Aerial photos over higher density areas were emphasized in part because snow cover in many areas was patchy, which created challenges for observers sighting caribou from survey aircraft. We expected that caribou on aerial photos would be found reliably, even with patchy snow cover. Survey blocks flown visually were designed to surround the photo blocks and to include a few outlying collared females; and fewer caribou were expected in these blocks. The photo survey blocks were flown with excellent field conditions (blue skies) on June 9 with coverage of 29 and 30%. On June 8 and 10, we surveyed the eight visual blocks with coverage of 15-20%. A helicopter-based composition survey was carried out June 11-14, 2021.

The estimates for the Bluenose-East herd in June 2021 were 12,863 (95%CI 10,816-15,298) breeding females, 13,991 (95%CI 11,805-16,585) adult females, and 23,202 (95%CI 19,247-20,822) adult caribou at least two years old. Estimates from 2018 were similar (not significantly different) at 11,675 (CI=9,971-13,670) breeding females, 13,988 (CI=12,042-16,249) adult females, and 19,294 caribou (95%CI=16,527-22,524) adult caribou at least two years old. The increase in estimated herd size was due to an increase in bulls as indicated by increasing fall bull-cow ratios; the adult female estimates indicated a stable population size.

These estimates suggest that the herd stabilized between 2018 and 2021, in contrast to the rapid decline observed from 2010 to 2018. Demographic indicators (adult cow survival rates, proportions of breeding females, bull:cow ratios, and calf:cow ratios) showed generally improved trends from 2015 to 2018 when compared to 2018 to 2021, consistent with stabilization indicated by the similarities between estimates from 2018 and 2021 calving ground surveys. Integrated Population Model analyses also suggested that the apparent stability of the Bluenose-East herd was partially due to increased calf productivity; however, adult female survival rates are still at levels lower than needed for herd recovery (increase).

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INTRODUCTION

This report describes results of a calving ground photo-survey of the Bluenose-East barren-ground caribou herd conducted in June 2021. This herd's calving ground (extent of calving area; see Russell et al. 2002) has been located in recent years west of Kugluktuk, and the summer range includes the calving ground as well as areas south and east of it. The herd's winter range is primarily south, southeast and east of Great Bear Lake (Figure 1). The Bluenose-East survey was conducted concurrently with a survey of the Bathurst calving ground; results of the Bathurst caribou survey are reported separately (Adamczewski et al. 2022c).

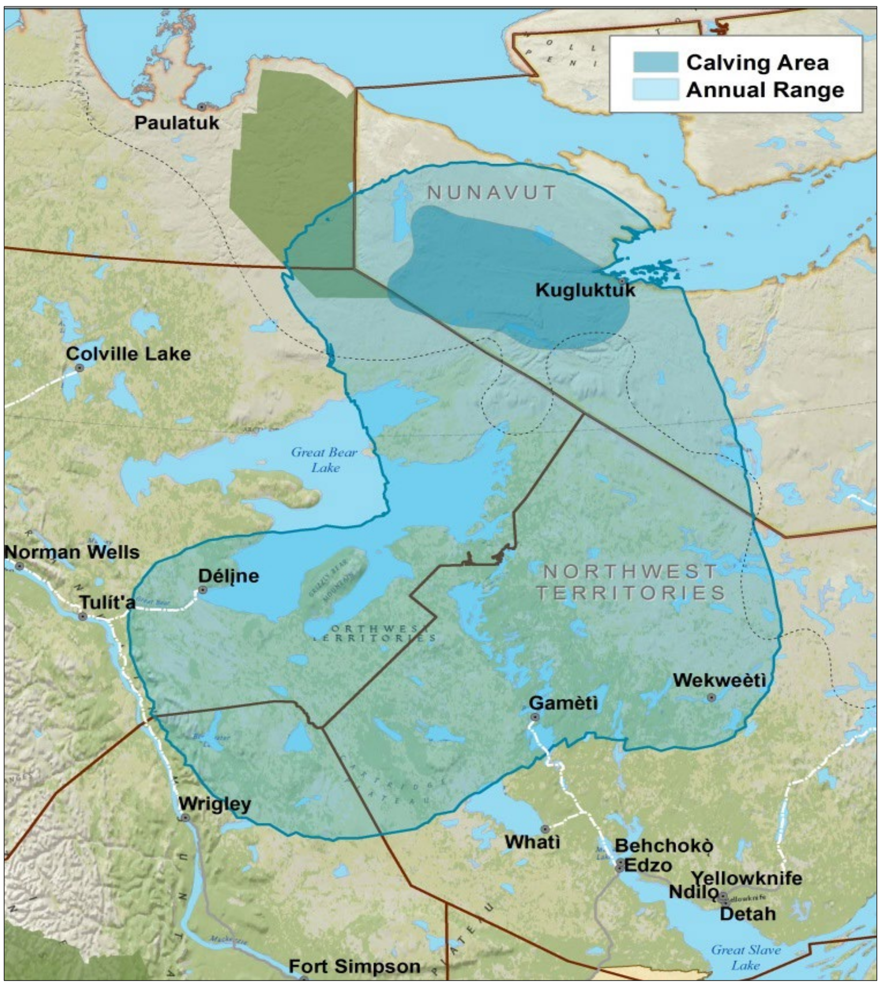

Figure 1. Annual range and extent of calving for the Bluenose-East herd, 1996-2009, based on accumulated radio collar locations of cows (Nagy et al. 2011). The calving area and a portion of the summer range are in Nunavut (NU) and the rest of the range is in the Northwest Territories (NWT).

In earlier years (2000-2010), post-calving surveys occurred for this herd (Patterson et al. 2004, Adamczewski et al. 2020) but surveys were challenged by the lack of consistent formation of the tightly packed caribou groups on which this type of survey is dependent. The Bluenose-East herd was surveyed in 2010 using both a calving ground photo-survey and a post-calving survey (Adamczewski et al. 2017). Both surveys in 2010 indicated that the herd was about 120,000 adult caribou. One further post-calving survey of this herd was attempted in 2012 but this survey failed due to lack of adequate aggregation in about half the herd. Since 2010, further calving ground photo surveys were successfully completed in 2013 (Boulanger et al. 2014b), 2015 (Boulanger et al. 2016) and 2018 (Boulanger et al. 2019). Based on these surveys, the herd was previously declining at an approximate rate of 20% per year 2010-2018 (Figure 2).

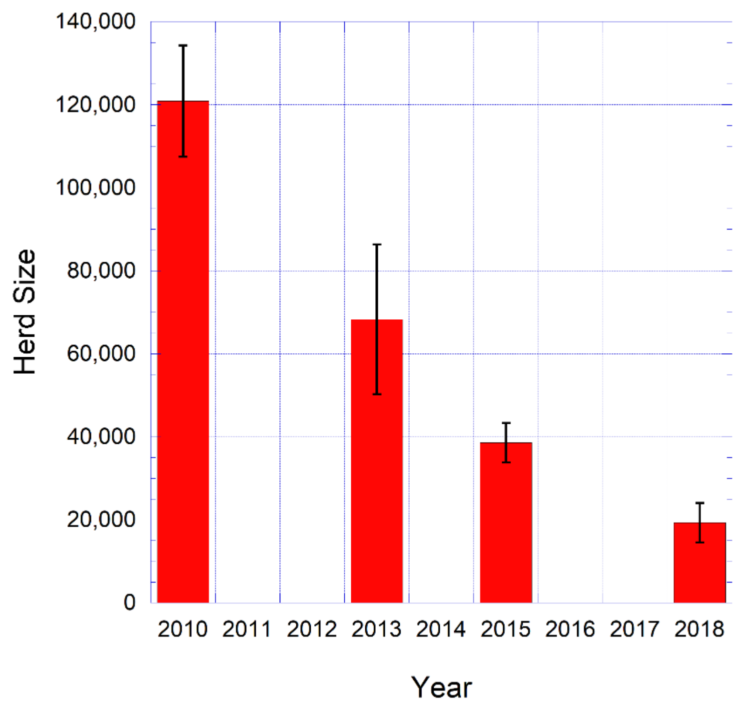

Figure 2. Extrapolated herd size in the Bluenose-East herd from 2010, 2013, 2015 and 2018 calving ground photo surveys.

Following the large decline detected during the 2018 survey of the Bluenose-East herd, the GNWT and the Tłı̨chǫ Government submitted a proposal to the Wek'èezhìı Renewable Resources Board (WRRB) to conduct more intensive monitoring of the herd, which was supported by the board (WRRB 2019). This included population surveys at two-year intervals rather than 3 years.

METHODS

Survey Limitations Resulting from COVID-19 Restrictions

Calving ground surveys of the Bathurst and Bluenose-East caribou herds were planned for June 2020, two years after the 2018 surveys. However, the global COVID-19 pandemic that began in early 2020 affected many people and processes world-wide, including some field work planned by ENR. Calving grounds of the Bathurst and Bluenose-East herds are both in NU and the main base of operations for surveys in June 2015 and 2018 was Kugluktuk. In the early months of 2020, travel restrictions in NU did not allow for NWT survey crews to travel into NU. As a result, the surveys planned for June 2020 were postponed to June 2021.

The shifting COVID-19 situation created challenges, as survey crews from the NWT would need to follow public health requirements in both territories. An approach that was acceptable to the Government of Nunavut (GN) public health office for the June calving ground surveys included use of the Coppermine Inn in Kugluktuk as an isolation "bubble" where survey participants would stay when not flying. All survey participants were from the NWT and were fully vaccinated against COVID-19.

COVID-19 requirements also affected the operations of the aerial photo planes. In June 2015 and 2018, these aircraft were based in Kugluktuk, but in 2021 the company had to base their aircraft in Yellowknife due to NWT and NU COVID-19 related travel restrictions. This change meant that the photo aircraft had a lengthy ferry flight to the two survey areas. In 2018 the aircraft were able to complete all aerial photos for the Bathurst and Bluenose-East calving grounds in one day. This was not possible in 2021, and a full day for aerial photos was needed for each of the two calving grounds.

In addition, a third Caravan survey aircraft could not be based at the Ekati mine-site in 2021 (as was used in 2018) due to COVID-19 constraints. Two Cessna Caravan aircraft based out of Kugluktuk were used for both Bathurst and Bluenose-East calving ground surveys.

Concerns over COVID-19 also influenced the decision of observers from some communities to participate. There were no community observers on the June 2021 surveys from Délı̨nę or Łutsel K'e, in large part due to COVID-19 concerns.

Collared Caribou Data

Twenty-five known Bluenose-East collared female caribou (or cows) were key to survey planning during the June 2021 survey. There were also 30 unassigned collared cows in the survey area west of Kugluktuk. In this context, "known" indicates collared cows whose location the previous year in June was known as being on the Bluenose-East calving ground. New collars on female caribou are usually placed in March when there can be substantial herd mixing, thus their earliest possible assignment to a herd will be that year in June when they normally separate out to the distinct calving grounds. Their previous history is unknown. Given the clear association of the unassigned cow collars with the Bluenose-East calving ground, effectively there were 55 collared Bluenose-East collared female caribou at the time of the June survey.

Movement rates of the collared females were monitored daily to help identify the timing of the peak of calving. Previous work (Boulanger et al. 2016, 2019) had shown that average daily movement rates of collared cows dropping and then staying below 5 km/day for a week or longer is a reliable indicator of the peak of calving. We also had information from two short reconnaissance flights carried out by Caravan on June 2 and June 4 in the Bluenose-East core calving area to check on the status of calving.

Reconnaissance Survey and Time Limitations

Unlike previous calving ground surveys for this herd, we did not fly a systematic reconnaissance survey to define distribution, relative numbers of caribou and approximate composition of caribou seen (breeding and non-breeding cows, calves, yearlings, bulls). This change from previous surveys was made largely because weather between June 2 and 7 was poor and little flying was possible. An assessment of time needed to complete the reconnaissance survey of both herds indicated that one and a half days would be needed for the Bathurst and a full day for the Bluenose-East calving ground. The main survey flying on these surveys is best timed over the 7-10 days during and after the peak of calving when cow movement rates remain low. A good weather window forecast for June 9 and 10 provided the opportunity to carry out the aerial photography on the Bathurst and Bluenose-East calving grounds. Consequently the reconnaissance survey was not flown and survey blocks[1] were designed around locations of collared female caribou for both calving grounds. Good weather days were used to fly photo and visual blocks June 8-11.

Design of Photo and Visual Survey Blocks

Aerial photo blocks were designed around the larger concentrations of collared female caribou. This was done in part because previous calving ground surveys had shown that clusters of collared Bathurst or Bluenose-East females reliably identified areas of concentration of female caribou from each herd. In addition, a high number of collared cows (25 known, 30 unassigned) in the Bluenose-East survey area increased our confidence that the collared cow locations defined the main distribution of female caribou on the calving grounds reliably. An emphasis was placed on aerial photo coverage in part because snow cover during the survey period was variable and in many areas was patchy. The patchy snow cover created challenges for observers in the Caravans and we expected

[1] In this report, the terms survey stratum (strata) and survey block (blocks) are used interchangeably.

that caribou on aerial photos would be found reliably despite the poor snow conditions, as was the case in 2018 for this herd (Boulanger et al. 2019).

Targets for ground coverage and numbers of lines in photo blocks and visual blocks were designed to consider optimal allocation and to reduce variance, although optimal allocation was not formally possible due to the lack of a reconnaissance survey. These targets were based in part on previous Bluenose-East calving ground surveys. More effort (higher coverage) was assigned to strata with higher expected densities of caribou and results of previous surveys suggested that there should be a minimum of ten transects in each stratum and about 20 transects/stratum for higher density areas (Boulanger et al. 2019). The target for ground coverage for the two photo blocks was 30% and targets for visual strata were 15-20%.

For the photo blocks, scenarios under a range of photo plane survey altitudes (based on cloud ceilings) were considered with the goal of having the photo strata in each calving ground flown in a single day by two photo planes at target coverage levels, while keeping within the budgeted numbers of photos (Figure 3). The challenge with this exercise was that if survey planes flew at lower altitudes, coverage would be reduced with increases in the number of photos required. An algorithm in R was designed to generate an estimate of photos required, coverage, and kilometers flown on transect based on survey constraints across a range of survey altitudes. Transect orientations within strata, transect shapefiles, and coverage estimates were generated and cross-validated using the *dssd* R package (Marshall 2021). The general strategy used was to set a lower limit on coverage (20-30%) and assess the number of transects that could be flown at lower survey altitudes within a single day with two photo planes. Using this approach ensured acceptable coverage if lower survey altitudes were required with additional coverage if weather permitted higher altitudes.

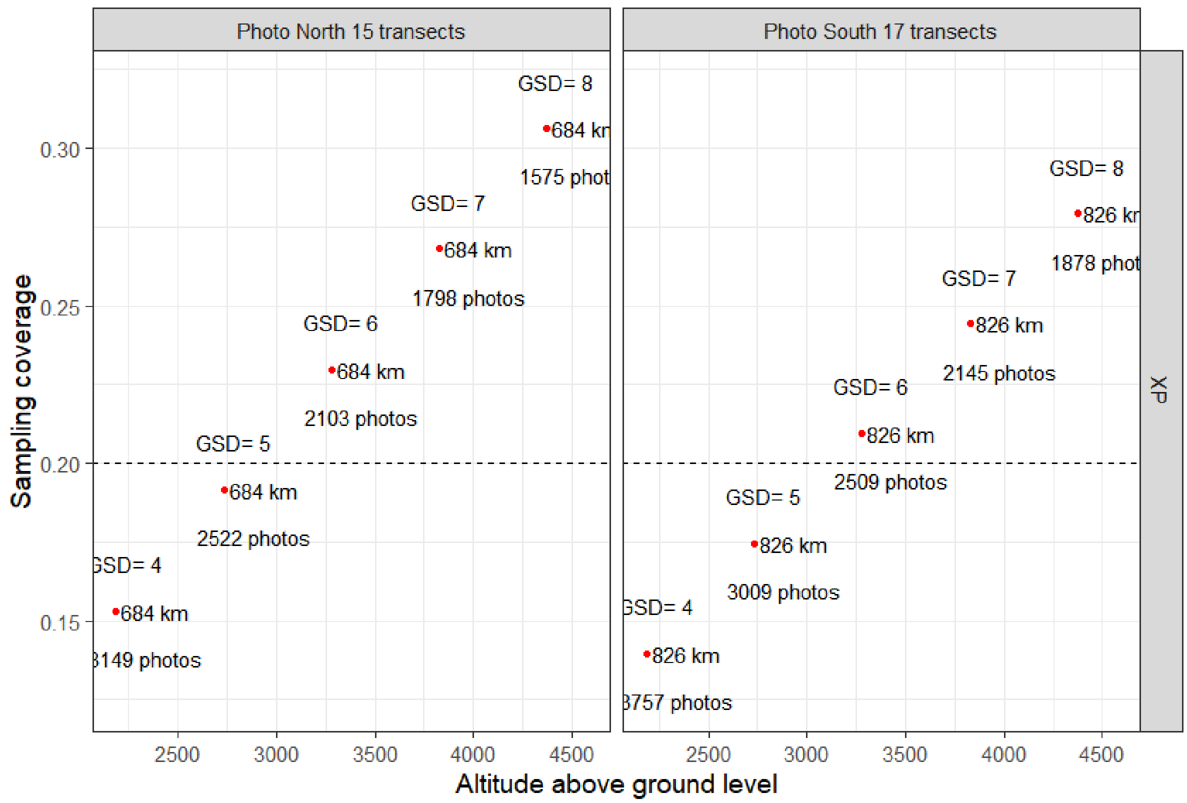

Figure 3. The relationships between coverage, altitude, GSD[2] and the number of photos required for coverage in the two Bluenose-East 2021 photo strata. Actual aerial photos were flown at GSD8 at about 4,300 feet above ground. At higher GSD and greater elevation, fewer photos are needed as strip coverage increases. We note that this relationship will vary depending on the dimensions of survey strata.

Survey strata were designed using ArcGIS (https://www.arcgis.com/index.html) and QGIS software (QGIS Foundation 2020) with transect lines drawn within strata using the *dssd* package (Marshall 2021) in program R (R core team 2018). Data were plotted using the *ggplot2* (Wickham 2009) with GIS manipulations using the simple features (*sf:* Pebesma 2018) R package.

Photographic Survey Blocks and Photo Interpretation

Two survey aircraft, a Piper PA46-310P Jet-prop DLX and a Piper PA31-310 Panther Navajo (Figure 4), each with a belly-mounted digital camera were used for the photo survey. The camera systems were from Vexcel Imaging in Graz, Austria (https://www.vexcel-imaging.com) and the cameras had a large format (17,310 x 11,310 pixels) analogous to an aerial film format of 23 cm x 15 cm scanned at 13 microns. The

[2] GSD is Ground Sample Distance, a term used in aerial photography for the distance between two consecutive pixel centers measured on the ground. Further information can be found at: https://support.pix4d.com/hc/en-us/articles/202559809-Ground-sampling-distance-GSD-in-photogrammetry

cameras are integrated into gyro-stabilized camera mounts and use imbedded airborne GPS (global positioning systems) and IMUs (inertial measurement units) to provide direct georeferenced images[3].

Figure 4. Piper PA31 Panther Navajo aircraft, one of two planes used on the Bluenose-East photo survey in June 2021 by GeodesyGroup Inc.

The two aircraft operated from Yellowknife as a base and re-fueled in Kugluktuk for the Bluenose-East survey. Survey altitude above ground level (AGL) to be flown for photos was determined at the time of stratification based on cloud ceilings and desired coverage. Coverage on each photo transect was continuous and overlapping so that stereo viewing of the photographed areas was possible.

Caribou on the aerial photos were counted by a team of photo interpreters using specialized software and glasses that allowed three-dimensional viewing of photographic images. These methods were consistent with those used for the June 2015 and 2018 Bathurst and Bluenose-East aerial photos. The number of caribou counted was tallied by stratum and transect and the exact survey strip width of photo transects was determined using the geo-referenced digital photos.

The highly variable and patchy snow cover on the Bluenose-East calving ground area made counting caribou on the aerial photos more difficult. Caribou on snow-free ground were easy to see, but caribou on small snow patches or on their edges required extra effort to find. As in 2018, two approaches were used to address this challenge with the aerial photos: (1) observers took extra time to search all photos carefully, and (2) a double

[3] Description provided by P. Gropp at GeodesyGroup in March 2022 is much more detailed and beyond the scope of this report.

observer method was used to estimate sightability of the caribou on photos for a subset of photos (Boulanger et al. 2019).

The double observer approach systematically resamples a subset of photos and estimates overall sightability in the stratum using a second independent photo interpreter. A target of about 200 photos was used, based on a similar re-analysis in 2018 (Boulanger et al. 2019). This two-stage approach to estimation, where one stage is used to estimate detection rates that are then used to correct estimates in the second stage, has been applied to a variety of wildlife species (Thompson 1992, Barker 2008, Peters et al. 2014). Systematic samples were taken by overlaying a grid over the photo transects and sampling photos that intersected the grid points.

This cross-validation process was modeled as a two-sample mark-recapture method with caribou being "marked" in the original count and then "re-marked" in the second count for each photo resampled. This approach avoids the assumption that the second counter detects all the caribou on the photo. The Huggins closed N model (Huggins 1991) in program MARK (White and Burnham 1999) was used to estimate sightability. A session-specific sighting probability model was used, allowing unique sighting probabilities for the first and second photo interpreter to be estimated. Model selection methods were then used to assess whether there were differences in sightability for different strata sampled. The fit of models was evaluated using the Akaike Information Criterion (AIC) index of model fit. The model with the lowest AIC_c score[4] was considered the most parsimonious, minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). Non-independence of caribou counted in photos most likely caused over-dispersion of binomial variances. The over-dispersion parameter (c-hat) was estimated as the ratio of the bootstrapped (photo-based) and simple binomial variance. Sightability-corrected estimates of caribou were then generated as the original estimate of caribou on each stratum divided by the photo sightability estimate for the stratum. The delta method (Buckland et al. 1993) was used to estimate variance for the final estimate, thus accounting for variance in the original stratum estimate and in the sightability estimate.

Visual Block Flying and Data Recording

Visual strata were surveyed from Caravan fixed-wing aircraft, following methods used in several previous calving ground surveys. Strip transects were 800 m in width, and caribou were counted within a 400 m strip on each side of the survey plane (Gunn and Russell 2008). For each side of the plane, strip width was defined by the wheel of the airplane on the inside, and a single thin rope attached to the wing strut that became horizontal during flight served as the outside strip marker. Planes were flown at an average survey speed of

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[4] The subscript "c" indicates an AIC score that is corrected for small sample sizes.

160 km/hour at an average altitude of 120 m above the ground to ensure that the strip width of the plane remained relatively constant.

Two observers, one seated in front of the other, and a recorder were used on each side of the airplane to minimize the chance of missing caribou (Figure 5). Previous research (Boulanger et al. 2010) demonstrated that two observers usually saw more caribou than a single observer. In addition, analysis of the sighting patterns of observer pairs allowed for assessment of what was likely missed (Boulanger et al. 2010, 2014a). Double observer methods have been used on other recent Bluenose-East calving ground photographic surveys (e.g. Boulanger et al. 2016, 2019). The two observers on the same side communicated to ensure that groups of caribou were not double counted. During visual survey flying, the intercom system was set up to separate the two sides of the aircraft, so that the two observers and recorder on each side could only hear participants on their side of the aircraft.

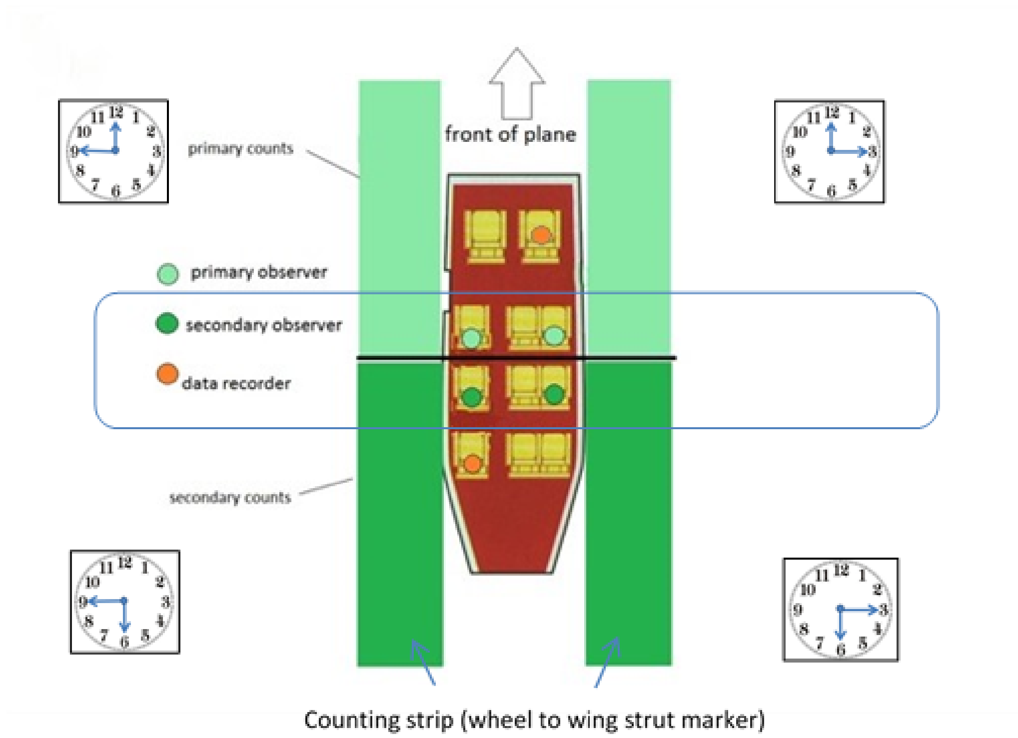

Figure 5. Observer and recorder positions for double observer methods on June 2021 caribou survey of Bluenose-East caribou. The secondary observer confirmed or called caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can be used to reference relative locations of caribou groups (e.g. "caribou group at 1 o'clock"). The recorder was seated behind the two observers on the left side, with the pilot in the front seat. On the right side the recorder was seated at the front of the aircraft and was also responsible for navigating in partnership with the pilot.

Visual surveys were conducted in eight strata that we expected to have lower densities of caribou based on numbers of collared caribou. These blocks surrounded the two photo blocks where higher caribou densities were expected.

Data were recorded on Trimble YUMA 2 tablets (Figure 6). Key attributes recorded were the numbers of caribou seen by each observer, and observations of the kind of caribou seen (newborn calves, cows with hard antlers, bulls, yearlings). Not all caribou could be classified from the Caravans due to the speed of the aircraft, and at minimum the number of adult caribou was recorded. For detailed classification, the helicopter-based composition data were used. As each data point was entered, a real-time GPS waypoint was generated, allowing geo-referencing of the survey observations. Observations of other large animals like moose, muskoxen, large carnivores and eagles were also recorded with a GPS location. Garmin 276cx GPS units were used that had a route to follow for each flight, and the track logs from these GPS units were recorded for mapping of survey flights. In addition, the pilots used their tablet GPS units with a ForeFlight program to enter and fly planned routes.

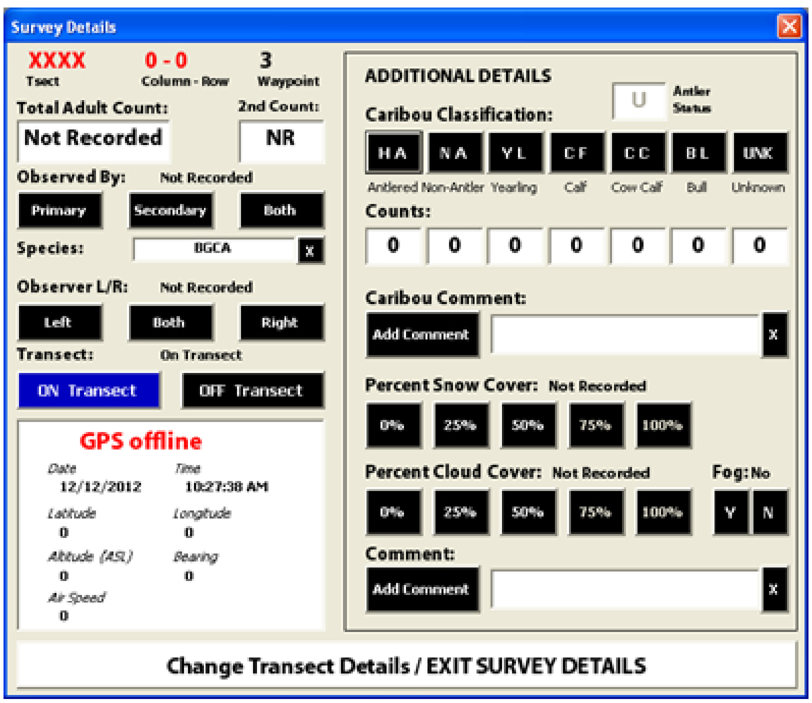

Figure 6. The tablet data entry screen used during visual survey flying on the Bluenose-East June 2021 survey. The unique segment unit number was also assigned by the software for each observation to summarize caribou density and composition along transect lines. A GPS waypoint was recorded for each observation.

Helicopter-based Composition Survey

The composition survey was flown on June 11, 12, 13 and 14. The composition survey crew classified caribou groups from an A-star helicopter using motion-stabilized binoculars.

Classification was carried out in all eight visual blocks and the two photo blocks, with greater effort in the photo blocks where more caribou were expected.

Caribou were classified following the methods of Gunn et al. (1997) (and see Bergerud 1964, Whitten 1995) where antler status, presence/absence of an udder, and presence of a calf are used to categorize breeding status of females (Figure 7). Presence of a newborn calf, presence of hard antlers signifying recent or imminent calving, and presence of a distended udder were all considered as signaling a breeding cow that had either calved, was about to calve, or had likely just lost a calf. Cows lacking any of these criteria and cows with new (velvet) antler growth were considered non-breeders. Newborn calves, yearlings and bulls were also classified.

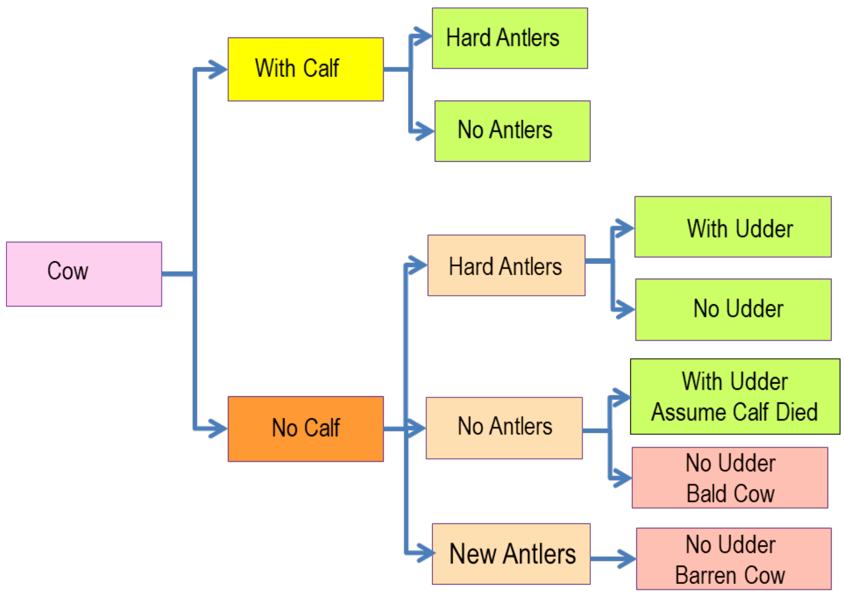

Figure 7. Classification of females used in composition survey of Bluenose-East caribou in June 2021. Green-shaded boxes were all classified as breeding females (diagram adapted from Gunn et al. 1997). Udder observation refers to a distended udder in a cow that has given birth or is about to. Hard antlers are from the previous year (usually white) and are distinct from new antlers growing in velvet (usually dark).

The numbers of female caribou in each group in the various classes were recorded as well as the numbers of newborn calves, bulls and yearlings (calves of the previous year). Bootstrap resampling methods (Manly 1997) were used to estimate standard errors and percentile-based confidence limits for the proportion of breeding caribou.

Estimation of Breeding Females, Adult Females and Adult Herd Size

The numbers of breeding females were estimated by multiplying the estimate of total caribou at least one year old on each stratum by the estimated proportion of breeding females in each stratum from the composition survey. This step essentially eliminated the non-breeding females, yearlings, and bulls from the estimate of total caribou on the calving ground.

The numbers of adult females at least two years old were estimated by multiplying the estimate of total caribou at least one year old on each stratum by the estimated proportion of adult females (breeding and non-breeding) in each stratum from the composition survey. This step essentially eliminated the yearlings and bulls from the estimate of total caribou on the calving ground. This estimate of adult females assumes that all breeding and non-breeding cows were within the survey blocks.

Each of the field measurements had an associated variance, and the delta method was used to estimate the total variance of breeding females under the assumption that the composition surveys and breeding female estimates were independent (Buckland et al. 1993).

Total herd size (adults at least two years old) was estimated by using the average of two recent estimates of the bull:cow ratio, from October 2020 and 2021, to extrapolate or "add on" the bulls to the estimate of adult females. This method of extrapolation was first used in the 2014 Qamanirjuaq caribou herd survey (Campbell et al. 2015), and has been used in other recent calving photo surveys for the Bluenose-East herd (Boulanger et al. 2016, 2019). This estimator uses the estimate of total adult females divided by the proportion of adult females in the herd from one or more fall composition surveys. This accounts for the bulls in the herd, very few of which are on the calving grounds in June. It makes no assumption about the pregnancy rate of the females and does not include the yearlings.

Trends in Numbers of Breeding Females, Adult Females and Herd Size

As an initial step, a comparison of the estimates from the 2018 and 2021 surveys was made using a simulation approach that assumed log-normal distributions of estimates to test for significance between survey estimates and generate confidence limits on overall (gross) change and yearly change in estimates (Manly 1997). One thousand simulations of estimates were generated from a log-normal distribution for each year. The proportion of simulations where gross change (the ratio of successive estimates) was >1 was tallied. If this proportion was <0.05 then a significant decline was suggested. Confidence limits were then derived based on the 2.5th and 97.5th percentile of the resulting distributions of gross change (GC) and annual change (with $\lambda = GC^{(1/\text{survey interval})}$). An underlying exponential rate of change was assumed with estimates of λ (where $\lambda = N_{t+1}/N_t$). If λ=1 then a population is stable; values > or <1 indicate increasing and declining populations. The rate of decline was also estimated as 1-λ.

Longer term trends (2010-2021) were estimated using Bayesian state space models, which are similar to previously used regression methods (Ordinary Least Squares, OLS, as described in Boulanger et al. 2011). However, hierarchical Bayesian models allow more flexible modeling of variation in trend through the use of random effects (Humbert et al. 2009, Kery and Royle 2016). This general approach is described further in the demographic model analysis in the next section.

Demographic Analyses: Bayesian State Space Integrated Population Model (IPM)

As with previous calving ground surveys of the Bluenose-East herd, demographic modeling was used to integrate the population estimates with information about herd vital rates to better understand the herd's demographics and trend. Up to 2017, an Ordinary Least Squares (OLS) model (White and Lubow 2002) was used for these analyses, as described by Boulanger et al. (2011) and updated after every calving ground photo survey. The Bayesian IPM (Buckland et al. 2004, Schaub and Kery 2022) was used after the 2018 Bathurst and Bluenose-East calving ground surveys (Adamczewski et al. 2019, Boulanger et al. 2019).

The Bayesian IPM uses a stage-based model that divides caribou into three age-classes, with survival rates determining the proportion of each age class that makes it into the next age class (Figure 8) and is identical to the previous OLS model. However, the Bayesian IPM method provides a much more flexible and robust method to estimate demographic parameters that takes into account process and observer error (see Thorley and Andrusak 2017, Ramey et al. 2018, Thorley and Boulanger 2019). One of the biggest differences is the use of random effects to model temporal variation in demographic parameters. A random effect flexibly and efficiently captures the variation in a parameter by assuming it is drawn from a particular underlying distribution with a central mean value. This contrasts with the OLS method where temporal variation was often not modeled or modeled with polynomial terms which assumed an underlying directional change over time.

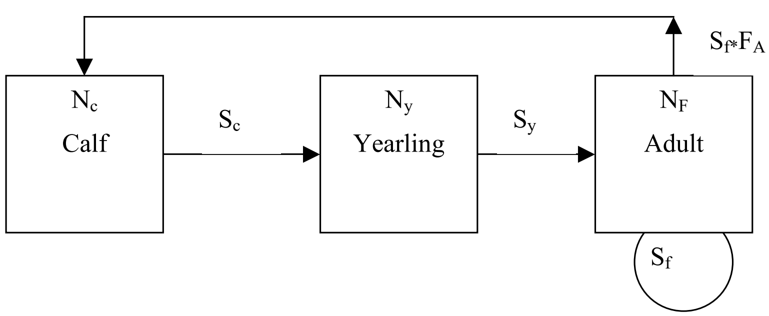

Figure 8. Underlying stage matrix life history diagram for the caribou demographic model used for Bluenose-East caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates of calves (S_c), yearlings (S_y) and adult females (S_f). Adult females reproduce dependent on fecundity (F_A) and whether a pregnant female survives to produce a calf (S_f). The male life history diagram was similar with no reproductive nodes.

We used breeding female estimates, as well as calf-cow ratios, bull-cow ratios (Adamczewski, Cluff et al. unpublished), estimates of the proportion of breeding females, and adult female survival rates from collared caribou to estimate the most likely adult female survival values that would result in the observed trends in all of the demographic indicators for the herd. Calf-cow ratios were recorded during fall (late October) and spring (late March/early April) composition surveys whereas proportion of breeding females was measured during June composition surveys conducted on the calving ground. Proportion of females breeding was estimated as the ratio of breeding females to adult females from each calving ground survey.

Collared caribou survival rates were estimated from caribou collar data between 2010 and 2021. Fates of collared caribou were determined by assessment of movement of collared caribou, with mortality being assigned to collared caribou based on lack of collar movement that could not be explained by collar failure or device drop-off. The data were summarized by month as live or dead caribou. Caribou collars that failed or were scheduled to drop off were removed from the analysis. Data were grouped by "caribou years" that began during calving of each year (June) and ended during the spring migration (May); for example, year 2020 began in June 2020 and ended in May 2021. The Kaplan-Meier method was used to estimate survival rates, accounting for the staggered entry and censoring of individuals in the data set (Pollock et al. 1989). This approach also ensured that there was no covariance between survival estimates for the subsequent demographic model analysis.

The entire Bluenose-East demographic data set (see Boulanger et al. 2019) was used for the analysis but modeling efforts were mainly focused on the more recent years, i.e. since 2018. It was assumed that a female calf born in a particular year would not breed in the fall after it was born, or the fall of its second year, but it could breed in its third year (see Dauphiné 1976 for age-specific pregnancy rates). Calves born in 2017 and 2018 had the most direct bearing on the number of new breeding females on the 2021 calving ground that were not accounted for in the 2018 breeding female estimate.

One potential issue with comparison of survival rates across years was that the Bluenose-East herd has had a continuing low level of harvest, although this was reduced as the herd declined after 2010. Harvest would affect cow and bull survival rates. We therefore added harvest rate to the model based on harvest estimates compared to estimated cow and bull abundance each year.

RESULTS

Survey Conditions

The Cessna Caravans with survey participants flew to Kugluktuk on the afternoon of June 1. Weather between June 2 and 7 was generally poor, with extensive low cloud and fog. Brief Caravan flights (about two hours each) were made over the Bluenose-East calving grounds June 2 and 4 to assess the status of calving. On June 8 weather improved and allowed Cessna Caravan flying, initially on the Bluenose-East calving ground on June 8 and 10, and on the Bathurst calving ground June 9-11. The photo-planes completed their work under blue skies on June 9 on the Bluenose-East calving ground and on June 10 on the Bathurst calving ground.

Caribou sighting conditions through the main survey period of June 9-11 were challenging due to a late spring with substantial snow cover remaining in the survey area (Figure 9). The snow cover varied from less than 5% to over 90% and some areas was a patchy mosaic. This made caribou more difficult to see, particularly small groups of one to ten, from Cessna Caravans flying at 160 km/hour.

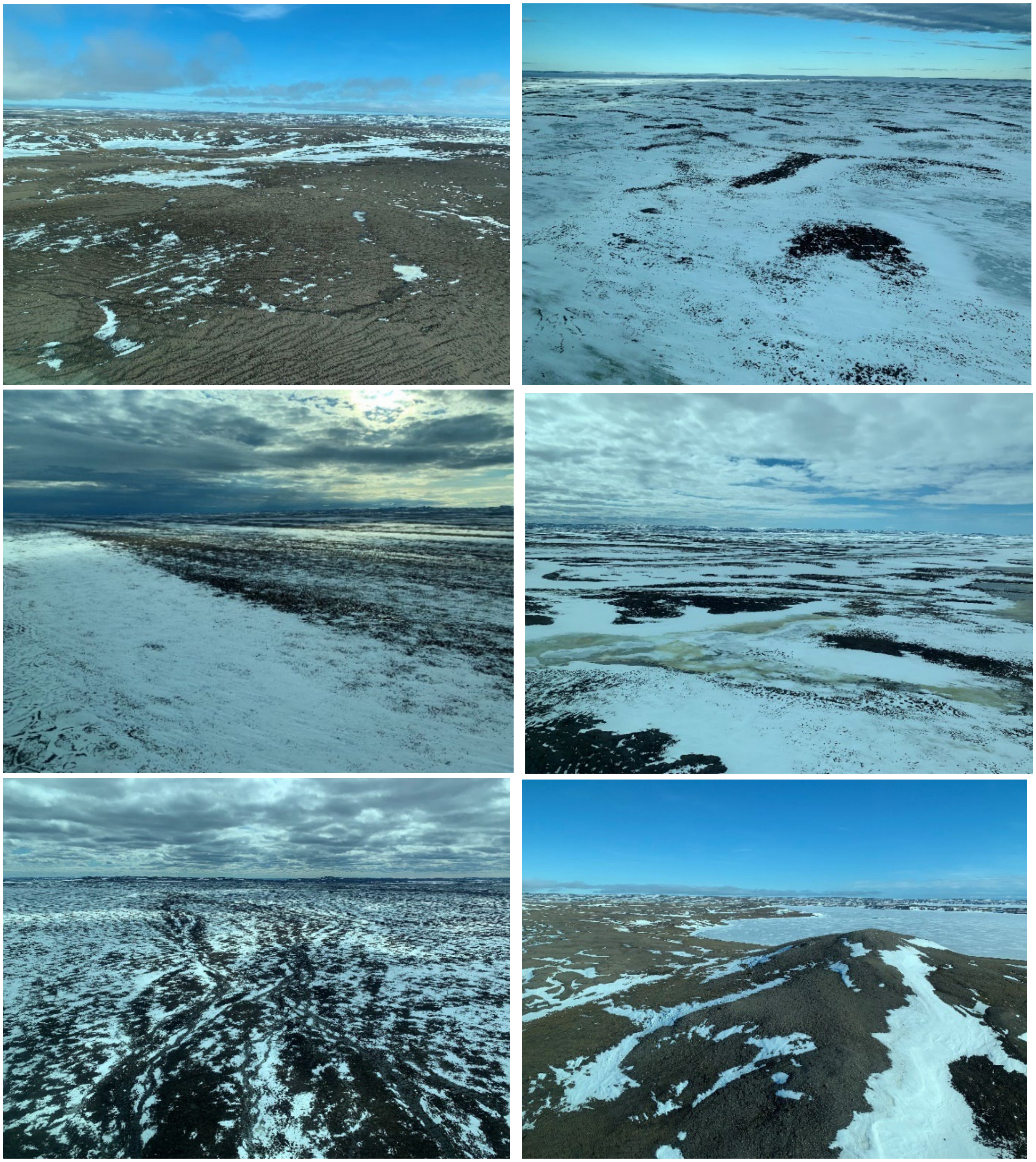

Figure 9. Photos of Bluenose-East survey conditions on June 8, 2021 when most visual blocks were surveyed. Aerial photos were taken June 9. Snow cover ranged from 90% or more to mostly bare ground, and in some areas was patchy.

Summary of Fixed-wing and Helicopter Flying

A summary of daily flying by fixed-wing aircraft and helicopters on the Bluenose-East calving ground survey is given in Table 1.

Table 1. Summary of visual survey flying on the June 2021 Bathurst (BAT) and Bluenose-East (BNE) calving ground surveys. Comp = composition survey; recon = reconnaissance flying; YK = Yellowknife. Flying by photo planes is not shown; Bluenose-East photo blocks were flown June 9 and Bathurst photo blocks June 10.

Date	**Caravan GZIZ**	**Caravan GDLC**	**Aviat Husky**	**A-Star FGSC**	**A-Star FYZF**
June 1	Arrive Kugluktuk	Arrive Kugluktuk	-	-	-
June 2	Calving status flight BNE core	-	-	-	-
June 3	-	-	Calving status flight BAT core west of Inlet	-	-
June 4	-	Calving status flight BNE core	Calving status flight BAT east of Inlet	-	-
June 5	-	-	-	-	-
June 6	-	-	-	-	-
June 7	-	-		-	-
June 8	BNE visuals	BNE visuals	Recon lines east of BAT Inlet	-	-
June 9	BAT visuals west	BAT visuals west	Recon lines east of BAT Inlet	-	-
June 10	BAT visuals east, BNE visuals	BAT visuals east		-	YK to BAT Inlet, to Kugluktuk, cache fuel BNE
June 11	BAT visual east, return YK	Return YK		YK to Kugluktuk, to BAT Inlet, comp	BNE comp
June 12	-	-		BAT comp	BNE comp
June 13	-	-		BAT comp	BNE comp
June 14	-	-		BAT comp, return YK	BNE comp
June 15	-	-		-	Return YK

Information on the Bathurst survey is included as the same Caravan crews flew the two surveys at about the same time. Due to poor weather, flying between June 2 and 7 was limited to reconnaissance flights to check on calving status (newborn calves as % of caribou seen) for the Bluenose-East herd on June 2 and 4.

Beginning June 8, weather improved and there were clear skies on June 9 when the Bluenose-East aerial photos were flown. Visual blocks on the Bluenose-East survey were flown primarily on June 8 with two final blocks flown June 10. The Bluenose-East helicopter-based composition survey was flown June 11-14. Weather was generally good during this final period of the survey, with occasional localized low cloud and fog.

Photo and Visual Survey Blocks

Photo and visual blocks for the Bluenose-East June 2021 calving ground survey are shown in Figure 10. As in past calving ground surveys (e.g. Boulanger et al. 2019), Bluenose Lake has been the traditional western end of the Bluenose-East calving distribution, and in that area there is sometimes limited overlap with Bluenose-West collared caribou at the eastern limits of their distribution. One collared cow shown in the Photo North as a Bluenose-West female was newly collared in March 2021 and re-assigned as Bluenose-East based on her further movements in the summer of 2021 with Bluenose-East caribou. One collared caribou female in Visual block 2 is identified as Bluenose-West (Figure 10) and based on summer 2021 movements, remained largely affiliated with the Bluenose-West herd. One collared cow in the Photo South block is identified as unassigned as she was not on any calving ground in June 2020; this female was associated with the Bathurst herd in the summer of 2020.

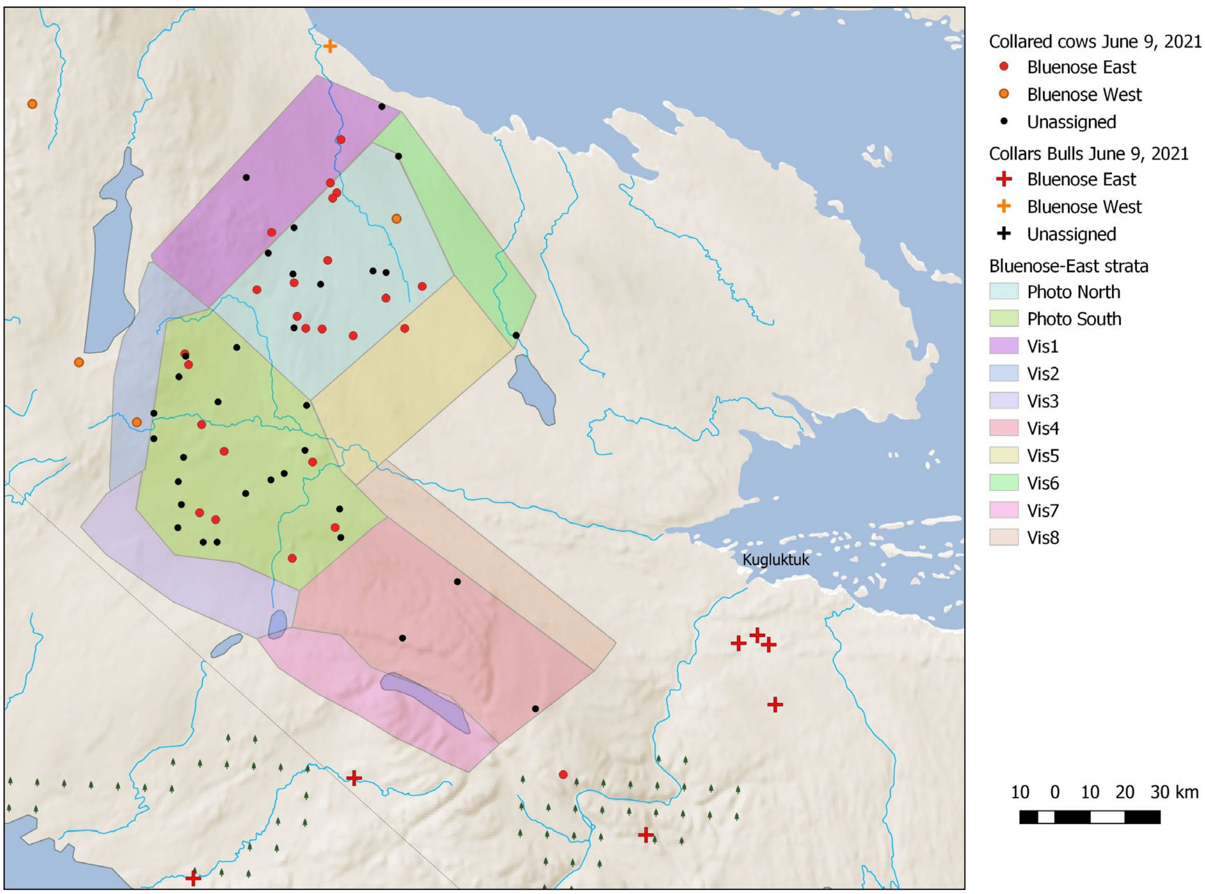

Figure 10. Photo and visual survey blocks for Bluenose-East calving ground survey in June 2021. The Bluenose-West collar in the Photo North was re-assigned as Bluenose-East based on further collar movements in 2021. The Bluenose-West collar in Visual 2 remained a Bluenose-West based on further collar movements.

The two photo blocks were defined to contain the main concentrations of collared known and unassigned female caribou in the survey area. The Photo North and South blocks included 21 of 25 known Bluenose-East collared cows and 24 of 30 unassigned collared cows. An emphasis was placed on including the main expected concentrations of female caribou in the photo blocks due to the patchy snow conditions.

Using survey strata dimensions sampling scenarios were developed that would allow sampling of both photo strata within a single survey day of flying at target levels of coverage (≥20%) for both survey strata. These scenarios that varied sampling coverage, numbers of photos, elevation flown above ground level, and Ground Sample Distance (GSD) options for the Photo North and Photo South blocks are shown in Figure 3. We designed sampling to ensure at least 20% coverage at lower survey altitudes (GSD 5 or 6). On June 9 under blue skies, 3,648 photos were taken at GSD 8 at an elevation above ground of about 4,300 feet. Coverage was 30% for the Photo North block and 29% for the Photo South block (Table 2) due to the higher survey altitude that was flown.

Table 2. Photo stratum characteristics and coverage for the Bluenose-East 2021 calving photo survey.

Stratum	**Stratum Area (km^2)**	**Transect Number**	**Mean transect length (km)**	**Length of Stratum (km)**	**Area Surveyed (km^2)**	**Total survey lines possible**	**Photo Numbers Taken**	**Ground Coverage (%)**
NORTH	2,596.9	15	39.21	66.23	780.79	49.4	1,575	30
SOUTH	3,410.6	17	42.75	79.77	981.58	59.51	1,878	29

Visual blocks were defined to surround the photo blocks and contain the additional four known and six unassigned cow collars in the area, with planned coverage of 15-20%. We assumed these outlying areas would have lower numbers of caribou. Because a reconnaissance survey to estimate caribou density was not flown, optimum allocation was not possible. At least ten transect lines were planned for each visual block, based on previous surveys. Characteristics of each visual block are shown in Table 3. Initial results of the visual survey indicated a substantial number of caribou observations in visual block 4 at the southeast end of the survey area; as a result, additional visual blocks were added north and south of that block. There were in total eight visual survey blocks. Most visual blocks were flown on June 8 (1-6), and on June 10 the last two visual blocks were flown (7 and 8).

Table 3. Visual stratum characteristics and coverage for the Bluenose-East 2021 calving photo survey.

Stratum	Stratum Area (km^2)	Transect Number	Mean transect length (km)	Length of Stratum (km)	Area Surveyed (km^2)	Ground Coverage (%)
Vis1	1,743.0	20	21.4	81.5	342.0	19.6
Vis2	720.6	16	10.5	68.7	134.2	18.6
Vis3	1,007.5	16	15.3	66.0	195.5	19.4
Vis4	2,515.4	14	35.4	71.1	396.4	15.8
Vis5	1,550.5	12	26.0	59.7	249.5	16.1
Vis6	861.2	13	12.6	68.5	130.7	15.2
Vis7	1,039.6	13	15.9	65.3	165.5	15.9
Vis8	971.3	17	11.7	95.0	159.2	16.4

Visual block 4 was designed in part to contain the "trailing edge" of the Bluenose-East migration movement north and west (Figure 11) as the paths of the collared cows had moved through that area. Previous surveys of this herd had shown that this trailing edge often contained variable numbers of non-breeding cows, yearlings and bulls, and a small number of breeding cows.

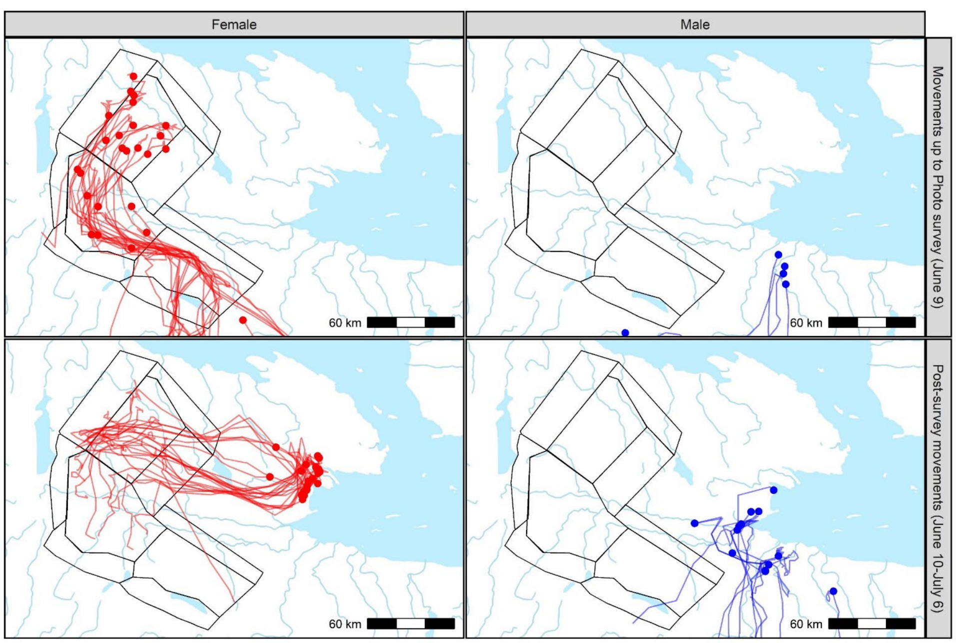

Figure 11. Movement paths of known collared Bluenose-East females (red) and males (blue) through the June 2021 survey blocks from May 1 to June 9 (the day of the aerial photos, top) and June 10 to July 6 (bottom), after the survey and into the post-calving period. There were no collared Bluenose-East bulls (known or unassigned) in the survey blocks on June 9; their movements north lagged behind those of the females in June 2021.

Peak of Calving and Movement Rates of Collared Female Caribou

Daily movement rates of known Bluenose-East collared cows in late May and through the first two weeks of June are shown in Figure 12. The peak of calving is considered close when the majority of collared female caribou exhibit movement rates of less than 5 km/day (Boulanger et al. 2016, 2019) and remain there for several days. For the Bluenose-East collared cows, daily movement rates on average were near 10 km/day May 25-June 2, then decreased June 3-5 and dropped below 5 km/day on June 6, 2021. Movement rates then remained near 5 km/day for the next ten days, with a slight trend toward increasing movement rates June 11-16. This suggested a peak of calving June 6-9, 2021. By comparison, daily movement rates of known collared Bathurst female caribou dropped below 5 km/day on June 3 and reconnaissance flights on June 3 and 4 suggested the peak of calving was close, with the peak occurring June 3-6, 2021 (Adamczewski et al. 2022c).

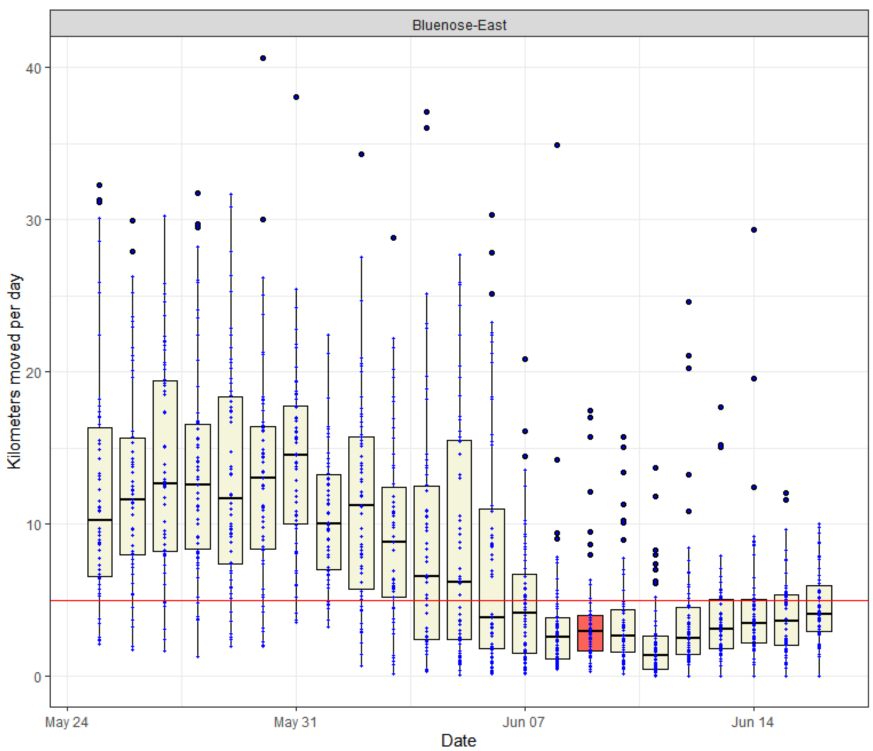

Figure 12. Daily movement rates of known collared Bluenose-East female caribou May 25 to June 16, 2021. The red bar shows the date aerial photos were taken (June 9). Most visual survey blocks were flown on June 8, with the remaining portions flown on June 10.

Reconnaissance Flights to Assess Calving Status June 2 and 4, 2021

Reconnaissance flights were flown through the main concentrations of known Bluenose-East collared cow to assess the status of calving on June 2 and 4 (Figure 13). On June 2, 46 groups were observed, of which 21 contained breeders (cows with calves or hard antlers). Of the breeder groups, 12 contained calves. In total 196 adult caribou were observed of which 23 were classified as breeders with ten calves counted (5.1 calves:100 adults). On June 4, 77 groups were observed, of which 38 contained breeders. Of the breeder groups, 11 contained calves. In total 115 adult caribou were observed of which 17 were classified as breeders with ten calves counted (7.0 calves:100 adults). Given the reconnaissance nature of the survey the counts of breeders were approximate. These results suggested calving had begun but the herd was not yet at the peak of calving.

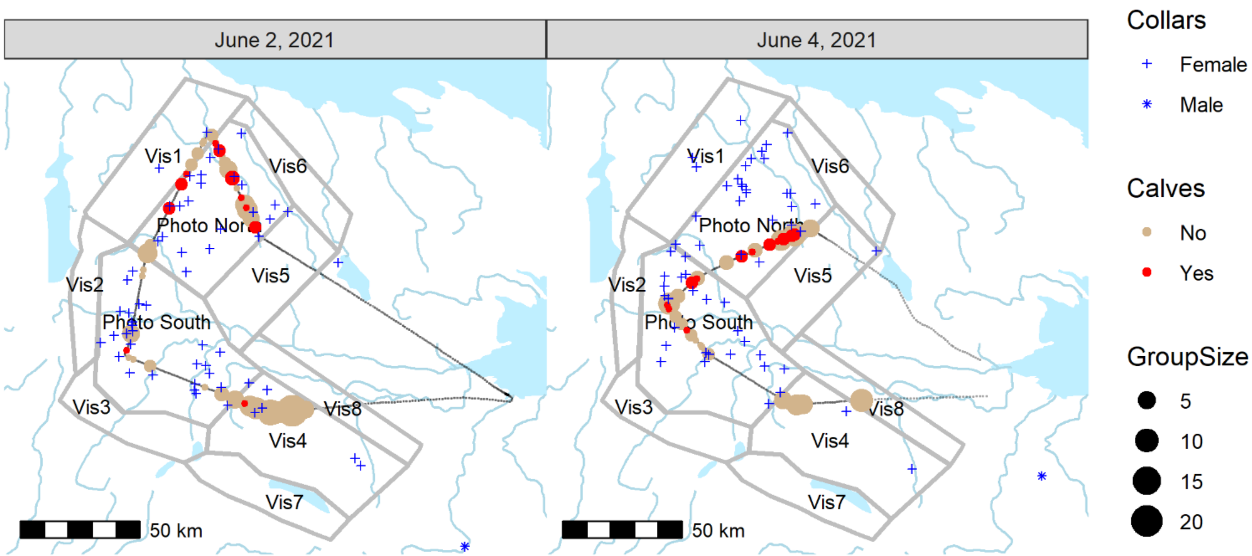

Figure 13. Reconnaissance flights carried out on June 2 and June 4 over the main Bluenose-East collared cow concentrations to assess status of calving. The presence of calves and group size is denoted for each observation. Also shown are the locations of collared females and males on the day of the survey.

Calving Ground Composition Survey Results

Helicopter flight lines and locations of caribou groups classified June 11-14, 2021 on the Bluenose-East calving ground are shown in Figure 14. Caribou were classified from the air using motion-stabilized binoculars. Total numbers of caribou classified in each category are shown in Table 5.

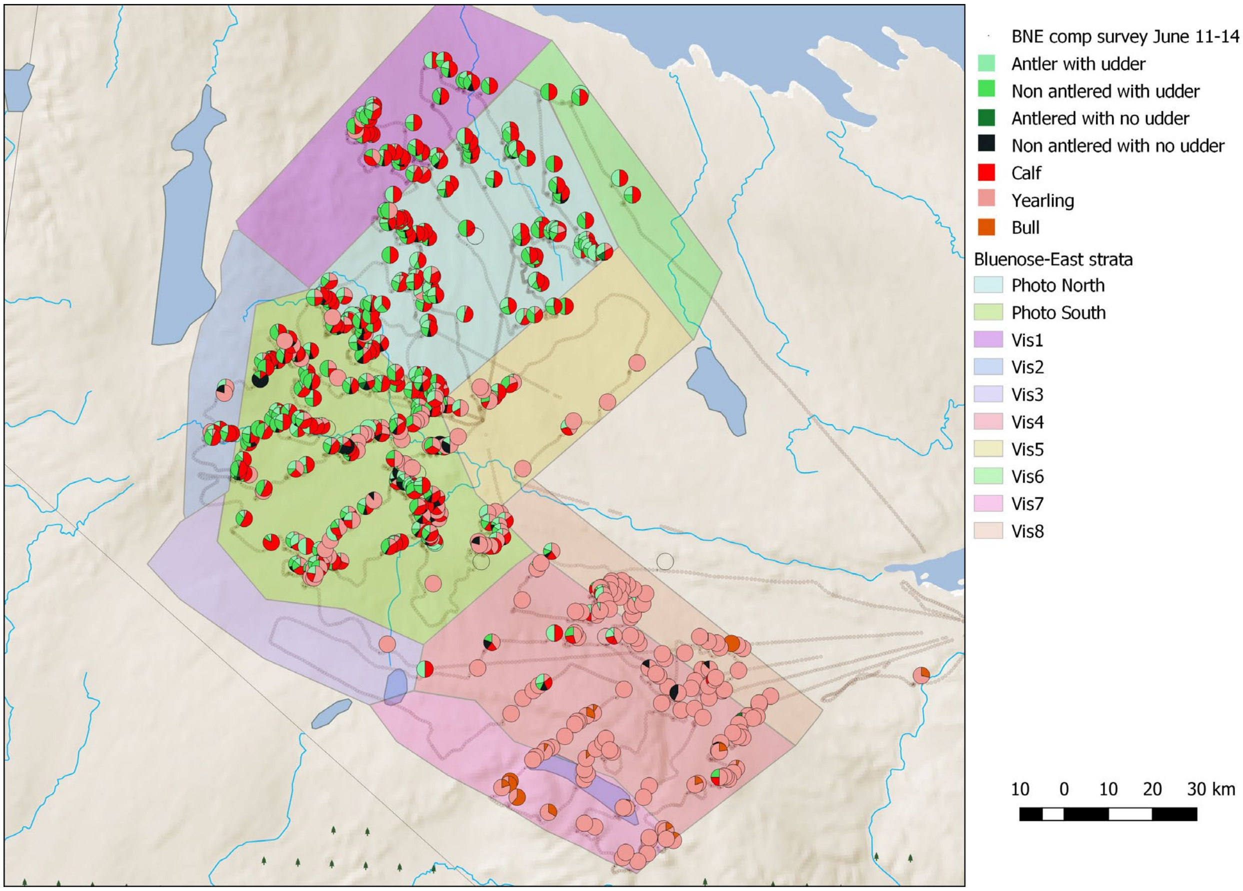

Figure 14. Helicopter flight lines and locations of caribou groups classified on the Bluenose-East calving ground June 11-14, 2021. Proportions of caribou classes are shown as pie chart sections.

A total of 8,166 caribou, including newborn calves, were classified June 11-14, 2021 on the Bluenose-East calving ground survey (Table 4). The largest numbers classified were in the Photo North block (2,634 caribou) and the Photo South block (3,568 caribou), which we expected would have most of the breeding and adult cows. We note that numbers of caribou classified in some strata, notably visual blocks 2, 3, 5 and 6, were fewer than 100 total, thus the limited sample size should be considered in assessing these results. For example, just one group of three yearlings was classified in visual block 3, which also had very few caribou based on the visual survey.

Table 4. Composition of caribou classified June 11-14, 2021 on Bluenose-East calving ground survey area. Vis = Visual Block.

Stratum (Block)	Breeding cows	Non-Breeding Cows	Total Cows	Calves	Bulls	Yearlings	Total Adult Caribou	Total All Caribou	Groups
Photo North	1,300	61	1,361	1,214	0	59	1,420	2,634	97
Photo South	1,471	216	1,687	1,330	0	551	2,238	3,568	223
Vis1	309	20	329	300	1	27	357	657	35
Vis2	31	1	32	32	0	10	42	74	8
Vis3	0	0	0	0	0	3	3	3	1
Vis4	34	10	44	22	15	562	621	643	90
Vis5	38	0	38	31	1	27	66	97	16
Vis6	8	0	8	7	0	0	8	15	4
Vis7	0	1	1	0	32	177	210	210	27
Vis8	7	0	7	2	1	255	263	265	25
Total	3,198	309	3,507	2,938	50	1,671	5,228	8,166	526

An overview of the composition survey results is provided in Figure 15. In the two photo blocks and in visual blocks 1, 2, 5 and 6, breeding cows and calves accounted for most of the caribou classified. In visual block 4 and the adjacent blocks 7 and 8, yearlings accounted for more than 85% of the caribou classified. Overall, yearlings accounted for 20.5% of all caribou classified and 32.0% of adult caribou classified. Very few bulls were recorded in any of the survey blocks, which is consistent with the lack of any bull collars in the survey area and the presence of bull collars further east and south of the calving grounds.

Detailed composition of categories of Bluenose-East breeding cows is shown in Table 5. Cows having no antlers, a distended udder and a calf (1,861) out-numbered cows having antlers, distended udders and a calf (1,286) with a ratio of about 1.4:1. Other categories of breeding cows were observed rarely. As pregnant cows usually shed their antlers shortly after giving birth, the ratio of these two categories of breeding cow should increase after the peak of calving. We note that cows having no antlers, a distended udder and a calf (1,212) out-numbered cows having antlers, a distended udder and a calf (204) in the Bathurst composition survey flown at the same time, with a ratio of about 6:1 (Adamczewski et al. 2022c). The higher ratio in the Bathurst herd is consistent with an earlier peak of calving in the Bathurst herd (estimated June 3-6; Adamczewski et al. 2022c) than in the Bluenose-East herd (June 6-9; this report); i.e. there were more days for Bathurst cows that had calved to shed their antlers.

Table 5. Detailed composition of categories of breeding and non-breeding cows on Bluenose-East June 2021 calving ground survey area. Antler = Hard Antler Present; Udder = Distended Udder Present; Calf = Calf Present. Non-Breeding Cows = No Hard Antler, No Distended Udder, No Calf. Vis = Visual Block.

Stratum (Block)	Total Cows	Non-Breeding Cows	Total Breeding Cows	Antler Udder Calf	No Antler Udder Calf	Antler Udder No Calf	Antler No Udder No Calf	No Antler Udder No Calf
Photo North	1,361	61	1,300	621	665	0	14	0
Photo South	1,687	216	1,471	484	954	0	33	0
Vis1	329	20	309	119	187	0	3	0
Vis2	32	1	31	12	19	0	0	0
Vis3	0	0	0	0	0	0	0	0
Vis4	44	10	34	22	11	0	1	0
Vis5	38	0	38	17	21	0	0	0
Vis6	8	0	8	4	4	0	0	0
Vis7	1	0	0	0	0	0	0	0
Vis8	7	0	7	7	0	0	0	0
Total	3,507	309	3,198	1,286	1,861	0	51	0

Overall, the largest numbers of cows were recorded in the Photo North and Photo South blocks and in visual block 1; relatively few cows were observed in the other visual blocks. Although numbers of caribou at least one year old recorded during visual surveys of blocks 4, 7 and 8 at the southern end of the survey area were substantial (Table 10), the composition survey results showed that at least 85% of these caribou were yearlings. These blocks had very few breeding or non-breeding cows.

Proportions of breeding cows and adult cows in each stratum, along with calf:cow ratios, are given in Tables 6a and 6b. Breeding females accounted for 91.5% of adult caribou in the Photo North block and 95.5% of adult females classified, which indicated that just 4.5% of the adult females in this block were non-breeding cows. In the Photo South block, breeding females accounted for 65.7% of adult caribou and 87.2% of adult females classified, indicating that 12.8% of adult females were non-breeding cows. Calf:cow ratios were uniformly high in breeding females across the survey blocks, including the Photo North (93 calves:100 cows) and Photo South (90 calves:100 cows) and adjacent visual blocks, with the exception of visual blocks 4, 7 and 8 at the south end of the survey area. There were very few breeding cows in these blocks, in which yearlings predominated. The high percentages of breeding females among adult females suggest exceptionally high pregnancy rates in the Bluenose-East herd in winter 2020-2021.

Table 6a. Proportions of breeding females and adult females in survey strata from June 2021 Bluenose-East calving ground composition survey. SE = Standard Error; CIL = 95% Confidence Interval Lower, CIU = 95% Confidence Interval Upper. Note some ratios are based on minimal samples so should be considered in that context.

Stratum	Breeding Females as % of Total Adults	SE	CIL	CIU	Adults Females as % of Total Adults	SE	CIL	CIU	Breeding Females as % of Adult Females	SE	CIL	CIU
Photo North	92	1	89	94	96	1	94	97	96	1	94	97
Photo South	66	2	62	69	75	2	72	79	87	1	85	89
Vis1	87	3	81	92	92	2	88	96	94	2	90	97
Vis2	74	13	41	93	76	11	48	93	97	5	83	100
Vis3	0	0	0	0	0	0	0	0	0	NA	NA	NA
Vis4	5	1	3	8	7	2	4	10	77	7	62	90
Vis5	58	12	31	77	58	12	31	77	100	0	100	100
Vis6	100	0	100	100	100	0	100	100	100	0	100	100
Vis7	0	0	0	0	0	0	0	0	0	0	0	NA
Vis8	3	1	1	5	3	1	1	5	100	0	100	100

Table 6b. Calf:Cow ratios in survey strata from June 2021 Bluenose-East calving ground composition survey. SE = Standard Error; CIL = 95% Confidence Interval Lower, CIU = 95% Confidence Interval Upper. Note some ratios are based on minimal samples so should be used with caution.

Stratum	Calves: 100 Cows for Breeding Females	SE	CIL	CIU	Calves: 100 Cows for Adult Females	SE	CIL	CIU
Photo North	93	1	91	95	89	1	87	91
Photo South	90	1	88	93	79	2	75	82
Vis1	97	1	95	100	91	2	87	95
Vis2	103	8	86	117	100	10	73	114
Vis3	0	NA	NA	NA	0	NA	NA	NA
Vis4	65	10	46	84	50	9	33	69
Vis5	82	6	67	91	82	6	67	91
Vis6	88	18	40	100	88	18	40	10
Vis7	0	NA	NA	NA	0	0	0	NA
Vis8	29	NA	0	100	29	NA	0	100

Incidental observations from the helicopter suggested that there were multiple cases of cows with twins, which could have contributed to the high calf:cow ratios observed in breeding cows. There were many instances in June 2021 where cows had two small calves following them closely. There were also many instances where small groups or portions of larger groups had three cows and four calves, or two cows and three calves, or four cows and five calves.

Overall, the spatial distribution of classes of caribou on the June 2021 Bluenose-East composition survey is consistent with patterns observed in other years: the front edge of the migration north has a high proportion of pregnant cows about to give birth, with increasing proportions of non-breeding cows and yearlings behind them, and bulls generally at the back end of the migration north.

Fall 2020 and 2021 Composition Survey Results

Composition surveys were flown in late October 2020 and 2021 near the peak of the breeding season to estimate bull:cow ratios and calf:cow ratios for the Bluenose-East herd (Adamczewski et al. 2022a and b). Both surveys included a high proportion of the collared cows and bulls in the herd, and there was no mixing of collared caribou from any other herd in the areas flown. The presence of relatively large rutting groups, and observations of prime bulls fighting and bulls closely following cows, suggested that the two surveys were timed close to the peak of the breeding season.

Bull:cow ratios in 2020 and 2021 were 63.3 and 68.7 bulls:100 cows (Tables 7a, 7b, 8a and 8b). As the ratios were similar and appeared to result from valid surveys, the average bull:cow ratio (66.0 bulls:100 cows) and proportion of females in the herd (among adults) of 60.3% (Table 9) from the two surveys were used in extrapolating the estimate of adult females to the estimate of adult herd size for the Bluenose-East herd in 2021.

Table 7a. Total numbers of calves, cows, young bulls, prime bulls, and caribou (including calves) classified in October 2020 in the Bluenose-East herd.

Calves	Cows	Young Bulls	Prime Bulls	Bulls Total	Total Caribou
522	1,010	362	277	639	2,171

Table 7b. Bull:cow ratio, calf:cow ratio and proportion of cows (among adults) in the Bluenose-East herd based on October 2020 composition survey. SE = Standard Error; CIL = 95% Confidence Interval Lower; CIU = 95% Confidence Interval Upper; CV = Coefficient of Variation.

Variable	Estimate	SE	CIL	CIU	CV (%)
Bulls: 100 cows	63.3	7.3	51.3	78.4	11.6
Calves: 100 cows	51.7	2.2	47.2	55.7	4.2
Proportion of cows %	61.2	2.7	56.0	66.1	4.5

Table 8a. Totals numbers of calves, cows, young bulls, prime bulls, and caribou (including calves) classified in October 2021 in the Bluenose-East herd.

Calves	Cows	Young Bulls	Prime Bulls	Bulls Total	Total Caribou
919	1,854	734	540	1,274	4,047

Table 8b. Bull:Cow ratio, calf:cow ratio and proportion of cows (among adults) in the Bluenose-East herd based on October 2021 composition survey. SE = Standard Error; CIL = 95% Confidence Interval Lower; CIU = 95% Confidence Interval Upper; CV = Coefficient of Variation.

Variable	Estimate	SE	CIL	CIU	CV (%)
Bulls: 100 cows	68.7	4.0	61.3	77.4	5.9
Calves: 100 cows	49.6	1.8	45.6	53.0	3.6
Proportion of cows %	59.3	1.4	56.4	62.0	2.4

Table 9. Combined (averaged) bull:cow ratio, calf:cow ratio and proportion of cows (among adults) in the Bluenose-East herd based on October 2020 and 2021 composition surveys. SE = Standard Error; CIL = 95% Confidence Interval Lower; CIU = 95% Confidence Interval Upper; CV = Coefficient of Variation.

Variable	Estimate	SE	CIL	CIU	CV (%)
Bulls:100 cows	66.0	5.9	56.3	77.9	9.0
Calves:100 cows	50.6	2.0	46.4	54.3	3.9
Proportion of cows %	60.3	2.2	56.2	64.0	3.6

Visual Survey Block Estimates and Double Observer Correction

Estimates of adult caribou (at least one year old) in the eight visual survey blocks are given in Table 10, together with corrected estimates that incorporate double observer analyses, which are described in Appendix 1. Overall, the total number of caribou at least one year old was 3,538 as recorded during the survey and 3,635 as corrected from double observer calculations, an increase of 2.7%.

Table 10. Estimates of caribou in visual survey strata from double observer and strip transect estimates for the Bluenose-East herd, June 2021. N = Estimate; SE = standard error; 95% CI = 95% Confidence Interval; CV = Coefficient of Variation.

Stratum	Caribou seen	Corrected double observer estimates					Uncorrected transect estimates (as recorded in field)		
		N	SE	95% CI		CV	N	SE	CV
Vis1	94	495	96.1	322	760	19.4%	479	127.8	26.7%
Vis2	54	300	59.5	191	472	19.8%	290	108.9	37.6%
Vis3	14	75	0.6	73	76	0.8%	72	26.3	36.4%
Vis4	247	1,603	326.4	995	2,581	20.4%	1,567	390.8	24.9%
Vis5	9	58	35.6	15	231	60.9%	56	30.5	54.5%
Vis6	6	42	14.7	19	93	35.3%	40	20.1	50.9%
Vis7	85	548	121.1	327	918	22.1%	534	102.1	19.1%
Vis8	82	515	95.5	340	781	18.5%	500	90.8	18.2%
Total	591	3,635	380.8	2,898	4,559	10.5%	3,538	449.0	12.7%

Of the visual blocks on this survey, visual block 4 had the largest estimated number of caribou at least one year old of 1,603, with visual blocks 1, 2, 7 and 8 each accounting for 300-548 caribou at least one year old. Visual blocks 3, 5 and 6 each accounted for <100 caribou. As noted in the preceding section, visual blocks 4 and adjacent blocks 7 and 8 were predominantly (over 85%) yearlings, thus contributed little to estimates of breeding and adult females.

Photo Strata Estimates and Double Observer Correction

Characteristics of the two Bluenose-East photo strata in June 2021 are given in Table 11. There were 15 transects in the Photo North stratum and 17 in the Photo South stratum. Ground coverage was 30% in the Photo North stratum and 29% in the Photo South stratum. The average strip width of photo strips was 1.34 km as obtained by geo-referencing. Estimated numbers of caribou at least one year old were similar for the two photo strata at about 7,300 each.

Table 11. Photo stratum dimensions, transect numbers, and numbers of caribou at least one year old counted on the strata, Bluenose-East June 2021 survey. These are not corrected for double-observer calculations.

Stratum	Area (km^2)	Transect Number	Mean transect length (km)	Stratum length (km)	Area Surveyed (km^2)	Total survey lines possible	Coverage (%)	Caribou counted	Estimated number caribou N
North	2,596.9	15	39.21	66.23	780.79	49.40	30	2,215	7,367
South	3,410.6	17	42.75	79.77	981.58	59.51	29	2,090	7,262

Densities of caribou on the Photo North and South transects were relatively even, which led to relatively limited variance and higher precision on resulting estimates (Figure 19).

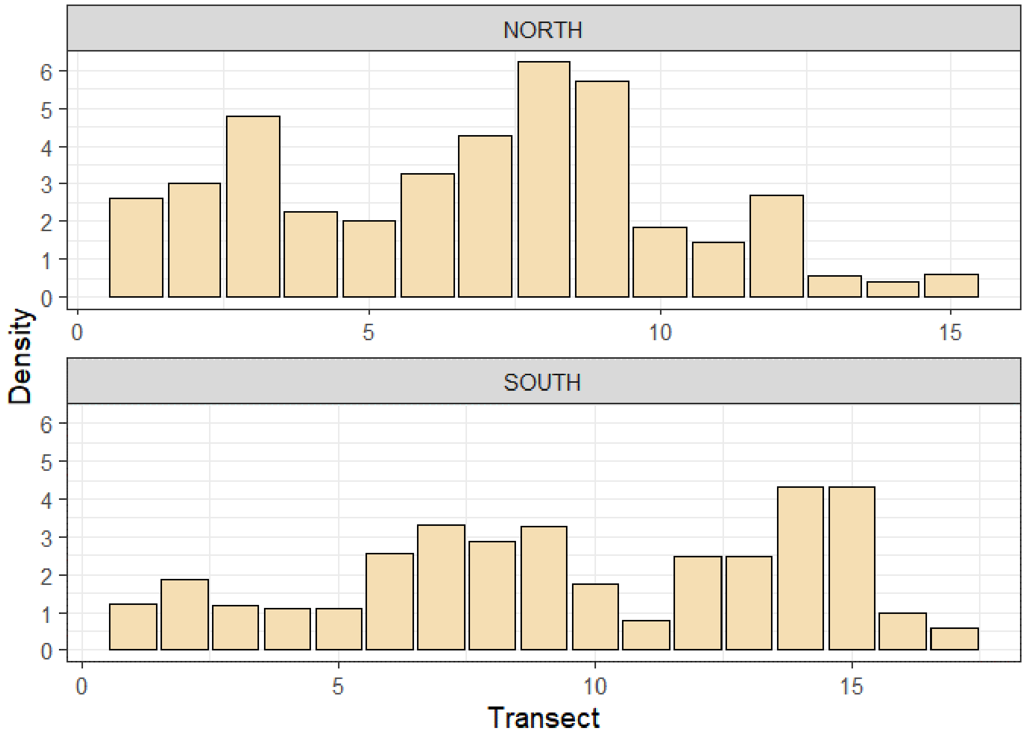

Figure 15. Transect densities (uncorrected) for the photo strata on the Bluenose-East June 2021 calving ground survey.

An example of a zoomed-in portion of an aerial photo from June 10, 2021 on the Bluenose-East calving ground survey area is shown in Figure 16. Composite photos strips making up the coverage on the Photo North and Photo South blocks are shown in Figures 17a and b, with red dots showing locations of caribou groups counted. A composite map of the survey area showing locations of caribou groups is in Figure 18.

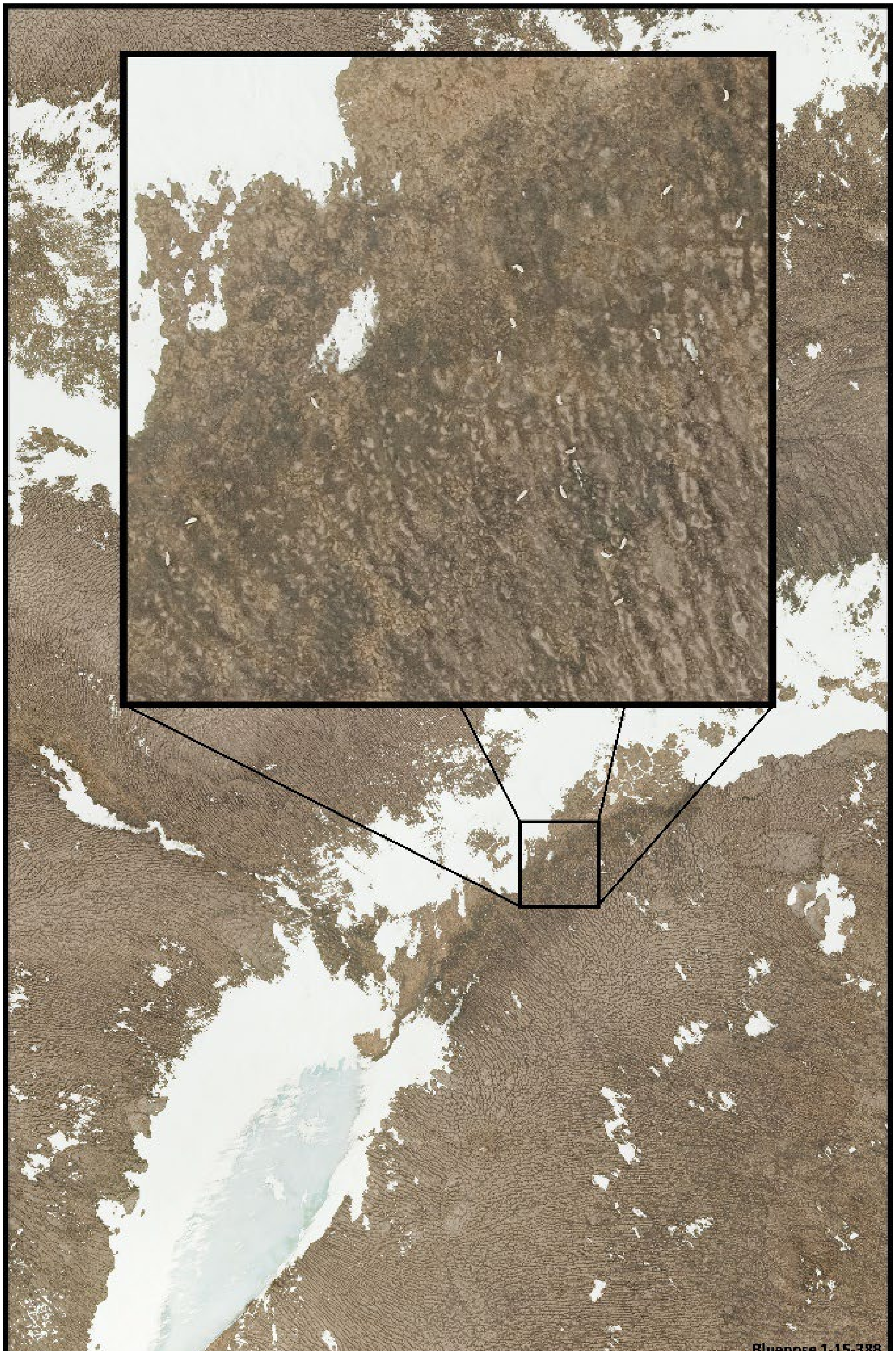

Figure 16. A zoomed-in portion of one of the aerial photos taken over the Bluenose-East calving ground on June 9, 2021. Several caribou can be seen on the bare ground.

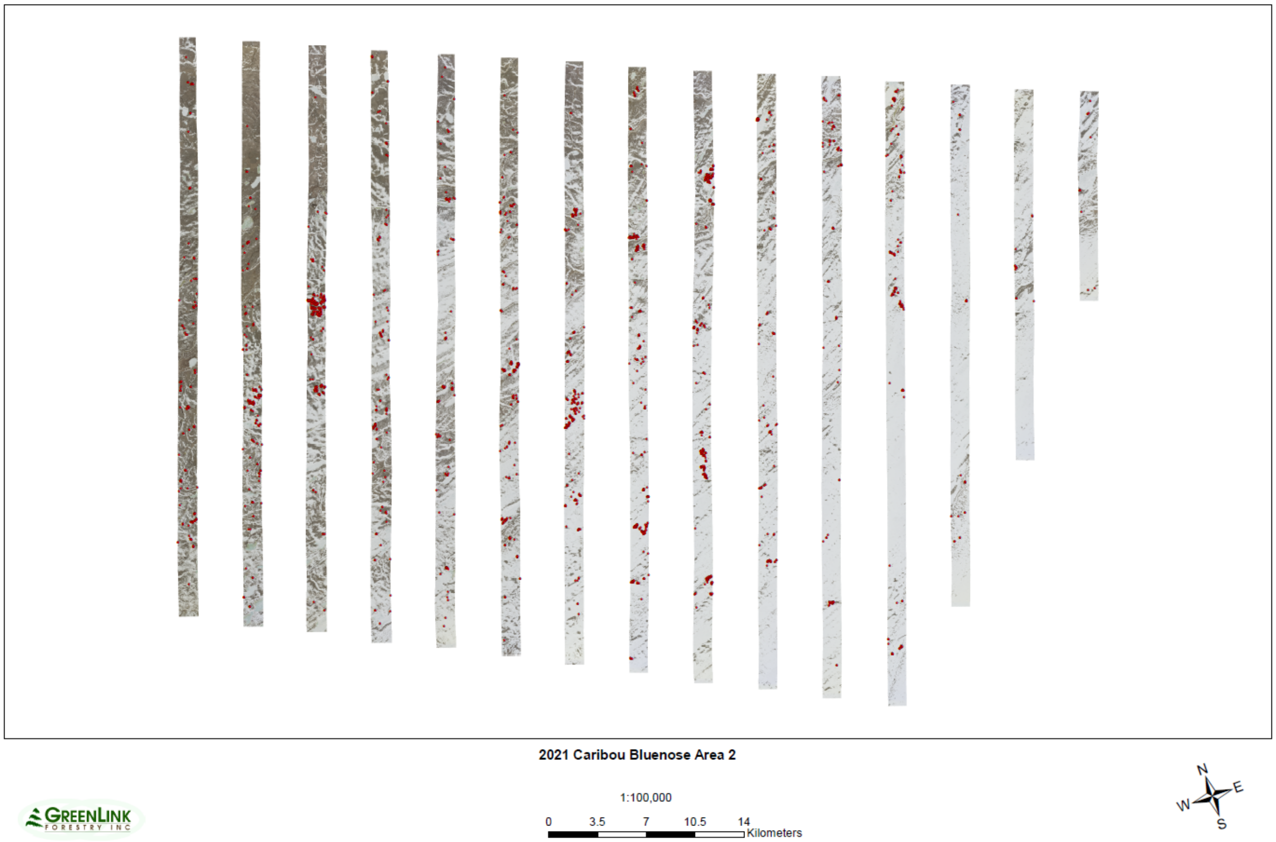

Figure 17a. A composite image of continuous aerial photo strips taken during the June 2021 Bluenose-East calving ground survey over the Photo North block west of Kugluktuk. Red dots show locations of caribou groups recorded. Coverage was 30%.

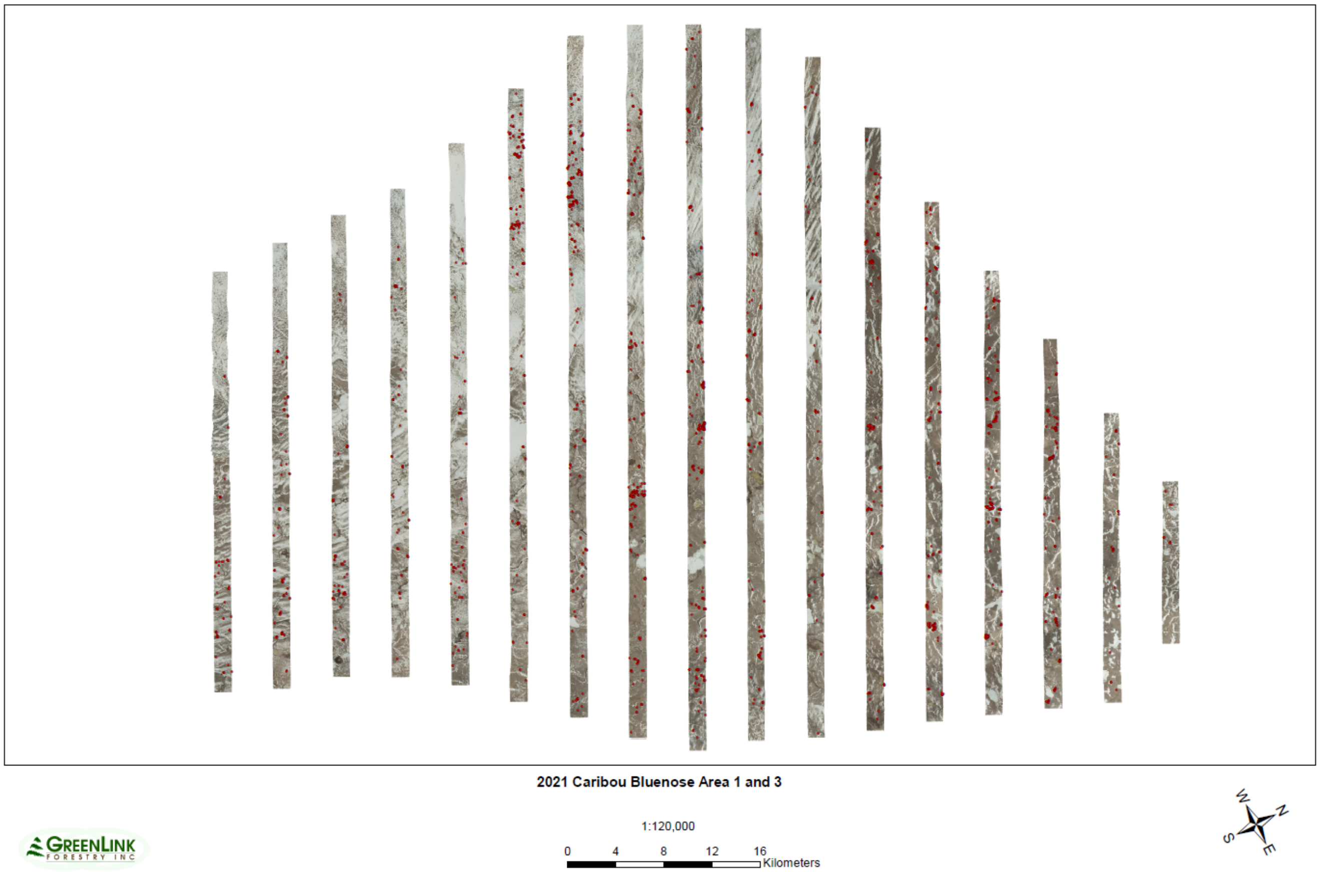

Figure 17b. A composite image of continuous aerial photo strips taken during the June 2021 Bluenose-East calving ground survey over the Photo South block west of Kugluktuk. Red dots show locations of caribou groups recorded. Coverage was 29%.

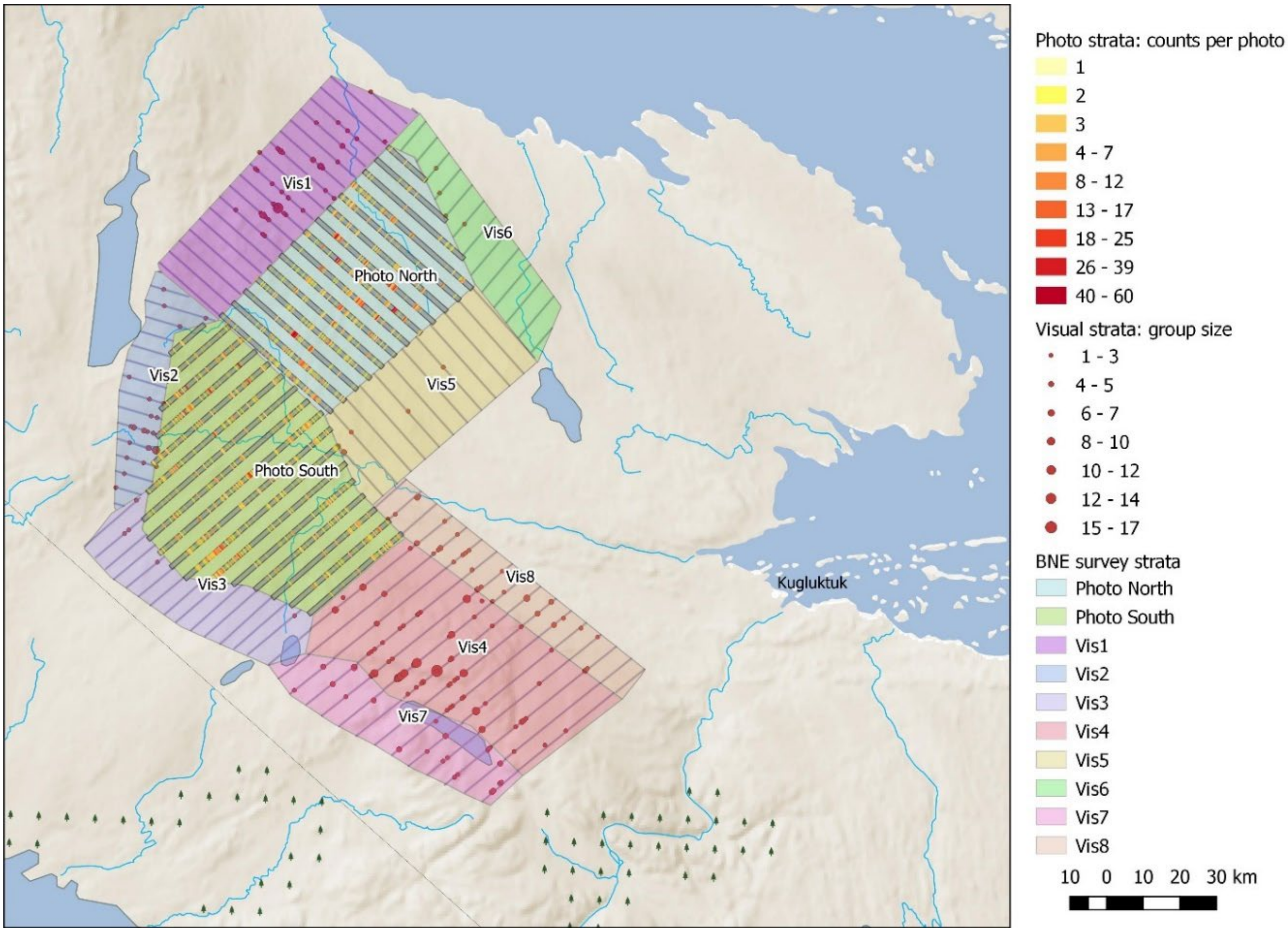

Figure 18. June 2021 Bluenose-East calving ground survey strata with groups of caribou seen on photo and visual transect lines. Group sizes on visual transects are shown as circles varying in size. Counts of caribou on aerial photos are shown as a colour gradation from lighter to darker (see legend).

The full Bluenose-East aerial photo set included 3,648 photos. A total of 187 photos were selected for cross validation. Details of this analysis are in Appendix 2. This sub-set contained photos with 0 counts but favored photos that had at least one caribou detected to ensure reasonable sample sizes for cross validation. Comparison of counts from the first and second observers suggested similar levels of sightability between north and south strata. The second observer was Derek Fisher, president of Greenlink Forestry and the most experienced photo analyst at the company.

A summary of the caribou counts for the two observers is in Table 12, and the uncorrected and corrected estimates of caribou at least one year old in the two photo strata are shown in Table 13. The net effect was an increase of 4.5 % from 14,629 caribou estimated from the initial counts to 15,289 caribou estimated with the double observer correction.

Table 12. First and second observer counts and detection rates of caribou at least one year old in the Photo North and Photo South blocks from the Bluenose-East June 2021 survey, from a sub-sample of 187 photos.

Stratum	Observer 1	Observer 2	Total caribou	Photo Number	Proportion sighted (Observer 1)
Photo North	364	380	380	84	0.958
Photo South	327	338	342	103	0.956
totals	691	718	722	187	0.957 (combined)

Table 13. Initial uncorrected estimates and corrected estimates of caribou at least one year old in the Photo North and Photo South blocks of the Bluenose-East June 2021 calving ground survey. Corrections were based on the detection rates in Table 13. N = estimated number; SE = Standard Error; P = Probability of Detection; CIL = Lower 95% Confidence Interval; CIU = 95% Upper Confidence Interval; CV = Coefficient of Variation.

Stratum	Strip-transect estimates of abundance(uncorrected)			Detection Rate			Corrected estimates of abundance				
	N	SE	CV	P	SE	CV	N	SE	CIL	CIU	CV
Photo Core	7,367.1	926.3	0.126	0.957	0.008	0.009	7,699	970.3	5,882	10,078	0.13
Photo East	7,262.0	734.5	0.101	0.957	0.008	0.009	7,590	770.3	6,124	9,407	0.10

Estimates of Adult and Breeding Females for Bluenose-East Herd

Summaries of the numbers of adult caribou at least one year old, adult females, and breeding females in the Bluenose-East June 2021 survey area are given in Tables 14 and 15.

Table 14. Numbers of adult caribou at least one year old and numbers of adult females estimated from the Bluenose-East June 2021 calving ground survey area. N = Estimate; SE = Standard Error; pf = proportion (as fraction of 1.0); CIL = Lower 95% Confidence Interval; CIU = 95% Upper Confidence Interval; CV = Coefficient of Variation.

Stratum	**Adult caribou (at least 1-year-old)**		**Proportion of adult females**		**Adult female estimate**				
	N	CV	pf	CV	N	SE	CIL	CIU	CV
Photo North	7,699	0.13	0.96	0.01	7,379	932.3	5,633	9,665	0.13
Photo South	7,590	0.10	0.75	0.02	5,721	595.2	4,591	7,129	0.10
Vis1	495	0.19	0.92	0.02	456	89.2	296	702	0.20
Vis2	300	0.20	0.76	0.15	229	56.7	130	402	0.25
Vis3	75	0.01	0.00		0	0.0			
Vis4	1,603	0.20	0.07	0.24	114	35.4	56	233	0.31
Vis5	58	0.61	0.58	0.21	33	21.7	8	143	0.66
Vis6	42	0.35	1.00	0.00	42	14.7	19	94	0.35
Vis7	548	0.22	0.005	1.01	3	2.7	0	19	0.90
Vis8	515	0.19	0.03	0.48	14	7.0	5	41	0.50
Total	18,925	0.07			13,991	1,112.0	11,805	16,582	0.13

Table 15. Numbers of adult caribou at least one year old and numbers of breeding females estimated from the Bluenose-East June 2021 calving ground survey area. N = Estimate; SE = Standard Error; pf = proportion (as fraction of 1.0); CIL = Lower 95% Confidence Interval; CIU = 95% Upper Confidence Interval; CV = Coefficient of Variation.

Strata	**Adult caribou (at least 1-year-old)**		**Proportion of breeding females**		**Breeding female estimate**				
	N	CV	pf	CV	N	SE	CIL	CIU	CV
Photo North	7,699	0.13	0.915	0.01	7,048	893.1	5,376	9,239	0.13
Photo South	7,590	0.10	0.657	0.03	4,989	526.5	3,991	6,236	0.11
Vis1	495	0.19	0.866	0.03	428	84.2	277	661	0.20
Vis2	300	0.20	0.738	0.18	221	59.4	120	406	0.27
Vis3	75	0.01	0.000	0.00	0	0.0			
Vis4	1,603	0.20	0.055	0.25	88	28.0	42	183	0.32
Vis5	58	0.61	0.576	0.21	33	21.7	8	143	0.66
Vis6	42	0.35	1.000	0.00	42	14.7	19	94	0.35
Vis7	548	0.22	0.000	0.00	0	0.0			
Vis8	515	0.19	0.027	0.48	14	7.0	5	41	0.50
Total	18,925	0.07			12,863	1,042.6	10,816	15,298	0.13

The total number of adult females in the survey area was estimated at 13,991, and 13,100 of these (93.6%) were in the two photo blocks (Table 14). Similarly, the total estimated number of breeding females was 12,863 and 12,037 of these (93.6%) were in the two photo blocks. Of the visual blocks, visual block 1 at the northwest end of the survey area accounted for the largest estimates of adult females (456) and breeding females (428) (Table 15) . Visual blocks 4, 7 and 8 at the southeast end of the survey area accounted for a substantial number of caribou at least one year old (2,666), however because these blocks were predominantly yearlings (at least 85%), the estimated numbers of adult females (131) and breeding females (102) in these three blocks were relatively small (Table 15).

Estimates of Bluenose-East Herd Size in 2021 and Comparison with 2018 Estimates

Estimates of the Bluenose-East adult herd size (caribou at least two years old) were generated by extrapolating from the adult female estimate using the combined 2020 and 2021 fall sex ratio for the herd (Table 16). Equivalent estimates from 2018 are included for comparison. In addition, estimates of breeding females, adult females and adult herd size for 2018 and 2021 are shown in Table 17 with gross change and yearly change (expressed as λ or lambda) between the two surveys. The estimates of adult females were nearly identical between 2018 and 2021 and λ was estimated at 1.0. The estimates of breeding females showed a small increase from 2018-2021 with a λ of 1.03. The estimates of adult herd size suggested an increase from 2018-2021 with a λ of 1.06; this change was almost entirely due to the recent increase in the bull:cow ratio for the herd based on October 2020 and 2021 fall surveys. The yearly rate of change confidence limits in all cases included a λ of 1.0, indicating that the changes in breeding females, adult females and herd size were not statistically significant between 2018 and 2021.

Table 16. Estimated herd size for the Bluenose-East herd (adults at least two years old) in 2021 and 2018 based on calving photo surveys. N = Estimate; SE = Standard Error; CIL = Lower 95% Confidence Interval; CIU = 95% Upper Confidence Interval; CV = Coefficient of Variation.

Survey Year	N	SE	CIL	CIU	CV
2021	23,202	2,029.2	19,247	27,971	0.09
2018	19,294	1,474.7	16,527	22,524	0.07

Table 17. Estimates of breeding females, adult females, and adult herd size in the Bluenose-East herd in 2018 and 2021, with gross change and yearly change rates. N = Estimate; SE = Standard Error; GC = Gross Change; λ = yearly change or lambda; CIL = Lower 95% Confidence Interval; CIU = 95% Upper Confidence Interval; CV = Coefficient of Variation.

Metric	Estimates for 2018 and 2021				Overall Change				Yearly Change			
	N_{2018}	SE	N_{2021}	SE	GC	SE	CIL	CIU	λ	SE	CIL	CIU
adult females	13,988	1,034.6	13,991	1,112.0	1.00	0.11	0.81	1.24	1.00	0.04	0.93	1.07
breeding females	11,675	904.4	12,863	1,042.6	1.10	0.12	0.88	1.37	1.03	0.04	0.96	1.11
herd	19,294	1,474.7	23,202	2,029.2	1.20	0.14	0.96	1.51	1.06	0.04	0.99	1.15

Trends in numbers of adult females, breeding females and adult herd size from 2010 to 2021 are shown in Figures 19 and 20. The 2021 results represent a major change from a steep decline in the years 2010 to 2018, with an annual rate of decline of about 20%, to a stable trend from 2018 to 2021.

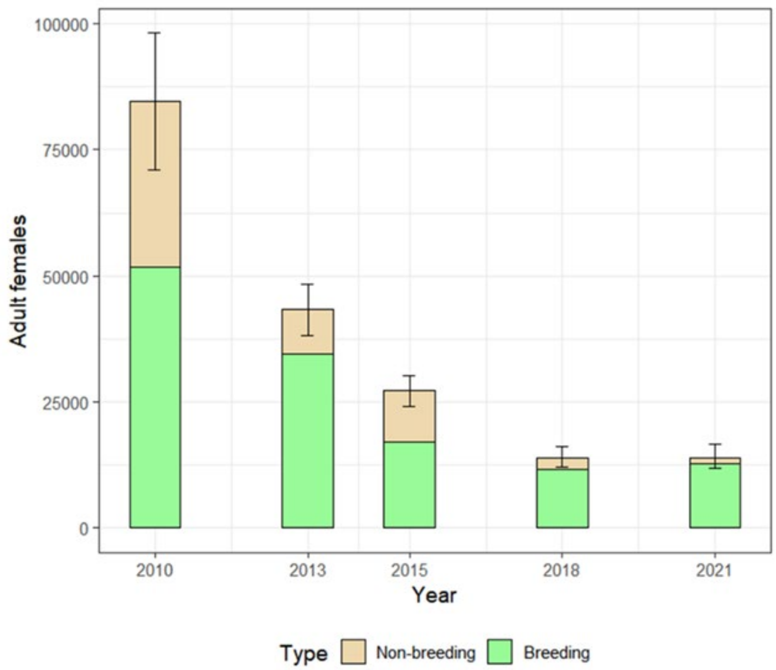

Figure 19. Change in estimated numbers of adult females (breeding and non-breeding) from 2010 to 2021 in the Bluenose-East caribou herd based on calving photo surveys.

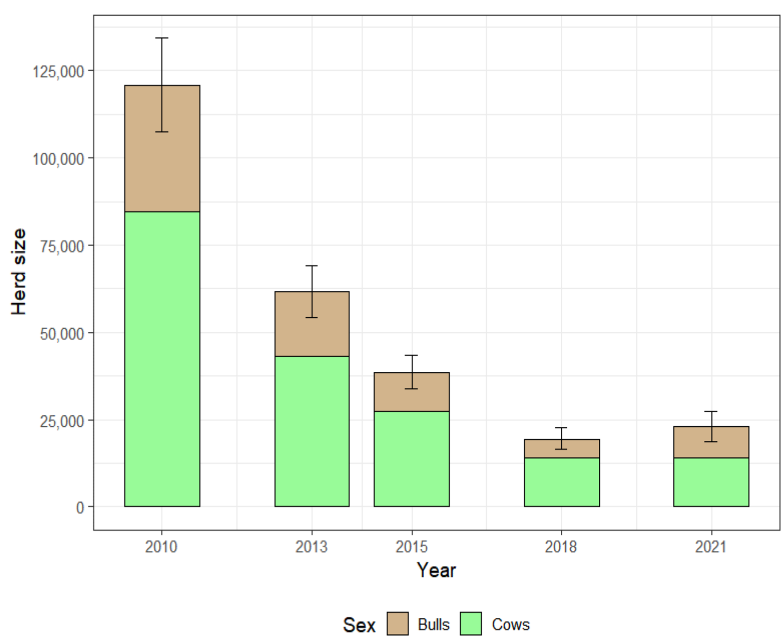

Figure 20. Change in estimated adult herd size (adults at least two years old) from 2010 to 2021 in the Bluenose-East caribou herd based on calving photo surveys.

Demographic Analysis of Bluenose-East Caribou Herd

In this section, recent trends in demographic indicators for the Bluenose-East herd based on field data are presented, followed by the results of analyses carried out using a Bayesian IPM. In previous calving photo survey reports (Boulanger et al. 2019), similar demographic analyses were included to better understand the decline in the herd.

Field Estimates of Bluenose-East demographics

Overall, demographic indicators in the herd have shown generally improving trends since 2018, with some indicators showing higher values in 2020 and 2021. A key indicator or vital rate is the survival rate of adult female caribou, as population trend is very sensitive to adult cow survival rate, with values of 83-87% generally associated with stable herds (Crête et al. 1996, Haskell and Ballard 2007, Boulanger et al. 2011, Boulanger and Adamczewski 2016). In the Bluenose-East herd, the average of collar-based survival rates 2015-2019 was 85%, and the estimate for 2020 was 89% (Figure 21). Cow survival was more variable 2010-2014 and tended to be lower; however, collar sample sizes were also lower over that period. Variance on collar-based cow survival estimates has remained high, thus there was no significant difference from 2018 to 2021.

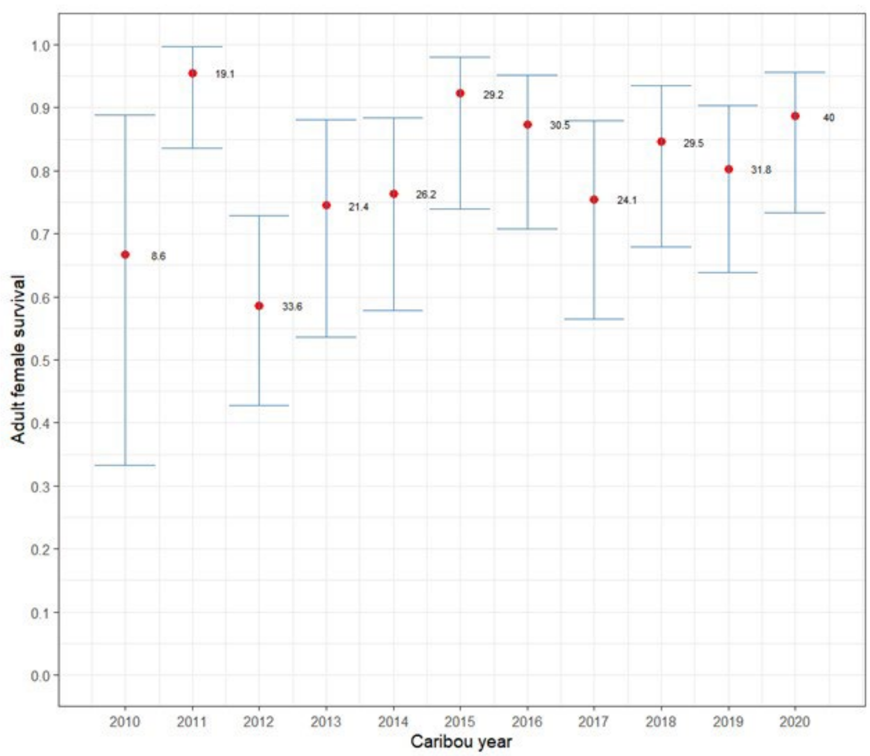

Figure 21. Annual collar-based cow survival rates in the Bluenose-East herd 2010-2020. Red dots show the estimates and the blue lines show 95% Confidence Intervals. The average number of collared cows monitored each month for each estimate are shown beside each estimate. A year begins in June of one year and ends the following May; e.g. year 2020 begins in June 2020 and ends in May 2021.

The percentage of adult cows that are breeding cows in June on the calving grounds is an index of the pregnancy rate the previous winter. In the Bluenose-East herd, the proportion of breeding cows has varied between 2009 and 2021 with significantly lower estimates in 2010 and 2015 than in 2018, 2019 and 2021 (Figure 22). The last three estimates are the highest over this period: 2018 (83%); 2019 (87.5%); 2021 (91.9%). There was no survey in June 2020 due to COVID-19 restrictions.

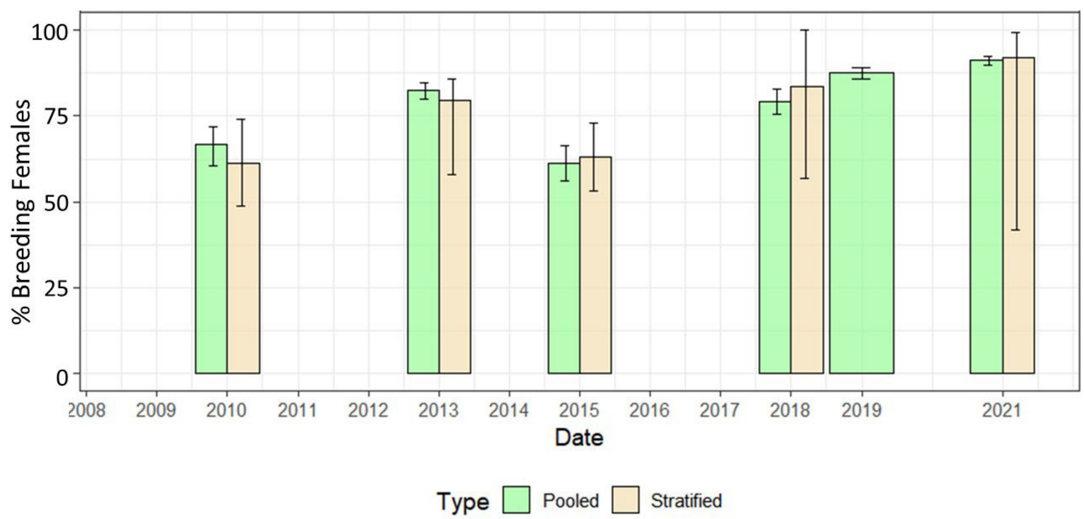

Figure 22. The proportion of breeding females as a % of adult females in June from calving ground composition surveys of the Bluenose-East herd 2009-2021. Only one survey in 2019 was carried out as a stand-alone composition survey; the rest were part of calving ground photo surveys. The stratified estimates (beige) consider relative abundance of caribou in individual survey blocks, while the pooled estimates (green) do not. Comparisons suggest there is little difference as the estimates from both methods tend to reflect composition in larger concentrations of caribou, where more caribou are classified.

While we do not have age-specific pregnancy data for Bluenose-East caribou, the exceptionally high proportion of breeding females in the herd in June 2021 suggests very high pregnancy rates in the winter of 2020-2021 and raises the possibility of higher pregnancy rates in younger females such as yearlings. In a large-scale study of the Qamanirjuaq herd in the late 1960s, age-specific pregnancy rates were 0 in calves, 1.8% in yearlings, 48% in two-year-olds and 90% in cows at least three years old (Dauphiné 1976). Well-fed female reindeer may breed in their first year in captivity (S. Kutz, University of Calgary personal communication 2018), in Alaskan free-ranging reindeer (Prichard et al. 1999), and in Norwegian semi-domesticated reindeer (Ropstad et al. 1991). Early pregnancy rates likely reflect rapid growth and fattening in young reindeer females, as the probability of pregnancy in caribou is strongly related to condition (Russell et al. 1998). Parker (1981) reported a pregnancy rate of 43% in yearling females in the George River herd in 1980 (9 of 21) when the herd was increasing, and Thomas and Kiliaan (1998) found a pregnancy rate of 12% (11 of 92) in yearling females in the relatively stable Beverly herd in the 1980s, thus yearling female caribou pregnancy rates show some variability and higher pregnancy rates are possible in growing populations.

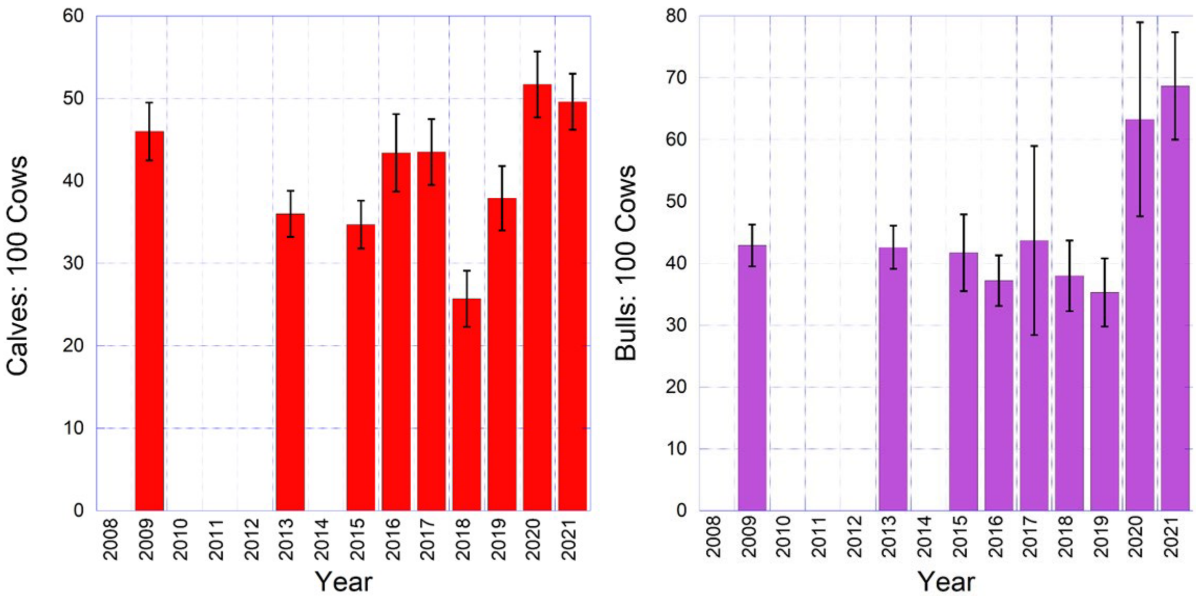

Figure 23. Calf:cow ratios (left, red) and bull:cow ratios (right, violet) estimated in the fall (usually late October) for the Bluenose-East herd 2009-2021, with 95% confidence intervals.

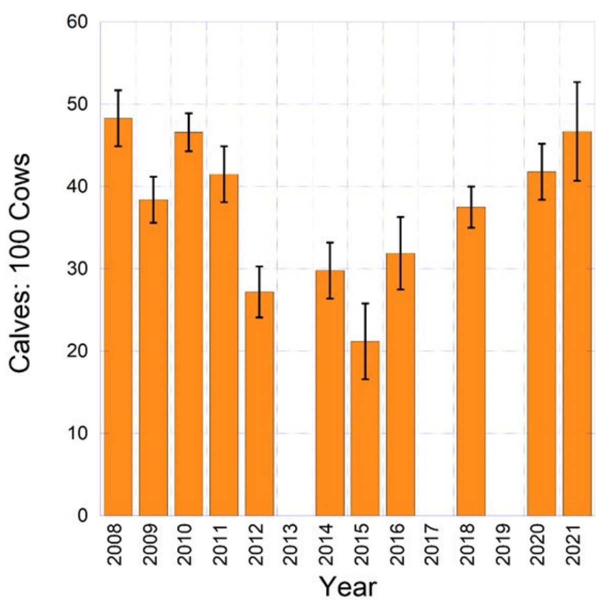

Figure 24. Calf:cow ratios estimated in late winter (usually March) for the Bluenose-East herd 2009-2021, with 95% confidence intervals.

Calf:cow ratios recorded in the fall (late October) from 2009 to 2021 varied between 25 and 52 calves:100 cows (Figure 23). Ratios in 2020 (51.7 calves:100 cows) and 2021 (49.6 calves:100 cows) were the highest value recorded over this period. Calf:cow ratios recorded in late winter (usually March) for this herd showed a generally similar pattern although ratios tended to be slightly lower in late winter than in the fall (Figure 24).

Bull:cow ratios estimated in the fall (late October) were generally around 40 bulls:100 cows from 2009 to 2019 (Figure 23). The ratios estimated in fall 2020 (63.3 bulls:100 cows) and 2021 (68.7 bulls:100 cows) were the highest recorded over this period. Both surveys appeared to be flown near the peak of the breeding season with good representation of the collared caribou in the herd (Adamczewski et al. 2022a, b). A similar ratio of 64 bulls:100 cows in the Bathurst herd was estimated in October 2020 (Adamczewski et al. 2022a). An estimate of the bull:cow ratio in the Bathurst herd was not possible in October 2021 due to extensive mixing with the much larger Beverly herd (Adamczewski et al. 2022b). The last period of widespread population growth in NWT mainland barren-ground caribou herds was in the early 1980s. The average bull:cow ratio recorded during six fall composition surveys during this period was 66 bulls:100 cows (in Gunn et al. 1997, p. 35), similar to the Bluenose-East ratios for 2020 and 2021 and the Bathurst herd in 2020.

Taken together, between 2018 and 2021, collar-based cow survival rates, proportion of breeding females in June, calf:cow ratios in October and March, and bull:cow ratios in October all showed some of the highest values recorded for this herd since 2009 and are consistent with an improving population trend over this period. We also note that yearlings accounted for 20.5% of all caribou classified and 32.0% of adult caribou classified during the Bluenose-East June 2021 composition survey; although the survey is not designed to estimate the proportion of yearlings in the herd, these percentages suggest a very healthy representation of yearlings (calves born 2020) in the herd.

Demographic Modeling of the Bluenose-East Herd

One of the challenges with interpretation of individual metrics of herd status (composition and population survey results) is understanding how they each contribute to overall herd trend and demography. The IPM was used to further understand demography by assessing changes in calf and adult survival rates and productivity and their contributions to the stabilizing trend in the Bluenose-East herd 2018-2021, in comparison to the previous rapid decline from 2010-2018. Additional details on the model are in Appendix 3.

One focus of demographic analysis was to assess if the apparent increase in bulls from fall composition surveys (and reflected in the estimate of adult herd size in 2021) was also indicated by bull collar survival and other indicators of productivity. Further investigation into the effect of environmental covariates on trend (up to 2020) is also described, as a follow-up to earlier analyses (Boulanger and Adamczewski 2017) using the MERRA climate database (Russell et al. 2013).

A random effects model was used to account for temporal variation in demographic parameters. The fit of the random effects IPM for the Bluenose-East herd was adequate for demographic indicators as suggested by overlap of confidence limits of predictions and field measurements (Figure 25).

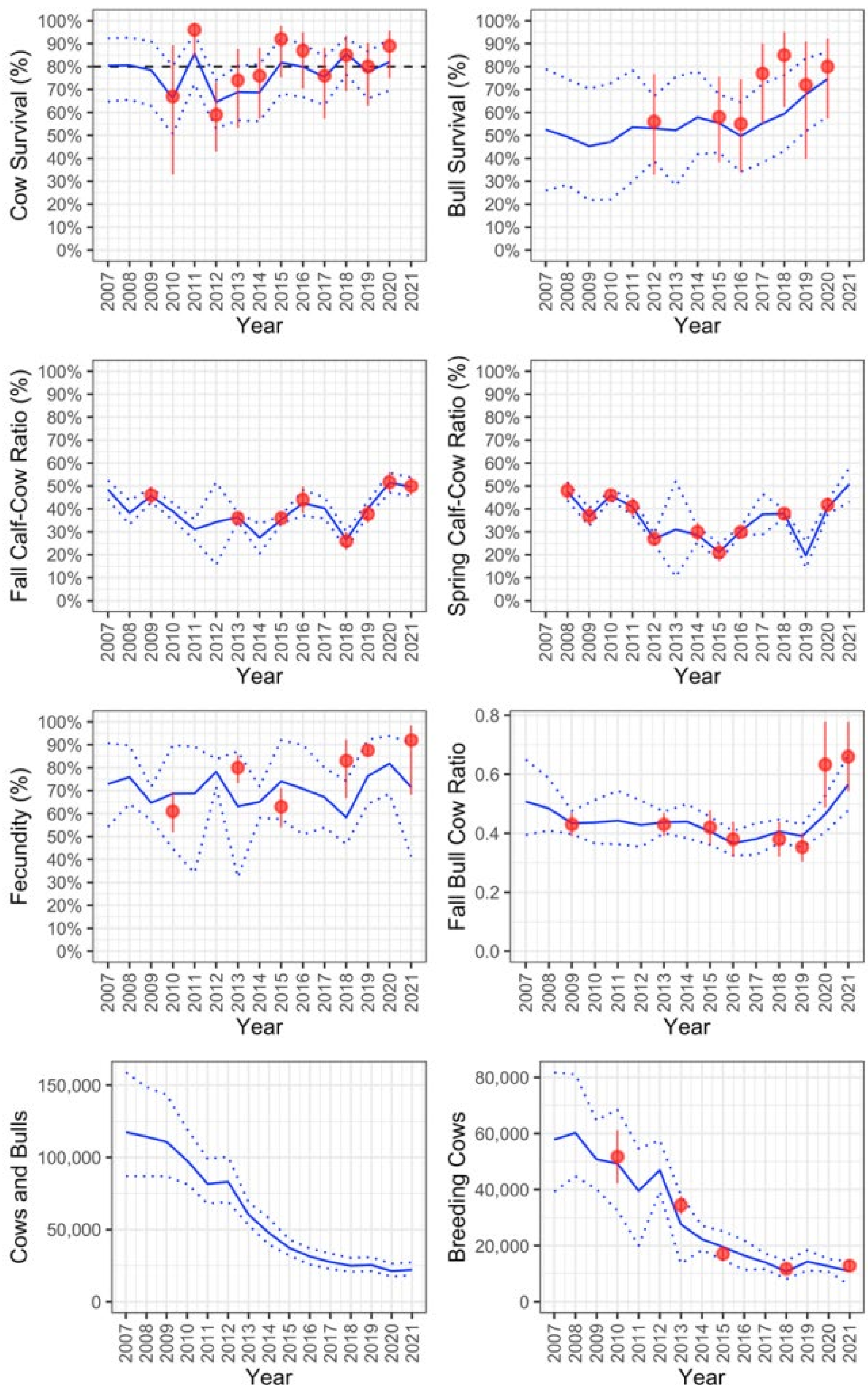

Figure 25. The fit of the IPM to estimates of survival, calf:cow ratios, fecundity, bull:cow ratios, numbers of adult cows and bulls, and numbers of breeding females for the Bluenose-East herd

2007-2021. The blue lines are model-based with variance as a dotted blue line, and the red dots are estimates from field surveys or collar data, with variance as red bars.

An increasing trend in bull survival and bull cow ratios was suggested by the IPM model as well as collar data (Figure 25 top right), consistent with the higher bull:cow ratios estimated in 2020 and 2021 from surveys.

There has been ongoing harvest of Bluenose-East caribou from 2010 to 2021, although harvest limits determined or recommended by the WRRB, the Belare wílé Gots’ę́ ʔekwę́ - Caribou for All Time (Délı̨nę 2016) and the NU Wildlife Management Board (NWMB) in 2016-2017 and 2018-2019 have resulted in decreased harvest rates of bulls and cows as the herd declined. The WRRB in 2019 determined a Total Allowable Harvest (TAH) limit of 193 bulls from the Bluenose-East herd in Wek’èezhìı (WRRB 2019); the NWMB in 2020 established a TAH of 170 Bluenose-East caribou for Kugluktuk harvesters (letter from NWMB to Government of Nunavut July 10, 2020); and the Belare wílé Gots’ę́ ʔekwę́ - Caribou for All Time (Délı̨nę 2021) plan established a harvest limit of 30 Bluenose-East caribou for Délı̨nę harvesters. Using IPM estimates of bulls and estimated harvest, annual levels of harvest ranged from 3 to 8% of the bull population prior to 2018 but then were reduced to 1-3% of the population after 2018.

Using harvest estimates it is possible to estimate natural survival with hunting mortality removed. Estimates of bull survival were mainly affected by hunting prior to 2016, after which harvest was limited to a low rate. An upward trend in bull survival is suggested after 2016 (Figure 26) and reflected in increasing bull-cow ratios (Figure 25). The increase in bull survival and bull cow ratios has resulted in a slight increase in the estimated bull population in 2021 (Figure 27).

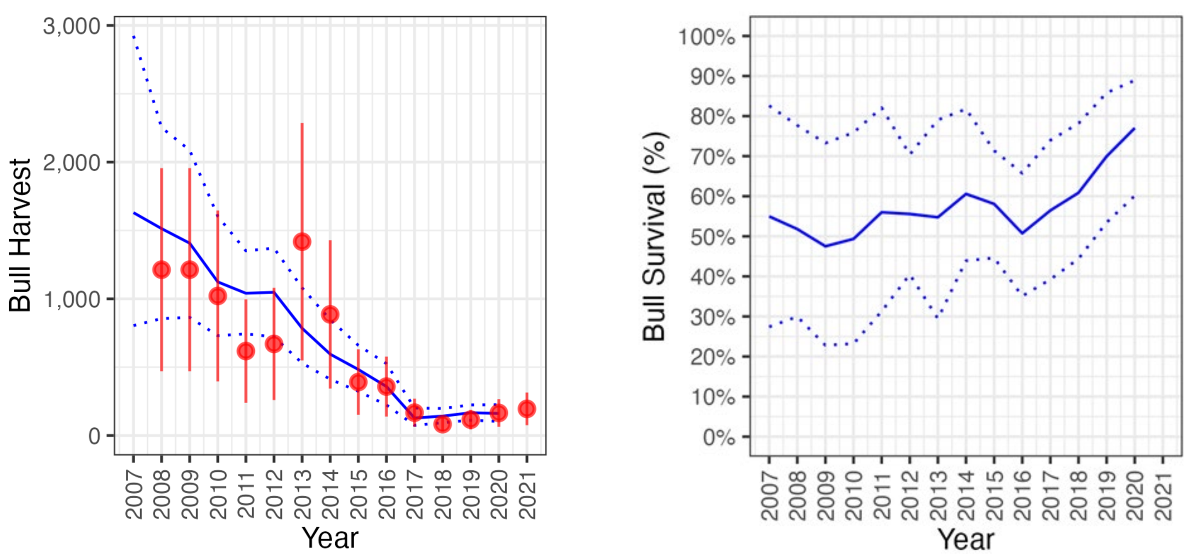

Figure 26. Estimated bull harvest rates (left) and model-based natural bull survival rates (right) in the Bluenose-East herd 2007-2021.

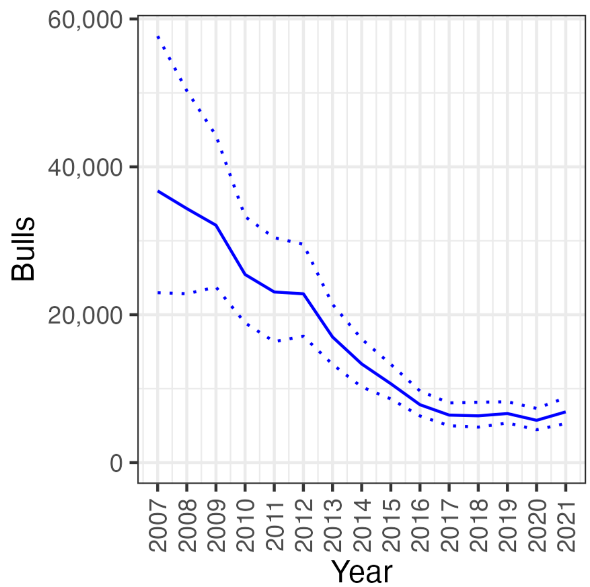

Figure 27. Model-based estimates of the number of bulls in the Bluenose-East herd 2007-2021.

The estimated cow harvest of the Bluenose-East herd between 2008 and2021 is shown in Figure 28 (left); harvest was between 1,000 and 2,000/year between 2008 and 2015, then declined to very low levels 2017-2021. Using IPM estimates of cows, the annual level of harvest ranged from 2 to 6% of the cow population from 2008 to 2016 but then was less than 1% after 2016. IPM estimates of observed mortality (natural and harvest mortality included) were slightly lower (≈2% difference) than observed survival during the time of higher harvest levels (up to 2016) but then were equivalent (<1% difference) to natural survival after 2016 (since harvest levels were very low). Estimates of adult female natural and observed survival were close to 0.83 (83%) from 2016 to 2021 (Figure 28 right) and were 0.82 (CI=0.70-0.92) from 2020 to 2021. This is close to the minimum level needed for herd stability at moderate levels of calf productivity. Previous modelling (Boulanger et al 2019) suggested adult survival levels of 0.83-0.92 were required for stability given historic ranges of productivity for the Bluenose-East herd. Therefore, the estimated levels of female survival would need to improve further to ensure stability and recovery of the herd. Investigation of environmental factors influencing survival is ongoing.

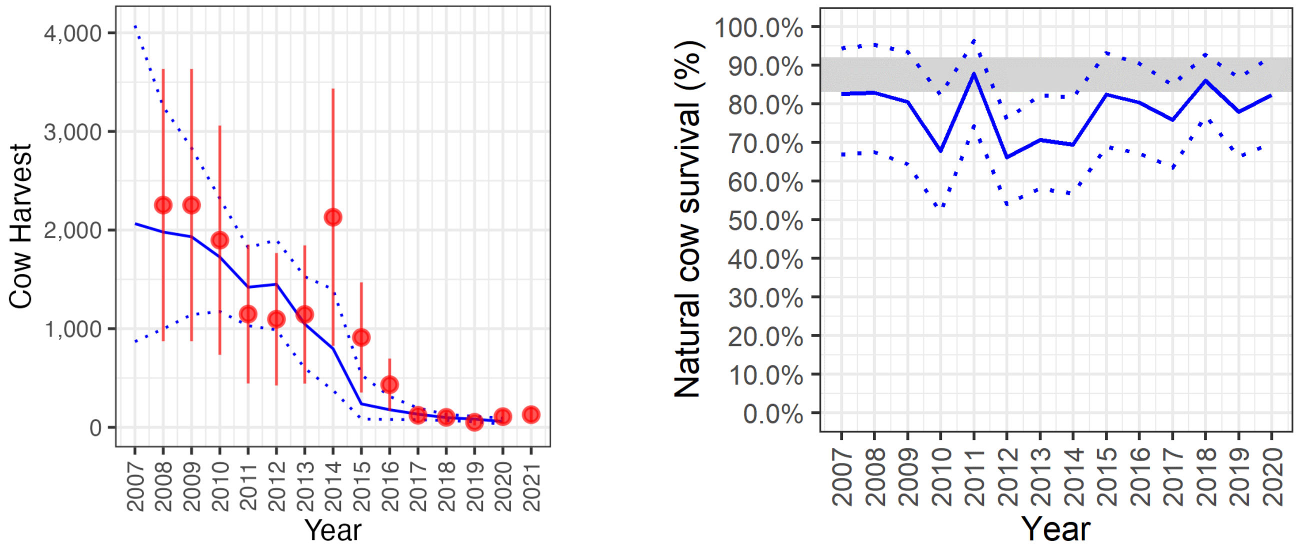

Figure 28. Estimated cow harvest from the Bluenose-East herd 2008-2021 (left) and model-based natural cow survival (right). The range of adult cow survival estimates needed for herd stability is shaded in grey.

Overall calf productivity, which is the proportion of adult females that produce a calf that survives the first year of life, can be derived as the product of fecundity (from the previous caribou year) and calf survival (from the current year) (Figure 29). Model-based estimates of calf survival suggest relatively low levels between 2010 and 2015 and an increasing trend since then, particularly since 2018. Fecundity also has shown an increase since 2007. The net result is higher productivity from 2018 to 2021 which is consistent with higher fall and late-winter calf:cow ratios in the herd recorded during this period. Spring calf-cow ratios are overlaid with productivity in Figure 29 and fall calf-cow ratios are shown in Figure 23. We note that productivity corresponds to the end of the caribou year (late May) whereas spring calf-cow ratios are estimated in March. The spring calf-cow ratio will index productivity if cow and calf survival rates are relatively similar from March to late May.

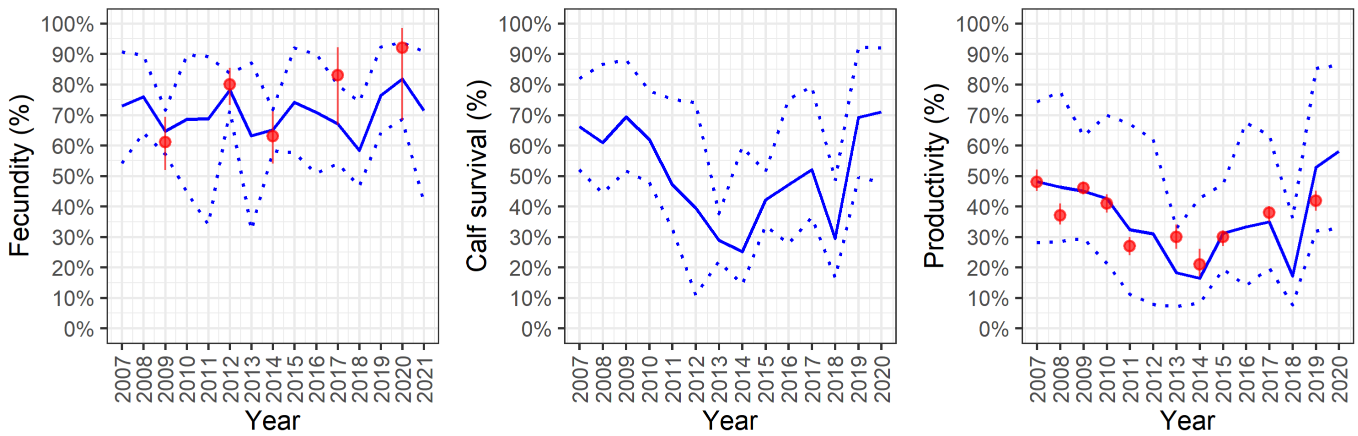

Figure 29. Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for Bluenose-East herd 2007-2021. Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year prediction of the model), are shown for reference purposes.

Analyses up to June 2020 were also carried out to assess trends over time in environmental variables from the MERRA climate database (Russell et al. 2013). These analyses showed a trend toward warmer spring temperatures from 2007 to 2014 and cooler spring temperatures from 2014 to 2020 (Figure 30). Parameters were most sensitive to the number of days up to June where the maximum temperature was >5° (GDD>5). However, this index is also related to overall temperature as well as insect harassment as indicated by an oesterid index. Cow survival, calf survival and fecundity all showed negative correlations with June Growing Degree Days (GDD, Figure 31).

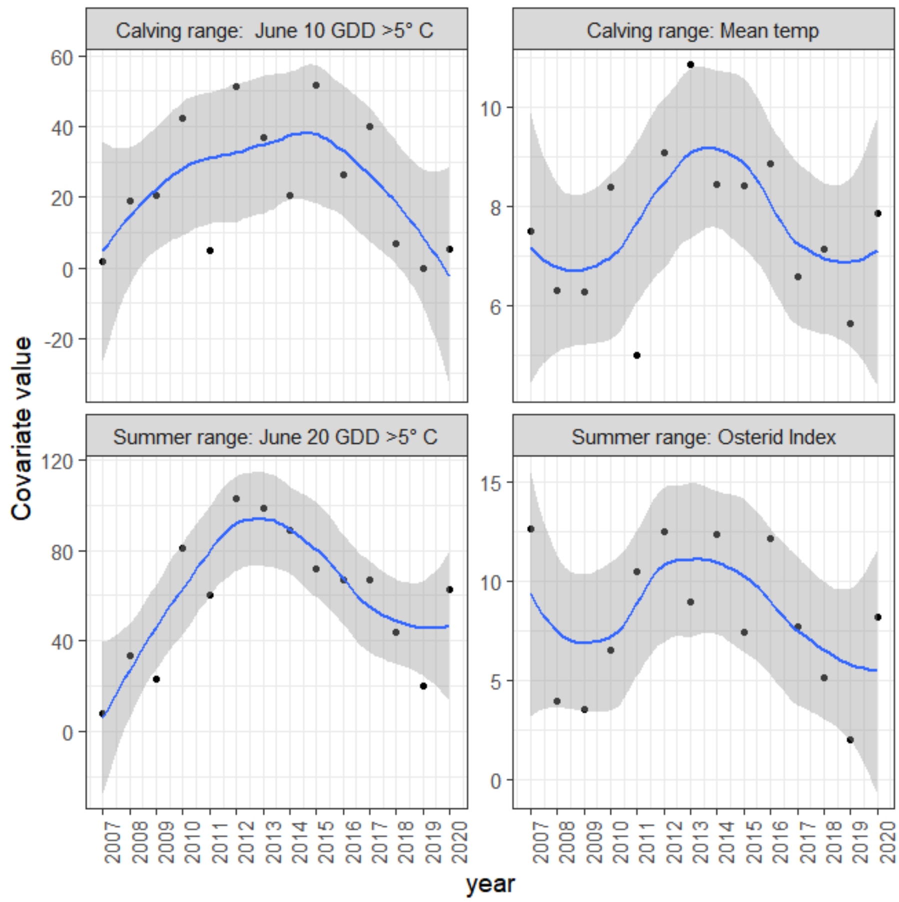

Figure 30. Trends in June GDD and related climatic covariates from the MERRA climate database over time (2007-2020) on the summer and calving ranges of the Bluenose-East caribou herd. A spline regression line was fitted to the data to describe overall trends.

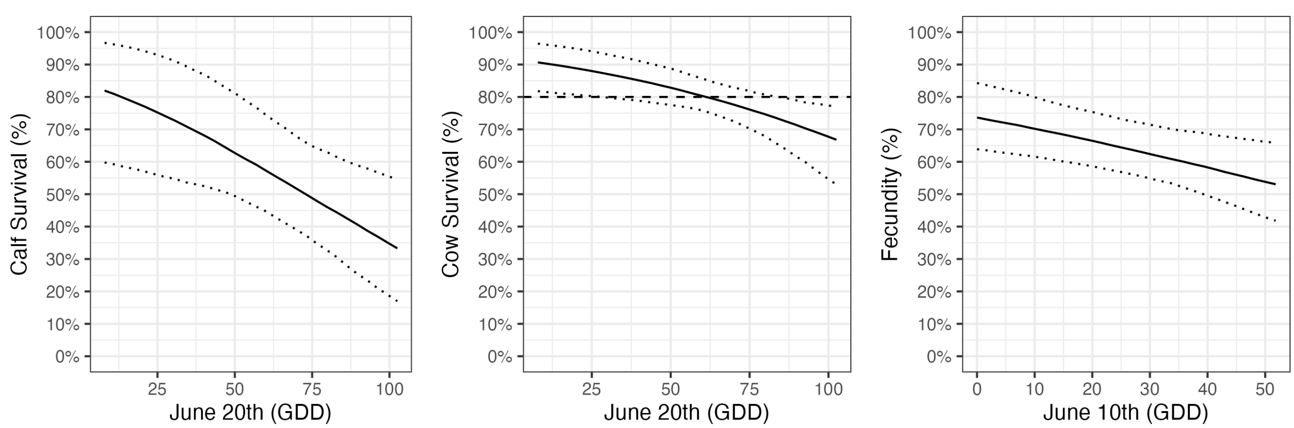

Figure 31. Estimated relationships between temperatures in June, expressed as cumulative GDD, and calf survival, cow survival and fecundity in the Bluenose-East caribou herd from IPM analyses.

The model was also used to estimate the population growth rate from 2008 to 2021 based on the estimates numbers of adult females (Figure 32). This suggested that the Bluenose-East cows were recovering from the decline experienced from 2012 to 2018. However, moderate levels of cow survival (Figure 28) may be limiting the herd's ability to increase.

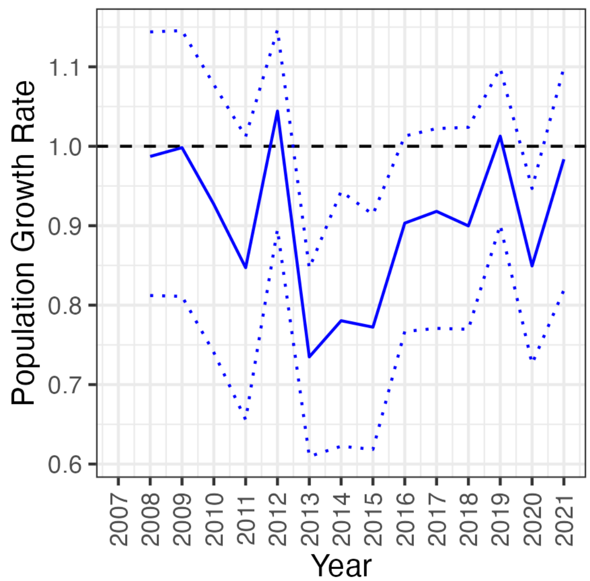

Figure 32. Model-based estimated population growth in the Bluenose-East herd 2008-2021 based on numbers of adult females. The black dotted line shows a growth rate of 1.0, which is a stable population.

Incidental Sightings

Incidental sightings of other wildlife during the visual survey flying and the helicopter-based composition survey are listed in Appendix 4. Of particular interest were the sightings of grizzly bears and wolves, which are effective predators of young caribou calves. It is important to note that sighting rates of large predators on caribou surveys tend to have high variability, thus are broad indices of abundance only. There were ten grizzly bears and three wolves seen during the visual survey flying and six grizzly bears and 0 wolves on the composition survey in June 2021; this continued a pattern of bear sightings being much more common than wolf sightings on the Bluenose-East calving grounds (Boulanger et al. 2019).

DISCUSSION

Survey Considerations

The June 2021 calving ground photo survey of the Bluenose-East herd was carried out following methods consistent with previous surveys of the herd since 2010. We acknowledge that the lack of an initial reconnaissance survey to estimate caribou densities is a departure from previous Bluenose-East calving ground surveys, however we believe that the design of the survey area west of Kugluktuk, with two photo blocks that had most of the calving cows and lower-density visual blocks surrounding it, was effective and very similar to the design that would have resulted after a reconnaissance survey. There were 25 known collared Bluenose-East female caribou and a further 30 unassigned female collared caribou (total 55) in the survey area at the time of the June 2021 survey. This number of collared female caribou is higher than in any previous surveys of this herd, and survey results indicated that the distribution of female caribou was well defined. Similar to 2018, a high percentage (about 94%) of breeding cows and adult cows were accounted for by the two photo blocks, with much lower numbers of breeding and non-breeding cows in the surrounding visual blocks. With an independent count of a sub-set of aerial photos and extra time taken by photo analysts to detect caribou on the photos, we believe the estimates of breeding and adult females and herd adults are reliable updates on estimates from previous calving ground surveys for this herd.

We suggest that it remains preferable to carry out a reconnaissance survey prior to defining photo and visual survey blocks on calving ground surveys when possible, as the reconnaissance survey provides useful information on distribution, relative abundance and approximate composition of caribou in the main calving area and in surrounding areas. The reconnaissance data provide empirical data that assist in designing survey blocks to reduce survey variance by increasing survey coverage in areas of higher density.

The single Bluenose-West collared caribou female present in Visual block 2 (Figure 9) raises the possibility that a limited number of Bluenose-West caribou were mixed with Bluenose-East caribou in that area. However, this block contributed small proportions of the overall estimates of 12,863 breeding females (221; 1.7%) and 13,991 adult females (229; 1.6%), thus likely had little influence on the Bluenose-East population estimate. There was also one unassigned collared cow in the Bluenose-East June 2021 survey area; her identity is somewhat unclear as she was not associated with any calving ground in June 2020, although her movements in summer 2020 suggested she was part of the Bathurst herd. Low rates of calving ground switches of collared female caribou between neighbouring herds have been documented in several NWT herds, including between the Bluenose-West and Bluenose-East herds (Davison et al. 2014, Adamczewski et al. 2020).

Demographics, Trend and Indicators

The 2021 Bluenose-East estimates of breeding females, adult females and adult herd size demonstrate a major change in population trend from the herd's rapid decline 2010-2018. Over that eight-year period, the herd had an annual rate of decline of about 20% and declined by half from 2015 to 2018 (Boulanger et al. 2019). Stabilization in the herd is consistent with generally improved demographic indicators in the herd from 2018 to 2021 compared to 2015 to 2018 although some ratios like calf:cow ratios show substantial year-to-year variability. The very high proportion of breeding females along with a high representation of newborn calves and yearlings on the calving ground in 2021, increased calf:cow ratios in October and March in 2020 and 2021, the increased bull:cow ratios in October 2020 and 2021, and increased estimates of cow and bull survival are all consistent with a herd that may be in the early stages of recovery.

The IPM analysis provides further inference on herd demography. First, the apparent increase in the Bluenose-East herd was mainly due to an increase in the bull population with adult female numbers being stable (Figure 20). The IPM analysis also suggests an increase in the bull segment as indicated by increasing bull survival rates (Figure 26) as well as increases in bull-cow ratios (Figure 25). Further detail on increased bull:cow ratios in the Bluenose-East herd is provided in Appendix 5. Second, estimates of cow survival have not increased substantially (Figure 28) suggesting stability rather than increase in the adult female segment of the herd. In this context, the apparent stability of the Bluenose-East herd is due to increased productivity as indicated by increased calf survival and fecundity (Figure 29), rather than substantial increases in cow survival. Previous analysis of environmental covariate data suggests that productivity and survival rates were reduced from 2007 to 2014 due to warm spring and summer temperatures. Reduction in spring and summer temperatures in subsequent years has correlated with an increased survival and productivity, contributing to herd stability (Figures 30, 21). Because of the time lag between calf production and recruitment to the adult age class the actual increase in herd size is becoming evident in calving ground surveys. We suggest that adult female survival rates will need to increase further to ensure recovery and overall resiliency of the herd. Additional demographic analysis of factors affecting cow survival and related demographics is ongoing.

We note that a number of observations from Inuit knowledge holders in Kugluktuk (A. Niptanatiak and A. Dumond) indicate that recent summer weather in the region has been relatively cool, wet and windy, resulting in less severe insect harassment and good feeding conditions for caribou. Trends in summer climate variables from the MERRA database are consistent with these observations; good summer feeding conditions likely lead to female caribou in good condition in the fall breeding season and a high pregnancy rate in the winter. Observations and knowledge from A. Niptanatiak have also suggested that when the twinning rate in caribou increases, this is a sign of a caribou herd entering an increasing phase. Our observations during the June 2021

Bluenose-East composition survey did not allow us to make a quantitative estimate of the proportion of cows with twins, but there were a number of anecdotal observations of assumed twinning. There are limited documented records of twins in caribou, however a study of reproduction in a Canadian reindeer herd 1976-1981 found that in 1978 and 1981, 24.7% of harvested females were carrying twins while the rate was 0.4% in the other years (Godkin 1986).

Despite the apparent stabilization of the herd and the improved demographic indicators, we suggest some caution from a management perspective, given the example of the Bathurst herd's decline 2006 to 2021 (see Adamczewski et al. 2022c). The most rapid decline in the Bathurst herd occurred between 2006 and 2009 from more than 100,000 to an estimated 32,000. Following the 2009 survey, harvest was reduced by more than 90% and March calf:cow ratios improved between 2009 and 2012. The 2012 Bathurst estimates indicated that the herd had stabilized and suggested that major harvest reduction contributed to stabilization. However, the 2015, 2018 and 2021 population estimates of the Bathurst herd all showed further decline, even with a harvest closure for the herd in the NWT and a minimal harvest in Nunavut. Population ecology in the Bathurst and Bluenose-East herds has been dynamic in the last ten years. While the demographic trends in the Bluenose-East herd from 2018 to 2021 are encouraging, compared to 2015 to 2018, the herd is still at low numbers and continuation of positive demographic indicators should not be assumed.

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Doug Charko provided detailed forecasts for weather in the two survey areas every morning, which was key to planning survey flying a few days ahead.

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Kerry and Irene Horn at the Coppermine Inn welcomed us throughout the survey, provided great food, and provided additional space for office work during the surveys (Figure 37). We thank Sam Kapolak and Boyd Warner for making Bathurst Inlet Lodge available for the Bathurst composition survey. This survey was primarily funded by Environment and Natural Resources (ENR), Government of Northwest Territories (GNWT). Bruno Croft at ENR provided daily collar movement maps and encouragement throughout the surveys. We thank Patricia Lacroix for formatting and finalizing the report to GNWT standards. Heather Sayine-Crawford as Wildlife and Fish Director and Brett Elkin as ENR Assistant Deputy Minister, Operations provided assistance and cheerful support throughout the operation.

We would like to note that the June 2021 calving ground surveys were affected by the COVID-19 pandemic, as were a great many other enterprises large and small across the globe. Unlike previous similar survey operations in 2015 and 2018, it was necessary to use the Coppermine Inn in Kugluktuk as our isolation "bubble". As a result, there was no participation from Kugluktuk as our host community. It was unfortunate that this was necessary in 2021 and we look forward to having full participation of NU observers and GN staff in future surveys.

Figure 33. Cessna Caravan C-GZIZ survey crew (left to right): Dylan Reid (pilot), Jan Adamczewski, Robin Abernethy, Judy Williams, Peter Crookedhand, Aimée Guile, Karin Clark and Earl Evans.

Figure 34. Cessna Caravan C-GDLC survey crew (left-right): Stefan Goodman, Roy Judas, Randi Jennings, Dean Cluff, Kevin Chan, Jess Hurtubise, and Fred Martin (pilot).

Figure 35. Acasta Heliflight C-FGSC survey crew: Geoff Furniss (pilot), Judy Williams, and Stefan Goodman.

Figure 36. Great Slave Helicopters C-FYZF survey crew: Tom Frith (pilot), Jan Adamczewski and Dean Cluff.

Figure 37. Irene and Kerry Horn, owners of the Coppermine Inn and our hosts in Kugluktuk. They celebrated their 50th wedding anniversary in June 2021.

LITERATURE CITED

Adamczewski, J., J. Boulanger, B. Croft, T. Davison, H. Sayine-Crawford and B. Tracz. 2017. A comparison of calving and post-calving photo-surveys for the Bluenose-East herd of barren-ground caribou in northern Canada in 2010. Canadian Wildlife Biology and Management 6:4-30.

Adamczewski, J. Boulanger, H. Sayine-Crawford, J. Nishi, D. Cluff, J. Williams, and L. M. LeClerc. 2019. Estimates of breeding females & adult herd size and analyses of demographics for the Bathurst herd of barren-ground caribou: 2018 calving ground photographic survey. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 279.

Adamczewski, J., J. Boulanger, A. Gunn, B. Croft, D. Cluff, B. Elkin, J. Nishi, A. Kelly, A. D'Hont and C. Nicolson. 2020. Decline in the Bathurst caribou herd 2006–2009: a technical evaluation of field data and modeling. Environment and Natural Resources, Government of Northwest Territories. Manuscript Report 287.

Adamczewski, J., D. Cluff, J. Williams and J. Boulanger. 2022a. October 2020 fall composition surveys of Bathurst and Bluenose-East barren-ground caribou herds. Environment and Natural Resources, Government of Northwest Territories. Manuscript Report (in prep.).

Adamczewski, J., J. Williams and J. Boulanger. 2022b. October 2021 fall composition survey of Bluenose-East barren-ground caribou herd. Environment and Natural Resources, Government of Northwest Territories. Manuscript Report (in prep.).

Adamczewski, J. Boulanger, J. Williams, D. Cluff, K. Clark, S. Goodman, K. Chan, R. Abernethy and J. Nishi. 2022c. Estimates of breeding females and adult herd size and analyses of demographics for the Bathurst herd of barren-ground caribou: 2021 calving ground photographic survey. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report (in prep.).

Barker, R. 2008. Theory and application of mark-recapture and related techniques to aerial surveys of wildlife. Wildlife Research 35:268-274.

Bergerud, A.T. 1964. A field method to determine annual parturition rates for Newfoundland caribou. Journal of Wildlife Management 28:477-480.

Boulanger, J. and J. Adamczewski. 2016. A General Approach to Harvest Modeling for Barren-ground Caribou Herds in the NWT and Recommendations on Harvest Based on Herd Risk Status. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report No 262.

Boulanger, J. and J. Adamczewski. 2017. Analysis of environmental, temporal, and spatial factors affecting demography of the Bathurst and Bluenose-East caribou herds: Draft report. Environment and Natural Resources, Government of Northwest Territories.

Boulanger, J., K.G. Poole, J. Williams, J. Nishi and B. Croft. 2010. Estimation of sighting probabilities from caribou calving ground surveys using double observer methods. Unpublished draft report. Governments of Northwest Territories and Nunavut.

Boulanger, J., M. Campbell, D. Lee, M. Dumond and J. Nishi. 2014a. A double observer method to model variation in sightability of caribou in calving ground surveys. Unpublished manuscript.

Boulanger, J., B. Croft and J. Adamczewski. 2014b. An estimate of breeding females and analyses of demographics for the Bluenose-East herd of barren ground caribou: 2013 calving ground photographic survey. Environment and Natural Resources, Government of Northwest Territories. File Report No. 143.

Boulanger, J., B. Croft, J. Adamczewski, D. Lee, N.C. Larter and L.M. Leclerc. 2016. An estimate of breeding females and analyses of demographics for the Bluenose-East herd of barren-ground caribou: 2015 calving ground photographic survey. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report No. 260.

Boulanger, J., J. Adamczewski, J. Nishi, D. Cluff, J. Williams, H. Sayine-Crawford and L. M. LeClerc. 2019. Estimates of breeding females & adult herd size and analyses of demographics for the Bluenose-East herd of barren-ground caribou: 2018 calving ground photographic survey. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report 278.

Boulanger, J., A. Gunn, J. Adamczewski and B. Croft. 2011. A data-driven demographic model to explore the decline of the Bathurst caribou herd. Journal of Wildlife Management 75:883-896.

Bradford, M.J., J. Korman and P.S. Higgins. 2005. Using Confidence Intervals to Estimate the Response of Salmon Populations (Oncorhynchus Spp.) to Experimental Habitat Alterations. Canadian Journal of Fisheries and Aquatic Sciences 62 (12): 2,716–26. https://doi.org/10.1139/f05-179.

Brooks, S., A. Gelman, G.L. Jones and X.-L. Meng, eds. 2011. Handbook for Markov Chain Monte Carlo. Boca Raton: Taylor & Francis.

Buckland, S.T., D.R. Anderson, K.P. Burnham and J.L. Laake. 1993. Distance Sampling. Estimating Abundance of Biological Populations. Chapman & Hall, London.

Buckland, S.T.N., K.B., L. Thomas and N.B. Koesters. 2004. State-space models for the dynamics of wild animal populations. Ecological Modeling 171:157-175.

Burnham, K.P. and D.R. Anderson. 1998. Model selection and inference: A practical information theoretic approach. Springer, New York, NY.

Campbell, M., J. Boulanger and D. Lee. 2015. Estimating abundance of the Qamanirjuaq mainland migratory barren ground caribou sub-population; June 2014. Government of Nunavut, Department of Environment, Technical Report Series - No: 01-2016.

Chow, Z. R., and S. Greenland. 2019. Semantic and Cognitive Tools to Aid Statistical Inference: Replace Confidence and Significance by Compatibility and Surprise. *arXiv:1909.08579 [q-Bio, Stat]*, September. http://arxiv.org/abs/1909.08579.

Crête, M.S., S. Couturier, J. Hearn and T.E. Chubbs. 1996. Relative contribution of decreased productivity and survival to recent changes in the demographic trend of the George River herd. Rangifer 9:27-36.

Dauphiné T.C. 1976. Biology of the Kaminuriak population of barren ground caribou, Part 4: Growth, reproduction and energy reserves. Canadian Wildlife Service Report No. 38, Canadian Wildlife Service.

Davison, T., H. Sawada, P. Spencer, M. Branigan and R. Popko. 2014. Calving Ground Fidelity of the Tuktoyaktuk Peninsula, Cape Bathurst, Bluenose-Westand Bluenose-East Barren-Ground Caribou Herds, Poster at North American Caribou Workshop, Whitehorse, YT.

Délı̨nę. 2021. Belare Wí le Gots'é ʔekwé – Caribou for All Time – A Délı nę Got'ı nę Plan of Action for 2021-2023. https://www.srrb.nt.ca/document-repository/public/public-hearings-registry/t-ch-ad-he-gots-ed-living-with-wildlife-caribou-predators-and-competitors-2021/02-2-submissions-proposals/2092-21-11-22-del-ne-belare-w-le-gots-e-ekwe-plan-pdf/file.

Fewster, R. M. 2011. Variance Estimation for Systematic Designs in Spatial Surveys. Biometrics 67:1518-1531.

Gelman, Andrew, Daniel Simpson, and Michael Betancourt. 2017. "The Prior Can Often Only Be Understood in the Context of the Likelihood." *Entropy* 19 (10): 555. https://doi.org/10.3390/e19100555.

Godkin, G.F. 1986. Fertility and twinning in Canadian reindeer. Rangifer Special Issue 1: 145-150.

Greenland, S. 2019. Valid *p* -Values Behave Exactly as They Should: Some Misleading Criticisms of *p* -Values and Their Resolution With *s* -Values. *The American Statistician* 73 (sup1): 106–14. https://doi.org/10.1080/00031305.2018.1529625.

Greenland, S., and C. Poole. 2013. Living with p Values: Resurrecting a Bayesian Perspective on Frequentist Statistics. *Epidemiology* 24 (1): 62–68. https://doi.org/10.1097/EDE.0b013e3182785741

Gunn, A., J. Dragon and J. Nishi. 1997. Bathurst Calving Ground Survey 1996. Resources, Wildlife and Economic Development, Government of Northwest Territories. File Report No 119.

Gunn, A. and D.E. Russell, editors. 2008. Monitoring Rangifer herds (population dynamics): Manual. Circumarctic Rangifer Monitoring and Assessment Network (CARMA), www.carmanetwork.com.

Haskell, S.P. and W.B. Ballard. 2007. Modeling the Western Arctic caribou herd during a positive growth phase: Potential effects of wolves and radio collars. Journal of Wildlife Management 71:619-627.

Heard, D.C. and M. Williams. 1990. Caribou project summary and review: Resources, Wildlife, and Economic Development, Government of Northwest Territories. Unpublished report

Heard, D.C. and J. Williams. 1991. Bathurst calving ground survey, June 1986. Government of Northwest Territories. Unpublished report

Huggins, R.M. 1991. Some practical aspects of a conditional likelihood approach to capture experiments. Biometrics 47:725-732.

Humbert, J.Y., L.S. Mills, J.S. Horne and B. Dennis. 2009. A better way to estimate population trends. Oikos 118:1,940-1,946.

Innes, S., M.P. Heidi-Jorgensen, J.L. Laake, K.L. Laidre, H.J. Cleator, P. Richard and R.E.A. Stewart. 2002. Surveys of belugas and narwhals in the Canadian High Arctic. NAMMMCO Scientific Publications No. 3.

Jolly, G.M. 1969. Sampling methods for aerial censuses of wildlife populations. East African Agricultural and Forestry Journal 34:46-49.

Kery, M. and J.A. Royle. 2016. Applied hierarchichal modeling in ecology: Analysis of distribution, abundance, and species richness in BUGS. Academic Press, London, England.

Kery, M. and M. Schaub. 2011. Bayesian population analyses using WinBugs: A hierarchical perspective. Volume 1.Academic Press, Watham, MA.

Krebs, C.J. 1998. Ecological Methodology (Second edition). Benjamin Cummins, Menlo Park, CA.

Laake, J., M.J. Dawson and J. Hone. 2008a. Visibility bias in aerial survey: mark-recapture, line-transect or both? Wildlife Research 35:299-309.

Laake, J., R.J. Guenzel, J.L. Bengtson, P. Boveng, M. Cameron and M.B. Hanson. 2008b. Coping with variation in aerial survey protocol for line-transect sampling. Wildlife Research 35:289-298.

Laake, J., D.L. Borchers, L. Thomas, D. Miller and J. Bishop. 2012. Mark-recapture distance sampling (MRDS) 2.1.0. R statistical package program.

Manly, B.F.J. 1997. Randomization and Monte Carlo Methods in Biology. 2nd edition. Chapman and Hall, NY.

Marshall, L. 2021. Distance Sampling Survey Design: dssd R package.

McElreath, R. 2016. Statistical Rethinking: A Bayesian Course with Examples in R and Stan. Chapman & Hall/CRC Texts in Statistical Science Series 122. Boca Raton: CRC Press/Taylor & Francis Group.

Nagy, J., D.L. Johnson, N.C. Larter, M. Campbell, A.E. Derocher, A. Kelly, M. Dumond, D. Allaire and B. Croft. 2011. Subpopulation structure of caribou (*Rangifer tarandus L.*) in Arctic and subarctic Canada. Ecological Applications 21:2,334-2,348.

Newman, K.B., S.T. Buckland, B.J.T. Morgan, R. King, D.L. Borchers, D.J. Cole, P. Besbeas, O. Gimenez, and L. Thomas. 2014. Modelling Population Dynamics: Model Formulation, Fitting and Assessment Using State-Space Methods. http://dx.doi.org/10.1007/978-1-4939-0977-3.

Norton-Griffiths, M. 1978. Counting Animals. 2nd edition. African Wildlife Leadership Foundation, Nairobi.

Parker, G. R. 1981. Physical and reproductive characteristics of an expanding caribou population (Rangifer tarandus caribou) in northern Labrador. Canadian Journal of Zoology 59: 1929-1940.

Patterson, B.R., B.T. Olsen and D.O. Joly. 2004. Population estimate for the Bluenose-East caribou herd using post-calving photography. Arctic 57:47-58.

Pebesma, E. 2018. Simple Features for R: Standardized Support for Spatial Vector Data. The R Journal 10:439-446.

Peters, W., M. Hebblewhite, K.G. Smith, S.M. Webb, N. Webb, M. Russell, C. Stambaugh and R.B. Anderson. 2014. Contrasting aerial moose population estimation methods and evaluating sightability in west-central Alberta, Canada. Wildlife Society Bulletin 38:639-649.

Plummer, M. 2015. "JAGS Version 4.0.1 User Manual." http://sourceforge.net/projects/mcmc-jags/files/Manuals/4.x/.

Pollock, K.H., S.R. Winterstein, C.M. Bunck and P.D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Prichard, A.K., G.L. Finstad and D.H. Shain. 1999. Lactation in yearling Alaskan reindeer: implications for growth, reproduction, and survival. Rangifer 19(2): 77-84.

QGIS Foundation. 2020 QGIS: A free and open geographic information system (www.qgis.org).

R Core Team. 2018. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. www.R-project.org/.

Ramey, R.R., J.L. Thorley and A.S. Ivey. 2018. Local and population-level responses of Greater sage-grouse to oil and gas development and climatic variation in Wyoming. Peer J. 6: doi:10.7717/peerj.5417.

Ropstad, E., D. Lenvik, E. Bø, M.M. Fjellheim and K. Romsås. 1991. Ovarian function and pregnancy rates in reindeer calves (*Rangifer tarandus*) in southern Norway. Theriogenology 36: 295-305.

Russell, D.E., K.L. Gerhart, R.G. White and D. Van de Wetering. 1998. Detection of early pregnancy in caribou: evidence for embryonic mortality. Journal of Wildlife Management 62:1,066-1,075.

Russell, D.E., G. Kofinas and B. Griffith. 2002. Barren-ground Caribou Calving Ground Workshop: Report of Proceedings. Canadian Widlife Service Technical Report No. 390.

Russell, D.E., P.H. Whitfield, J. Cai, A. Gunn, R.G. White and K.G. Poole. 2013. CARMA's MERRA-based caribou range climate database. Rangifer 33:145-152.

Schaub, M. and M. Kery. 2022. Integrated Population Models. Academic Press, London, UK.

Thomas, D.C., and H.P.L. Kiliann. 1998. Fire-caribou relationships: (II) Fecundity and physical condition of the Beverly herd. Technical Report Series No. 310. Canadian Wildlife Service, Edmonton, Alberta. 96pp.

Thompson, S.K. 1992. Sampling. John Wiley and Sons, New York.

Thorley, J.L. and G.F. Andrusak 2017. The fishing and natural mortality of large, piscivorous Bull Trout and Rainbow Trout in Kootenay Lake, British Columbia (2008–2013). Peer J. 5:doi 10.7717/peerj.2874.

Thorley, J.L. and J. Boulanger. 2019. Bluenose-East Caribou Herd Population Analysis 2018. *in* J. Boulanger, J. Adamczewski, J. Nishi, D. Cluff, J. Williams and L.M. LeClerc. 2019. An estimate of breeding females and analyses of demographics for the Bluenose-East herd of barren-ground caribou: 2018 calving ground photographic survey. Environment and Natural Resource, Government of Northwest Territories.

White, G.C. and K.P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study Supplement 46:120-138.

White, G.C. and B. Lubow. 2002. Fitting population models to multiple sources of observed data. Journal of Wildlife Management 66:300-309.

Whitten, K.R. 1995. Antler loss and udder distention in relation to parturition in caribou. Journal of Wildlife Management. Journal of Wildlife Management 59:273-277.

Wickham, H. 2009. ggplot2: Elegant graphics for data analysis. Springer, NY.

WRRB (Wek'èezhìı Renewable Resources Board). 2019. Report on a Public Hearing Held by the Wek'èezhìı Renewable Resources Board 9-11 April 2019 in Behchokǫ̀, NT & Reasons for Decisions Related to a Joint Proposal for the Management of the Sahtì Ekwǫ̀ (Bluenose-East Caribou) Herd to the Tłı̨chǫ Government (TG) and Department of Environment & Natural Resources (ENR), Government of Northwest Territories in response to the "Joint Proposal on Management Actions for the Bluenose-East ʔekwǫ̀ (Barren-ground caribou) Herd: 2019 – 2021". http://wrrb.ca/public-information/public-registry.

Appendix 1: Double Observer Analysis of Caribou Counts from Visual Strata

Introduction

A double observer method was used to estimate the sighting probability of caribou during visual surveys. Experience with previous surveys had shown that two observers usually saw more caribou than one observer (Boulanger et al. 2014a, 2019). Analysis of the observations from each observer's independent counts allows for an assessment of his/her ability to sight caribou, and the effects of covariates like weather conditions and caribou group size can be assessed in the analysis (Boulanger et al. 2010, 2014a). A brief summary of the double observer analyses and results were given in the Methods and Results sections, and a more detailed description is provided here. As the Bathurst and Bluenose-East surveys were flown at about the same time by the same aircraft and observers, the analyses were carried out once for both surveys.

Methods

The double observer method involves one primary observer who sits in the front seat of the plane and a secondary observer who sits behind the primary observer on the same side of the plane (Figure 38). The method followed five basic steps:

1 - The primary observer called out all groups of caribou (number of caribou and location) he/she saw within the 400 m wide strip transect before they passed about halfway between the primary and secondary observer. This included caribou groups that were between approximately 12 and 3 o'clock for right side observers and 9 and 12 o'clock for left side observers. The main requirement was that the primary observer be given time to call out all caribou seen before the secondary observer called them out.

2 - The secondary observer called out whether he/she saw the caribou that the first observer saw and observations of any additional caribou groups. The secondary observer waited to call out caribou until the group observed passed about half-way between observers (between 3 and 6 o'clock for right side observers and 6 and 9 o'clock for left side observer).

3 - The observers discussed any differences in group counts to ensure that they were calling out the same groups or different groups and to ensure accurate counts of larger groups.

4 - The data recorder categorized and recorded counts of caribou groups into primary (front) observer only, secondary (rear) observer only, or both, entered as separate records.

5 - The observers switched places approximately half-way through each survey day (i.e. on a break between early and later flights) to monitor observer ability. The recorder noted the names of the primary and secondary observers.

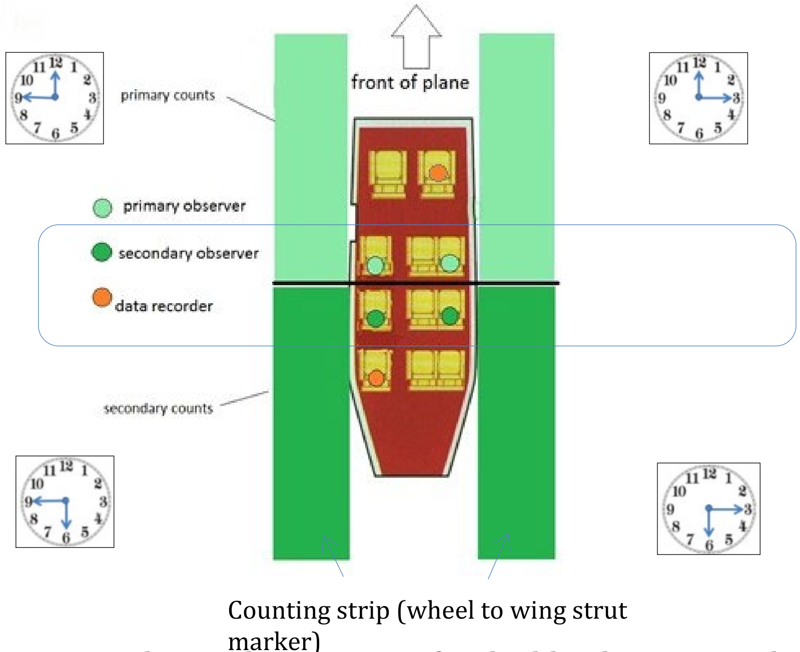

Figure 38. Observer and recorder positions for double observer methods on June 2018 caribou survey of Bathurst caribou. The secondary observer confirmed or called caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can be used to reference relative locations of caribou groups (e.g. “caribou group at 1 o’clock”). The recorder was seated behind the two observers on the left side, or with the pilot in the front seat. On the right side the recorder was seated at the front of the aircraft and was also responsible for navigating in partnership with the pilot.

The statistical sample unit for the survey was groups of caribou, not individual caribou. Recorders and observers were instructed to consider individuals to be those caribou that were observed independent of other individual caribou and/or groups of caribou. If sightings of individuals were influenced by other individuals, then the caribou were considered a group and the total count of individuals within the group was used for analyses.

The results were used to estimate the proportions of caribou that were likely missed, and numbers of caribou estimated on the visual survey blocks east and west of Bathurst Inlet were corrected accordingly.

A full independence removal estimator which models sightability using only double observer information (Laake et al. 2008a, b) was used to estimate and model sighting probabilities. In this context, double observer sampling can be considered a two-sample mark-recapture trial in which some caribou are seen (“marked”) by the (“session 1”) primary observer, and some of these are also seen by the second observer (“session 2”). The second observer may also see caribou that the first observer did not see. This process is analogous to mark-recapture except that caribou are sighted and re-sighted rather than marked and recaptured. In the context of dependent observer methods, the sighting probability of the second observer was not independent of the primary observer. To accommodate this removal, models were used which estimated *p* (the initial probability of sighting by the primary and secondary observer) and *c* (the probability of sighting by the second observer given that it had been already sighted by the primary observer). The removal model assumed that the initial sighting probability of the primary and secondary observers was equal. Observers were switched midway in each survey day (on most days there were two flights with a re-fueling stop between them), and covariates were used to account for any differences that were caused by unequal sighting probabilities of primary and secondary observers.

One assumption of the double observer method is that each caribou group seen has an equal probability of being sighted. To account for differences in sightability the covariates listed in Table 18 were also considered. Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. An observer order covariate was modeled to account for variation caused by observers switching order. If sighting probabilities were equal between the two observers, it would be expected that order of observers would not matter and therefore the confidence limits for this covariate would overlap 0. This covariate was modeled using an incremental process in which all observer pairs were tested followed by a reduced model where only the beta parameters whose confidence limits did not overlap 0, were retained. Snow and cloud cover were modeled as a continuous (snow or cloud) or categorical covariate (snow_factor or cloud_factor) based on the categorical entries in the tablets.

Table 18. Covariates used to model variation in sightability for double observer analysis for Bathurst and Bluenose-East caribou surveys in June 2021.

Covariate	Acronym	Description
Observer pair	obspair	each unique observer pair
Group size	size	size of caribou group observed
Herd/calving ground	Herd (h)	Calving ground/herd being surveyed.
Snow cover	snow	snow cover (0, 25, 75, 100%)
Cloud cover	cloud	cloud cover (0, 25, 75, 100%)
Cloud cover*snow cover	Cloud*snow	Interaction of cloud and snow cover

Data from both the Bluenose-East and Bathurst herd calving grounds surveys were used in the double observer analysis given that the two planes flew the visual surveys for both calving grounds at about the same time. It was possible that different terrain and weather patterns on each calving ground might affect sightability, and therefore herd/calving ground was used as a covariate in the double observer analysis. Estimates of total caribou that accounted for any caribou missed by observers were produced for each survey stratum.

The fit of models was evaluated using the AIC index of model fit. The model with the lowest AIC_c score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). The difference in AIC_c values between the most supported model and other models (ΔAIC_c) was also used to evaluate the fit of models when their AIC_c scores were close. In general, any model with a ΔAIC_c score of <2 was worthy of consideration.

Estimates of herd size and associated variance were estimated using the mark-recapture distance sampling (MRDS) package (Laake et al. 2012) in program R program (R Development Core Team 2018). In MRDS, a full independence removal estimator which models sightability using only double observer information (Laake et al. 2008a, b) was used. This made it possible to derive double observer strip transect estimates. Strata-specific variance estimates were calculated using the formulas of (Innes et al. 2002). Standard errors and variance estimates were calculated using the S2 estimator for sequential line transects (Fewster 2011). Estimates from MRDS were cross checked with strip transect estimates (that assume sightability=1) using the formulas of Jolly (1969)(Krebs 1998). Data were explored graphically using the ggplot2 (Wickham 2009) R package and QGIS software (QGIS Foundation 2020).

Results

Unlike previous surveys there was no reconnaissance survey in 2021 for either herd, therefore only data from the visual surveys were used in the analysis. Observers were grouped into pairs which were used for modeling the effect of observer on sightability. The relatively small size of the crews resulted in four primary pairs of observers, all of whom switched places during the survey (Table 19). The probabilities of sighting (one-secondary/total sightings) were remarkably similar between pairs, compared to previous years.

Table 19. Double observer pairings with associated summary statistics for Bluenose-East and Bathurst caribou surveys in June 2021. Single observer probabilities are estimated as (one-secondary/total sightings) and double observer probabilities are estimates as one-(one-single p)^2.

	Frequencies				Probabilities	
Observer Pair #	Secondary	Primary	Both	Total observations	Single observer pair	Double observer pair
1	30	25	83	138	0.78	0.95
2	29	31	113	173	0.83	0.97
3	30	38	120	188	0.84	0.97
4	25	24	65	114	0.78	0.95

Frequencies of observations as a function of group size, survey, and phase suggested that approximately 70% of the single caribou were seen by both observers in most cases (Figure 39). As group size increased the proportion of observations seen by both observers increased.

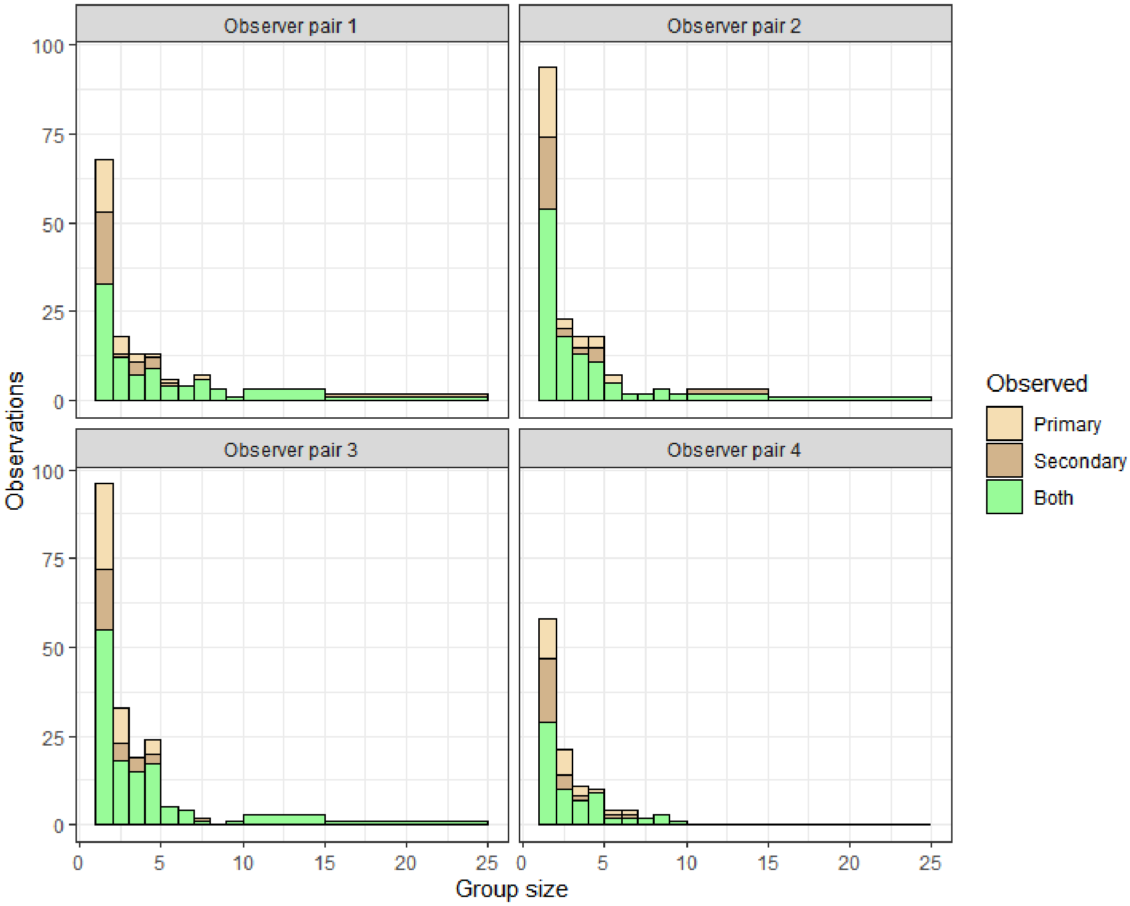

Figure 39. Frequencies of double observer observations by group size, survey phase and survey for Bluenose-East and Bathurst 2021 calving ground surveys. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

The percentage of snow observed during surveys ranged between 25 and 75% with a suggestion of lower sightability at higher snow levels, as determined by the relative proportion of groups seen by both observers for each binned category (Figure 40). We note that the tablet computers limited snow cover categories to 0, 25, 50, 75 or 100%, whereas actual snow cover ranged from 1% to 95% (See Figure 8).

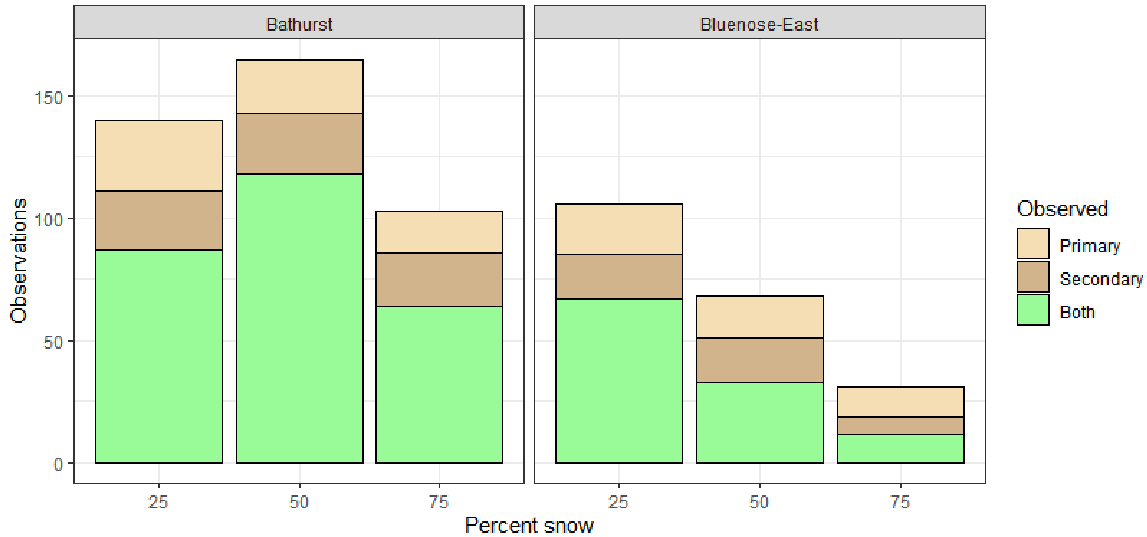

Figure 40. Percentage snow cover on Bathurst and Bluenose-East calving grounds during visual survey flying June 8-11, 2021.

Cloud cover ranged from 0-75% with a small amount of 100% cloud cover on the Bluenose-East calving ground (Figure 41). There was minimal suggestion of cloud cover affecting sightability. We note that the tablet entries limited cloud cover categories to 1, 25, 50, 75 and 100%, whereas actual cloud cover included finer-scale categories.

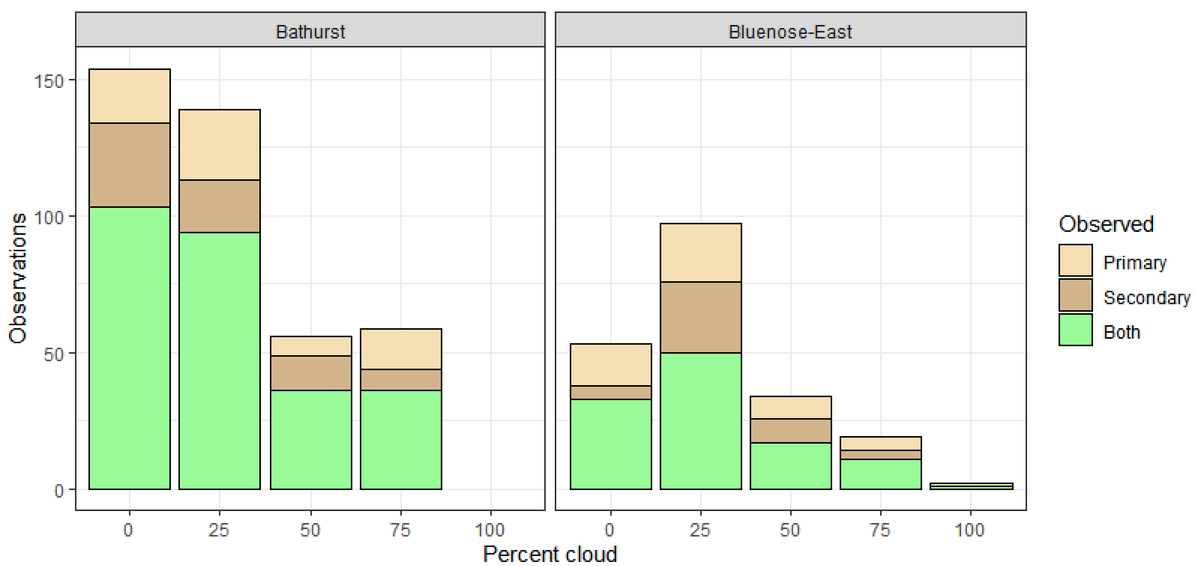

Figure 41. Percentage cloud cover over Bathurst and Bluenose-East calving grounds June 8-11, 2021 during visual survey flying.

Model selection identified a strong effect of the log of group size with less influence of other covariates (Model 1: Table 20).

Table 20. Double observer model selection using Huggins mark-recapture models in program MARK for Bluenose-East and Bathurst June 2018 caribou surveys. Covariates follow Table 1 in the methods section of the report. AIC_c, the difference in AIC_c values between the *i*th and most supported model 1 (ΔAIC_c), Akaike weights (w_i), and number of parameters (K), and deviance (Dev) are presented.

Model #	Model	AICc	ΔAIC_c	wi	K	Dev
1	logsize	584.23	0.00	0.20	2	-290.1
2	logsize + snowc	585.09	0.86	0.13	3	-289.5
3	logsize + Herd	585.88	1.65	0.09	3	-289.9
4	logsize + $BAsnow^2$ + BNEsnow	586.08	1.85	0.08	4	-288.9
5	logsize + Herd*snow	586.16	1.93	0.08	4	-289.0
6	logsize + cloud	586.24	2.01	0.07	3	-290.1
7	logsize + Herd + snow	586.47	2.24	0.06	4	-289.1
8	logsize + snowc + snowcloud	586.71	2.48	0.06	4	-289.3
9	logsize + snow + cloud + snowcloud	586.79	2.56	0.06	5	-288.3
10	logsize + snow_factor	587.16	2.93	0.05	4	-289.5
11	logsize + cloud_factor	587.27	3.03	0.04	5	-288.5
12	size	587.74	3.51	0.03	2	-291.8
13	logsize + observers	587.92	3.69	0.03	5	-288.8
14	logsize + snow_factor + cloudc	589.25	5.02	0.02	5	-289.5
15	logsize + snow_factor + cloud_factor	590.95	6.72	0.01	7	-288.2
16	constant	594.66	10.43	0.00	1	-296.3
17	Herd	595.66	11.42	0.00	2	-295.8
18	snow	595.67	11.44	0.00	2	-295.8
19	cloud	596.70	12.47	0.00	2	-296.3
20	cloud_factor	597.65	13.42	0.00	4	-294.7
21	snow_factor	597.67	13.44	0.00	3	-295.8
22	snow + cloud + snowcloud	597.99	13.76	0.00	4	-294.9
23	observers	598.11	13.88	0.00	4	-295.0

The effect of snow as an additive effect to the log of group size also had some support as indicated by a ΔAIC_c of 0.86. The effect of herd (calving ground) was weak (model 3). The interaction of herd (calving ground) and snow cover was also tested (models 4 and 5) with lower support. Other factor such as observers (model 23), cloud cover (models 6, 9 and 11) and the interaction of cloud and snow cover (model 8) showed little support. The minimal observer effect was also suggested by summaries of estimates with and without the double observer correction (Table 21).

Plots of single and double observation probabilities from model 2 showed lower probabilities for individual or smaller group sizes, especially in higher snow cover (Figure 42). Detection probabilities for both observers combined are above 0.9 for all group sizes. The mean detection probability (across all groups) was 0.78 (CI=0.76-0.80) for 2021 compared to 0.66 (CI=0.60-0.72) and 0.91 (CI=0.88-0.92) for the 2018 and 2015 Bluenose-East and Bathurst calving ground surveys.

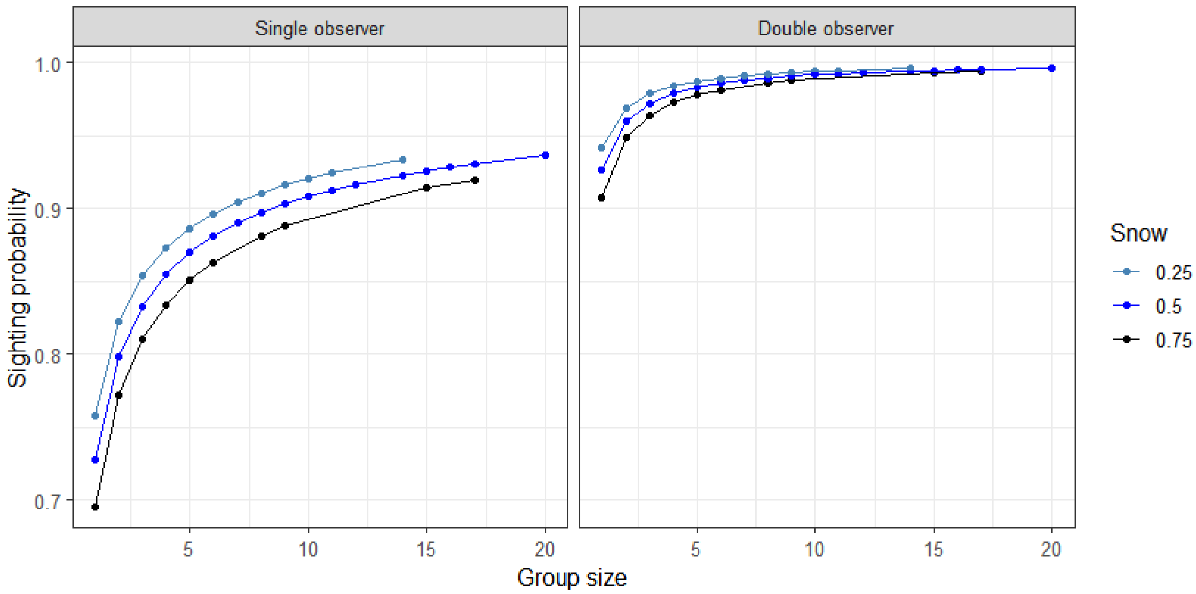

Figure 42. Estimated double observer probabilities from model 2 (Table 23) by snow cover, from Bathurst and Bluenose-East calving ground survey flying June 8-11, 2021.

Estimates from Model 1 (Table 20) were used for abundance estimates. Estimates from model 2 (logsize+snow) which displayed lower support were very close (9,557 compared to 9,449) suggesting minimal change in estimates due to inclusion of snow as a covariate (Table 23). Double observer estimates (using the MRDS R package) were 2.4% higher than the un-corrected standard strip transect estimates. Precision for the double observer estimate was higher which was due to the use of the S2 variance estimator that takes into account similarity in distributions of caribou on adjacent transects (Fewster 2011). If the non-systematic variance estimator is used (as is for the standard strip transect estimator) then the CV increases to 9.4% which is higher than the standard strip transect estimator. Overall precision of the estimates was good with a CV of 7.1%.

Estimates of adult caribou (at least one year old) in the eight Bluenose-East visual survey blocks are given in Table 21, together with corrected estimates that incorporate double observer analyses. Overall, the total number of caribou at least one year old was 3,538 as recorded during the survey and 3,635 as corrected from double observer calculations using Model 1 in Table 20, an increase of 2.7%.

Table 21. Estimates of caribou in visual survey strata from double observer and strip transect estimates for the Bluenose-East herd, June 2021. N = Estimate; SE = standard error; 95% CI = 95% Confidence Interval; CV = Coefficient of Variation.

Stratum	Caribou seen	Corrected double observer estimates					Uncorrected transect estimates (as recorded in field)		
		N	SE	95% CI		CV	N	SE	CV
Vis1	94	495	96.1	322	760	19.4%	479	127.8	26.7%
Vis2	54	300	59.5	191	472	19.8%	290	108.9	37.6%
Vis3	14	75	0.6	73	76	0.8%	72	26.3	36.4%
Vis4	247	1,603	326.4	995	2,581	20.4%	1,567	390.8	24.9%
Vis5	9	58	35.6	15	231	60.9%	56	30.5	54.5%
Vis6	6	42	14.7	19	93	35.3%	40	20.1	50.9%
Vis7	85	548	121.1	327	918	22.1%	534	102.1	19.1%
Vis8	82	515	95.5	340	781	18.5%	500	90.8	18.2%
Total	591	3,635	380.8	2,898	4,559	10.5%	3,538	449.0	12.7%

Appendix 2. Double Observer Analysis of a Sub-set of Aerial Photo Counts from Bluenose-East June 2021 Photo Strata

Counts of caribou at least one year old from the aerial photos were assessed through a double observer analysis, where an initial observer counted a sub-set of photos and a second observer independently counted the same photos. This double-count analysis was also carried out for the 2018 Bathurst and Bluenose-East calving ground surveys (Adamczewski et al. 2019, Boulanger et al. 2019), when similar patchy snow conditions made identification of caribou on photos more difficult. A brief summary was included in the main text and greater detail is provided here.

The full Bluenose-East aerial photo set included 3,648 photos. Re-counting photos that had some caribou on them was of greatest interest, however it was also important to sub-sample photos where no caribou were seen. A total of 187 photos were selected for cross validation (Figure 43). This sub-set contained photos with 0 counts but favored photos that had at least one caribou detected to ensure reasonable sample sizes for cross validation. Comparison of counts from the first and second observers suggested similar levels of sightability between north and south strata.

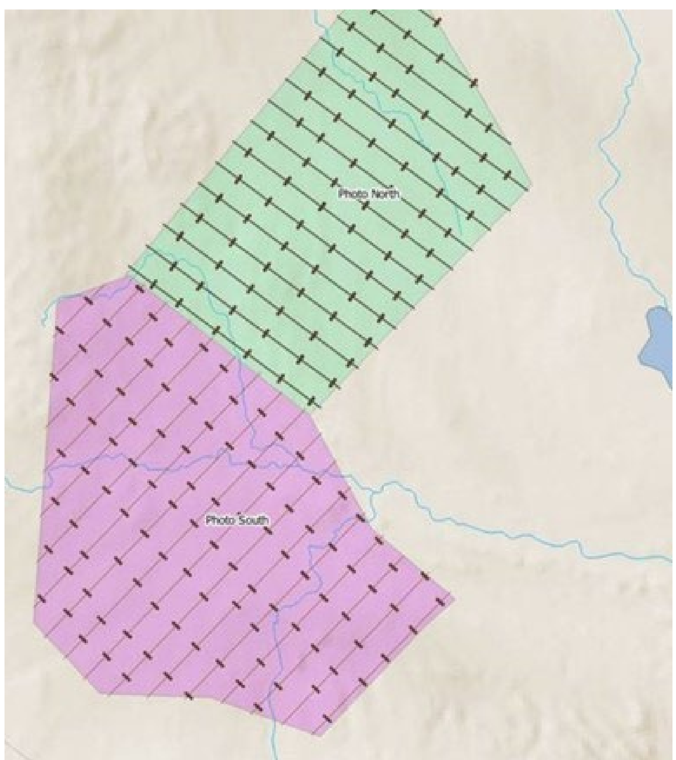

Figure 43. Locations of aerial photos sub-sampled from the Photo North and Photo South survey blocks from the June 2021 Bluenose-East calving ground photo survey.

The second observer for this analysis was Derek Fisher, president of Greenlink Forestry and the most experienced photo analyst at the company. A summary of the caribou counts for the two observers is in Table 22. The comparison indicates that the first observer found 95.7% of the caribou on the photos in the sub-set of 187 photos. Comparison of binomial and bootstrap variances suggested moderate overdispersion with a c-hat value of 1.12.

Table 22. First and second observer counts and detection rates of caribou at least one year old in the Photo North and Photo South blocks from the Bluenose-East 2021 calving ground survey, from a sub-sample of 187 photos.

Stratum	Observer 1	Observer 2	Total caribou	Photo Number	Proportion sighted (Observer 1)
Photo North	364	380	380	84	0.958
Photo South	327	338	342	103	0.956
totals	691	718	722	187	0.957 (combined)

Table 23. MARK closed model selection for photo cross-validation from Bluenose-East 2021 calving ground survey. Quasi Akaike Information Criterion ($QAIC_c$), the difference in $QAIC_c$ between the most supported model and given model $\Delta QAIC_c$, the model weight (wi), number of parameters (K) and quasi-Deviance (QDeviance) is given

Model	QAICc	Delta QAICc	QAICc Weights	Num. Par	QDeviance
Observers	266.96	0.00	0.731	2	6,106.0
Observer 1 X strata	268.95	2.00	0.269	3	6,106.0
All equal	285.33	18.38	0.000	1	6,126.4

Model selection in program MARK suggested that the main difference in sightability was observer, not strata. The resulting estimate of photo sightability for the primary observer with variance is in Table 24.

Table 24. Estimate of caribou sightability for the primary observer from MARK analysis for sub-set of Bluenose-East 2021 aerial photos. SE = Standard Error; CIL = 95% Confidence Interval Lower; CIU = 95% Confidence Interval Upper.

Label	Estimate	SE	CIL	CIU
Primary p	0.957	0.008	0.938	0.970

The uncorrected and corrected estimates of caribou at least one year old in the two photo strata are shown in Table 25. The net effect was an increase of 4.5 % from 14,629 caribou estimated from the initial counts to 15,289 caribou estimated with the double observer correction.

Table 25. Initial uncorrected estimates and corrected estimates of caribou at least one year old in the Photo North and Photo South blocks of the Bluenose-East June 2021 calving ground survey. Corrections were based on the detection rates in Table 13. N = estimated number; SE = Standard Error; P = Probability of Detection; CIL = Lower 95% Confidence Interval; CIU = 95% Upper Confidence Interval; CV = Coefficient of Variation.

Stratum	**Strip-transect estimates of Numbers (uncorrected)**			**Detection Rate**			**Corrected estimates of Numbers**				
	N	SE	CV	P	SE	CV	N	SE	CIL	CIU	CV
Photo Core	7,367.1	926.3	0.126	0.957	0.008	0.009	7699	970.3	5,882	10,078	0.13
Photo East	7,262.0	734.5	0.101	0.957	0.008	0.009	7590	770.3	6,124	9,407	0.11

Appendix 3. Demographic Analysis with IPM Model in R Code

This appendix details the development of the Bayesian IPM analysis. The primary IPM R coding was developed by Joe Thorley (Poisson Consulting, poissonconsulting.ca) in collaboration with John Boulanger (Thorley and Boulanger 2019). The demographic model used was similar to the OLS model used in previous analyses (Boulanger et al 2011). The primary development was to evolve model fitting to a more robust Bayesian IPM state space approach. The objective of this appendix is to provide a brief description of the model used in the analysis rather than a complete description of the Bayesian model approach. Readers interested in the Bayesian modelling approach should consult Schaub and Kery (2022) which is an excellent introduction to IPM Bayesian analysis.

Data Preparation

The estimates of key population statistics with standard errors and lower and upper bounds were provided in the form of an csv spreadsheet and prepared for analysis using R version 4.1.2 (R Core Team 2018).

Statistical Analysis

Model parameters were estimated using Bayesian methods. The estimates were produced using JAGS (Plummer 2003). For additional information on Bayesian estimation the reader is referred to McElreath (2016).

Unless stated otherwise, the Bayesian analyses used weakly informative normal and half-normal prior distributions (Gelman et al. 2017). The posterior distributions were estimated from 1,500 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kery and Schaub 2011, 38–40). Model convergence was confirmed by ensuring that the potential scale reduction factor $\hat{R} \leq 1.05$ (Kery and Schaub 2011, 40) and the effective sample size (Brooks et al. 2011) ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, 61).

The parameters are summarised in terms of the point *estimate*, *lower* and *upper* 95% credible limits (CLs) and the surprisal *s-value* (Greenland 2019). The estimate is the median (50th percentile) of the MCMC samples while the 95% CLs are the 2.5th and 97.5th percentiles. The s-value can be considered a test of directionality. More specifically it indicates how surprising (in bits) it would be to discover that the true value of the parameter is in the opposite direction to the estimate. An s-value (Chow and Greenland 2019) is the Shannon transform (-log to base 2) of the corresponding p-value (Kery and Schaub 2011; Greenland and Poole 2013). A surprisal value of 4.3 bits, which is equivalent to a p-value of 0.05 indicates that the surprise would be equivalent to throwing 4.3 heads in a row. The condition that non-essential explanatory variables have s-values ≥4.3 bits provides a useful model selection heuristic (Kery and Schaub 2011).

The results are displayed graphically by plotting the modeled relationships between particular variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively, while random variables are held constant at their typical values (expected values of the underlying hyperdistributions) (Kery and Schaub 2011, 77–82). When informative, the influence of particular variables is expressed in terms of the *effect size* (i.e., percent or n-fold change in the response variable) with 95% credible intervals (CIs, Bradford, Korman, and Higgins 2005). Data are indicated by points (with lower and upper bounds indicated by vertical bars) and estimates are indicated by solid lines (with CIs indicated by dotted lines).

The analyses were implemented using R version 4.1.2 (R Core Team 2018 and the mbr family of packages.

Model Descriptions

The data were analysed using a state-space population model (Newman et al. 2014).

Population

The cow and bull harvest, fecundity, breeding cow abundance, cow survival, bull survival, fall bull to cow, fall calf to cow and spring calf to cow ratio data complete with standard errors were analysed using a stage-based state-space population model similar to Boulanger et al. (2011). Key assumptions of the female stage-based state-space population model include:

- Calving occurs on the 11th of June (with a year running from calving to calving).
- Natural survival of cows from calving to the following year varies continually and randomly by year.
- Natural survival of bulls from calving to the following year varies randomly by year.
- Cow and bull natural survival is constant throughout the year in any given year.
- Harvest of cows and bulls occurs on the 15th of January.
- Harvest rate varies by harvest period (the second harvest period occurs from 2001-2009) and continually by year by harvest period for cows and bull.
- Yearling survival to the following year is the same as cow natural survival.
- Calf survival varies between the summer and winter seasons and randomly by year.
- Calf sex ratio is 1:1.
- Proportion of breeding cows is the fecundity in the previous year.
- Fecundity varies randomly by year.
- Female yearlings are indistinguishable from cows in the fall and spring surveys.
- The uncertainty in the number of breeding cows in the initial year is described by a positively truncated normal distribution with a mean of 50,000 and a standard deviation of 10,000.
- The number of cows in the initial year is the number of breeding cows in the initial year divided by the fecundity in a typical year.

- The prior for the bull to cow ratio in the initial year is a normal distribution with a mean of 0.5 and standard deviation of 0.15 that is truncated between 0.3 and 0.7.
- The number of calves in the initial year is the number of breeding cows in the initial year.
- The number of yearlings in the initial year is the number of calves in the initial year multiplied the calf survival in a typical year.
- The uncertainty in each data point is normally distributed with a standard deviation equal to the provided standard error.

Population

```
.model {
 bSurvivalCow ~ dnorm(0, 2^-2)
 bSurvivalBull ~ dnorm(0, 2^-2)
 bFecundity ~ dnorm(0, 2^-2)
 bSurvivalCalfSummerAnnual ~ dnorm(0, 2^-2)
 bSurvivalCalfWinterAnnual ~ dnorm(0, 2^-2)

 for(i in 1:nHarvestPeriodCow) {
  bHarvestRateCow[i] ~ dnorm(-5, 2^-2)
  bHarvestRateCowYear[i] ~ dnorm(0, 2^-2)
 }
 for(i in 1:nHarvestPeriodBull) {
  bHarvestRateBull[i] ~ dnorm(-5, 2^-2)
  bHarvestRateBullYear[i] ~ dnorm(0, 2^-2)
 }

 sSurvivalCowAnnual ~ dnorm(0, 1^-2) T(0,)
 sSurvivalBullAnnual ~ dnorm(0, 1^-2) T(0,)
 sSurvivalCalfAnnual ~ dnorm(0, 1^-2) T(0,)
 sFecundityAnnual ~ dnorm(0, 1^-2) T(0,)
 for(i in 1:nAnnual){
  bSurvivalCowAnnual[i] ~ dnorm(0, sSurvivalCowAnnual^-2)
  bSurvivalBullAnnual[i] ~ dnorm(0, sSurvivalBullAnnual^-2)
  bSurvivalCalfAnnual[i] ~ dnorm(0, sSurvivalCalfAnnual^-2)
  bFecundityAnnual[i] ~ dnorm(0, sFecundityAnnual^-2)

  logit(eSurvivalCow[i]) <- bSurvivalCow + bSurvivalCowAnnual[i]
  logit(eSurvivalBull[i]) <- bSurvivalBull + bSurvivalBullAnnual[i]
  logit(eFecundity[i]) <- bFecundity + bFecundityAnnual[i]
  logit(eSurvivalCalfSummerAnnual[i]) <- bSurvivalCalfSummerAnnual + bSurvivalCalfAnnual[i]
  logit(eSurvivalCalfWinterAnnual[i]) <- bSurvivalCalfWinterAnnual + bSurvivalCalfAnnual[i]
  logit(eHarvestRateCow[i]) <- bHarvestRateCow[HarvestPeriodCow[i]] + bHarvestRateCowYear[HarvestPeriodCow[i]] * Annual[i]
  logit(eHarvestRateBull[i]) <- bHarvestRateBull[HarvestPeriodBull[i]] + bHarvestRateBullYear[HarvestPeriodBull[i]] * Annual[i]
 }
 bBreedingCows1 ~ dnorm(50000, 10000^-2) T(0,)
 bBullsCows1 ~ dnorm(0.5, 0.15^-2) T(0.3, 0.7)

 logit(eFecundity1) <- bFecundity
 logit(eSurvivalCalfSummerAnnual1) <- bSurvivalCalfSummerAnnual
 logit(eSurvivalCalfWinterAnnual1) <- bSurvivalCalfWinterAnnual

 bCows[1] <- bBreedingCows1 / eFecundity1
 bBulls[1]<- bCows[1] * bBullsCows1
 bCalves[1] <- bBreedingCows1
 bYearlings[1] <- bCalves[1] * eSurvivalCalfWinterAnnual1^(154/365) * eSurvivalCalfWinterAnnual1^(211/365)
 bSpringCalfCow[1] <- bCalves[1] / (bCows[1] + bYearlings[1] / 2)
```

```
for(i in 1:nAnnual) {
  eJuneToFallCor[i] <-  FallCalfCowDays[i] / 365

  eFallCows[i] <- bCows[i] * eSurvivalCow[i]^eJuneToFallCor[i]
  eFallBulls[i] <- bBulls[i] * eSurvivalBull[i]^eJuneToFallCor[i]
  eFallYearlings[i] <- bYearlings[i] * eSurvivalCow[i]^eJuneToFallCor[i]
  eFallCalves[i] <- bCalves[i] * eSurvivalCalfSummerAnnual[i]^eJuneToFallCor[i]

  bFallBullCow[i] <- (eFallBulls[i] + eFallYearlings[i]/2) / (eFallCows[i] + eFallYearlings[i]/2)
  bFallCalfCow[i] <- eFallCalves[i] / (eFallCows[i] + eFallYearlings[i]/2)
}

for(i in 2:nAnnual) {
  eFallToJanCor[i] <- (218 - FallCalfCowDays[i-1])/365
  eJanToSpringCor[i] <- (SpringCalfCowDays[i] - 218) / 365
  eSpringToJuneCor[i] <- (365 - SpringCalfCowDays[i]) / 365

  eJanCows[i] <- eFallCows[i-1] * eSurvivalCow[i-1]^eFallToJanCor[i]
  eJanBulls[i] <- eFallBulls[i-1] * eSurvivalBull[i-1]^eFallToJanCor[i]
  eJanYearlings[i] <- eFallYearlings[i-1] * eSurvivalCow[i-1]^eFallToJanCor[i]

  eSpringCows[i] <- eJanCows[i] * (1 - eHarvestRateCow[i]) * eSurvivalCow[i-1]^eJanToSpringCor[i]
  eSpringBulls[i] <- eJanBulls[i] * (1 - eHarvestRateBull[i]) * eSurvivalBull[i-1]^eJanToSpringCor[i]
  eSpringYearlings[i] <- eJanYearlings[i] * eSurvivalCow[i-1]^eJanToSpringCor[i]

  eSpringCalves[i] <- bCalves[i-1] * eSurvivalCalfSummerAnnual[i-1]^(154/365) * eSurvivalCalfWinterAnnual[i-1]^((SpringCalfCowDays[i] -
154) / 365)

  bSpringCalfCow[i] <- eSpringCalves[i] / (eSpringCows[i] + eSpringYearlings[i]/2)

  bCows[i] <- (eSpringCows[i] + eSpringYearlings[i] / 2) * eSurvivalCow[i-1]^eSpringToJuneCor[i]
  bBulls[i] <- eSpringBulls[i] * eSurvivalBull[i-1]^eSpringToJuneCor[i] + eSpringYearlings[i] / 2 * eSurvivalCow[i-1]^eSpringToJuneCor[i]
  bYearlings[i] <- bCalves[i-1] * eSurvivalCalfSummerAnnual[i-1]^(154/365) * eSurvivalCalfWinterAnnual[i-1]^(211/365)
  bCalves[i] <- bCows[i-1] * eSurvivalCow[i-1] * (1 - eHarvestRateCow[i]) * eFecundity[i-1]
}

for(i in 2:nAnnual) {
  HarvestedCows[i] ~ dnorm(eJanCows[i] * eHarvestRateCow[i], HarvestedCowsSE[i]^-2)
  HarvestedBulls[i] ~ dnorm(eJanBulls[i] * eHarvestRateBull[i], HarvestedBullsSE[i]^-2)
}

for(i in CowSurvivalAnnual) {
  CowSurvival[i] ~ dnorm(logit(eSurvivalCow[i]), CowSurvivalSE[i]^-2)
}

for(i in BullSurvivalAnnual) {
  BullSurvival[i] ~ dnorm(logit(eSurvivalBull[i]), BullSurvivalSE[i]^-2)
}

for(i in CowsAnnual) {
  BreedingProportion[i] ~ dnorm(logit(eFecundity[i-1]), BreedingProportionSE[i]^-2)
  eBreedingCows[i] <- bCows[i] * eFecundity[i-1]
  BreedingCows[i] ~ dnorm(eBreedingCows[i], BreedingCowsSE[i]^-2)
}

for(i in FallBCAnnual) {
  FallBullCow[i] ~ dnorm(bFallBullCow[i], FallBullCowSE[i]^-2)
}
```

```
for(i in FallAnnual) {
  FallCalfCow[i] ~ dnorm(bFallCalfCow[i], FallCalfCowSE[i]^-2)
}

for(i in SpringAnnual) {
  SpringCalfCow[i] ~ dnorm(bSpringCalfCow[i], SpringCalfCowSE[i]^-2)
}
```

Block 1. The model description.

Variables

```
.model {
 bSurvivalCow ~ dnorm(0, 2^-2)
 bSurvivalBull ~ dnorm(0, 2^-2)
 bFecundity ~ dnorm(0, 2^-2)
 bSurvivalCalfSummerAnnual ~ dnorm(0, 2^-2)
 bSurvivalCalfWinterAnnual ~ dnorm(0, 2^-2)

 bSurvivalCowJune20GDD ~ dnorm(0, 2^-2)
 bFecundityF_June10GDD ~ dnorm(0, 2^-2)
 bSurvivalCalfJune20GDD ~ dnorm(0, 2^-2)

 for(i in 1:nHarvestPeriodCow) {
  bHarvestRateCow[i] ~ dnorm(-5, 2^-2)
  bHarvestRateCowYear[i] ~ dnorm(0, 2^-2)
 }
 for(i in 1:nHarvestPeriodBull) {
  bHarvestRateBull[i] ~ dnorm(-5, 2^-2)
  bHarvestRateBullYear[i] ~ dnorm(0, 2^-2)
 }

 sSurvivalCowAnnual ~ dnorm(0, 1^-2) T(0,)
 sSurvivalBullAnnual ~ dnorm(0, 1^-2) T(0,)
 sSurvivalCalfAnnual ~ dnorm(0, 1^-2) T(0,)
 sFecundityAnnual ~ dnorm(0, 1^-2) T(0,)
 for(i in 1:nAnnual){
  bSurvivalCowAnnual[i] ~ dnorm(0, sSurvivalCowAnnual^-2)
  bSurvivalBullAnnual[i] ~ dnorm(0, sSurvivalBullAnnual^-2)
  bSurvivalCalfAnnual[i] ~ dnorm(0, sSurvivalCalfAnnual^-2)
  bFecundityAnnual[i] ~ dnorm(0, sFecundityAnnual^-2)

  logit(eSurvivalCow[i]) <- bSurvivalCow + bSurvivalCowAnnual[i] + bSurvivalCowJune20GDD * June20GDD[i]
  logit(eSurvivalBull[i]) <- bSurvivalBull + bSurvivalBullAnnual[i]
  logit(eFecundity[i]) <- bFecundity + bFecundityAnnual[i] + bFecundityF_June10GDD * F_June10GDD[i]
  logit(eSurvivalCalfSummerAnnual[i]) <- bSurvivalCalfSummerAnnual + bSurvivalCalfAnnual[i] + bSurvivalCalfJune20GDD * June20GDD[i]
  logit(eSurvivalCalfWinterAnnual[i]) <- bSurvivalCalfWinterAnnual + bSurvivalCalfAnnual[i] + bSurvivalCalfJune20GDD * June20GDD[i]
  logit(eHarvestRateCow[i]) <- bHarvestRateCow[HarvestPeriodCow[i]] + bHarvestRateCowYear[HarvestPeriodCow[i]] * Annual[i]
  logit(eHarvestRateBull[i]) <- bHarvestRateBull[HarvestPeriodBull[i]] + bHarvestRateBullYear[HarvestPeriodBull[i]] * Annual[i]
 }
 bBreedingCows1 ~ dnorm(50000, 10000^-2) T(0,)
 bBullsCows1 ~ dnorm(0.5, 0.15^-2) T(0.3, 0.7)

 logit(eFecundity1) <- bFecundity
 logit(eSurvivalCalfSummerAnnual1) <- bSurvivalCalfSummerAnnual
 logit(eSurvivalCalfWinterAnnual1) <- bSurvivalCalfWinterAnnual

 bCows[1] <- bBreedingCows1 / eFecundity1
```

```
bBulls[1]<- bCows[1] * bBullsCows1
bCalves[1] <- bBreedingCows1
bYearlings[1] <- bCalves[1] * eSurvivalCalfWinterAnnual1^(154/365) * eSurvivalCalfWinterAnnual1^(211/365)
bSpringCalfCow[1] <- bCalves[1] / (bCows[1] + bYearlings[1] / 2)

for(i in 1:nAnnual) {
  eJuneToFallCor[i] <-  FallCalfCowDays[i] / 365

  eFallCows[i] <- bCows[i] * eSurvivalCow[i]^eJuneToFallCor[i]
  eFallBulls[i] <- bBulls[i] * eSurvivalBull[i]^eJuneToFallCor[i]
  eFallYearlings[i] <- bYearlings[i] * eSurvivalCow[i]^eJuneToFallCor[i]
  eFallCalves[i] <- bCalves[i] * eSurvivalCalfSummerAnnual[i]^eJuneToFallCor[i]

  bFallBullCow[i] <- (eFallBulls[i] + eFallYearlings[i]/2) / (eFallCows[i] + eFallYearlings[i]/2)
  bFallCalfCow[i] <- eFallCalves[i] / (eFallCows[i] + eFallYearlings[i]/2)
}

for(i in 2:nAnnual) {
  eFallToJanCor[i] <- (218 - FallCalfCowDays[i-1])/365
  eJanToSpringCor[i] <- (SpringCalfCowDays[i] - 218) / 365
  eSpringToJuneCor[i] <- (365 - SpringCalfCowDays[i]) / 365

  eJanCows[i] <- eFallCows[i-1] * eSurvivalCow[i-1]^eFallToJanCor[i]
  eJanBulls[i] <- eFallBulls[i-1] * eSurvivalBull[i-1]^eFallToJanCor[i]
  eJanYearlings[i] <- eFallYearlings[i-1] * eSurvivalCow[i-1]^eFallToJanCor[i]

  eSpringCows[i] <- eJanCows[i] * (1 - eHarvestRateCow[i]) * eSurvivalCow[i-1]^eJanToSpringCor[i]
  eSpringBulls[i] <- eJanBulls[i] * (1 - eHarvestRateBull[i]) * eSurvivalBull[i-1]^eJanToSpringCor[i]
  eSpringYearlings[i] <- eJanYearlings[i] * eSurvivalCow[i-1]^eJanToSpringCor[i]

  eSpringCalves[i] <- bCalves[i-1] * eSurvivalCalfSummerAnnual[i-1]^(154/365) * eSurvivalCalfWinterAnnual[i-1]^((SpringCalfCowDays[i] -
154) / 365)

  bSpringCalfCow[i] <- eSpringCalves[i] / (eSpringCows[i] + eSpringYearlings[i]/2)

  bCows[i] <- (eSpringCows[i] + eSpringYearlings[i] / 2) * eSurvivalCow[i-1]^eSpringToJuneCor[i]
  bBulls[i] <- eSpringBulls[i] * eSurvivalBull[i-1]^eSpringToJuneCor[i] + eSpringYearlings[i] / 2 * eSurvivalCow[i-1]^eSpringToJuneCor[i]
  bYearlings[i] <- bCalves[i-1] * eSurvivalCalfSummerAnnual[i-1]^(154/365) * eSurvivalCalfWinterAnnual[i-1]^(211/365)
  bCalves[i] <- bCows[i-1] * eSurvivalCow[i-1] * (1 - eHarvestRateCow[i]) * eFecundity[i-1]
}

for(i in 2:nAnnual) {
  HarvestedCows[i] ~ dnorm(eJanCows[i] * eHarvestRateCow[i], HarvestedCowsSE[i]^-2)
  HarvestedBulls[i] ~ dnorm(eJanBulls[i] * eHarvestRateBull[i], HarvestedBullsSE[i]^-2)
}

for(i in CowSurvivalAnnual) {
  CowSurvival[i] ~ dnorm(logit(eSurvivalCow[i]), CowSurvivalSE[i]^-2)
}

for(i in BullSurvivalAnnual) {
  BullSurvival[i] ~ dnorm(logit(eSurvivalBull[i]), BullSurvivalSE[i]^-2)
}

for(i in CowsAnnual) {
  BreedingProportion[i] ~ dnorm(logit(eFecundity[i-1]), BreedingProportionSE[i]^-2)
  eBreedingCows[i] <- bCows[i] * eFecundity[i-1]
  BreedingCows[i] ~ dnorm(eBreedingCows[i], BreedingCowsSE[i]^-2)
```

```
}

for(i in FallBCAnnual) {
  FallBullCow[i] ~ dnorm(bFallBullCow[i], FallBullCowSE[i]^-2)
}

for(i in FallAnnual) {
  FallCalfCow[i] ~ dnorm(bFallCalfCow[i], FallCalfCowSE[i]^-2)
}

for(i in SpringAnnual) {
  SpringCalfCow[i] ~ dnorm(bSpringCalfCow[i], SpringCalfCowSE[i]^-2)
}
```

Block 2. The model description.

Results

Tables

Population

Table 1. Parameter descriptions.

Parameter	Description
Annual	The year as a integer starting at 1
bBreedingCows1	The number of breeding cows in the initial year
bBullsCows1	The bull to cow ratio in the initial year
bFecundity	The proportion of cows breeding in a typical year
bHarvestRateBull[i]	The log-odds probability of a bull being harvested in year 0 for the i^{th} HarvestPeriod
bHarvestRateBullYear[i]	The change in bbHarvestRateBull by year for the i^{th} HarvestPeriod
bHarvestRateCow[i]	The log-odds probability of a cow being harvested in year 0 for the i^{th} HarvestPeriod
bHarvestRateCowYear[i]	The change in bbHarvestRateCow by year for the i^{th} HarvestPeriod
BreedingCows[i]	The data point for the number of breeding cows in the i^{th} year
BreedingCowsSE[i]	The standard error for BreedingCows[i]
BreedingProportion[i]	The data point for the log-odds proportion of cows breeding in the i^{th} year
BreedingProportionSE[i]	The standard error for BreedingProportionSE[i]
bSurvivalBull	The log-odds bull survival in a typical year
bSurvivalBullAnnual[i]	The random effect of the i^{th} Annual on bSurvivalBull
bSurvivalCalfAnnual[i]	The random effect of the i^{th} Annual on bSurvivalCalfSummerAnnual and bSurvivalCalfWinterAnnual
bSurvivalCalfSummerAnnual	The log-odds summer calf survival if extended for one year
bSurvivalCalfWinterAnnual	The log-odds winter calf survival if extended for one year
bSurvivalCow	The log-odds cow (and yearling) survival in a typical year
bSurvivalCowAnnual[i]	The random effect of the i^{th} Annual on bSurvivalCow
BullSurvival[i]	The data point for log-odds bull survival from the $i\text{-}1^{th}$ year to the i^{th} year
BullSurvivalSE[i]	The standard error for BullSurvival[i]
CowSurvival[i]	The data point for log-odds cow survival from the $i\text{-}1^{th}$ year to the i^{th} year
CowSurvivalSE[i]	The standard error for CowSurvival[i]
FallBullCow[i]	The data point for the bull cow ratio in the fall of the i^{th} year

Parameter	Description
FallBullCowSE[i]	The standard error for FallBullCow[i]
FallCalfCow[i]	The data point for the calf cow ratio in the fall of the i^{th} year
FallCalfCowSE[i]	The standard error for FallCalfCow[i]
HarvestedBulls[i]	The data point for the number of bulls harvested in January of the i^{th} year
HarvestedBullsSE[i]	The standard error for HarvestedBulls[i]
HarvestedCows[i]	The data point for the number of cows harvested in January of the i^{th} year
HarvestedCowsSE[i]	The standard error for HarvestedCows[i]
SpringCalfCow[i]	The data point for the calf cow ratio in the spring of the i^{th} year
SpringCalfCowSE[i]	The standard error for SpringCalfCow[i]
sSurvivalBullAnnual	The SD of bSurvivalBullAnnual
sSurvivalCalfAnnual	The SD of bSurvivalCalfAnnual
sSurvivalCowAnnual	The SD of bSurvivalCowAnnual

Table 2. Model coefficients.

term	estimate	lower	upper	svalue
bBullsCows1	0.4627304	0.3133596	0.6647996	10.5517083
bFecundity	0.8944075	0.4064118	1.4246045	10.5517083
bHarvestRateBull[1]	-3.0652695	-3.8427653	-2.2794567	10.5517083
bHarvestRateBull[2]	-5.2094039	-8.1695864	-2.4058419	10.5517083
bHarvestRateBullYear[1]	0.0016994	-0.1089912	0.1033494	0.0508664
bHarvestRateBullYear[2]	0.1195506	-0.1009243	0.3434809	1.7219855
bHarvestRateCow[1]	-3.6403574	-4.8647537	-2.7575493	10.5517083
bHarvestRateCow[2]	-3.0353909	-6.4710053	-0.0507604	4.4856191
bHarvestRateCowYear[1]	-0.0050570	-0.1904327	0.2042319	0.0830842
bHarvestRateCowYear[2]	-0.1806448	-0.4336199	0.0900315	2.4379661
bSurvivalBull	0.3445717	-0.0144082	0.7612225	4.0125495
bSurvivalCalfSummerAnnual	-0.4799657	-1.1140995	0.2202996	2.4379661
bSurvivalCalfWinterAnnual	0.6722065	0.0203889	1.3499821	4.6209709
bSurvivalCow	1.2558628	0.8533475	1.6816293	10.5517083
sFecundityAnnual	0.5258422	0.2431000	1.0829505	10.5517083
sSurvivalBullAnnual	0.5951187	0.2568139	1.1216009	10.5517083
sSurvivalCalfAnnual	0.8640223	0.5008599	1.5283023	10.5517083
sSurvivalCowAnnual	0.6232061	0.2735724	1.2177869	10.5517083

Table 3. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
15	19	3	500	100	351	1.008	TRUE

Appendix 4. Incidental Sightings of Other Mammals and Eagles on Bluenose-East 2021 Calving Ground Survey

Incidental sightings of other mammals and eagles during the visual flying and composition survey portions of the Bluenose-East 2021 calving ground survey are listed in Table 26. Because large predators like bears, wolverines and wolves are relatively rare, sighting rates of these species from caribou surveys tend to be highly variable and should be considered broad indices of relative abundance of these species. Of particular interest were observations of grizzly bears and wolves, which are known to be effective predators of young caribou calves. On the composition survey, there were six grizzly bears and no wolves seen, while on the visual flying, ten bears and three wolves were recorded. This continues a trend of grizzly bear sightings out-numbering wolf sightings on the Bluenose-East calving ground (Boulanger et al. 2019) and on the Bathurst calving ground (Adamczewski et al. 2022c).

Table 26. Incidental sightings of other wildlife species on Bluenose-East calving ground survey June 2021.

Species/Metric	Visual Flying Total	Visual Flying Notes	Composition Survey Total	Composition Survey Notes
Bald Eagle	4		1	1,1
Golden Eagle	7		0	1,1
Grizzly Bear	10 (8)	2 sightings uncertain	6	2x1, 2x2
Moose	7		0	
Muskox	27	6 groups	34	6,10,18
Wolverine	0		0	
Wolf	3		0	
Survey Hours	25.8		25.7	
Ferry Hours	4.6		15.7	
Total Hours	30.4		41.4	

Appendix 5. Increased Fall Bull:Cow Ratios in the Bathurst and Bluenose-East Caribou Herds 2020-2021

Much of the text in this appendix is drawn from a report on fall 2020 composition surveys of the Bluenose-East and Bathurst herds (Adamczewski et al. 2022a) and a report on a fall 2021 composition survey of the Bluenose-East herd (Adamczewski et al. 2022b). A fall 2021 bull:cow ratio for the Bathurst herd could not be estimated due to extensive mixing of Bathurst and Beverly collared caribou. As the increasing trends in bull:cow ratios were similar in the two herds, results for both herds are included here. The text was updated in March 2022 to address questions from the WRRB to TG and ENR in letters March 25, 2022.

Possible Reasons for Increased Bull:Cow Ratios in the Bluenose-East and Bathurst Herds

The bull:cow ratios recorded in October 2020 for the Bathurst and Bluenose-East herds were higher than had been found in previous fall surveys for both herds in the last ten to 12 years. The bull:cow ratio estimated for the Bluenose-East herd in October 2021 was slightly higher than the Bluenose-East ratio from October 2020, which suggested confirmation of the increased bull:cow ratio. These ratios could be affected by a number of factors, which are reviewed briefly below.

(1) **Timing of the survey:** A survey at the peak of the rut is most likely to include all sex and age classes in the herd, while a survey well after the peak of the rut may result in lower bull:cow ratios if the rutting aggregations have started to break up and some of the bulls have begun to segregate away from the females as they begin winter. From this perspective, the October 2020 surveys appeared to be timed close to the peak of the rut, based on multiple observations of bulls fighting and bulls following cows closely. The peak of calving likely occurred about a week into June 2019 and 2020 (Adamczewski et al. 2019b, 2020a). Assuming a gestation of 230 days, this would mean a peak in breeding around October 19, close to the timing of the Oct. 2020 surveys. The October 2021 Bluenose-East fall survey was very similarly timed and also included multiple observations of bulls fighting and bulls closely following cows. In comparison, the fall 2019 surveys were carried out November 3-6 (Williams and Cluff 2019) and resulted in much lower bull:cow ratios. These surveys may have been two weeks or more past the peak of the rut, with the possibility of some of the males having separated from the females.

(2) Spatial variation and adequacy of sampling: Regional bull:cow ratios in the Bluenose-East survey in October 2020 varied widely, from 52.3: 100 in the North area to 84.5: 100 in the Central area and 122.6:100 in the South area. The latter two results could in part have resulted from relatively small sample numbers. Had one or the other of these smaller samples not been included, the overall bull:cow ratio would have been lower. In October 2021, bull:cow ratios showed a similar degree of regional variation, except with the higher ratios in the North rather than the South: 93.7:100 in the North area, 65.8:100 in the Central area, and 57.0:100 in the South area. This range of results underscores the importance of sampling across the range of the herd and sampling in proportion to relative numbers of caribou. We used the collared caribou in the herds in the vicinity of the survey flying as our primary measure of the herd's distribution and relative numbers in sampled areas. For the Bluenose-East herd in 2020, areas sampled included 46 of 50 collars in the herd and there was greater sampling in areas with more caribou. In this respect the survey should have been representative of the herd. Similarly, in October 2021, 51 of 52 females collared caribou and 14 of 15 male collared caribou were in areas flown, and more caribou were sampled where there were higher numbers. There were no collars from other herds in the Bluenose-East areas flown in 2020 and 2021.

For the Bathurst herd, 12 of 50 collars (24%) were in an area east of Contwoyto Lake in October 2020 that was not sampled and had multiple Beverly collared caribou, while the area that was flown had 38 of 50 (76%) of the Bathurst collars and no Beverly or Bluenose-East collars mixed in. It is possible that including that eastern portion of the herd could have altered the survey bull:cow ratio, thus these results should be used with some caution. We note that bull:cow ratios estimated for the Bathurst herd 2006-2020 varied substantially year to year, although it seems unlikely that the true bull:cow ratio actually varied to this extent; this would suggest that adequacy of fall sampling has been somewhat variable.

(3) Misclassification of cows and bulls: Classification from a helicopter of caribou walking or running does not allow for extended observation of single animals. Cows and young bulls are often similar in body size and may be similar in their antlers. It is possible that cows and young bulls could occasionally be misclassified, particularly if the caribou did not have its tail lifted when classified. This could bias the results if smaller adults were consistently misclassified as cows or young bulls. However, prime bulls with large antlers are unmistakable and unlikely to be misclassified. Misclassification is unlikely to have affected more than a small percentage of the cows and young bulls in the surveys.

(4) **A real increase in bull:cow ratios in both herds:** Demographic indicators in the Bathurst and Bluenose-East caribou herds have shown improving trends 2018-2021, particularly in the Bluenose-East herd, as detailed in the 2021 calving ground photo surveys for the two herds. Improved bull:cow ratios in the Bathurst and Bluenose-East herds in 2020 and 2021 may be a further indicator of improving demographics in the two herds. The last period of widespread growth in NWT mainland barren-ground caribou herds was in the early 1980s. The average bull:cow ratio recorded during 6 fall composition surveys during this period was 66 bulls:100 cows (in Gunn et al. 1997, p. 35).

Insights on bull:cow ratios and bull survival from demographic modeling: Demographic modeling of the Bathurst and Bluenose-East described in the main text of this report and the Bathurst survey calving ground report (Adamczewski et al 2022) also suggests an increase in bull numbers and bull:cow ratios. Below is a synopsis of findings related to bull-cow ratios.

For the Bathurst herd, a moderate increase in field estimates of bull:cow ratios occurred from 2014-2020 in comparison to a larger increase from 2008 to 2010 (Figure 44). We note that compared to the Bluenose-East herd, the increase from 2018 to 2020 was moderate with overlap of confidence limits of the estimates. The integrated population model (the blue line in the figure below) predicted stability of the Bathurst bull:cow ratio from 2015 to 2020.

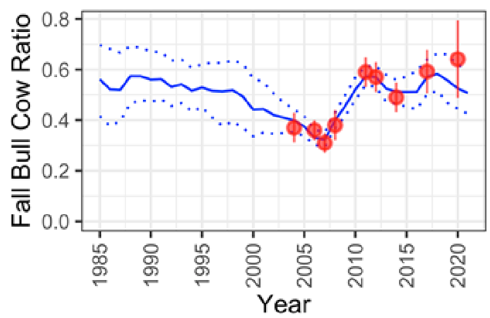

Figure 44. IPM estimates of bull-cow ratio for the Bathurst herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

Changes in bull:cow ratios can be due to differential changes in bull and cow survival. Estimates of bull and cow survival from collared caribou (with IPM predictions in blue) suggest a potential increasing trend in cow survival with stable bull survival (Figure 45). Low precision of the bull collar survival data limits interpretation of bull survival trends.

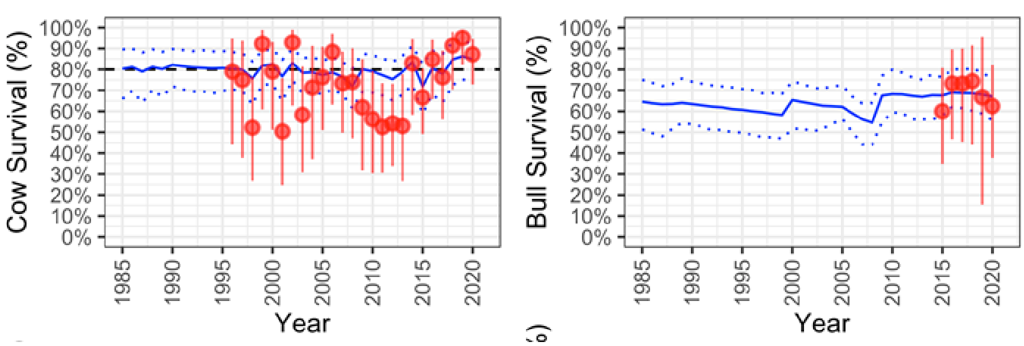

Figure 45. IPM estimates of cow and bull survival for the Bathurst herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

Increases in bull:cow ratios can also be related to increases in productivity; birth ratios of about 50:50 males:females and a large calf cohort or cohorts increase the male:female ratio in young caribou, which offsets higher mortality rates of bulls and increases the overall bull:cow ratio. The IPM uses estimates of fecundity (proportion of females pregnant) and calf survival (a derived parameter) to estimate productivity which is the product of the previous year's fecundity times calf survival. Comparison of productivity with bull:cow ratios does suggest some correspondence between increases in productivity and increases in bull cow ratio (Figure 46). For example, productivity was higher from 2008 to 2011, which corresponds to an increase in bull:cow ratios in 2012. Productivity then dropped to lower/moderate levels with a slight increasing trend from 2013 to 2020, which corresponds to a slight increase in bull cow ratios. Therefore, the slight increase in Bathurst bull:cow ratios is partially supported by increases in productivity.

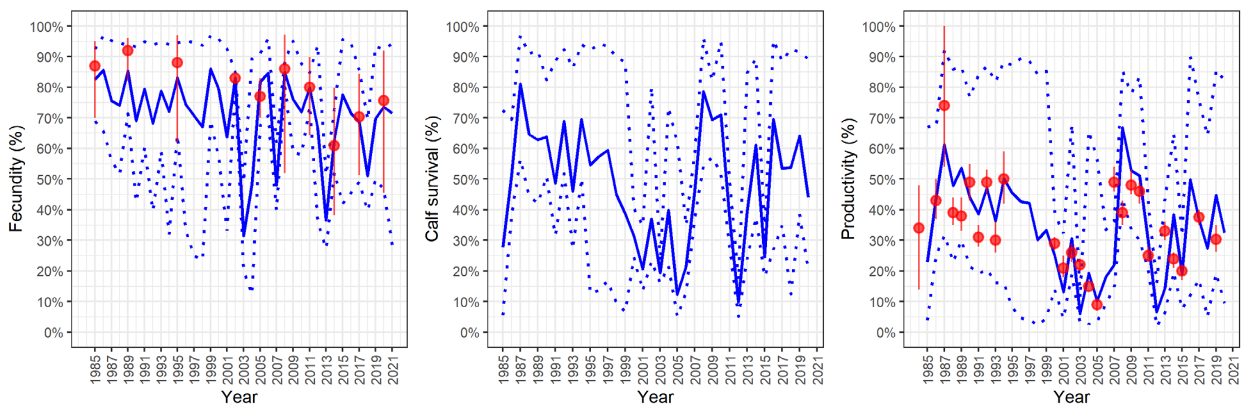

Figure 46. Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for the Bathurst herd 1985-2020.

Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year prediction of the model), are shown for reference purposes.

The fidelity of bulls to the Bathurst herd was analyzed in detail in the fall 2020 composition survey report (Adamczewski et al. 2022a). This analysis did suggest that switching of Bathurst bulls to the Beverly herd occurred in 2020. However, low sample sizes of bull collars of known herd membership precluded estimation of switching rates.

As described in the main report, the Bluenose East herd did display a marked increase in the bull-cow ratios recorded in the fall in 2020 and 2021 (Figure 47).

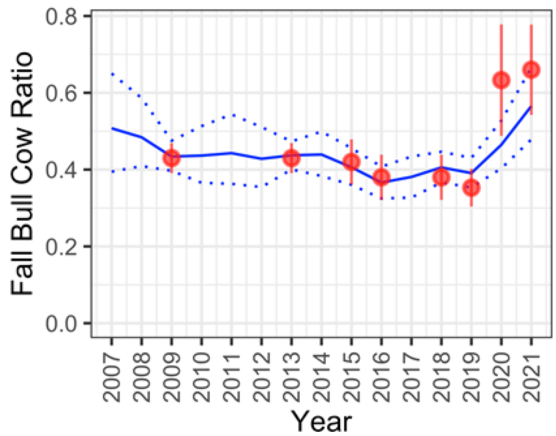

Figure 47. IPM estimates of bull-cow ratio for the Bluenose-East herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

During this time Bluenose-East cow survival was relatively constant, however, collar-based and IPM estimates of bull survival did suggest an increase, which supports the increase in bull:cow ratios (Figure 48).

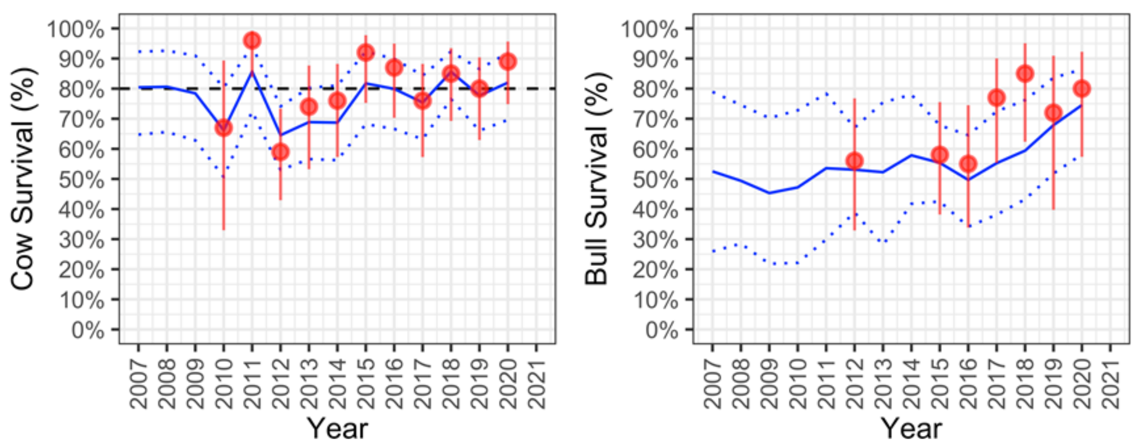

Figure 48. IPM estimates of cow and bull survival for the Bluenose-East herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

There was also an increase in productivity of Bluenose-East calves from 2018-2020 (Figure 49), which would also increase the bull cow ratio as discussed for the Bathurst herd: an initial male:female ratio of 50:50 in large calf cohorts would lead to more young males and an increased bull:cow ratio.

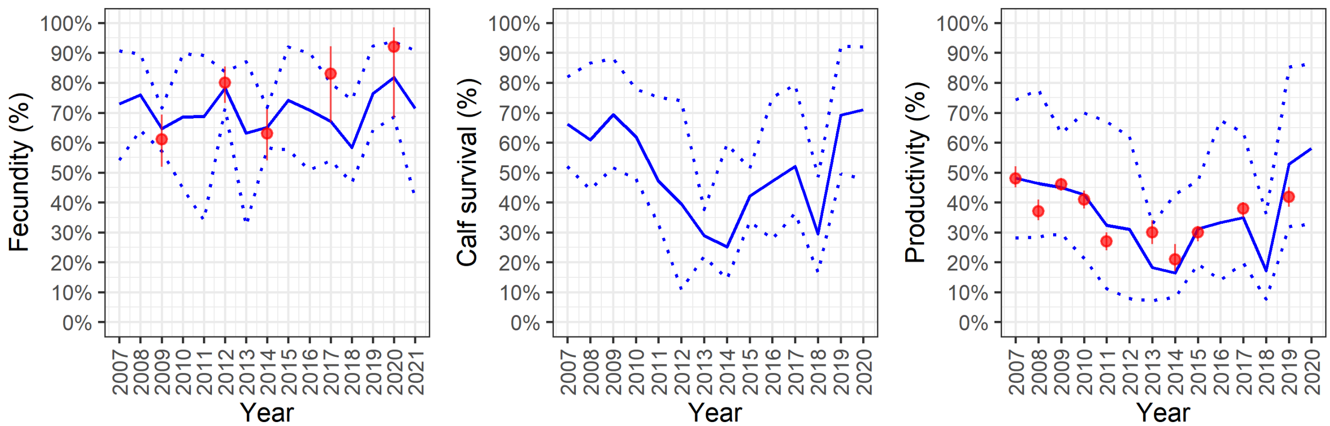

Figure 49. Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for Bluenose-East herd 2007-2021. Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year prediction of the model), are shown for reference purposes.

Therefore, the increases in bull:cow ratio and increase in bull numbers of the Bluenose-East herd are supported by the IPM analyses and various field demographic indicators.

A Comparison with Bull:Cow Ratios in the Western Arctic Herd (WAH), Alaska

The challenges of obtaining a bull:cow ratio fully representative of a migratory caribou herd numbering many thousands are not unique to surveys of the Bathurst and Bluenose-East herds. The following paragraph from Dau (2015) summarizes some of the challenges encountered in fall surveys of the WAH in Alaska.

"Sexual segregation and our inability to sample the entire population during fall probably account for more annual variability in the estimated bull:cow ratio than actual changes in population composition. The low value of 38 bulls:100 cows in 2001 was probably a result of spatial segregation and incomplete sampling of the entire herd rather than an actual short-term drop in the proportion of bulls in the population. Because of this measurement error, the bull:cow ratio reported here should be viewed with caution. We think these data probably reflect trends in bull:cow ratios reasonably accurately; however, the actual values could be higher or lower."

The graph below is from Dau (2015) and shows bull:cow ratios in the WAH from the 1970s to 2014 (Figure 50). This herd was increasing in the 1980s and early 1990s, at high numbers of over 400,000 1993-2003, and has had a declining trend since about 2003.

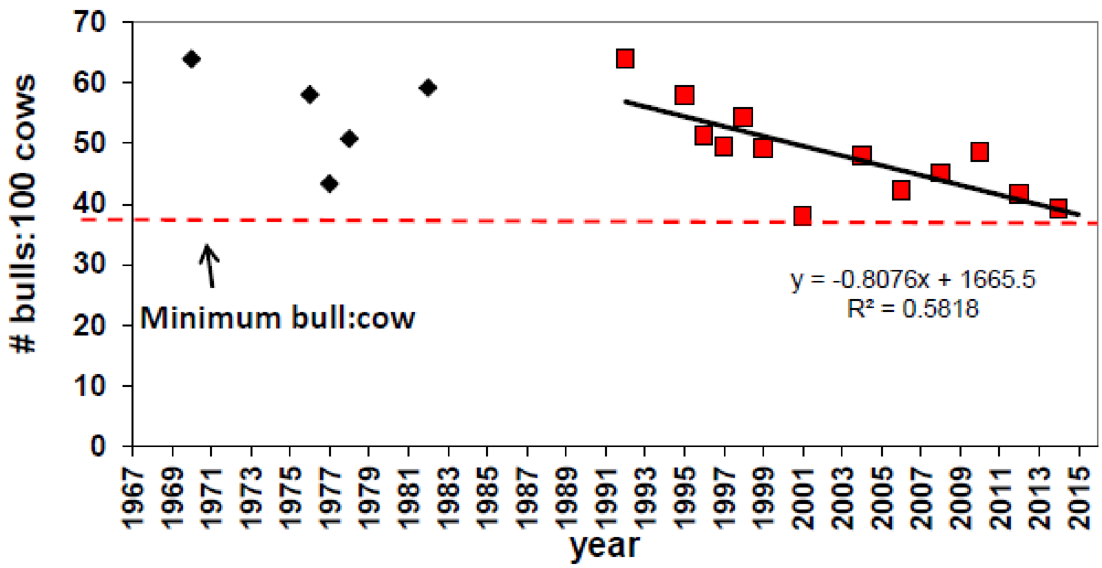

Figure 50. Fall bull:cow ratios, Western Arctic caribou herd, 1976-2014. No trend line shown for 1970-1982 because yearly survey methods varied. (Originally Figure 27 in Dau 2015; figure caption as presented in that report).

The overall range in bull:cow ratios in this herd has varied between 1991 and 2015 from a high of more than 60:100 in 1991, when the herd was still increasing, to a low of 38-40:100 in 2001 and 2014. The overall range in sex ratios is similar to the range reported for the Bathurst and Bluenose-East herds 2006-2020, although somewhat lower ratios were recorded for the Bathurst herd 2006-2008 during a period of rapid decline. Bull:cow ratios were higher during periods of herd increase and lower during periods of decline in the WAH.

Possible Role of Emigration in Increased Bull:Cow Ratios in the Bluenose-East and Bathurst Herds

Recent emigration events from the Bathurst herd to the Beverly herd as documented from collared caribou females that switched calving grounds included six of 34 known Bathurst collared cows that in early June 2021 (2) or later in June (4) switched to the Beverly calving ground. If Bathurst bulls did not emigrate to the Beverly distribution at similar rates, the potential exists for an increased Bathurst bull:cow ratio in the fall that reflects greater emigration rates in cows than in bulls. An evaluation of bull fidelity in Bathurst caribou in 2020 suggested some emigration to the Beverly herd but sample sizes were too low to quantify the extent of switching (Adamczewski et al. 2022a).

Emigration in collared bulls is more difficult to assess than in collared cows. Distribution of collared bulls in June is spatially more variable than in cows; some bulls may still be on the wintering ranges while other bulls may be near the calving grounds or just south of them. As such, herd affiliation of some bull collars in June is not easy to define. In addition, bull collar numbers are usually much lower than cow collar numbers, creating a more limited sample. In 2021-2022, the only month when bull collars in the Bathurst, Bluenose-East and Beverly herds were clearly separated was July. Newly placed bull collars were assigned to herds at that time because of that separation. However, by August, mixing of Bathurst and Beverly collared caribou had begun and continued through the fall of 2021 and winter 2021-2022 (Appendix 4 in Adamczewski et al. 2022c).

Locations of Bathurst cow and bull collars were assessed in the breeding season in October 2021(Appendix 3 in Adamczewski et al. 2022c) but there were no clear patterns, rather a mix of Bathurst and Beverly cow and bull collars (including switchers) across the range. An assessment of Bathurst bull collar fidelity could be made in July 2022 as the likeliest time for Bathurst bulls to be sufficiently separated from other herds.

Emigration is unlikely to have had any influence on bull:cow ratios in the Bluenose-East herd. Collared cows and bulls in this herd have shown no sign of emigrating to neighbouring ranges, even in winters like 2020-2021 when there was mixing of Bluenose-East, Beverly and Bathurst collared caribou.

Overall, given the similar tendencies in both the Bluenose-East and Bathurst herds toward improved demographic indicators and a stabilizing herd trend from 2018 to 2021 (more noticeably in the Bluenose-East herd), the increased fall bull:cow ratios in both herds are most likely a reflection of increased bull survival rates, in part resulting from higher calf recruitment. Higher bull:cow ratios over 60:100 were shown in NWT herds in the 1980s when herds were increasing (Gunn et al. 1997) and in the WAH herd when that herd was increasing (Dau 2015). The challenges of obtaining a representative herd sex ratio near the peak of the breeding season were apparent in Dau's (2015) summary; we similarly noted substantial regional variation in sex ratio in the Bluenose-East fall 2020 and 2021 surveys. Differential rates of cow and bull emigration from the Bathurst distribution to the Beverly could influence herd sex ratios, but are unlikely to have affected the Bluenose-East herd.