JUNE 2023 CALVING GROUND SURVEYS: BLUENOSE-EAST AND BATHURST BARREN-GROUND CARIBOU HERDS

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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 4-13, 2023 west of Kugluktuk in Nunavut. The survey was flown to develop updated estimates of numbers of breeding females, adult females and herd size. The Bluenose-East survey included a helicopter-based composition survey June 11-13 to estimate the proportions of breeding females and calf: cow ratios. A composition survey was also flown over the Bathurst herd's calving ground west of Bathurst Inlet June 14-15, and results of this survey are included here. An integrated population model was used with updated demographic data from both herds to better understand recent trends.

The Bluenose-East caribou composition survey resulted in estimates of 80.9% (CI=78.2-83.3) cows breeding (breeding females/adult females) and 86.3 calves: 100 cows (CI=84.5-88.0) in breeding females. The estimate of Bluenose-East breeding females in June 2023 was 18,580 (95%CI 15,225-22,674), compared to 12,863 (10,816-15,298) in 2021, the estimate of adult females was 24,466 (20,550-29,129), compared to 13,991 (11,805-16,585) in 2021, and the estimate of adult caribou in the herd at least two years old including males was 39,525 (33,021-47,310) compared to 23,202 (19,247-27,971) in 2021. The 2023 Bluenose-East estimates appeared very reliable, with excellent conditions for the aerial photos and visual surveys leading to a relatively low overall coefficient of variation of 8.7%.

The increase in Bluenose-East adult females 2021-2023 was statistically significant with an estimated annual rate of increase of 32% (CI=18-48%). This estimated rate of increase is beyond the known maximum rate of increase for caribou and reindeer (28%/year), however the lower end of the confidence interval of the trend estimate is within the range of known caribou rates of increase. The annual increase estimated 2018-2023 was 12% (CI=7-17%) which is within the range previously observed for other migratory caribou herds.

A variety of factors may have caused the large apparent rate of increase in the Bluenose-East herd 2021-2023 and the population model was used to help assess potential reasons. Of the possible explanations for the Bluenose-East increase 2021-2023 considered, model scenarios combining negatively biased collar survival rates, a survey under-estimate in 2021 and potential immigration from the Beverly herd resulted in more moderate Bluenose-East annual increases of up to 11% from 2018 to 2023. Given uncertainty about the true rate of increase and underlying factors since 2018, a cautious approach to herd management may be wise, pending results of further surveys and monitoring.

The June 2023 composition survey of the Bathurst herd resulted in estimates of 83.1% cows breeding (CI=78.8-86.8%) and 67.1 calves: 100 (CI=60.1-72.8) cows among breeding cows. The proportion of cows breeding was similar between the two herds, but the calf: cow ratio

in breeding females was notably lower in the Bathurst herd, suggesting relatively high calf mortality in this herd in the first week to ten days.

Movement of known collared Bathurst females in June to the Beverly calving ground in 2023 (four of 21 known collared cows) was similar to Bathurst to Beverly movements in 2018, 2019, and 2021. Population modeling suggested that if emigration was removed, then the demographic status of the Bathurst herd varied between annual growth rates of 0.80-1.0 from 2020 to 2023. If emigration of cows to the Beverly herd was included, then the observed trend of the Bathurst herd was approximately 0.80 in 2023, suggesting that emigration was a key driver in recent herd trend. The model estimated 4,241 (CI=2,771-6,193) cows and bulls in the Bathurst herd in June 2023 compared to a survey estimate of 6,851 (3,895-12,050) in 2022.

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INTRODUCTION

The Bluenose-East herd calving grounds have been found in recent years west of Kugluktuk, Nunavut (NU) and the summer range includes the calving grounds as well as areas south and east of it. The winter range is primarily south, southeast and east of Great Bear Lake, where it may overlap with the Bathurst herd (Figure 1). The Bathurst herd's calving grounds have been found west of Bathurst Inlet since 1996 (Gunn et al. 2008; Figure 1). The herd's range in NU includes the calving grounds and a large part of the summer range. The rest of the Bathurst herd's historic range, including much of the winter range, is primarily in the Northwest Territories (NWT), and in some past years has extended as far south as northern Saskatchewan. Ranges of the Bluenose-East and Beverly herds are west and east of the Bathurst range, respectively.

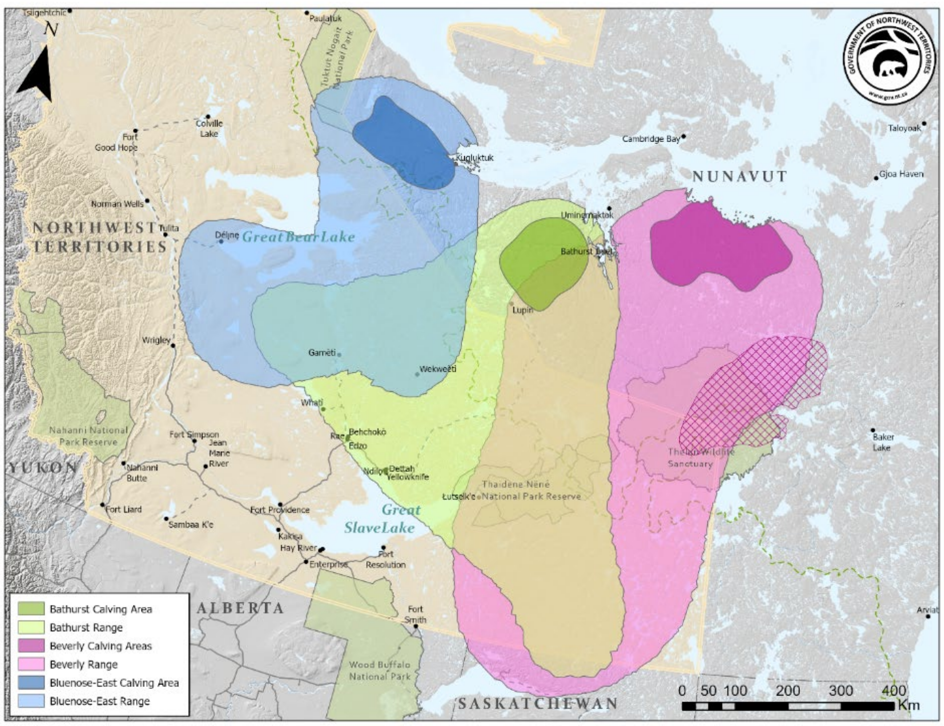

Figure 1. Annual ranges and calving grounds of the Bluenose-East, Bathurst, and Beverly [1] herds are shown on this map, based on accumulated radio collar locations of cows (Nagy et al. 2011). All three herds have calving grounds in NU and a substantial portion of the winter range in the NWT.

The June 2021 Bluenose-East calving ground survey resulted in estimates of breeding females and adult females that showed that the herd stabilized between 2018 and 2021 after

[1] The Beverly herd described in this report is the herd defined by the Government of Nunavut (GN) as calving in the central and eastern Queen Maud Gulf (Campbell et al. 2019). This herd may not correspond exactly to the Beverly herd defined prior to 2009 with an inland calving ground south of Garry Lakes (Adamczewski et al. 2015).

a large decline between 2010 and 2018 (Boulanger et al. 2022). The extrapolated estimate of adult caribou in the herd was higher in 2021 than in 2018, though not significantly (Figure 2). The slightly higher 2021 herd estimate reflected an increased bull: cow ratio documented in October 2020 and 2021 (Adamczewski et al. 2022 b, c). Positive demographic indicators for this herd 2018-2021 (proportions of breeding females in June, collar-based cow survival rates, bull: cow ratios and calf: cow ratios) were all consistent with a stabilizing trend (Boulanger et al. 2022). June calving ground photo surveys of the Bluenose-East herd every two years were part of the more intensive monitoring of this herd proposed by Government of Northwest Territories (GNWT) and the Tłı̨chǫ Government (GNWT and TG 2019b) and supported by the Wek'èezhìı Renewable Resources Board in 2019 (WRRB; WRRB 2019b).

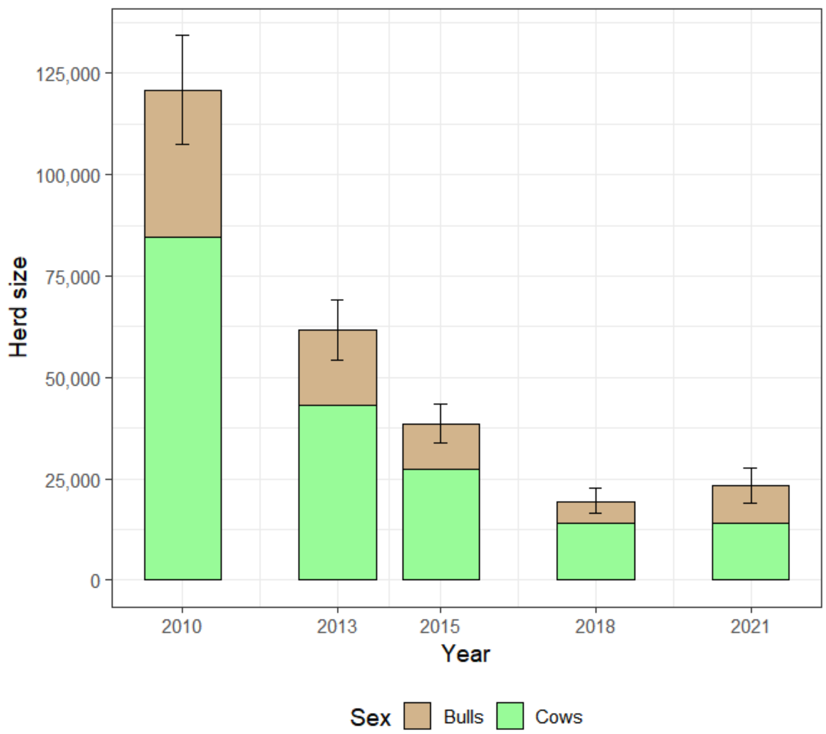

Figure 2. Estimates of herd size in the Bluenose-East caribou herd 2010-2021 based on calving ground photo surveys.

Calving ground photo surveys of the Bathurst herd (Heard 1985) have been conducted since the 1980s when the herd was at peak numbers and the herd's range was much larger (Mennell 2021). Herd estimates from 2009 to 2022 are shown in Figure 3.

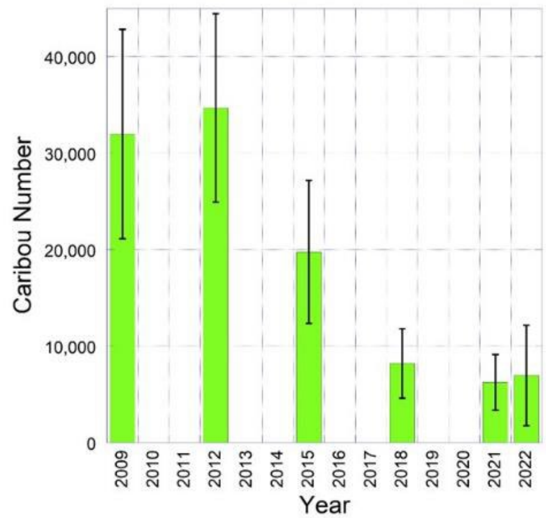

Figure 3. Estimates of herd size in the Bathurst caribou herd 2009-2022 based on extrapolated calving ground photo surveys. Confidence limits (95%) are indicated by error bars.

In 1986, the Bathurst herd was estimated at 472,000, thus the decline to less than 7,000 in 2021-2022 was nearly 99% (Adamczewski et al. 2023a). The last calving photo survey of the Bathurst herd was in 2022 and resulted in an estimate of 6,851 (95% CI= 3,895-12,050), very similar to the 6,243 adults (3,950-9,134) estimated in 2021 (Adamczewski et al. 2022a). Following the continuing decline demonstrated by the 2018 survey of the Bathurst herd, the GNWT and Tłı̨chǫ Government (2019a) in 2019 proposed more intensive monitoring of the herd, which was supported by the WRRB (WRRB 2019a). This included annual June composition surveys to monitor initial calf productivity, a proxy for pregnancy rate, and calf: cow ratios in breeding females about a week after the peak of calving, which can provide an index of early calf mortality rates.

This report describes results of a calving ground photo survey of the Bluenose-East caribou herd conducted in June 2023. The main purpose of the survey was to generate updated estimates of numbers of breeding females, total females, and adult caribou at least two years old in the herd, to compare to results of similar previous surveys. The Bluenose-East survey included a composition survey to document the proportions of breeding females and other sex and age classes on the calving ground and early calf: cow ratios. A composition survey on the Bathurst herd's calving ground west of Bathurst Inlet was also carried out in June 2023, and the results are included in this report. Demographic modeling of the Bluenose-East and Bathurst herds was carried out to integrate the most recent survey results from 2023 with earlier datasets and a summary of the modeling outcomes is included for both herds. As the increase in Bluenose-East herd estimates from 2021-2023 was substantial, an assessment was also made of factors that could have contributed to the apparent increase.

METHODS

The calving ground survey was conducted as a sequence of steps described briefly below, then in greater detail in following text.

1. Locations from collared caribou, historic records of calving ground use, and systematic aerial reconnaissance surveys of the Bluenose-East calving area were used to identify core calving areas between Kugluktuk and Bluenose Lake in NU.
2. A systematic reconnaissance survey was conducted where transects at 10 km intervals were flown to determine areas where breeding females were concentrated, as well as concentrations of bulls, yearlings, and non-breeding cows on or near the calving ground. Densities of caribou were classified as Low (<1 caribou/km^2), Medium Low (1-5 caribou/km^2), Medium High (5-9.9 caribou/km^2), and High (>10 caribou/km^2). 10 km segments were also classified by whether they contained breeding caribou (females with calves, hard antlers or a distended udder).
3. Timing of calving was assessed by evaluating the proportion of cows with newborn calves seen during flights and from reduced movement rates of collared cows at calving.
4. Using data from the reconnaissance survey, geographic areas called strata (or blocks) were delineated for sampling, either by the photo plane or visually, with the most sampling effort dedicated to areas with the highest densities of female caribou.
5. The highest density block was flown by the photo-plane and lower-density blocks were flown visually.
6. Near the end of the aerial survey conducted with the photo-plane and by visual survey, a composition survey was conducted using a helicopter. Each stratum was surveyed to determine the proportions of breeding and non-breeding female caribou, as well as bulls, yearlings, and newborn calves.
7. Estimates of adult and breeding females were derived using the estimates of total one-year-old or older caribou within each stratum, and the proportions of adult or breeding females within that stratum.
8. The adult female estimate was used in combination with the estimated proportion of females in the herd from one or more fall composition surveys to estimate overall herd size.

Collared Caribou Data

As in previous calving photo surveys, locations of satellite-collared female caribou were key to planning survey flying and survey block design. Overall movement paths of collared cows migrating north to the Bluenose-East, Bathurst, and Beverly calving grounds from May 1 to June 15 are shown in Figure 4. The collar locations of June 15 are also shown.

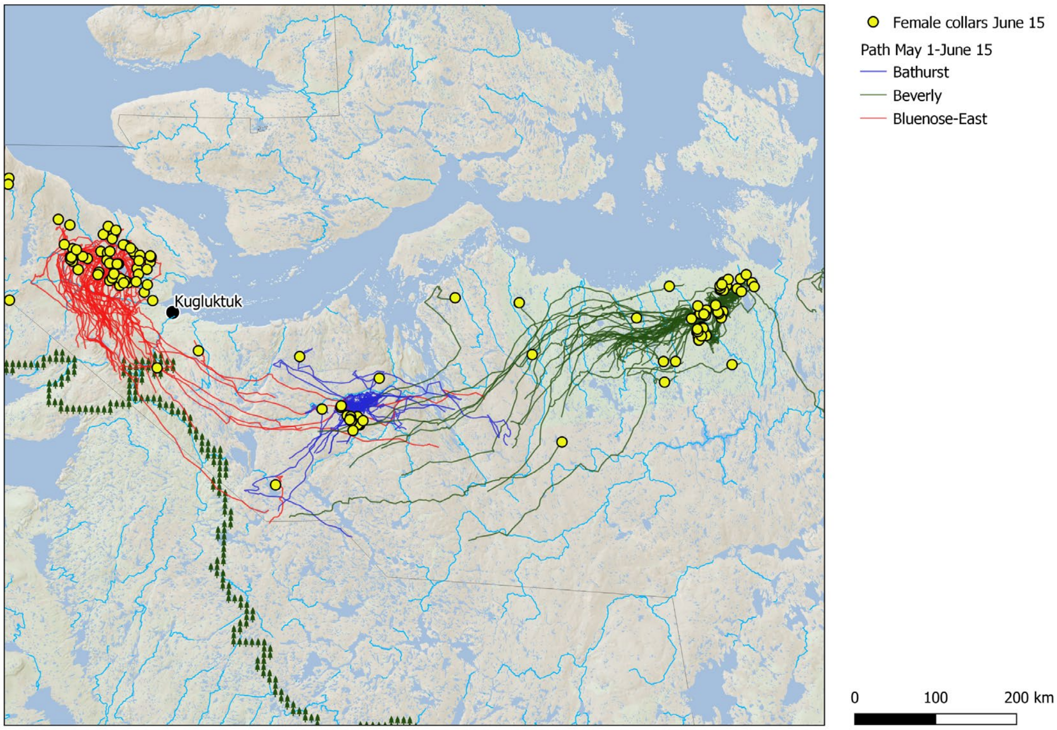

Figure 4. Movements of collared female caribou of the Bluenose-East (n=60), Bathurst (n=30), and Beverly (n=53) herds to their respective calving grounds, May 1 to June 15, 2023. Known collared cows and newly collared ones are included.

There were 33 known[2] Bluenose-East collared cows and 26 cows newly[3] assigned to the Bluenose-East herd at the time of the June 2023 survey. As shown in Figure 4, several Bluenose-East females had moved north in May with Bathurst and Beverly collared cows and some were east and south of Bathurst Inlet. However, these Bluenose-East females moved westward late in May toward the Bluenose-East calving ground. One known Bluenose-East female stayed on the Bathurst calving ground through June 2023. Two known Bluenose-East females were well south of the Bluenose-East calving ground mixed with bulls; we believe these were most likely non-breeding females and part of the southern "trailing edge" of the migrating herd mixed with bulls and yearlings. One further Bluenose-East collared cow was among very low numbers of caribou surveyed on June 4 north of the main calving concentrations; this female was slightly north of the survey blocks flown June 8 and 9. In addition, there was one collared cow that the GN had captured in NU west of Garry Lakes

[2] In this context, known Bluenose-East collared cows were ones whose previous year's June location was on the Bluenose-East calving ground. Cows found on a new calving ground (e.g. Bathurst in 2022 and Beverly in 2023) were re-assigned to the new herd in June.

[3] Female caribou were captured on the winter range with mixed herds in March 2023; 26 of these were found on the Bluenose-East calving ground in June 2023, thus assigned then as Bluenose-East females.

area in April 2023 that was on the Bluenose-East calving ground in June 2023, then continued to move with Bluenose-East collared caribou through the remainder of 2023.

There were 21 known Bathurst collared cows that migrated north in May 2023. Of these, 17 were found in the main Bathurst calving concentration west of Bathurst Inlet. The other four Bathurst cows moved north with the bulk of the Beverly collared cows in May and remained there through June. A further 13 cows newly collared in March 2023 were found on the Bathurst calving ground in June and assigned as Bathurst cows, thus there were effectively 30 Bathurst collared cows on the calving ground (17 known, 13 new) at the time of the June 2023 survey, along with one Bluenose-East collared cow.

There were 12 known Beverly collared cows in the Queen Maud Gulf lowlands on the Beverly herd's calving grounds in June 2023 and a further 41 cows newly collared in March 2023. The number of new Beverly cow collars was much greater than the target number in March 2023; the extensive mixing of all three herds in March 2023 (Adamczewski et al. 2024c) meant that multiple collars intended for Bathurst cows ended up on Beverly cows. Effectively there were 53 Beverly collared cows in June 2023, along with four Bathurst collared cows that had switched.

Reconnaissance Surveys

Reconnaissance surveys have been used in past Bluenose-East calving ground surveys (e.g. Boulanger et al. 2019) to define the distribution of caribou on the calving ground, including relative densities and approximate composition (cows with calves, hard-antlered cows, non-breeding cows, yearlings and bulls). Although the speed of the Cessna Caravans on survey (minimum 160 km/hr) did not allow for all individual caribou to be classified, substantial representation of the main sex and age classes could be determined. Locations of satellite collared cows were key to defining the survey area. Outlying areas were also flown, particularly south of the main concentrations of calving cows. Previous surveys had shown that caribou densities at the south end of the calving ground were sometimes substantial and included cows with calves along with a mixture of non-breeding cows, yearlings and bulls. The concentrations of caribou at the southern/southeastern end of the distribution in early June are often referred to as the "trailing edge" of the migration. North-south lines at 10 km spacing were flown by the Cessna Caravans. The results were mapped to assess density and composition of caribou seen, and these results were then used to design a central photo block and surrounding visual blocks[4].

Design of Photo and Visual Blocks

The main objective of the survey was to obtain precise and accurate estimates of breeding female caribou and adult female caribou on the calving ground. To achieve this, the survey

[4] In this report, we use the terms survey block and survey stratum interchangeably.

area was stratified following the results of the systematic reconnaissance survey, a procedure in which neighboring segments with similar density were grouped into contiguous areas so that each stratum enveloped distributions of similar caribou densities. In addition, stratification was used to determine if a stratum required the use of a photo survey plane, or if visual estimates could be used. Calving ground surveys in the 1980s had shown that larger groups of caribou could not be counted reliably by observers in fixed-wing aircraft but aerial photos could produce reliable counts of higher densities of caribou (Heard and Jackson 1990). In this survey, a single higher-density stratum was identified; this stratum was planned for survey by the photo-plane. Other strata that had lower densities of caribou were planned for visual survey. Given that the objective of the survey was to estimate breeding and adult females, the survey emphasized areas that contained primarily females.

Once the survey strata were delineated, an estimate of caribou numbers was derived from the reconnaissance data (Jolly 1969). The relative population size of each stratum and the degree of variation of each estimate were used to allocate the number of transects to each stratum.

Two potential strategies for allocation were considered for the aerial survey. First, optimal allocation of survey effort was considered based on sampling theory (Heard 1985, Thompson 1992, Krebs 1998). Optimal allocation basically assigned more effort to strata with higher densities given that the amount of variation in counts is proportional to the relative density of caribou within the stratum. Optimal allocation was estimated using estimates of population size for each stratum and survey variance.

If strata were reasonably small, then optimal allocation was further adjusted to ensure an adequate number of transect lines. Previous surveys suggested that there should be a minimum of ten transects per stratum with closer to 20 transects being optimal for high density areas. In general, coverage should be at least 15% with higher levels of coverage for high density strata. In the context of sampling, increasing the number of lines in a stratum is “insurance” in that it minimizes the influence of any one line on estimate precision. As populations become more clustered, a higher number of transect lines is required to achieve adequate precision (Thompson 1992, Krebs 1998). An allocation program was scripted in R based on formulae in Thompson (1992).

For the photo block, scenarios under a range of survey altitudes (based on cloud ceilings) were considered with the goal of having the photo stratum flown in a single day by one photo plane on two flights at target coverage levels, while keeping within the budgeted numbers of photos to be taken (4,000). The trade-off with this assessment was that for surveys flown at lower altitudes, coverage would be reduced and the number of photos needed would increase. An algorithm in R (R Development Core Team 2024) generated the estimates 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 (25-30%) and assess the number of transects that could be flown at lower survey altitudes within a single day, with two flights by one photo plane. This approach ensured acceptable coverage if lower survey altitudes were required, and with additional coverage if weather permitted higher altitudes. Experience in June 2021 and 2022 had shown that aerial photos taken at GSD8[5] about 4,300 feet above ground level under blue skies resulted in photos with well-defined images of caribou (Boulanger et al. 2022, Adamczewski et al. 2022a, 2023a).

For visual blocks, sampling had a target of 15-20% coverage, along with the goal of having all Bluenose-East visual blocks flown within one survey day with two aircraft. Survey strata were designed using ArcGIS and QGIS software (QGIS Foundation 2020) with transect lines drawn within strata using the *dssd* package (Marshall 2021) in program *R* (R Core Development Team 2024). Data were plotted using the *ggplot2* (Wickham 2009) with GIS manipulations using the simple features (*sf:* Pebesma 2018) R package.

Photographic Survey Block and Photo Interpretation

GeodesyGroup Inc. aerial survey company (High River, AB) was contracted for the aerial photography. They used a Piper PA31-310 Panther Navajo with a digital camera mounted in the aircraft's belly. The camera systems were from Vexcel Imaging in Graz, Austria (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 cameras were integrated into gyro-stabilized camera mounts and used imbedded airborne GPS (global positioning systems) and IMUs (inertial measurement units) to provide direct geo-referenced images.

The Navajo aircraft initially flew from High River, Alberta (AB) to Yellowknife June 7, then flew to Kugluktuk in the morning of June 8. A photo block with lines was designed by J. Boulanger and provided to the Geodesy photographer L. Rawlinson at midday and the Navajo began flying photo lines that afternoon. Survey altitude above ground level (AGL) to be flown for photos was determined at the time of stratification based on cloud ceilings and the 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 (GreenLink Forestry Inc., Edmonton, AB) using specialized software and glasses that allowed three-dimensional viewing of photographic images, consistent with methods used for the June

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[5] GSD is a term used in aerial photography. Ground Sampling Distance (GSD) is the distance between two consecutive pixel centers measured on the ground. The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details are. Further information is at: https://support.pix4d.com/hc/en-us/articles/202559809-Ground-sampling-distance-GSD-in-photogrammetry.

2015, 2018, 2021 and 2022 Bluenose-East and Bathurst aerial photo interpretation. The number of caribou counted was tallied by stratum and transect. The exact survey strip width and survey area of photo transects were determined using the geo-referenced digital photos.

Ground conditions in June 2023 included a high proportion of bare ground, which made caribou easier to detect from the Caravans and on aerial photos. As a result, a second independent count, as used in 2018 and 2021 (Boulanger et al. 2019, 2022, Adamczewski et al. 2019, 2022a) when snow conditions were a challenging patchwork, was not done. However, as part of the company's quality control monitoring, the most experienced photo analyst at Greenlink carried out a second count of 246 photos.

Reconnaissance and Visual Block Flying and Data Recording

Reconnaissance surveys and visual strata were flown in two Cessna Caravans owned by North-Wright Airways Ltd. following methods used in several previous calving ground surveys (original methods in Norton-Griffiths 1978; Figure 5).

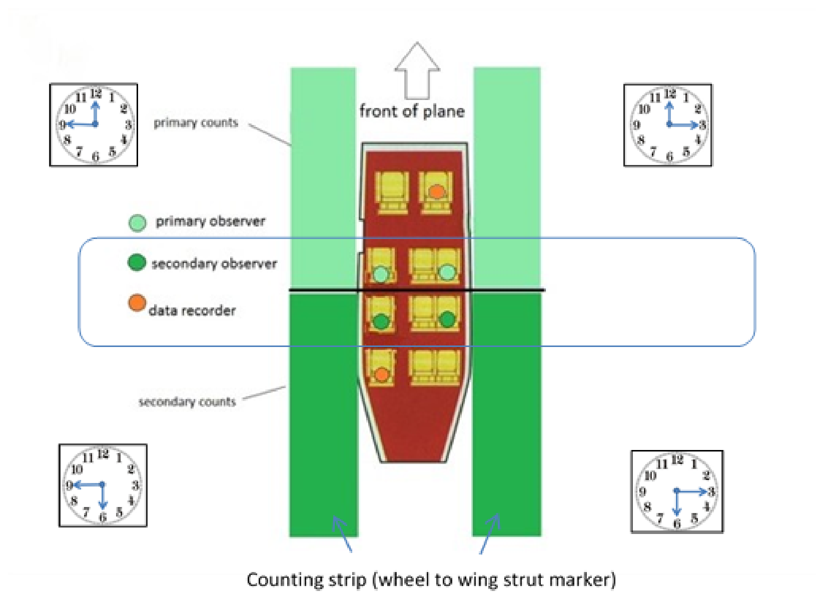


Figure 5. Observer and recorder positions for double observer methods on June 2023 caribou survey of Bluenose-East caribou.

Strip transects were 800 m in width, and caribou were counted within a 400 m strip on each side of the survey plane. 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 160 km/hr 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. 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.

Previous analysis (Boulanger et al. 2010) demonstrated that two observers usually saw more caribou than a single observer. Further analysis of the sighting patterns of observer pairs allowed for an assessment of what was likely missed (Boulanger et al. 2010, 2014a). Double observer methods have been used on other recent Bluenose-East and Bathurst calving ground photographic surveys (e.g. Adamczewski et al. 2022a, 2023a, Boulanger et al. 2022). The two observers on the same side communicated to ensure that groups of caribou were not double counted. During the visual and reconnaissance survey flying, the intercom system was connected 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. Visual surveys were conducted in six strata surrounding the photo block, where lower densities of caribou were expected based on past survey results and on numbers of collared caribou.

Data were recorded on Trimble YUMA 2 tablets. Key attributes recorded were the numbers of caribou seen by each observer, and information on the composition of caribou seen (newborn calves, breeding cows, non-breeding cows, bulls, yearlings). Not all caribou could be classified from the Caravan because of the speed of the aircraft, and at a 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. 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 Caravan pilot used a tablet GPS unit with a ForeFlight program to enter and fly planned routes.

Check of Visual Survey Lines Compared to Photo Lines

A test of visual survey methods with the Caravans was flown on June 9 after visual survey block coverage was complete. Reconnaissance surveys had showed that densities of caribou on the Bluenose-East calving ground were primarily low-moderate and caribou group sizes were commonly between 1 and 25-30. Under these conditions, visual surveys using the double observer method could result in estimates of caribou density potentially similar to those from the aerial photos. Studies in the 1980s had shown that visual survey methods were not suitable for survey conditions where densities were high (>10 caribou/km^2) and particularly where group sizes were large (>100), as observers could not count these groups from a fixed-wing aircraft and had to provide an estimated count of the group size (Heard

1985, Heard and Jackson 1990). Visual counts under these conditions led to abundance estimates that were low, often by half or more, when compared to estimates that included aerial photos of high-density areas (Heard and Jackson 1990). Calving ground surveys since the 1980s have still included visual flying over low-density areas. A portion of the photo block on the Bluenose-East calving ground in June 2023 was re-flown with the Caravans on June 9, with 15 transects that were exactly on the lines flown June 8 and 9 by the photo plane. These flights allowed for a side-by-side comparison of visual counts and photo-based counts.

Helicopter-Based Composition Surveys

The Bluenose-East composition survey was flown on June 11, 12, and 13 in an A-star helicopter operated by Acasta Heliflight Ltd. with the machine based in Kugluktuk. A temporary cache of eight 45-gallon drums of jet fuel was placed in a central location on the calving ground just before the survey began, and the empty drums were removed at the end of the survey. Caribou were classified from the air using motion-stabilized binoculars. Classification was carried out in the six visual blocks and the photo block, with greater effort in the photo block, where more caribou were expected. To minimize stress to caribou groups with newborn calves, most of the classification was carried out with the helicopter hovering in one position and the caribou moving away at a walking or trotting pace. In situations where caribou were running hard or they were in rugged terrain such as boulder fields, classification was suspended.

The composition survey of the Bathurst herd west of Bathurst Inlet was carried out on June 14 and 15 with the helicopter based at the Marine Laydown Area (MLA) site owned by B2Gold, formerly Sabina Gold and Silver. A set of east-west survey lines about 4 km apart and bracketing the locations of collared cows, along with the collared cow locations, was used to find and classify caribou groups.

Caribou were classified following the methods of Gunn et al. (1997) where antler status, presence/absence of an udder, and presence of a calf are used to categorize breeding status of females (Figure 6). The 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, or 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. In this classification, breeding females and non-breeding females include two-year-old females and females ≥3 years old.

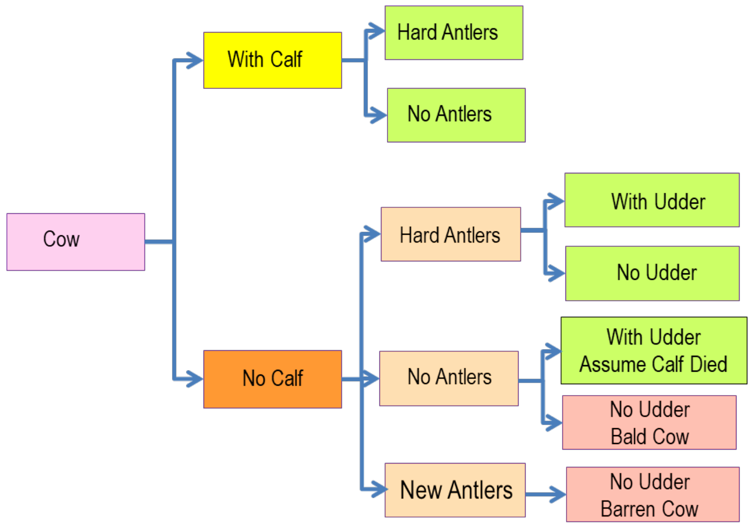


Figure 6. Classification of females used in composition survey of Bluenose-East and Bathurst caribou in June 2023. Green-shaded boxes were all classified as breeding females (diagram adapted from Gunn et al. 1997). Udder observation refers to a distended udder in a cow that has given birth or is about to. Hard antlers (usually white) are from the previous year and are distinct from new antlers growing in velvet (usually dark).

The numbers of each class of caribou in each group were recorded; a key estimate was the proportion of breeding female caribou on the calving ground. Bootstrap resampling methods (Manly 1997) were used to estimate standard errors and percentile-based confidence limits for the proportion of breeding caribou.

Estimation of Bluenose-East Breeding Females, Adult Females and Adult Herd Size

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 eliminated the non-breeding females, yearlings, and bulls from the estimate of total caribou on the calving ground.

The number of adult females at least two years old was 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 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 ≥2 years old 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 a recent estimate of the bull: cow ratio from October 2022 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. 2015a), and has been used in other recent calving photo surveys for the Bluenose-East and Bathurst herds (e.g. Adamczewski et al. 2022a, Boulanger et al. 2022). This estimator uses the estimate of total adult females divided by the proportion of adult females in the herd (sex ratio) 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 Bluenose-East Breeding Females, Adult Females and Herd Size

A comparison of the estimates from the 2021 and 2023 surveys was made by estimating annual change as lambda (λ). 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 >1 or <1 show increasing and declining populations respectively. A simulation approach was used that assumed log-normal distributions of estimates to test for significance between survey estimates and generate confidence limits on yearly change in estimates (Manly 1997).

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

As with previous calving ground surveys of the Bluenose-East and Bathurst herds, demographic modeling was used to integrate the population estimates with information about herd vital rates to better understand the herd's demographics and trend. In earlier years (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 IPM fitted in a Bayesian framework (hereafter 'Bayesian IPM'; Buckland et al. 2004, Kery and Schaub 2011, Schaub and Kery 2022) was used after the 2018, 2021 and 2022 Bluenose-East and Bathurst calving ground surveys (Adamczewski et al. 2019, 2022a, 2023a, Boulanger et al. 2019, 2022).

The Bayesian IPM is 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 7) and is identical to the previous OLS model.

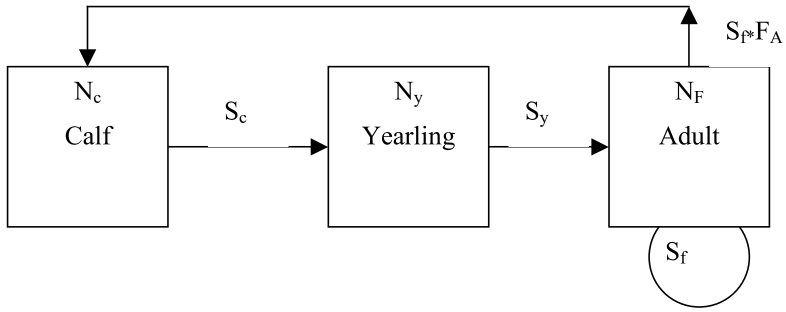


Figure 7. The stage matrix life history diagram for the caribou demographic model used for Bluenose-East caribou in 2023. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival 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.

However, the Bayesian IPM method provides a much more flexible and robust method for estimating demographic parameters that consider process and observer error. 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. 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.

The breeding and adult female estimates in June, calf-cow ratios in October and March, bull-cow ratios in October, estimates of the proportion of breeding females in June, and adult female survival rates from collared caribou were used to estimate the most likely survival, abundance, and fecundity values that would result in the observed trends in all the demographic indicators for the Bathurst and Bluenose-East herds. The most recent values from 2023 were included where possible, in combination with earlier results. A summary of the modeling outcomes is included in the current report to provide a more complete evaluation of survey results. Details on the IPM approach, which was conducted in collaboration with Joe Thorley (www.poissonconsulting.ca), are given in Appendix 2.

Assessment of Factors Contributing to Increase from 2021-2023

Initial assessment of the Bluenose-East survey results from 2021 and 2023 suggested that the estimated increases in breeding females and adult females (31-32%/year) were beyond the limits of biological increase in a caribou herd. Bergerud (2000) noted that predator-free island populations of caribou and reindeer could reach maximum annual rates of increase of 28%. The estimated increases from 2021-2023 were also difficult to reconcile with the existing demographic data (calf: cow ratios, collar-based survival, etc.). A number of assessments were made to try to account for the high rate of increase from 2021 to 2023.

Analyses included assessment matrix model analysis to assess likely rates of increase that were feasible under observed demographic parameter values for the Bluenose-East herd. Assessment of potential survey bias in 2018 and 2021 due to poor sighting conditions was considered as well as the potential for movement of caribou from adjoining herds. Increases in productivity due to breeding of yearling females were considered. Each of these potential scenarios was considered by the IPM to allow a data-driven assessment of factors causing increase.

RESULTS: BLUENOSE-EAST SURVEY

Survey Conditions and Daily Flying

The Cessna Caravans used for fixed-wing flying in June 2023 for the Bluenose-East survey were based at Kugluktuk from June 2-10 (Figure 8). The two Caravans flew south on June 10 at the end of the survey.

Figure 8. Cessna Caravan C-GDLC at Kugluktuk airport in June 2023 with survey crew (left to right: pilot Kyle Newhook, pilot Laura Simpson, Karin Clark and Robin Abernethy (ECC), Edward Doctor (YKDFN), Brent Taniton (DRRC), Aimee Guile (WRRB), Wayne Mercredi (NSMA), Roy Judas (TG), Earl Evans (NWTMN), John Boulanger (IER), Judy Williams and Stefan Goodman (ECC). Not pictured, but also part of the survey were Lisa-Marie Leclerc (GN), Regan Adjun and Jeffrey Niptanatiak (KAA)[6] and Jan Adamczewski (ECC). Photo J. Adamczewski.

The Acasta HeliFlight Ltd. A-star helicopter used for composition surveys flew from Yellowknife to Kugluktuk on June 9 and slung eight drums of jet fuel to a temporary field cache on the Bluenose-East calving ground that day. The Bluenose-East composition survey was flown June 11, 12 and 13 and based in Kugluktuk (Figure 9). The empty drums at the

[6] ECC = Government of Northwest Territories Environment and Climate Change; YKDFN = Yellowknives Dene First Nation; DRRC = Délı̨nę Renewable Resources Council; WRRB = Wek'èezhìı Renewable Resources Board; NSMA = North Slave Métis Alliance; TG = Tłı̨chǫ Government; NWTMN = Northwest Territories Métis Nation; GN = Government of Nunavut Environment; KAA = Kugluktuk Angoniatit Association.

temporary fuel cache were removed from the field on June 13 to Kugluktuk. The helicopter and survey crew then flew east to start the Bathurst composition survey on June 14 and was based at the MLA site at Bathurst Inlet. The Bathurst composition survey was completed June 15 and the helicopter and crew returned to Yellowknife the same day. A summary of daily flying by the Caravans is in Table 1a and a summary of the helicopter flying is in Table 1b.

Figure 9. A-Star helicopter C-GCHH used for Bluenose-East and Bathurst June 2023 calving ground composition surveys, at Kugluktuk airport.

Table 1a. Summary of Caravan flying on the June 2023 Bluenose-East calving ground survey. Recon = reconnaissance flying; YK = Yellowknife; Kug = Kugluktuk; N Wells = Norman Wells. Flying by photo plane is not shown; Bluenose-East photo block was flown June 8 and 9.

Date	Caravan GZIZ	Caravan GDLC
June 1	Position N Wells to YK 2.3 hours	Position N Wells to YK 2.3 hours
June 2	Ferry YK to Kug 2.1 hours	Ferry YK to Kug 2.1 hours
June 3	No flying; caribou movement rates still high	No flying; caribou movement rates still high
June 4	Bluenose-East first recon 4.3 hours	Bluenose-East first recon 4.7 hours
June 5	No flying; targeting June 8 and 9 for weather window	No flying; targeting June 8 and 9 for weather window
June 6	No flying; poor weather	No flying; poor weather
June 7	No flying; poor weather	No flying; poor weather
June 8	Bluenose-East second recon 2.7 hours; Bluenose-East visual blocks 4.8 hours; total 7.5 hours	Bluenose-East second recon 2.7 hours; Bluenose-East visual blocks 4.3 hours; total 7.0 hours
June 9	Bluenose-East visual blocks 4.7 hours; Bluenose-East photo trials 1.9 hours; total 6.6 hours	Bluenose-East visual blocks 4.4 hours; Bluenose-East photo trials 2.1 hours; total 6.5 hours
June 10	Ferry Kug to YK 2.2 hours	Ferry Kug to YK 2.0 hours; YK to Délı̨nę 1.9 hours; Délı̨nę to N Wells 0.7 hours; total 4.6 hours
June 11	Position YK to N Wells 2.4 hours	-
Total Hours	Recon 7.0 hours; visual 11.4 hours; ferry 9.0 hours; total 27.4 hours	Recon 7.4 hours; visual 9.9 hours; ferry 9.8 hours; total 27.1 hours.

Table 1b. Summary of daily flying by A-Star helicopter C-GCHH on Bluenose-East and Bathurst composition surveys in June 2023. MLA = Marine Laydown Area site at Bathurst Inlet; Kug = Kugluktuk; YK = Yellowknife; Bat = Bathurst; comp = composition.

Date	A-Star GCHH
June 9	3.0 hours ferry YK to Kug; 2.6 hours slinging eight drums to field cache; total 5.6 hours
June 10	Poor weather; no flying
June 11	Bluenose-East comp survey 8.2 hours
June 12	Bluenose-East comp survey 8.1 hours
June 13	Bluenose-East comp survey 4.4 hours; 1.3 hours slinging eight empty drums to Kug
June 14	Ferry 1.4 hours Kug to Bat survey area, then MLA site; Bat comp 6.3 hours
June 15	Bat comp 4.3 hours; ferry 3.0 hours to Lupin, then YK
Total Hours Bluenose-East	Bluenose-East comp 20.7 hours survey; ferry hours, including slinging drums, 6.9 hours; total 27.6 hours
Total Hours Bat	Bat comp 10.7 hours; ferry hours 4.4; total 15.1 hours

Caribou sighting conditions through the main survey period of June 4-15 were very good, with predominantly bare ground on both the Bluenose-East and Bathurst calving grounds (Figure 10).

Figure 10. Photos of Bluenose-East and Bathurst survey conditions between June 4 and 16, 2023. Snow cover was very limited and rarely exceeded 5%. Photos J. Adamczewski.

Snow conditions were similar to minimal snow conditions in June 2022 (Adamczewski et al. 2023a) and contrasted with much more challenging patchy snow conditions a year earlier in June 2021 (Adamczewski et al. 2022a, Boulanger et al. 2022). These conditions gave us confidence that we were seeing a high proportion of the caribou and other wildlife, including single caribou and small groups.

Collared Cow Movement Rates

Movement rates of the collared caribou females were monitored daily to help identify the timing of the peak of calving. Previous experience (Nishi et al. 2007, 2014, Boulanger et al. 2017, 2019) had shown that average daily movement rates of collared cows dropping and then staying below 5 km/day were a reliable indicator of the peak of calving. Movement rates for the Bluenose-East collared caribou showed a decrease May 26-29, then an increase followed by a drop below 5 km/day June 4 (Figure 11). Movement rates remained below 5 km/day until June 11, then showed an increasing trend June 11-15. These trends suggested a peak of calving around June 4-6, 2023 for the Bluenose-East herd.

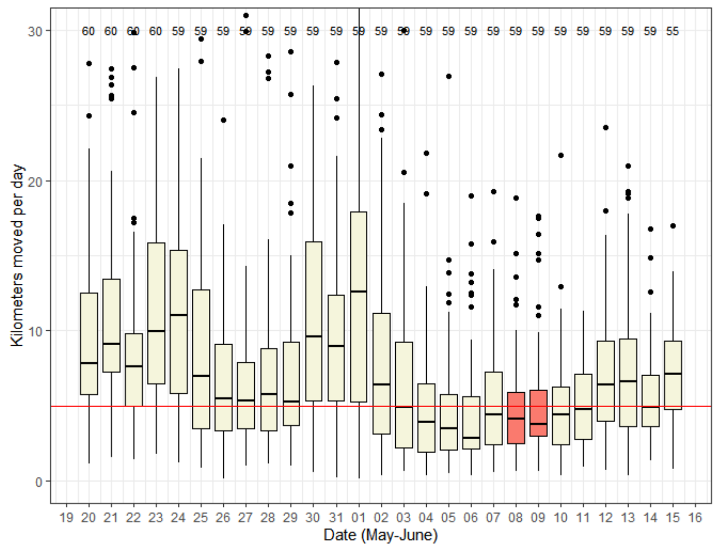


Figure 11. Movement rates for Bluenose-East collared females in late May and early June 2023. The sample size of collars for each day is shown above each boxplot. The red boxplots delineate the dates when the aerial photos were taken and visual blocks were flown.

Movement rates of the Bathurst collared cows showed patterns that were more difficult to interpret (Figure 12).

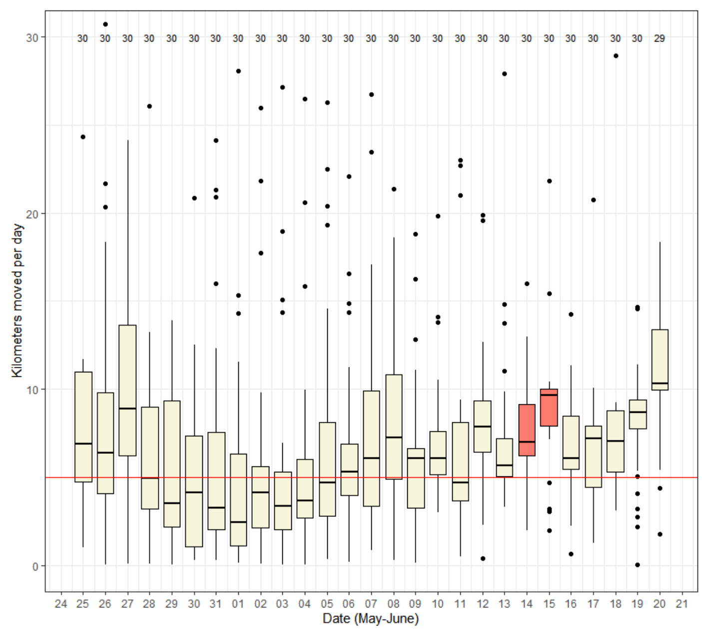


Figure 12. Female collar movement rates for the Bathurst herd in late May and early June 2023. The red boxplots indicate dates when the Bathurst composition survey occurred. Collar sample sizes are given above each boxplot.

Bathurst collared cow movement rates dropped below 5 km/day on May 29 and remained below 5 km/day until June 5, then showed a variable and erratic pattern until June 21 with only one day (June 11) being below 5 km/day. It is possible that the decrease in movement rates in late May was in part a result of most Bathurst collared cows being on site on the Bathurst calving grounds in late May.

Reconnaissance Surveys June 4 and June 8

An initial reconnaissance survey of the Bluenose-East calving ground was flown on June 4 with north-south flight lines spaced 10 km apart. The survey area was designed primarily around locations of 59 female collared Bluenose-East caribou. We assumed that the 26 newly collared cows found on the Bluenose-East calving ground could then be assigned to the Bluenose-East herd. Observers also recorded observations of cows with newborn calves to provide information on how far calving had progressed.

Results of the June 4 reconnaissance survey are shown in Figure 13a as squares, each representing the density of caribou found in one 10 km segment of the flight lines. Overall, densities varied from Low (<1 caribou/km²) to Medium Low (1-5 caribou/km²) and Medium High (5-9.9 caribou/km²) in a central area with most of the collared caribou and in the southeast area just west of Kugluktuk (Figure 13a).

Results of the June 4 reconnaissance survey are shown in Figure 13b with composition of the caribou seen in each 10 km segment. The central area with most of the collared cows had mostly cows and calves, with some segments having hard-antlered cows. The presence of at least one newborn calf resulted in that segment being identified as breeding cows with calves. Towards the south end of the survey area, there were fewer cows with calves and larger numbers of non-breeding cows, yearlings and some bulls. There were occasional cows with calves in the southeast corner of the survey area, mixed with non-breeding cows, yearlings and bulls.

Observations of cows with newborn calves on June 4 showed that between 5 and 30% of the cows had a newborn calf, and all calves seen were tiny and not very mobile. These observations suggested that the peak of calving was likely imminent, consistent with the drop in daily movement rates of collared cows below 5 km/day on June 4. The peak of calving was likely June 4-6 for the Bluenose-East herd in June 2023.

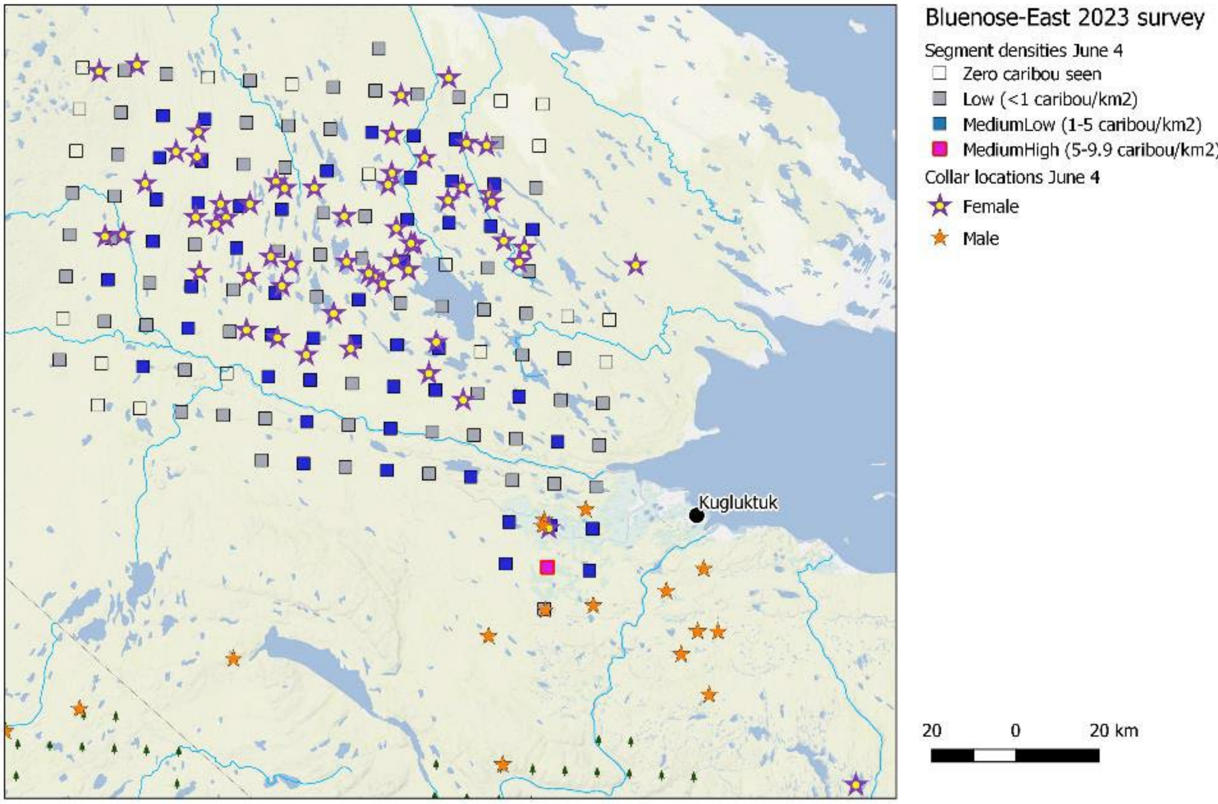


Figure 13a. Densities of caribou observed on June 4, 2023 reconnaissance survey of Bluenose-East calving grounds. Each box represents densities in a 10-km segment along north-south lines.

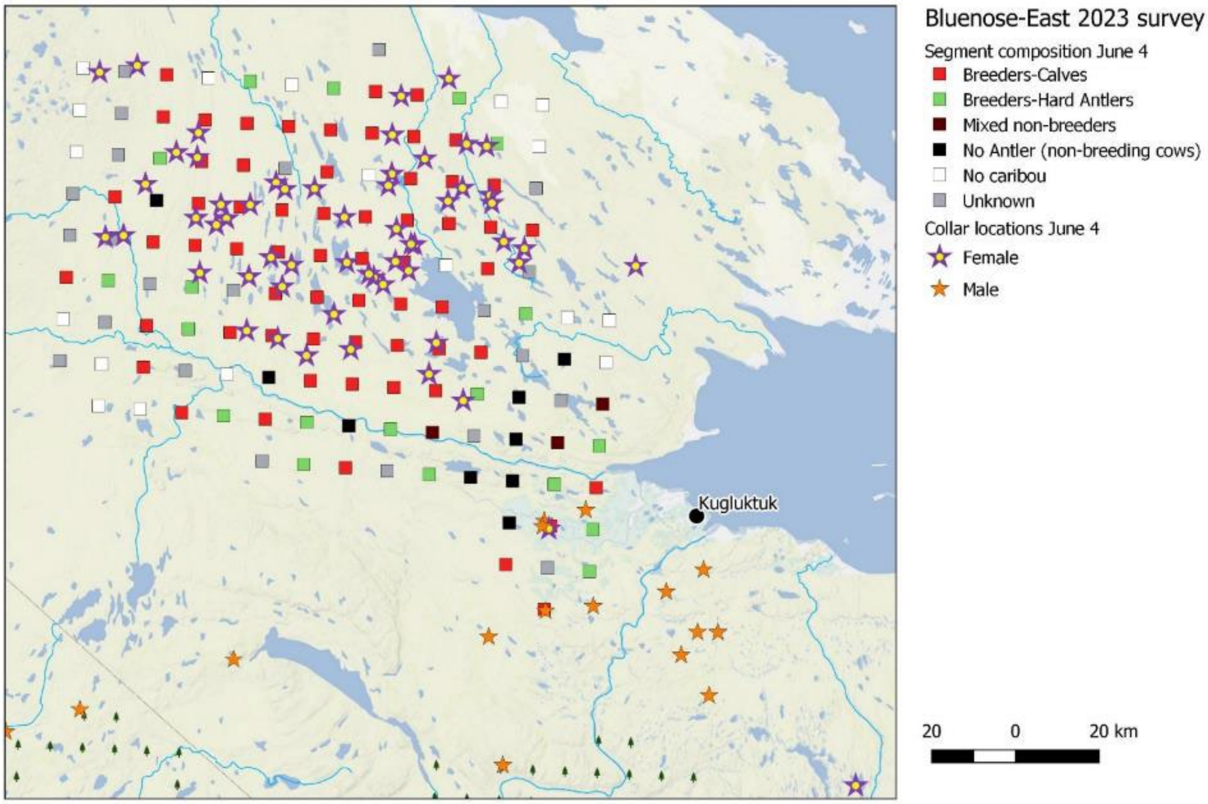


Figure 13b. Composition of caribou observed on June 4, 2023 reconnaissance survey of Bluenose-East calving grounds. Each box represents densities in a 10-km segment along north-south lines.

A good weather window was expected June 8 and 9 and plans were made to fly the aerial photos during this time along with visual survey blocks. A further reconnaissance survey was planned for the early portion of June 8 to update and refine the information gained on June 4. In particular, additional coverage at the south end of the survey area was planned as substantial numbers of caribou, including some cows with calves, had been seen in the southeast portion of the June 4 reconnaissance survey.

Densities of caribou observed on June 8 were similar to those recorded on June 4 (Figure 14a). The additional coverage at the south end of the distribution showed low numbers of caribou, except for the southeast portion of the distribution near Kugluktuk. Composition of caribou observed on June 8 was also similar to the pattern seen on June 4 (Figure 14b). There were fewer segments with hard-antlered cows and more with cows and calves, as expected with calving further advanced. No cows with calves were seen in the far south region, but some cows with calves were again observed in the southeast part of the survey area.

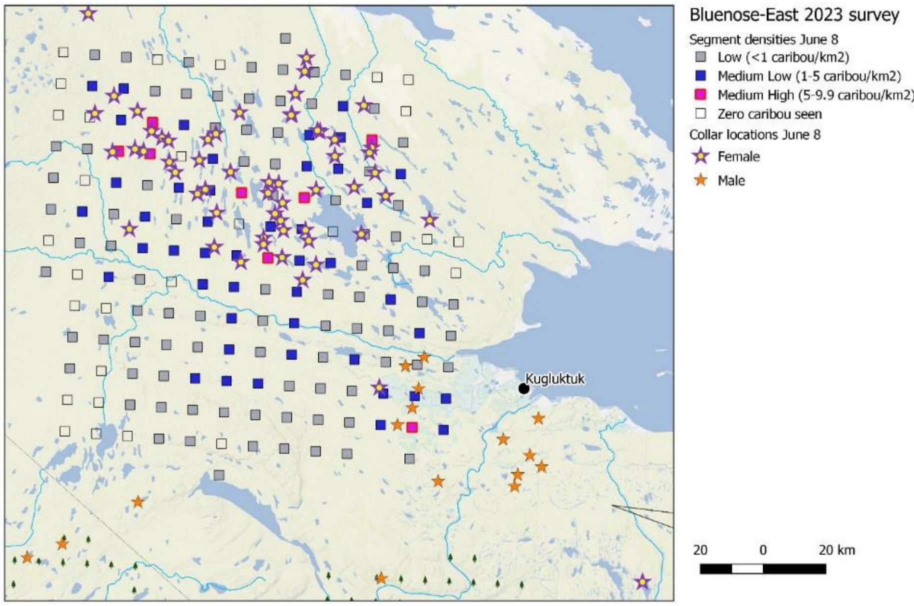


Figure 14a. Densities of caribou observed on June 8, 2023 reconnaissance survey of Bluenose-East calving grounds. Each box represents densities in a 10-km segment along north-south lines.

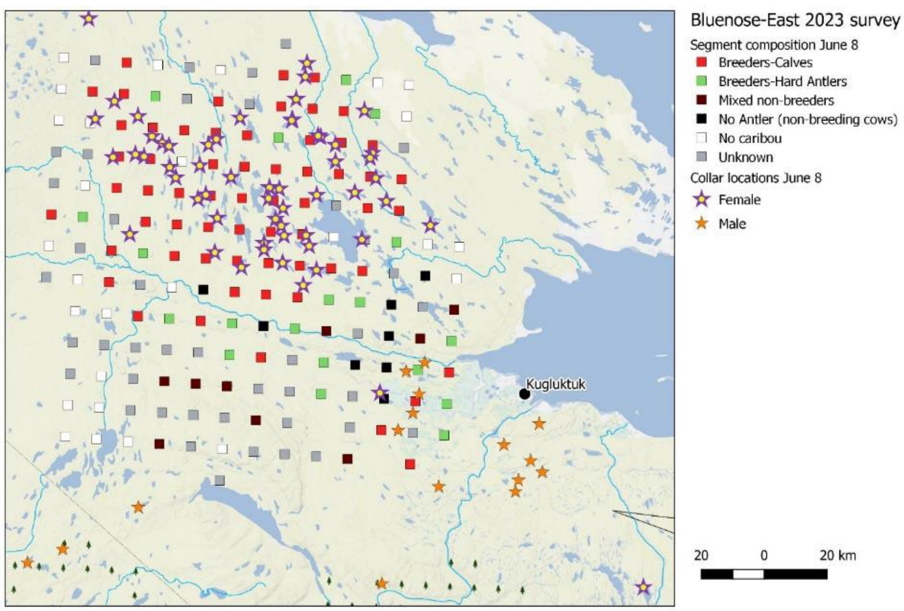


Figure 14b. Composition of caribou observed on June 8, 2023 reconnaissance survey of Bluenose-East calving grounds. Each box represents densities in a 10-km segment along north-south lines.

Photo and Visual Survey Block Design and Lines

The photo survey block was completed in two flights; one flight was completed in the afternoon of June 8, but a technical camera issue prevented completion of the second flight that day. The technical issue was resolved and the second flight was completed in the morning of June 9. The flights amounted to approximately 1,000 km of flying on transect. The target GSD/altitude was GSD=6 which met the target number of photos (4,000) with a coverage level of 27% (Figure 15). Given potentially blue skies on June 8 and 9, GSD=8 was also considered. In the end, GSD=8 was flown (elevation of about 4,300 feet above ground) with a coverage of 34.8%.

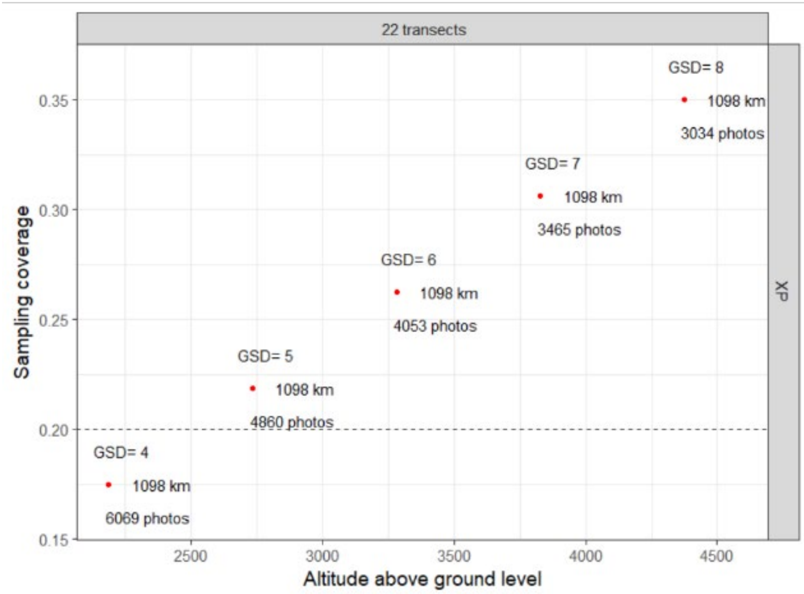


Figure 15. Ground coverage of aerial photos as a function of altitude and GSD for Bluenose-East photo stratum in June 2023. At higher elevations or GSD values, ground coverage is higher and fewer photos are needed to achieve the desired coverage.

The visual survey was designed to be flown in two survey days, which amounted to approximately 2,200 km of on transect flying. Optimal allocation methods were used to assign effort to each visual stratum based on variance and relative densities of caribou (Table 2). Densities were relatively even in all strata except the Visual Southeast, which had higher densities. Therefore, the allocation program suggested reasonably even effort (coverage) for strata when based on density (Coverage N in table 2). The Visual Southeast likely contained a lower proportion of cows and therefore it was given similar coverage as other strata despite having higher densities. Allocations based on standard error (SE) also suggested similar coverage for Visual North and South strata. The Visual East and West strata were adjusted to have over ten lines for valid estimates of standard error.

The resulting strata dimensions and coverage are shown in Table 3. The Visual Far South stratum was designed from the reconnaissance survey data flown in this area on the morning of June 8. This showed low numbers of caribou overall and no cows with calves, and therefore reconnaissance-level coverage of 8% was adequate. Other visual strata had coverage of 19-20%.

Table 2. Allocation results for visual strata for Bluenose-East June 2023 calving ground photo survey. Vis = Visual; CV – Coefficient of Variation; SE – Standard Error.

Stratum	Area km²	Reconnaissance Estimates		Allocation Targets				Adjusted Target Lines
		Density	CV	Lines SE	Lines N	Coverage SE	Coverage N	
Visual East	1,083.6	0.42	23.1%	4	6	6%	11%	12
Visual North	1,887.2	0.53	30.3%	27	21	20%	15%	28
Visual South	2,571.3	0.93	16.4%	22	24	20%	21%	25
Visual SE	2,459.8	1.49	19.4%	23	21	30%	28%	15
Visual West	789.1	0.48	27.8%	5	9	7%	15%	13

Table 3. Photo and visual survey strata final dimensions for the 2023 Bluenose-East calving ground survey. Details on the Photo Trials flying at bottom of table are described further on in the report.

Stratum	Stratum Area (km²)	Transect Number	Mean transect length (km)	Length of Stratum (km)	Area Surveyed (km²)	Ground Coverage (%)
Photo	4,343.9	22	49.7	87.4	1,509.8	34.8% at GSD=8
Visual East	1,090.7	12	22.7	81.5	215.3	19.7%
Visual North	1,893.5	29	17.2	66.0	389.0	20.5%
Visual South	2,598.0	25	28.9	71.1	523.0	20.1%
Visual SE	2,462.9	15	41.0	59.7	474.4	19.3%
Visual West	797.2	13	15.9	68.5	162.1	20.3%
Visual Far South	2,484.8	10	31.9	68.7	202.0	8.1%
Photo Trials	1,658.9	15	27.8	59.7	331.5	20.0%

The transect lines planned for the photo and visual survey blocks are shown in Figure 16. The photo block had most (46 of 56 ≈ 82%) of the collared female caribou within the survey blocks, thus was anticipated to have the largest numbers of female caribou. Only during the reconnaissance survey early on June 8 was the Visual Far South stratum flown. The Visual Southeast block boundaries were extended slightly towards Kugluktuk to reflect the large numbers of caribou observed in that area during ferry flights to and from the main survey area. In addition to the 46 collared Bluenose-East females in the photo block, there were ten in the visual blocks (Visual East 2, Visual North 5, Visual South 1, Visual Southeast 1, Visual West 1, Visual Far South 0). As noted earlier, there were two known Bluenose-East collared cows further south in the "trailing edge" with bulls (Figure 16); these were likely non-breeding females. One further known Bluenose-East cow was within areas surveyed on June 4 and associated with very low numbers of caribou; this collared cow was slightly north of the survey blocks on June 8 and 9.

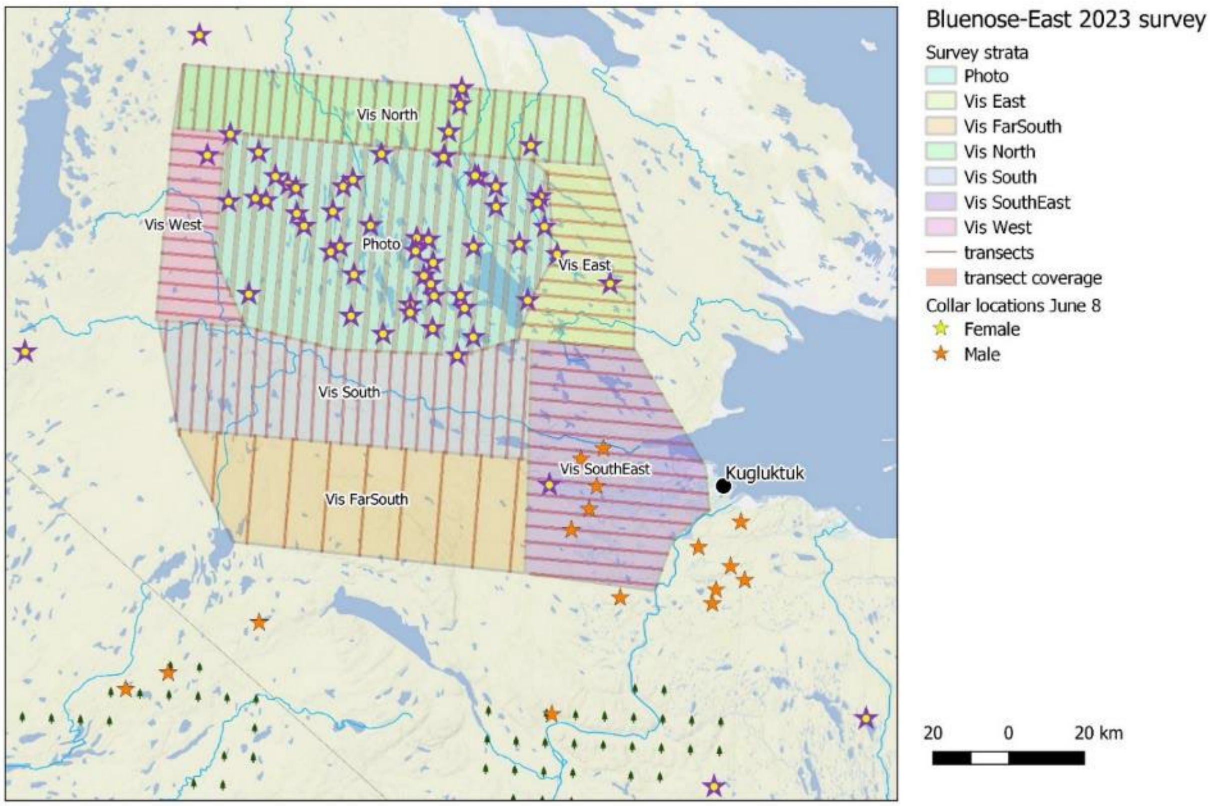


Figure 16. Survey strata and planned survey lines for Bluenose-East June 2023 calving ground photo survey. Collar locations for female and male caribou are from June 8. All strata were flown June 8 and 9.

Visual Survey Block Estimates

Estimates of caribou at least one-year-old from Bluenose-East June 2023 visual surveys are shown in Table 4. The overall estimate of caribou at least one-year-old in the six visual strata was 14,041 (11,912-16,549) with a correction based on double-observer analyses. Appendix 1 has details of the double observer analysis. The Visual South (4,993) and Visual Southeast (SE) (4,390) strata accounted for the largest portions of the total abundance estimates while the Visual East (445) and West (126) strata had relatively few caribou. Double observer estimates (using the MRDS R package) were approximately 4% (528 caribou) higher than estimates from the standard strip transect estimator, which used the counts as recorded. Precision of the double observer estimate was similar but a bit lower than the strip transect estimator (higher CV) despite added complexity of double observer models; this was due to the use of the S2 variance estimator that considers similarity in distributions of caribou on adjacent transects (Fewster 2011). Overall precision of the visual estimates was good with an overall CV of 7.9%.

Table 4. Estimates of caribou at least one-year-old in visual survey strata from double observer and strip transect calculations for the Bluenose-East June 2023 calving ground survey. The number of caribou sighted on transect, estimates of abundance (N), standard error (SE), 95% Confidence Limits Upper and Lower (CIL & CIU) and coefficient of variation (CV) are given for the double observer model (Model 1, Table 3, Appendix 1) and the standard strip transect estimator.

Stratum	# caribou	Double observer estimates (Corrected for sightability)					Strip-transect estimates (Uncorrected for sightability)		
		N	SE	CIL & CIU		CV	N	SE	CV
Visual East	87	445	133.2	218	912	29.9%	441	117.1	26.6%
Visual Far South	158	2,077	400.4	1,271	3,394	19.3%	1,944	373.9	19.2%
Visual North	306	1,512	310.8	980	2,333	20.6%	1,490	262.3	17.6%
Vis South	950	4,993	451.8	4,108	6,069	9.0%	4,719	662.1	14.0%
Visual SE	829	4,390	856.7	2,811	6,856	19.5%	4,304	652.5	15.2%
Visual West	125	623	112.1	408	950	18.0%	615	96.3	15.7%
Total	2,455	14,041	1,107.1	11,912	16,549	7.9%	13,512	1,046.8	7.7%

Check of Visual Survey Lines Compared to Photo Lines

To compare estimates of caribou density from visual flying with those from aerial photos, a portion of the photo block flown on June 8 and 9 was flown again by the Caravans on June 9 (Figure 17); this was termed the Photo Trials stratum. Survey methods with the Caravans remained the same as for reconnaissance and visual flying: 400 feet (120 m) above ground with 400 m strip widths on either side of the plane. An estimate was derived for the Photo Trials strata of 6,647 caribou at least one-year-old (SE=803.8, 95%CIL 5,035 and CIU 8,776, CV=12.1%). Results from this stratum are compared with results from the relevant aerial photo lines.

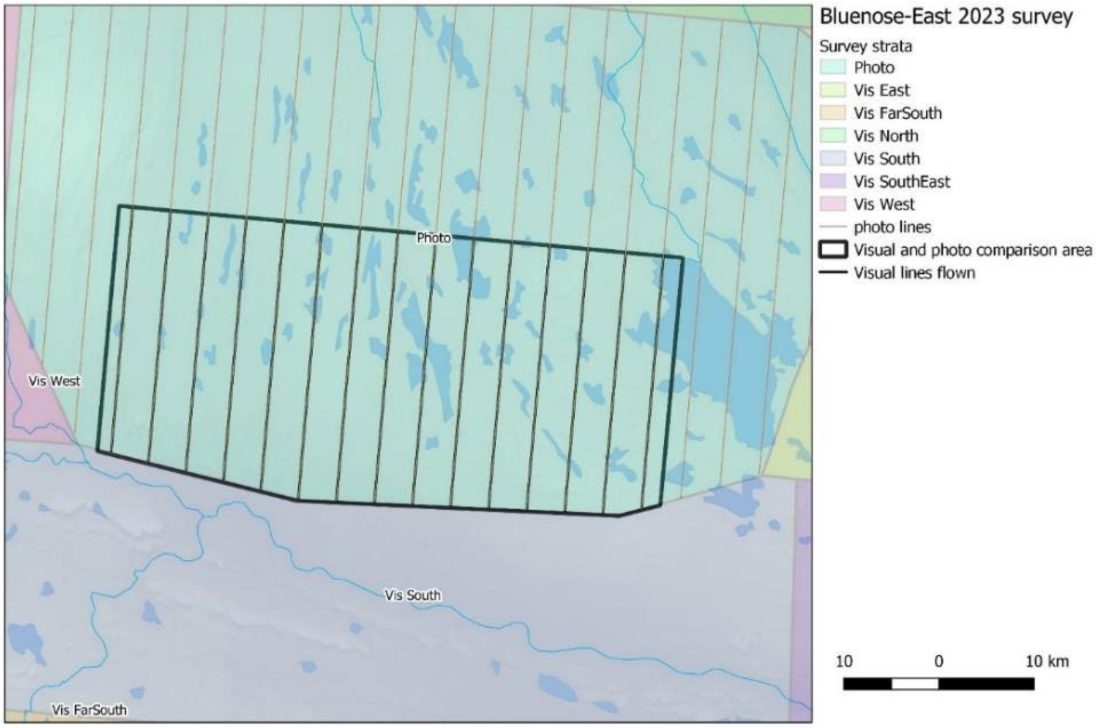


Figure 17. Photo Trials block (black outline) where visual lines were flown directly over photo lines to allow an empirical comparison of methods. Photo lines (the full photo block and entire lines in brown) were flown on June 8 and 9 by the photo plane and the 15 shorter visual lines in the polygon were flown on June 9 by the Caravans.

Aerial Photo Composite and Example Photos

A composite view of the 22 aerial photo transect lines and locations of caribou seen on the Bluenose-East June 2023 survey (Figure 18) shows a wide distribution across the entire block, with caribou most concentrated on lines 12-18.

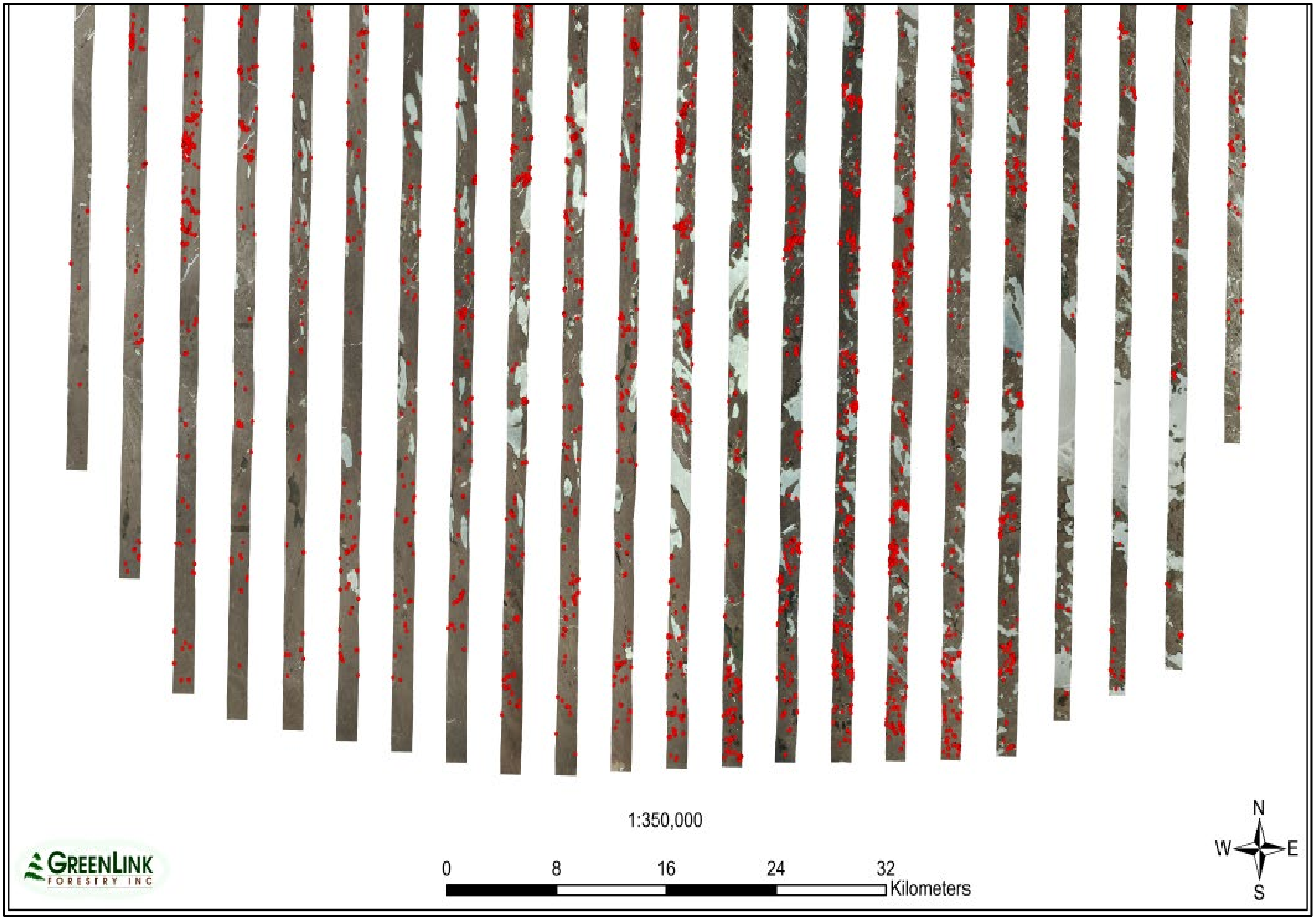


Figure 18. Composite view of 22 aerial photo transect lines from Bluenose-East June 2023 calving ground survey. Line 1 starts at left. Red dots indicate locations of caribou groups. White areas are predominantly frozen lakes and ponds.

Zoomed-in views of two aerial photos clearly show individual caribou (Figure 19 a, b) even though the photos were taken at about 4,300 feet above ground.

Figure 19a. Zoomed-in view of caribou on Bluenose-East calving ground in June 2023 from an aerial photo (example 1).

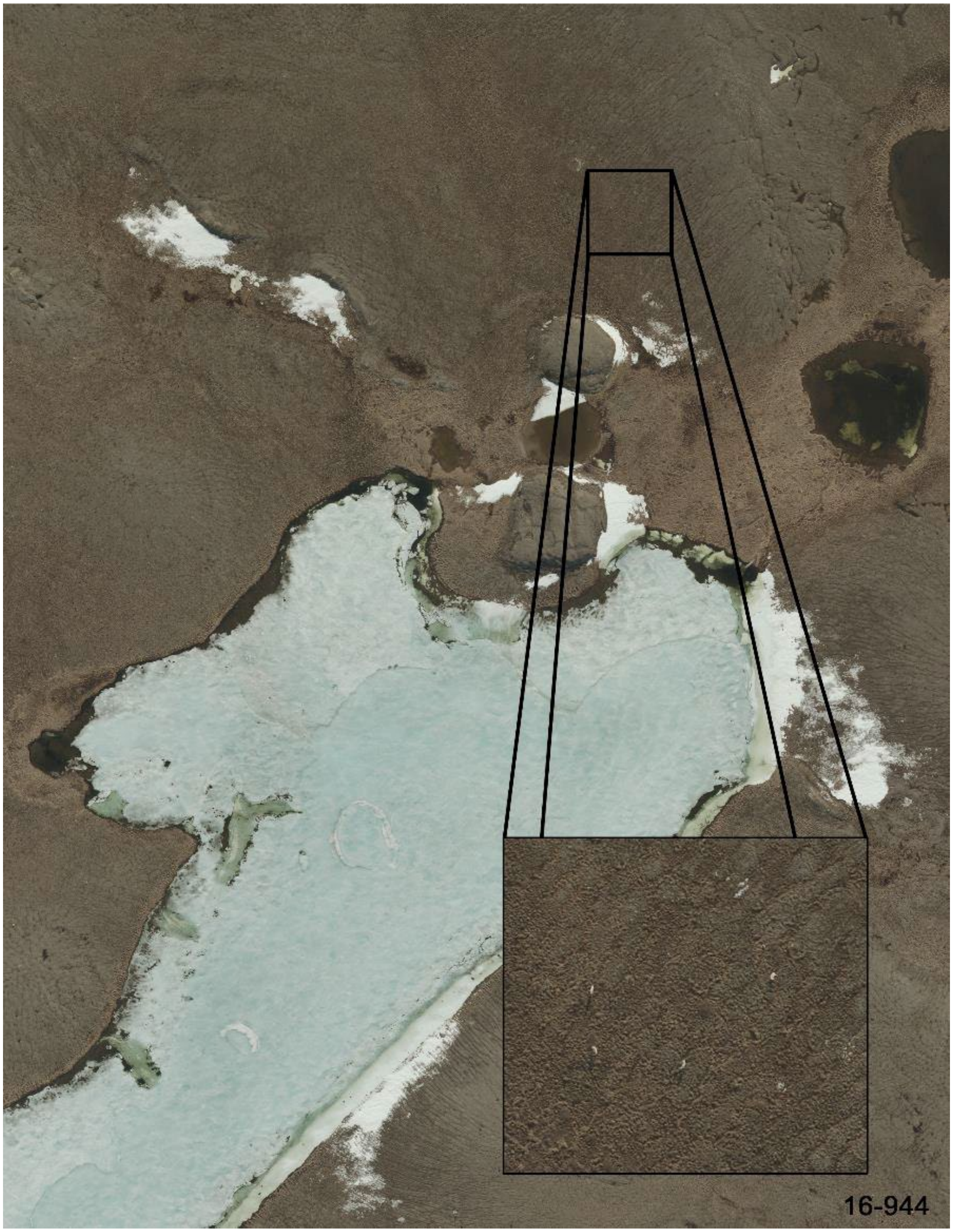


Figure 19b. Zoomed-in view of caribou on Bluenose-East calving ground in June 2023 from an aerial photo (example 2).

Groups of caribou on the Bluenose-East calving ground in June 2023 varied in size. One example (Figure 20a) shows a portion of a photo with a total of 77 caribou in three groups of 6, 29 and 52. A second example (Figure 20b) shows a total of 82 caribou on a portion of a photo, but the distribution is more diffuse and distinct groups are not as readily identified.

These two examples are broadly representative of what was seen on this calving ground in June 2023 and in other years. Most caribou groups seen from the Caravans in June 2023 numbered 30 or fewer.

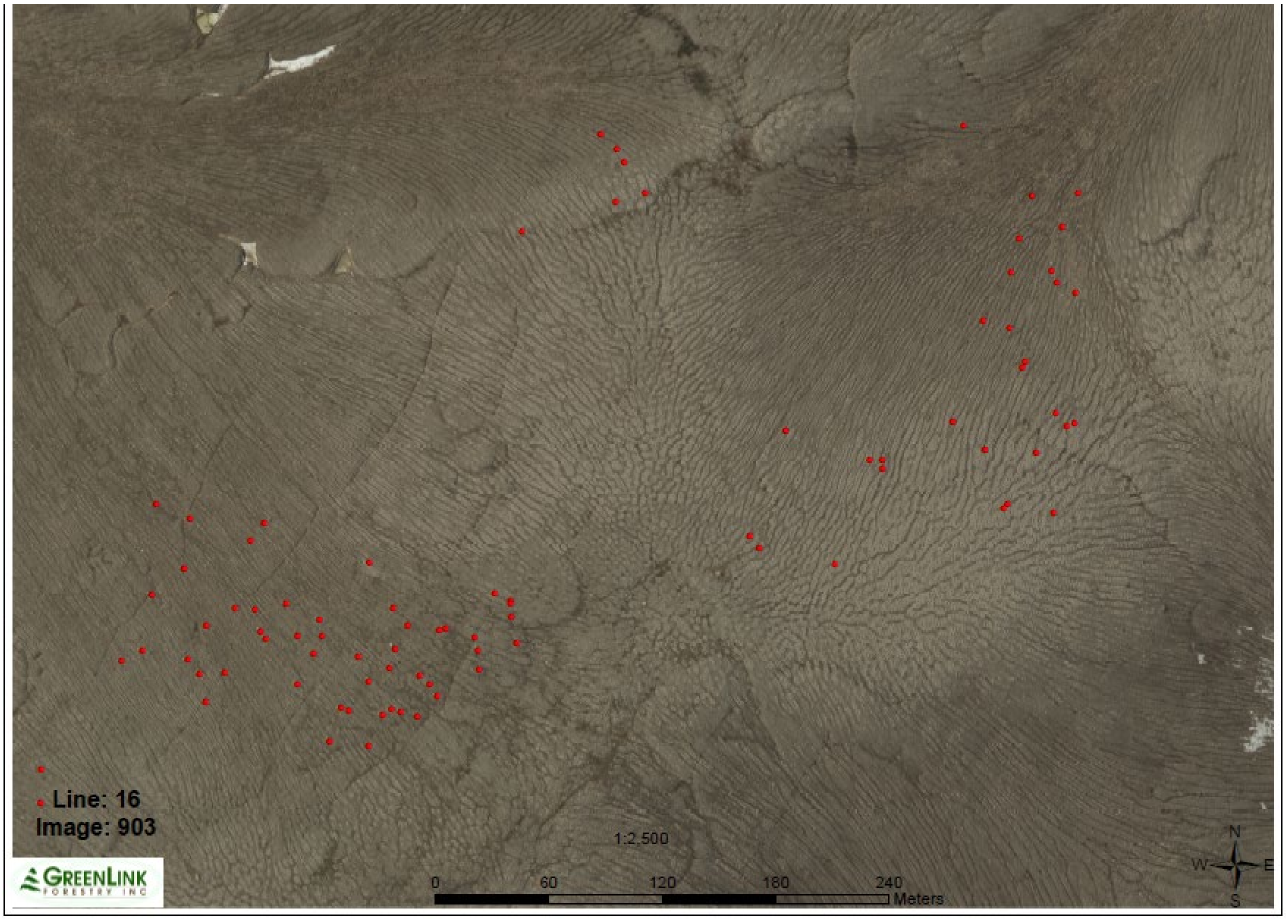


Figure 20a. Distribution of caribou on aerial photos of Bluenose-East calving ground in June 2023 (example 1). Red dots show locations of individual caribou. There are six caribou in a small group near the top, 52 caribou in the group at bottom left, and 29 caribou in the more diffuse group at top right (overall 77 caribou on the photo segment).

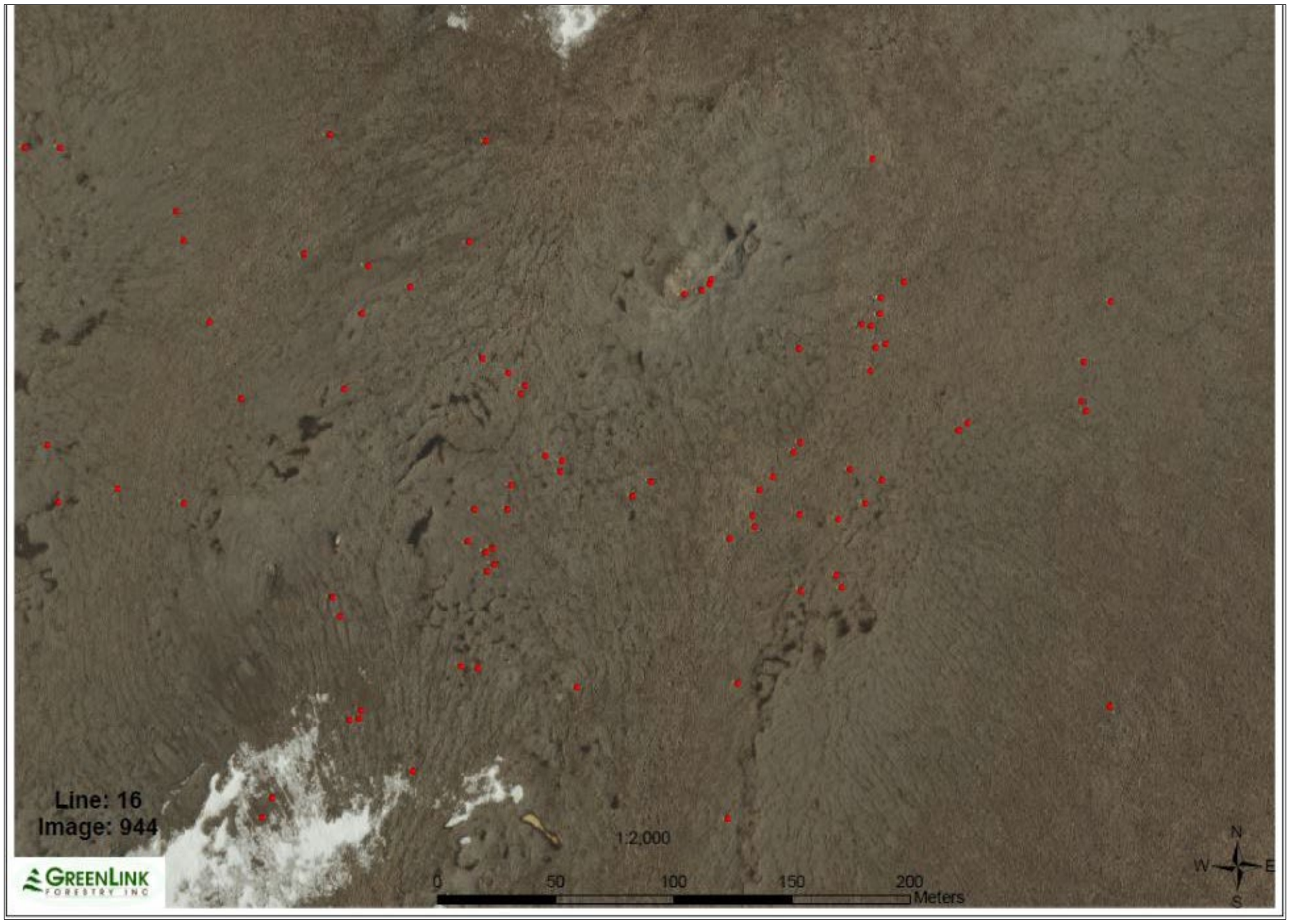


Figure 20b. Distribution of caribou on aerial photos of Bluenose-East calving ground in June 2023 (example 2). There are 82 caribou but the distribution is diffuse and groups are less easy to identify.

Photo and Visual Survey Results

Lines flown on the Bluenose-East June 2023 calving ground survey photo and visual blocks are shown in Figure 21. Caribou were recorded on 3,127 photos taken across the photo block with somewhat higher numbers on lines 12-18 (line 1 is at far left). The Visual West, North, East and Far South blocks all had few caribou. The Visual South block also had few caribou except near the northern border of this block, just south of substantial numbers of caribou at the south end of the photo block. The Visual Southeast block, at the south end, had generally more caribou than the other visual blocks; these were mostly bulls and there was also a mix of yearlings, non-breeding cows and some breeding females. The average densities of caribou on the photo transect lines (n=22) varied from 1-2 caribou/km^2 to a maximum of just under 12 caribou/km^2, with most transect lines having about 5 caribou/km^2 (Figure 22).

In the 2018 and 2021 Bluenose-East calving ground photo surveys, challenging snow conditions made caribou more difficult to see. To check whether caribou might be missed on aerial photo counts, independent second counts of a sub-set of about 200 photos were carried out by the most experienced photo analyst at Greenlink Forestry (see Boulanger et al. 2019, 2022). These resulted in increases on photo counts of about 3% and indicated that a high percentage of the caribou were found despite the snow conditions. In June 2023, the very limited snow cover and excellent sighting conditions suggested that second counts of the aerial photos were not needed. However, Greenlink carried out a second count of 246 photos from the 2023 photo set as part of quality control monitoring. This resulted in an additional 31 caribou found after the initial count total of 3,092 caribou, a difference of 1%. This suggested that the 2023 aerial photo counts were reliable.

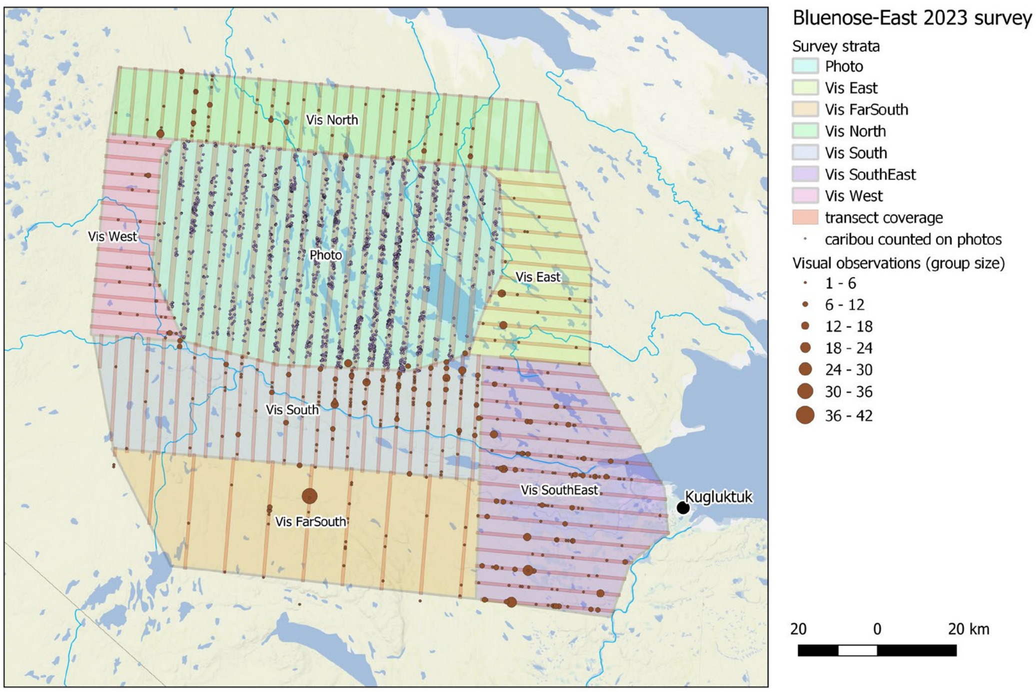


Figure 21. June 2023 Bluenose-East calving ground survey photo and visual survey blocks. In the photo block, dots show the individual caribou observed. In the visual blocks, circles show locations of groups seen and the size of the circle shows the group size. Circles in the photo block are not scaled to size as there were too many.

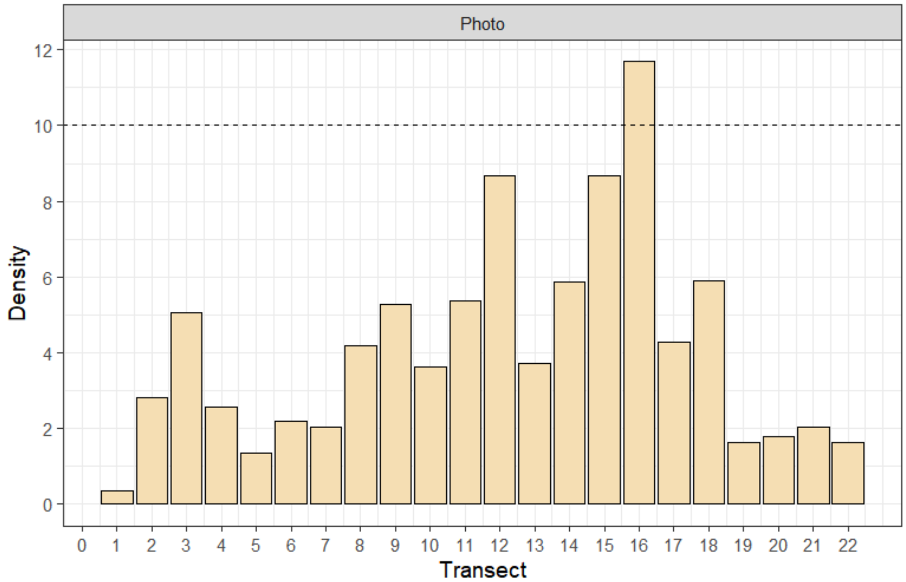


Figure 22. Estimated caribou densities (caribou/km^2) on transect lines for the photo stratum in the Bluenose-East June 2023 calving ground survey. Dotted line shows 10 caribou/km^2.

The overall estimate of caribou at least one-year-old in the photo and visual strata was 33,226, with 19,186 of these (57.7%) in the photo stratum and the rest in the six visual strata (Table 5).

Table 5. Estimates of 1+ year old caribou in photo and visual strata of the 2023 Bluenose-East calving ground survey. N = estimated caribou number; SE = Standard Error; CL and CU = 95% Confidence Interval Lower and Upper; CV = Coefficient of Variation.

Stratum	N	SE	CIL & CIU		CV (%)
Photo	19,186	2,135.2	15,233	24,165	11.1
Visual East	445	133.2	218	912	29.9
Visual Far South	2,077	400.4	1,271	3,394	19.3
Visual North	1,512	310.8	980	2,333	20.6
Visual South	4,993	451.8	4,108	6,069	9.0
Visual SE	4,390	856.7	2,811	6,856	19.5
Visual West	623	112.1	408	950	18.0
Total	33,226	2,405.1	28,577	38,633	7.2

Comparison of Visual and Photo-based Estimates of Caribou Numbers

Comparison of transect-specific densities for photo, visual (strip-transect), and double observer estimate revealed uneven patterns in densities for each transect (Figure 23). These differences could be based on different strip widths of photo and visual counts, different timing of surveys, or difference in the efficiency of each method. Differences between visual and double observer counts were minimal compared to photo and visual methods.

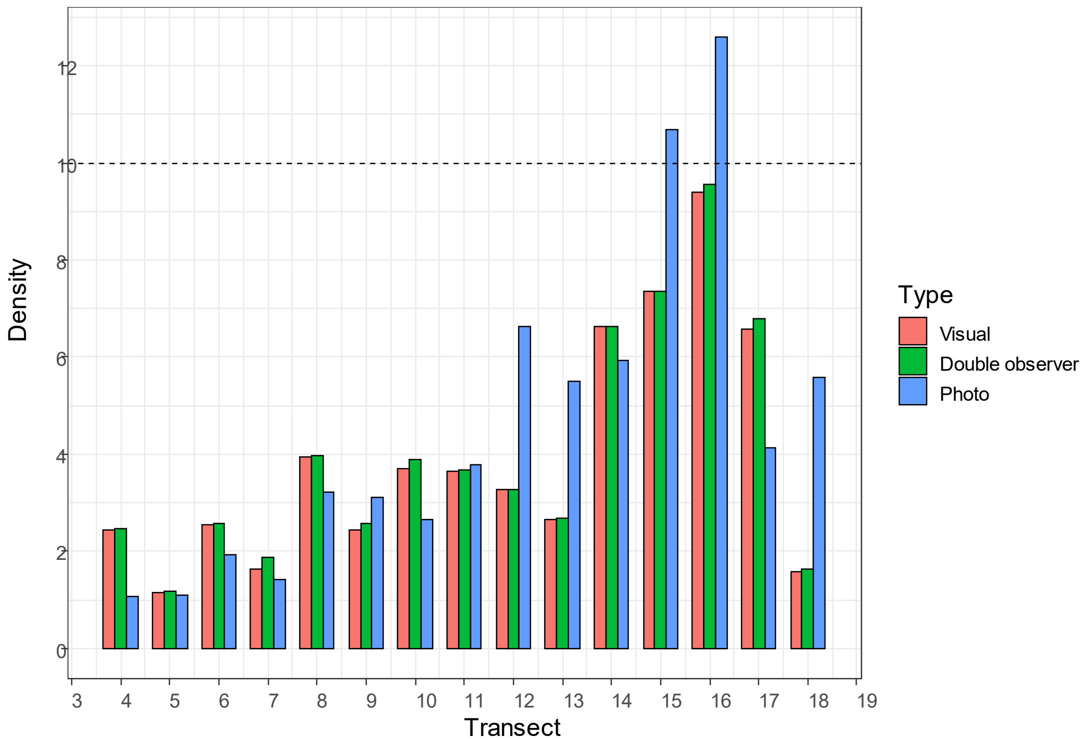


Figure 23. Transect-specific densities (caribou/km²) for the comparison of photo, visual (uncorrected) and double observer (corrected) estimates. Dotted line shows a density of 10 caribou/km², the threshold for high density.

More revealing is a plot of transect densities from photo counts and double observers paired by transect (Figure 24). This suggested minimal differences between photo and visual counts with a slight tendency of visual counts to be higher up to an approximate transect density of 5 caribou/km². Densities of greater than 10 caribou/km² are usually the threshold for use of the photo plane. In that context, there was an approximately even spread of points on either side of the 1:1 line of agreement in Figure 24, suggesting that on average visual surveys/double observer estimates were unbiased compared to photo counts at low-moderate densities (below 5 caribou/km²). At higher densities, the limited data suggested visual counts would be somewhat low. The obvious limitation of this comparison is low sample sizes of points, especially with transect densities from 5 to 10/km².

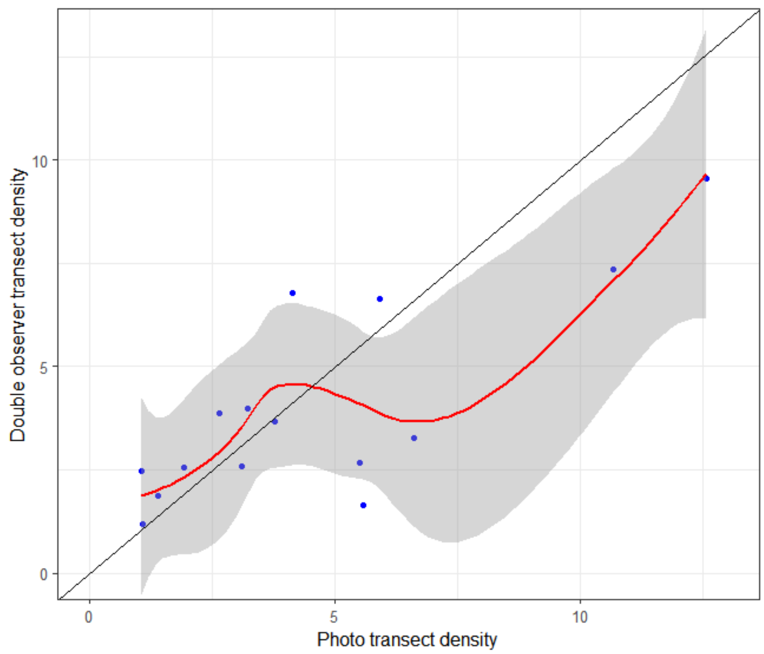


Figure 24. Double observer versus photo transect densities (caribou/km^2) on the 2023 Bluenose-East calving ground survey. A 1:1 line of agreement is shown. A generalized additive model smooth curve is fit through the data to show dominant trends.

Overall, photo estimates for the entire Photo Trials comparison stratum were 14% higher than double observer visual estimates, which was mainly attributed to higher counts from photos on the two high density lines. A similar comparison was done during the 2013 Bluenose-East Survey (Boulanger et al. 2014b) where photo counts were 7% higher than double observer visual counts on a set of transect lines flown by the photo plane as well as by visual methods.

Bluenose-East June Composition Survey

Flight lines for the Bluenose-East composition survey June 11-13 are shown in Figure 25 with collared cow locations. Movements of collared caribou were minimal between June 8-9 when the photo and visual survey flying occurred and the days of the composition survey June 11-13. Flight lines were designed to ensure adequate coverage of each survey block, with more caribou groups classified in the blocks with more caribou. Composition of groups classified is shown in Figure 26 as pie charts where pie sectors indicate percentages of caribou classes recorded. Total numbers of caribou classified in each survey block are listed in Table 6a.

Overall, 6,356 caribou, including calves, were classified in the June survey. Of these, 4,572 (71.9%) were classified in the Photo block, which reflected the high relative abundance of caribou in that block. The fewest caribou were classified in the Visual Far South block, which reflected the scarcity of caribou in that area.

Cows with calves predominated at the northern end of the Bluenose-East distribution, and most of the cows were non-antlered (Figure 26). Towards the southern end of the distribution, yearlings and non-breeding cows occurred more frequently. Bulls were scarce in the northern and central parts of the survey area and were most common in the Visual South and Southeast survey blocks. There were five bull collars in the Visual Southeast block. The Visual Southeast block had the most varied composition with 158 cows (107 non-breeding), 28 calves, 254 bulls, and 168 yearlings.

A more detailed summary of classes of cows identified during the composition survey is given in Table 6b. Of the 2,162 breeding cows classified, 1,627 (75.2%) were non-antlered with a distended udder, while the other 535 cows still had hard antlers and a distended udder. A high percentage of non-antlered cows with newborn calves June 11-13 is consistent with an approximate peak of calving June 4-6, as estimated earlier based on collared cow movement rates and observations of cows with calves from June 4-13. Pregnant cows with hard antlers would be expected to shed those antlers soon after giving birth (Bergerud 1976), thus most pregnant cows that gave birth June 4-6 would have had about a week to shed their antlers by June 11-13.

Among the key results from the composition survey is the proportion of breeding females (as a percentage of all adult females) and this was estimated at 80.9% (78.2, 83.3; Table 7). This is an index of pregnancy rate in adult females in the herd. A second key result is the calf: cow ratio in breeding females, which can provide an index of early calf mortality; this was estimated at 86.3 calves: 100 breeding females (84.5, 88.0).

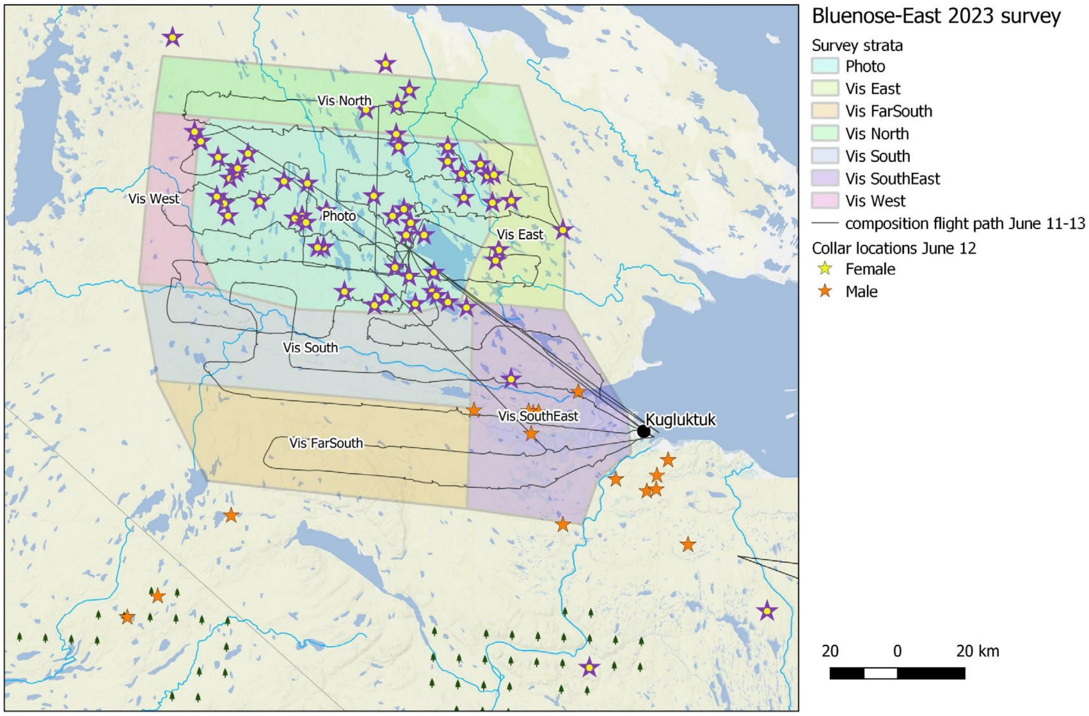


Figure 25. Helicopter-based flight lines and collar locations for Bluenose-East composition survey June 11-13, 2023. Collar locations are from June 12.

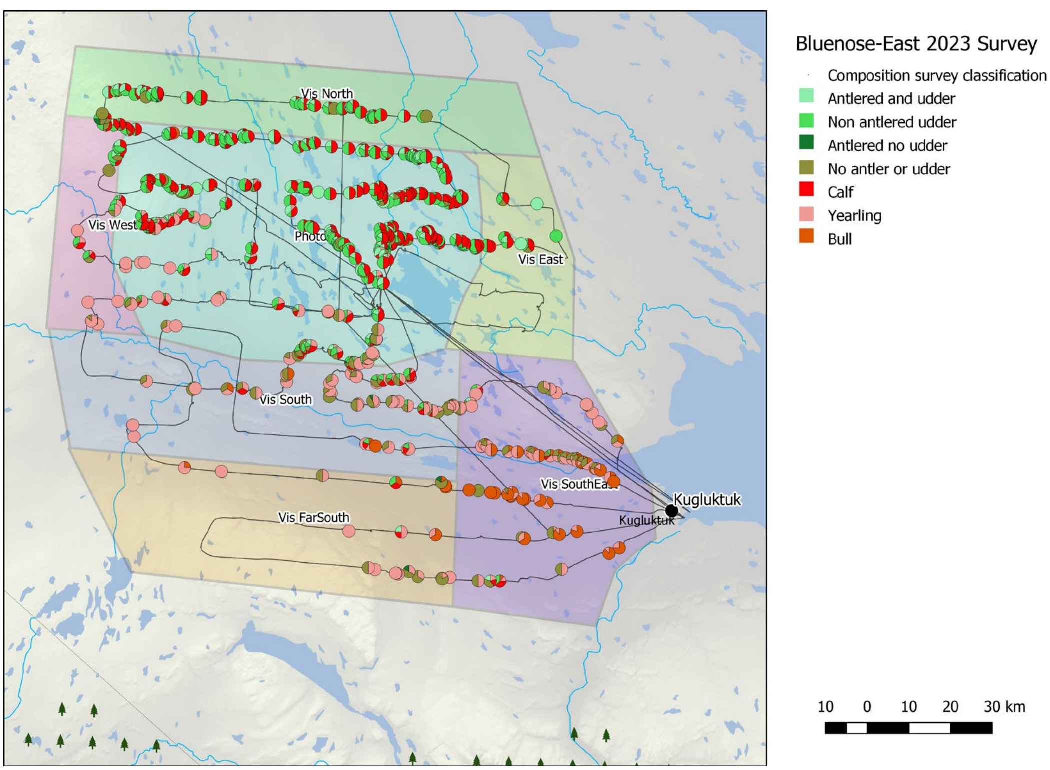


Figure 26. Flight lines and locations of groups classified for Bluenose-East June 2023 composition survey. Composition is shown as pie charts, where pie sectors indicate percentages of each class.

Table 6a. Summary of numbers of caribou in each class identified during classification survey of the Bluenose-East herd in June 2023. Total caribou includes calves.

Stratum	# Groups	Breeding Cows	Non-Breeding Cows	Cows Total	Calves	Bulls	Yearlings	Total Caribou
Photo	376	2,169	306	2,475	1,878	4	215	4,572
Visual East	27	138	15	153	123	0	0	276
Visual Far South	20	4	19	23	2	10	31	66
Visual North	42	171	25	196	146	0	1	343
Visual South	67	39	107	146	33	14	138	331
Visual SE	102	35	123	158	28	254	168	608
Visual West	24	65	23	88	51	0	21	160
Totals	658	2,621	618	3,239	2,261	282	574	6,356

Table 6b. Detailed summary of classes of cows and bulls classified during Bluenose-East June 2023 composition survey.

Stratum	Cows				Calves	Bulls		Yearlings
	Antler Udder	Antler No Udder	No Antler Udder	No Antler No Udder		Young	Prime	
Photo	535	7	1,627	306	1,878	4	0	215
Visual East	21	0	117	15	123	0	0	0
Vis Far South	1	2	1	19	2	8	2	31
Visual North	41	2	128	25	146	0	0	1
Visual South	2	1	36	107	33	8	6	138
Visual SE	4	1	30	123	28	113	141	168
Visual West	15	0	50	23	51	0	0	21
Totals	619	13	1,989	618	2,261	133	149	574

Table 7. Ratios expressed as percentages from Bluenose-East June 2023 composition survey. The estimates are pooled across all survey strata. SE = standard error; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation.

Percentage/Ratio	Estimate	SE	CIL	CIU	CV
Breeding Cows (breeding cows/1 year-old caribou)	64.0	2.1	59.6	68.0	3.3%
Cows (cows/1 year-old caribou)	79.1	1.6	75.5	82.2	2.1%
Cows Breeding (breeding cows/cows)	80.9	1.3	78.2	83.3	1.6%
Calves/Cows (all cows)	69.8	1.5	66.8	72.7	2.1%
Calves/Breeding Cows	86.3	0.9	84.5	88.0	1.0%
Yearlings (yearlings/1-year-old caribou)	14.0	1.1	11.9	16.3	8.1%
Bulls (bulls/1-year-old caribou)	6.9	1.0	5.0	9.1	14.7%

Bluenose-East Fall Composition Surveys

A fall composition survey of the Bluenose-East and Bathurst herd was conducted from October 20 to 26, 2023 (Adamczewski et al. 2024d). Table 8 summarizes the results of this survey.

Table 8. Summary of 2023 fall composition survey of the Bluenose-East herd. Total number of caribou classified includes calves.

Summary Numbers			Counts of Groups Classified				
# Groups Classified	# Caribou Classified	Mean Group Size	Cows	Bulls Young	Bulls Prime	Bulls Total	Calves
102	2,144	15.9	1,023	260	335	595	526

Estimates of bull-cow ratios and the proportion of cows among adults from fall surveys 2020-2023 are shown in Table 9. Estimates of bull-cow ratio and proportion of cows among adults suggest relatively stable values with bull-cow ratios varying from 58.2 to 68.7 bulls: 100 cows and the proportion of cows varying from 0.59 to 0.632 (Table 9). The mean of the 2022 and 2023 estimates for proportion of cows (0.619) was used for the 2023 Bluenose-East extrapolated herd estimate.

Table 9. Fall composition ratios for the Bluenose-East herd from 2020-2023. Also listed are the means of the 2022 and 2023 values which were used for extrapolated herd estimates. SE = standard error; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation.

Year	Estimate	SE	CIL & CIU		CV (%)
Bull-Cow Ratio					
2020	63.3	7.3	51.3	78.4	11.6
2021	68.7	4.0	61.3	77.4	5.9
2022	64.8	3.9	57.3	72.7	6.0
2023	58.2	3.0	52.8	64.6	5.1
Mean 2022-2023	61.5	3.4	55.0	68.7	5.6
Proportion of Cows					
2020	0.612	0.027	0.560	0.661	4.5
2021	0.593	0.014	0.564	0.620	2.4
2022	0.607	0.014	0.579	0.636	2.4
2023	0.632	0.012	0.607	0.654	1.9
Mean 2022-2023	0.619	0.013	0.593	0.645	2.1

Estimates of Adult Females and Breeding Females for Bluenose-East Herd

Estimates of total caribou at least one-year-old in survey strata and composition survey results were combined to estimate adult female (Table 10) and breeding female (Table 11) numbers. Estimates were precise with CV's of less than 10% for both adult females and breeding females.

Table 10. Adult Bluenose-East female estimates for 2023 based on total numbers of caribou on the calving ground and proportions of adult females from composition surveys. Vis = Visual; SE = standard error; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation.

Stratum	**Adult caribou (at least one-year-old)**		**Proportion of adult females**		**Adult female number**				
	N	CV	Value	CV	N	SE	CIL	CIU	CV
Photo	19,186	11.1	0.919	1.1	17,626	1,971.6	13,978	22,226	11.2
Vis East	445	29.9	1.000	0	445	133.2	217	911	29.9
Visual Far South	2,077	19.3	0.359	24.9	746	235.3	338	1,646	31.5
Vis North	1,512	20.6	0.995	0.4	1,504	309.3	975	2,321	20.6
Vis South	4,993	9.0	0.490	7.6	2,446	288.5	1,897	3,153	11.8
Vis SE	4,390	19.5	0.272	12.1	1,196	274.4	709	2,016	22.9
Vis West	623	18.0	0.807	10.9	503	105.9	307	823	21.0
Total	33,226	7.2			24,466	2,055.6	20,550	29,129	8.4

The overall estimates of adult females and breeding females were 24,466 and 18,580 respectively. The photo block accounted for 72.0% of the adult females and 83.1% of the breeding females. The Visual North and South blocks had the highest numbers of adult females among the visual blocks. Only the Visual North block had a substantial number of breeding females; the Visual South block had mostly non-breeding females.

Table 11. Bluenose-East breeding female estimates for 2023 based on total numbers of caribou on the calving ground and proportions of breeding females from composition surveys. Vis = Visual; SE = standard error; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation.

Stratum	Adult caribou (at least one-year-old)		Proportion of breeding females		Breeding female number				
	N	CV	Value	CV	N	SE	CIL	CIU	CV
Photo	19,186	11.1	0.805	2.0	15,447	1,745.8	12,221	19,525	11.3
Vis East	445	29.9	0.902	3.5	401	121.0	195	826	30.2
Vis Far South	2,077	19.3	0.063	41.7	130	59.7	42	400	45.9
Vis North	1,512	20.6	0.868	4.2	1,312	275.3	843	2,042	21.0
Vis South	4,993	9.0	0.131	20.0	653	143.4	409	1,044	22.0
Vis SE	4,390	19.5	0.060	30.7	265	96.3	118	597	36.3
Vis West	623	18.0	0.596	15.2	372	87.6	215	644	23.5
Total	33,226	7.2			18,580	1,783.1	15,225	22,674	9.6

Extrapolated Herd Estimate for Bluenose-East Herd

Bluenose-East herd size was estimated using the mean 2022-2023 bull cow ratio (61.5 bulls: 100 cows) and related mean proportion of cows (0.619) among adults, as listed in Table 9. The herd estimate of 39,525 was relatively precise, with a CV of 8.7% (Table 12).

Table 12. Estimated herd size using the mean of fall 2022 and 2023 composition estimates of proportion of adult females (0.619). SE = standard error; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation.

Estimate	SE	CIL and CIU		CV (%)
39,525	3423.1	33,021	47,310	8.7

Trends in Bluenose-East Breeding Females, Adult Females and Herd Size

Estimates of adult females and herd size increased by about 75% between 2021 and 2023 (Gross Change or GC, the simple ratio of the 2023 estimate to the 2021 estimate), which constitutes a 31-32% annual increase or an annual population growth rate (λ) of 1.31-1.32. This increase was statistically significant as indicated by confident limits on λ that did not overlap 1 (Table 13). Changes between the 2018 and 2023 estimates of adult females and herd size (Table 14) indicated a more modest annual increase of 12-15%. These changes were also statistically significant with confidence limits on λ that did not overlap 1.

Table 13. Estimates of overall and annual change in adult females, breeding females and herd size from 2021-2023 in the Bluenose-East herd. N = Estimate; SE = standard error; GC = Gross Change; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation; λ = Lambda.

Group	N_{2021}		N_{2023}		N_{2023}/N_{2021}				Annual change (λ)			
	N	SE	N	SE	GC	SE	CIL & CIU		λ	SE	CIL and CIU	
Adult females	13,991	1,112.0	24,466	2,055.6	1.75	0.20	1.39	2.19	1.32	0.08	1.18	1.48
Breeding females	12,863	1,042.6	18,580	1,783.1	1.44	0.18	1.13	1.85	1.20	0.08	1.06	1.36
Herd size	23,202	2,029.2	39,525	3,423.1	1.70	0.21	1.34	2.17	1.31	0.08	1.16	1.47

Table 14. Estimates of overall and annual change in adult females, breeding females and herd size from 2018-2023 in the Bluenose-East herd. N = Estimate; SE = standard error; GC = Gross Change; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation; λ = Lambda.

Group	N_{2018}		N_{2023}		N_{2023}/N_{2018}				Annual change (λ)			
	N	SE	N	SE	GC	SE	CIL & CIU		λ	SE	CIL and CIU	
Adult females	13,988	1,034.6	24,466	2,055.6	1.75	0.20	1.40	2.18	1.12	0.02	1.07	1.17
Breeding females	11,675	904.4	18,580	1,783.1	1.59	0.20	1.25	2.02	1.10	0.03	1.05	1.15
Herd size	19,294	1,474.7	39,525	3,423.1	2.05	0.24	1.63	2.57	1.15	0.03	1.10	1.21

A plot of adult female estimates from 2010-2023 shows that the estimate from 2023 (24,466) was close to levels in 2015 (27,246; Figure 27).

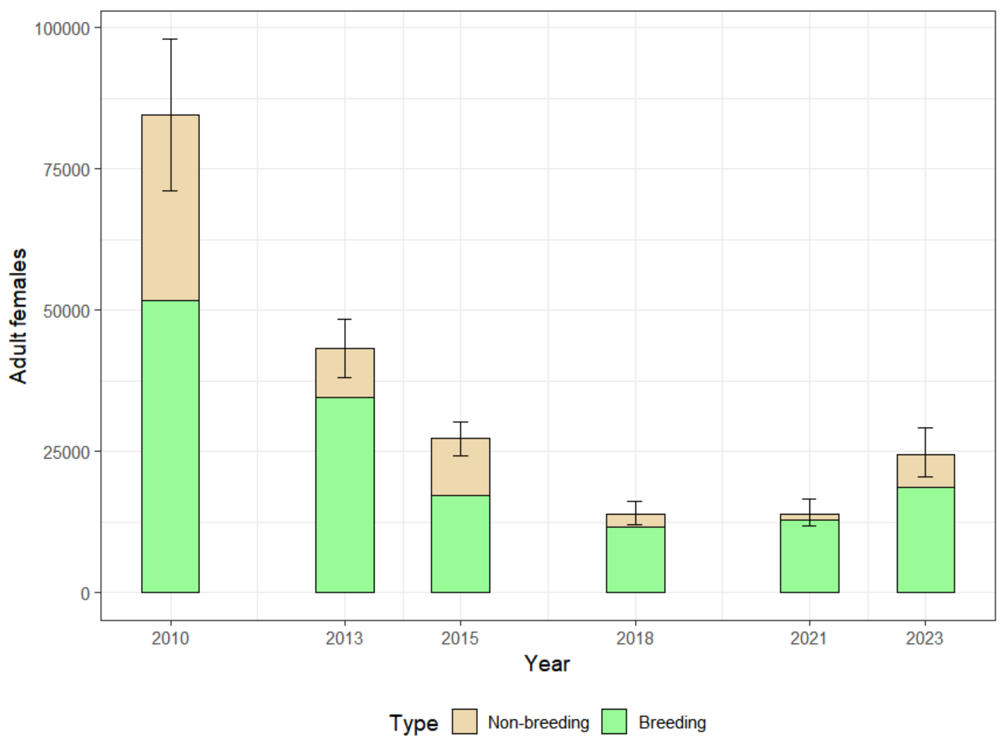


Figure 27. Bluenose-East adult female estimates from 2010 to 2023. Sub-bars delineate the proportion of adult females that were breeding (green) and non-breeding (brown).

A plot of herd size estimates from 2010 to 2023 (Figure 28) mirrors the adult female trend with overall herd size for 2023 (40,306) being similar to levels in 2015 (38,592). The relative proportion of bulls in the herd has increased since 2018 as indicated by the difference in bull-cow ratios in 2018 (38.0), 2022 (64.8) and 2023 (58.0).

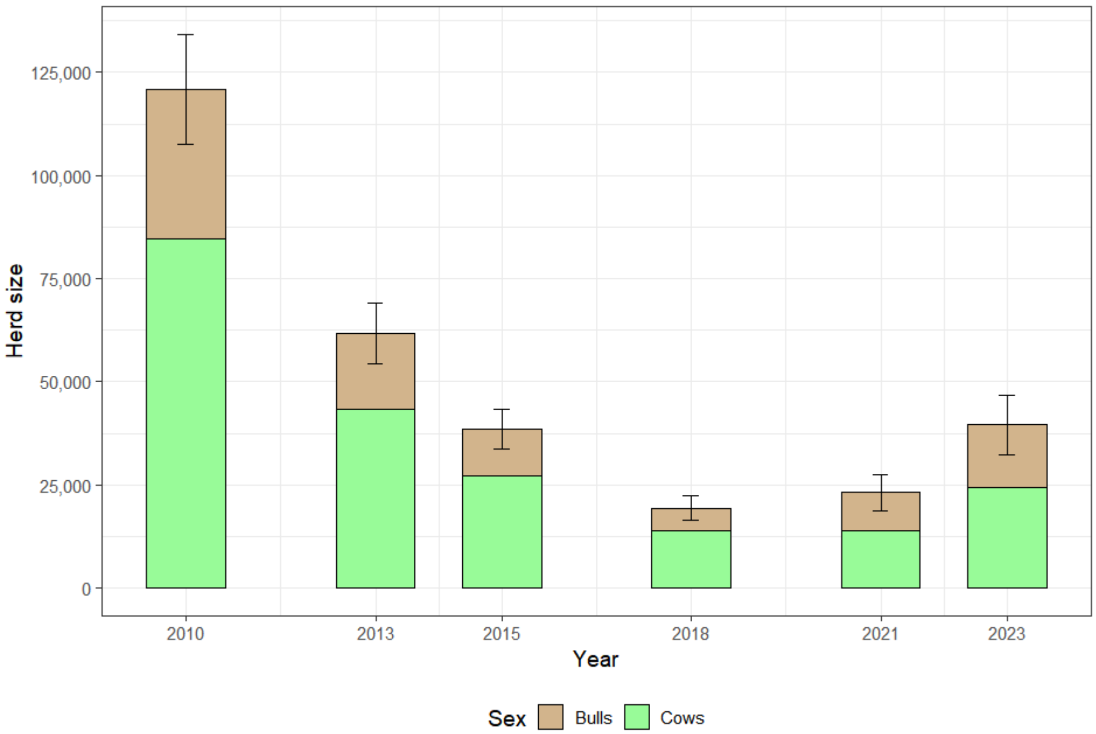


Figure 28. Bluenose-East herd estimates from 2010 to 2023. Sub-bars delineate proportion of females (green) and males (brown).

Demographic Indicators for the Bluenose-East Herd

In this section, field-based demographic indicators for the Bluenose-East herd have been updated to include results from 2022 to 2023, including collar-based cow survival, the proportion of breeding females on the calving grounds, calf: cow and bull: cow ratios recorded in the fall, and calf: cow ratios in late winter. These indicators are included to provide a comprehensive picture of the herd's status in 2023. This section is followed by a summary of updated demographic modeling of the herd.

To assess collar-based cow survival, the monthly status of Bluenose-East cows was summarized with tallies of live cows and mortalities for each month. Using these tallies, survival rate was estimated using the Kaplan-Meir estimator (Figure 29). Collar numbers increased in 2016 to more than 20 for most years, with previous estimates based on lower numbers of collars, reducing the precision of estimates. In general, given overlapping confidence intervals and large variance around annual estimates, trends are best assessed by averaging over a period of two to three years. The year for these estimates begins at calving in June and ends at the end of the following May, thus year 2022 is from June 2022 to May 2023.

Collar-based cow survival in the Bluenose-East herd was estimated at 83% (68-92%) in 2020, 85% (73-92) in 2021, and 81% (70-89) in 2022, and has averaged about 83% from

2018 to 2022. These cow survival rates are associated with a stable population trend in migratory caribou herds (Crête et al. 1996, Boulanger et al. 2011); higher survival estimates (at least 90%) would be expected in increasing herds (ibid.).

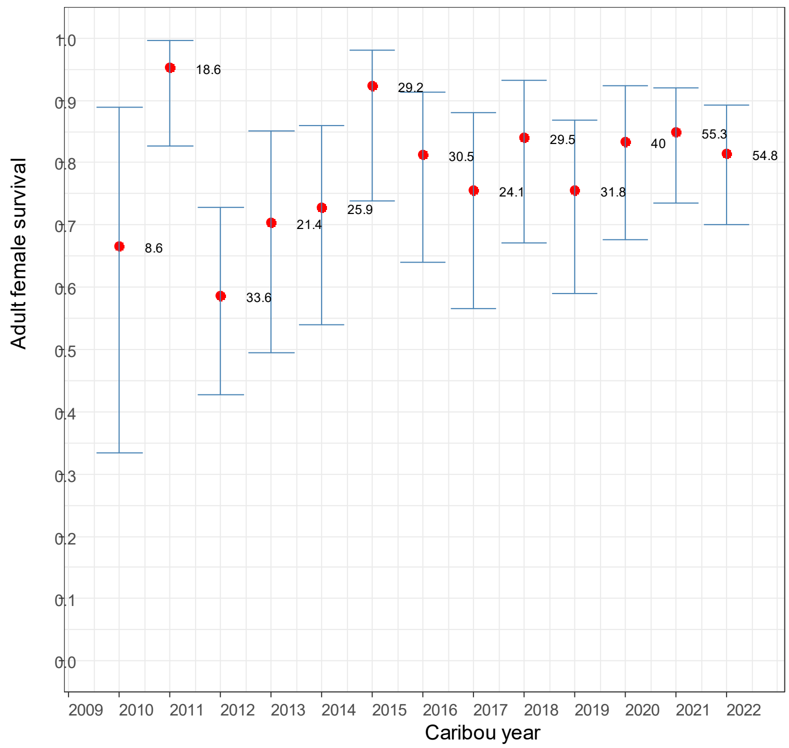


Figure 29. Annual collar-based cow survival estimates for the Bluenose-East herd from 2010 to 2022. Red dots are the annual estimates, with 95% confidence intervals as blue bars. Numbers beside the red dots show the average number of collared females available for the estimate. The year begins in June at calving and ends the following May; e.g. the year 2022 extends from June 2022 to May 2023.

Collar-based cow survival was also assessed separately for the calving/summer/fall period (June-October) and the winter/spring migration period (November-May). Results suggest a trend toward higher values in the summer, which is offset by a trend toward lower survival rates in the winter (Figure 30).

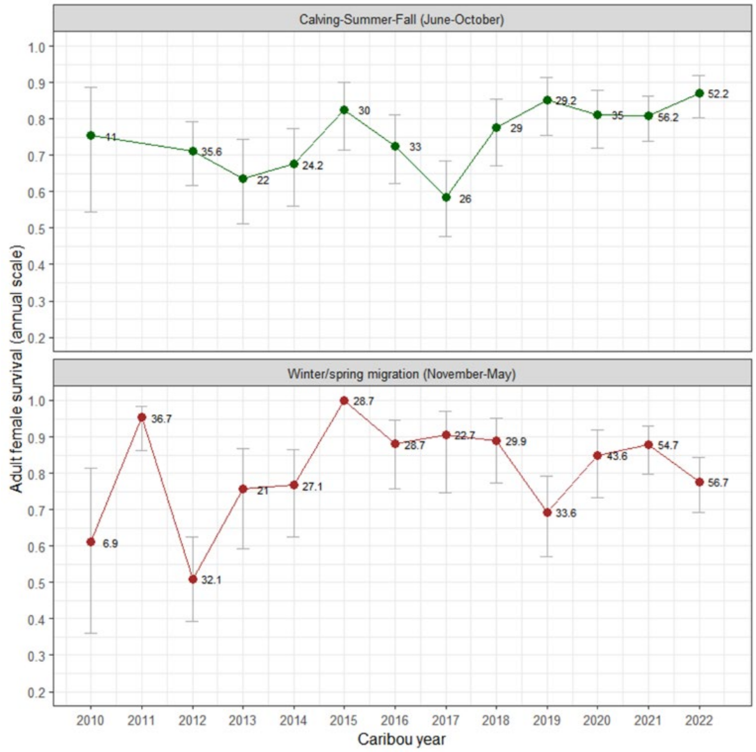


Figure 30. Collar-based cow survival estimates for the Bluenose-East herd from 1996 to 2022 for June-October (top) and November-May (bottom). Red or green dots are the estimates, with 95% confidence intervals as blue bars. Numbers beside the red dots show the average number of collared females available for the estimate. Survival rate estimates are expressed on an annual scale to facilitate comparison.

Composition surveys carried out in June on the calving grounds result in an estimate of the proportion of breeding females among all adult females. Results from June 2023 for the Bluenose-East herd are shown along with results from previous June surveys for this herd since 2010 (Figure 32). The proportion of breeding females in the herd in the last four surveys was 87.5% in 2019, 91.9% in 2021, 86.2% in 2022, and 80.9% in 2023, which suggests consistently high pregnancy rates over this period. In years of calving ground photo surveys (all years except 2019 and 2022), the composition surveys have been stratified based on survey blocks during calving photo surveys. Observations in 2019 and 2022 were pooled as there were no survey blocks and these were stand-alone composition surveys. A comparison of pooled and stratified estimates has shown that there is little difference. All values in Figure 31 are based on pooled estimates.

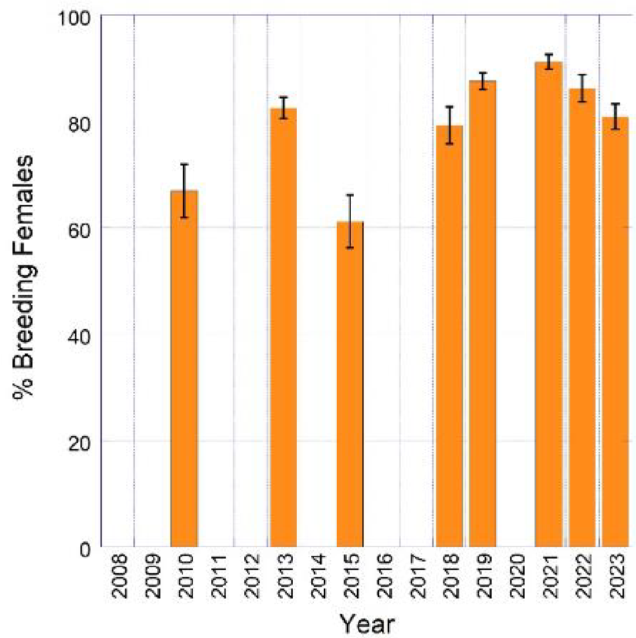


Figure 31. Estimated proportion of breeding females in the Bluenose-East herd during June calving ground surveys from 2010 to 2023. Surveys in 2019 and 2022 were stand-alone composition surveys while surveys in other years were part of calving ground photo surveys. To ensure comparability of numbers, all values shown are pooled.

Composition surveys have also been carried out for this herd in late October during the breeding season. At this time, all sex and age classes of caribou are mixed and rutting groups of hundreds or thousands may form. These surveys result in estimates of the sex ratio (bulls: 100 cows) and a calf: cow ratio that is an index of calf survival through the first four and a half months, although the calf: cow ratio is also affected by the pregnancy rate the previous winter and initial calf productivity in June.

Fall surveys of the Bluenose-East herd in October 2020, 2021, 2022 and 2023 have resulted in estimates of 51.7, 49.6, 52.3, and 51.4 calves: 100 cows, respectively, and these four values have been the highest recorded between 2009 and 2023 (Figure 32). These represent very healthy fall calf ratios consistent with strong demographic indicators in the herd since 2018-2019.

These fall surveys have resulted in bull: cow ratios in October 2020, 2021, 2022 and 2023 of 63.3, 68.7, 64.8 and 58.2 bulls: 100 cows, respectively, and these four values are the highest recorded in the herd since 2009 (Figure 33). The average bull: cow ratio recorded during six fall composition surveys of increasing caribou herds in the 1980s was 66 bulls: 100 cows (in Gunn et al. 1997, p. 35). Improved bull survival in the Bluenose-East herd is consistent with a stabilizing trend documented in the 2021 calving ground survey for this herd (Boulanger et al. 2022) and healthy demographic indicators 2019-2023.

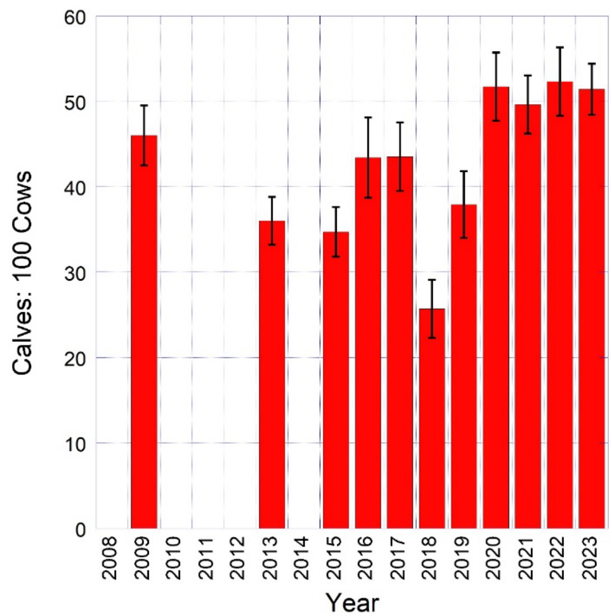


Figure 32. Calf: cow ratios estimated in the Bluenose-East caribou herd in the fall between 2009 and 2023. Surveys were carried out in late October during the breeding season.

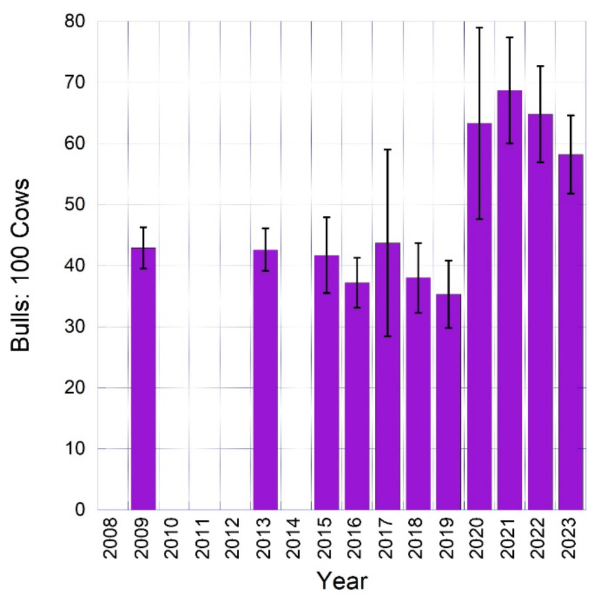


Figure 33. Bull: cow ratios estimated in the Bluenose-East caribou herd in the fall between 2009 and 2023. Surveys were carried out in late October during the breeding season.

A further composition survey has been carried out for the Bluenose-East herd in late winter, usually March. At this time, calves of the previous year are about nine and a half months old and the calf: cow ratio is an index of calf survival over this period. March calf: cow ratios are usually similar to calf: cow ratios the previous October or slightly lower, which suggests that most calf mortality occurs in the summer, and winter survival rates of calves are similar to those of adults. Late-winter calf: cow ratios in the Bluenose-East herd were relatively high

2008-2011 when the herd was still large, then lower 2012-2016 during years of decline, and have shown an improving trend 2016-2022 (Figure 34). Calf: cow ratios in March 2021, 2022 and 2023 were 46.7, 46.9 and 40.9 calves: 100 cows and suggest healthy calf recruitment in the herd over this period, consistent with other strong demographic indicators since 2018-2019. The March 2023 composition surveys of the Bluenose-East, Bathurst and Beverly herds were flown with a particularly high degree of herd mixing, which somewhat reduced confidence in how representative the results were for the Bluenose-East herd (Adamczewski et al. 2024c).

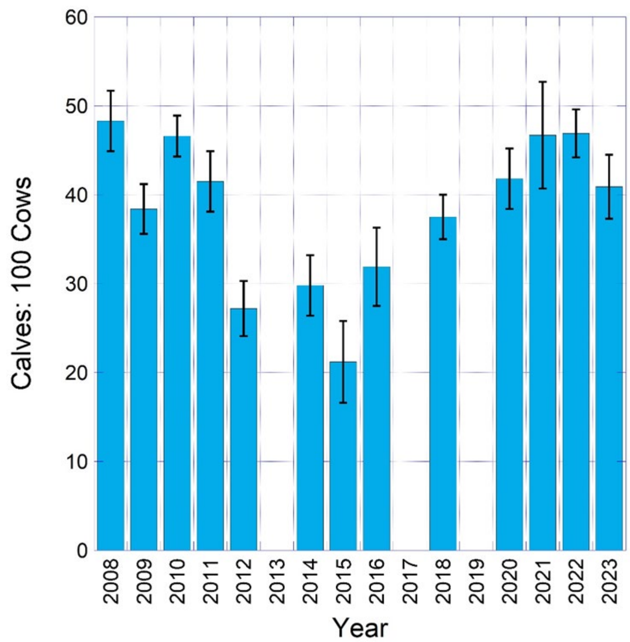


Figure 34. Late-winter calf: cow ratios estimated in the Bluenose-East caribou herd between 2009 and 2023. Surveys were carried out in March.

Integrated Population Modeling of the Bluenose-East Herd

Fit of Base Random Effects IPM Model

The IPM was fitted to the demographic data to assess overall demographic trend in the Bluenose-East herd. Previous calving ground survey reports for this herd (e.g. Boulanger et al. 2019, 2022) have similarly included updated demographic modeling. Data used for the IPM include collar-based survival rates, composition survey data, and calving ground survey estimates, as summarized in previous sections. In general, the random effects model fit the field data reasonably well (Figure 35) as indicated by closeness of IPM estimates to field values and overlap of confidence limits from field estimates and IPM estimates.

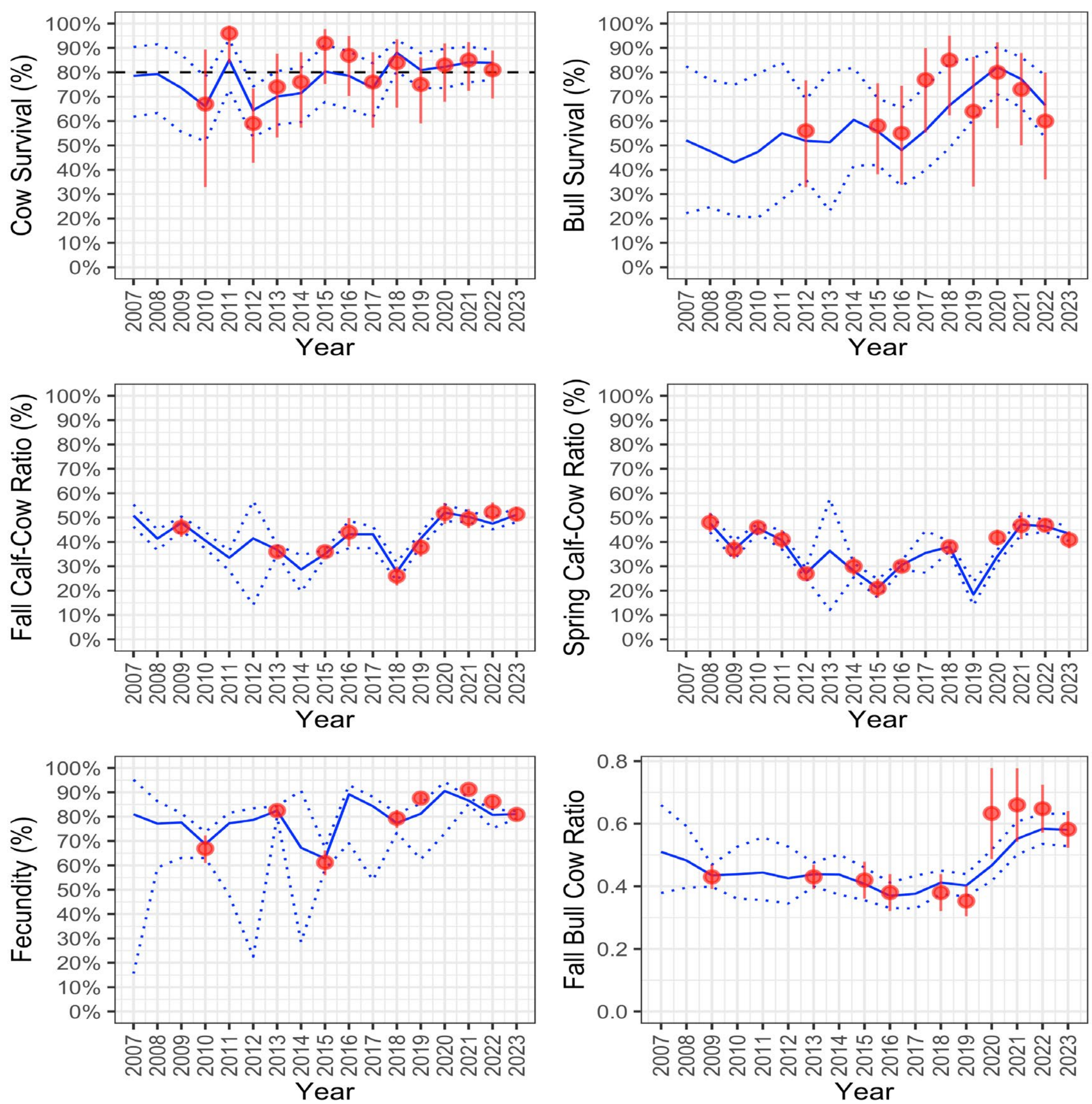


Figure 35. Fit of IPM to composition data and survey data from the Bluenose-East herd 2007-2023. The blue lines are IPM estimates with hashed blue lines as confidence limits. The red dots are field estimates with confidence limits indicated by red lines.

The model was also fitted to the adult female estimates for the Bluenose-East herd 2010-2023 from calving ground surveys (Figure 36). In this case, the model underestimated the 2023 survey estimate. This result suggested that the 2023 population estimates were higher than would be expected based on the other demographic data.

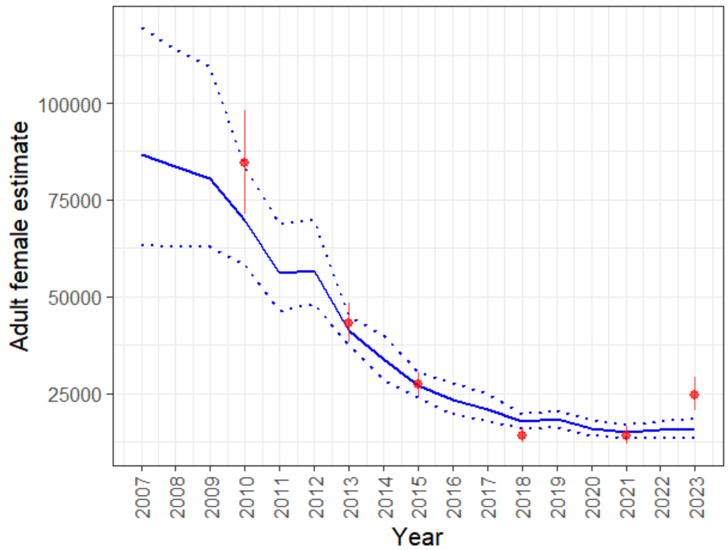


Figure 36. Fit of the IPM (blue line) to estimates of adult females in the Bluenose-East herd 2010-2023 from calving ground photo surveys (red circles).

In the next section we detail potential reasons for the higher 2023 estimates and then use the IPM to further explore scenarios for increase of the Bluenose-East herd.

Analysis of Apparent Increase in Bluenose-East Abundance 2018-2023

Maximum Likely Demographic Increase

One relevant question is what demographic values would create an overall increase if the estimates from 2021 and 2023 are used at face value. The estimate of annual change (λ) between 2021 and 2023 in adult female numbers was 1.32 (CI=1.18-1.48). If the 2021 data point is eliminated, then the estimate of annual change between 2018 and 2023 is a more moderate 1.12 (CI=1.07-1.17). We note there is uncertainty in each of the λ estimates as indicated by confidence limits on each estimate.

A stage-based matrix model, which is the underlying demographic model of the IPM, was run across a range of adult female survival and calf survival values with fecundity held constant at 0.90. The resulting λ values were then estimated as the dominant eigenvalue of the matrix model (Figure 37).

It was not possible to get a λ value of 1.32 under the most optimistic combination of cow and calf survival rates. A λ value of 1.17 (the lower CI limit on 2021-2023 trend) would require a combination of cow survival of 95%, calf survival of ≈70%, and yearlings breeding at 40%. It was marginally possible to get a λ value of 1.12 if adult female survival was high (above 90%) and calf survival was very high (50-60%). The effect of 40% of yearlings breeding only increased the predicted rate of change marginally.

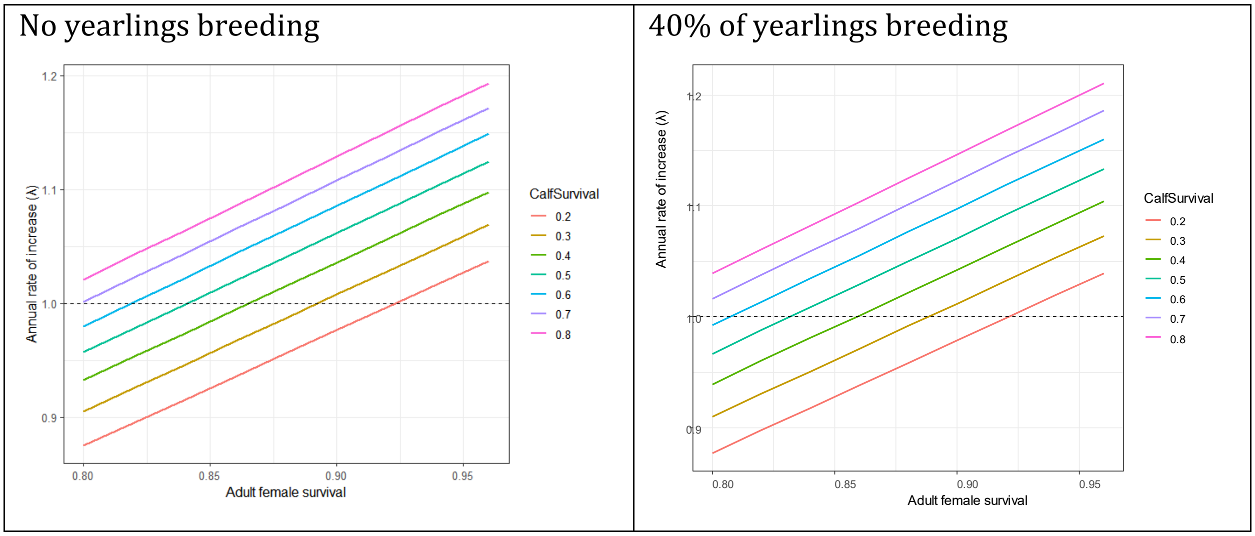


Figure 37. Values of λ in adult females as a function of adult female and calf survival values with a constant fecundity of 0.9. Yearling survival was set equal to adult female survival. A scenario was run that allowed 40% of yearlings to breed (right).

The main outcome of this modeling assessment was that the apparent increase of adult females between 2021 and 2023 (λ of 1.32) was not biologically plausible and did not fit with the demographic indicators observed in the herd. A λ of 1.12 from 2018-2023 was possible but did not fit the data from the field (collar-based survival, calf-cow ratios) well. The lower confidence limit (1.07) of the 2018-2023 adult female trend estimate was more in the range of observed demographic parameters.

Maximum Observed Empirical Increase in Other Caribou Herds

In a review of caribou demography, Bergerud (2000) noted "When caribou are introduced into systems without predators, such as islands, they generally increase at annual rates approaching r_{max} (or λ) of 1.28". Under these conditions, mortality rates of calves and adults would be minimal and productivity would be very high. In the migratory tundra George River herd in Québec/Labrador, Bergerud et al. (2008, p. 3) noted the following survey estimates for the herd over a 30-year period:

1958: 15,000

1973: 105,000

1976: 176,000

1982: 271,000

1984: 472,000

1988: 700,000

Annual estimates of λ over these six estimates are 1958-1973 1.14; 1973-1976 1.19; 1976-1982 1.08; 1982-1984 1.32, 1984-1988 1.10 and 1958-1988 1.13-1.14. Bergerud et al.

(2008) also described the conditions of very limited harvest and very low wolf numbers that existed at the beginning of this 30-year period of sustained growth. Recognizing potential limitations of these surveys over such a huge range in herd sizes, the George River example suggests that a λ of about 1.13 is possible for a migratory tundra caribou herd under near-ideal conditions, similar to the 1.12 estimated for the Bluenose-East herd based on the 2018 and 2023 estimates.

The apparent 75% increase in adult females between 2021 and 2023 was substantially higher than predicted by demographic modeling and did not fit well with observed demographic indicators. Two further questions were whether there was a negative bias in survey results from 2018 and 2021 and whether that bias could have played a role in the apparent increase 2018-2023 and 2021-2023, and whether immigration to the Bluenose-East herd from the larger Beverly herd could have contributed to the apparent increase in the Bluenose-East herd 2021-2023. A summary on these two questions is included here.

Survey Bias in 2018 and 2021

Compared to the 2023 survey, conditions for surveys in 2018 and 2021 were marginal in terms of sightability, with patchy snow cover making caribou difficult to see, particularly small groups or single caribou (Boulanger et al. 2019, 2022). These conditions did not occur in 2023. We considered whether these conditions could have affected survey estimates from 2018 and 2021.

In 2018 and 2021, a large proportion of the calving ground survey area was surveyed using photo-planes on the assumption that the aerial photos could be searched carefully and that a high percentage of the caribou would be found despite the poor snow conditions. In 2018, 2021 and 2023, 93%, 94% and 72% of the adult female estimates respectively came from photo strata. The percentages of cow collars found in the photo blocks can also serve as an index of relative numbers of cow caribou: 28 of 30 collars or 93.3% in 2018, 45/55 or 81.8% in 2021, and 45/55 or 81.8% in 2023. In addition, a sub-set of photos was counted independently in 2018 and 2021 (Boulanger et al. 2019, 2022). These counts indicated that a very high percentage of the caribou on the aerial photos was found in both cases and corrections based on the second counts were about 3% (Boulanger et al. 2019, 2022). While this estimate suggests that sightability was high on photos it still relies on the same assumptions as visual surveys (as discussed in the subsequent paragraphs).

We note that if only the photo estimates are used to estimate change in adult females the resulting yearly estimates of change (λ) are 1.06 and 1.16 for the intervals of 2018-2023 and 2021-2023 respectively, suggesting a large-scale increase occurred between 2018/2021 and 2023 if inference is just based on the photo survey blocks. Therefore, the apparent increase in caribou is likely not an artifact of visual survey bias.

Double observer methods were used on the visual blocks in all three years (2018, 2021 and 2023), and in other previous surveys. The dependent double observer method used in surveys uses the proportion of caribou missed by the primary observer to estimate detection probabilities of single and combined double observers. It assumes that observers have roughly equal sighting probabilities and differences in sighting probabilities can be accounted for using covariates as detailed in Appendix 2. Bias in sighting probabilities and abundance estimates may occur if there is high heterogeneity (unequal sighting probabilities of caribou groups) that is not accounted for by covariates (Laake et al. 2008a, Laake and Collier 2024) especially if some caribou groups have very low sighting probabilities so that they are nearly "invisible" to observers. In this case estimates of sighting probability become positively biased (basically only the easy to observe caribou are observed) leading to negatively biased abundance estimates. In 2021 and partially in 2018 patchwork "salt and pepper" snow conditions combined with cloud cover could have created low and heterogenous sighting probabilities leading to negatively biased double observer visual estimates. We assume that lower sightability due to ground conditions had a lesser influence on photos since photo interpreters could scan photos repeatedly and for longer time periods, increasing overall sighting probabilities on the photos and therefore reducing potential heterogeneity bias.

Of 2018 and 2021, the 2021 survey is most suspect given that no reconnaissance surveys were conducted so that each area was only sampled once, leading to a greater possibility that low sightability affected estimates. In contrast, in 2018 reconnaissance and visual surveys were conducted therefore allowing two samples of visual sampling areas. Also, reconnaissance surveys in 2018 allowed more precise delineation of photo stratum areas whereas blocks in 2021 were based entirely on collared caribou locations.

On balance, it is possible that the numbers of caribou estimated from visual blocks in 2018 and 2021 resulted in under-estimates; this was more likely an issue in 2021 due to the lack of information from a reconnaissance survey and the higher proportion of collared cows that year found in visual blocks. The numbers of caribou estimated from the photo blocks in 2018, 2021 and 2023 were likely accurate and in all three years these photo block estimates accounted for a high percentage of the adult females on the calving ground. The 2023 survey had excellent sighting conditions and two reconnaissance surveys to base survey blocks on, thus this survey had none of the potential issues of the 2018 and 2021 surveys and the estimates should be reliable.

Movement between Herds

Inference from Adult Female Collared Caribou

Under most conditions, emigration from one barren-ground caribou herd to another is thought to occur at relatively low rates based on movements of collared female caribou.

Previous calving ground survey reports (e.g. Boulanger et al. 2019, 2022) have assessed movements of adult female collared cows between the Bluenose-East herd and its neighbouring herds the Bluenose-West and Bathurst herds. Fidelity of female collared cows has been in the range of 97-99%, with an occasional single collared cow moving to a neighbouring herd and an equally low rate of movement (1-3%) in the reverse direction. Other assessments (Davison et al. 2014, Adamczewski et al. 2020) have shown that similarly low rates of switches between neighbouring calving grounds are the normal pattern in NWT barren-ground caribou herds. One-directional movements of Bathurst caribou to the Beverly calving ground have been at unusually high rates (17-27%) in 2018, 2019, 2021 and 2023 (Adamczewski et al. 2023a, this report), and this emigration has been a serious concern for the Bathurst herd given its current size and trend. We assessed the possibility that the apparent increase in the Bluenose-East herd 2021-2023 could have in part resulted from an influx of caribou from another herd.

Records of collared adult cows with June locations in consecutive years from 2016-2023 showed little evidence of directional movement to the Bluenose-East herd (Figure 38). One Bluenose-East cow moved to the Bathurst calving ground in 2019 and a second Bluenose-East female moved to the Bathurst calving ground in 2023, and there were no Bathurst or Beverly cows that moved to the Bluenose-East calving ground over this period. Over the same period, one Bluenose-East collar calved on the Bluenose-West calving ground and there were no other switchers between these two calving grounds over this period (Figure 38). One collared cow monitored by the GN was captured west of Garry Lakes in NU in April 2023 and was found on the Bluenose-East calving ground in June 2023. These isolated movements are within the low rate of movements (1-3%) between neighbouring herds described earlier.

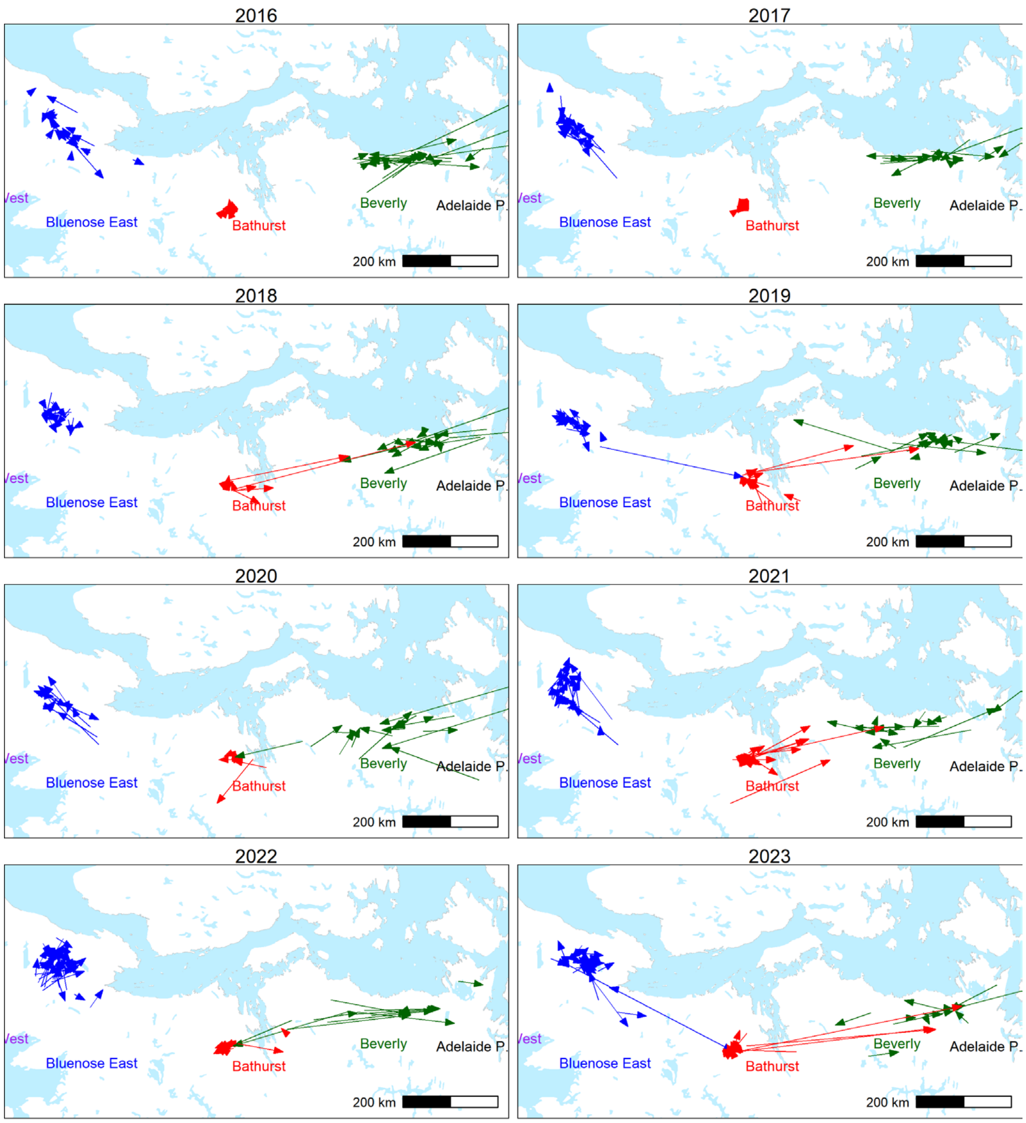


Figure 38. Mean locations of collared females at current year (arrow-head) compared to previous year (arrow tail) for females collared in successive years, from the Bathurst, Bluenose-East and Beverly herds from 2016-2023. Arrows are coloured based on previous year calving ground/herd designation.

Inference from Winter Overlap and Migration Paths of Collared Caribou

Evaluation of the years in which Bathurst-to-Beverly emigration occurred at higher rates showed that this emigration was more likely to happen following winters in which mixing of Bathurst and Beverly herds based on collars was extensive. The potential for movement to or from the Bluenose-East herd could also increase if the herd is extensively mixed with other herds. Winter overlap has increased between the Bluenose-East and other herds after 2020 (Figure 39). In 2022 and 2023 the Bluenose-East and other herds were heavily overlapping in March and even April.

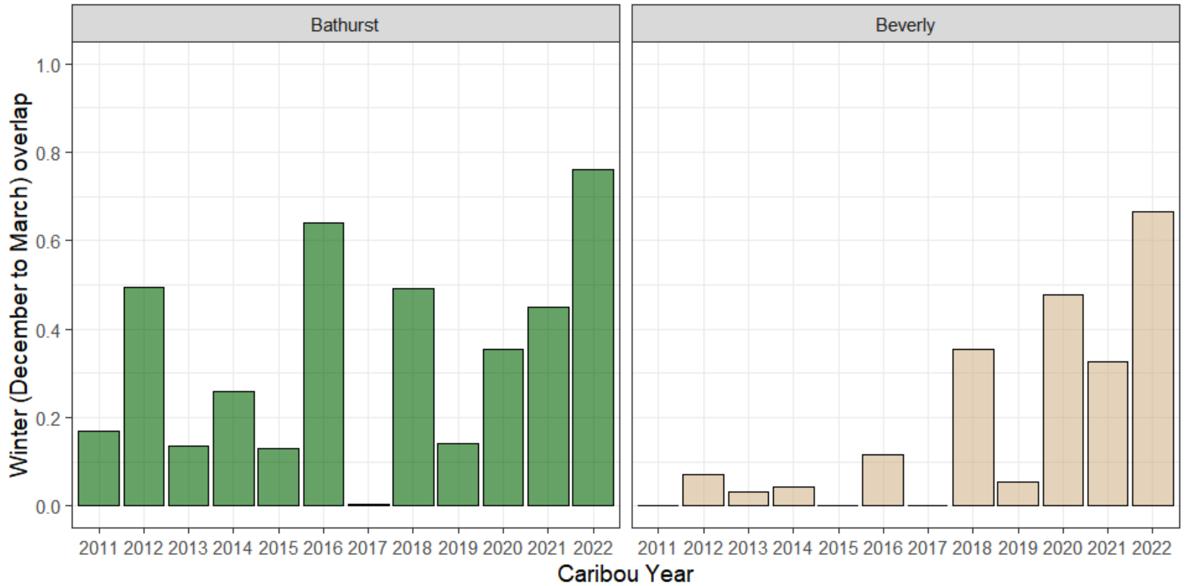


Figure 39. Winter (December to March) overlap of the Bluenose-East herd with the Bathurst and Beverly herds. See Appendix 3 for more details on the estimation of overlap.

Spring migration paths for the Bluenose-East, Bathurst and Beverly collared cows in 2023 (Figure 40) showed several Bluenose-East and Bathurst collared cows that moved north and east with Beverly cows to the east of Bathurst Inlet and then made a turn to the west to end up on the Bluenose-East and Bathurst calving grounds. There were also some Beverly cows that initially moved north toward the Bluenose-East calving ground, then made a turn east to end up on the Beverly calving ground several hundred kilometres to the east. As noted earlier, there was one collared cow monitored by the GN that was captured in NU west of Garry Lakes in April 2023 that ended up on the Bluenose-East calving ground in June 2023 and moved with Bluenose-East collared cows during the remainder of 2023. We note that herd classification for each herd movement path in Figure 40 is based upon the calving ground they ended up on in June 2023 as opposed to the calving ground where they calved in 2022. For example, of the 55 Bluenose-East collared cow paths shown in Figure 40, 33 were from Bluenose-East cows that had calved on the Bluenose-East calving ground in 2022 and 26 were collared in 2023 and therefore could have occurred previously on the calving ground of another herd.

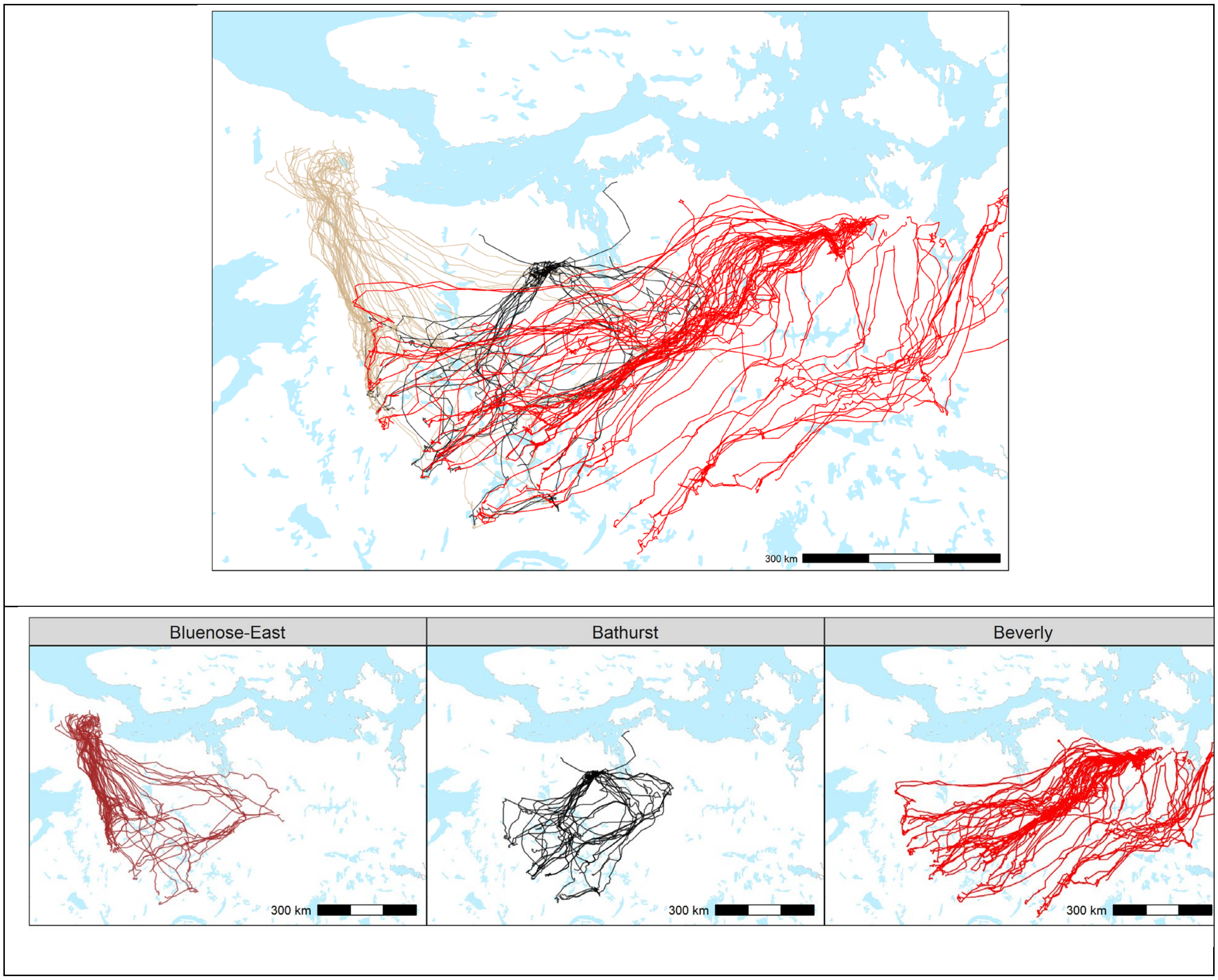


Figure 40. Migration paths northward of the Beverly collared caribou cows (red) compared to Bluenose-East caribou (tan) and Bathurst caribou (black) from April to May 2023. Collars are classified by the calving ground they were on in 2023.

There were also several collared cows monitored by the GN from the Wager Bay, Lorillard, Ahiak, and Qamanirjuaq herds that were also within the NWT in winter 2022-2023 (Figure 41). Herd size estimates in 2021 were Ahiak 39,100, Wager Bay 45,000, and Lorillard 33,500 (Campbell et al. 2022) and Qamanirjuaq 252,900 (2023). There were thus substantial portions of seven herds within the eastern NWT in winter 2022-2023 with various degrees of mixing, creating the potential for inter-herd movement among them.

While there was no direct evidence of emigration of cows from the Bathurst and Beverly herds to the Bluenose-East herd, it is possible that some movement occurred due to overlap of wintering caribou as well as unusual migration paths in the spring. We note that collared caribou are primarily older (3+ year old cows) which may be more likely to show fidelity to calving areas. In contrast, calves of the year and yearling caribou are not collared. These cohorts can represent 20-30% of female caribou during the migration; since these caribou do not have collars, undetected migration could occur in these age classes.

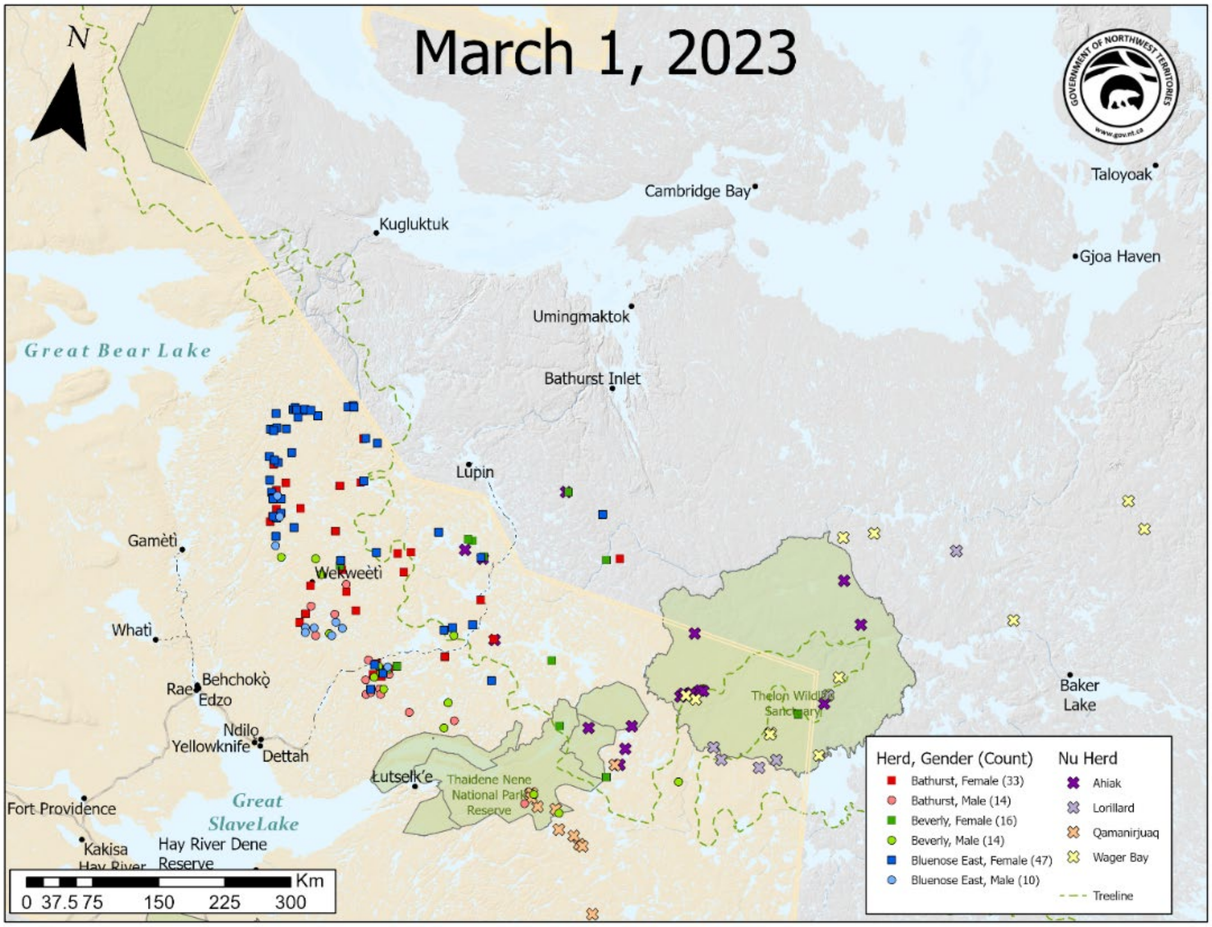


Figure 41. Locations of satellite collared caribou from the Bathurst, Bluenose-East and Beverly herds (maintained by the GNWT) and the Qamanirjuaq, Ahiak, Wager Bay and Lorillard herds (maintained by the GN) on March 1, 2023[7]. Some of the GN collars were further east and are not shown.

Power to Detect Switching between Herds Based on Collared Adult Female Caribou

The challenge with detecting and estimating emigration events between caribou herds is the limited sample size of collared cows of known herd membership. A set of simulations was carried out to assess the level of emigration that would likely be detected by collared caribou, using the numbers of known collared cows in each herd in spring 2023 (Figure 42). Details of this analysis are given in Appendix 4.

[7] Locations of Qamanirjuaq, Ahiak, Wager Bay and Lorillard collared caribou were provided courtesy of M. Campbell, GN.

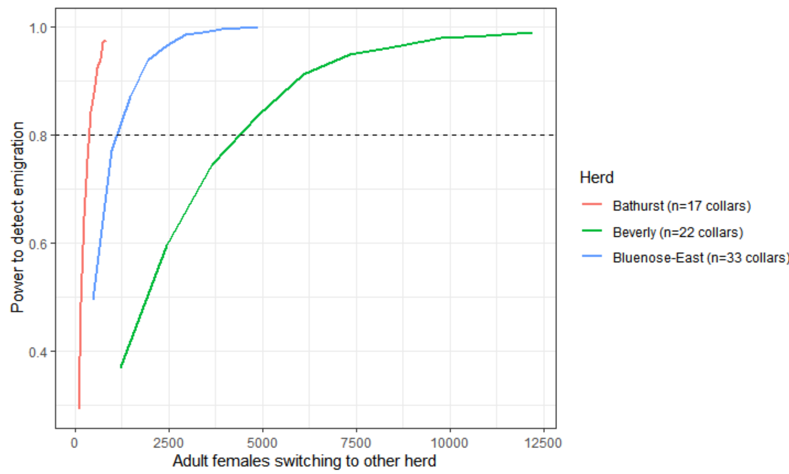


Figure 42. Power to detect emigration events from caribou herds as a function of emigration rate and collar sample size in 2023 in the Bathurst, Beverly and Bluenose-East herds. Details of the power analysis are given in Appendix 4.

With a power to detect change threshold of 0.80, 17 known Bathurst cows, 22 known Beverly cows and 33 known Bluenose-East cows, up to about 4,200 adult females could have emigrated from the Beverly herd before power reached the 0.8 threshold. In contrast, approximately 350 and 1,100 Bathurst and Bluenose-East adult females could emigrate before power reached the 0.8 threshold. Overall, this power analysis suggests that low levels of movement between herds (emigration rates <5-7%) could be missed when collar sample sizes were low. In larger herds such as the Beverly, this could amount to up to 4,200 adult females emigrating without this movement being detected by collared caribou movements. However, it is likely that more pronounced (larger scale) emigration events would be detected from collar movements. Maintaining adequate numbers of collared caribou will be important to assessing movement rates between herds. For example, if annual survival of adult females is 80% then at least 38 collars would be needed to maintain a sample size of 30 known collars in a herd.

Integrated Population Model Analysis of Factors Influence Estimates of Abundance

Survey and Demographic Factors

Each of the potential factors (survey bias, movement from other herds, and demographic factors) discussed previously potentially affected lack of fit of the IPM model to the 2023 estimate (Figure 36). To explore this lack of fit further, we ran a few other models to see if a better model fit could be attained by relaxing some of the IPM model constraints as well as adding additional parameters to the model. The model run scenarios included:

- *Yearlings breeding*: A proportion of female yearlings breeding based on literature that suggested that yearlings can breed at significant percentages when a herd is increasing (Parker 1981, Thomas and Kiliaan 1998). The IPM was modified to allow yearlings to breed at levels observed in other studies.

- *IPM survival rate estimates for 2019-2023:* Collar-based cow survival rate estimates from 2019-2023 were removed from the input data set to assess levels of survival that would be required to create the observed increase. Some studies suggested that collar-based cow survival estimates can be negatively biased (Haskell and Ballard 2007, Prichard et al. 2012) and removing these data tested model sensitivity to this assumption. By eliminating the field estimates, the IPM estimated survival based on other field indicators (i.e., abundance, calf-cow ratios etc.) without being constrained by the field estimates for this period.
- *No 2021 field estimate*: The 2021 adult female estimate was removed to test IPM sensitivity to this data point. Visual survey conditions were poor during the 2021 survey, which could have led to a negative bias in estimated caribou numbers from the visual blocks. This topic is explored further in subsequent sections. Removal of this data point tested model sensitivity to this assumption. A model was also attempted that eliminated the 2018 data point. However, this model displayed poor fit to productivity parameters and was not pursued further.
- *All survey/demographic factors:* The IPM was run with yearlings breeding, no 2021 field estimate, and no collar-based survival estimates from 2019-2023 to test if these factors combined would create a noticeable increase.

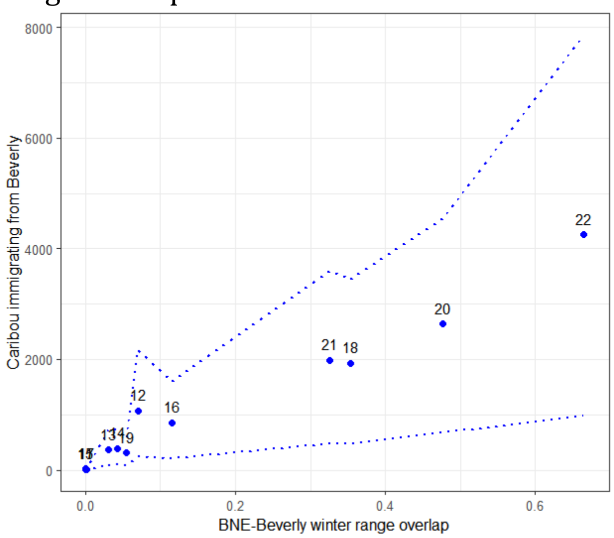
Exploratory Analysis of Immigration into Bluenose-East from Beverly

An additional exploratory immigration scenario was added to modeling where immigration from the Beverly herd was modelled based on winter range overlap between the Bluenose-East and Beverly herds (as discussed in detail in subsequent sections). To do this an emigration parameter was introduced which was the proportional amount of increase in Bluenose-East cows each year due to immigration. It was assumed that adult females, female yearlings, and calves would emigrate based on the relative proportions of each class in the Bluenose-East herd. This proportional increase parameter was constrained to be a function of winter range overlap (Figure 39) so that immigration only occurred when winter range overlap was >0 and increased as winter range overlap increased. Unlike the Bathurst IPM, immigration was not estimated based on collar movements. Instead, the inner covariance of parameters, along with the degree of overlap was used for estimates. One way of conceptualizing this approach is that the number of new cows entering the population is constrained by not just population survey estimates but also composition survey calf-cow and bull-cow ratios. For example, a large-scale immigration of cows into the Bluenose-East in any year would reduce the bull-cow and calf-cow ratios (unless bulls and calves immigrate at the same rate as the cows). Therefore, the fit of data to bull: cow and calf: cow ratios would be influenced by the level of immigration.

Figure 43 illustrates potential estimated levels of immigration based on winter range overlap and the proportional amount of each class immigrating. Overall levels of emigration from the

Beverly herd were in the range of levels where power to detect immigration from the Beverly was low (Figure 42). The emigration parameter was significant, suggesting that additional variation in demographic parameters could be explained by emigration. However, this finding should be interpreted cautiously given the lack of direct evidence for emigration. It is also worth noting that there was overlap to varying degrees in the eastern NWT of seven migratory barren-ground caribou herds in winter 2022-2023 (Figure 41) and this could have led to interchange among any of them. There could have been movement between the Bluenose-East herd (to or from) and one or more other herds.

A) Estimated emigration based on winter range overlap



B) Proportion of age cohorts estimated to be emigrating

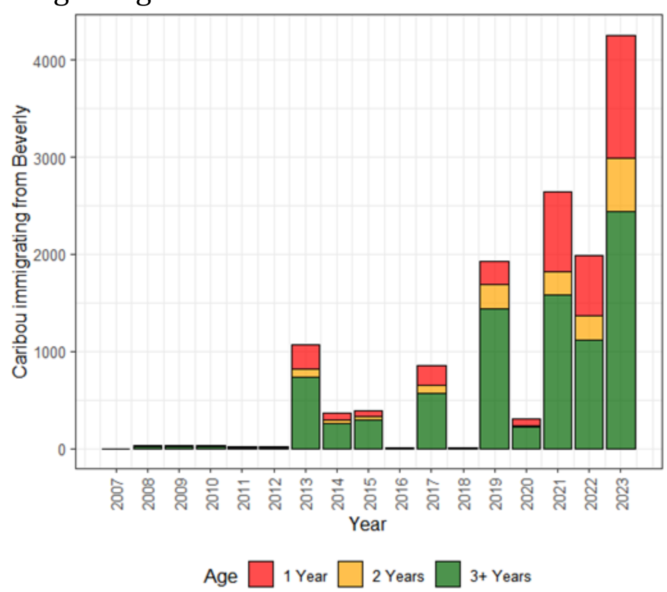


Figure 43. Estimated emigration from the IPM model based on winter range overlap (Figure 39). The right figure (A) shows estimated emigration as a function of winter range overlap with year of survey showed next to each data point.

Evaluation of Results

The fit of the IPM to each scenario was evaluated for key demographic parameters. IPM estimates of calf: cow ratios fit the observed data well across all scenarios (Figure 44). In contrast, the IPM predicted lower bull: cow ratios for all scenarios up to 2022 with agreement in 2023. This result suggested that the IPM predicted either higher cow numbers or lower bull numbers than suggested by the bull: cow ratio. One assumption of the base IPM is that the main factors influencing bull and cow numbers are demographic (births and deaths) rather than movement of caribou to or from other herds. As discussed later, and demonstrated in the Bathurst IPM analysis, this assumption may not be as valid in recent years, which may have influenced field-based bull: cow ratios.

Interestingly, the yearling female breeding scenario did not change calf: cow ratios. The likely reason for this is that ultimately, productivity is constrained by calf: cow ratio values; essentially, calves resulting from yearling pregnancies should be found and counted in composition surveys. Therefore, increases in productivity caused by yearlings breeding can only increase up to values that will fit the observed calf-cow ratios.

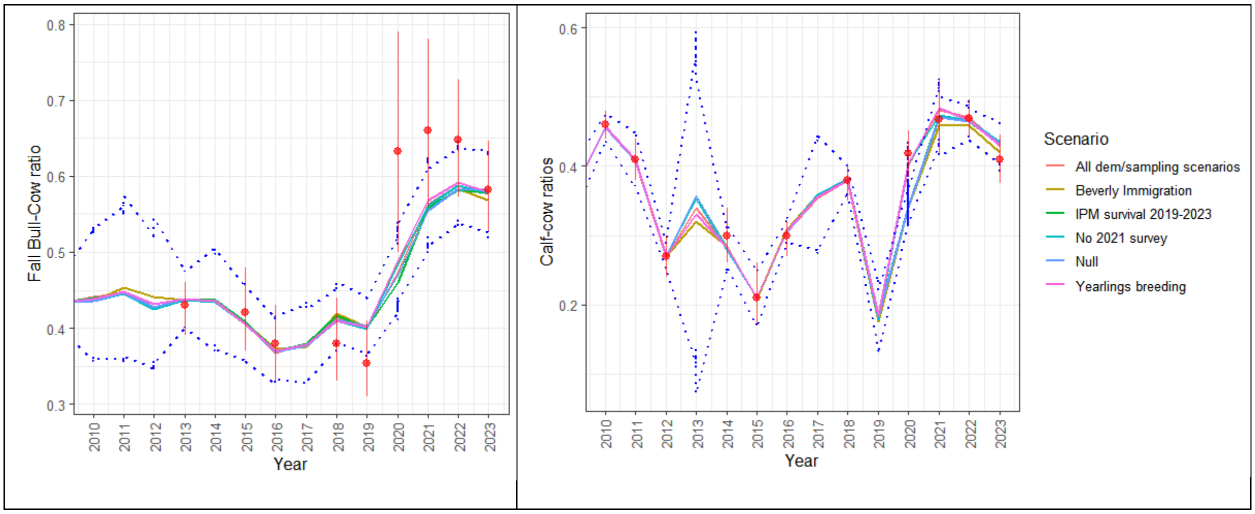


Figure 44. Bull: cow and calf: cow ratios for Bluenose-East herd 2010-2023 from the model and from survey estimates across various demographic scenarios. Red circles and error bars are from field estimates and the colored lines represent model outcomes from scenarios described earlier. Blue dashed lines are confidence limits for the null model.

Cow survival values were higher in the 2022 caribou year when survival was not constrained by field values from 2019-2023 or when all scenarios were run at once (Figure 45). Minimal change in adult survival when field estimates were removed may seem surprising, however, the IPM also uses calf: cow ratios and bull: cow ratios to estimate adult cow survival. For example, if cow survival could increase by a large amount, it would also reduce bull: cow ratios and calf: cow ratios. Therefore, these field estimates also constrain adult cow survival to values that will fit the other field data indicators.

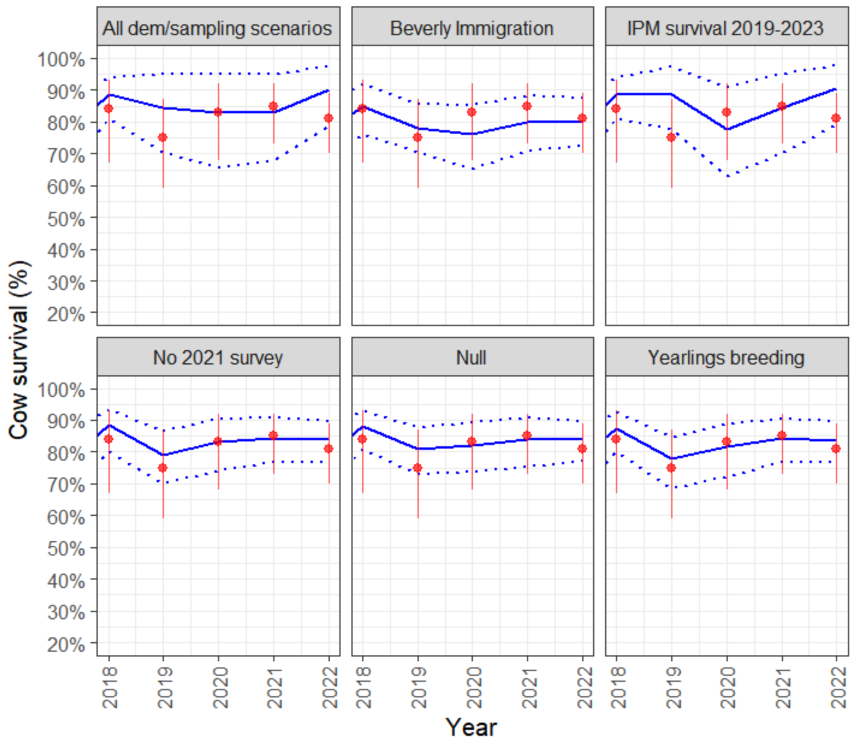


Figure 45. Cow survival estimates for Bluenose-East herd 2010-2023 from IPM across various demographic scenarios. As in other figures, red circles and error bars are from collar-based field estimates.

The resulting model-based estimates of adult cows were still relatively low compared to the estimate of 24,446 in 2023 (Figure 46) with confidence of the all demographic/sampling and immigration scenarios intersecting confidence limits of the 2023 field estimate. However, they were all higher than the estimate in 2021 (13,806) with the IPM predicting a moderate increase across all scenarios.

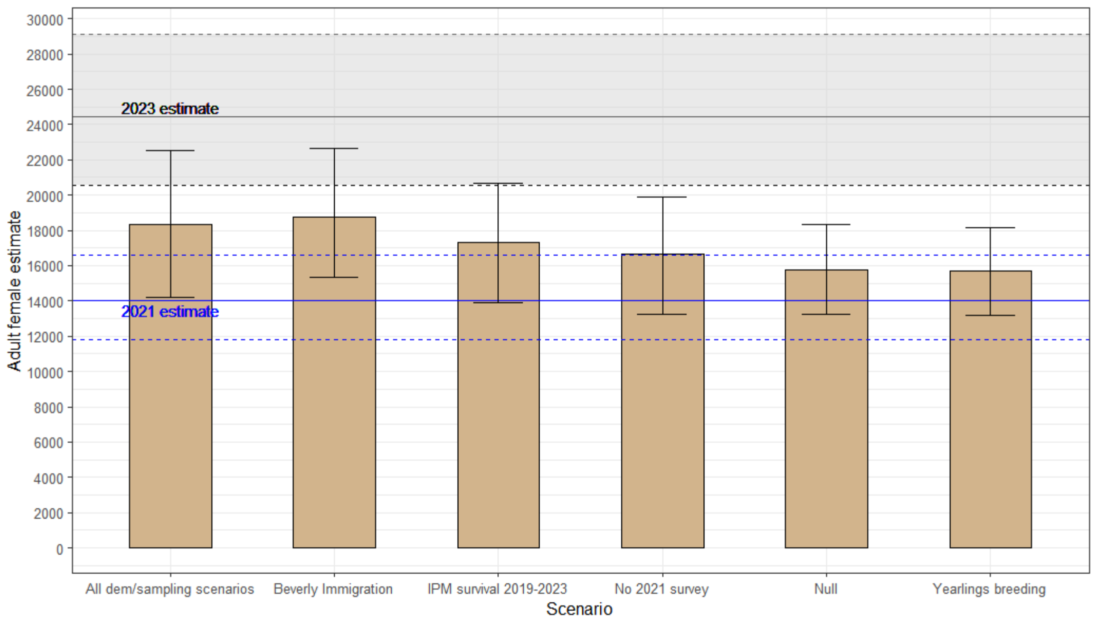


Figure 46. Estimates of Bluenose-East adult cow numbers in 2023 across various IPM demographic scenarios. The field (survey) estimate, and confidence limits of the adult female numbers are indicated by shaded values.

Estimates of yearly change (λ) from 2010-2023 suggest that the main increases occurred from 2021 to 2023 regardless of scenario (Figure 47). However, the increase was highest for the immigration and IPM survival scenarios. Thus, a demographic increase was predicted under these scenarios, just not at the level shown by field estimates.

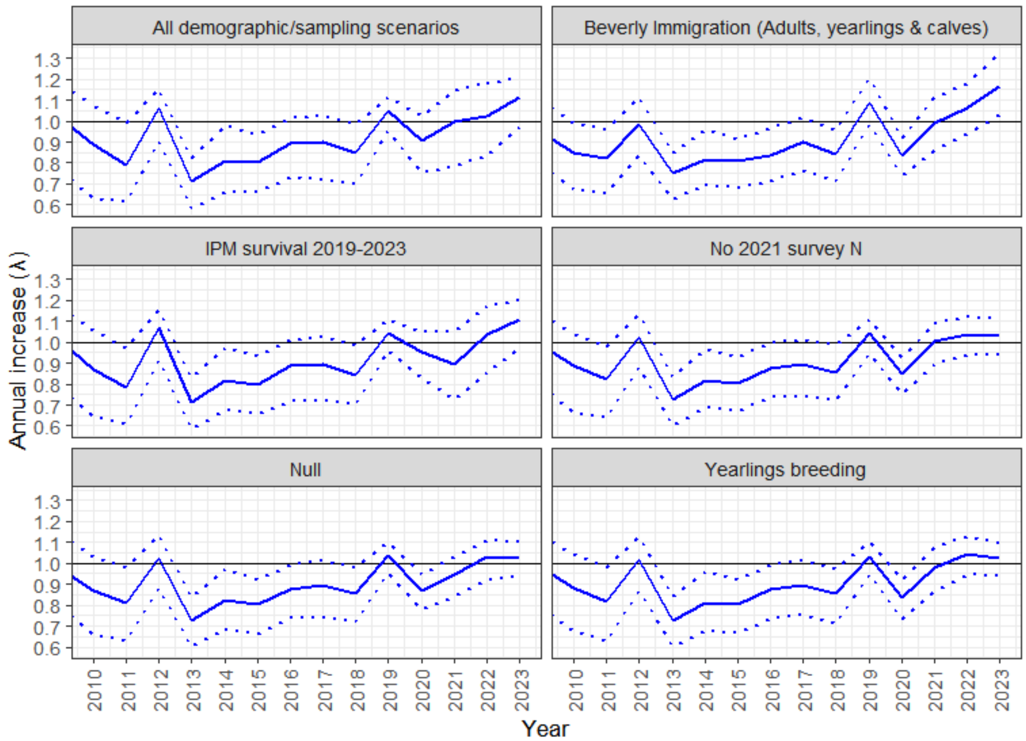


Figure 47. Estimates of annual change (λ) in Bluenose-East adult females 2019-2023 across various IPM demographic scenarios. A λ value of 1 is indicated by a horizontal line. Confidence limits are given as hashed lines around model predictions.

Synopsis of Results

A summary of potential reasons for the apparent increase of the Bluenose-East herd 2018-2023 is shown in Table 15. This includes results from the population modeling as well as possible survey bias and potential immigration to the Bluenose-East herd. Only the emigration, IPM survival rate, and all demographic/sampling model scenarios resulted in recent trends in the range of 10-11% annual increase with confidence limits intersecting the lower confidence limit of the 2023 adult female estimate (Figure 46). Elimination of the 2021 survey did not cause a large herd increase presumably due to the effect of moderate adult survival rates on herd trend.

Table 15. Potential reasons for increase in Bluenose-East herd between 2018 and 2023.

Potential reason for increase	Assumptions	Estimated Effect
Demographic increase	Survival rates and other metrics in the IPM are unbiased so that the IPM estimate is unbiased. In this case the increase came from other sources such as emigration from other herds.	IPM model predicted a moderate (3%) annual increase as opposed to the observed 32% annual increase 2021-2023.
Demographic increase with negatively biased calving ground estimate in 2021	The 2021 estimate underestimated adult females due to poor visibility of caribou on visual blocks and lack of a reconnaissance survey leading to a negative bias in IPM estimate.	If the 2021 estimate is not used in the IPM the predicted annual increase from 2018-2023 is 4%. A model with 2018 and 2021 estimates not used exhibited poor fit to the data.
Demographic increase with negatively biased survival rates	Negatively biased collar-based adult survival rates caused IPM to underestimate growth.	Eliminating survival rate estimates from 2019 to 2023 results in a 11% annual increase, which is a more reasonable fit for the 2018-2023 annual rate of increase but not the 2021-2023 apparent increase.
Yearlings breeding increased growth rates of herd	Yearlings created added productivity leading to a higher rate of increase.	Adding yearling pregnancy to the IPM did not increase herd growth substantially since calf-cow ratios constrain productivity estimates in the spring. A higher calf-cow ratio would have been observed if productivity was increased.
Undetected movement from neighboring herds	Increase is partially due to emigration from the Beverly to the Bluenose-East herd by adult cows, but also by yearlings and calves of the previous year.	Power analyses suggest up to 4,000 Beverly adult cows could emigrate annually to the Bluenose-East herd before power to detect=0.8. Migration paths suggest some Beverly collars started on the migration to the Bluenose-East calving ground before turning to the east in 2023. An annual increase up to 11% occurs with the IPM emigration model. However, there was winter overlap of the Bluenose-East herd with multiple herds in 2022-2023, thus movement to or from the Bluenose-East herd could have occurred.

We note that the potential reasons in Table 15 are not mutually exclusive, i.e., a combination of factors might explain the numbers and apparent rate of change. For example, combining all scenarios except immigration created model-based annual increase levels up to 10% in the Bluenose-East herd from 2021-2023. Overall, we believe that the apparent increases 2021-2023 and 2018-2023 were most likely the result of a combination of factors, including under-estimation of herd size in 2021 and possibly 2018 from poor caribou visibility on visual flying, under-estimation of cow survival rates based on collared cows, and potentially undetected immigration from another herd to the Bluenose-East herd. The 2023 survey results had excellent caribou visibility and high precision and should be reliable. The herd in 2023 was clearly increasing, although a more moderate annual rate of increase (6-11%) than the 31-32% annual increase that the 2021 and 2023 estimates taken at face value, is suggested by modeling and other analyses.

RESULTS: BATHURST JUNE COMPOSITION SURVEY

Survey Results

The Bathurst composition survey was flown June 14 and 15 (Figure 48) with the helicopter leaving Kugluktuk and then based at the MLA site near Bathurst Inlet. Nearly all the 30 collared Bathurst cows (17 known and 13 new) and one Bluenose-East collared cow were tightly clustered in an area about 5x15 km, with just three collared cows outside this concentrated area. While the main survey effort was focused on the caribou groups associated with the collars, the area surrounding the main cluster was searched using 13 east-west lines spaced about 4 km apart to provide spatial coverage.

Overall, 1,841 caribou were classified from 81 groups, including newborn calves (Table 16). Caribou groups found near the main cluster of cow collars were primarily cow-calf groups with some yearlings and non-breeding cows (Figures 49, 50). Outside of the main cow-calf concentration with nearly all the collared cows, groups found were smaller and consisted almost entirely of yearlings and bulls. Nearly all the cow-calf groups were relatively large, numbering hundreds, in contrast to the smaller and more dispersed groups seen on the Bluenose-East calving ground.

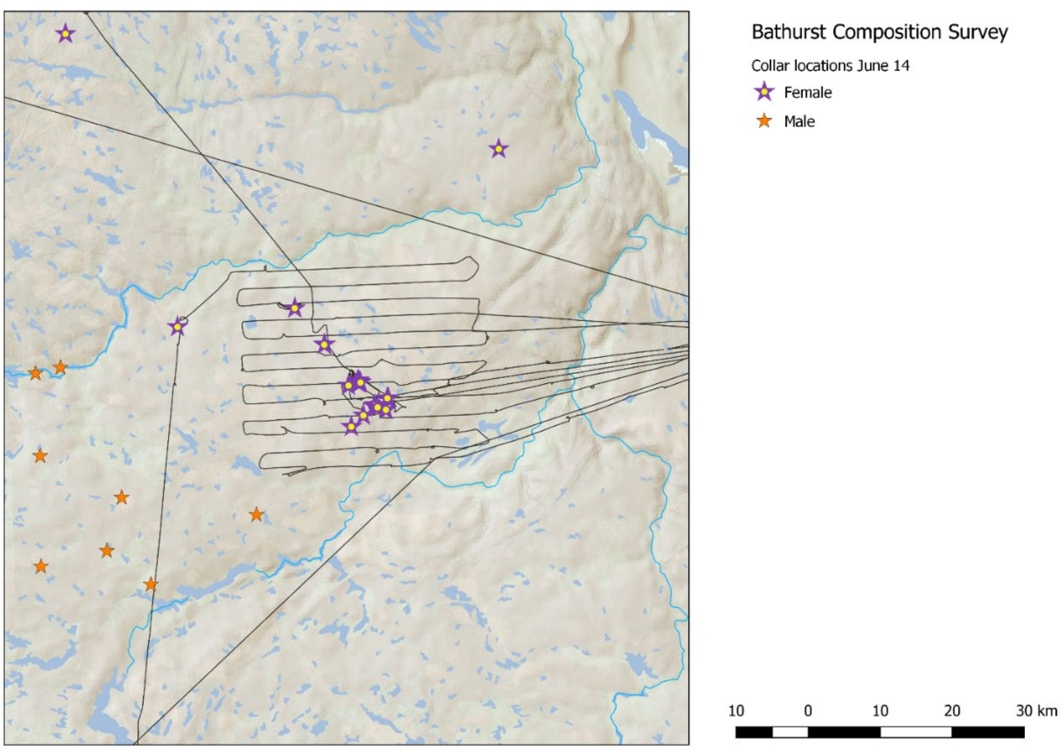


Figure 48. Composition flight lines and collared cow and bull locations on the Bathurst calving ground in June 2023.

Table 16. Summary of numbers of caribou in each class identified during classification survey of the Bathurst herd in June 2023. Total caribou includes calves.

# Groups	Breeding Cows	Non-Breeding Cows	Cows Total	Calves	Bulls	Yearlings	Total Caribou
81	858	173	1,032	576	71	162	1,841

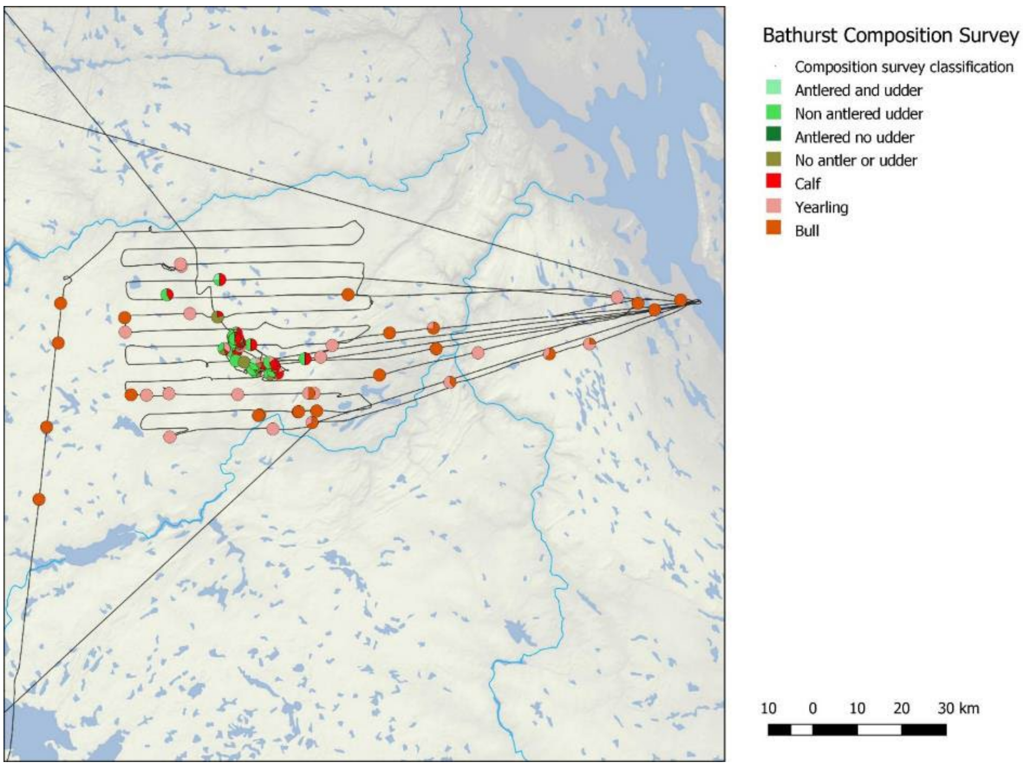


Figure 49. Locations and composition of caribou groups classified during the June 2023 Bathurst composition survey. Pie charts are used to show relative proportions of caribou classes identified.

More detailed information on classes of cows and bulls in the survey (Table 17) includes 838 un-antlered cows with distended udders and just 20 cows with hard antlers and distended udders, which resulted in 97.7% of the breeding cows being un-antlered. The equivalent value for the Bluenose-East herd was 75.2%. The very low percentage of cows still with hard antlers in the Bathurst herd may suggest that the peak of calving in this herd could have happened earlier than in the Bluenose-East herd. The Bathurst survey was slightly later than the Bluenose-East survey (June 14-15 vs June 11-13), which left an additional two to three days for Bathurst cows to shed their antlers; this could have contributed to this higher percentage. The Bathurst collar movement rate data (Figure 12) were somewhat ambiguous for detecting the peak of calving as no clear sustained drop in collar movement was seen between the end of migration and before the caribou moved to the post-calving period. On balance, a slightly earlier peak of calving could have occurred in the Bathurst herd, possibly June 1-3, although the supporting evidence is limited.

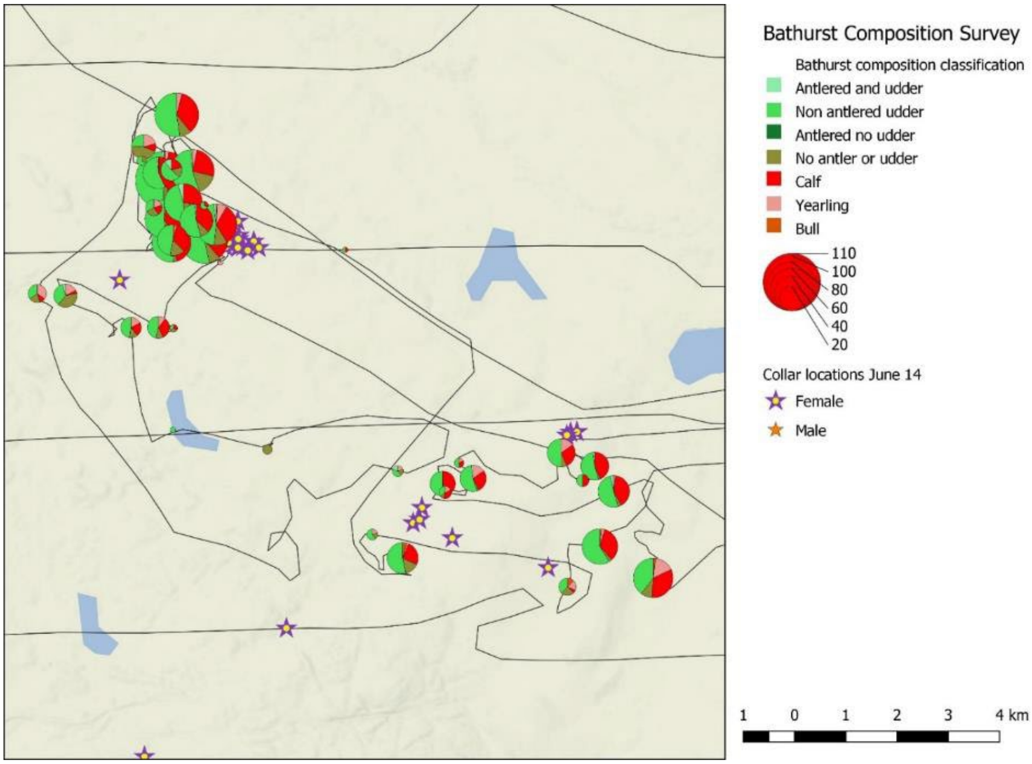


Figure 50. A close-up of composition observations in the core area of the Bathurst calving ground in June 2023. The size of the circles is in proportion to the number of cows observed in each group.

Table 17. Detailed summary of classes of cows and bulls classified during Bathurst June 2023 composition survey.

Cows				**Calves**	**Bulls**		**Yearlings**
Antler Udder	**Antler No Udder**	**No Antler Udder**	**No Antler No Udder**		**Young**	**Prime**	
20	0	838	173	576	30	41	162

The proportion of breeding cows on the Bathurst calving ground was 83.1% (Table 18), similar to the 80.9% found in the Bluenose-East composition survey.

Table 18. Proportions and ratios from Bathurst June 2023 composition survey. SE = standard error; CIL = 95% Confidence Lower; CIU = 95% Confidence Upper; CV = Coefficient of Variation.

Proportion/Ratio	Estimate	SE	CIL	CIU	CV
Breeding Cows (breeding cows/one year-old caribou)	67.8%	3.5	60.2	73.8	5.2%
Cows (cows/1-year-old caribou)	81.6%	3.1	74.4	86.9	3.9%
Cows Breeding (breeding cows/cows)	83.1%	2.1	78.8	86.8	2.5%
Calves/Cows (all cows)	55.8	3.6	48.3	62.6	6.5%
Calves/Breeding Cows	67.1	3.2	60.1	72.8	4.8%
Yearlings (yearlings/1-year-old caribou)	12.8%	2.3	8.9	17.9	18.0%
Bulls (bulls/1-year-old caribou)	5.6%	1.5	3.2	9.2	27.1%

Notably, however, just 67.1 calves: 100 cows (60.1, 72.8) in Bathurst breeding females were estimated, substantially lower than the 86.2 calves: 100 cows in breeding cows estimated in the Bluenose-East herd. This may indicate a greater early calf mortality in the Bathurst herd than in the Bluenose-East herd. We note however that the Bathurst June composition survey was slightly later than the Bluenose-East survey and it is also possible that the peak of calving in the Bathurst herd was slightly earlier, thus there was also a slightly longer period for newborn Bathurst calves to be exposed to predation before the survey occurred.

Demographic Indicators for the Bathurst Herd

In this section, field-based demographic indicators for the Bathurst herd updated to include results from 2022-2023 are reviewed, including collar-based cow survival, the proportion of breeding females on the calving grounds, and calf: cow and bull: cow ratios recorded in the fall and late winter.

To assess collar-based cow survival, the monthly status of Bathurst cows was summarized with tallies of live cows and mortalities for each month. Using these tallies, survival rate was estimated using the Kaplan Meir estimator (Figure 51). Collar numbers increased in 2016 to more than 20 for most years, with previous estimates based on lower numbers of collars, reducing the precision of estimates. Given overlapping confidence intervals and large variance around annual estimates, trends are best assessed by averaging over a period of two to three years.

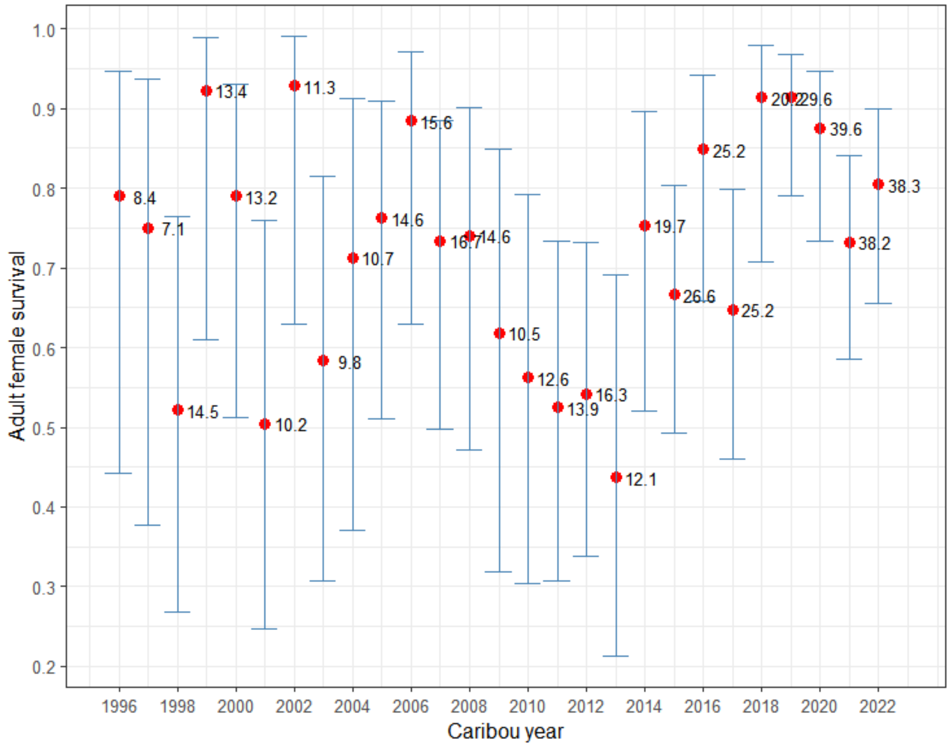


Figure 51. Annual collar-based cow survival estimates for the Bathurst herd from 1996 to 2022. Red dots are the annual estimates, with 95% confidence intervals as blue bars. Numbers beside the red dots show the average number of collared females available for the estimate. Variance has been high, particularly in earlier years when there were few collars. The year begins in June at calving and ends the following May; e.g. the year 2020 extends from June 2020 to May 2021.

Cow survival rates varied around the 80% level from about 2014 onward, with consistently lower values 2009-2013. Collar-based cow survival was over 90% in 2018 and 2019 and estimated at 87% in 2020, however the estimates for 2021 (73%) and 2022 (80.5%) were somewhat lower. Survival was estimated at 80.5% (CI=65.6-89.9%) for 2022. Sample sizes of collars remain limited and variance around annual estimates is still substantial.

Cow survival rates were also estimated for the spring-fall period (June - October) and early winter to spring migration (November - May) (Figure 52); these showed relatively high cow survival in both seasonal periods in 2018-2020, and somewhat lower values in 2021 and 2022.

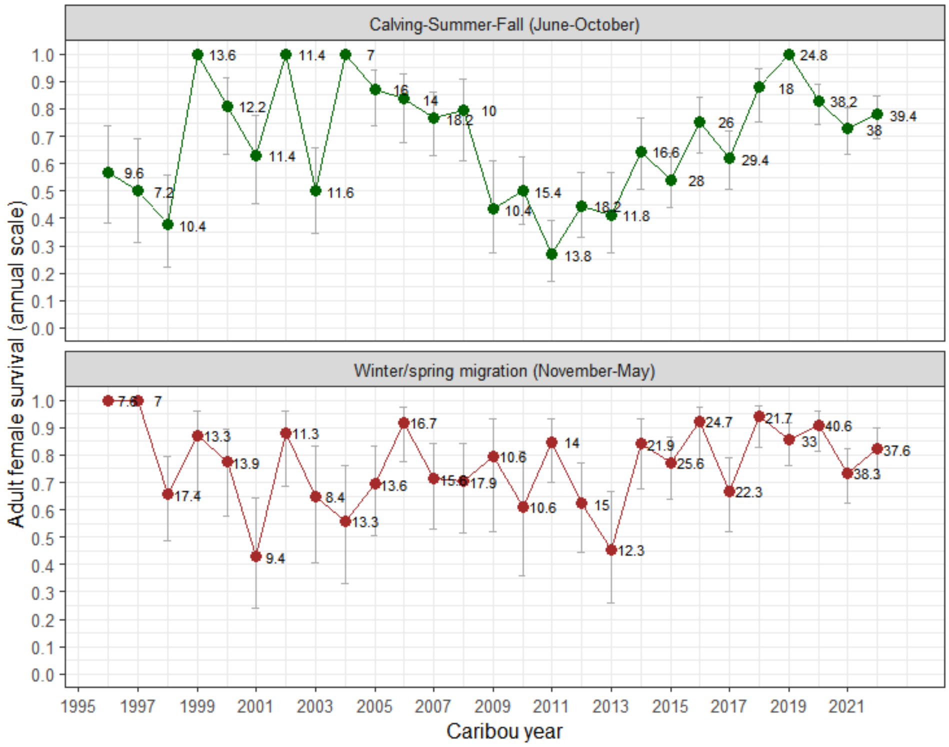


Figure 52. Annual collar-based cow survival estimates for the Bathurst herd from 1996 to 2022 for two seasonal periods (June-October and November-May). Dots are the annual estimates, with 95% confidence intervals as blue bars. Numbers beside the dots show the average number of collared females available for the estimate.
Seasonal survival rate estimates are expressed on the annual scale to facilitate comparison.

The proportion of breeding females in June on the calving grounds (breeding females as % of total females) provides an index of the pregnancy rate over the previous winter. In the Bathurst herd, the proportion of breeding females 2009-2021 was variable; recent values have been 86% in 2019, 72% in 2018, 77.6% in 2021, 79.8% in 2022, and 83.1% (Figure 53). Some years (notably 2015) had lower fecundity that was potentially associated with high drought conditions and severe insect harassment the previous summer, which could have led to poor condition of females in the breeding season (Boulanger and Adamczewski 2024).

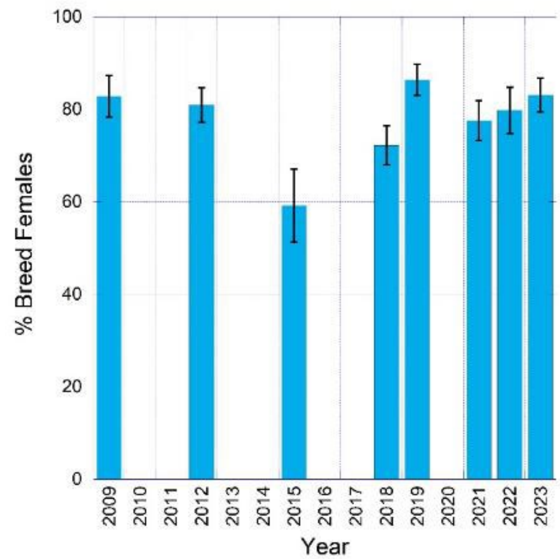


Figure 53. Proportion of breeding females on the Bathurst calving ground from composition surveys near the peak of calving, 2009-2023. All surveys except 2019 and 2023 were part of calving photo surveys. Pooled estimates are shown for consistency; the 2019 and 2023 composition surveys were stand-alone surveys with no survey blocks defined. Comparison of pooled and stratified estimates suggests there is little difference in estimates.

Fall calf: cow and bull: cow ratios for the Bathurst herd 2006-2023 are shown in Figure 54.

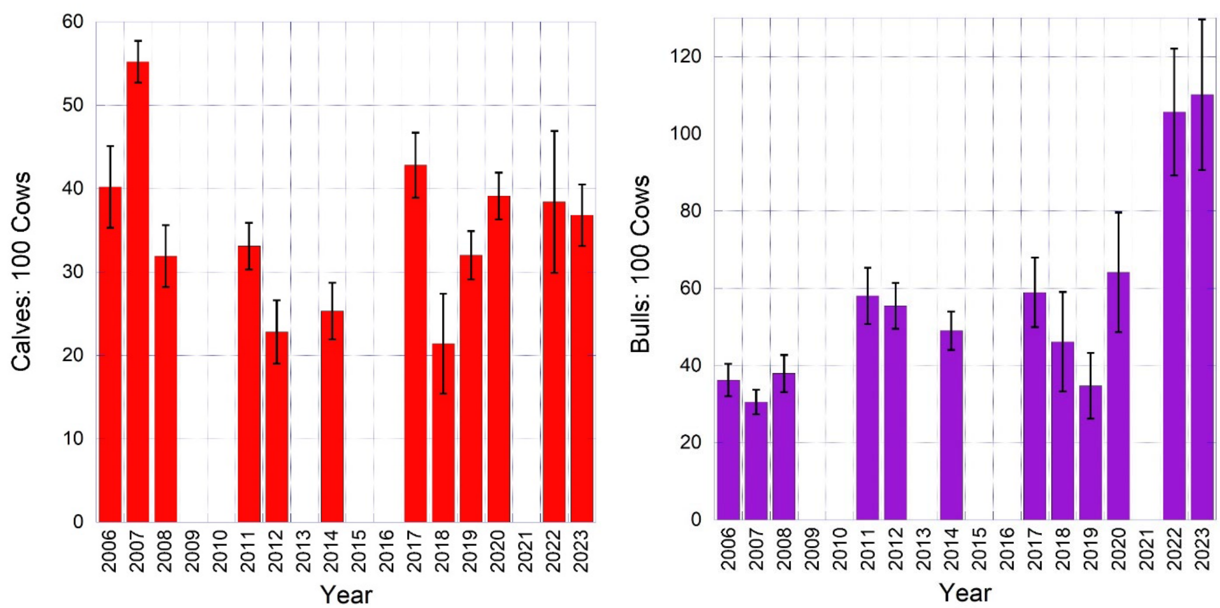


Figure 54. Fall calf: cow ratios (left) and bull: cow ratios (right) for the Bathurst herd 2006-2023. Means are shown with 95% Upper Confidence Intervals.

The ratio of 36.8 calves: 100 cows estimated for the Bathurst herd in October 2023 was similar to the ratios estimated in October 2022 (38.4) and October 2020 (39.1). The recent Bathurst fall calf: cow ratios have consistently been lower than fall ratios in the Bluenose-

East herd (Figure 31). In part this may reflect early calf mortality being higher on the Bathurst calving ground; previously in this report we noted the calf: cow ratio in breeding females of 67.1 calves: 100 cows in June 2023 for the Bathurst herd, compared to 86.3: 100 in the Bluenose-East herd.

Fall bull: cow ratios in the Bathurst have shown an unusual trend. A survey in fall 2020 included about ¾ of the Bathurst cow and bull collars and there were no Bluenose-East and Beverly collars mixed in; this survey resulted in an estimate of 64.1 bulls: 100 cows, similar that year to the ratio in the Bluenose-East herd. A reliable Bathurst bull: cow ratio could not be estimated in fall 2021 due to extensive Bathurst/Beverly mixing. The bull: cow ratio estimated in fall 2022 (105.6) appeared initially as implausible (Adamczewski et al 2024) but the ratio in fall 2023 (110.1) was similar. Both these estimates were based on caribou classified in areas with only Bathurst collars (2022) or predominantly Bathurst collars (2023). Sex ratios tend to average about 50 bulls: 100 cows in caribou (Bergerud 2000) and caribou populations with more bulls than cows are essentially unknown.

A potential explanation for the recent high Bathurst bull: cow ratios could be differential movement of cows and bulls between the Bathurst and Beverly herds. One-directional movement of Bathurst collared cows to the Beverly range was documented in 2018 (3 of 11, 27.2%), 2019 (3 of 17, 17.6%), 2021 (6 of 34, 17.6%) and 2023 (4 of 21, 19.0%). If Bathurst bulls did not move east to the Beverly range over this period at similar rates, then potentially the male-female ratio would increase over time. An initial analysis of fidelity of collared bull caribou to their summer ranges in July[8] suggests that there was little or no switching of collared bulls between the Bathurst, Bluenose-East and Beverly herds in recent years, albeit based on much lower collar numbers (Boulanger unpublished). This initial result suggests that the emigration of some Bathurst cows to the Beverly range has not been accompanied by similar emigration of Bathurst bulls, which could have contributed to the very high Bathurst bull: cow ratios in October 2022 and 2023.

There has been just one successful March composition survey for the Bathurst herd since 2016, which resulted in a ratio of 30.4 calves: 100 cows in March 2020 (Figure 55). A valid estimate was possible that winter as the Bathurst collared caribou were relatively separate from the neighbouring Bluenose-East and Beverly collared caribou. March surveys of the Bathurst herd were attempted in 2021, 2022 and 2023, but a reliable calf: cow ratio could not be generated due to extensive mixing with Beverly caribou and some mixing with Bluenose-East caribou (Adamczewski et al. 2023b, 2024a, 2024b). Mixing of Bathurst and Beverly caribou also prevented estimating Bathurst calf: cow ratios in March 2017, 2018, and 2019.

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[8] In recent years, bulls newly collared in March are assigned to a herd in July as bulls are most clearly separated spatially between herds at that time.

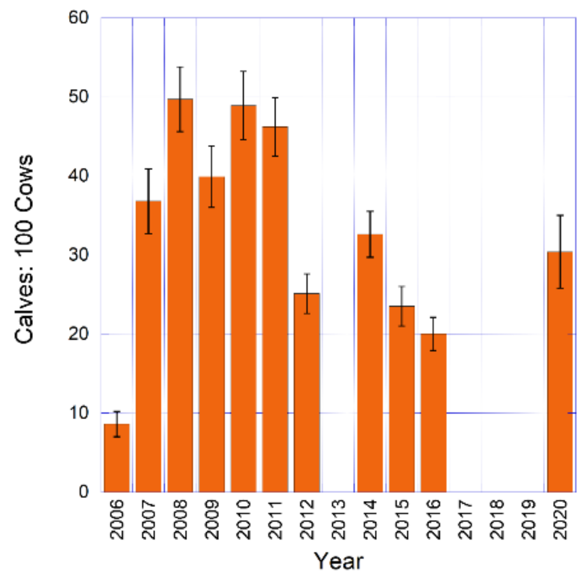

Figure 55. Late-winter calf: cow ratios estimated for the Bathurst herd 2006-2020 from composition surveys.

Integrated Population Modeling of the Bathurst Herd

An IPM was applied to the Bathurst data set, as after previous caribou calving ground surveys (Figure 56). A modification on this iteration of the modeling was to assess Bathurst bull fidelity by a model run that included emigration of bulls, including yearling bulls, at the same rate as Bathurst cow emigration, and a model run that did not include bull emigration.

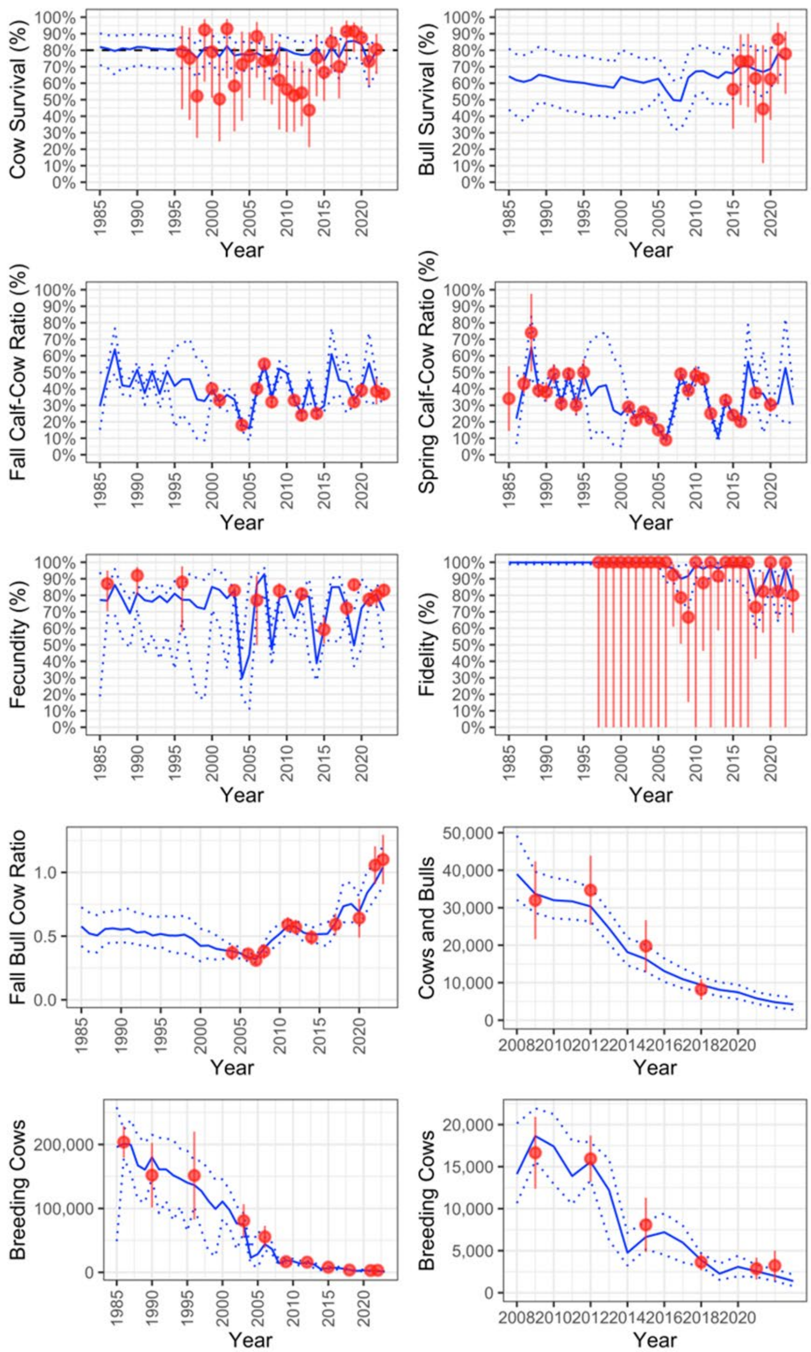

Figure 56. Fit of IPM to demographic data for the Bathurst herd 1986-2023. The blue lines are IPM estimates with hashed blue lines as confidence limits. The red dots are field estimates with 95% confidence limits indicated by red lines. This model run did not include Bathurst bull emigration to the Beverly herd.

Models where bulls did not emigrate to the Beverly herd showed better fit to bull: cow ratios in 2022 and 2023 than models that included Bathurst bull emigration (Figure 57). An increase in bull: cow ratios was suggested even with emigration to the Beverly herd due to increasing bull survival rates and reasonable productivity. The fit of the data to cow survival in 2023 was better for the no bull emigration model. These results suggest that the increase in bull: cow ratios was demographically feasible due to increased bull survival, reasonable productivity, and emigration of cows to the Beverly herd.

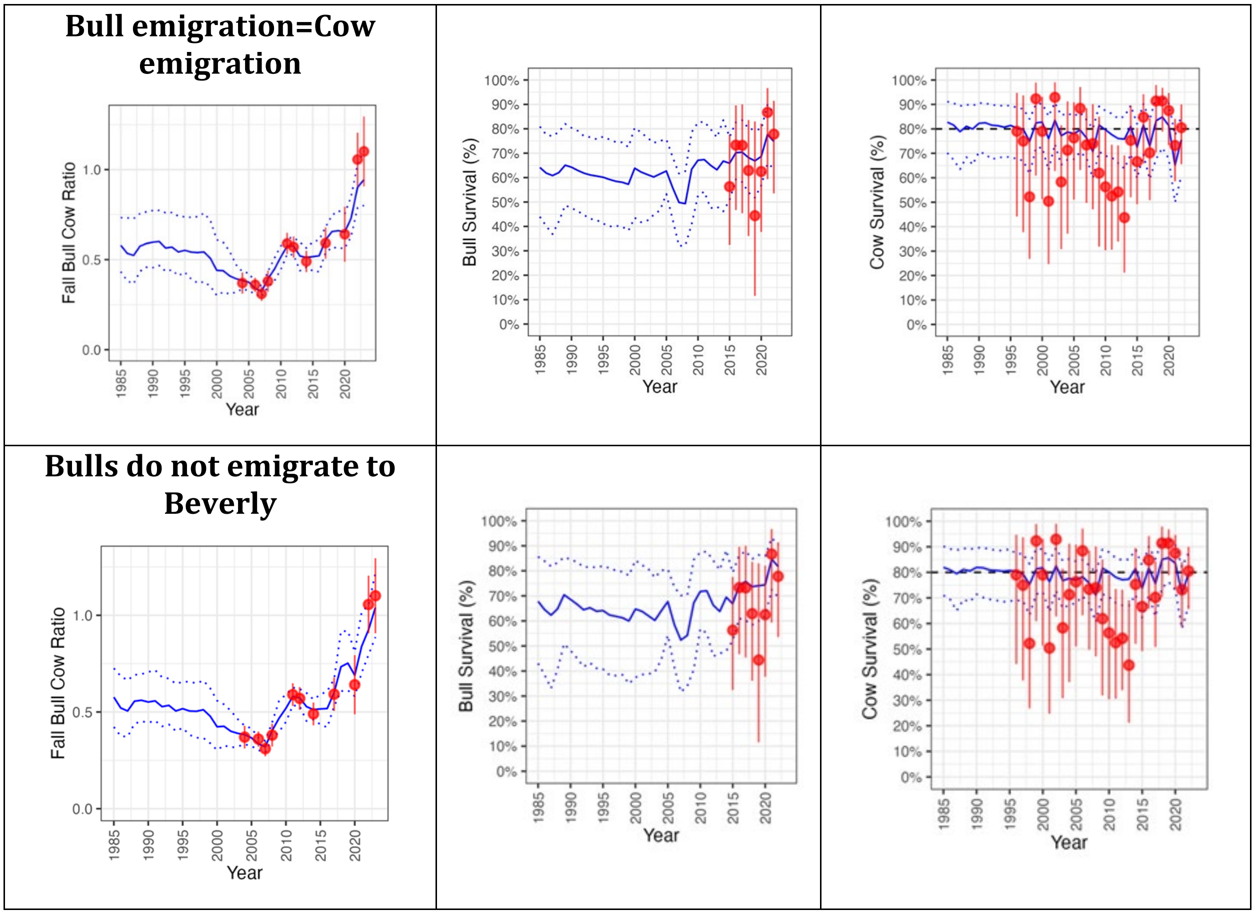

Figure 57. Fit of the IPM to Bathurst demographic data with and without bull emigration to the Beverly herd, 1986-2022. The blue lines are IPM estimates with hashed blue lines as confidence limits. The red dots are field estimates with confidence limits indicated by red lines.

Known collared Bathurst cows emigrated to the Beverly calving distribution at a rate of 19.0% (4/21) in 2023, which followed a winter of extensive mixing with Beverly and Bluenose-East caribou (Figure 58). One (of 33 ≈ 3%) known Bluenose-East collared females switched to the Bathurst calving ground in 2023. This movement was not considered in the IPM analysis.

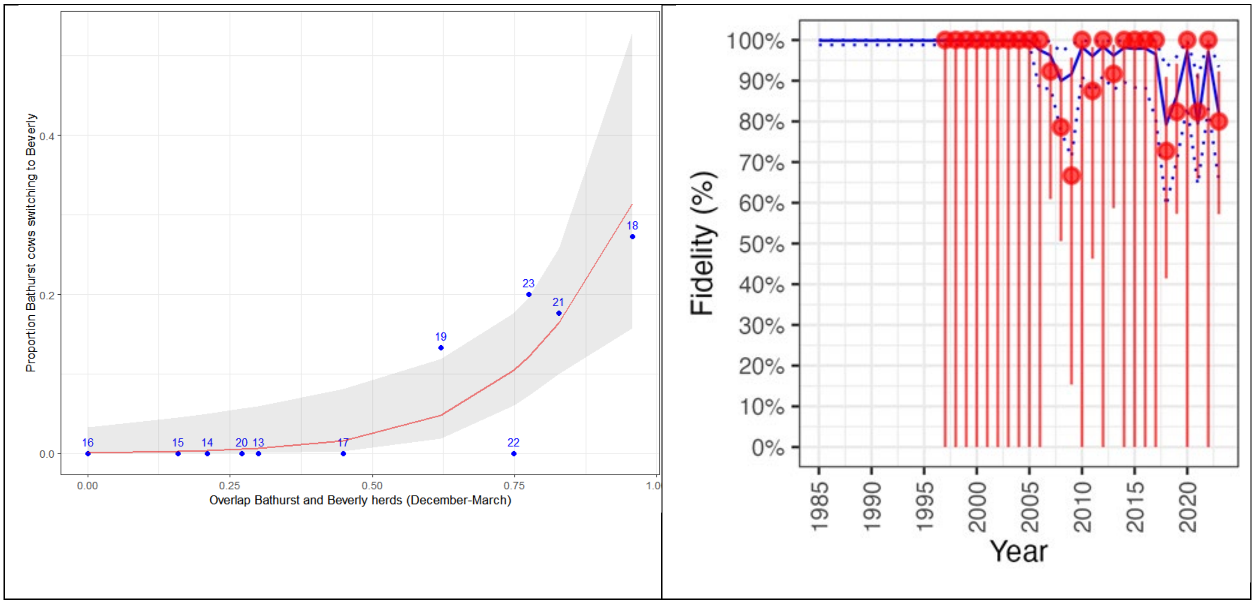

Figure 58. left: Proportion of collared Bathurst cows switching to the Beverly herd in relation to winter overlap of Bathurst and Beverly collared cows; individual years shown as the last two digits (22=2022). Right: fidelity of known Bathurst collared cows by year and IPM estimates of fidelity (1-emigration rate).

The demographic trend based on demography with no emigration from the herd estimates a 10% annual decline with stability suggested in 2018 and 2023 (Figure 59). However, the observed trend including emigration results in an estimate of 15-20% annual decline.

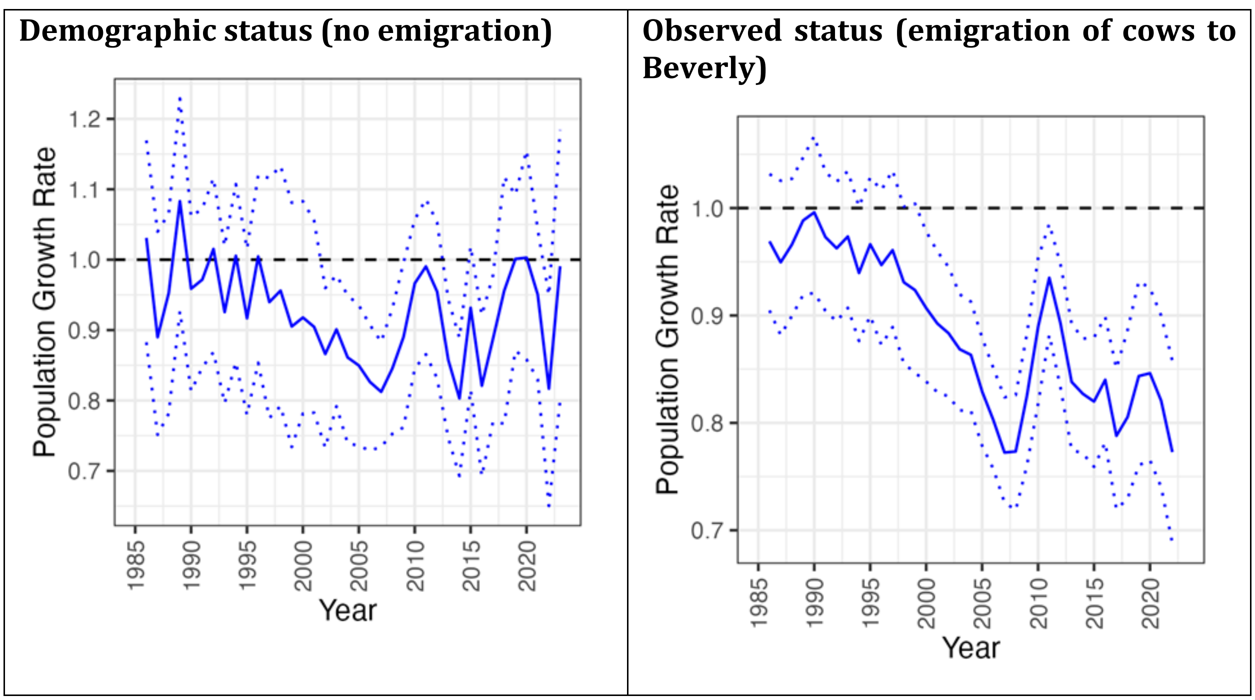

Figure 59. Population growth rate (λ) in the Bathurst herd based on the population model from 1986-2023 with no emigration (left) and with emigration of Bathurst cows (right). The solid blue lines represent model predictions and confidence limits are the hashed blue lines.

The resulting model-based adult female population trajectory (Figure 60) with emigration shows a decline with a model-based estimate of adult females in 2023 of 2,006 (CI=1,286-2,696).

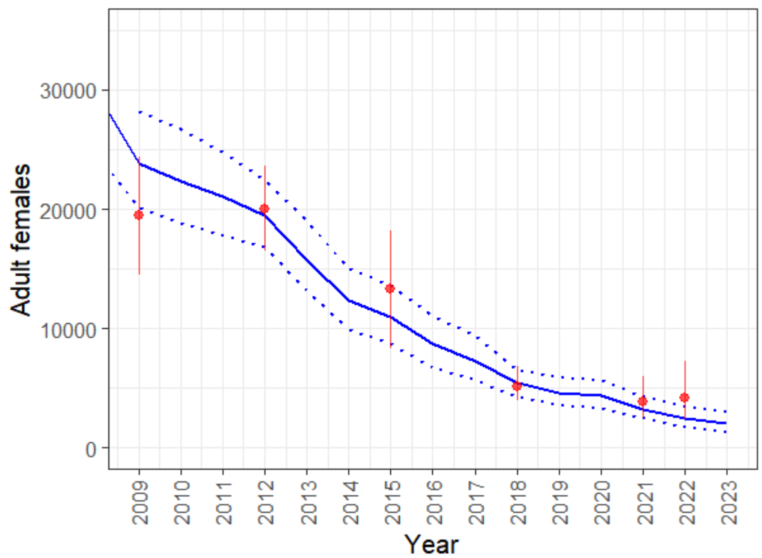

Figure 60. IPM estimates of Bathurst adult female numbers (blue line with confidence intervals as dotted blue lines) 2009-2023 with field estimates shown as red dots and associated confidence limits.

In contrast, the trend in bull numbers shows stability up to 2012, coinciding with an increase in bull/cow ratios followed by a decline and approximate stability from 2022-2023, given no emigration to the Beverly herd (Figure 61).

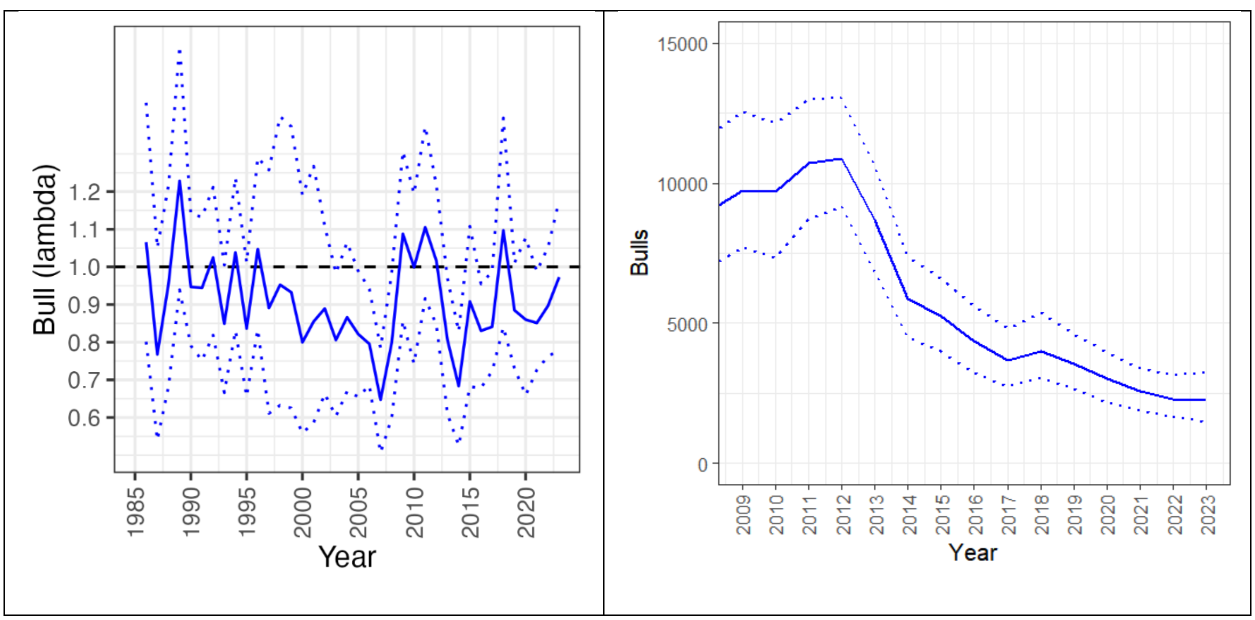

Figure 61. Model-based estimates of Bathurst bull population trend (λ) and associated recent population trajectory of the Bathurst bull population.

If the model-projected cow and bull populations are added together, the resulting estimated Bathurst herd size in 2023 is 4,241 (CI=2,771-6,193) in 2023 (Figure 62). Estimates from the IPM fall within the confidence limits of extrapolated herd estimates from surveys carried out to date.

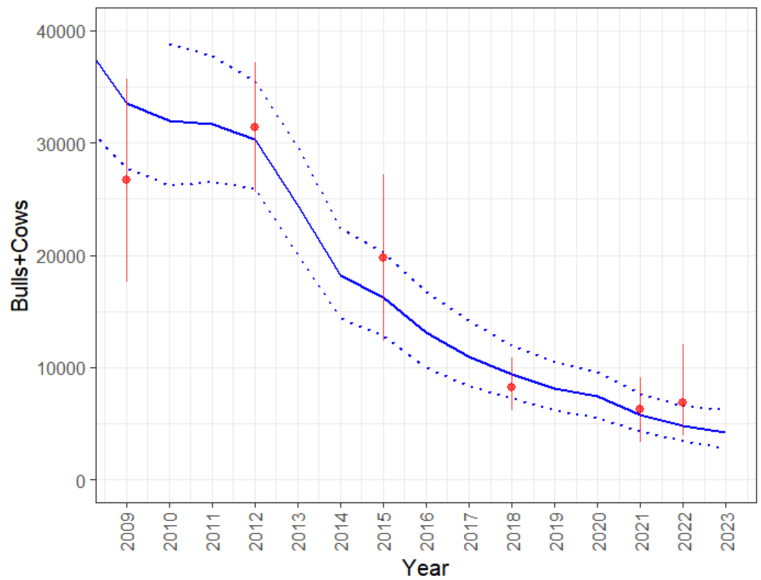

Figure 62. Model-based estimates of Bathurst bull and cow numbers (herd estimates) 2009-2023. Extrapolated herd estimates from calving ground photo surveys are shown with confidence limits in red.

Incidental Sightings of Other Large Mammals and Eagles

A summary of incidental sightings of other large mammals and eagles observed during the June 2023 calving ground surveys is given in Tables 19 and 20. There were 15 grizzly bears observed during the Bluenose-East composition survey, compared to 19 on the Bathurst composition survey.

Table 19. Incidental sightings of other wildlife species on Bluenose-East calving ground survey June 2023. Reconnaissance flights June 4 and 8 are included as Bathurst recon and visual flights June 8 and 9 were included in that category. Recon = reconnaissance; Comp = Composition; (e.g. for muskoxen) 5x1 = 5 singles; (e.g. for bears) 1+2 = female bear + 2 cubs.

Species	Recon Totals	Recon Notes	Visual Totals	Visual Notes	Comp Totals	Comp Notes
Bald Eagle	0		1		2	1, 1
Golden Eagle	2	1, 1	2	1, 1	2	1, 1
Grizzly Bear	11	3x1, 1+1, 1+2, 3	21	7x1, 1+1, 1+2, 1+2, 2x2, 3	12+3	4x1, 1+1, 1+2, 3x2
Moose	1		4	1, 3		
Muskox	35	5x1, 3x2, 4x3, 4, 8	83	12x1, 6x2, 7x3, 5, 2x8, 17	34+1	1, 3x2, 3, 9, 15+1
Wolf	2	1, 1	2	1, 1		
Survey Hours	14.4		21.3		20.7	

Table 20. Incidental sightings of other wildlife species on Bathurst calving ground composition survey in June 2023. Recon = reconnaissance; Comp = Composition; (for muskoxen) 5x1 = 5 singles; 15+6 = 15 adults + 6 calves; (for bears) 1+2 = female bear + 2 cubs.

Species	Comp Totals	Comp Notes
Bald Eagle		
Golden Eagle		
Grizzly Bear	19	4x1, 1+1, 1+2, 1+3, 3x2
Moose	4	1, 1, 2
Muskox	83+10	3x1, 1+1, 3, 4+3, 13, 2x14, 15+6, 16
Wolf	3	1, 2
Survey Hours	10.7	

DISCUSSION

Bluenose-East Survey

The population modeling and analyses of potential survey bias and immigration to the Bluenose-East herd described earlier suggested a number of overall conclusions.

Overall Conclusions

First, the June 2023 Bluenose-East calving ground survey had nearly ideal conditions and the estimates of breeding females, adult females and herd size should be reliable. Caribou sighting conditions from the Caravans were excellent, with very little snow cover and most groups being relatively small and easily counted. The aerial photos were taken under blue skies with ideal light conditions. Distribution of caribou across the survey area varied but was much less clumped than on recent Bathurst calving ground surveys, leading to limited variation in counts between survey lines and a low overall Coefficient of Variation (CV) of 8.7% on the herd estimate. While the possibility exists that the 2021 and 2018 herd estimates were potentially somewhat low due to poor sighting conditions on visual blocks with patchy snow cover, these concerns do not apply to the 2023 Bluenose-East estimate.

Second, the Bluenose-East herd in 2023 was clearly increasing, even if the apparent increase from the 2021 and 2023 estimates was biologically unrealistically high. A large percentage of the adult females and breeding females counted in the 2018, 2021 and 2023 calving ground surveys was from the photo blocks. We note that if only the photo estimates are used to estimate change in adult females, the resulting yearly estimates of change (λ) are 1.06 and 1.16 for the intervals of 2018-2023 and 2021-2023 respectively, suggesting a large-scale increase occurred between 2018/2021 and 2023 if inference is just based on the photo survey blocks. Those counts should be reliable despite the poor snow conditions in 2018 and 2021, as independent second counts and extra time taken to count caribou on the photos in those years indicated that a high percentage of the caribou were found on the photos from each survey.

Third, the proportion of breeding females and calf: cow ratios in June, fall calf: cow and bull: cow ratios and late-winter calf: cow ratios in the Bluenose-East herd all have shown consistently strong values since 2018. Adult female collar-based survival rates have been moderate suggesting stability or an increasing herd. Observations from Kugluktuk HTO members of Bluenose-East caribou and from the summer-fall observations of the Tłįchǫ Government Ekwǫ̀ Nàxoèdee K'è observers (summarized in Appendices 7 and 8) have shown that calves have been large and in good condition, adult males and females have been in good to excellent condition, and there have been high proportions of calves, yearlings and young bulls and cows in the herd. There have been ground-based observations of cows with twins in several years in the summer since 2019 (A. Niptanatiak, Kugluktuk, pers. comm. 2024) and occasionally on October and March aerial composition surveys, although the numeric extent of twinning has been difficult to document.

Fourth, the apparent 31-32% annual increase in Bluenose-East adult females, breeding females and herd size from 2021-2023 is beyond what is biologically possible for a caribou herd under ideal predator-free conditions (λ of 1.28) and does not match well with demographic indicators in the herd such as collar-based cow survival and calf: cow ratios. The lower confidence limit of this estimate (1.18) is still above likely levels of increase. A rate of increase (λ) of 1.12 (CI=1.07-1.17) as estimated from the 2018 and 2023 herd estimates (12% annual increase; CI=7-17%) is biologically more plausible and similar to the values of 1.13-1.14 estimated for the George River herd over a 30-year period of sustained growth (Bergerud et al. 2008). However, the point estimate of 12% annual increase still does not closely match the observed vital rates estimated for the Bluenose-East herd.

A number of factors could have contributed to the high apparent herd growth rate 2018-2023 and particularly 2021-2023, and we suspect that a combination of factors was involved:

(1) The 2021 and possibly the 2018 herd estimates could be somewhat low due to the poor sighting conditions and caribou missed on visual blocks. Of particular relevance is 2021 where no reconnaissance survey was conducted which would have allowed a secondary assessment of relative abundance on the calving ground. However, a high percentage of the estimated caribou numbers on the Bluenose-East calving grounds were in all three years (2018, 2021 and 2023) derived from the aerial photo blocks and we believe those counts were reliable in all three surveys. Thus, the overall trend estimated from the 2018, 2021 and 2023 surveys should be reliable, with true herd size possibly slightly larger in 2018 and particularly in 2021.

(2) Immigration to the Bluenose-East herd from another herd, particularly the Beverly herd, could have occurred and inflated the Bluenose-East estimate in 2023, given the extensive mixing of the Bluenose-East, Bathurst and Beverly herds in winter 2022-2023. Records of collared caribou in these three herds and in other NWT herds indicate that fidelity of collared caribou cows to calving grounds is normally very high (96-99%; Davison et al. 2014, Adamczewski et al. 2020, Boulanger et al. 2022). Direct evidence of switching from another herd to the Bluenose-East herd in 2023 is limited to one GN female caribou collared in April 2023 in NU and found on the Bluenose-East calving ground in June 2023. Power analysis suggests that up to about 4,000 Beverly caribou could have emigrated to other herds, including the Bluenose-East herd, undetected by the limited numbers of collared caribou. An exploratory IPM immigration model estimated that an increase of 11% from 2022-2023 could possibly be partly attributed to emigration from the Beverly herd (Figure 46), however, this result should be interpreted cautiously given lack of direct evidence of emigration.

Extensive mixing of seven herds in winter 2022-2023 in the eastern NWT created multiple opportunities for inter-herd movement.

(3) The cow survival rate has long been known as the vital rate to which population trend is most sensitive in caribou (Fancy et al. 1994, Crête et al. 1996, Boulanger et al. 2011). Collar-based cow survival rates have averaged about 83% in the Bluenose-East herd in recent years, consistent with a stable herd trend; values of at least 90% would be expected in an increasing herd (Boulanger et al. 2011). In an increasing Western Arctic Herd, Prichard et al. (2012) found that collar-based cow survival rates slightly under-estimated the likely true cow survival rate. Haskell and Ballard (2007) similarly concluded that collar-based cow survival rates were negatively biased and failed to predict the Western Arctic Herd's growth 1976-1990. The possibility exists that true herd-wide adult cow survival rate in the Bluenose-East herd 2019-2023 has been higher than estimated from the limited collar sample. The IPM scenario where recent collar-based estimates were eliminated (therefore not constraining the IPM to meet these values) did result in increased survival rates as well as abundance estimates. The resulting increase from 2021 to 2023 (11%) was closer to field-based levels (Figure 46).

Uncertainty in the estimated rate of increase in the Bluenose-East herd 2021-2023 and 2018-2023 and in the underlying reasons for increase suggest that caution should be considered for herd management actions including harvest, pending further surveys and monitoring. Harvest simulations were employed (Appendix 5) to assess likely short-term (three year) consequences of a number of harvest scenarios and considering three underlying herd trends. Simulations based on a moderate level of underlying herd increase suggested that the herd could tolerate low levels of harvest and still continue to increase.

Integrated Population Model Outcomes and Further Applications

The IPM could not exactly meet the 2023 estimates of herd abundance regardless of the scenario that was simulated. However, some scenarios were within the lower limit of the 2023 estimate confidence limit. It is not possible to know whether this difference was due to violated assumptions of the IPM, biased field estimates that go into the IPM, or simply lack of precision of field estimates. We suspect a combination of factors produced the apparent increase 2021-2023, rather than a single reason for lack of fit to field estimates.

Future analyses will further assess bull fidelity, which may have affected bull: cow ratios. The assessment of collar fates and survival rates is ongoing, along with the assessment of emigration and immigration rates of collared caribou from neighboring caribou herds. In this context, maintaining high sample sizes of collared caribou is essential to detect small-moderate movements of collared caribou among herds. The immigration model developed for the Bluenose-East IPM demonstrates one potential approach to assess the potential impact of movement on herd demography. If movement continues between herds, it may be optimal to develop IPM models that treat each herd as a meta-population. Regardless, results show how the IPM approach can be used to help better understand the complex demographics of herds and assess the reliability of various field data sources.

Reliability of Visual Surveys

Comparison of visual (uncorrected), double observer, and photo counts in the Photo Trials block suggested similar counts when transect densities were lower (<5 caribou/km^2), with higher counts for photos as density increased (Figure 24). This comparison was not perfect given the different strip widths of photo and visual surveys as well as different times in which the transects were flown (visual counts afternoon of June 9 and photo lines late June 8 and early June 9). Overall, photo estimates for the entire comparison stratum were 14% higher than double observer visual estimates, which was mainly attributed to higher counts in the two high density lines. A similar comparison of the same transects being flown visually and by the photo plane was made during the 2013 Bluenose-East calving ground survey (Boulanger et al. 2014b) where photo counts were 7% higher than double observer counts. These results suggest that visual counts likely have minimal bias when densities are lower (<5 caribou/km^2) with potential bias toward visual under-estimates at higher densities.

Ground conditions for sighting caribou, including singles and small groups, were ideal in 2023 and therefore this comparison did not consider the effect of marginal survey conditions as in previous surveys (e.g. Bluenose-East in 2018 and 2021, Boulanger et al. 2019 and 2022). An ongoing analysis of the Beverly June 2023 calving ground survey which used video cameras on some survey strata to provide a second count for observers should provide further inference on counting and sightability bias in caribou surveys. Previous comparisons in the 1980s had clearly demonstrated a strong bias toward under-estimation of simple visual counts compared to photo counts when caribou groups were large (hundreds) and observers could only make educated guesses as to their numbers (Heard and Jackson 1990).

One potential reason for the apparent increase in the 2023 Bluenose-East surveys from 2018 and 2021 was negative bias of visual and double observer surveys in 2018 and 2021. A question then becomes how we might improve methods to reduce bias when survey conditions are poor.

One approach that would improve double observer estimates is the use of independent rather than dependent observer methods. Independent observer methods, where the two observers do not communicate caribou that they observed has less assumptions (such as equal detection probabilities of the two observers) and allows a more refined and likely less biased estimate of sightability (Buckland et al. 2004, Laake et al. 2008a, Buckland et al. 2010, Laake and Collier 2024).

Another approach that could be considered is distance sampling where observers record distance bins where caribou are observed (i.e., 0-200, 200-400, 400-1,000, 1,000-1,500 m). Using this approach relaxes the assumption that all caribou are observed in the 0-400 m strip. This method has been successfully employed on the Dolphin-Union (Campbell et al. 2021) and Baffin Island caribou surveys (Campbell et al. 2015b); we note though that these surveys were for small numbers of caribou widely dispersed and they may not be practical in high density areas. The main challenge to these approaches is reconciling observations of the two observers by data recorders and increased observer training for distance methods. For these reasons, they are most applicable to lower density areas. Some aircraft (e.g. the Cessna Caravans used in 2023) are not well suited to the tight circling that distance sampling requires. One approach could be to use traditional strip transect approaches to higher density areas during the reconnaissance phase of the survey while applying distance/independent observer approaches to visual surveys of moderate to lower density areas.

A third approach would be to fly further side-by-side comparisons of photo lines and visual lines when caribou sighting conditions are poor. In the end if groups of caribou have very low detection probabilities due to extremely poor sightability, then it is likely that no visual approach can provide unbiased estimates. In these cases, using aerial photos for lower-density blocks may provide a better estimate, however, this could substantially increase the aerial photography needed and associated time and costs. This approach also assumes that all caribou are detected. Therefore, a double independent observer approach to photo counts, as done in previous surveys, e.g. Bluenose-East in 2018 and 2021 (Boulanger et al. 2019, 2022), should be applied to photo survey data when survey conditions are marginal.

Bathurst Composition and Population Trend

In June 2023, only a composition survey of the Bathurst calving ground was flown, not a calving ground photo survey, however updated estimates of Bathurst vital rates and updated demographic modeling were included in this report. One of the likely factors contributing to the Bathurst herd trend is emigration to the Beverly herd. Model-based estimates of demographic trend based on demography with no emigration from the herd include a 10% annual decline with stability suggested in 2018 and 2023 (Figure 59). However, the model-based trend including the observed emigration results in an estimate of 15-20% annual decline. For evaluation of management actions such as predator control, the demographic status without emigration is most applicable. For evaluation of present status, the trend with emigration is most applicable. The IPM estimated 2,006 (CI=1,286-2,696) adult females and 4,241 (CI=2,771-6,193) cows and bulls in the Bathurst herd in June 2023. As noted above, however, there were no corresponding field estimates of Bathurst adult cows and bulls in 2023 with which to inform, and compare to, the IPM-generated herd estimate, nor did this IPM update consider potential immigration into the Bathurst herd during a period of high winter overlap with the Bluenose-East and Beverly herds. Further development of the IPM for the Bathurst herd is planned to consider these scenarios.

It is notable that recent estimates of vital rates in the Bathurst herd have consistently been lower than in the Bluenose-East herd. For example, collar-based cow survival for 2020, 2021, and 2022 averaged 80.4% in the Bathurst herd and 83% in the Bluenose-East herd. Fall calf: cow ratios in the Bathurst herd for 2020, 2022 and 2023 averaged 38.1 calves: 100 cows, while fall ratios in the Bluenose-East herd in the same years averaged 51.8 calves: 100 cows.

Greater early calf mortality on the calving grounds may have contributed to the demographic disparity between the two herds. In June 2023 the calf: cow ratio in breeding cows was 86.3 calves: 100 cows in the Bluenose-East herd and 67.1 calves: 100 cows in the Bathurst herd. Distribution of calving cows on the two calving grounds has shown very different patterns: the Bluenose-East calving ground is relatively large and the many dispersed groups of caribou are often small (<30). Nearly all the Bathurst calving females were in a few larger groups each numbering hundreds and concentrated within an area of about 5x15 km. We observed 15 grizzly bears on the Bluenose-East calving grounds in June 2023 and 19 grizzly bears on the Bathurst calving grounds during composition surveys. Finding and preying on concentrated Bathurst newborn calves in a limited number of groups in a small area could be relatively easy for bears, compared to finding the much more widely dispersed Bluenose-East newborn calves in numerous relatively small groups. An ongoing DNA-based grizzly bear survey in NU (Malik Awan, GN) will provide density estimates of grizzly bears in the Bathurst range.

Importance of Monitoring Inter-herd Movement

The results of the June 2023 Bluenose-East population surveys and Bathurst composition survey resulted in trends in adult female and bull numbers that were not easily explained using traditional analyses and modeling that assume minimal movement for bulls and cows between neighboring herds. An example of this is the large observed increase in the Bluenose-East herd 2021-2023. Extensive mixing of seven caribou herds in winter 2022-2023 (Bathurst, Beverly, Bluenose-East, Qamanirjuaq, Wager Bay, Lorillard and Ahiak) created the potential for movement among these herds, including potential movement to or from the Bluenose-East herd, that the limited collar numbers could not detect. Spring migration paths northward of collared cows showed multiple cases of cows headed for the "wrong" calving ground, then making a late turn toward their expected calving grounds. A further example is the large observed increase in bull-cow ratios in the Bathurst herd in 2022 and 2023. It is possible that this was partially due to increased productivity and bull survival, however, it is possible that emigration of Bathurst cows to the Beverly herd that did not occur in Bathurst bulls contributed to this increase. The challenge in monitoring movement of cows and bulls between herds is the relatively low sample size of collared caribou. It is essential that reasonable sample sizes of collared caribou with collars that last for at least two to three years are deployed, to allow better understanding of the role of movement in overall herd status and dynamics.

A series of monthly collared caribou maps that include the Bathurst, Bluenose-East and Beverly herds from October 2022 to October 2023 is included as Appendix 6 to illustrate the mixing of the three herds in winter 2022-2023, spring movements north and the degree of separation seasonally among the three herds.

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APPENDICES

Appendix 1. Double Observer Analysis of Visual Survey Data

A summary of double observer methods and calculations was included in Methods and Results of the main text. This appendix provides greater detail on the calculations that were made.

Methods

A double observer method was used to estimate the sighting probability of caribou during visual surveys. 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 1). The method followed five basic steps:

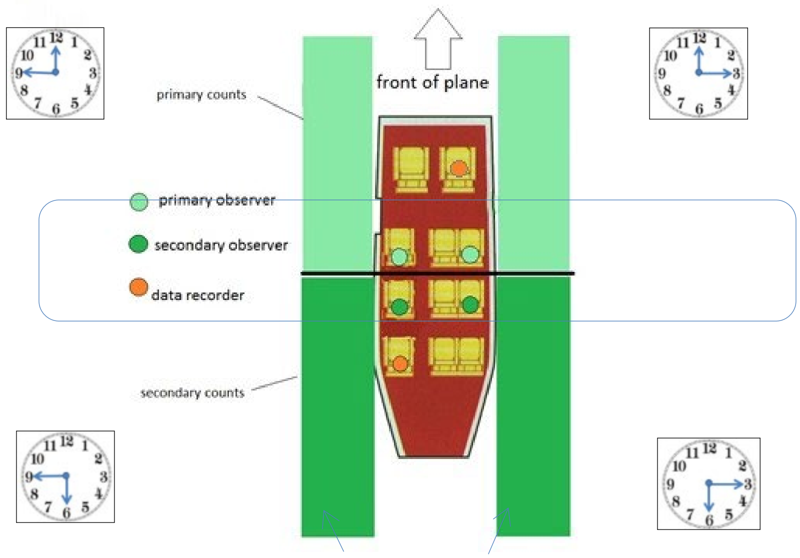
1 - The primary observer called out all groups of caribou (number of caribou and location) he/she saw within the 400 m wide strip transect before they passed about halfway between the primary and secondary observer. This included caribou groups that were between approximately 12 and 3 o'clock for right 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 halfway 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 halfway 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.



Counting strip (wheel to wing strut

Figure 1. Observer and recorder positions for double observer methods on June 2023 survey of the Bluenose-East caribou herd. 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 refer 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.

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 two 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, Laake et al. 2008b) 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, we also considered the following covariates in the analysis (Table 1). Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. Group size was modelled using a straight additive term and log transformed group size. The log-transformed group size modeled a situation where lower sighting probabilities occurred for smaller group sizes. Survey phase was also considered. In the reconnaissance phase, effort was partially dedicated to classification of caribou which may have reduced detection probabilities compared to visual surveys. An additional survey phase, photo trials, where a portion of the photo strata was surveyed to compare with photo counts, was also added, assuming that attention may have been higher in this area which also had higher densities of caribou compared to other visual strata. Snow and cloud cover was modeled as a categorical covariate based on the categorical entries in the tablets.

Table 1. Covariates used to model variation in sightability for double observer analysis for Bluenose-East caribou survey in June 2023.

Covariate	Acronym	Description
observer pair	obs	each unique observer pair
group size	size	size of caribou group observed
	logsize	Log of group size
Phase	Phase	Reconnaissance, Visual, and photo trials
	Phase2	Reconnaissance, Visual
snow cover	snow	snow cover (0, 25, 75, 100)
cloud cover	cloud	cloud cover (0, 25, 75, 100)

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 2024). In MRDS, a full independence removal estimator which models sightability using only double observer information (Laake et al. 2008a, Laake et al. 2008b) 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

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 who all switched places during the survey (Table 2). The proportion switching indicates the proportion of observations from the first and second observer in each pair. It should be close to 0.5 for each observer if observers switched evenly. Switching occurred relatively evenly for all pairs except pair two. The probabilities of sighting (1-secondary/total sightings) were relatively high. Observer pair three had slightly lower sighting probabilities than the other observer pairs. Sighting probabilities were relatively high presumably due to lack of snow cover in most of the survey area.

Table 2. Double observer pairings with associated summary statistics for Bluenose-East June 2023 caribou survey. Single observer probabilities are estimated as (1-secondary/total sightings) and double observer probabilities are estimates as $1-(1-\text{single } p)^2$. Percent switching is the proportion of observations for each observer in a pair.

Observer information	Frequencies				Switching	Probabilities	
Pair Number	Secondary	Primary	Both	Total Observations	Observer 1/ Observer 2	Single Observer	Double Observer
1	36	18	387	441	0.45/0.55	0.92	0.99
2	22	15	360	397	0.87/0.13	0.94	1.00
3	66	58	270	394	0.46/0.54	0.83	0.97
4	54	34	376	464	0.42/0.58	0.88	0.99

Frequencies of observations as a function of group size, survey, and phase suggested that approximately 72% of the single caribou were seen by both observers (Figure 2). As group size increased the proportion of observations seen by both observers increased.

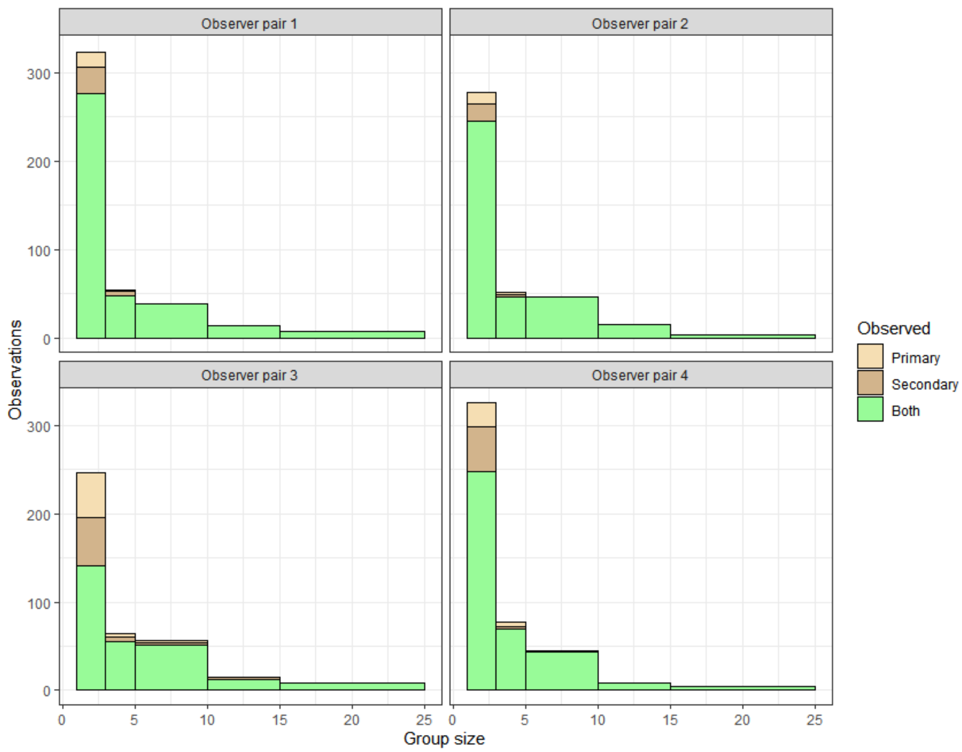


Figure 2. Frequencies of double observer observations by group size, survey phase and survey for Bluenose-East 2023 calving ground survey. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

Survey phase had some influence on detection probabilities with reconnaissance phase showing slightly lower detection probabilities of smaller size groups compared to visual and photo trials. Photo trials had higher sightability with very few observations seen only by single observers (Figure 3).

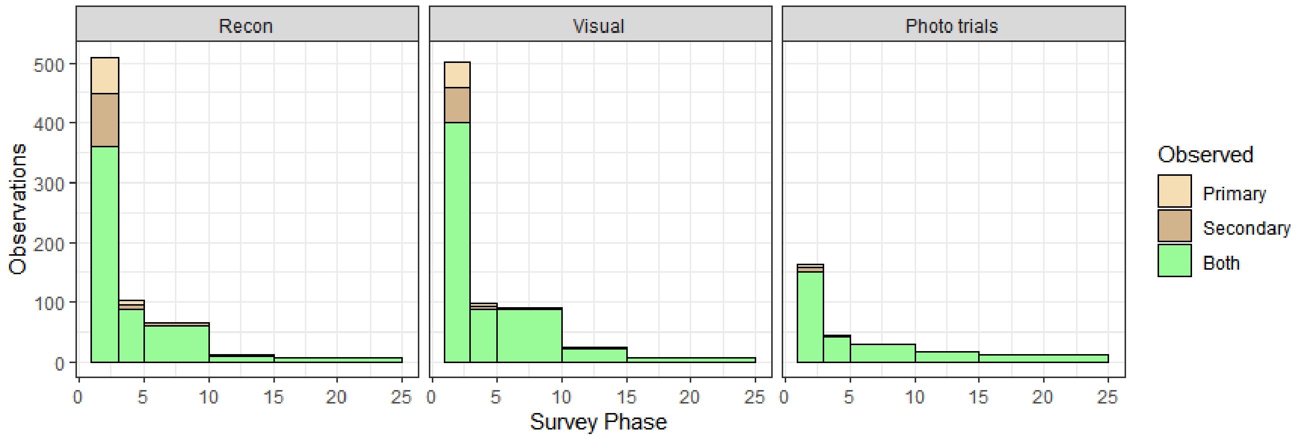


Figure 3. Proportions of observations by survey phase during Bluenose-East June 2023 calving ground survey. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

The percentage of snow observed during surveys was nearly all 0-25% (Figure 4) suggesting that variation in snow cover likely did not influence sighting probabilities. We note that the 0-25% category was one of the limited categories available in the Yuma tablet programs; in reality, snow cover was nearly always well below 5% (Figure 10).

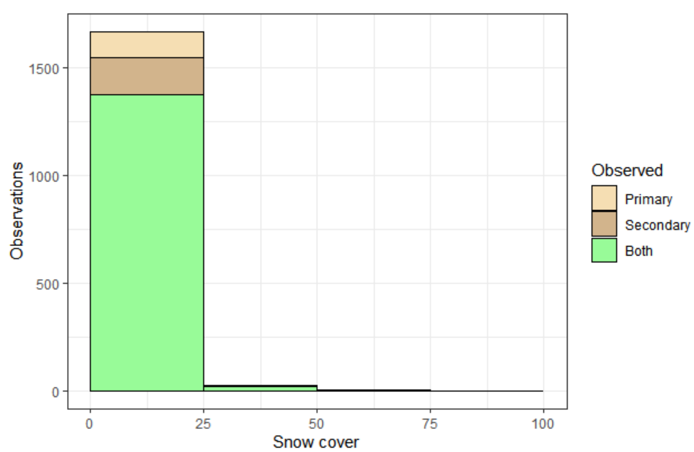


Figure 4. Percentage snow cover estimated during the Bluenose-East 2023 calving ground survey.

Cloud cover was primarily 0-25% or 75-100% throughout the survey (Figure 5). We note here also that the tablet computers had a limited number of categories available for cloud cover.

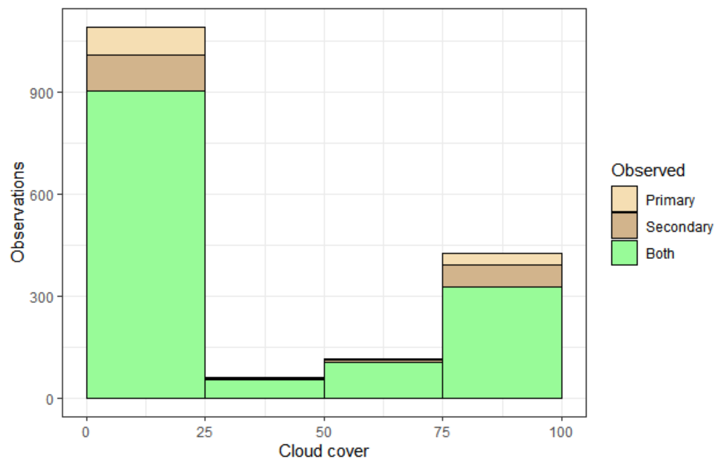


Figure 5. Percentage cloud cover estimated during the Bluenose-East June 2023 calving ground survey.

Model selection results indicated effects of phase, observer pair, and the log of group size on double observer probabilities (Table 3: Model 1). Univariate model results suggested that the log of group size (Model 8) had the strongest effect followed by observer pair (Model 10) and phase (Model 11). A model that had an interaction of observer pair and log of group size was tied for support with the additive observer and group size model.

Table 3. Double observer model selection for June 2023 Bluenose-East June survey. 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 log-likelihood (LL) are presented.

Model #	Model	AICc	ΔAIC$_c$	wi	K	LL
1	Phase + obs + logsize	1,058.37	0.00	0.51	7	-521.9
2	Phase + obs * logsize	1,058.99	0.62	0.38	10	-519.0
3	Phase2 + obs + logsize	1,061.42	3.05	0.11	6	-524.5
4	obs + logsize	1,069.21	10.84	0.00	5	-529.5
5	obs + size	1,076.30	17.93	0.00	5	-533.0
6	Phase + logsize	1,085.94	27.57	0.00	4	-538.9
7	Phase + size	1,091.17	32.80	0.00	4	-541.5
8	logsize	1,098.92	40.55	0.00	2	-547.4
9	size	1,104.39	46.02	0.00	2	-550.2
10	obs	1,120.26	61.88	0.00	4	-556.0
11	Phase	1,123.64	65.27	0.00	3	-558.8
12	Phase2	1,128.72	70.35	0.00	2	-562.3
13	cloud	1,131.57	73.19	0.00	5	-560.6
14	snow	1,139.05	80.68	0.00	4	-565.4
14	constant	1,143.06	84.69	0.00	1	-570.5

Plots of single and double observation probabilities from model 1 showed lower probabilities for individual or smaller group sizes with the pronounced differences in the recon phase (Figure 6). Detection probabilities for both observers combined were above 0.8 for all group sizes. The results of these plots illustrate that lower single observer probabilities mainly existed for single caribou or smaller groups, but the overall effect of lower single observer sighting probabilities was offset by having two observers, which resulted in relatively high double observer probabilities.

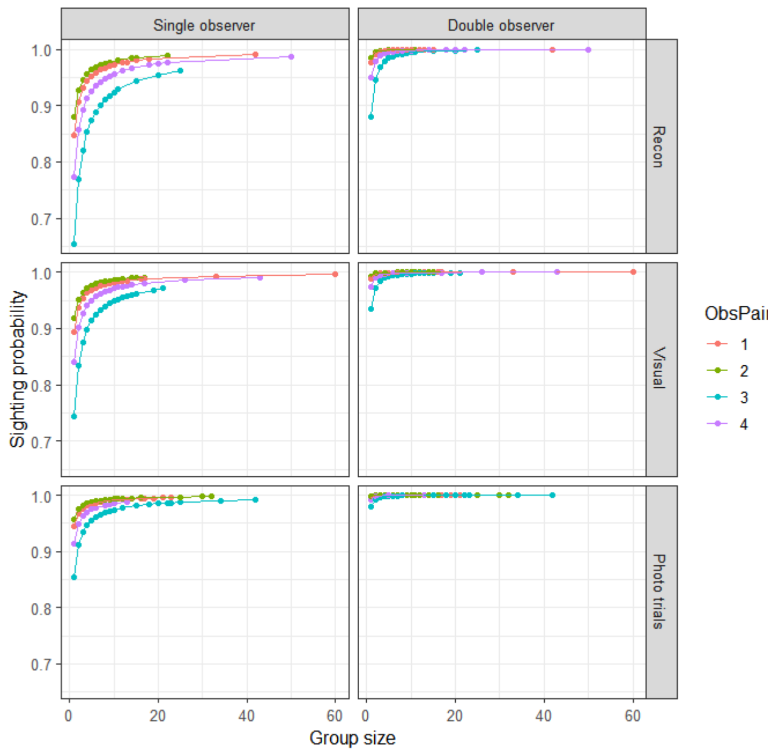


Figure 6. Estimated double observer probabilities from model 2 (Table 3) by observer pair, for June 2023 Bluenose-East caribou survey.

Estimates of Total Caribou in Visual Strata

Estimates from Model 1 (Table 3 Phase + obs + logsize) were used for abundance estimates. Estimates from Model 2 (Phase + obs*logsize) which displayed lower support were very close (14,041 compared to 14,043) suggesting minimal change in estimates due to inclusion of the interaction term (Table 3). Double observer estimates were about 4% (528 caribou) higher than the standard strip transect estimator that assumes perfect sightability on the survey strip (Table 4). Precision for the double observer estimate was similar to the strip transect estimator despite added complexity of double observer models, 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). Overall precision of the overall estimates was good with an overall CV of 7.9%.

Table 4. Estimates of caribou in visual survey strata from double observer and strip transect estimates for the Bluenose-East June 2023 survey. The number of caribou sighted on transect, estimates of abundance (N), standard error (SE), confidence limit (CI) and coefficient of variation (CV) are given for the double observer model (Model 1, Table 3) and the standard strip transect estimator.

Stratum	Caribou counted	Double observer estimates (model 1)					Strip-transect estimates		
		N	SE	CI		CV	N	SE	CV
Visual East	87	445	133.2	218	912	29.9%	441	117.1	26.6%
Visual Far South	158	2,077	400.4	1,271	3,394	19.3%	1,944	373.9	19.2%
Visual North	306	1,512	310.8	980	2,333	20.6%	1,490	262.3	17.6%
Visual South	950	4,993	451.8	4,108	6,069	9.0%	4,719	662.1	14.0%
Visual SE	829	4,390	856.7	2,811	6,856	19.5%	4,304	652.5	15.2%
Visual West	125	623	112.1	408	950	18.0%	615	96.3	15.7%
Total	2455	14,041	1,107.1	11,912	16,549	7.9%	13,512	1,046.8	7.7%

An additional estimate was derived for the photo trials strata of 6,647 caribou (SE=803.8, CI=5,035-8,776, CV=12.1%). A discussion of this estimate in comparison to the photo plane estimate is covered in the main survey report.

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Appendix 2. Details of Integrated Population Model (IPM) Analyses of the Bluenose-East and Bathurst herds

Integrated Population Model analysis was performed in collaboration with Joe Thorley (www.poissonconsulting.ca). Details are given on the Bluenose-East and Bathurst base IPM models. Further information including code and results for individual scenario analyses is available upon request to the authors.

Bluenose-East Integrated Population Model

Suggested citation: Thorley, J.L. and Boulanger, J. (2024) Bluenose-East Caribou Herd Population Analysis 2023. A Poisson Consulting Analysis Appendix in Boulanger, J., J. Adamczewski, J. Williams, S. Goodman, K. Clark, R. Abernathy and L. LeClerc. 2024. June 2023 Calving Ground Surveys: Bluenose-East and Bathurst Barren-Ground Caribou Herds. Environment and Climate Change, Government of the Northwest Territories.

Data Preparation

The estimates of key population statistics with standard errors (SEs) and lower and upper bounds were provided in the form of an csv spreadsheet and prepared for analysis using R version 4.3.2 (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). Schaub and Kery (2022) provide an excellent description of IPMs.

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 1500 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).

Parameters are summarized 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 sensitivity of the estimates to the choice of priors was examined by multiplying the standard deviations of the normal priors by ten and using the split $\hat{R}$ (after collapsing the chains) to compare the posterior distributions (Thorley and Andrusak 2017). A split $\hat{R} \leq 1.1$ was taken to indicate low sensitivity.

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 et al. 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 4.3.2 (R Core Team 2020) and the embr (Poisson Consulting, 2024) family of packages.

Model Descriptions

The data were analyzed using a state-space population model (Newman et al. 2014). Parameters are described in Table 1 and model coefficients are in Table 2. A summary of model fit is in Table 3.

Population

The cow and bull harvest, fecundity, breeding cow abundance, cow survival, bull survival, fall bull cow, fall calf cow and spring calf cow ratio data complete with standard errors were analyzed 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)
- Cow natural survival from calving to the following year varies continually and randomly by year.
- Bull natural survival 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.

- The calf sex ratio is 1:1.
- Fecundity varies randomly by year.
- In an average year two-year-old cows have a fecundity of 0.25.
- Female yearlings are indistinguishable from cows in the fall and spring surveys.
- The uncertainty in the number of cows in the initial year is described by a positively truncated normal distribution with a mean of 75,000 and a standard deviation of 25,000.
- The number of bulls in the initial year relative to the number of cows is described by a beta distribution with an alpha of 11 and a beta of 11.
- The number of calves in the initial year relative to the number of cows is described by a beta distribution with an alpha of 19 and a beta of 3.
- The number of yearlings in the initial year relative to the number of cows is described by a beta distribution with an alpha of 11 and a beta of 11.
- The number of two-year-old cows in the initial year relative to the number of cows is described by a beta distribution with an alpha of 3 and a beta of 19.
- The uncertainty in each data point is normally distributed with a standard deviation equal to the provided standard error.

Table 1. Parameter description for the Bluenose-East IPM.

Parameter	Description
Annual	The year as a integer starting at 1
BreedingCowsSE[i]	The standard error for BreedingCows[i]
BreedingCows[i]	The data point for the number of breeding cows in the i^{th} year
BreedingProportionSE[i]	The standard error for BreedingProportionSE[i]
BreedingProportion[i]	The data point for the log-odds proportion of cows breeding in the i^{th} year
BullSurvivalSE[i]	The standard error for BullSurvival[i]
BullSurvival[i]	The data point for log-odds bull survival from the $i-1^{th}$ year to the i^{th} year
CowSurvivalSE[i]	The standard error for CowSurvival[i]
CowSurvival[i]	The data point for log-odds cow survival from the $i-1^{th}$ year to the i^{th} year
FallBullCowSE[i]	The standard error for FallBullCow[i]
FallBullCow[i]	The data point for the bull cow ratio in the fall of the i^{th} year
FallCalfCowSE[i]	The standard error for FallCalfCow[i]
FallCalfCow[i]	The data point for the calf cow ratio in the fall of the i^{th} year
HarvestedBullsSE[i]	The standard error for HarvestedBulls[i]
HarvestedBulls[i]	The data point for the number of bulls harvested in January of the i^{th} year
HarvestedCowsSE[i]	The standard error for HarvestedCows[i]
HarvestedCows[i]	The data point for the number of cows harvested in January of the i^{th} year
SpringCalfCowSE[i]	The standard error for SpringCalfCow[i]
SpringCalfCow[i]	The data point for the calf cow ratio in the spring of the i^{th} year
bBreedingCows1	The number of breeding cows in the initial year

Parameter	Description
bBullsCows1	The bull to cow ratio in the initial year
bFecundityCow	The log-odds proportion of three year and older cows breeding in a typical year
bFecundityTwolingCow	The log-odds proportion of two year old cows breeding in a typical year
bHarvestRateBullYear[i]	The change in bbHarvestRateBull by year for the i[th] HarvestPeriod
bHarvestRateBull[i]	The log-odds probability of a bull being harvested in year 0 for the i[th] HarvestPeriod
bHarvestRateCowYear[i]	The change in bbHarvestRateCow 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
bSurvivalBullAnnual[i]	The random effect of the i[th] Annual on bSurvivalBull
bSurvivalBull	The log-odds bull survival in a typical year
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
bSurvivalCowAnnual[i]	The random effect of the i[th] Annual on bSurvivalCow
bSurvivalCow	The log-odds cow (and yearling) survival in a typical year
sSurvivalBullAnnual	The SD of bSurvivalBullAnnual
sSurvivalCalfAnnual	The SD of bSurvivalCalfAnnual
sSurvivalCowAnnual	The SD of bSurvivalCowAnnual

Table 2. Model coefficients for the Bluenose-East IPM

term	estimate	lower	upper	svalue
bBullsCows1	0.4655423	0.2839381	6.621614e-01	10.5517083
bCalvesCows1	0.8866488	0.7443797	9.702303e-01	10.5517083
bCows1	86574.8315935	62102.8229142	1.218529e+05	10.5517083
bFecundityCow	3.3470533	2.0964358	5.000995e+00	10.5517083
bHarvestRateBull[1]	-3.1290369	-3.9231427	-2.337708e+00	10.5517083
bHarvestRateBull[2]	-4.4419455	-6.4791760	-2.139834e+00	10.5517083
bHarvestRateBullYear[1]	0.0102792	-0.1039145	1.160579e-01	0.2467866
bHarvestRateBullYear[2]	0.0551102	-0.1206841	1.979826e-01	1.0261875
bHarvestRateCow[1]	-3.7139594	-4.8725573	-2.779540e+00	10.5517083
bHarvestRateCow[2]	-4.3027503	-6.7430258	-1.287063e+00	7.7443533
bHarvestRateCowYear[1]	0.0105256	-0.1733038	2.170423e-01	0.1476311
bHarvestRateCowYear[2]	-0.0749473	-0.3203315	1.130927e-01	0.9837522
bSurvivalBull	0.4909423	0.1097234	9.381811e-01	5.7968208
bSurvivalCalfSummerAnnual	-1.1957419	-1.6023575	-8.097458e-01	10.5517083
bSurvivalCalfWinterAnnual	0.3796238	-0.0863463	8.570576e-01	3.2029801
bSurvivalCow	1.3301764	1.0310259	1.670729e+00	10.5517083
bTwolingsCows1	0.1247538	0.0324806	3.066552e-01	10.5517083
bYearlingsCows1	0.4746291	0.2864834	6.737806e-01	10.5517083
sFecundityAnnual	2.1158734	1.2290632	3.762975e+00	10.5517083
sSurvivalBullAnnual	0.7536839	0.4534848	1.206781e+00	10.5517083
sSurvivalCalfAnnual	0.6331283	0.4071569	1.021540e+00	10.5517083
sSurvivalCowAnnual	0.5490871	0.3051908	9.762127e-01	10.5517083

Table 3. Model fit and convergence summary for Bluenose-East IPM. The number of years in the input data set (*n*), the number of model parameters (*K*), the number of MCMC chains used for model runs (*nchains*), the number iterations run for each chain (*niters*), the number of initial thinning runs (*nthin*), effective sample sizes for parameters (*ess*), the scale reduction factor (*rhat*) and eventual model convergence status are listed. Each of these statistics is described in the methods and/or Schaub and Kery (2022).

n	K	nchains	niters	nthin	ess	rhat	converged
17	22	3	500	100	244	1.012	TRUE

Bathurst Integrated Population Model

Suggested citation: Thorley, J.L. and J. Boulanger. 2023. Bathurst Caribou Herd Population Analysis 2023. A Poisson Consulting Analysis Appendix. in .Boulanger, J., J. Adamczewski, J. Williams, S. Goodman, K. Clark, R. Abernathy and L. LeClerc. 2024. June 2023 Calving Ground Surveys: Bluenose-East and Bathurst Barren-Ground Caribou Herds. Environment and Climate Change, Government of the Northwest Territories.

Similar data preparation and methods were employed for the Bathurst and Bluenose-East IPM.

Model Description

The cow and bull harvest, fecundity, breeding cow abundance, cow survival, bull survival, fall bull cow, fall calf cow and spring calf cow ratio data complete with standard errors together with cow collar fidelity data were analyzed 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)
- Cow natural survival from calving to the following year varies continually and randomly by year.
- Bull natural survival 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.
- 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.
- The calf sex ratio is 1:1.
- The proportion of breeding cows is the fecundity the previous year.
- Fecundity varies randomly by year.
- Female yearlings are indistinguishable from cows in the fall and spring surveys.
- Emigration which occurs in the spring is constant until 2005 whereupon it changes and varies randomly by year.

- The cow collar fidelity is binomially distributed.
- 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 normal distribution with a mean of 200,000 and a standard deviation of 50,000 that is positively truncated at 50,000 breeding cows.
- 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 by the calf survival in a typical year.
- The uncertainty in each data point with a standard error is normally distributed with a standard deviation equal to the provided standard error.

Parameters are described in Table 4 and model coefficients are in Table 5. A summary of model fit is in Table 6.

Table 4. Parameter descriptions for the Bathurst IPM.

Parameter	**Description**
Annual	The year as a integer starting at 1
BreedingCowsSE[i]	The standard error for BreedingCows[i]
BreedingCows[i]	The data point for the number of breeding cows in the i^{th} year
BreedingProportionSE[i]	The standard error for BreedingProportionSE[i]
BreedingProportion[i]	The data point for the logistic proportion of cows breeding in the i^{th} year
BullSurvivalSE[i]	The standard error for BullSurvival[i]
BullSurvival[i]	The data point for logistic bull survival from the i-1^{th} year to the i^{th} year
CollarsFidelity[i]	The total number of collared cows remaining with the herd in the spring of the i^{th} year
CollarsTotal[i]	The total number of collared cows in the spring of the i^{th} year
CowSurvivalSE[i]	The standard error for CowSurvival[i]
CowSurvival[i]	The data point for logistic cow survival from the i-1^{th} year to the i^{th} year
FallBullCowSE[i]	The standard error for FallBullCow[i]
FallBullCow[i]	The data point for the bull cow ratio in the fall of the i^{th} year
FallCalfCowSE[i]	The standard error for FallCalfCow[i]
FallCalfCow[i]	The data point for the calf cow ratio in the fall of the i^{th} year
HarvestedBullsSE[i]	The standard error for HarvestedBulls[i]
HarvestedBulls[i]	The data point for the number of bulls harvested in January of the i^{th} year
HarvestedCowsSE[i]	The standard error for HarvestedCows[i]
HarvestedCows[i]	The data point for the number of cows harvested in January of the i^{th} year
SpringCalfCowSE[i]	The standard error for SpringCalfCow[i]
SpringCalfCow[i]	The data point for the calf cow ratio in the spring of the i^{th} year
bBreedingCows1	The number of breeding cows in the initial year

Parameter	Description
bBullsCows1	The bull to cow ratio in the initial year
bFecundityAnnual[i]	The random effect of the i^{th} Annual on bFecundity
bFecundity	The log-odds probability of a cow breeding in a typical year
bFidelityAnnual[i]	The random effect of the i^{th} Annual on bFidelity
bFidelity[i]	The log-odds probability of a cow remaining with the herd in a typical year in the i^{th} FidelityPeriod
bHarvestRateBullYear[i]	The change in bbHarvestRateBull by year for the i^{th} HarvestPeriod
bHarvestRateBull[i]	The log-odds probability of a bull being harvested in year 0 for the i^{th} HarvestPeriod
bHarvestRateCowYear[i]	The change in bbHarvestRateCow 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
bSurvivalBullAnnual[i]	The random effect of the i^{th} Annual on bSurvivalBull
bSurvivalBull	The log-odds bull survival in a typical year
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
bSurvivalCowAnnual[i]	The random effect of the i^{th} Annual on bSurvivalCow
bSurvivalCow	The log-odds cow (and yearling) survival in a typical year
sFecundityAnnual	The SD of bFecundityAnnual
sFidelityAnnual	The SD of bFidelityAnnual
sSurvivalBullAnnual	The SD of bSurvivalBullAnnual
sSurvivalCalfAnnual	The SD of bSurvivalCalfAnnual
sSurvivalCowAnnual	The SD of bSurvivalCowAnnual

Table 5. Model coefficients for the Bathurst IPM.

term	estimate	lower	upper	svalue
bBullsCows1	5.136353e-01	3.216414e-01	7.020817e-01	10.5517083
bCalvesCows1	6.935697e-01	5.228393e-01	8.683632e-01	10.5517083
bCows1	2.521636e+05	2.160808e+05	2.978752e+05	10.5517083
bFidelity[1]	6.466819e+00	4.312788e+00	9.401494e+00	10.5517083
bFidelity[2]	3.217204e+00	2.427601e+00	4.608949e+00	10.5517083
bHarvestRateBull[1]	-3.032998e+00	-3.801487e+00	-2.288854e+00	10.5517083
bHarvestRateBull[2]	-6.819929e+00	-9.150633e+00	-4.457191e+00	10.5517083
bHarvestRateBull[3]	-3.191979e+00	-4.820876e+00	-1.612072e+00	10.5517083
bHarvestRateBullYear[1]	6.963660e-02	-5.690700e-03	1.451622e-01	3.8374627
bHarvestRateBullYear[2]	2.189510e-01	1.053586e-01	3.274628e-01	8.9667458
bHarvestRateBullYear[3]	-4.633740e-02	-9.640430e-02	5.469000e-03	3.6568905
bHarvestRateCow[1]	-3.368178e+00	-3.856382e+00	-2.978699e+00	10.5517083
bHarvestRateCow[2]	-6.101135e+00	-8.049131e+00	-4.250474e+00	10.5517083
bHarvestRateCow[3]	-7.741231e+00	-9.757824e+00	-5.952003e+00	10.5517083
bHarvestRateCowYear[1]	3.714570e-02	-3.599000e-03	8.206860e-02	3.5404810
bHarvestRateCowYear[2]	1.684258e-01	7.996900e-02	2.562304e-01	10.5517083

term	estimate	lower	upper	svalue
bHarvestRateCowYear[3]	-1.658590e-02	-7.710880e-02	4.769530e-02	0.7524266
bSurvivalBull	9.362052e-01	7.028343e-01	1.228678e+00	10.5517083
bSurvivalCalfSummerAnnual	-9.373148e-01	-1.377568e+00	-3.951689e-01	8.9667458
bSurvivalCalfWinterAnnual	1.793066e-01	-2.694865e-01	6.748978e-01	1.1444405
bSurvivalCow	1.555662e+00	1.367522e+00	1.811929e+00	10.5517083
bTwolingsCows1	1.225720e-01	3.001540e-02	3.002669e-01	10.5517083
bYearlingsCows1	5.126442e-01	3.216427e-01	6.933010e-01	10.5517083
sFecundityAnnual	1.643214e+00	1.113604e+00	2.446617e+00	10.5517083
sFidelityAnnual	1.349751e+00	4.797834e-01	2.686984e+00	10.5517083
sSurvivalBullAnnual	5.461477e-01	2.425063e-01	9.404520e-01	10.5517083
sSurvivalCalfAnnual	9.832040e-01	7.026946e-01	1.397254e+00	10.5517083
sSurvivalCowAnnual	5.129349e-01	3.118153e-01	7.938741e-01	10.5517083

Table 6. Model fit summary for the Bathurst IPM. The number of years in the input data set (*n*), the number of model parameters (*K*), the number of MCMC chains used for model runs (*nchains*), the number iterations run for each chain (*niters*), the number of initial thinning runs (*nthin*), effective sample sizes for parameters (*ess*), the scale reduction factor (*rhat*) and eventual model convergence status are listed. Each of these statistics is described in the methods and/or Schaub and Kery (2022).

n	K	nchains	niters	nthin	ess	rhat	converged
39	67	3	500	200	309	1.012	TRUE

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Appendix 3. Further Details on Analysis of Collar Movements, Overlap and Migration Paths

Collar Switching and Movement between Herds

Under most conditions, emigration from one barren-ground herd to another is thought to occur at relatively low rates based on movements of collared female caribou. Previous calving ground survey reports (Boulanger et al. 2022) have assessed movements of collared cows between the Bluenose-East herd and its neighbouring herds the Bluenose-West and Bathurst herds. Fidelity has been in the range of 97-99%, with an occasional single cow moving to a neighbouring herd and an equally low rate of movements in the reverse direction. Movements of Bathurst caribou to the Beverly calving ground have been at higher rates in 2018, 2019, 2021 and 2023 (Adamczewski et al. 2022), and this emigration is a concern for the herd given its current size and trend. We assessed the possibility that the apparent increase in the Bluenose-East herd 2021-2023 could have in part resulted from an influx of caribou from another herd.

Switching Detected Based on Collars of Known Adult Females

Figure 1 below shows collar switching of known adult female caribou in the Bathurst, Bluenose-East and Beverly herds since 2016. In 2023, three Bathurst cows switched to the Beverly distribution and 1 Bluenose-East cow switched to the Bathurst distribution. Sample sizes of cows of known herd origin were 17, 22 and 33 caribou for the Bathurst, Beverly, and Bluenose-East herds. One female caribou collared by GN in the Garry Lakes area in April 2023 was found on the Bluenose-East calving ground in June 2023.

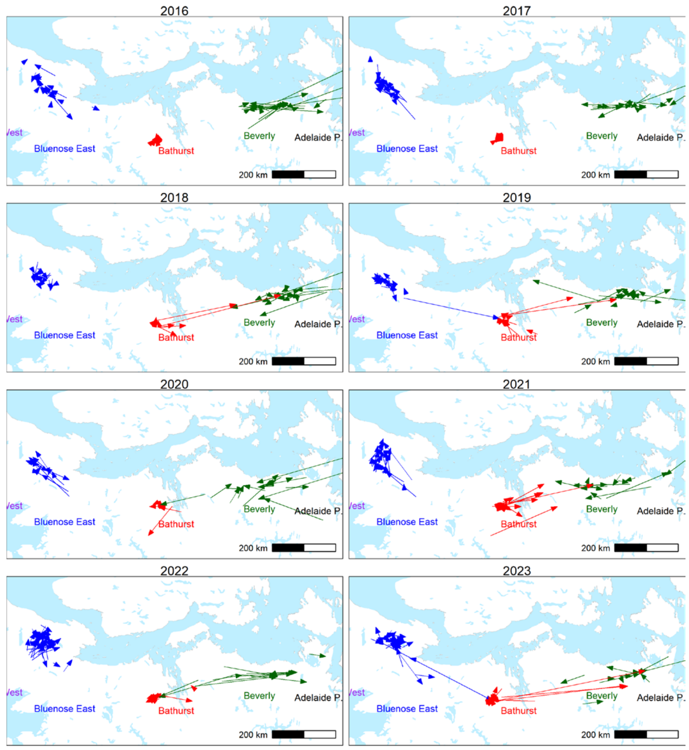

Figure 1. Mean locations of collared females from June 6 to 12 at current year (arrowhead) compared to previous year (arrow tail) for females collared in successive years, from the Bathurst, Bluenose-East and Beverly herds from 2016-2023. Arrows are colored based on previous year calving ground/herd designation.

We further assessed switching between the Bluenose-West and Bluenose-East herds (Figure 2). The location of calving was relatively close in 2022, however no switching between herds was documented except in 2018 when one Bluenose-East collar calved on the Bluenose-West calving ground.

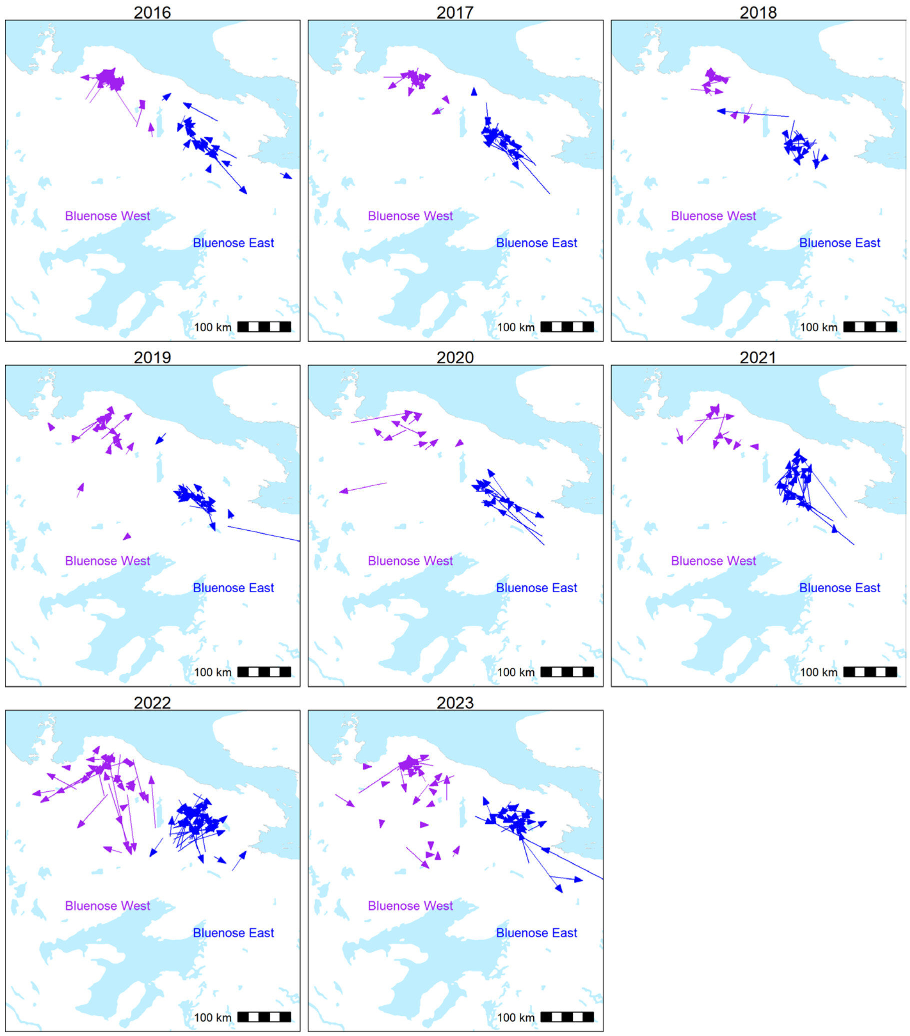

Figure 2. Mean locations of collared females at current year (arrowhead) compared to previous year (arrow tail) for females collared in successive years for Bluenose-East and Bluenose-West herds. Arrows are colored based on previous year calving ground/herd designation.

Potential Emigration Events based on Winter Overlap and Migration Paths

One challenge with documenting switching between herds is low sample sizes of collared caribou with two or more years of data to allow documentation of calving ground fidelity or switching. The degree of overlap between the Bathurst, Bluenose-East and Beverly herds has increased especially in April at the beginning of northward migration (Figure 3). Analysis with the Bathurst herd has suggested that the probability of movement from the Bathurst to the Beverly herd in June increases with extensive overlap during the previous winter.

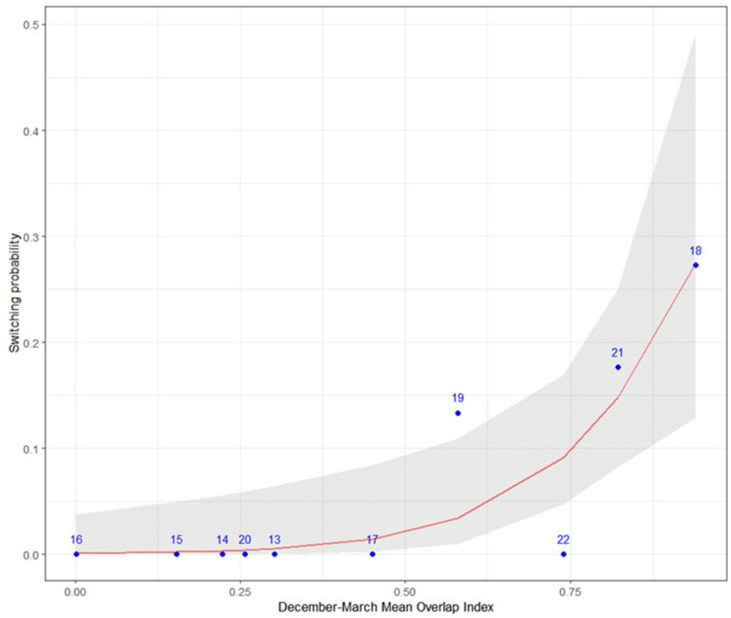

Figure 3. Estimates of the probability of switching of collared cows from the Bathurst herd to the Beverly herd based on degree of overlap between the two herds in winter.

The potential for movement to or from the Bluenose-East herd could also increase if the herd is extensively mixed with other herds. The plot below (Figure 4) demonstrates that winter overlap has increased between the Bluenose-East and other herds after 2020. In 2022 and 2023 the BNE and other herds were completely overlapping in March and even April (in 2023).

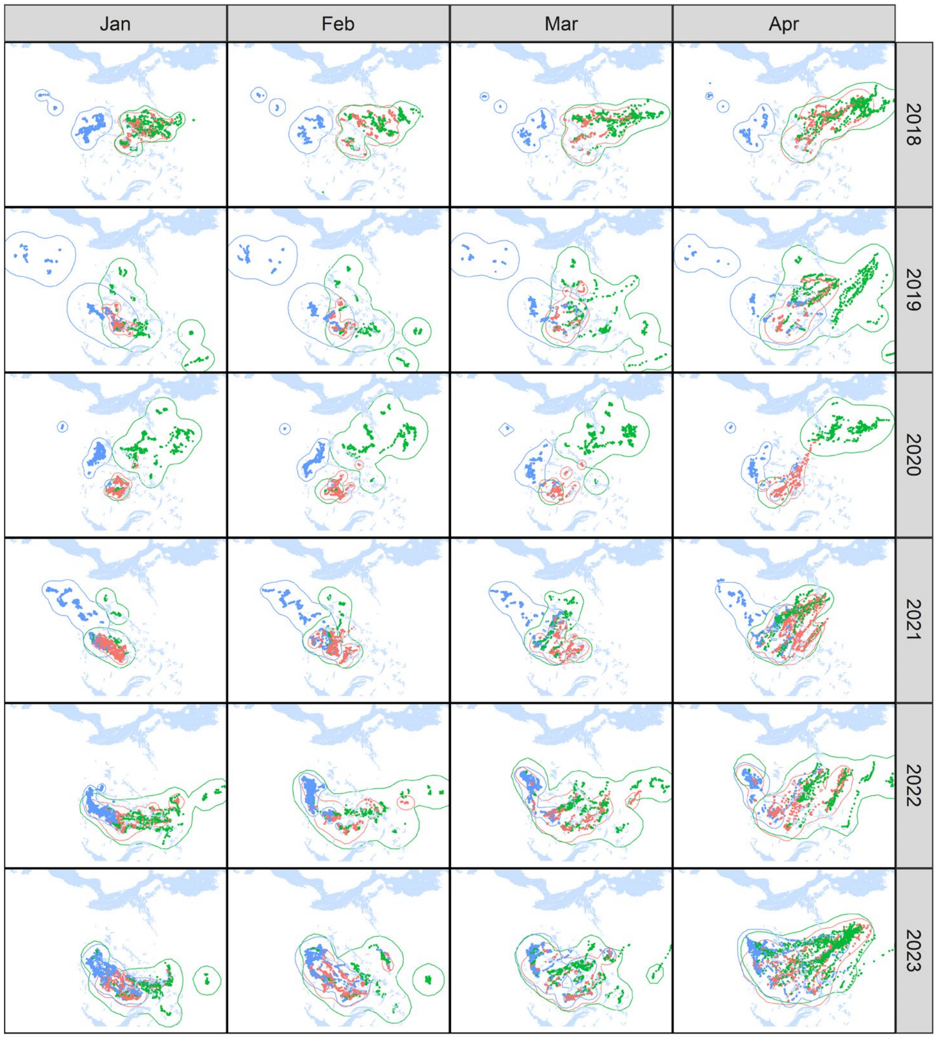

Figure 4. Overlap of Bluenose-East (blue), Bathurst (red) and Beverly (green) collared caribou locations and 95% kernel polygons around the collars. Note that year in this plot is calendar year. It will correspond to the preceding caribou year.

Winter overlap was estimated using the Bhattacharyya's affinity index for December to March for each calving ground year. Results showed an increase in overlap of the Bluenose-East and Beverly herd starting in the winter 2018 calving ground year (December 2018-March 2019; Figure 5).

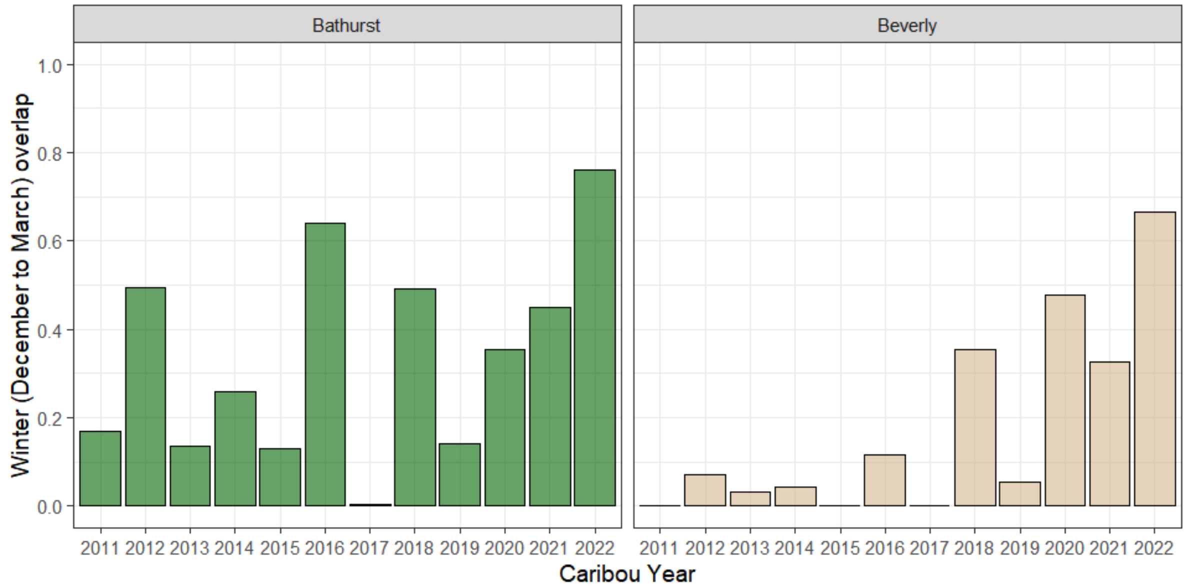

Figure 5. Degree of winter (December to March) overlap of the Bluenose-East herd with the Bathurst and Beverly herds, 2011-2022 using Bhattacharyya's affinity index.

Winter range overlap and subsequent migration paths were compared further by plotting paths for the three herds from March to May for 2018-2023 (Figure 6). A few patterns were evident. A general trend of migration path convergence seemed to be occurring with the Beverly and Bathurst herds moving west and some Bluenose-East caribou heading east. The Bluenose-East caribou displayed a relatively similar south to north pattern of migration in most years except years where the Beverly extended further west (2019 and 2021-2023). In this case a portion of collars deviated more to the east before migrating back to the Bluenose-East calving ground in late May and early June. In 2023, some of the cows that calved on the Bluenose-East calving ground were east of Bathurst Inlet in May, which is more traditionally winter range of the Beverly. The Beverly herd extended further to the southwest in winters of 2021 and 2023. In 2023, Beverly collars wintered further west with three collars (BGCA23208, BGCA23219 and BGCA19334) initially heading toward the Bluenose-East calving ground before taking an abrupt turn east near Great Bear Lake.

The Bathurst herd displayed the most variation in migration paths where there was overlap with the Beverly herd. Given overlap on winter ranges and similarity of early migration paths, it is possible that interchange of caribou occurred between herds with the potential of some Beverly cows occurring on the Bluenose-East range in 2023 given the behaviour of the three collared Beverly cows.

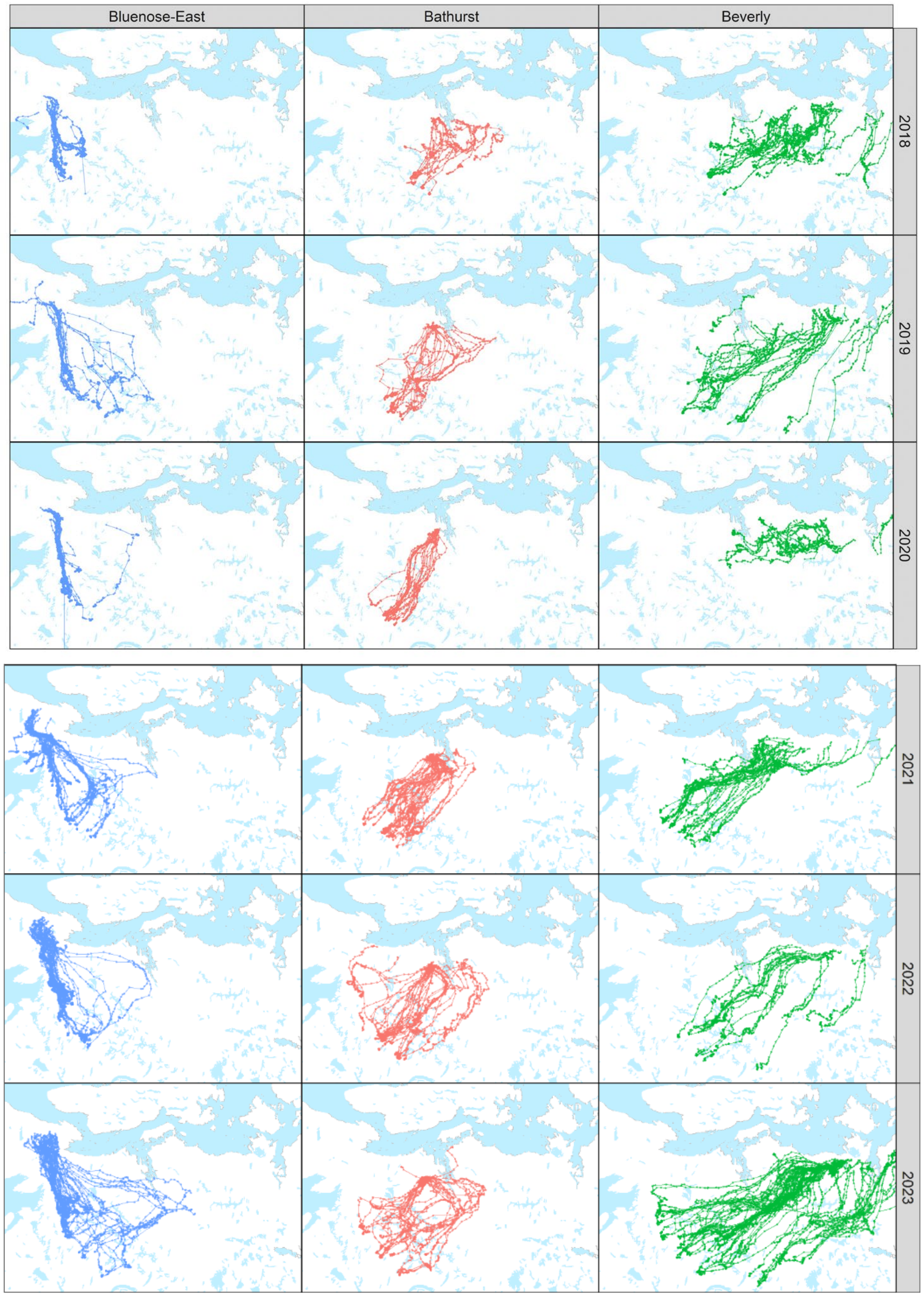

Figure 6. Spring migration paths (March to May) of collared cows from the Bluenose-East, Bathurst and Beverly herds 2018-2023.

A close up of 2023 better shows similarity of earlier migration paths for the Bluenose-East and Beverly herds (Figure 7) with many Beverly collars heading towards the Bluenose-East calving ground before turning to the east and heading straight east to the Beverly calving ground.

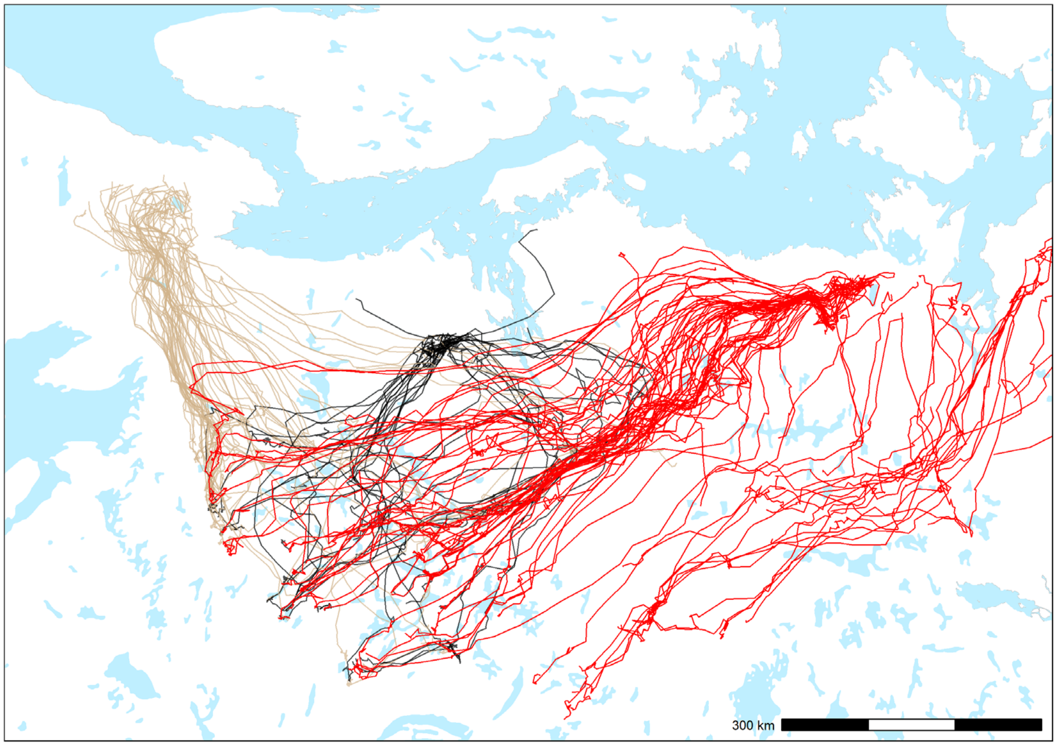

Figure 7. Migration paths of the Beverly collared caribou (red) in comparison to Bluenose-East caribou (tan) and Bathurst (black) from April to May 2023.

While there is no direct evidence of immigration of cows from the Bathurst and Beverly herds to the Bluenose-East, it is possible that some movement occurred due to overlap of wintering caribou as well as migration paths in the spring.

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Boulanger, J., J. Adamczewski, J. Williams, D. Cluff, K. Clark, S. Goodman, K.S. Chan and R. Abernathy. 2022. 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. Environment and Natural Resources, Government of the Northwest Territories.

Appendix 4. Power and Precision to Detect Emigration Events based on Collars

The challenge with detecting and estimating emigration events between caribou herds is the limited sample size of collared cows of known herd membership; only collared caribou with consecutive years of known calving ground location can be used. Usually, sample sizes of collars with known herd status ranged from 7-40 cows, which is relatively small given caribou herds number in the thousands.

To better understand our ability to detect emigration events, we conducted a set of simulations to assess the power and precision to detect and estimate emigration events based on total numbers of adult females, and the number of females collared that had known herd membership (were detected in the calving ground in the previous year). The simulations basically modelled a population of adult females of which varying numbers were collared. Emigration was simulated by randomly sampling (without replacement) a proportion of the adult females based on an assumed emigration rate. For each simulated emigration random sample, the presence and number of collared females was tabulated. Power was then estimated as the proportion of simulations that had at least one collar present. In other words, power was the probability that at least one collared caribou was within the group of cows emigrating. An estimate of emigration rate was derived for each simulation as the number of collars in the sample divided by total collars deployed. An estimate of precision of the estimated emigration rate was based on the standard deviation of emigration rates from simulations. Bias was based on the mean estimated emigration rate compared to the simulated emigration rate. Each combination of herd size, collar number, and assumed emigration rate was re-sampled 1,000 times.

For simulations, collar numbers were varied from 5 to 30 with emigration rates ranging from 0.02-0.2. The range of 0 to 0.2 represented the range observed in the Bathurst herd (to Beverly) in the majority of years monitored (Appendix 3, Figure 3). The range of collars was based on numbers of cows with known herd membership for each herd from 2012-2023 (Table 1). Adult female estimates were based on the most recent surveys (Beverly (2018): 61,070 adult females, Bathurst (2022): 4,179 adult females, and Bluenose-East (2023): 24,466 adult females).

Table 1. Sample sizes of collared adult females of known herd membership for the Bathurst, Bluenose-East and Beverly herds, 2012-2023.

	Herd		
Year	Bathurst	Beverly	Bluenose-East
2012	7	7	7
2013	10	7	24
2014	4	10	17
2015	13	24	18
2016	20	26	24
2017	20	17	26
2018	8	22	16
2019	14	17	18
2020	10	16	15
2021	28	20	26
2022	23	12	43
2023	17	22	33
Average	14.5	16.7	22.3

Simulation results suggested that the ratio of herd size to collar number did not affect power to detect emigration events. The simple reason for this is that the number of emigrating caribou increased linearly with assumed emigration rate (Figure 1). Thus, the ratio of collars to emigrating caribou and subsequent probability of detecting a collar remained constant given that collars were randomly dispersed among the emigrating adult caribou.

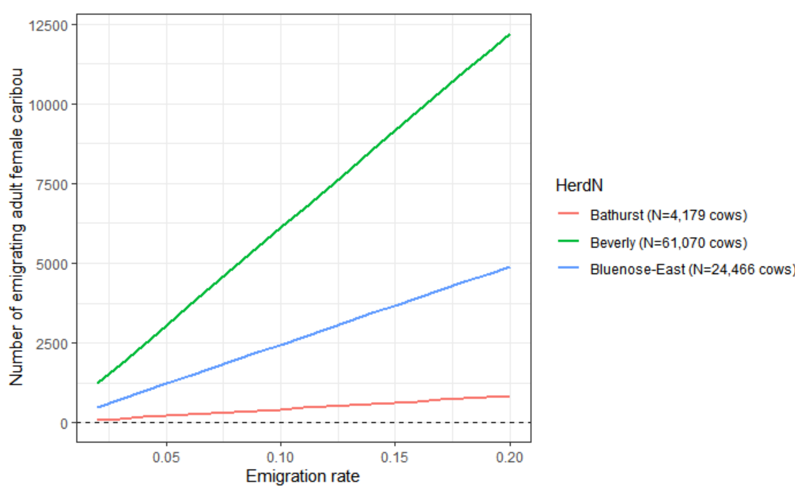

Figure 1. Number of emigrating adult females as a function of herd size (adult female numbers) and emigration rate. Differential sizes of herds create a large difference in the number of emigrating caribou.

The power to detect emigration events was mainly influenced by the number of collars (Figure 2). If collar sample size was low (5), power never reached the 0.8 threshold level.

Collar sample sizes of at least 20 were needed to detect emigration rates of 5% and 30 to detect rates of 3-4%. Precision of estimates was acceptable (CV <0.1) only when collar sample size was at least 15.

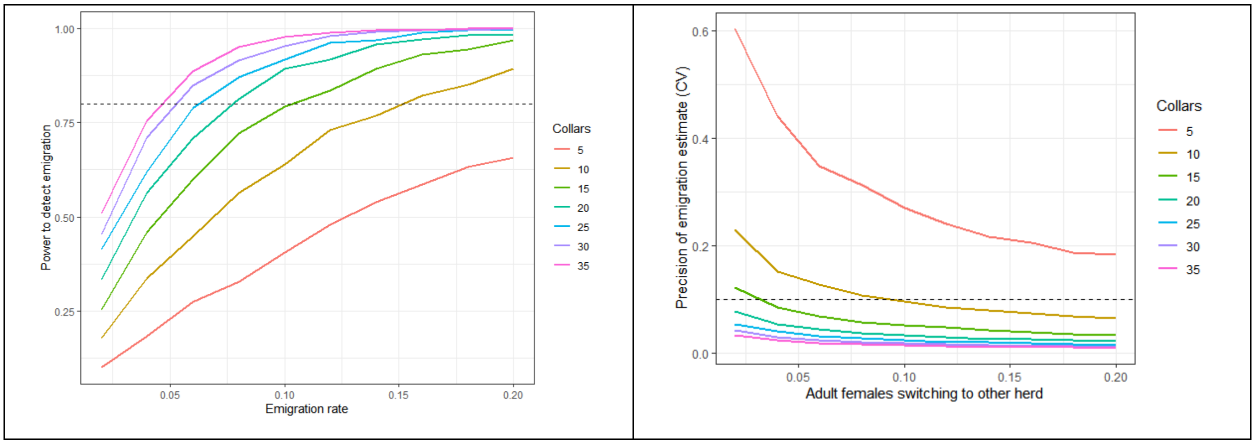

Figure 2. Power and precision to detect and estimate emigration events as a function of emigration rate and collar sample size.

Of most interest was whether collar sample sizes were adequate to detect emigration in 2023 based on collar sample sizes in each herd. In this case, emigration events of approximately 5%, 7% and 9% could be detected for the Bluenose-East, Beverly, and Bathurst herds based on the number of known collars in each herd (Figure 3).

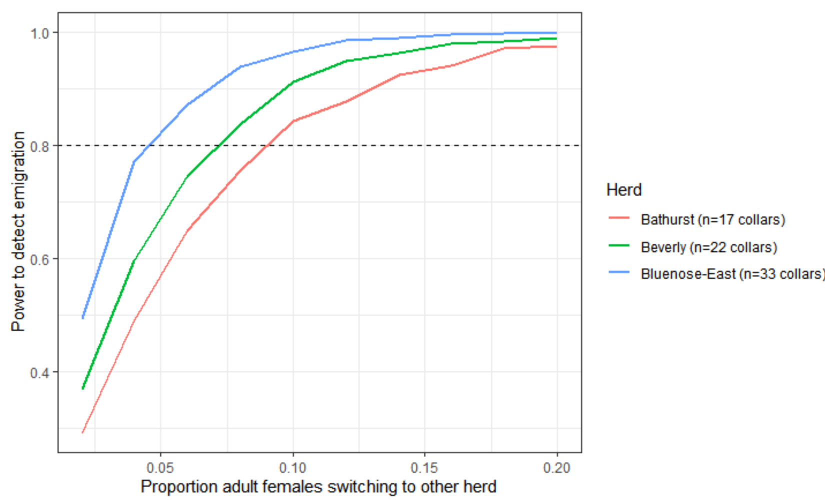

Figure 3. Power to detect emigration events as a function of emigration rate and collar sample size in the Bathurst, Beverly and Bluenose-East caribou herds given current herd sizes and collar numbers.

The relationship in Figure 12 could be expressed as the number of emigrating caribou associated with power to detect change of 0.8 (Figure 4) which is simply the product of the number of adult females and emigration rate. In this case, power is affected by the assumed adult females and a subsequent range of values of emigrating females. The range is most pronounced for the Beverly given its larger number of adult females (61,070). In this case, up to approximately 4,200 adult females could have emigrated from the Beverly before power reached the 0.8 threshold. In contrast, approximately 350 and 1,100 Bathurst and Bluenose-East adult females, respectively, could emigrate before power reached the 0.8 threshold.

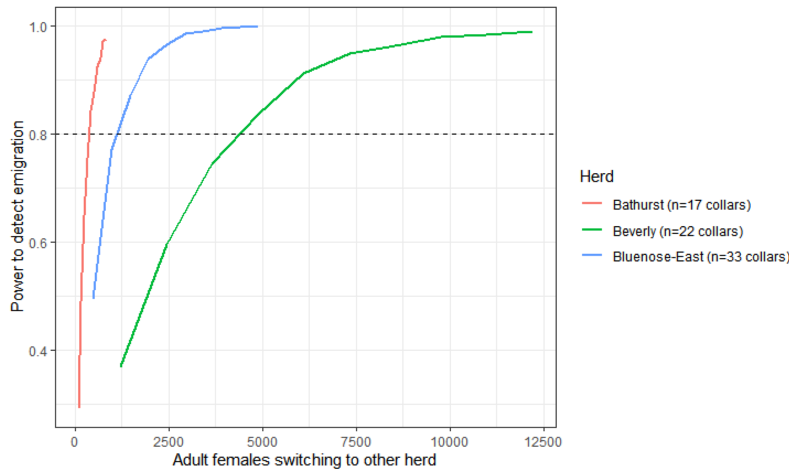

Figure 4. Power to detect emigration events between caribou herds as a function of emigration rate and collar sample size in 2023 in the Bathurst, Beverly and Bluenose-East herds.

Estimated emigrating caribou and power to detect emigration can be seen across the range of collar sample sizes in Figure 5. In this context, emigration from Bathurst has minimal impact on other herd sizes compared to the Beverly or Bluenose-East herds.

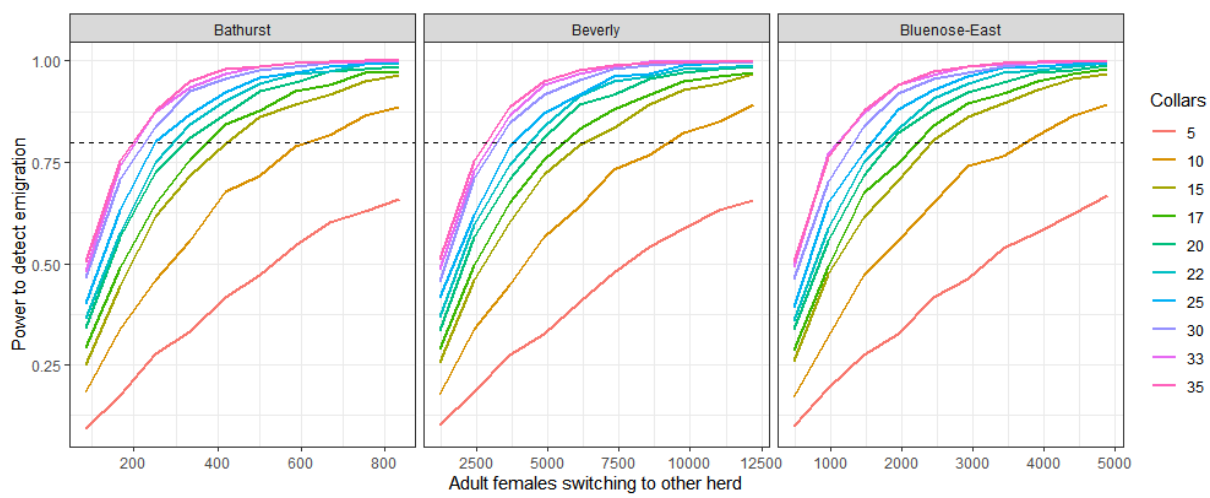

Figure 5. Estimated number of emigrating caribou for each herd as a function of power to detect emigration in the Bathurst, Beverly and Bluenose-East herds.

Overall, this power analysis suggests that lower levels (emigration rates <5-7%) could be missed when collar sample sizes were lower. In larger herds such as the Beverly, this could amount to up to 4,000 adult females. However, it is unlikely that more pronounced emigration events would not be detected.

We also note that collaring does not target calves of the previous year, yearlings, or younger caribou. Therefore, it is possible that emigration/immigration rates based on adult females may under-represent the younger caribou if they are more likely to switch herds during migration.

A few general conclusions can be made from this analysis. First, it is possible that smaller levels of emigration/immigration between herds could be occurring without detection by collared caribou given the relatively low sample size of collars that have known herd membership. The relative implications of these events on herd status depends on herd size. Emigration events from the Bathurst have relatively little impact on other herds. However, immigration into the Bathurst could have a larger impact on Bathurst herd size. Emigration events from the Beverly herd could have a higher impact on other herds given its larger size. To confront these issues, it is important to maintain relatively high sample sizes of collars of known herd membership which means a higher sample size of deployed collars each year. For example, if annual survival of adult females is 0.8 then at least 38 collars would be needed to maintain a sample size of 30 known collars. Scheduling collar release to occur after calving in June (as opposed to the spring before calving) would also increase known herd collar sample sizes. Increasing the duration of collar programming from three to five years before being released could be considered. A collar lasting five years would need a larger battery and a heavier collar, and an individual caribou would need to carry the collar for a longer period.

Appendix 5. Harvest Simulations for the 2023 Bluenose-East Herd

Following the release of the Bluenose-East 2023 herd estimates in November 2023, we carried out a set of harvest simulations for the Bluenose-East herd for 2023-2026 to provide information to support discussions about changes to harvest levels. These simulations were carried out in March 2024. A condensed summary of the results was made available to the Nunavut Wildlife Management Board for a meeting March 26, 2024 and that summary is included here at the end of the appendix.

Introduction

This report briefly summarizes harvest simulations for the Bluenose-East herd based on the 2023 calving ground survey. As detailed in previous sections of the report updated estimates of demographic parameters based on the recent calving ground survey results, recent collar data and other demographic indicators. The methodology used for simulations followed the original generic harvest model approach (Boulanger and Adamczewski 2016). For this approach harvest simulations were conducted across a range of harvest levels using different future demographic scenarios for the Bluenose-East herd.

The underlying 3-stage (calves-yearlings-adults) demographic model is similar to the Integrated Population Model (IPM) used to analyze demography for the Bluenose-East and Bathurst Herds (Boulanger et al. 2011, Boulanger et al. 2022). As in the IPM, it is assumed that the majority of harvest occurs in January. To simulate harvest, the number of cows and bulls are estimated at the end of December of each year based on bull and cow survival. Harvest then occurs to these caribou reducing bulls and cows by the simulated harvest numbers and proportions. The number of remaining caribou in January is then used to estimate the number of caribou on the calving ground in June of the next year. Using this approach accounts for survival of caribou up to and after harvest as well as harvest each year.

One of the challenges with harvest simulations was defining future demographic scenarios for the Bluenose-East herd given the uncertainty in mechanisms for the increase in herd size from the 2023 survey. As detailed in the main calving ground surey report, it is possible that one mechanism for an increase in herd size was immigration of yearling and adult females from the Beverly herd to the Bluenose-East. IPM analyses that used all data sources could not fit the increase in abundance 2021-2023, thus we suspected some level of immigration could have occurred. Direct evidence for such immigration to the Bluenose-East herd based on collars was lacking but collar numbers to assess this were low. In this case the increase in herd size could have been driven both by demography and immigration. For harvest modeling, which involves prediction of herd size in future years, the most applicable scenario is demographic increase based upon survival rates and productivity of the herd as opposed to assumed immigration from other herds. For this reason, harvest simulations that focus on demographic scenarios are emphasized in harvest simulations.

Methods

The following simulations were considered (Table 1). First, a stable population simulation was conducted with parameters based upon the IPM demographic analysis. Adult female and yearling survival values (0.84) were based on the mean IPM adult female survival value from 2021-2023. This value was slightly higher than the collar-based estimate of 0.81 from the same period. Adult male survival values and productivity (Sc*Fa) were also based on mean IPM estimates from 2021-2023. Second, an increasing "IPM" simulation was conducted with adult female survival, yearling, and productivity set at higher IPM levels estimated from 2021-2023. The adult female and yearling survival levels (0.87) were equal to those from an IPM run with the 2021 survey and collar-based survival values excluded; this scenario had a λ of 1.046. An additional increase simulation was added so that the observed trend (λ) in females equaled the observed level from 2018-2023 of 1.11. For this scenario, adult survival, bull survival, calf survival, and fecundity were increased to the maximum yearly estimated IPM values. This was the most optimistic demographic scenario and should be considered cautiously. Finally, a decreasing scenario based on low productivity was simulated which was based on lower productivity values observed from 2021-2023.

As discussed later, the effect of immigration was not directly considered in simulations given the uncertainty in the level of immigration that occurred up to 2023 and added uncertainty that future immigration might occur. However, it is possible that the trajectories up to 2023 were influenced by immigration. Given this, the most applicable scenarios are based upon IPM values (i.e., Stable and High IPM survival scenarios).

Table 1. Demographic scenarios considered in harvest simulations for the Bluenose-East caribou herd in 2023. Sf = cow survival rate; Sc = calf survival rate; Sm = bull survival rate; Sy = yearling survival rate; Fa*Sc = calf productivity as the product of pregnancy and calf survival rates.

Scenario	**Calf Productivity**	**Survival**				**Pregnancy Rate**	**λ (cows only)**
	Fa*Sc	Cow (Sf)	Calf (Sc)	Bull (Sm)	Yearling (Sy)	Fa	
Stable females (IPM estimates 2020-3)	0.457	0.840	0.550	0.730	0.840	0.830	1.001
Increasing (High IPM productivity/survival)	0.515	0.870	0.620	0.730	0.870	0.830	1.046
Increasing (2018-23 trend)	0.564	0.910	0.62	0.770	0.910	0.910	1.110
Declining (low productivity)	0.357	0.840	0.430	0.730	0.840	0.830	0.973

As an initial cross check, demographic parameters for the female segment of the population were analyzed using a stage-based matrix model to determine stable age distributions as well as estimate the resulting deterministic λ for adult females for each set of simulation parameters in Table 1. This resulted in λ estimates that ranged from 0.97 to 1.11.

The herd size estimate for 2023 (39,525) was used as the starting point for simulations with bull and cow numbers based on the mean bull cow ratio from 2018-2023 (0.615). The resulting numbers of cows and bulls in the herd were 24,466 and 15,059 bulls respectively. Constant λ values and stable age distributions were assumed in all simulations. Harvest levels of 0-1,600 were simulated which comprised 0-4% of the 2023 herd size. Simulations were kept to a short interval of three years (2023-2026) to coincide with the usual three-year survey interval. Simulations were conducted in the R statistical package (R Development Core Team 2009) with demographic analyses conducted using base R software and the *demogR* package (Jones 2007). Results were plotted using the *ggplot2* package with summaries using the *dplyr* package (Wickham 2009, Wickham 2011).

Results

Overall Effect of Harvest

Figure 1 shows projected herd size in 2026 across a range of harvest levels (x-axis) and % bulls in the harvest. Herd size was above 2023 levels for the two increasing simulation scenarios regardless of harvest level. Moderate decreases occurred for the stable population scenario.

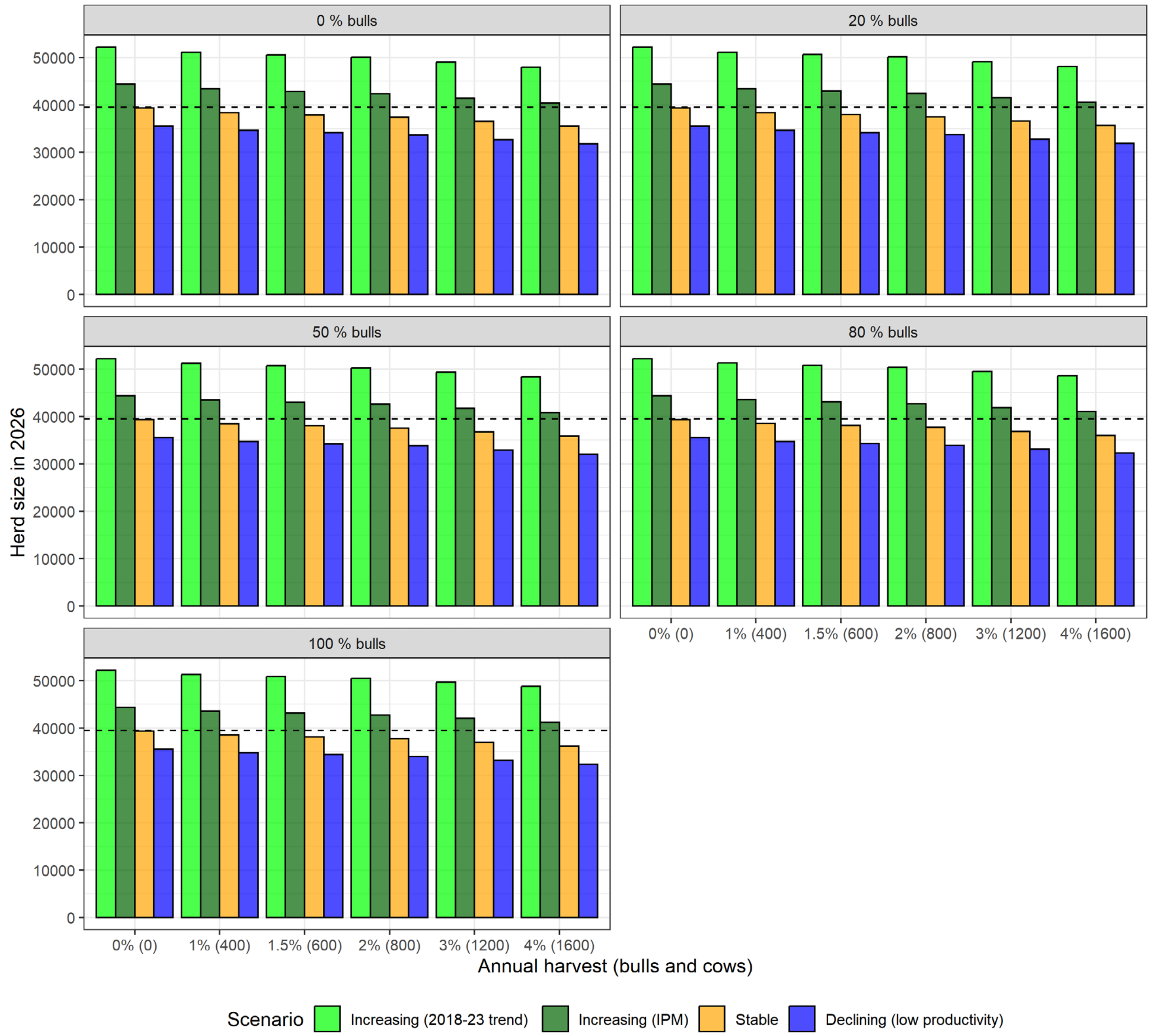

Figure 1. Projected Bluenose-East herd size in 2026 across a range of harvest and demographic scenarios (Table 1). Harvest is expressed both as the percentage of the 2023 herd estimate (39,525) and number of caribou harvested.

Figure 2 shows herd trajectories from 2023-2026 for each productivity scenario.

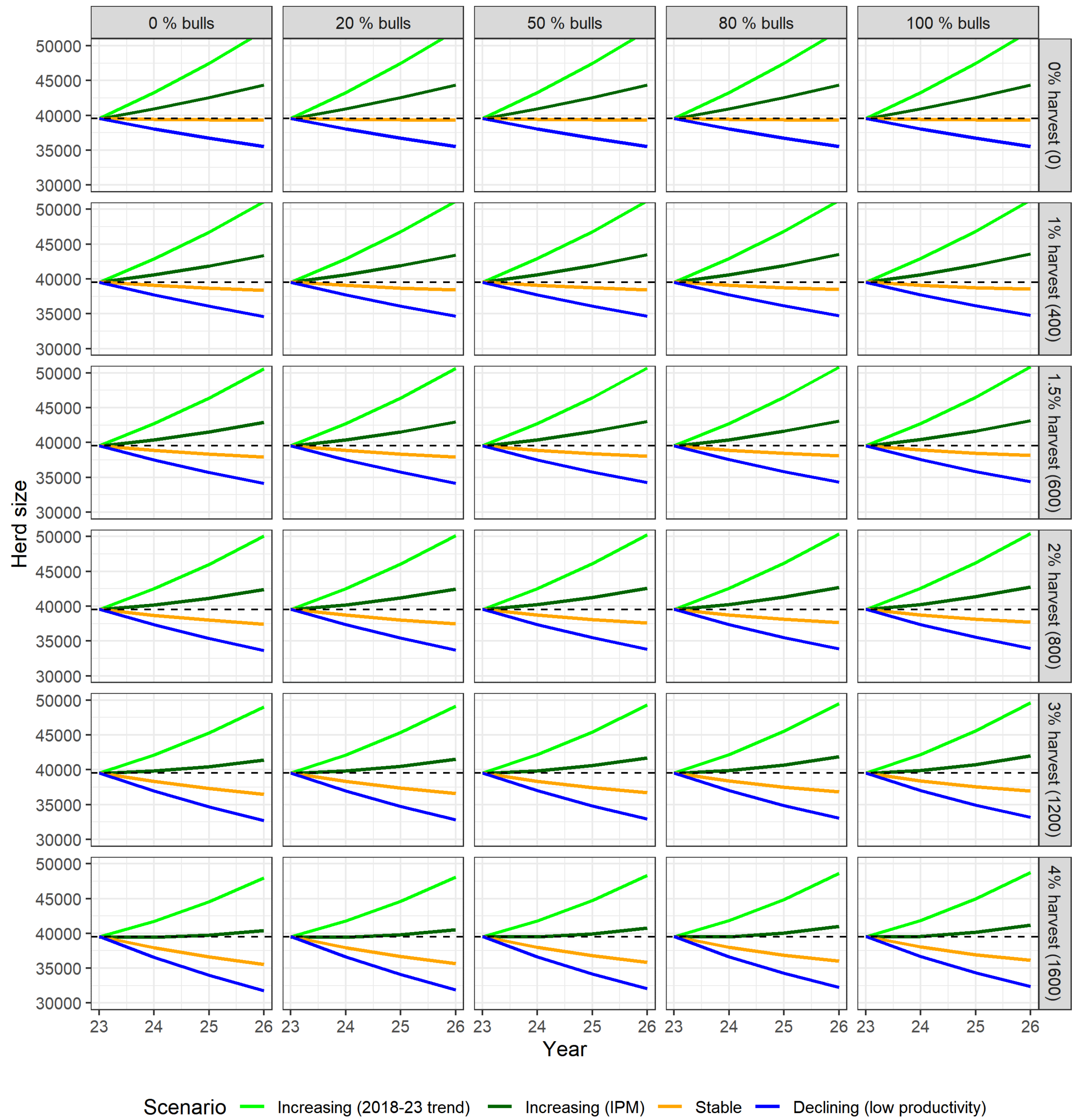

Figure 2. Projected herd trajectories for the Bluenose-East herd 2023-2026 across a range of harvest and demographic scenarios (Table 1). Harvest is expressed both as the percentage of the 2023 herd estimate (39,525) and number of caribou harvested.

Effect of the Harvest on Bull-cow Ratio

One important point to consider with bull-dominated harvest is the effect on the bull-cow ratio. Figure 3 shows change in bull-cow ratio across the range of harvest and percent bulls in the harvest. Noticeable decreases occur in bull-cow ratio when harvest levels are above 800 and percent bulls are greater than 80%. Bull-cow ratios increase when the all-cow harvest occurs due to the decline in cow numbers compared to bull numbers.

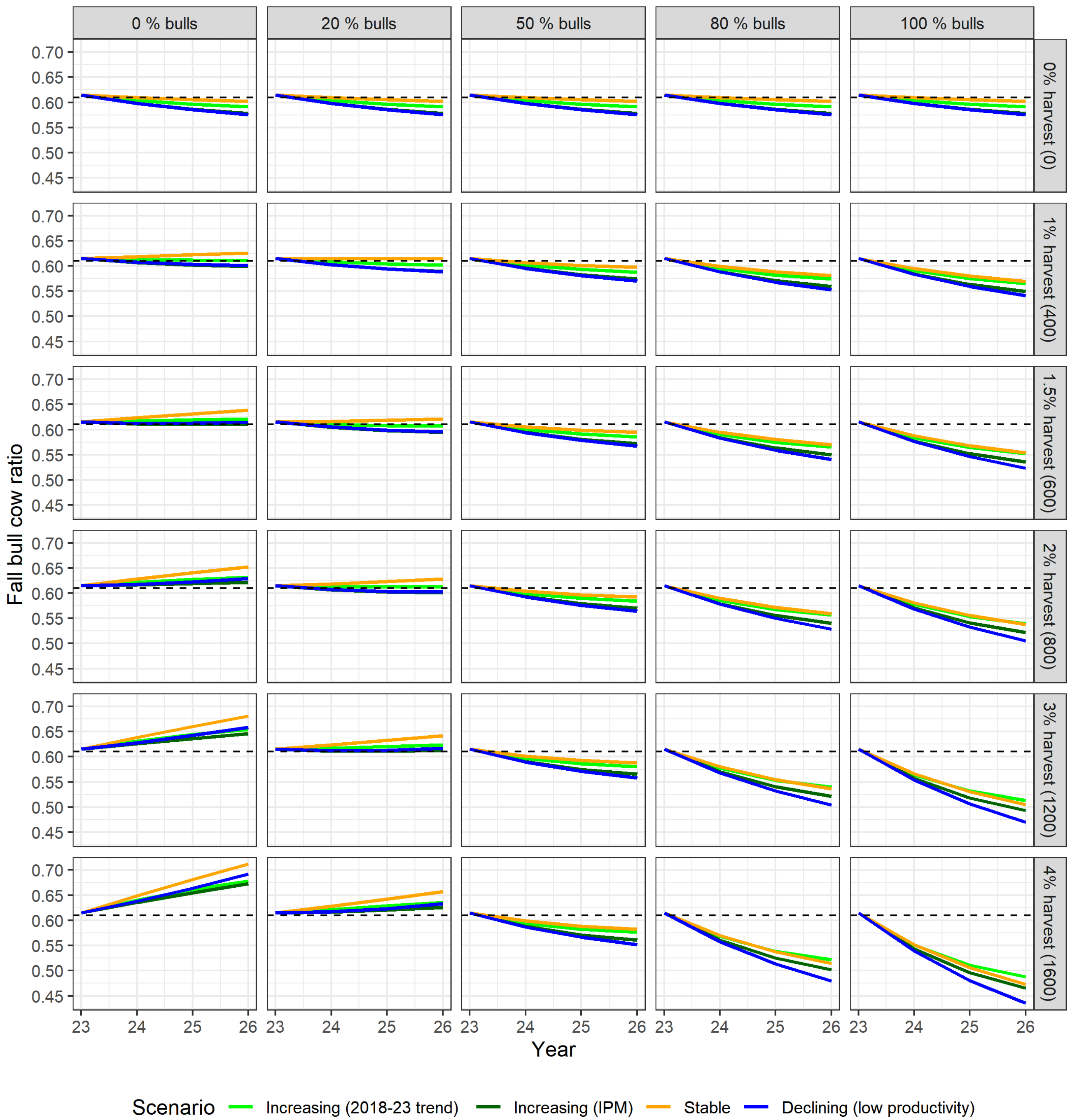

Figure 3. Projected bull-cow ratios in the Bluenose-East herd 2023-2026 across a range of harvest and demographic scenarios (Table 1). Harvest is expressed both as the percentage of the 2023 herd estimate (39,525) and number of caribou harvested.

Figure 4 shows predicted bull cow ratios in 2026 for the BNE herd; these are essentially the end-points of the changing ratios shown in Figure 3. Again, this shows reasonable decline in bull-cow ratios when harvest levels are above 800 with greater than 80% bulls.

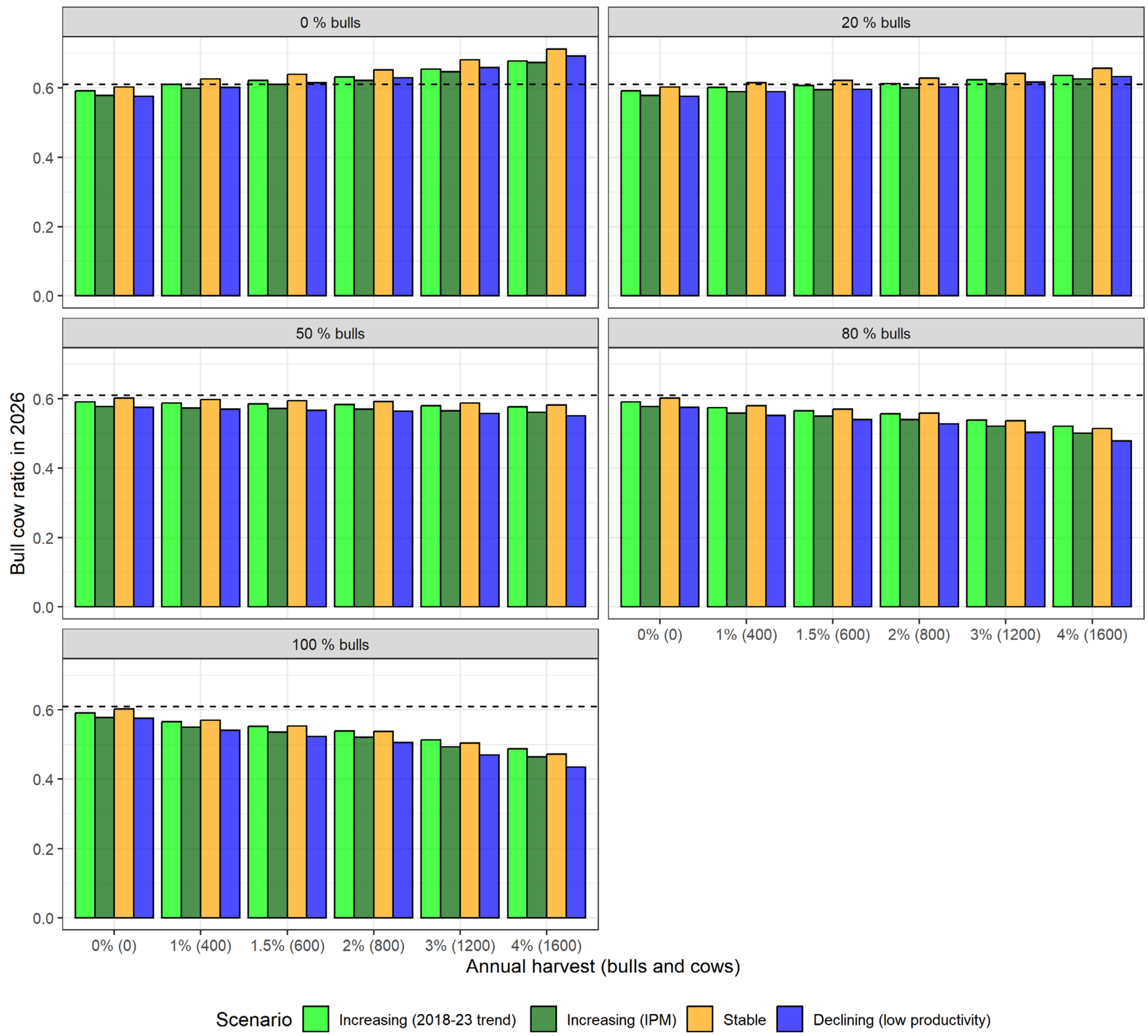

Figure 4. Projected bull-cow ratios in the Bluenose-East herd in 2026 across a range of harvest and demographic scenarios (Table 1). Harvest is expressed both as the percentage of the 2023 herd estimate (39,525) and number of caribou harvested.

Effect of Harvest as Herd Size Changes

One question that has come up is the seemingly minimal effect of lower harvest levels on population trend. The main reason for this is that at these levels a relatively small proportion of the herd is being harvested as demonstrated in Figure 5, and thus harvest accounts for only a small proportion of the herd and mortality rates are predominantly natural. Once harvest level becomes higher (1,200 or higher) the proportion of the herd harvested changes dependent on the underlying demographic scenario.

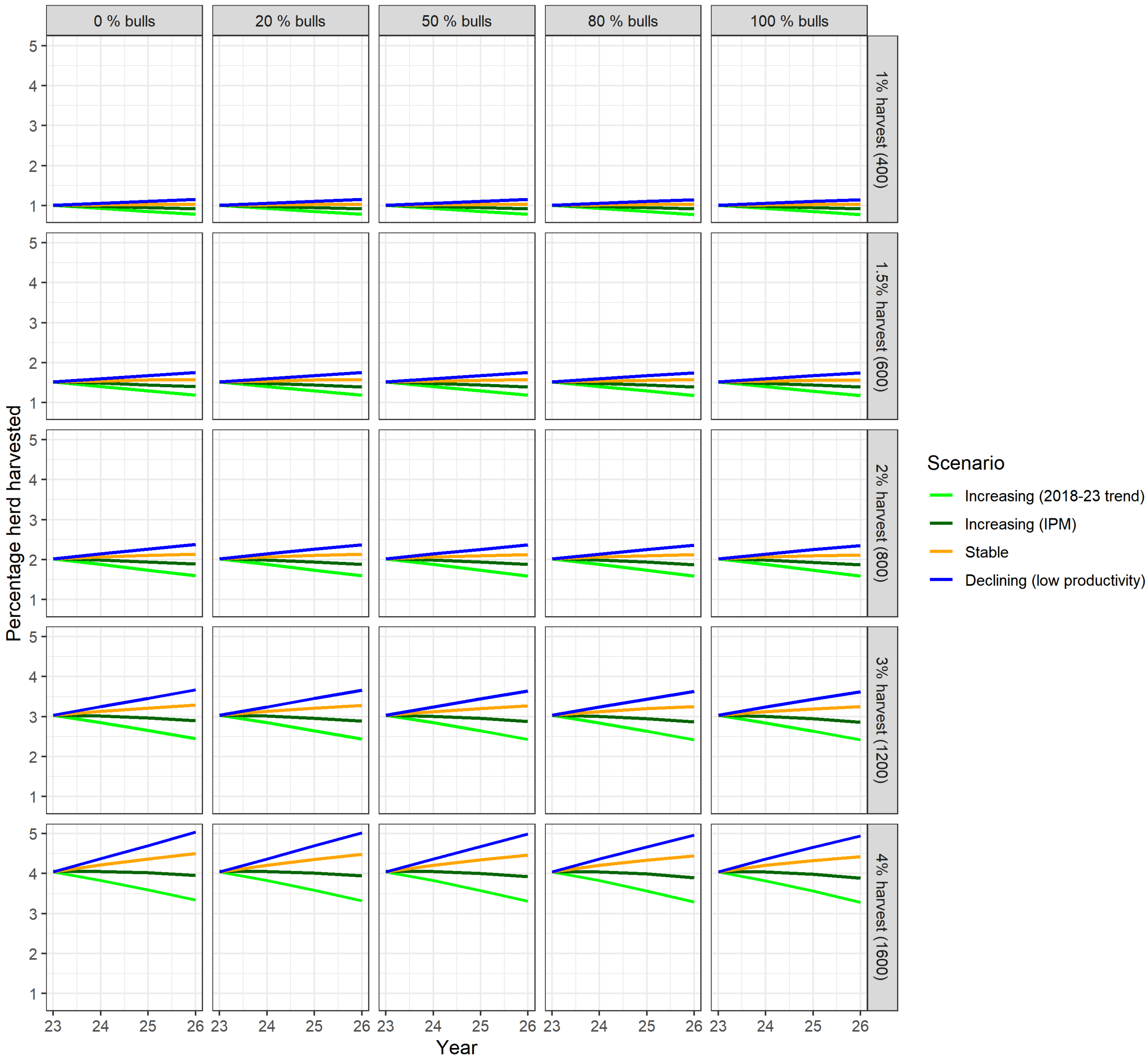

Figure 5. Proportion of the Bluenose-East herd harvested from 2023-2026 across a range of harvest and demographic scenarios (Table 1). Harvest is expressed both as the percentage of the 2023 herd estimate (39,525) and number of caribou harvested.

Sex-specific Effects of Harvest

Bull numbers in 2023 (15,059) were lower than females (24,455) and therefore harvest will affect bulls more than cows. If the harvest remains at a constant number of caribou/year and the herd is declining, then the incremental effect of the harvest harvest-caused mortality keeps increasing and can lead to a downward acceleration (Figure 6); then harvest adds substantially to the natural mortality rates. This effect was shown for the Bathurst herd in 2006-2009 (Boulanger et al. 2011), when harvest levels remained at 4,000-6,000/year as the herd declined rapidly. These effects are less pronounced for females in the current simulations; however, the increasing proportion of males being harvested should be noted at higher (>1,200) bull-dominated harvest levels. Also, female harvest levels will be 5% or higher if there is an all-female harvest of 1,200 or higher.

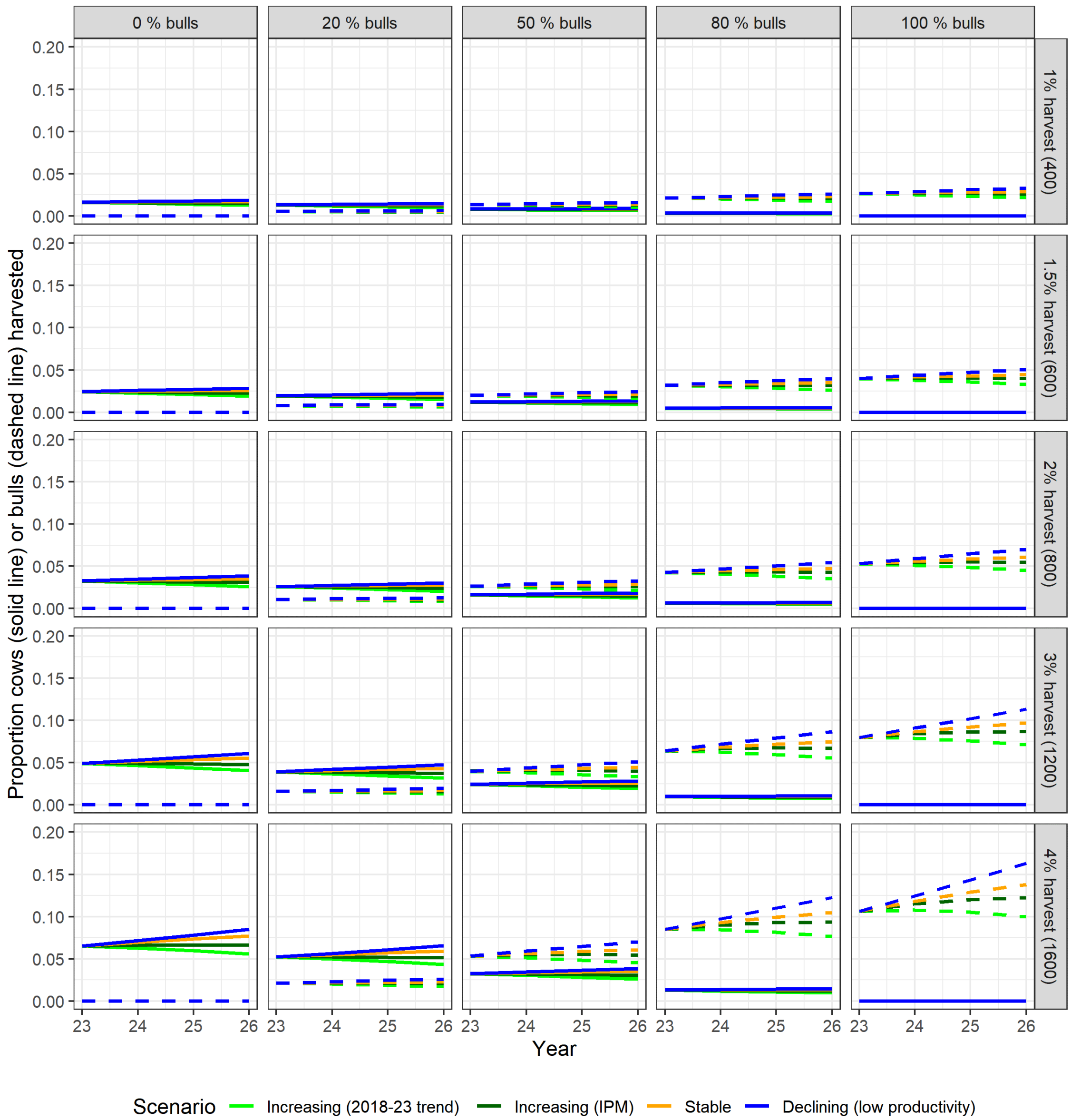

Figure 6. Proportion of the Bluenose-East herd harvested from 2023-2026 across a range of harvest and demographic scenarios (Table 1). Solid lines indicate female trajectories and hashed lines indicate male trajectories. Harvest is expressed both as the percentage of the 2023 herd estimate (39,525) and number of caribou harvested.

Discussion

The general results of harvest simulation suggest that the herd can tolerate low-moderate levels of harvest with minimal impact on overall herd status. One of the challenges of these simulations was assessing future status of the herd given uncertainty in mechanisms behind the increase in the 2023 estimates. Demographic indicators suggested higher productivity and moderate survival which resulted in a slightly increasing trend. However, the 2023 herd estimates suggested a higher rate of increase than that predicted by demographic analyses. In other sections of the report, we discuss the possibility of immigration from other herds as one potential mechanism of increase. The main point is that if immigration did partially cause the increase, and demographic indicators, namely adult female survival, are still at moderate levels then the herd will be less robust to harvest pressure unless immigration continues to occur. For this reason, we focus simulations on moderate levels of increase (the IPM scenario) and suggest that the 2018-2023 increase scenario is interpreted cautiously.

We also suggest that sex-specific impacts of harvest be considered when setting harvest limits. The effect of harvest on bulls will be greater given the lower number of bulls compared to cows in the Bluenose-East herd (Figure 6). Therefore, the effect of higher harvest levels on bulls (if the harvest is bull-dominated) could be substantial leading to reduced bull-cow ratios (Figure 4).

An Assessment of Likely Consequences of Various Harvest Levels for the Bluenose-East Caribou Herd 2023-2026

Background

A June 2023 calving photo survey of the Bluenose-East caribou herd resulted in an adult female estimate of 24,466 and a herd size estimate of 39,525, both substantial increases over the 2021 and 2018 estimates. Previously, the herd had shown a large decline 2010-2018 and then appeared to stabilize 2018-2021. From 2018 to 2023, demographic indicators such as calf: cow and bull: cow ratios have been consistent with a positive herd trend. Local knowledge in recent years from the Kugluktuk Hunter and Trappers Organization (KHTO) and the Tłı̨chǫ Ekwǫ̀ Nàxoèdee K'è ground-based caribou observation indicate that Bluenose-East caribou have been in very good condition, summer feeding conditions have been good, and that calves, yearlings and young cows and bulls have been abundant.

There have been restrictions on total allowable harvest of the Bluenose-East herd in Nunavut under the Nunavut Wildlife Management Board and the KHTO plan (currently 170[9] with an up to 1:1 female to male harvest sex ratio), in the Sahtú Settlement Area under the Délı̨nę Belare Wíle Gots'e´ʔekwe´plan (currently 30 bulls), and in Wek'èezhìı under the Wek'èezhìı Renewable Resources Board (currently 193 bulls for all user groups). These restrictions

[9] This harvest limit was increased in 2024 to 450 caribou (either sex) by recommendation of the NWMB.

were put in place between 2019 and 2021 after the large decline of this herd between 2010 and 2018. Given the herd's change to a stable trend 2018-2021 and an increasing trend 2021-2023, some hunters have expressed interest in considering an increase in total allowable harvest.

This document summarizes main outcomes of a harvest modeling exercise carried out to assess likely consequences of a range of harvest levels and harvest sex ratios for the Bluenose-East herd on a short-term basis, 2023-2026. The model projections are not predictions, but rather are suggestions of likely trend under a defined set of conditions. Previously, likely effects of harvest on a barren-ground caribou herd under a wide range of conditions were described by Boulanger and Adamczewski (2016); the current assessment was specific to the Bluenose-East herd in 2023.

In this brief summary, we highlight main trends in the modeling results described in detail above. We hope these results will assist wildlife managers in considering how various levels of harvest might affect the herd.

Basic Model Values Used

The model caribou herd was assumed to start at 39,525 adults (the 2023 Bluenose-East estimate), including 24,466 cows and 15,059 bulls. Possible future trends of a stable herd (population growth rate or λ of 1.00), a moderately increasing trend (λ of 1.05 or 5% increase/year) and a more rapidly increasing trend (λ of 1.11 or 11% increase/year) were used. A declining trend was also used in the model runs but is omitted here for simplicity. Calf productivity and survival rates of cows, calves, yearlings and bulls were set to fit each population trend and then remained at those values through the simulations. The modeled interval was three years, to match a commonly used survey interval. Experience has also shown that this herd's dynamics can change quickly, which is another reason this modeling was restricted to a short three-year time interval. In particular, recent monitoring indicates that summer feeding conditions and the severity of the insect season are important for Bluenose-East caribou growth, condition and pregnancy rate, and weather can vary widely from year to year. Harvest levels of 0, 400, 600, 800, 1200, and 1600 caribou were used, which represent 0%, 1.0%, 1.5%, 2.0%, 3.0%, and 4.0% of the 2023 herd size. Harvest sex ratio was varied between 0, 20, 50, 80 and 100% bulls.

Effect of a Variable Harvest Rate on Herd Trend

In Figure 6, projected herd trend 2023-2026 is shown as a series of graphs corresponding to 0, 1, 1.5, 2, 3 and 4% harvest levels. Harvest sex ratio was kept at 50% bulls in all cases. In each case, underlying herd trends (with no harvest) of stable, increasing moderately at 5%/year and increasing rapidly at 11%/year were used. Projected herd size in 2026 is shown; values were rounded to the nearest hundred caribou.

With no harvest, the herd increasing at 11%/year would increase to 52,200 by 2026, the herd increasing at 5%/year would increase to 44,400 by 2026 and the stable herd would remain at the starting level of 39,525.

In the herd increasing at 11%/year, harvest of all levels between 1% and 4% of the herd would result in an increasing herd by 2026. At the highest harvest level of 4%, the herd would be at 48,400 in 2026 compared to 52,200 with no harvest. In this case, the underlying balance between births and deaths is strongly positive, thus the harvest levels simulated would slow the population's growth rate somewhat, but the herd would continue to increase.

In the herd increasing at 5%/year, the herd would again continue to increase with all levels of harvest considered. However, at a 4% harvest level, the growth rate of the herd would be relatively slow and the herd would be at 40,800 in 2026 compared to 44,400 with no harvest. In this situation the underlying balance between births and deaths is positive, though not as much as in the herd increasing at 11%/year.

In the herd with an underlying stable trend, all levels of harvest would result in a declining trend, although the rate of decline would be relatively low under most harvest conditions. The effect of lower levels of harvest would be limited, but with a 4% harvest the herd would be projected at 35,800 in 2026 compared to the herd remaining approximately at the starting size of 39,525 with no harvest. In this case the underlying balance with no harvest is equal between deaths and births, thus any additional deaths from harvest will result in a declining trend.

To assess potential effects of variation in harvest sex ratio on likely herd trend, four examples are provided in Figure 7: 2% harvest of 100% bulls, 2% harvest of 0% bulls (all cows), 4% harvest of 100% bulls and 4% harvest of 0% bulls (all cows). Results were similar for the four cases considered. Herd size projected for 2026 based on an underlying trend of 5% annual increase is projected to be 40,400 with a 4% all-cow harvest compared to 41,200 with a 4% all-bull harvest. The relatively similar results for all-cow and all-bull harvests reflect a number of factors: the projection period is short (three years) and a difference between all-bull and all-cow harvests would accumulate over a longer time period; the harvest rates simulated are generally low; and the herd has had a healthy bull: cow ratio and good calf recruitment. A large cow harvest in a declining herd would be expected to have a stronger effect on herd trend, particularly if it continues for many years.

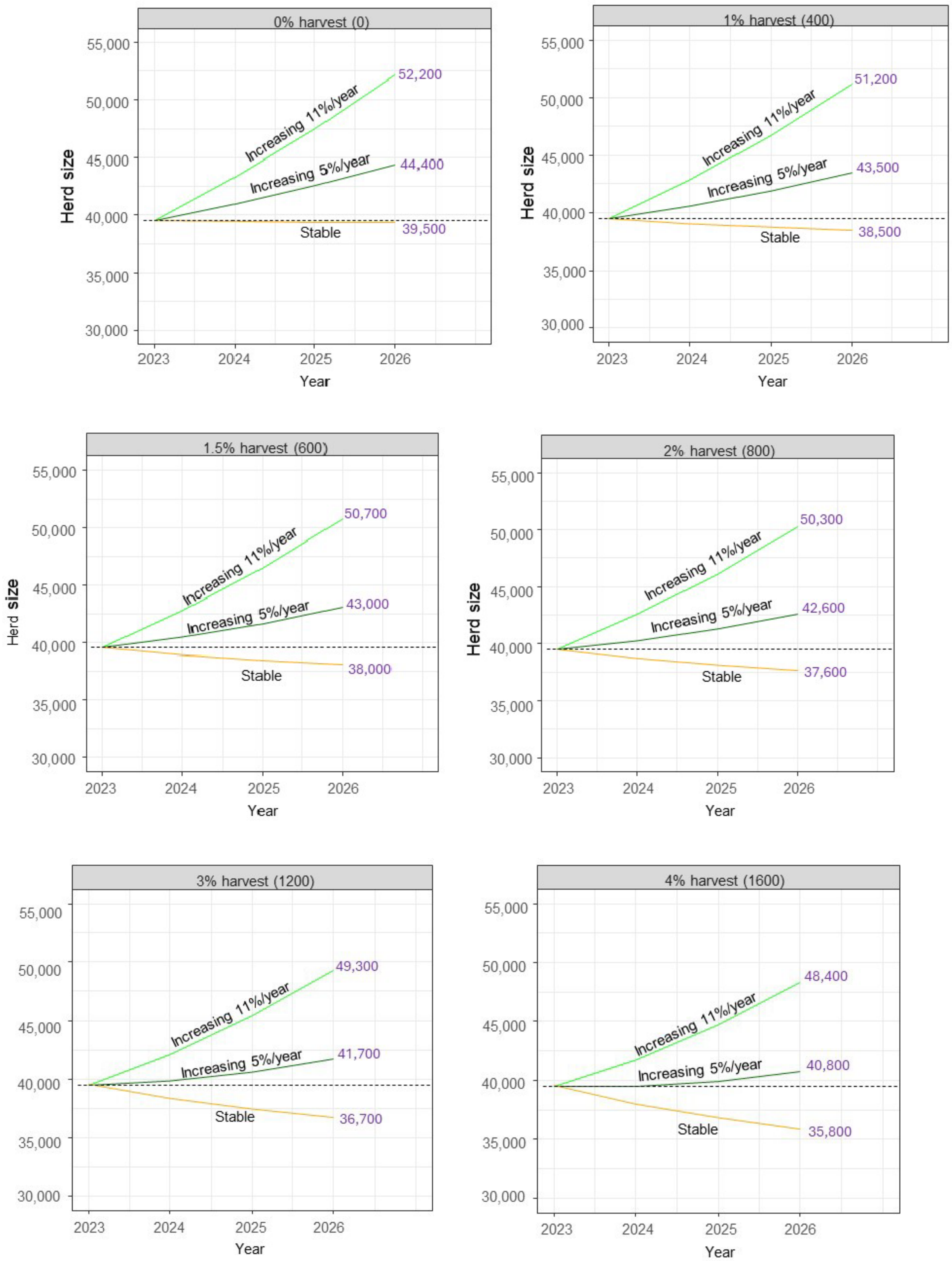

Figure 6. Harvest modeling projections of Bluenose-East herd size in 2026 with three underlying population trends and harvest levels of 0, 1, 1.5, 2, 3 and 4% of the 2023 herd estimate. Sex ratio of the harvest was 50% bulls. Starting herd size was 39,525 in all cases. Projected herd size in 2026 is shown in purple, rounded to nearest 100.

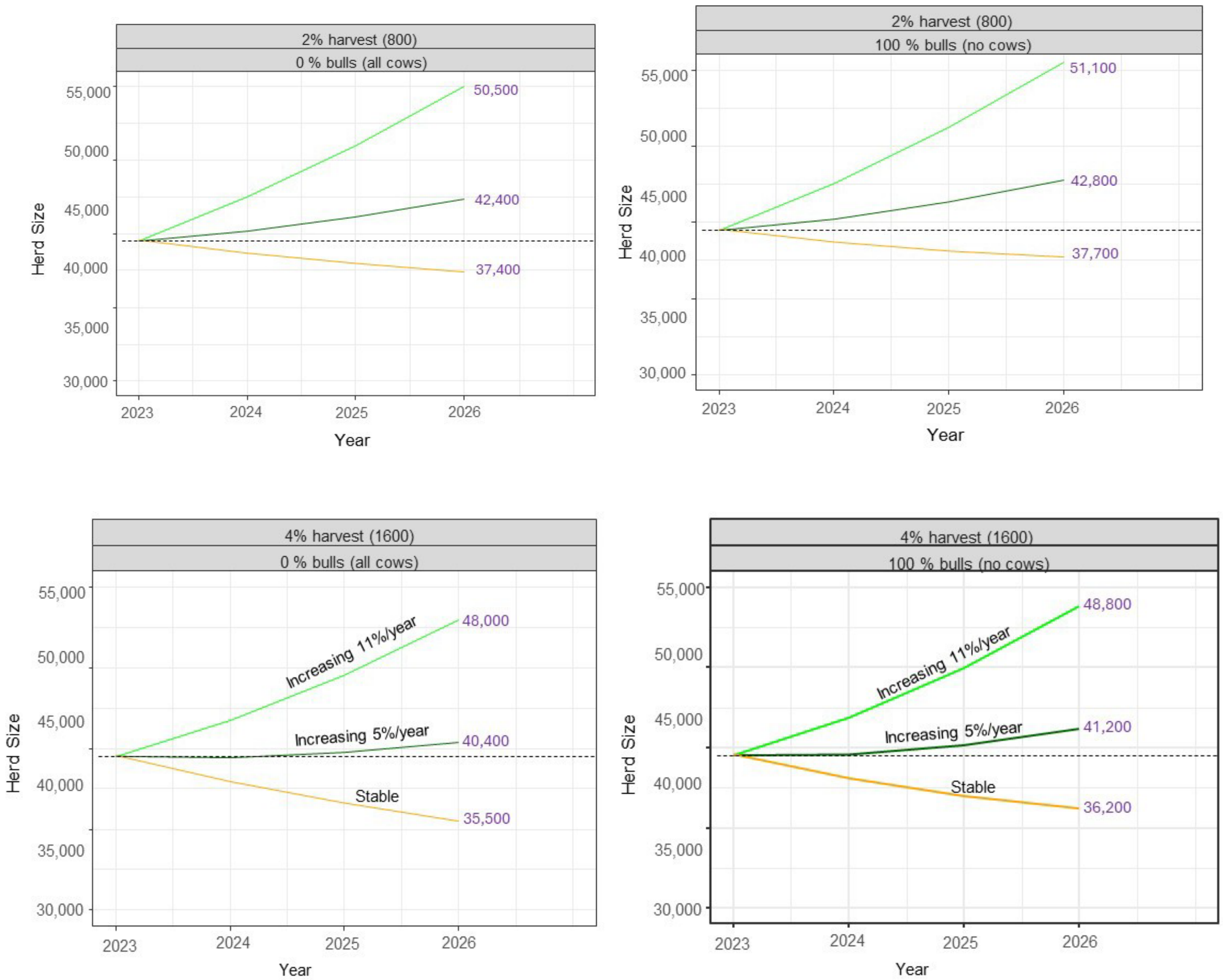

Figure 7. Harvest modeling projections of Bluenose-East herd size in 2026 with three underlying population trends, harvest levels of 2% (top) and 4% (bottom) of the 2023 herd estimate. Sex ratio of the harvest was 0% bulls (all cows) on the left and 100% bulls (no cows) on the right. Starting herd size was 39,525 in all cases. Projected herd size in 2026 is shown in purple, rounded to nearest 100.

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Appendix 6. Monthly Maps of Locations of Collared Bathurst, Bluenose-East and Beverly caribou, October 2022 to October 2023

A series of monthly maps of satellite collared caribou in the Bathurst, Bluenose-East and Beverly herds from October 2022 to October 2023 is provided in this appendix. The main purposes were to provide a spatial context for the fall and winter 2022-2023 leading up to the June 2023 calving ground survey of the Bluenose-East herd and to show the degree of mixing through the year.

In October 2022 (Figure 1) the three herds were largely separate and moving generally southward, and by mid-November the three herds showed a convergence and increased mixing. Between November 2022 and March 2023 (Figures 2-6) there were limited directional movements overall, and extensive mixing of the three herds. In April there was substantial movement east of some Beverly, Bathurst and Bluenose-East collared cows (Figure 7). By mid-May collared cows from all three herds were moving towards their respective calving grounds (Figure 8). A few Bluenose-East and Bathurst collared cows moved east of Bathurst Inlet, then turned westward. All the Bluenose-East collared females continued on to the Bluenose-East calving ground except one, which stayed on the Bathurst calving ground in June (Figure 9). Of 21 known Bathurst collared cows, 17 were found on the Bathurst calving ground west of Bathurst Inlet, while four moved east with the main aggregation of Beverly cows in the Queen Maud Gulf lowlands. In mid-June the three herds were well separated and this continued into July (Figures 10-11). In August the three herds were moving southward and dispersed over a wide area (Figure 12), and through September and October (Figures 13-14) the movement south and overall separation of the herds continued.

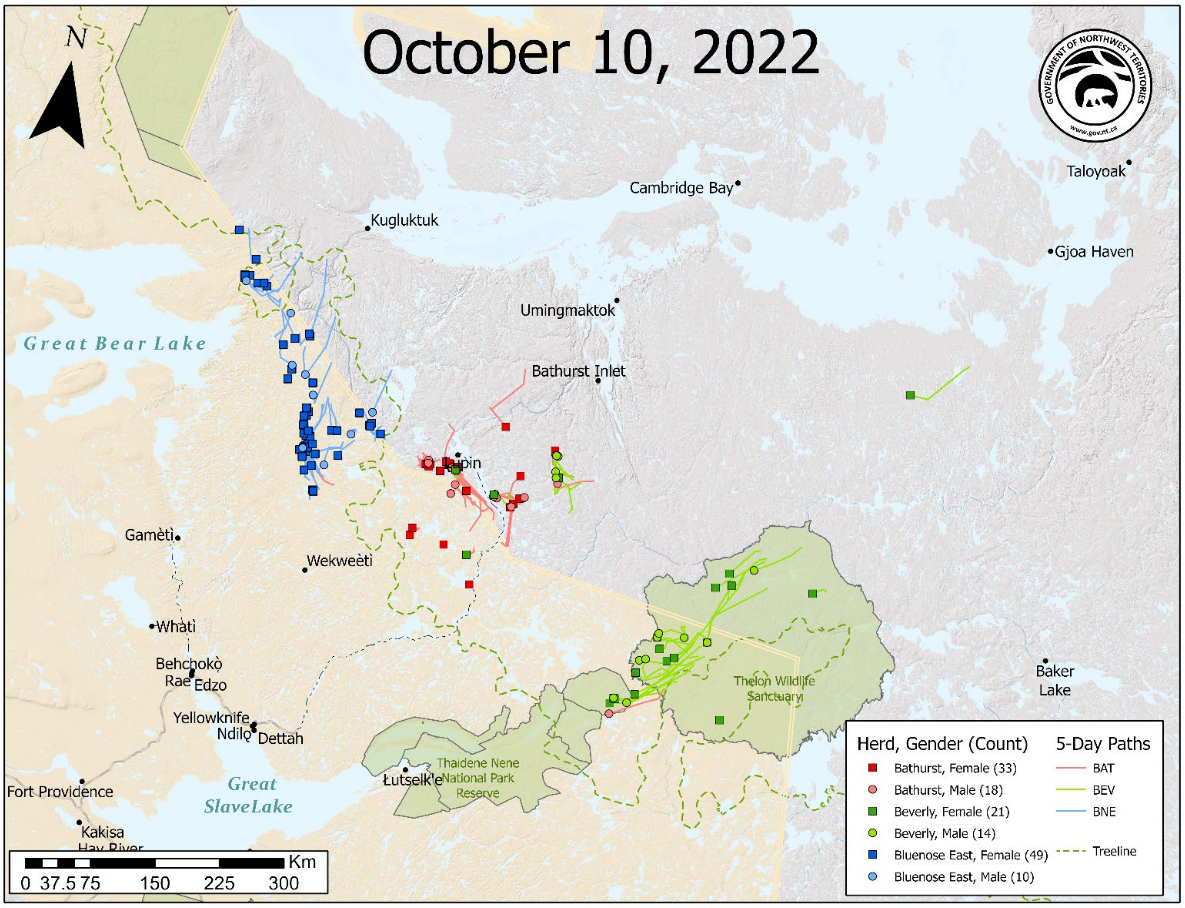


Figure 1. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in October 2022. Lines behind the locations show the last five days of movement of each collared caribou.

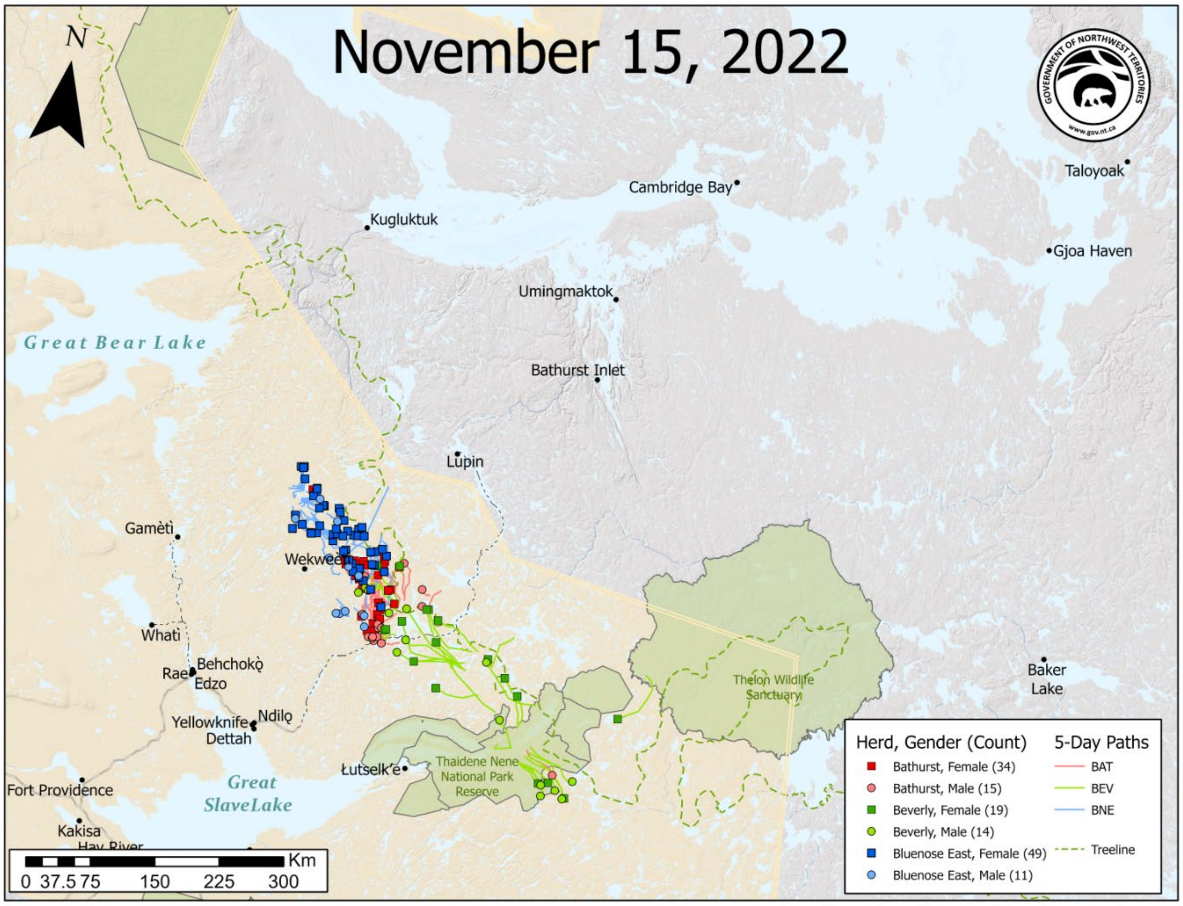


Figure 2. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in November 2022. Lines behind the locations show the last five days of movement of each collared caribou.

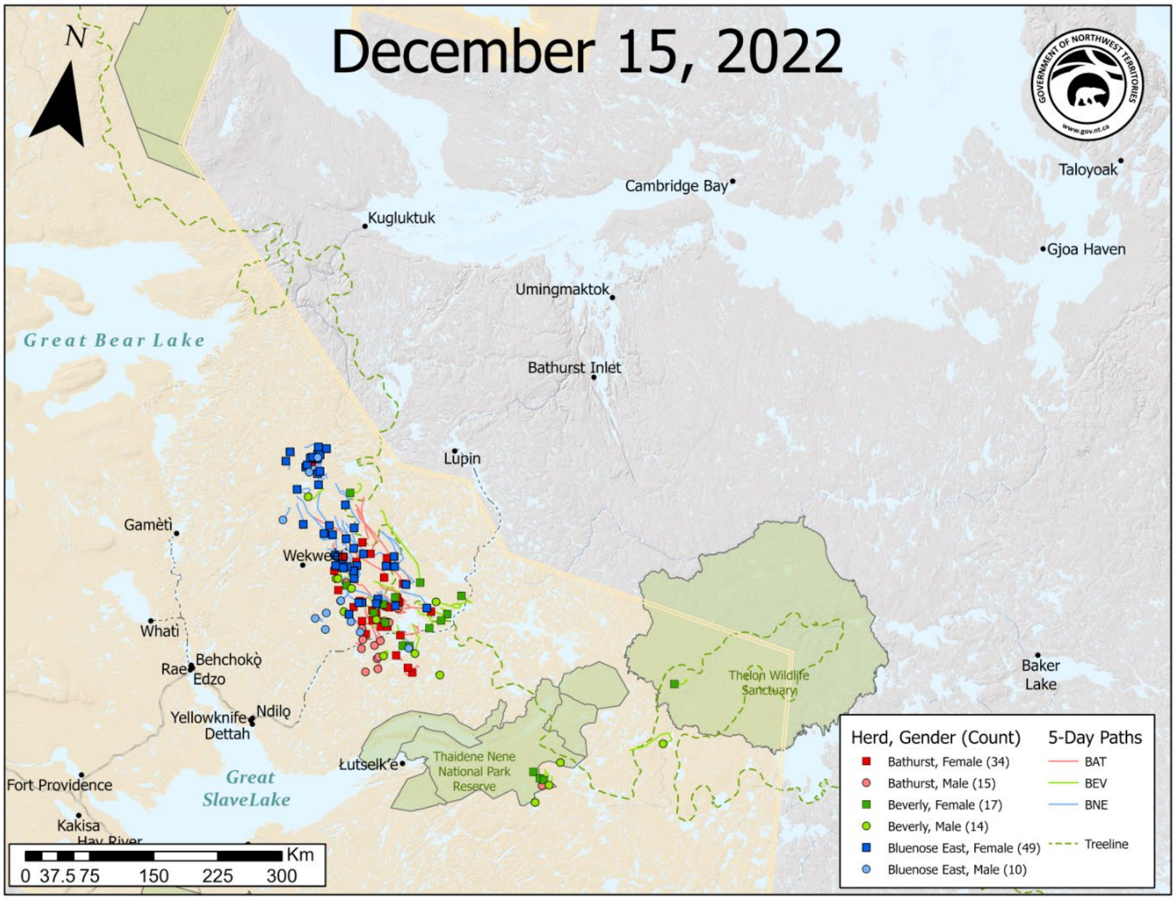


Figure 3. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in December 2022. Lines behind the locations show the last five days of movement of each collared caribou.

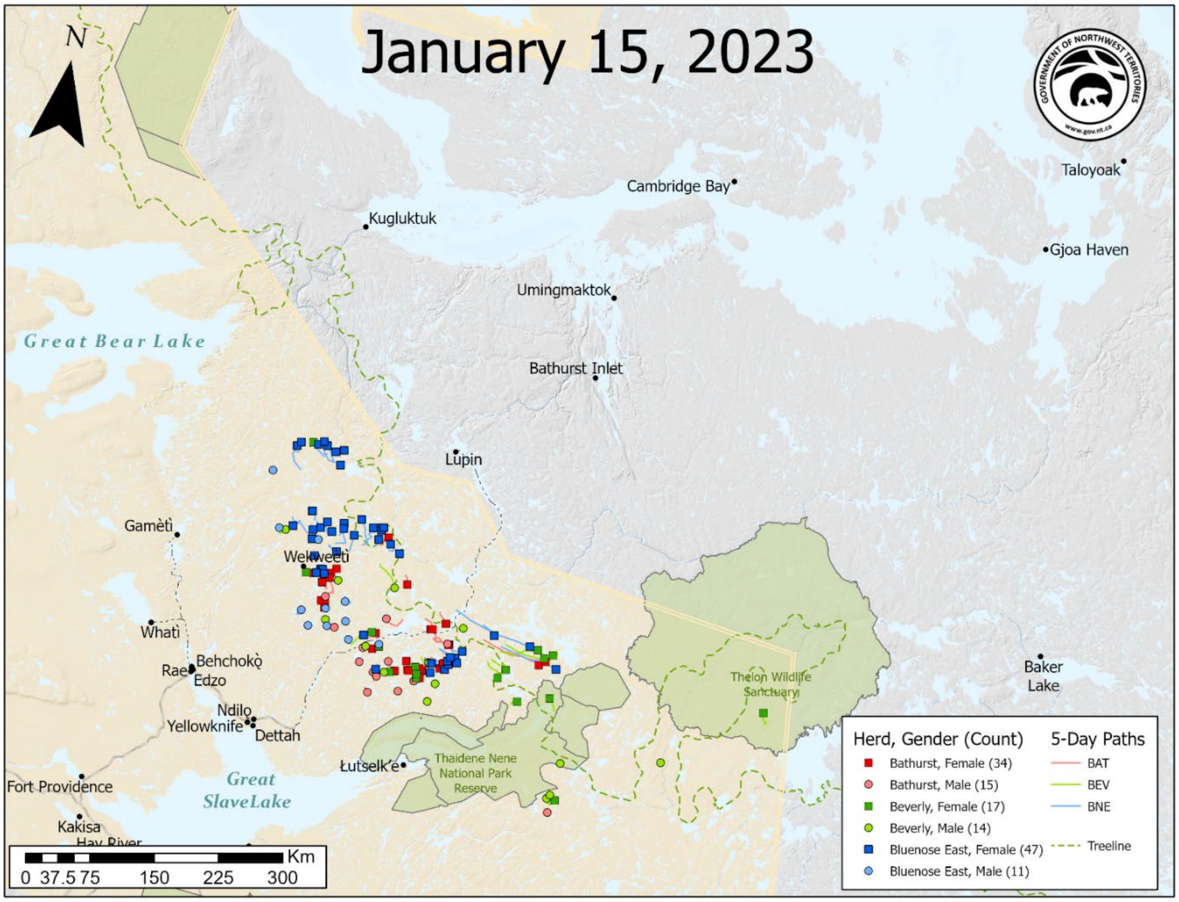


Figure 4. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in January 2023. Lines behind the locations show the last five days of movement of each collared caribou.

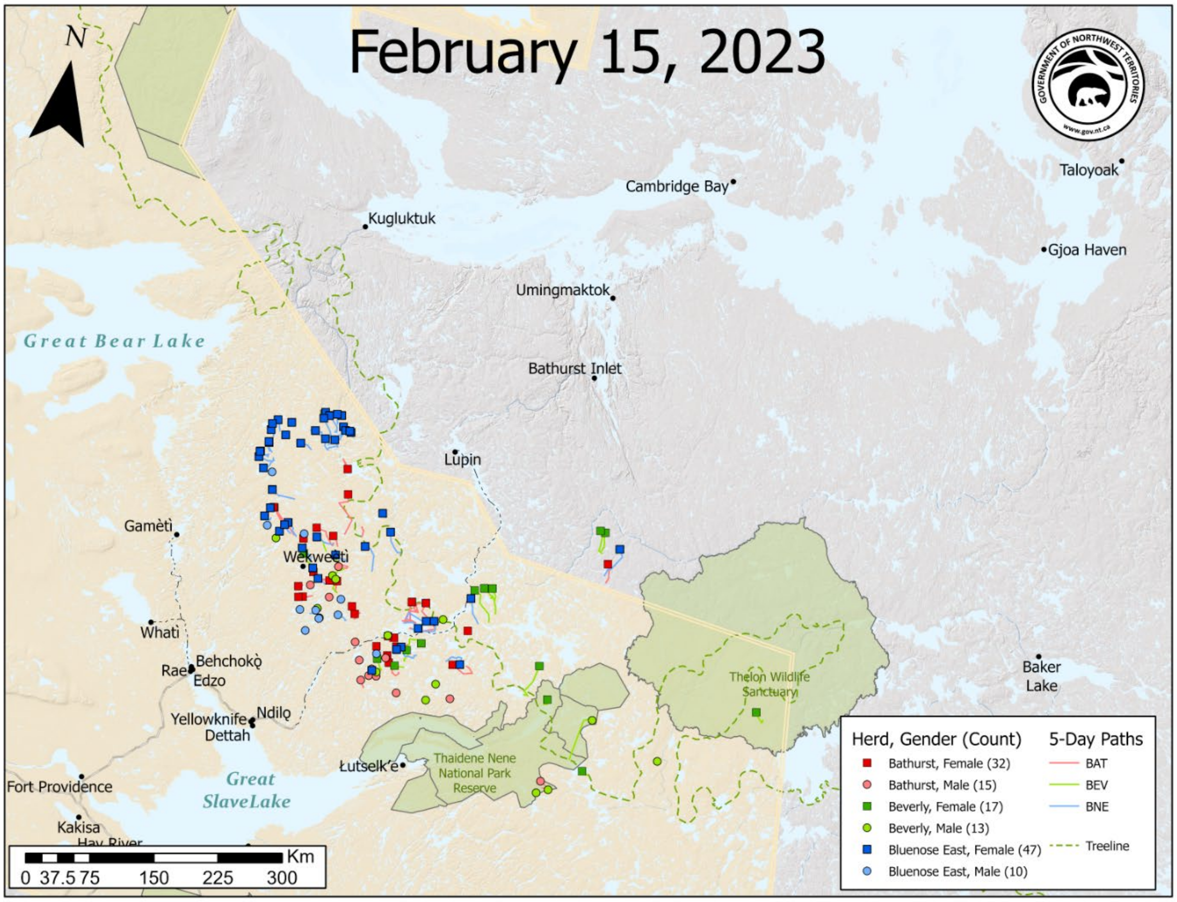


Figure 5. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in February 2023. Lines behind the locations show the last five days of movement of each collared caribou.

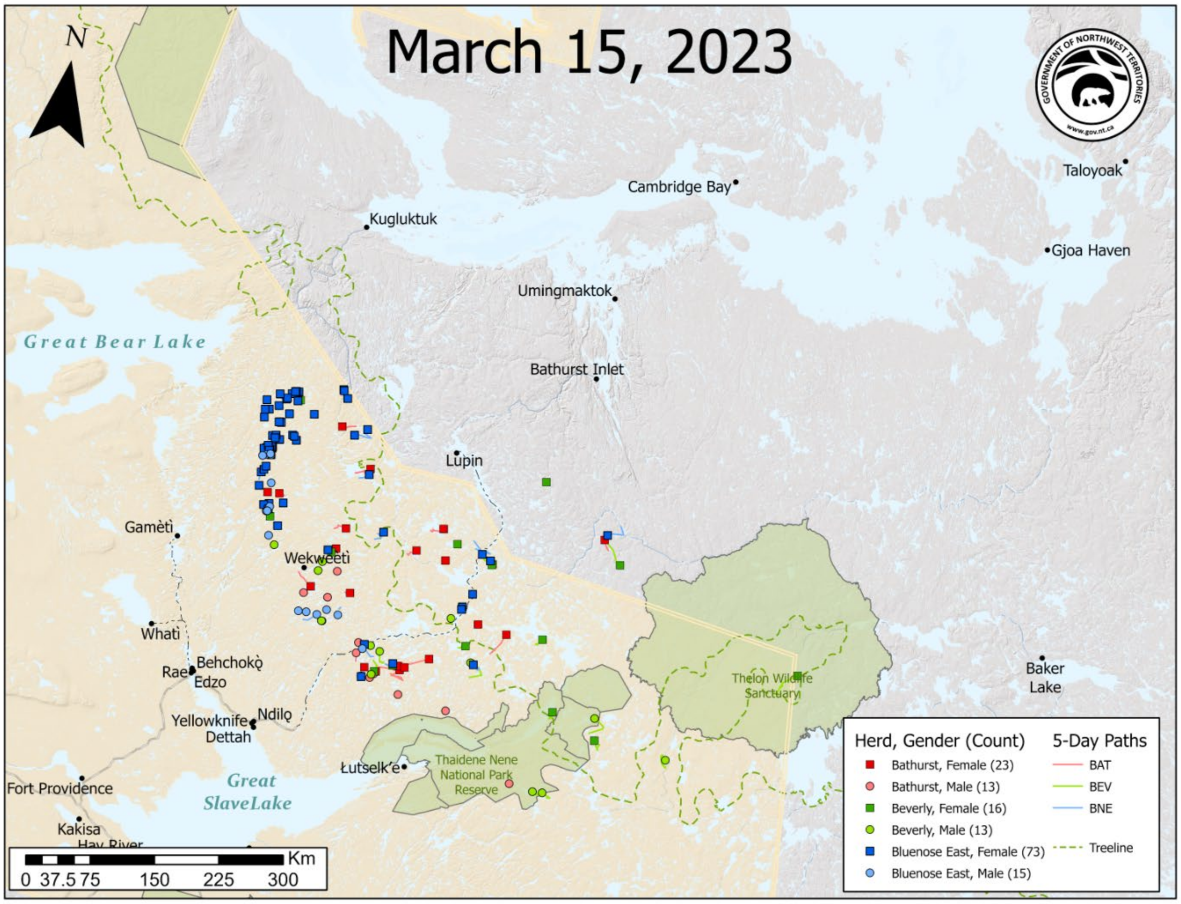


Figure 6. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in March 2023. Lines behind the locations show the last five days of movement of each collared caribou.

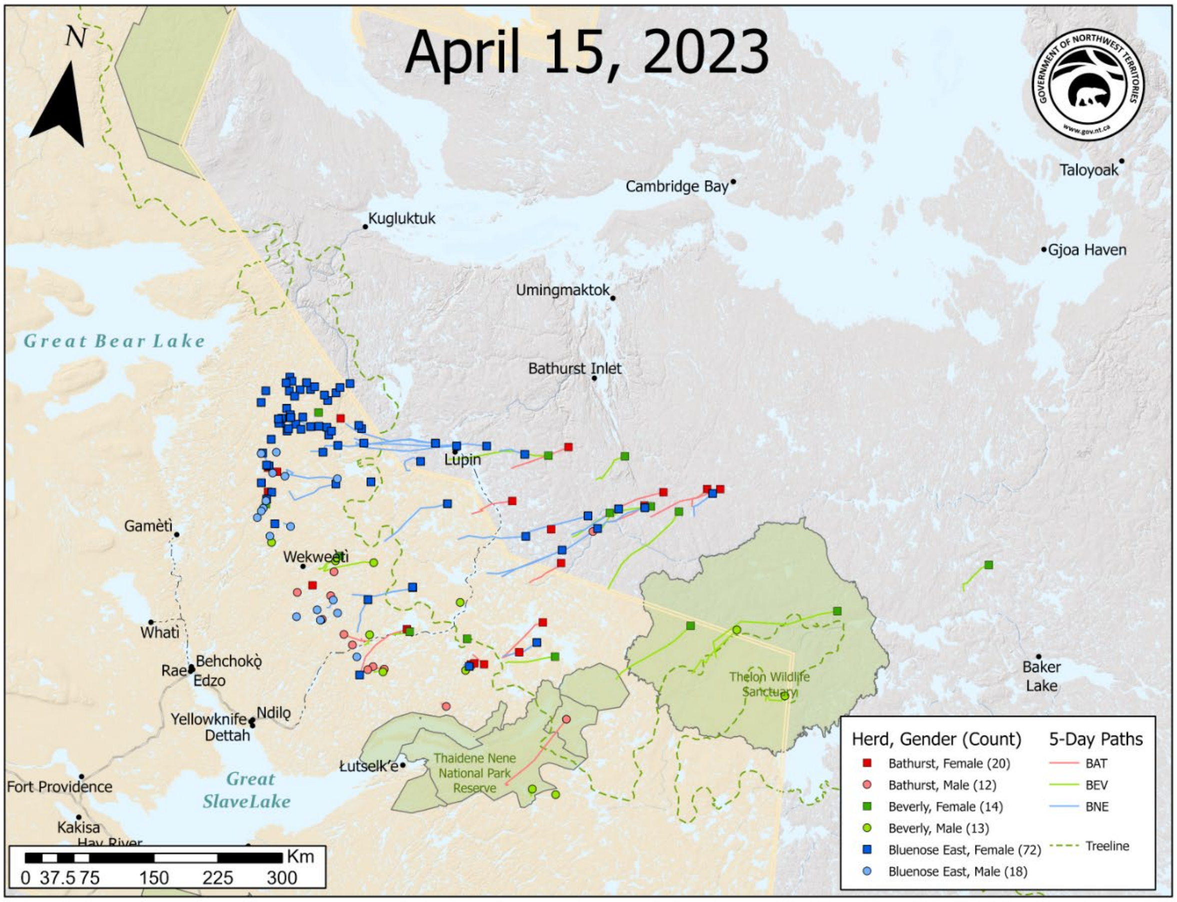


Figure 7. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in April 2023. Lines behind the locations show the last five days of movement of each collared caribou.

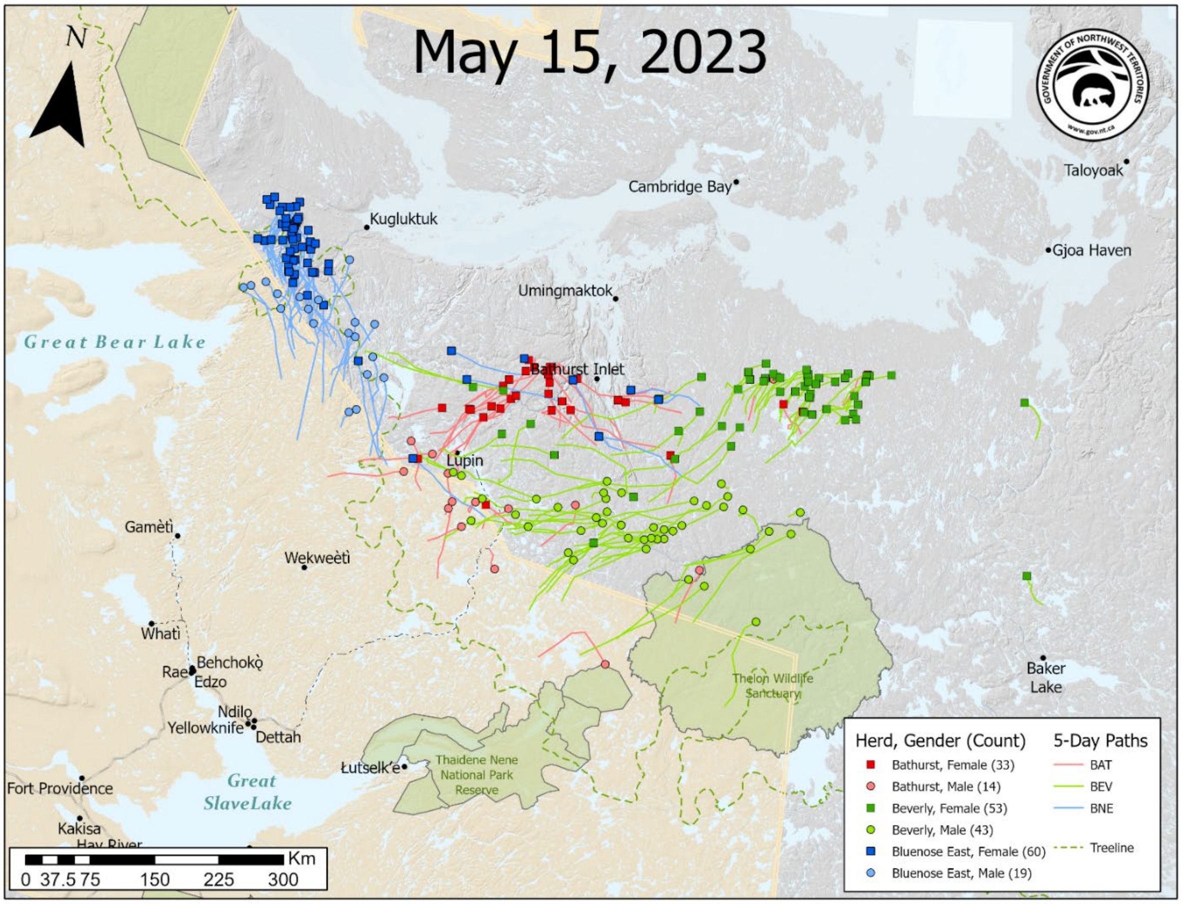


Figure 8. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in May 2023. Lines behind the locations show the last five days of movement of each collared caribou.

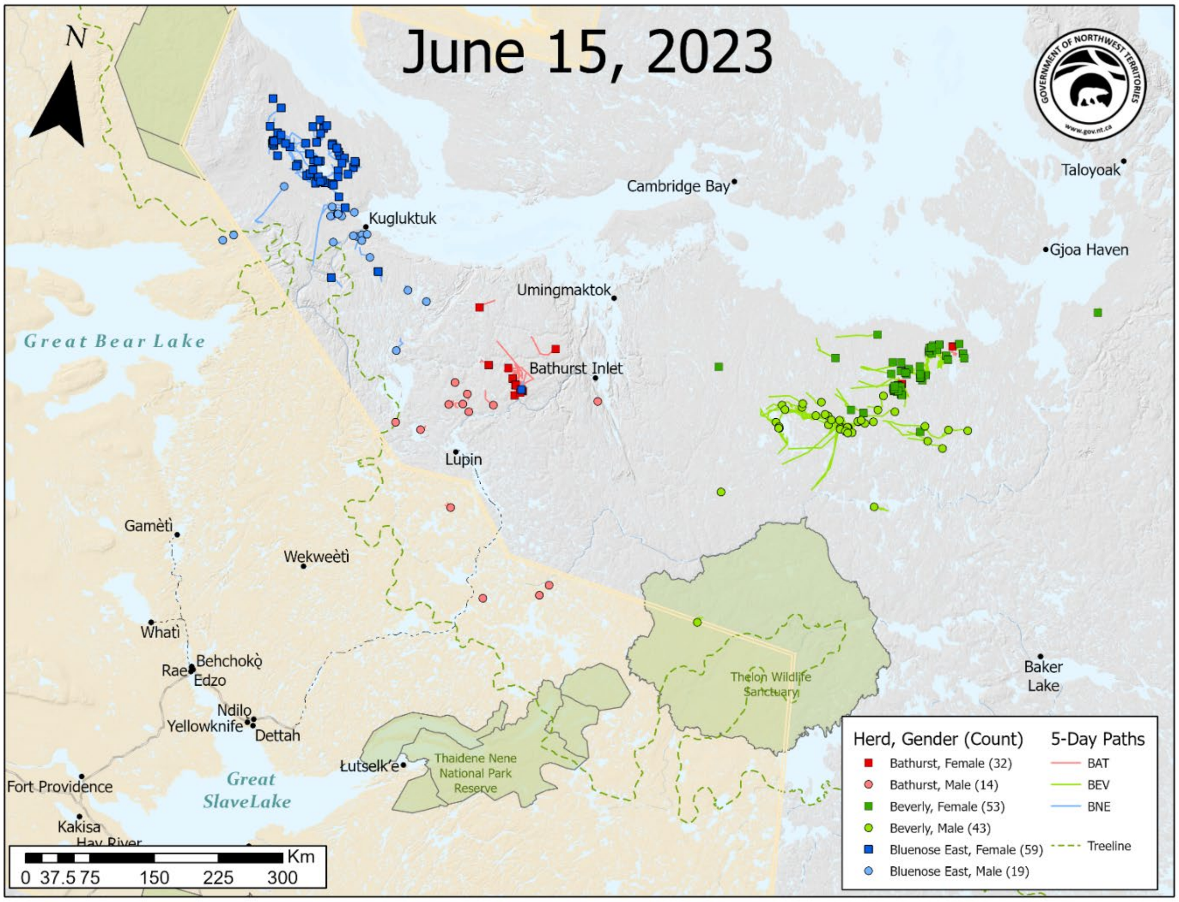


Figure 9. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in June 2023. Lines behind the locations show the last five days of movement of each collared caribou.

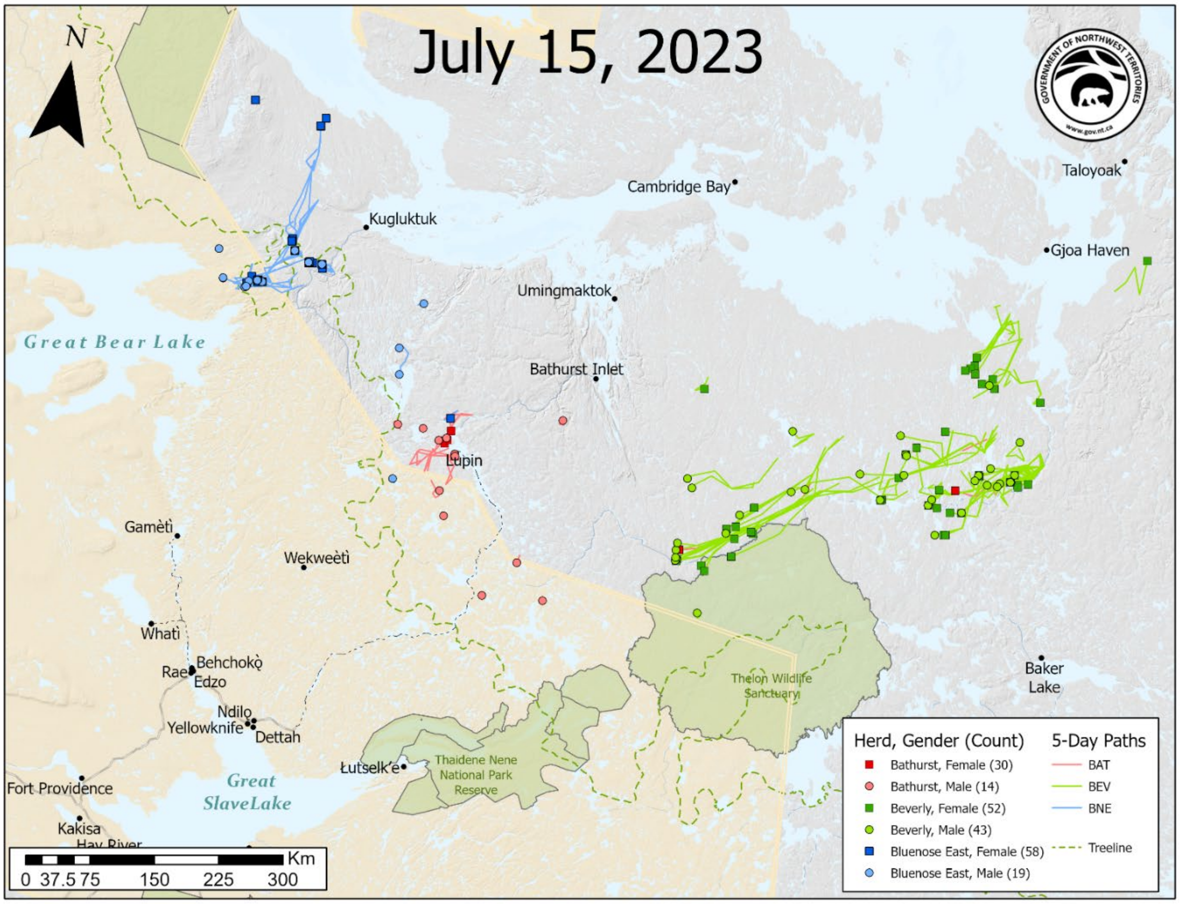


Figure 10. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in July 2023. Lines behind the locations show the last five days of movement of each collared caribou.

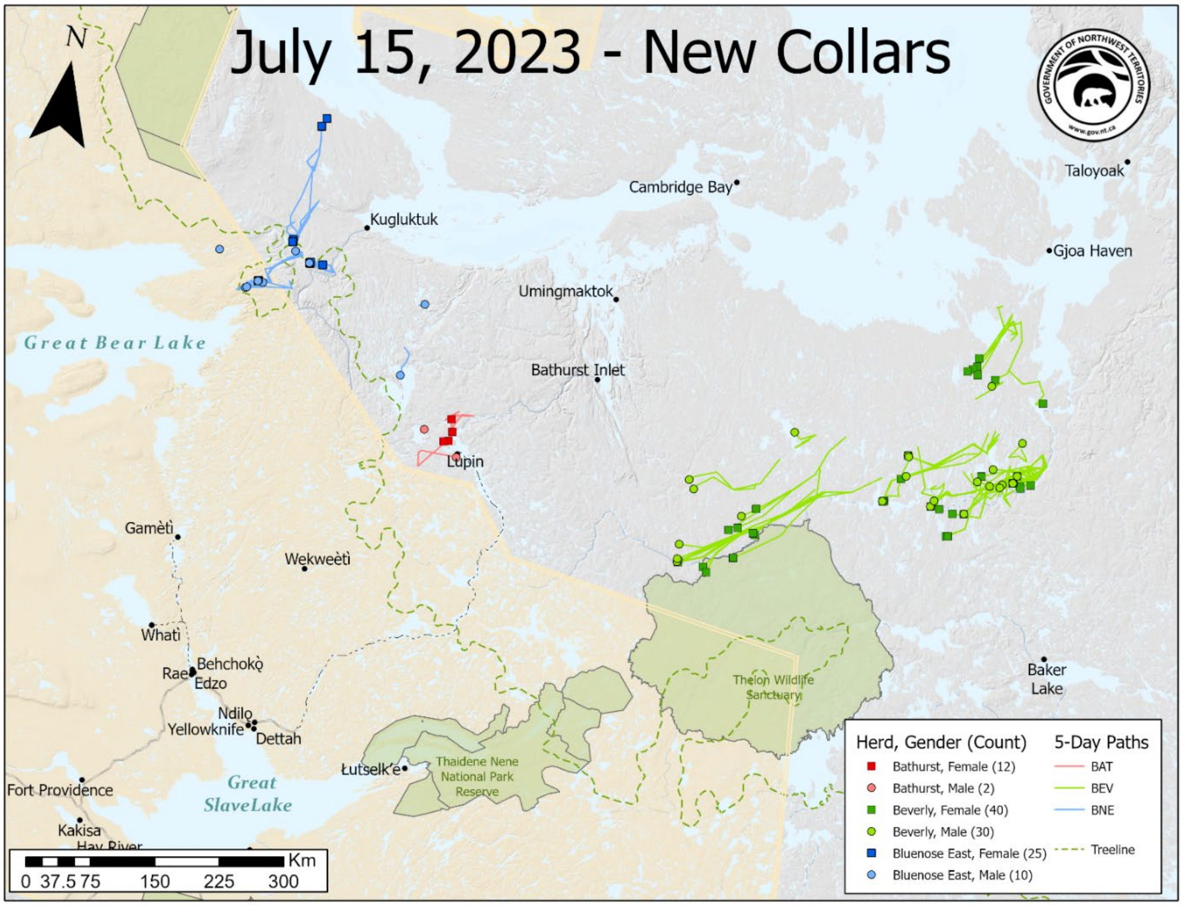


Figure 11. Locations of newly collared Bluenose-East, Bathurst and Beverly caribou males and females in July 2023. Lines behind the locations show the last five days of movement of each collared caribou. These caribou were captured and fitted with collars in March 2023.

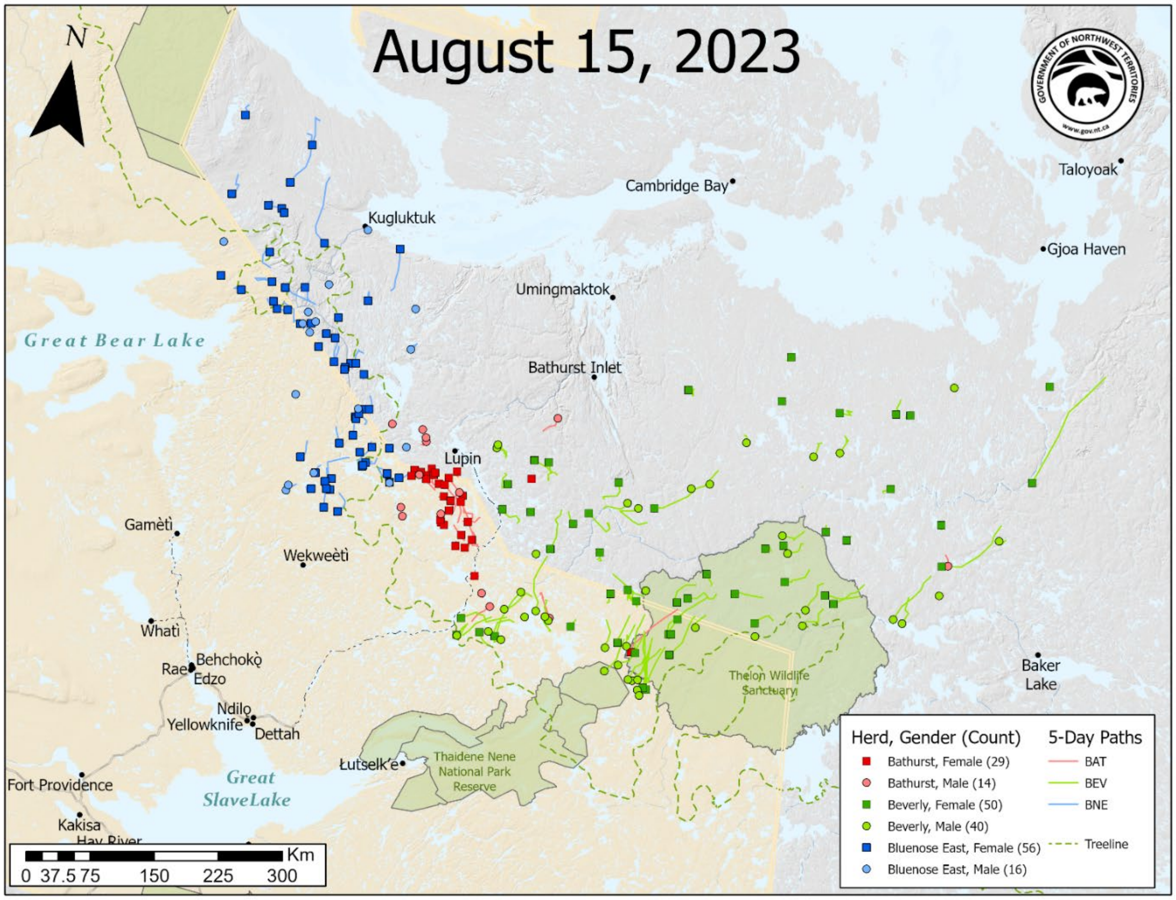


Figure 12. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in August 2023. Lines behind the locations show the last five days of movement of each collared caribou.

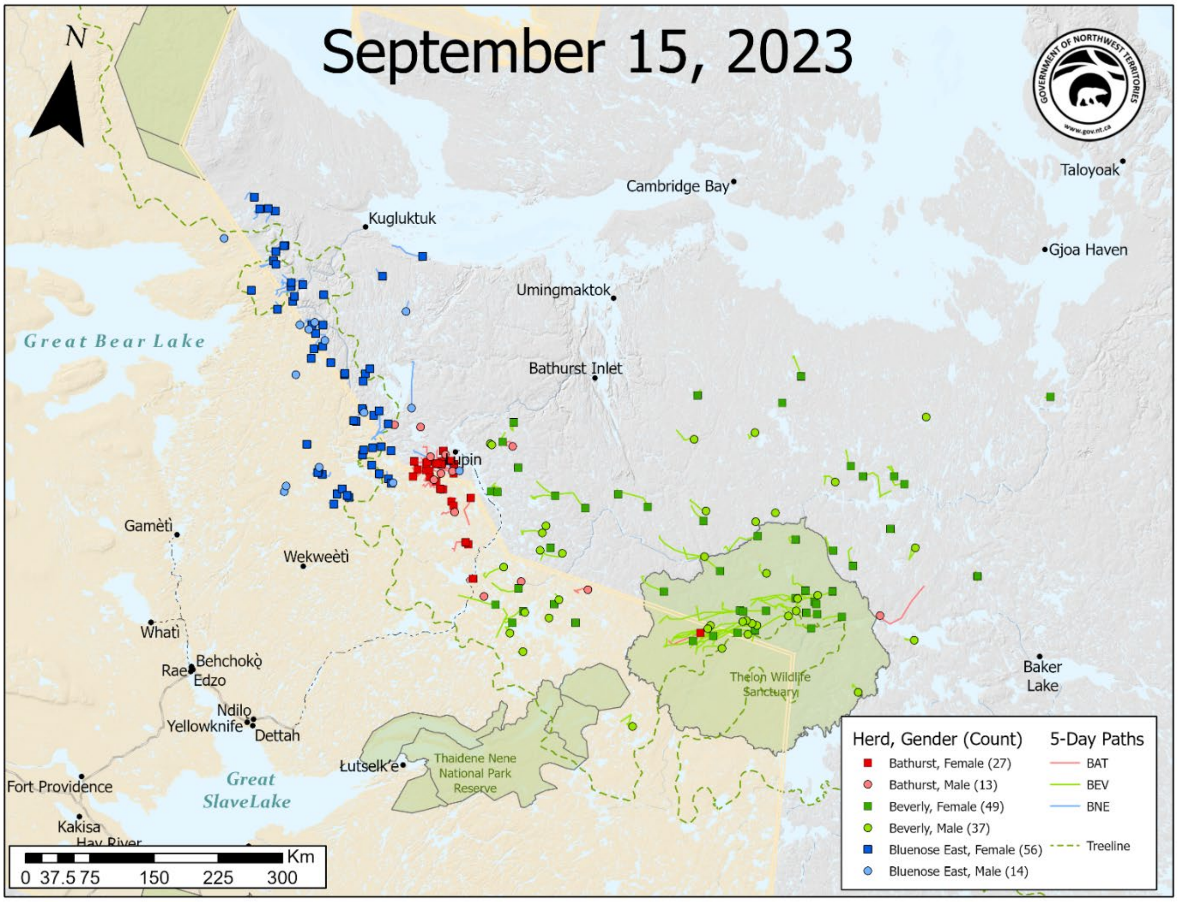


Figure 13. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in September 2023. Lines behind the locations show the last five days of movement of each collared caribou.

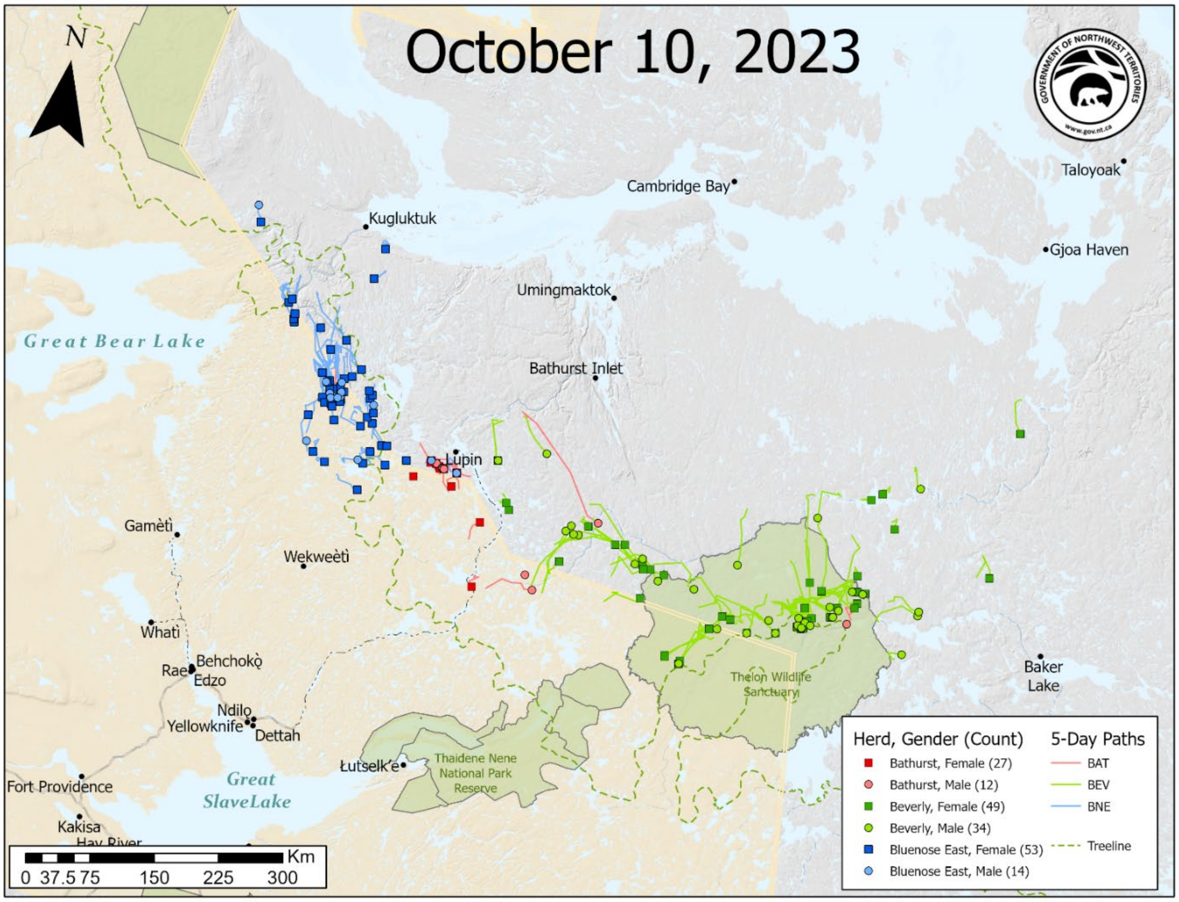
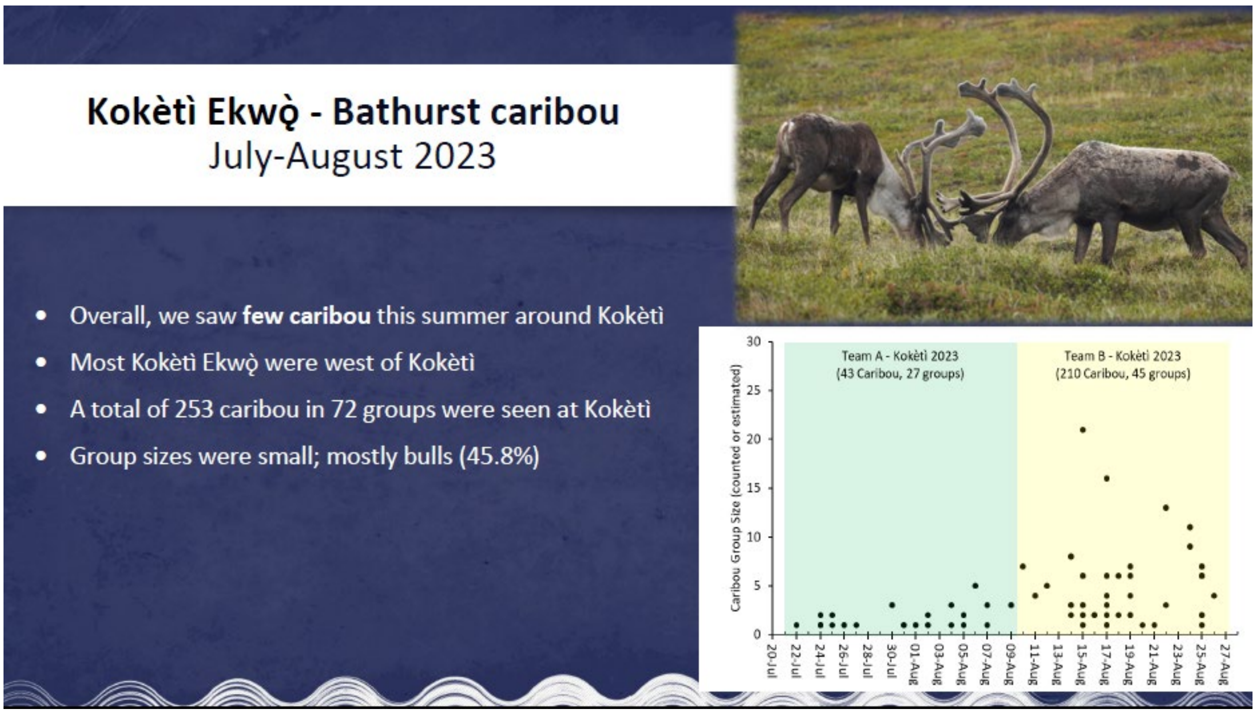


Figure 14. Locations of collared Bluenose-East, Bathurst and Beverly caribou males and females in October 2023. Lines behind the locations show the last five days of movement of each collared caribou.

Appendix 7. Summary of Tłı̨chǫ Government's Ekwǫ̀ Nàxoèdee K'è Caribou Monitoring (Courtesy of P. Jacobsen, Tłı̨chǫ Government, December 2022 and February 2023)

The following slides were provided by Petter Jacobsen, Tłı̨chǫ Government, in February 2024, based on presentations by Tłı̨chǫ Government staff at meetings on caribou. One presentation was at a meeting of the Advisory Committee for Cooperation on Wildlife Management (ACCWM) in November 2023 on Bluenose-East caribou, and the other was at a meeting of the Bathurst Caribou Advisory Committee (BCAC) on Bathurst caribou. Trends in the information are referred to in the discussion of this report, however the source slides are shown here to fully recognize the source material.



Body Condition

In July and August; most caribou were in overall in healthy and good condition. In August; caribou were becoming fat

- Out of 102 bulls in 32 groups observed; 51% of bulls were fat and 48 % were good condition, 1 bull observed as thin.
- Of 35 cows in 18 groups; only 23% scored were fat, while 74% were in good condition, and 1 cow was skinny
- Of 20 calves: 20% were fat and 80% in good condition. No thin calves.

Injuries: out of 253 caribou seen in July and August, no lameness, limping or foot injuries were observed

Bulls

Groups	Fat	Good	Thin	Total
32	52	49	1	102
	51%	48%	1%	100%

Cows

Groups	Fat	Good	Thin	Total
18	8	26	1	35
	23%	74%	3%	100%

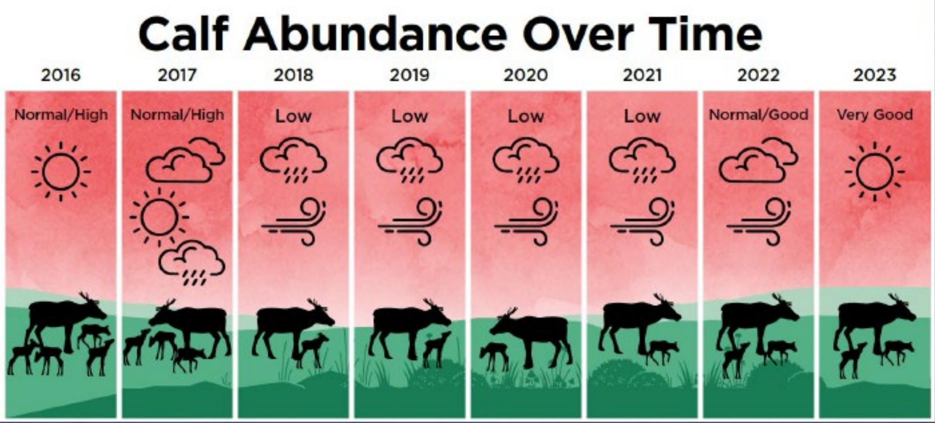
Calves

Groups	Fat	Good	Thin	Total
13	4	16	0	20
	20%	80%	0%	100%

Kokètì Ekwǫ̀ Cows and Calves

- Estimated **51.2 calves per 100 cows** (SE 13.2) based on 16 caribou groups (23 cows and 13 calves).
  - This ratio is **very good** for late summer: shows that many calves survive during spring & summer
- Estimate is likely **not representative** of the Bathurst herd due to **small sample size** and few animals observed
- On August 26, 2023 – saw a cow with 2 calves; possibly twins

"In August; many of the cows and calf groups observed had a 1:1 ratio; indicating good population growth"
-John F. Koadloak



2019 – we observed 89 groups, and counted ***31 calves per 100 cows***

2020 – we observed 37 groups, and counted ***29 calves to 100 cows***

2021 – we observed 69 groups, and counted ***39 calves to 100 cows***

2022 – we observed 44 groups, and counted ***48 calves to 100 cows***

2023 – we observed 16 groups and counted ***51 calves to 100 cows***

- The good habitat (2018-21) and caribou health provides the necessary environmental conditions for the population to grow, but many groups had few calves until,
- Summer 2022 and 2023 we observed groups with more calves

Tłı̨chǫ Ndek'àowo
Tłı̨chǫ Government

Sahtì Ekwǫ̀

Bluenose East Caribou

Deèzàatì – Point Lake

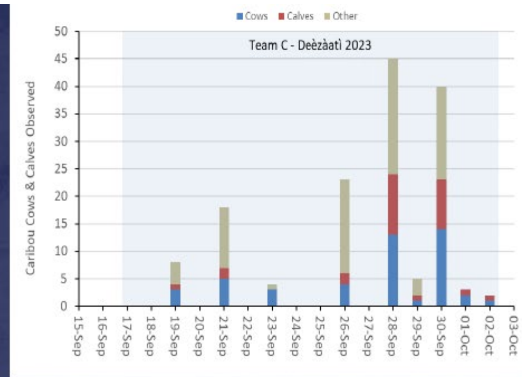
September & October 2023

Tłı̨chǫ Ndek'àowo
Tłı̨chǫ Government

Sahtì Ekwǫ

One team at Deèzàatì (Point Lake) September 15 - October 4

Total of 238 caribou were observed in 32 groups. Most groups were small, no larger herds.



Estimated an average calf: cow ratio of **60 calves per 100 cows** (± 10 SE).

- This ratio suggests **high calf** survival through spring and summer.
- Often challenging to differentiate calf from yearling
- Calves born in June have been **growing well and are healthy**.

Likely not representative of the herd due to small sample of caribou groups: based on 46 cows and 28 calves.

Tsıa (calves) – grown large bodies and long antlers by September

Tsıdaa and *Yagoa*

In 2022, we saw a **high proportion of *tsıdaa and yagoa*** (young bull & young cows).

In September 2023, we continued to see **many young caribou**

Good sign to see high proportion of young caribou: *yagoo and yagoa*. Indicate that most calves and yearlings survive overwinter

"You can tell all caribou around here are young,
because of the way they are moving.
They are moving fast – bouncing & trotting"
-Joe Zoe

In 2022 we saw many fat and healthy bulls; with big antlers and big bellies. In 2023, did not see any large bulls around Deèzàatì

Body Condition & Health – September 2023

Overall, most caribou were healthy and in good & fat body condition.

- Of 25 bulls in 10 groups observed; all the bulls (100%) were fat, no skinny bulls
- Of 27 cows in 12 groups; 89% were fat, and 7% in good condition. 1 skinny cow was noted.
- Of 16 calves in 9 groups; 44% were fat, and 56% in good condition. No thin calves were seen.

Injured BNE caribou at Deèzàatì - October 2023

- One cow had an injured back left hoof.
- She had taken refuge by the shoreline by herself. When we approached by boat, the cow was limping slowly and carefully only a few meters away, then stopped.
- The foot was very swollen, and she did not put any weight on the hoof.
- The animal had likely been injured for a long time; she was skinny, and her tail was down even though she was afraid of us.

Appendix 8. 2023 Summary of Kugluktuk Angoniatit Association Observations of Bluenose-East Caribou

The following summary was provided in March 2024 by Amanda Dumond, manager of the Kugluktuk Angoniatit Association (Hunters & Trappers Organization) in Kugluktuk, NU. It was presented to a meeting of the Advisory Committee for Cooperation on Wildlife Management (ACCWM) in November 2023 on the status of Bluenose-East caribou and is included as written.

Kugluktuk Angoniatit Association Hunters & Trappers Organization
PO Box 309, Kugluktuk NU X0B 0E0 ● Phone: (867) 982-4908 ● Email: kugluktuk@krwb.ca

For the past number of years, Kugluktuk community members have seen an increase in the Bluenose-East caribou. This includes more caribou overall but also a higher number of calves, with many cows with twins. Observations over the past few years have also shown many surviving yearlings and lots of young and adult bulls.

Smaller herds were observed, especially during the fall.

The grizzly bear population has been increasing for a number of years throughout the Bluenose-East caribou range. Wolves continue to be a huge presence.

In prior years leading up to 2023, we had cool temperatures and dry vegetation due to little rain throughout the summer. This led to a shorter mosquito (and other insects) season. In 2023, the summer season was very hot and dry, there were a lot of horseflies and small biting insects, but the mosquito season was short. We had good rain in the fall so the vegetation was very healthy. Berries were abundant and bigger than normal. The winds in the past few summers also kept the insect harassment to a minimum.

Most of the caribou harvests were very healthy, even caribou harvested in June and July. Animals had good amounts of fat. The hides in the fall were very nice.

Amanda Dumond

Manager