Government of Northwest Territories Gouvernement des Territoires du Nord-Ouest

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

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ABSTRACT

This report describes the results of a calving ground photo survey of the Bathurst barren-ground caribou herd conducted June 1-14, 2021 west and east of Bathurst Inlet in Nunavut. The main objectives were to estimate the numbers of breeding females, adult females, and adults in the herd, and to compare results to previous calving ground surveys of this herd, the last in 2018. A calving ground survey of the Bluenose-East caribou herd was carried out simultaneously and results from that survey are reported separately.

The photo survey blocks were flown with excellent field conditions (blue skies) on June 10 and visual survey blocks surrounding the photo blocks were flown on June 9, 10 and 11. A helicopter-based composition survey was carried out between June 11 and 14. Some known[1] (collared) Bathurst caribou cows were located east of the Inlet during calving (6 of 34), mixed with larger numbers of Beverly caribou. Subsequently, collared Bathurst caribou within this area moved east toward the Beverly calving ground, while the caribou west of the Inlet (28 of 34 known collars) moved south and west toward the Bathurst summer range. The estimates of the Bathurst herd are therefore based on the survey results west of Bathurst Inlet.

The estimate of Bathurst breeding females in June 2021 was 2,878 (95%CI 1,778-4,660), the estimate of total females was 3,808 (95%CI 2,435-5,955), and the estimate of adult caribou in the herd (at least two years old) including males was 6,243 (95%CI 3,950-9,134). The extrapolated estimate is based on an October 2020 fall sex ratio estimated for the Bathurst herd. This herd estimate represents an annual rate of decline of about 8% since 2018, when the herd estimate was 8,207 caribou. The annual rate of decline from 2015 to2018 was about 25%.

If the Bathurst caribou that calved east of the Inlet are considered to be part of the Bathurst herd, estimates would be 3,474 (95%CI 2,090-5,772) breeding females, 4,596 (95%CI 2,857-7,392) adult females, and 7,535 (95%CI 4,638-11,239) adult caribou. These estimates assume that numbers of Bathurst cows east of the Inlet were in proportion to relative collar numbers of known Bathurst cows on the two sides of the Inlet (west 28, east 6). This herd estimate also uses the October 2020 sex ratio for the herd. These numbers suggest that the herd was approaching stability in 2021 based on the balance between deaths and recruitment of young. An integrated population model fitted to Bathurst survey results also suggested an increasing trend in survival rates of 0.85 (CI=0.76-0.92) in 2021 for adult females and increased calf survival rates of approximately 0.5 for the past three years.

[1] In this context, "known" indicates collared cows whose location the previous year in June was known as being on the Bathurst calving ground.

The apparent emigration of known female Bathurst collared caribou (six of 34, 17.6%) in June 2021 continued a pattern from 2018 (three of 11, 27.2%) and 2019 (three of 17, 17.6%) of unidirectional Bathurst collared caribou switching to the calving ground of the Beverly herd. In each winter before these June emigrations, Bathurst and Beverly collared caribou were heavily mixed, with the Bathurst herd out-numbered more than 12:1 by the much larger Beverly herd, based on 2018 population estimates. In 2021, emigration of Bathurst caribou may be a greater concern for the herd's future than numeric decline. Continued monitoring of Bathurst caribou movement patterns with adequate collar numbers and surveys to assess abundance and trend will be essential in the next few years.

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INTRODUCTION

The Bathurst herd's calving grounds have been situated west of Bathurst Inlet since 1996 (Gunn et al. 2008; Figure 1). The herd's range in Nunavut (NU) includes the calving grounds as well as a large part of the summer range. The remainder 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.

In recent years (2009-2021) the herd's range has contracted substantially in size and the southern limit of the annual range has shifted northward as the herd has declined to low numbers. The herd has wintered near tree-line or on the tundra since 2014-2015. This herd has long been a key country food and cultural resource for Indigenous peoples in the NWT (Zoe 2012, Legat et al. 2014, Jacobsen et al. 2016), and the decline and associated harvest restrictions (WRRB 2010, 2016) have resulted in hardships in many communities. This herd was harvested by NWT resident hunters and big-game outfitters until 2010 (Boulanger et al. 2011, Adamczewski et al. 2020), when all hunting was closed other than a limited Indigenous harvest.

This report describes results of a calving ground photo survey of the Bathurst caribou herd conducted in June of 2021. The main purpose of the survey was to generate updated estimates of breeding females, total females, and the adult caribou (males and females) in the herd. A survey of the Bluenose-East herd's calving grounds west of Kugluktuk (Figure 1) was carried out at the same time with the results reported under separate cover (Boulanger et al. 2022).

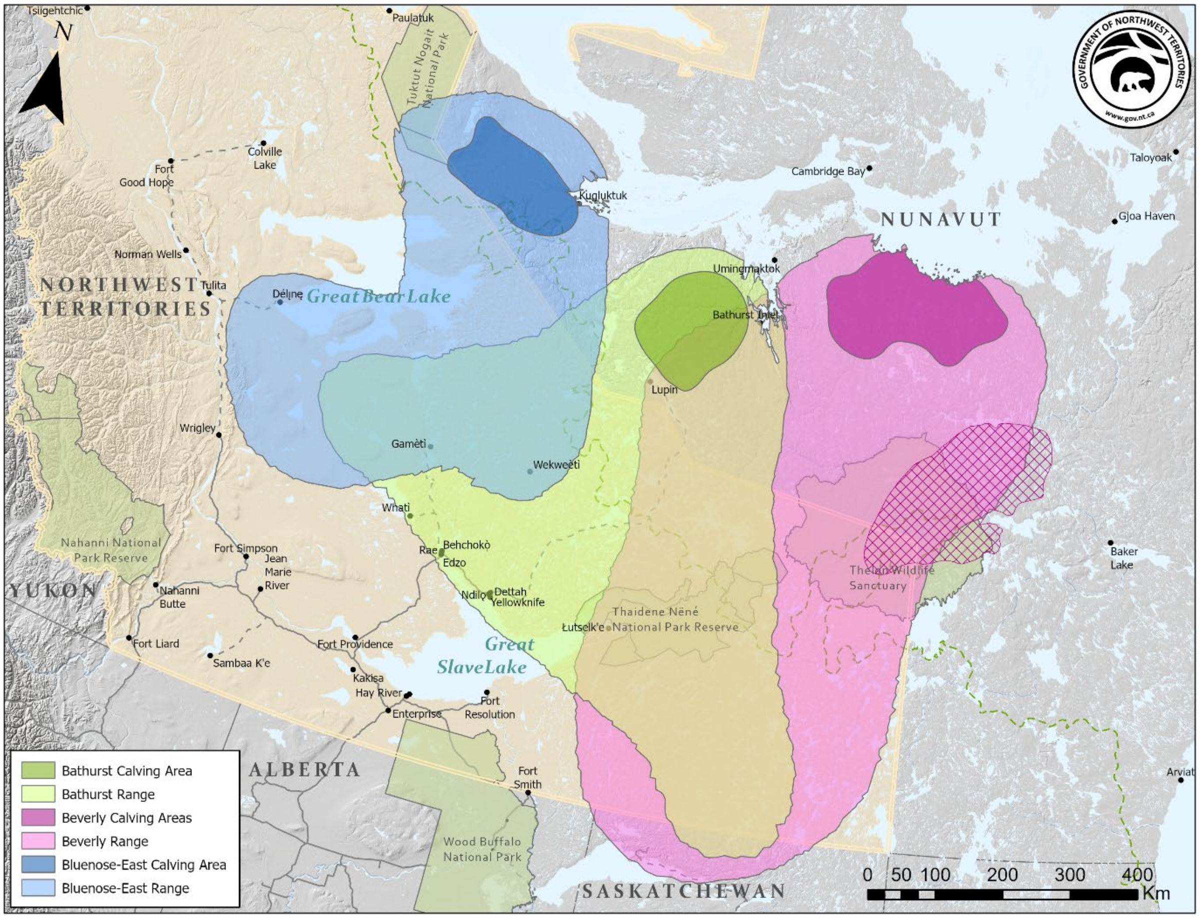

Figure 1. Annual ranges and calving grounds of the Bluenose-East, Bathurst, and Beverly [2] herds, based on accumulated radio collar locations of cows (Nagy et al. 2011). Other herd ranges west and east of these three herd ranges were omitted for simplicity.

Calving ground photo surveys of the Bathurst herd (Heard 1985, Heard and Williams 1990, 1991) have been carried out since the 1980s when the herd was at peak numbers; in 1986 the herd was estimated at 472,000 (Figure 2). Survey methods since the 1980s have remained consistent, with refinements over the years to improve the precision of the estimates and the extrapolation calculations (Adamczewski et al. 2017).

[2] 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. 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).

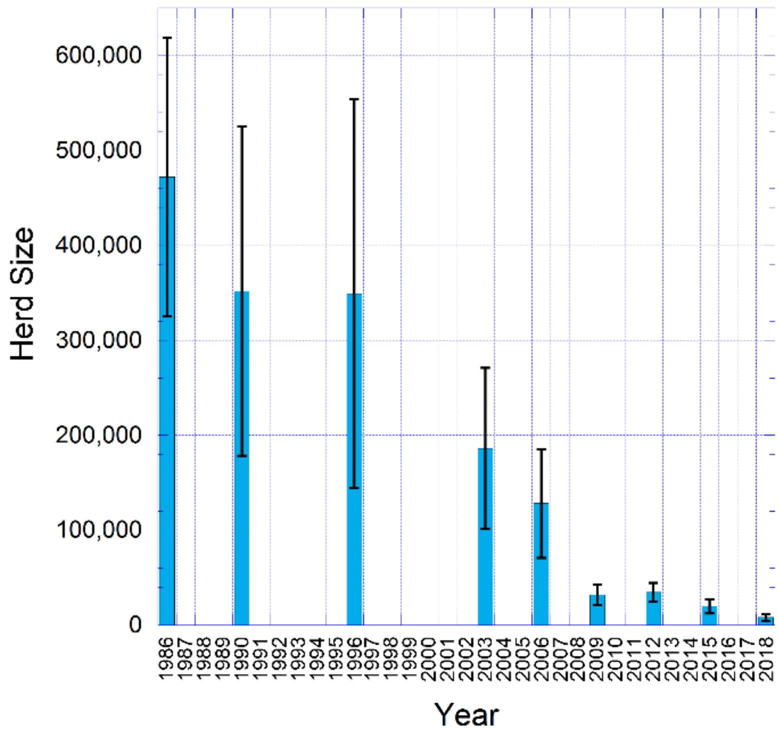

Figure 2. Estimates of the size of the Bathurst herd from 1986 to 2018, based on calving ground photo surveys. Estimates are shown with 95% Confidence Intervals.

Similar surveys of the Bathurst herd have been carried out at three-year intervals since 2003, when a substantial decline in the herd was detected. The herd initially declined slowly in the 1990s and then more rapidly after 2003. The most rapid decline was between 2006 and 2009 when the herd decreased from 128,000 to just 32,000 in three years (annual rate of decline 36%) (Nishi et al. 2007, 2014). A demographic evaluation of the herd's decline until 2009, including the role of an annual harvest of 4,000-6,000 caribou/year in the accelerated decline from 2006 to 2009, was carried out by Boulanger et al. (2011). The last calving photo survey of the Bathurst herd was in 2018 (Adamczewski et al. 2019). Recent calving photo survey reports have included an assessment of demographic factors contributing to the decline, which included low adult cow and bull survival, low pregnancy rates in some years, and low calf survival. Harvest of the Bathurst herd was significantly reduced in 2010 and has been close to 0 since 2015 in the NWT (Adamczewski et al. 2019), thus contributing very little to the herd's decline in recent years.

Following the large declines detected during the 2018 survey of the Bathurst herd, the GNWT and Tłı̨chǫ Government (2019) proposed more intensive monitoring of the herd, which was supported by the Wek'èezhìı Renewable Resources Board (WRRB 2019). This included population surveys at two-year intervals rather than three years.

In addition to numeric decline, emigration of some animals from the Bathurst herd to the neighbouring Beverly calving grounds in the Queen Maud Gulf lowlands, beginning in 2018, was identified by the movement of Bathurst collared cows. Prior to 2018, rates of switching between the Bathurst herd and its neighbours the Bluenose-East and Beverly herds were between 2 and 4%, occurring in both directions about equally (Adamczewski et al. 2019)[3]. Switching rates were similarly reported in other NWT herds (Davison et al. 2014). However, in 2018, three of 11 known Bathurst cows (27.3%) and in 2019, three of 17 known Bathurst cows (17.6%; Adamczewski et al. 2019) were found on the Beverly calving grounds in June. There was no evidence of any of these collared caribou returning to the Bathurst herd. There were no Beverly-to-Bathurst collared cow switches in these years.

While the numbers of collars were limited, demographic analysis of the Bathurst herd in 2018 suggested that a loss of about 30% of the herd's cows to the Beverly herd in 2018 would be a reasonable fit with the overall decline (Adamczewski et al. 2019). No Bathurst collared cows emigrated to the Beverly calving ground in June 2020, following a winter in which there was limited overlap of Bathurst and Beverly collared caribou. In the winter of 2020-2021, overlap of Bathurst and Beverly collared caribou was extensive, with potential for further emigration of Bathurst caribou to the neighbouring Beverly calving grounds.

[3] In June 2019 one Bluenose-East collared cow switched to the Bathurst calving ground. Occasional switches like this at low rates between neighbouring herds have been documented for Bathurst and other NWT herds of barren-ground caribou.

METHODS

Survey Limitations Resulting from COVID Restrictions

Calving ground surveys of the Bathurst and Bluenose-East caribou herds were planned for June 2020, following a decision to shorten the survey interval from three to two years when the June 2018 surveys for these herds showed large continuing declines (GNWT and Tłı̨chǫ Government 2019; WRRB 2019). However, the global COVID-19 pandemic that began in early 2020 affected many people and processes world-wide, including some field work planned by the Department of Environment and Natural Resources (ENR). Calving grounds of the Bathurst and Bluenose-East herds are both in NU and the main base of operations for surveys in June 2015 and 2018 was Kugluktuk. In the early months of 2020, travel restrictions in NU did not allow NWT survey crews to travel into NU. As a result, the surveys planned for June 2020 were postponed to June 2021.

The shifting COVID-19 situation also created challenges in 2021. An approach using the Coppermine Inn as an isolation "bubble" for survey crews when not flying was approved by the Government of Nunavut public health office for the June 2021 calving ground surveys. Concerns over COVID-19 influenced the decisions of observers from some communities to participate. There were no community observers on the June 2021 surveys from Délı̨nę or Łutsel K'e, in large part due to COVID-19 concerns.

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

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

Collared Caribou Data

Thirty-four known Bathurst collared female caribou were key to survey planning during the June 2021 survey. There were also 15 unassigned collared cows in the survey area near Bathurst Inlet. In this context, "known" indicates collared cows whose location the previous year in June was known as being on the Bathurst calving ground. New collars on female caribou are usually placed in March when there can be substantial herd mixing, thus their earliest possible assignment to a herd will be that year in June when they normally separate out to the distinct calving grounds. Their previous history is unknown.

Of the 34 known Bathurst cow collars, 28 were in the main area west of Bathurst Inlet that the herd had used since 1996. This included two collared cows that were at the south end of Bathurst Inlet[4]. Six known Bathurst female collars were east of Bathurst Inlet; of these, two had moved east in early June with the Beverly herd based on movements paralleling those of Beverly collared cows. Another four known Bathurst collared cows were just east of Bathurst Inlet during the survey period and in the eventual survey area. Ten of the unassigned cow collars were west of Bathurst Inlet and five were east of the Inlet, all within the June survey area. At the time of the June 2021 survey, there were ten known Beverly collared cows and 14 unassigned cow collars mostly further east in the Queen Maud Gulf lowlands. One collared Beverly cow was just north of the eventual survey area east of Bathurst Inlet, and one collared Beverly bull was within that eventual survey area.

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, then staying below 5 km/day is a reliable indicator of the peak of calving. We also had information from two reconnaissance flights carried out with an Aviat Husky on June 3 in the Bathurst core calving area west of Bathurst Inlet and on June 4 east of the Inlet, which provided further information on how far calving had progressed in those areas.

Reconnaissance Survey and Time Limitations

Unlike previous calving ground surveys for this herd, we were not able to fly a systematic reconnaissance survey to define distribution, relative numbers of caribou and approximate composition of caribou seen (breeding and non-breeding cows, calves, yearlings, bulls). This change from previous surveys was made largely because weather between June 2 and 7 was poor and little flying was possible. An assessment of time needed to complete the reconnaissance surveys of both herds indicated that one and a half days would be needed for the Bathurst and a full day for the Bluenose-East calving ground. Daily collar movement rates and observations from reconnaissance flights on June 3 by an Aviat Husky through the Bathurst main cluster of collared cows west of Bathurst Inlet suggested a peak of calving between June 3 and 6. In this type of survey, the main survey flying is best timed over the 7-10 days during and after the peak of calving when cow movement rates remain low. A good weather window forecast for June 9 and 10 provided the opportunity to carry

[4] These two collared cows at the south end of Bathurst Inlet are grouped with the "west" collars as they later moved west and south with the main group of Bathurst collared cows, in contrast to the collared caribou east of the Inlet that all moved east.

out the aerial photography on the Bathurst and Bluenose-East calving grounds. Consequently, the reconnaissance survey was not flown and survey blocks[5] were designed around locations of collared female caribou for both calving grounds. Good weather days were used to fly photo and visual blocks June 8-11.

Design of Photo and Visual Survey Blocks:

Aerial photo blocks were designed around the larger concentrations of collared female caribou. This was done in part because previous calving ground surveys had shown that clusters of collared Bathurst or Bluenose-East females reliably identified areas of concentration of female caribou from each herd. In addition, a high number of collared cows (34 known, 15 unassigned) in the Bathurst Inlet survey area at the time increased our confidence that the collared cow locations defined the main distribution of female caribou on the calving grounds reliably, and that survey blocks could be designed with confidence around these collared caribou. An emphasis was placed on aerial photo coverage in part because snow cover during the survey period was variable and in many areas was very patchy. The patchy snow cover created challenges for observers looking for caribou, particularly if they were in small groups (one to ten). We expected that caribou on aerial photos would be found reliably despite the poor snow conditions, as was the case in 2018 (Adamczewski et al. 2019).

A photo stratum was defined west of Bathurst Inlet where the largest numbers of known collared Bathurst cows were concentrated. This photo core stratum had 25 of 34 known Bathurst collared cows and a further ten unassigned collared cows. This concentration was consistent with several previous calving ground surveys of this herd, including 2015 and 2018. In addition, we delineated a photo block east of Bathurst Inlet based on the presence of four known Bathurst collared cows and five unassigned collared cows. A reconnaissance survey flown in the Aviat Husky on June 4 east of Bathurst Inlet suggested that there were significant numbers of caribou in that area and that calving was occurring.

Survey blocks to be flown visually were designed to include areas surrounding the photo blocks in all directions on both sides of Bathurst Inlet, and to include a few outlying collared females. We assumed these outlying areas would have lower numbers of caribou. The initial results of the Bathurst visual flying indicated a substantial number of caribou observations in the eastern-most visual block east of Bathurst Inlet; as a result, an additional visual block was added on the eastern boundary of that block. There were in total nine visual survey blocks.

Targets for ground coverage and numbers of lines in photo blocks and visual blocks were designed to consider optimal allocation and to reduce variance. These targets were based

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

in part on previous Bathurst calving ground surveys. More effort (higher coverage) was assigned to strata with higher expected densities of caribou. Results of previous surveys suggested that there should be a minimum of ten transects in each stratum and about 20 transects/stratum for higher density areas (Boulanger et al. 2019). In general, coverage should be at least 15% with higher levels of coverage for higher density strata, for adequate precision. The target for ground coverage for the photo core (west) block was 50% and for the photo east block was 30%. Targets for visual strata were 15-20%.

For the photo blocks, scenarios under a range of survey altitudes (based on cloud ceilings) were considered with the goal of having the photo strata in each calving ground flown in a single day by two photo planes at target coverage levels, while keeping within the budgeted numbers of photos to be taken (Figure 3).

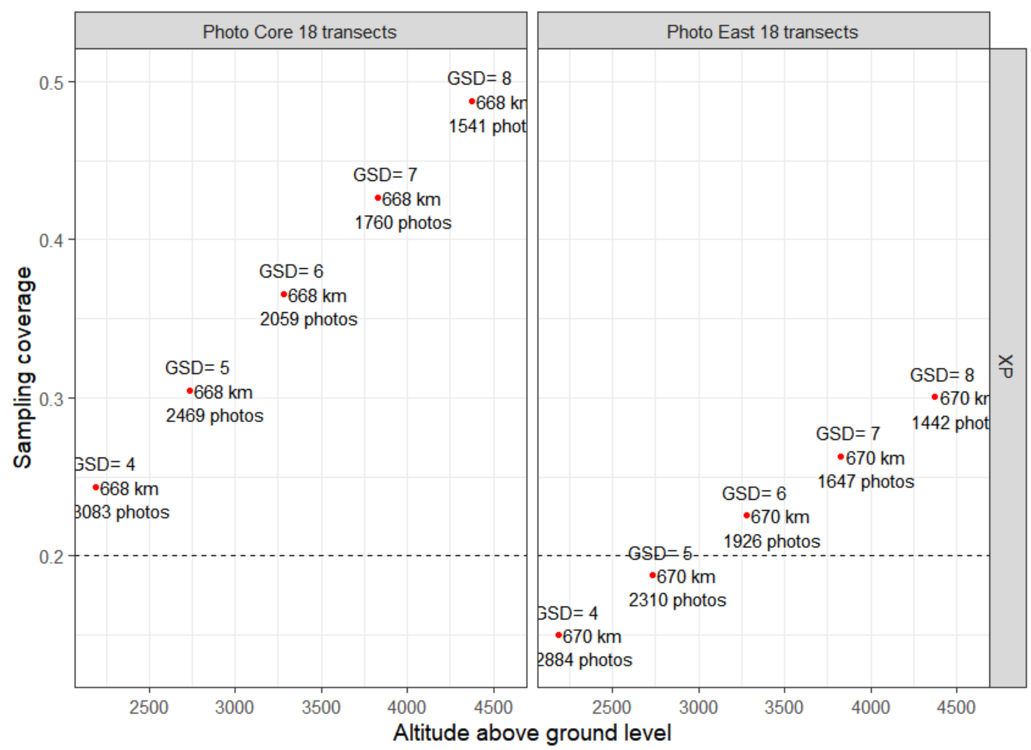

Figure 3. The relationships between coverage, altitude, km flown on strata, GSD[6] (the resolution of the aerial photos), and the number of photos required for ground coverage in the Bathurst 2021 photo strata.

The trade-off with this exercise was that for surveys flown at lower altitudes, coverage is reduced and the number of photos needed is increased. An algorithm in R (R core team

[6] 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. Further information is at: https://support.pix4d.com/hc/en-us/articles/202559809-Ground-sampling-distance-GSD-in-photogrammetry.

2018) was designed to generate 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 shape files and coverage estimates were generated and cross-validated using the *dssd* R package (Marshall 2021). The general strategy used was to set a lower limit on coverage (20-30%) and assess the number of transects that could be flown at lower survey altitudes within a single day with two photo planes. Using this approach ensured acceptable coverage if lower survey altitudes were required with additional coverage if weather permitted higher altitudes.

For visual blocks, sampling was designed to meet target coverage levels with the goal of having all Bathurst visual blocks flown within two survey days. Because reconnaissance data were not available, visual blocks were set to buffer photo blocks with sufficient coverage and line numbers to allow valid estimates. 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 2009). Data were plotted using the *ggplot2* (Wickham 2009) with GIS manipulations using the simple features (*sf:* Pembesma 2018) R package.

Photographic Survey Blocks and Photo Interpretation

GeodesyGroup Inc. aerial survey company (High Level, AB) was contracted for the aerial photography in the 2021 June surveys. They used two survey aircraft, a Piper PA46-310P Jet-prop DLX and a Piper PA31-310 Panther Navajo (Figure 4), each with a digital camera mounted in the belly of the aircraft. The camera systems were from Vexcel Imaging in Graz, Austria (www.vexcel-imaging.com) and the cameras have 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 are integrated into gyro-stabilized camera mounts and use imbedded airborne GPS (global positioning systems) and IMUs (inertial measurement units) to provide direct georeferenced images[7].

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

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

The two aircraft operated from Yellowknife as a base and re-fueled at the Lupin mine site for the Bathurst survey. Survey altitude above ground level (AGL) to be flown for photos was determined at the time of stratification based on cloud ceilings and desired coverage. Both aircraft were used for the Bathurst photo blocks on June 10 with excellent survey conditions (blue skies). 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.) using specialized software and glasses that allowed three-dimensional viewing of photographic images, consistent with methods used for the June 2015 and 2018 Bathurst and Bluenose-East 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 was determined using the geo-referenced digital photos.

The highly variable and patchy snow cover near Bathurst Inlet made counting caribou on the aerial photos more difficult. Caribou on snow-free ground were easy to see, but caribou on small snow patches or on their edges required extra effort to find. The snow conditions were similar to those encountered in June 2018 (Adamczewski et al. 2019). As in 2018, two approaches were used to address this challenge with the aerial photos: (1) observers took extra time to search all photos carefully, and (2) a double observer method was used to estimate sightability of the caribou on photos for a subset of photos.

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

This cross-validation process was modeled as a two-sample mark-recapture method with caribou being “marked” in the original count and then “re-marked” in the second count for each photo resampled. This approach avoids the assumption that the second counter detects all the caribou on the photo. The Huggins closed N model (Huggins 1991) in program MARK (White and Burnham 1999) was used to estimate sightability. A session-specific sighting probability model was used, allowing unique sighting probabilities for the first and second photo interpreter to be estimated. Model selection methods were then used to assess whether there were differences in sightability for different strata sampled. The fit of models was evaluated using the Akaike Information Criterion (AIC) index of model fit. The model with the lowest AIC_c score[8] was considered the most parsimonious, minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). Non-independence of caribou counted in photos most likely caused over-dispersion of binomial variances. The over-dispersion parameter (c-hat) was estimated as the ratio of the bootstrapped (photo-based) and simple binomial variance. Sightability-corrected estimates of caribou were then generated as the original estimate of caribou on each stratum divided by the photo sightability estimate for the stratum. The delta method (Buckland et al. 1993) was used to estimate variance for the final estimate, thus accounting for variance in the original stratum estimate and in the sightability estimate.

Visual Block Flying and Data Recording

Visual strata were flown in two Caravan fixed-wing aircraft following methods used in several previous calving ground surveys (original methods in Norton-Griffiths 1978). Strip transects were 800 m in width, and caribou were counted within a 400 m strip on each side of the survey plane (Gunn and Russell 2008). For each side of the plane, strip width was defined by the wheel of the airplane on the inside, and a single thin rope attached to the wing strut that became horizontal during flight served as the outside strip marker. Planes were flown at an average survey speed of 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 (Figure 5). Previous research (Boulanger et al. 2010) demonstrated that two observers usually saw more caribou than a single observer. In addition, analysis of the sighting patterns of observer pairs allowed for assessment of what was likely missed (Boulanger et al. 2010, 2014). Double observer

[8] The subscript “c” indicates an AIC score that is corrected for small sample sizes.

methods have been used on other recent Bathurst and Bluenose-East calving ground photographic surveys (e.g. Adamczewski et al. 2019, Boulanger et al. 2016, 2019). The two observers on the same side communicated to ensure that groups of caribou were not double counted. During visual survey flying, the intercom system was set up to separate the two sides of the aircraft, so that the two observers and recorder on each side could only hear participants on their side of the aircraft.

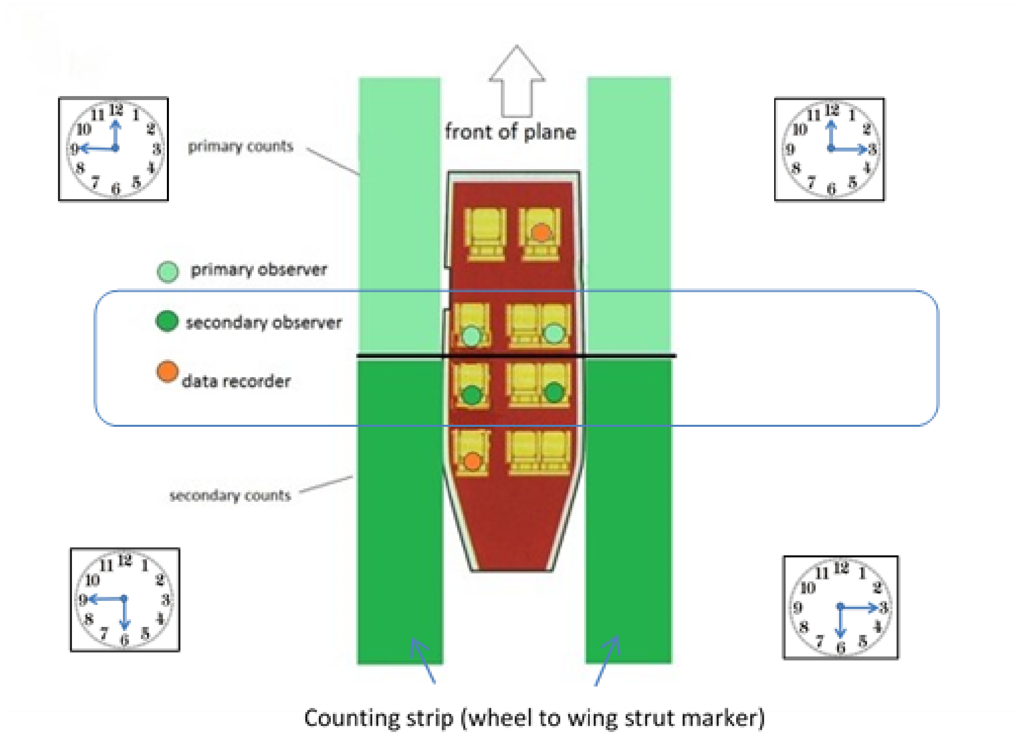

Figure 5. Observer and recorder positions for double observer methods on June 2021 caribou survey of Bathurst caribou. The secondary observer confirmed or called caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can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

Visual surveys were conducted in nine strata where lower densities of caribou were expected based on numbers of collared caribou. Four of these surrounded the photo core block (west of Bathurst Inlet), four surrounded the photo east block (east of Bathurst Inlet), and one was at the south end of Bathurst Inlet.

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

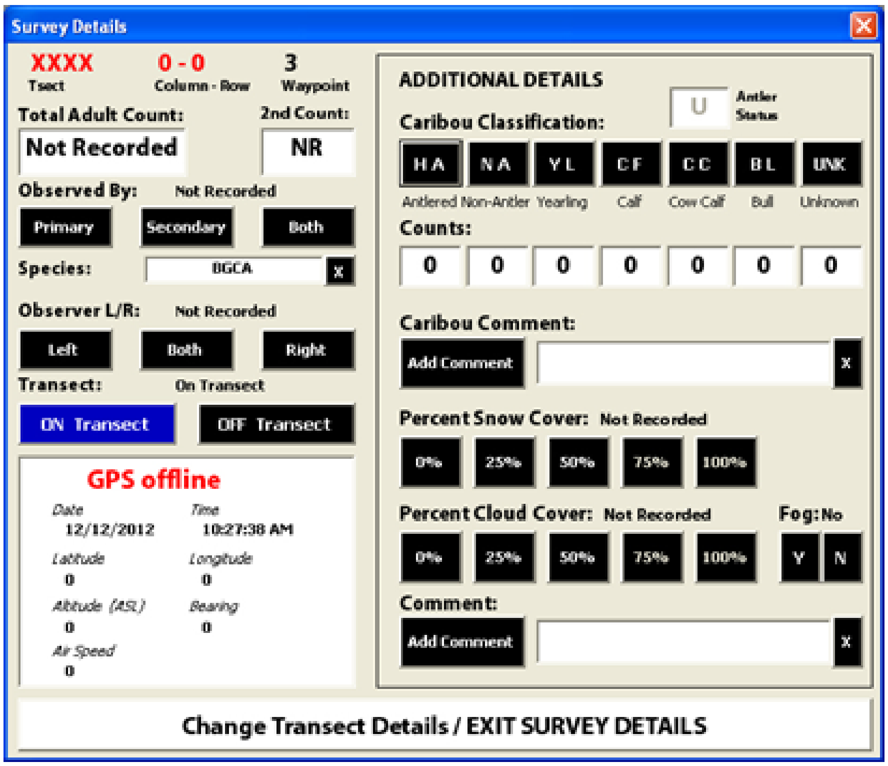

Figure 6. The tablet data entry screen used during visual survey flying on the Bathurst June 2021 survey. The unique segment unit number was also assigned by the software for each observation to summarize caribou density and composition along transect lines. A GPS waypoint was recorded for each observation.

Helicopter-Based Composition Survey

The composition survey was flown on June 11, 12, 13 and 14 in an A-star helicopter. The composition survey crew classified larger groups (i.e., more than about 30) on the ground using a spotting scope, and classified smaller groups primarily from the air, using motion-stabilized binoculars. Classification was carried out in all nine visual blocks and the two photo blocks, with greater effort in the blocks where more caribou were expected.

Caribou were classified following the methods of Gunn et al. (1997) (and see Bergerud 1964, Whitten 1995) where antler status, presence/absence of an udder, and presence of a calf are used to categorize breeding status of females (Figure 7). Presence of a newborn calf, presence of hard antlers signifying recent or imminent calving, and presence of a distended udder were all considered as signaling a breeding cow that had either calved, 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.

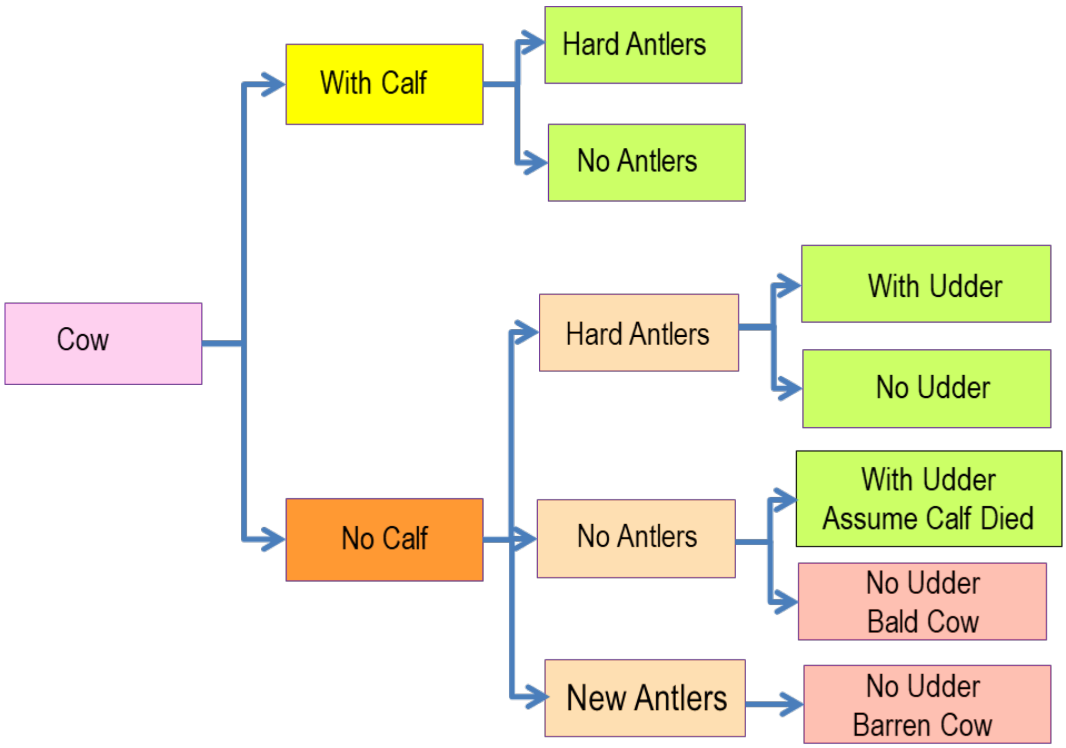

Figure 7. Classification of females used in composition survey of Bathurst caribou in June 2021. Green-shaded boxes were all classified as breeding females (diagram adapted from Gunn et al. 1997). Udder observation refers to a distended udder in a cow that has given birth or is about to. Hard antlers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

The number of caribou in each group was recorded as well as the numbers of bulls and yearlings (calves of the previous year) to estimate the proportion of breeding 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 Breeding Females, Adult Females and Adult Herd Size

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

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

Total herd size (adults at least two years old) was estimated by using a recent estimate of the bull:cow ratio from October 2020 to extrapolate or "add on" the bulls to the estimate of adult females. This method of extrapolation was first used in the 2014 Qamanirjuaq caribou herd survey (Campbell et al. 2015), and has been used in other recent calving photo surveys for the Bathurst and Bluenose-East herds (e.g. Adamczewski et al. 2019, Boulanger et al. 2017, 2019). 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 Breeding and Adult Females

As an initial step, a comparison of the estimates from the 2018 and 2021 surveys was made using a simulation approach that assumed log-normal distributions of estimates to test for significance between survey estimates and generate confidence limits on overall (gross) change and yearly change in estimates (Manly 1977). One thousand simulations of estimates were generated from a log-normal distribution for each year. The proportion of simulations where gross change (the ratio of successive estimates) was greater than 1 was tallied. If this proportion was less than 0.05 then a significant decline was suggested. Confidence limits were then derived based on the 2.5th and 97.5th percentile of the resulting distributions of gross (GC) and annual change (with $\lambda = GC^{(1/\text{survey interval})}$). An underlying exponential rate of change was assumed with estimates of λ (where $\lambda=N_{t+1}/N_t$). If λ=1 then a population is stable; values > or <1 indicate increasing and declining populations respectively. The rate of decline was also estimated as 1- λ.

Longer term trends (2010-2021) were estimated using Bayesian state space models, which are similar to previously used regression methods (Ordinary Least Squares, OLS, as described in Boulanger et al. 2011). However, hierarchical Bayesian models allow more flexible modeling of variation in trend through the use of random effects (Humbert et al. 2009, Kery and Royle 2016, Schaub and Kery 2022). This general approach is described further in the demographic model analysis in the next section.

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

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

The Bayesian IPM 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 8) and is identical to the previous OLS model. However, the Bayesian IPM method provides a much more flexible and robust method to estimate demographic parameters that takes into account process and observer error. 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.

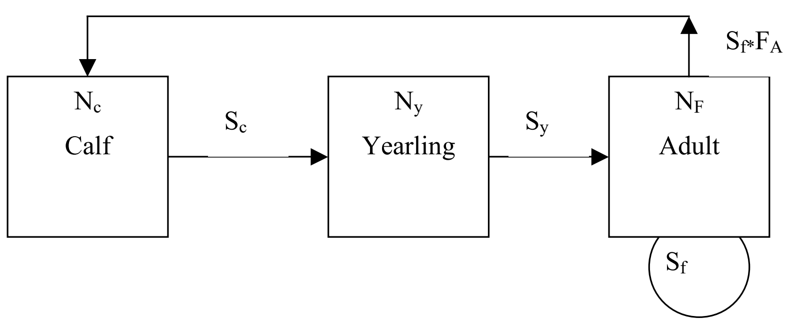

Figure 8. The stage matrix life history diagram for the caribou demographic model used for Bathurst caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates of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

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

Collared caribou survival rates were estimated from collar data for caribou between 1996 and 2021. Fates of collared caribou were determined by assessment of movement of collared caribou, with mortality being assigned to collared caribou based on lack of collar movement that could not be explained by collar failure or device drop-off. The data were summarized by month as live or dead caribou. Caribou collars that failed or were scheduled to drop off were removed from the analysis. Data were grouped by "caribou years" that began during calving of each year (June) and ended during the spring migration (May). The Kaplan-Meier method was used to estimate survival rates, accounting for the staggered entry and censoring of individuals in the data set (Pollock et al. 1989). This approach also ensured that there was no covariance between survival estimates for the subsequent demographic model analysis.

The entire Bathurst demographic data set that started in the 1980s (Boulanger et al. 2011, Adamczewski et al. 2019) was used for the analysis but modeling efforts and inference were focused on the more recent years, i.e. since 2018. It was assumed that a female calf born in a particular year would not breed in the fall after it was born, or the fall of its second year, but it could breed in its third year (see Dauphiné 1976 for age-specific pregnancy rates). Calves born in 2017 and 2018 had the most direct bearing on the number of new breeding females on the 2021 calving ground that were not accounted for in the 2018 breeding female estimate.

One potential issue with comparison of survival rates across years was that the Bathurst herd had significant harvest until 2010, which reduced survival rates. We therefore added harvest rate to the model based on harvest estimates compared to estimated cow and bull abundance each year. Demographic modeling of the herd's trend and size in 2021 had to also take into consideration the emigration of Bathurst caribou to the Beverly herd's range, based on collared caribou movements 2018-2021.

Estimation of Bathurst Herd, Including Potential Emigration to Beverly Range

The 2021 estimates of Bathurst breeding cows, adult cows and herd size were based on survey results from the west side of Bathurst Inlet. In addition, we derived an estimate of

Bathurst caribou on the east side of Bathurst Inlet that may have emigrated to the Beverly range, which was based on two assumptions: a) the 6 collared Bathurst cows that were east of the Inlet at the time of survey and the proportion of the Bathurst herd they represented (6 of 34) had joined the Beverly herd; and b) bulls emigrated from the Bathurst herd at the same rate as cows. The first assumption was supported by the late and continued movement of some collared cows east of the Inlet (Bathurst, Beverly, and unassigned) to the Beverly calving and post-calving ground in June/July of 2021. The estimates of Bathurst caribou west and east of the Inlet were also calculated separately on the premise that the Bathurst caribou east of the Inlet were still part of the Bathurst herd at the time of the June survey.

The estimates of adult females and herd size for the Bathurst herd in 2021 were influenced by movement of Bathurst collared cows to the Queen Maud Gulf coastal calving and post-calving ground of the Beverly herd (Campbell et al. 2019). The proportion of the Bathurst herd that may have been lost to emigration and the potential size of the Bathurst herd if this emigration event had not occurred were estimated using 2 approaches.

The ratio of known Bathurst collared caribou calving west of Bathurst Inlet to total known Bathurst collars (28/34 = 82.4%) east and west of Bathurst Inlet provides a simple estimate of fidelity to the calving ground; 17.6% of the Bathurst herd females were east of the Inlet and 82.4% were west of the Inlet. An estimate of total females to the east and west of the inlet could then be derived as the estimate west of the Inlet divided by the proportion of cows west of the Inlet (0.824). This general estimator is an approximation of the Lincoln-Petersen mark-recapture estimator (N_{LP}) expressed below:

$$N_{LP} = \frac{(C+1)}{(R+1)/(M+1)}$$

where M is the number of Bathurst female collared caribou (34), R is the number of Bathurst collared female caribou detected in the calving ground area west of Bathurst Inlet (28), and C is the estimate of total adult cows (N_{AF};) (Seber 1982, Krebs 1998). We used a variance estimator proposed by Innes et al. (2002) that considers both variance in the proportion of collars and the adult female estimate:

$$var(N_{LP}) = N_{LP}^2(CV^2(p_{LP}) + CV^2(N_{AF})$$

where the coefficient of variation is calculated by the following formula:

$$CV = \sqrt{\frac{var(x)}{x^2}}$$

The variance of the Lincoln-Petersen estimate of capture probability (p_{LP}) was estimated based on the hypergeometric probability distribution, which is assumed with the Lincoln-Petersen estimator (Thompson 1992). We note that the Lincoln-Petersen estimator has also been applied to estimate caribou not in survey strata during a survey of the Dolphin and Union caribou herd (Dumond and Lee 2013).

A secondary estimate of Bathurst herd size east and west of the Inlet was derived using the IPM from model runs where fidelity was equal to 1 for 2021. This estimate provided a model-based estimate of the Bathurst herd with and without emigration based on all available data sources (survival, composition (recruitment) and survey data).

RESULTS

Survey Conditions

The Cessna Caravans with survey participants flew to Kugluktuk on the afternoon of June 1. Weather between June 2 and 7 was generally poor, with extensive low cloud and fog. Reconnaissance flights to assess calving status of Bathurst caribou were flown by an Aviat Husky on June 3 and 4. On June 8 weather improved and allowed Cessna Caravan flying, initially on the Bluenose-East calving ground on June 8 and 10, and on the Bathurst calving ground June 9-11. The photo-planes completed their work on June 9 on the Bluenose-East calving ground and on June 10 on the Bathurst calving ground.

Caribou sighting conditions through the main survey period of June 9-11 were challenging due to the late spring thaw with substantial snow cover in the survey area on either side of Bathurst Inlet (Figure 9). The snow cover varied from less than 5% to well over 90% and in some areas was a patchy mosaic. This made caribou more difficult to see, particularly small groups of one to ten, from Cessna Caravans flying at 160 km/hr. We reasoned that aerial photo coverage of the higher numbers of caribou would still provide accurate counts of caribou, as caribou would still be reliably seen on high-resolution photos that could be searched carefully and repeatedly (Adamczewski et al. 2019).

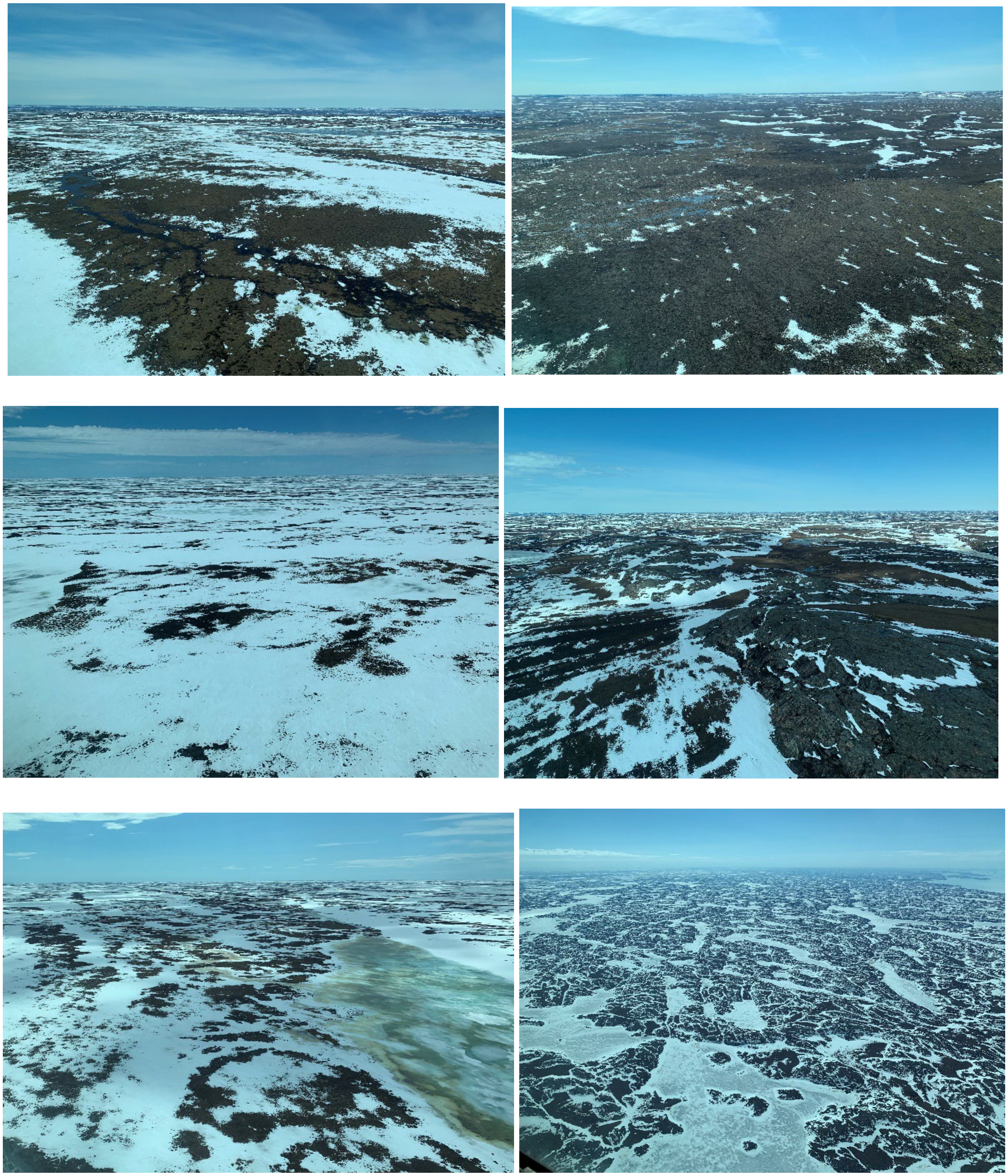

Figure 9. Photos of Bathurst survey conditions on June 10, 2021. Snow cover varied from more than 90% to 5% or less and was often patchy.

Summary of Fixed-wing and Helicopter Flying

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

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

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

Bluenose-East survey information is included in Table 1 as the Cessna Caravans flew both surveys at about the same time. Due to generally poor weather, flying between June 2 and 7 was limited to reconnaissance flights to check on calving status (newborn calves as % of caribou seen) for the Bathurst herd June 3 in the core area west of Bathurst Inlet and on June 4 east of the Inlet.

Beginning June 8, weather improved with clear skies on June 10 when the Bathurst aerial photos were flown. Visual blocks on the Bathurst survey were flown on June 9 mostly west of Bathurst Inlet, and on June 10 and 11 mostly east of the Inlet. The Bathurst helicopter-based composition survey was flown June 11-14, in part based on the ground for larger groups and in part from the air for smaller groups. Weather was generally good during this final period of the survey.

Photo and Visual Survey Blocks

Photo and visual blocks for the Bathurst 2021 calving ground survey are shown in Figure 10a, and a second view of the survey area at a different scale that more fully shows locations of bull collars is in Figure 10b. As described earlier, these blocks were designed based primarily on locations of collared Bathurst cows.

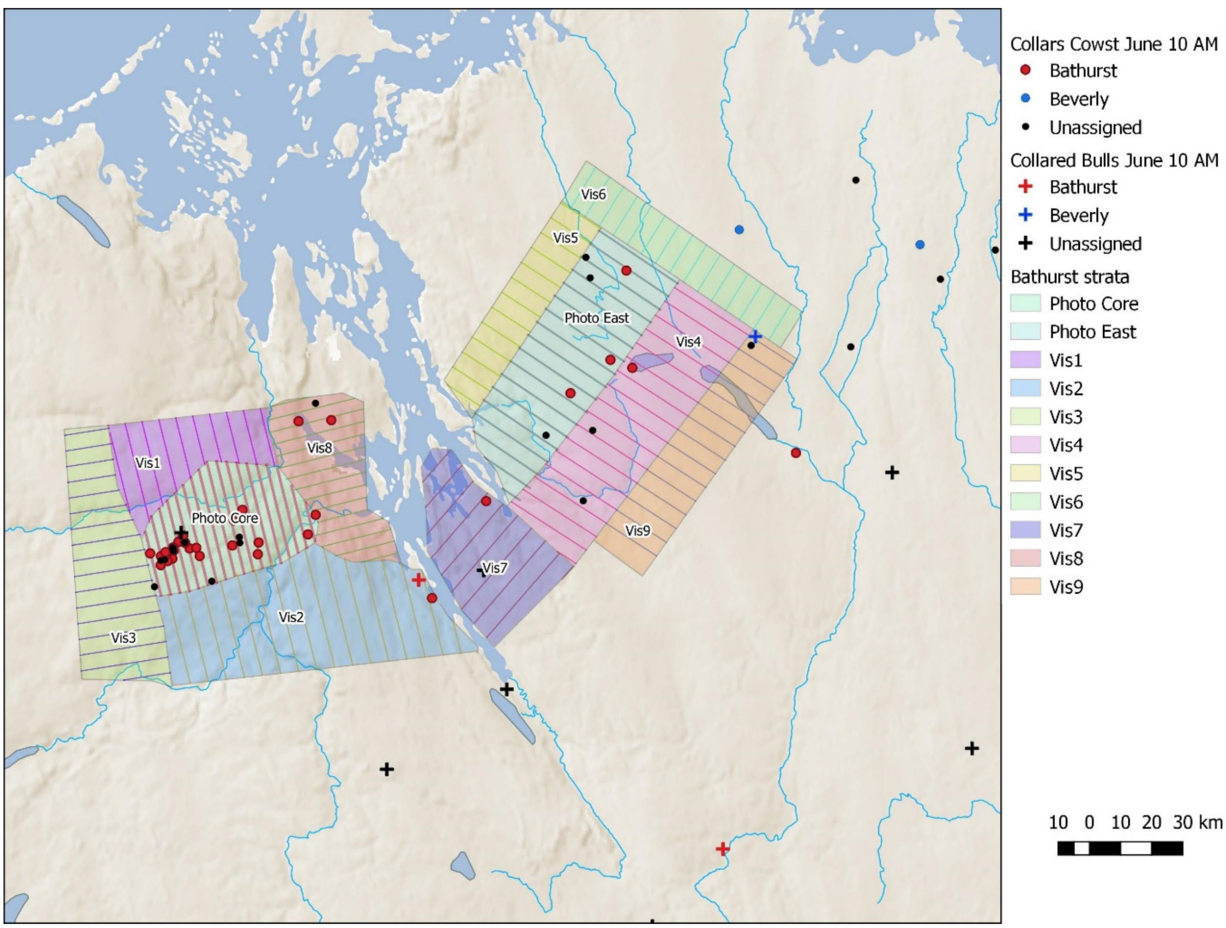

Figure 10a. Photo and visual survey blocks west and east of Bathurst Inlet in June 2021. Collared caribou locations are from June 10, when the aerial photos were flown. Visual blocks were flown June 9, 10 and 11. Flight lines are shown for each block. Known Bathurst collared cows in visuals 2 and 7 (one each) were grouped with the "west" collars due to their movement south and west after the survey.

Previous experience with Bathurst calving ground surveys assisted in designing survey strata; for example, the area directly south of the main Bathurst collared cow cluster west of the Inlet (visual 2) was expected to have a portion of the "trailing edge" of caribou (often yearlings, non-breeding cows and a few bulls) that follow behind the migrating pregnant cows.

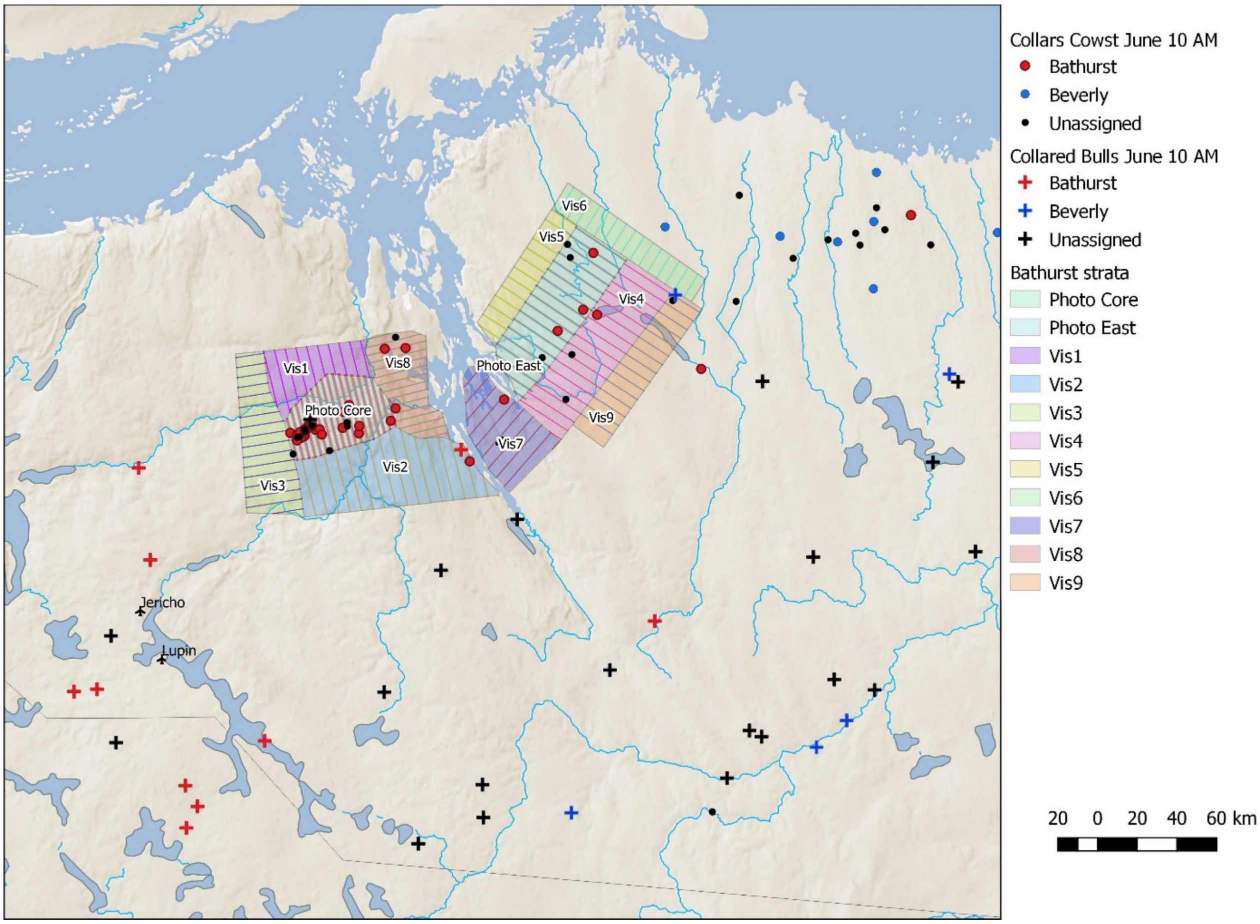

Figure 10b. Photo and visual blocks west and east of Bathurst Inlet in June 2021, with a larger area shown to identify bull collars south of the calving ground survey area.

West of Bathurst Inlet, there was one main cluster of 25 known Bathurst collared cows, along with nine unassigned cows and one unassigned bull; this was identified as the Photo Core block, with a target of 50% coverage on aerial photos. An additional three known Bathurst cows and one unassigned cow were in visual blocks that surrounded the photo core, along with one known Bathurst bull. Coverage of visual blocks west of the Inlet was planned for 15-20%.

East of Bathurst Inlet, there were six known Bathurst collared cows. Two of these were already east of the survey area by June 10, in the vicinity of Beverly collared caribou and were assumed at the time of the June survey as likely emigrants. Four were within the eastern survey blocks. There were also six unassigned cow collars in the eastern part of the survey area. Results of a reconnaissance flight east of Bathurst Inlet on June 4 suggested substantial numbers of caribou east of the Inlet, including cows with newborn calves. Based on this information, a second photo block was defined east of Bathurst Inlet with target coverage of 30%. There was a known Beverly bull collar within the visual blocks east of the Inlet, as well as a known Beverly cow collar just north of the survey area.

Strata and associated transects were designed to ensure at least 30% coverage in the photo core stratum and 20% coverage in the Photo East stratum based on logistic considerations (photo plane km flying, number of photos that were budgeted). The number of kilometers that could be flown in a single day by the two photo-planes (including ferrying from Yellowknife and to Lupin for refueling) limited the number of km flown on transect to approximately 1,300 km. Options at varying elevations and at varying levels of coverage were shown in Figure 3. An algorithm was designed using the program R to generate estimates of photos required, coverage, and kilometers flown on transect based on survey constraints across a range of survey altitudes. Transect orientations within strata and coverage, and transect shapefiles were generated and cross-validated using the *dssd* R package. From this exercise, it was decided that the lowest feasible GSD level would be five with a corresponding survey altitude of 2,734 feet (833 m), with the hope that higher altitudes could be flown which would reduce the number of photos required and increase coverage. On June 10 under clear skies, the 2,963 photos were taken at GSD eight at an elevation above ground of about 4,300 feet. Flying at this elevation meant that fewer photos could be taken to achieve the desired coverage. Actual coverage was 46% for the Photo Core block and 30% for the Photo East block (Table 2).

Table 2. Photo stratum characteristics and coverage for Bathurst 2021 photo survey.

Stratum	Stratum Area (km^2)	Transect Number	Mean transect length (km)	Length of Stratum (km)	Area Surveyed (km^2)	Total survey lines possible	Photo Numbers Taken	Ground Coverage
CORE	1690.0	18	30.37	55.6	784.20	38.9	1,541	46%
EAST	2443.4	18	28.19	86.7	723.80	60.5	1,441	30%

Visual blocks were defined to surround the photo east block and contain the additional known and unassigned cow collars in the area, with planned coverage of 15-20%. Characteristics of each visual block are shown in Table 3.

Table 3. Visual stratum characteristics and coverage for Bathurst 2021 photo survey.

Stratum	Stratum Area (km²)	Number of Transects	Mean transect length (km)	Length of Stratum (km)	Area Surveyed (km²)	Ground Coverage
Vis1	1113	10	21.8	51.0	174.5	15.7%
Vis2	2965	16	32.0	92.7	409.6	13.8%
Vis3	1784	17	21.2	84.2	288.3	16.2%
Vis4	2579	18	26.5	97.2	382.0	14.8%
Vis5	1054	13	14.7	71.9	152.4	14.5%
Vis6	1196	15	14.2	84.4	170.0	14.2%
Vis7	1579	10	25.5	62.0	203.7	12.9%
Vis8	1334	15	22.9	58.3	274.7	20.6%
Vis9	1538	15	18.0	85.3	216.3	14.1%

Because a reconnaissance survey to estimate caribou density was not flown, optimum allocation was not possible. At least ten transect lines were planned for each visual block, based on previous surveys. Initially, Visual Block 4 was the furthest east of the blocks situated east of the Inlet, however initial analysis of results from this block, flown June 10, showed higher caribou numbers than expected, and an additional block (Visual 9) was flown further east on June 11 to better define distribution in that area.

Collared Caribou Movements Before, During and After Calving

Spring movements (May 1 to June 9) of known Bathurst and Beverly collared cow and bull caribou paralleled each other in a northeasterly direction (Figure 12, top). Most of the Bathurst known collared cows congregated on the calving ground west of Bathurst Inlet, an area that has been used by this herd since 1996 (Gunn et al. 2008). Four known Bathurst cows were east of Bathurst Inlet on June 10 and within the survey area, while another two known Bathurst cows were further east and east of the survey area (Figure 12, middle). The distribution of known Beverly cows on June 10 began near the eastern end of the Bathurst Inlet survey area and continued to the east in the Queen Maud Gulf lowlands. Collared Bathurst bulls were mostly south and west of the survey area on June 10 and collared Beverly bulls were widely distributed and moved generally east and north in parallel to collared Beverly cows. One known Beverly bull was within the June 2021 survey area east of Bathurst Inlet. The numbers of known Beverly collared cows (10) and bulls (8) in early June 2021 were low, given the herd's estimated size in 2018 of about 103,000 caribou (Campbell et al. 2019), hence this herd's distribution was not well defined.

Following the survey period, between June 11 and July 8, collared cow and bull caribou (known Bathurst and unassigned) west of Bathurst Inlet (including two known Bathurst cows south of the Inlet) moved in a southwest direction toward Contwoyto Lake (Figure

12, bottom), which has been the traditional summer range of the Bathurst herd in recent years. East of Bathurst Inlet, the known Bathurst, known Beverly, and unassigned cows all moved further east into the Beverly calving distribution. We assume that the caribou surveyed from June 9 to 11 in that area also moved eastward as shown by the collared caribou. While they will be tracked over time, the working assumption is that these collared caribou, and the portion of the herd they represent, may not return to re-join the Bathurst herd. These early summer collared caribou movements after calving were important to interpreting the results of the June 2021 Bathurst calving ground survey.

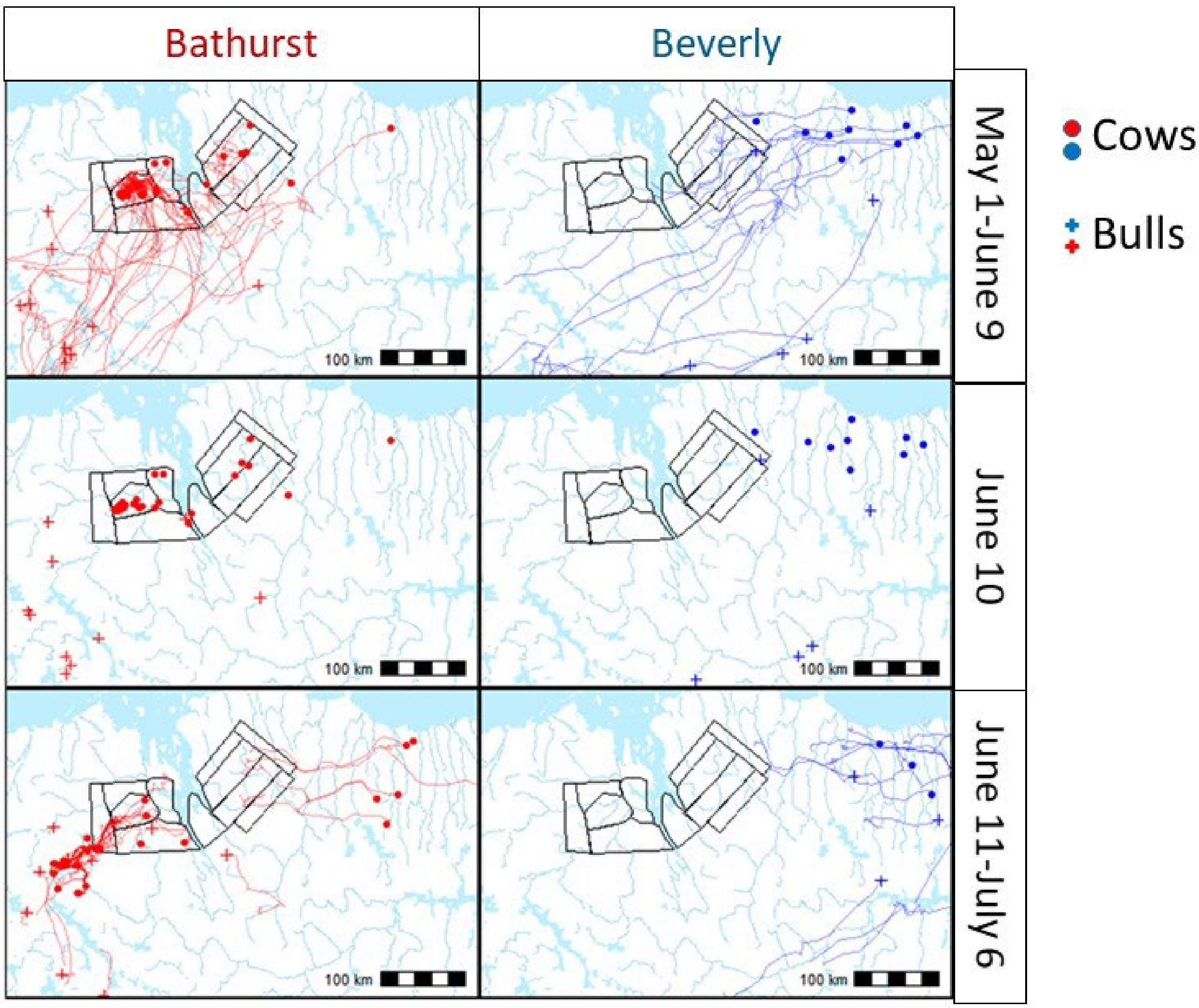

Figure 12. Movements of known collared Bathurst (left, red) and known collared Beverly (right, blue) caribou in the pre-survey period (May 1 – June 9), on the day of the Bathurst aerial photos (June 10), and in the post-survey period (June 11 – July 6). Collared cows are circles and bulls are crosses.

An additional view of female collared caribou movements is shown in Figure 13, which includes the movements of unassigned collared female caribou. These maps make clear the lack of separation of Bathurst and Beverly caribou east of the Inlet and the degree of movement of collared Beverly and unassigned cows through the survey area east of the Inlet.

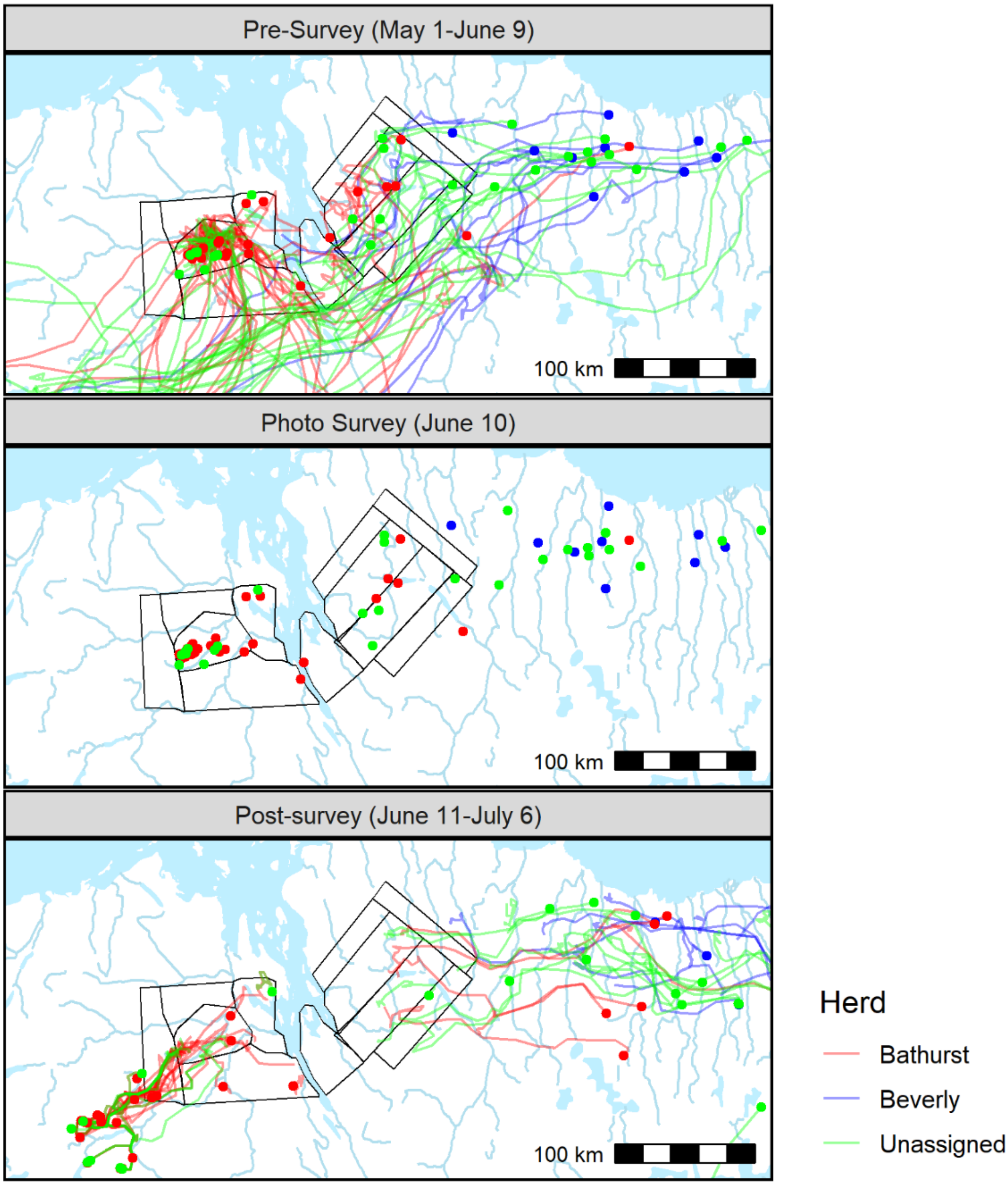

Figure 13. Movement patterns of collared female caribou before, during and after the June 2021 Bathurst calving ground survey. Known Bathurst females are in red, known Beverly females are in blue and unassigned females are in green.

A further perspective on collared female caribou movements in the spring in the Bathurst herd and for the neighbouring Bluenose-East and Beverly herds over the last six years (2016-2021) is shown in Figure 14.

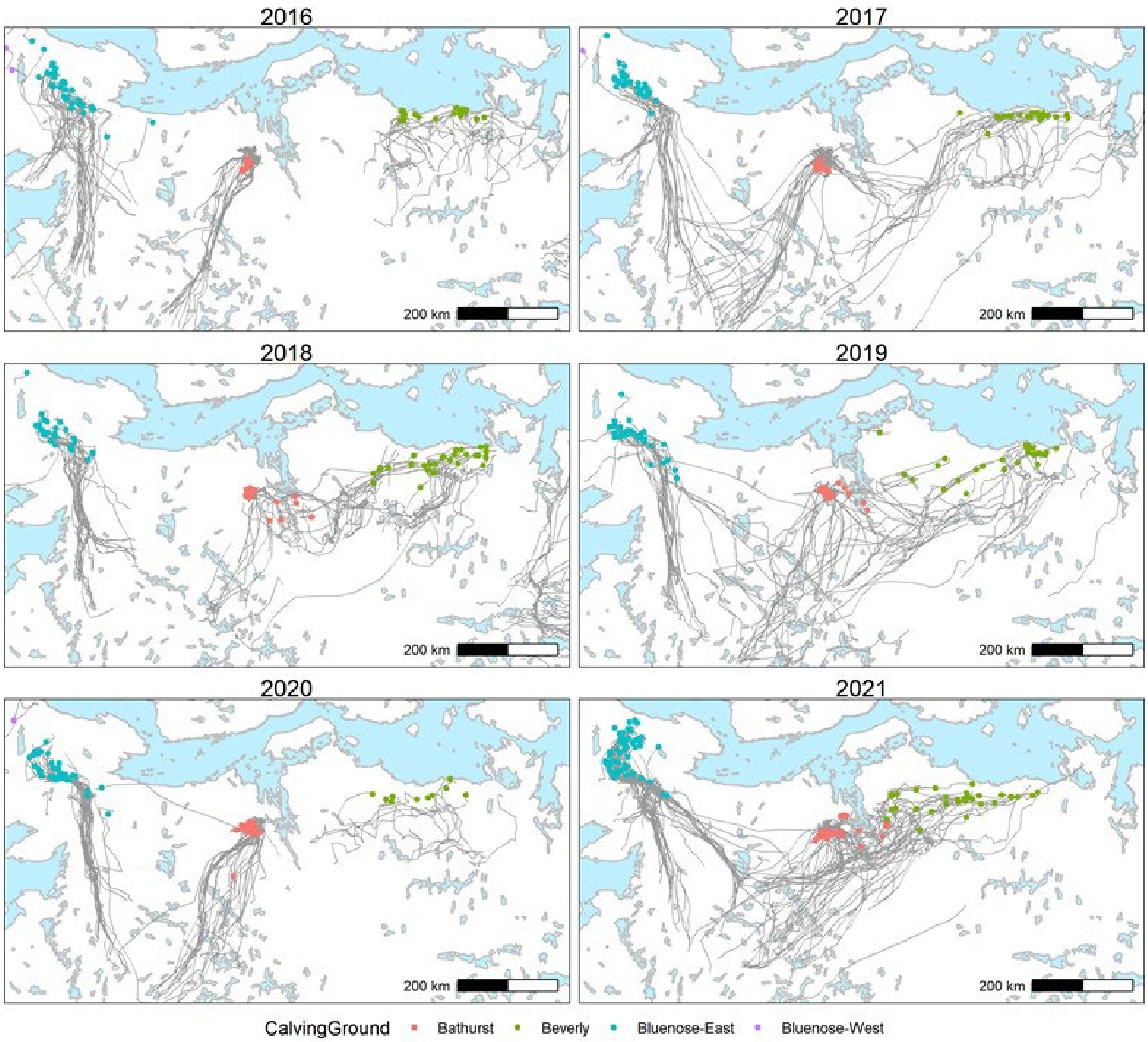

Figure 14. Northward movements of known collared Bluenose-East (blue), Bathurst (red) and Beverly (green) collared female caribou 2016-2021. The movements started on May 1 and the end locations are for June 16.

The northward migrations of females in the three herds show a trend toward decreased separation of the Bathurst and Beverly herds from 2016 to 2021. In 2016, the three herds wintered separately and their movements to their calving grounds were well separated. In 2017, there was some winter mixing of Bathurst and Bluenose-East caribou but they separated at calving; there was also some mixing of Bathurst and Beverly caribou, which resulted in some Bathurst cows moving northeast but then turning northwest to the

Bathurst calving ground. In 2018, there was some mixing of Bathurst and Beverly migration paths into June, a few Bathurst collared cows calved east of the Inlet, and 3 of 11 known Bathurst cows moved east with the Beverly herd. In 2019, the Bathurst and Beverly northward migrations were again mixed and three of 17 Bathurst cows were located in the Beverly calving distribution; a few Bathurst collared cows were east of Bathurst Inlet and there were Beverly cows not far east of them. In 2020, overlap between the three herds was more limited in the winter; migration paths were separate and distribution at calving was separate. In 2021, the degree of mixing of Bathurst and Beverly migration paths was the most extensive to date and there was no separation of Bathurst and Beverly cows east of the Inlet. Separation did occur later in June (Figure 12) but six of 34 known Bathurst cows joined the Beverly calving distribution.

Peak of Calving and Movement Rates of Collared Female Caribou

Daily movement rates of known Bathurst and Beverly collared cows in late May and through the first two weeks of June are shown in Figure 15. The peak of calving is considered close when the majority of collared female caribou exhibit movement rates of less than 5 km/day (Nishi et al. 2007, 2014; Boulanger et al. 2017, 2019) and remain there for several days.

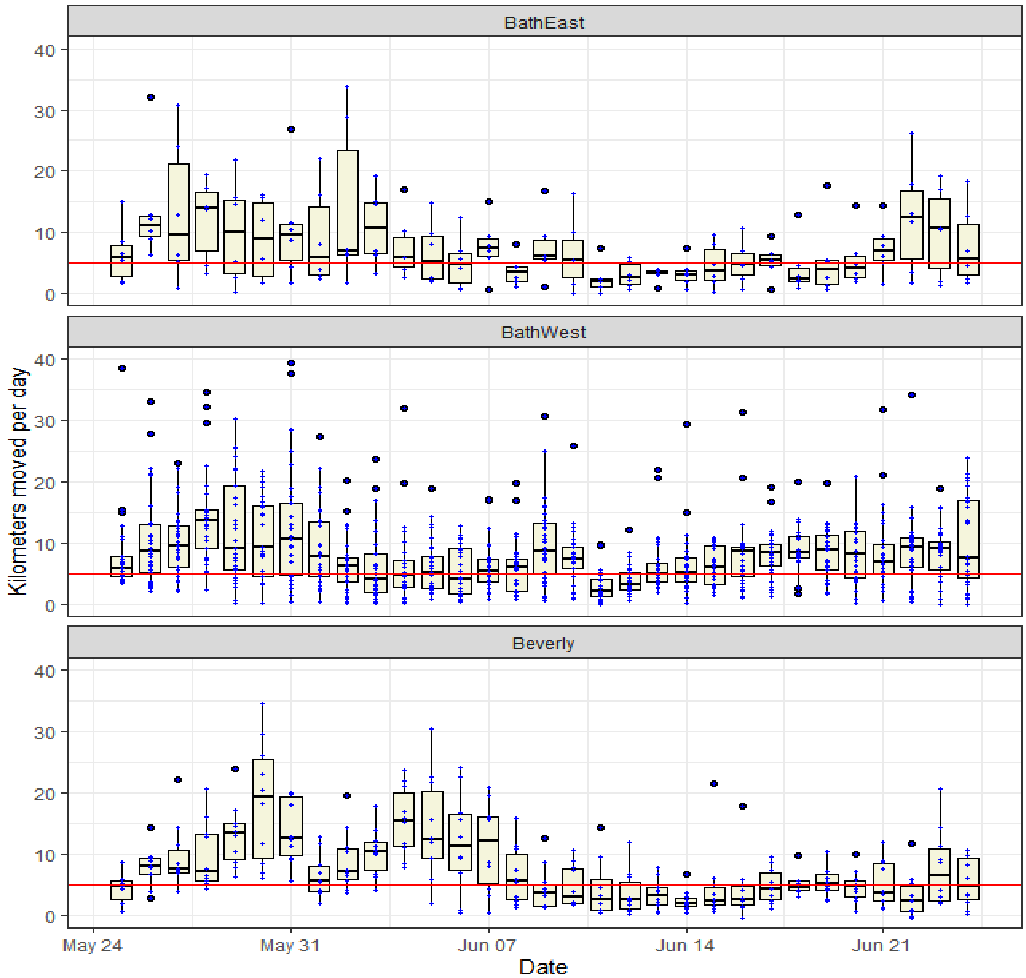

Figure 15. Daily collared caribou movements of known Bathurst collared cows east of Bathurst Inlet (top; n=6), west of Bathurst Inlet (middle; n=28) and Beverly cows (bottom; n=10) before, during and after calving in late May and June 2021. The boxplots contain the 25th and 75th percentile of the data with the median shown by the central bar in each plot. The ranges up to the 95th percentile are depicted by the lines with outlier points shown as larger dots. The red line indicates a movement rate of 5 km/day.

For the Bathurst cows, daily movement rates on average dropped below 5 km on June 3, 2021, then remained near 5 km/day for the next week, although there was an increase to somewhat higher movement rates June 9 and 10. Movement rates dropped again thereafter. Aerial photos were taken June 10 and visual strata were surveyed June 9, 10 and 11, thus remaining within the approximately one-week window of low cow movement rates after the peak of calving.

We note that many of the Bathurst collared cows and Beverly collared cows moved north relatively early in 2021 and several of the Bathurst cows were on the main calving area in late May. This might account in part for the relatively low movement rates in the last week of May for both herds.

For the Beverly collared cows, mean daily movement rates dropped below 5 km/day on June 8 and then remained low for the next week. This suggested that the peak of calving was about June 8-11 in this herd. This somewhat later peak of calving is consistent with results of previous calving ground surveys of this herd (e.g. June 2018; Campbell et al. 2019).

Calving Ground Composition Survey Results

Helicopter flight lines and locations of caribou groups classified June 11-14, 2021 west and east of Bathurst Inlet are shown in Figure 16. Smaller groups were generally classified from the air, while larger groups of 30 or more caribou were classified from the ground. A total of 3,977 caribou, including newborn calves, were classified on either side of Bathurst Inlet (Table 4).

Table 4. Composition of caribou classified June 11-14, 2021 on Bathurst calving ground survey area, east and west of Bathurst Inlet. Vis = Visual Block.

Stratum (Block)	Breeding cows	Non-Breeding Cows	Total Cows	Calves	Bulls	Yearlings	Total Adult Caribou	Total All Caribou	Groups
Photo Core	823	186	1,009	507	4	95	1,108	1,615	38
Photo East	474	131	605	425	75	70	750	1,175	79
Vis1	1	3	4	1	24	17	45	46	11
Vis2	4	29	33	4	146	96	275	279	33
Vis3	1	4	5	0	8	14	27	27	5
Vis4	82	142	224	62	83	122	429	491	58
Vis5	6	15	21	5	34	26	81	86	22
Vis6	13	11	24	10	13	9	46	56	10
Vis7	0	0	0	0	7	4	11	11	3
Vis8	17	19	36	15	38	19	93	108	25
Vis9	0	18	18	0	41	24	83	83	17
Total	1,421	558	1,979	1,029	473	496	2,948	3,977	301

The largest numbers classified were in the Photo Core block (1,615 caribou) and the Photo East block (1,175 caribou), which we expected would have most of the breeding cows. We note that numbers of caribou classified in Visual Blocks 1, 3, 5, 6, 7 and 9 were fewer than 100 total, thus the limited sample size should be considered in assessing these results.

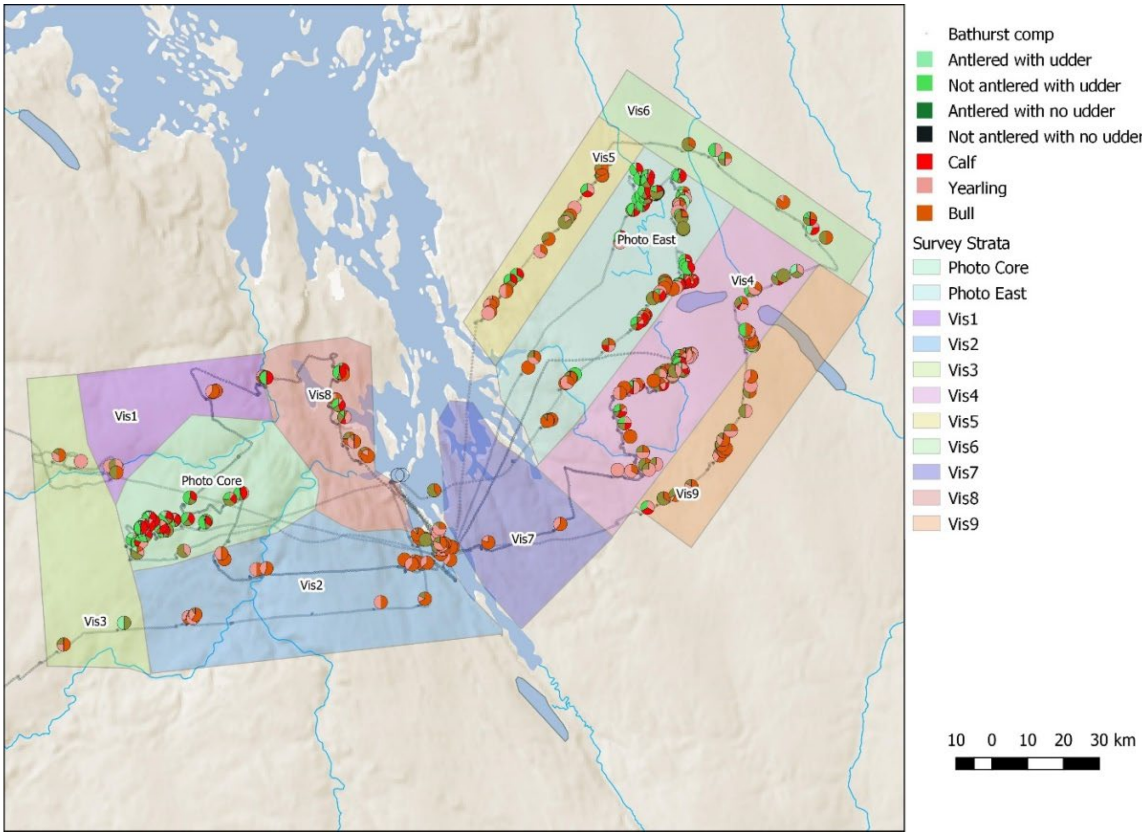

Figure 16. Flight lines and locations of caribou groups classified west and east of Bathurst Inlet June 11-14, 2021. Composition of each group is shown as a pie chart reflecting relative proportions of each class of caribou.

An overview of the composition survey results is provided in Figure 17. In the two photo blocks, breeding cows and calves accounted for most of the caribou classified. In five of the nine visual survey blocks, bulls accounted for the highest percentage of caribou classified, and yearlings accounted for the second-largest percentage in most of the visual blocks. Non-breeding cows outnumbered breeding cows in all but one of the visual blocks.

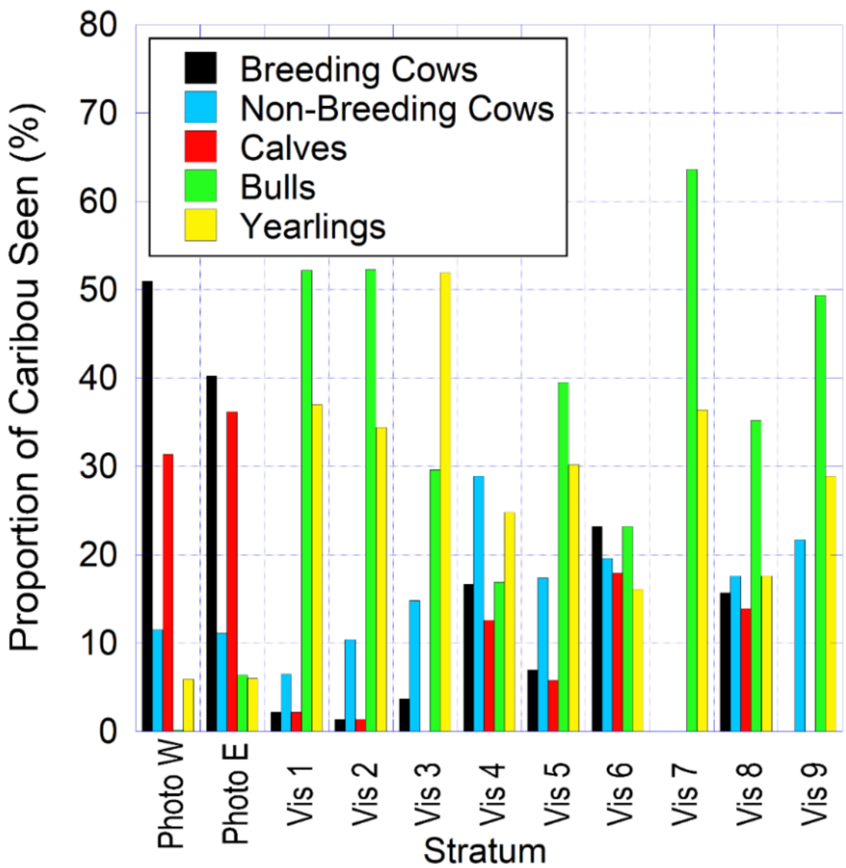

Figure 17. Proportions (%) of total numbers of caribou classified in each survey block during the composition survey on the Bathurst calving ground survey area west and east of Bathurst Inlet.

Detailed composition of categories of breeding cows is shown in Table 5. Cows having no antlers, a distended udder and a calf (1212) out-numbered cows having antlers, a distended udder and a calf (204) by about 6:1. Other categories of breeding cows were observed rarely. As pregnant cows usually shed their antlers shortly after giving birth, this ratio is consistent with a peak of calving several days earlier. Proportions of breeding cows and adult cows in each stratum, along with calf:cow ratios, are given in Tables 6a and 6b.

Table 5. Detailed composition of categories of breeding and non-breeding cows on Bathurst June 2021 calving ground survey area. Antler = hard antler present; Udder = distended udder present; Calf = calf present. Non-breeding cows = no hard antler, No distended udder, no calf. vis = visual block.

Stratum (Block)	Total Cows	Non-Breeding Cows	Total Breeding Cows	Antler Udder Calf	No Antler Udder Calf	Antler Udder No Calf	Antler No Udder No Calf	No Antler Udder No Calf
Photo Core	1,009	186	823	133	687	0	3	0
Photo East	605	131	474	50	422	0	2	0
Vis1	4	3	1	0	1	0	0	0
Vis2	33	29	4	0	4	0	0	0
Vis3	5	4	1	1	0	0	0	0
Vis4	224	142	82	13	69	0	0	0
Vis5	21	15	6	0	6	0	0	0
Vis6	24	11	13	7	6	0	0	0
Vis7	0	0	0	0	0	0	0	0
Vis8	36	19	17	0	17	0	0	0
Vis9	18	18	0	0	0	0	0	0
Total	1,979	558	1,421	204	1,212	0	5	0

Table 6a. Proportions of breeding females and adult females in survey strata from June 2021 Bathurst calving ground composition survey. SE = standard error; CIL = 95% confidence interval lower, CIU = 95% confidence interval upper. Note some ratios are based on minimal samples so should be considered in that context.

Stratum	Breeding Females as % of Total Adults	SE	CIL	CIU	Adults Females as % of Total Adults	SE	CIL	CIU	Breeding Females as % of Adult Females	SE	CIL	CIU
Photo Core	74	2	69	78	91	1	88	93	82	2	78	85
Photo East	63	6	49	74	81	4	71	88	78	4	69	85
Vis1	2	3	0	11	9	7	2	27	25	24	0	85
Vis2	1	1	0	5	12	3	6	20	12	9	0	29
Vis3	4	6	0	20	19	11	6	43	20	16	0	50
Vis4	19	4	12	26	52	3	45	58	37	5	25	46
Vis5	7	4	0	18	26	8	12	44	29	14	0	57
Vis6	28	8	12	45	52	9	32	65	54	13	29	78
Vis7	0	0	0	0	0	0	0	0	0	NA	NA	NA
Vis8	18	8	6	36	39	9	22	58	47	12	69	69
Vis9	0	0	0	0	22	6	12	33	0	0	0	0

Table 6b. Calf:cow ratios in Survey Strata from June 2021 Bathurst calving ground composition survey. SE = standard error; CIL = 95% confidence interval lower, CIU = 95% confidence interval upper. Note some ratios are based on minimal samples so should be used with caution.

Stratum	Calves:100 Cows for Breeding Females	SE	CIL	CIU	Calves:100 Cows for Adult Females	SE	CIL	CIU
Photo Core	62	4	54	70	50	4	43	58
Photo East	90	2	84	93	70	4	59	77
Vis1	100	0	100	100	25	24	0	80
Vis2	100	0	100	100	12	9	0	29
Vis3	0	0	0	0	0	0	0	0
Vis4	76	7	62	87	28	5	16	37
Vis5	83	15	50	100	24	12	0	48
Vis6	77	15	38	100	42	12	14	61
Vis7	0	NA	NA	NA	0	NA	NA	NA
Vis8	88	8	67	100	42	17	17	61
Vis9	NA	NA	NA	NA	0	0	0	0

Breeding females accounted for 74% of adult caribou in the Photo Core block and 82% of adult females classified, which indicated that about 18% of the adult females in this block were non-breeding cows. In the Photo East block, breeding females accounted for 63% of adult caribou and 78% of adult females classified, indicating that 22% of adult females were non-breeding cows.

As the peak of calving for the Bathurst herd was estimated for June 3-6 and the composition survey was flown June 11-14, a high proportion of the calves should have been born by the time the classification was carried out. In the Photo Core block, a ratio of 62 calves:100 cows was estimated for breeding females, and in the Photo East block, a ratio of 90 calves:100 cows was estimated for breeding females.

Breeding cows were a variable proportion of the caribou classified in the nine visual blocks, with the highest proportion of caribou in Visual Block 6 (23.2%), which was north of the Photo East block. In total, the nine visual blocks together accounted for a total of just 142 breeding cows, while the Photo Core accounted for 823 and the Photo East block 474.

Composition from June Reconnaissance Flights by D. Olesen

The flight in the Aviat Husky on June 3, 2021 in an area that became the Photo Core block west of Bathurst Inlet was planned around locations of the main cluster of cow collars in that area (Figure 18). The categories of caribou recorded do not correspond exactly to those used during the helicopter-based composition survey. Cows and calves were nearly all the caribou seen, with a ratio of 22.3 calves:100 adults, suggesting that the peak of calving was near.

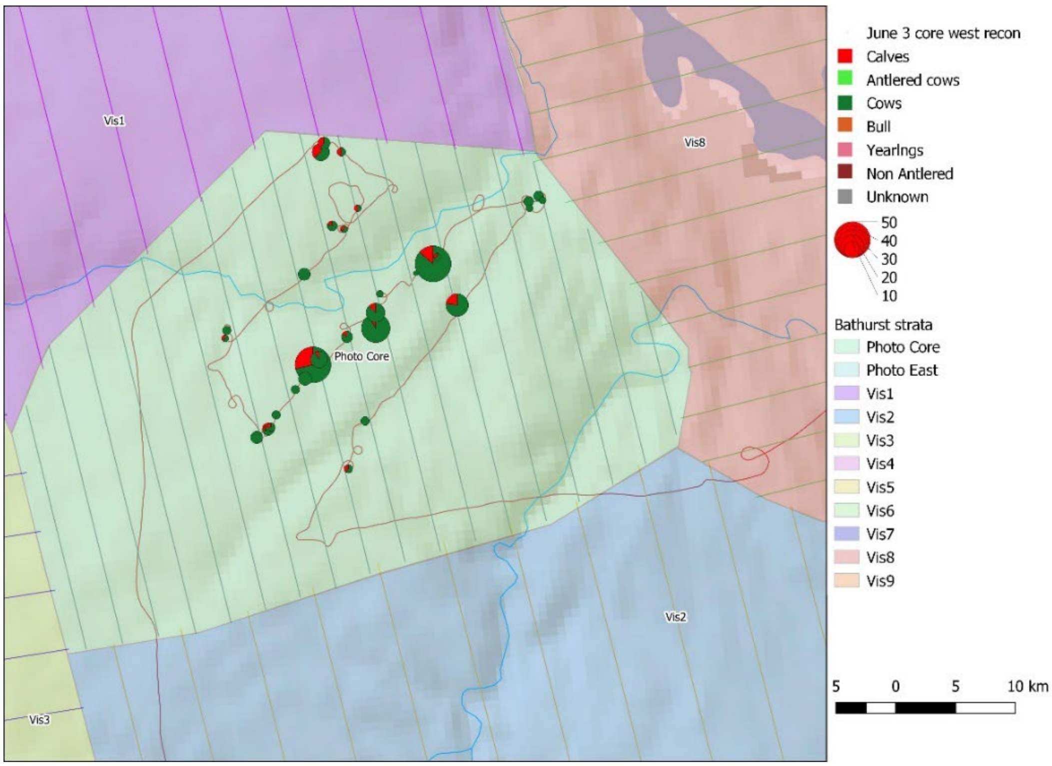

Figure 18. Composition and group sizes of caribou recorded on June 3, 2021 in an Aviat Husky, on a flight through the main core calving concentration west of Bathurst Inlet and guided by collared cow locations. Sizes of circles are proportionate to group size and percentages of cows, calves and other caribou sex/age classes are shown as pie chart sections.

A second reconnaissance survey flight was carried out on June 4, 2021 in the Aviat Husky on the east side of Bathurst Inlet (Figure 19) around locations of collared female caribou. In some areas, principally the north end of what became the Photo East block, there were mostly cows with calves. Further east there were fewer cows with calves and a greater mix of sex and age classes of caribou (Table 7). In total 44 calves and 247 adults were seen, with a ratio of 17.8 calves:100 adults, also suggesting that the peak of calving was close in the area surveyed.

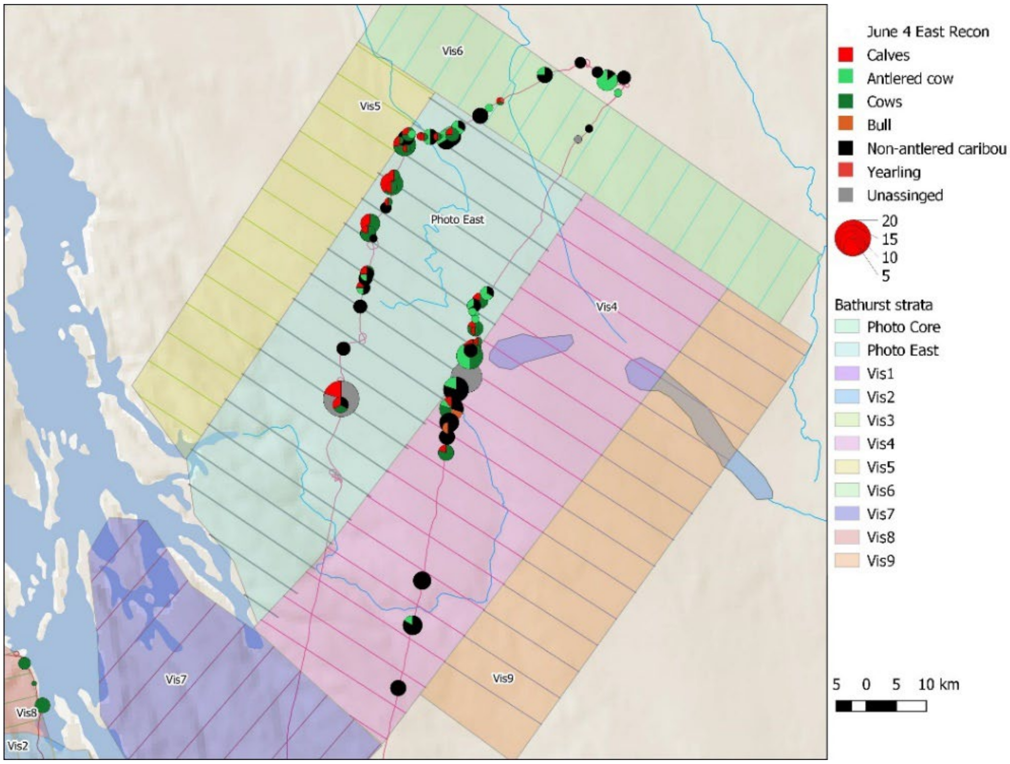

Figure 19. Composition and group sizes of caribou recorded on June 4, 2021 in an Aviat Husky, on a flight east of Bathurst Inlet guided by locations of collared caribou. Sizes of circles are proportionate to group size and percentages of cows, calves and other caribou sex/age classes are shown as pie chart sections.

Table 7. Numbers and composition of caribou recorded in the Husky on flights in the Bathurst Inlet area June 3, 4, 8 and 9, 2021. Types of caribou classified do not correspond exactly to categories recorded on helicopter-based composition survey.

Date	Non-Antlered Caribou	Antlered Cows	Cows	Calves	Yrlgs	Bulls	Unknown	Total Number Caribou	# Groups
6/03/21	0	0	290	67	0	10	0	367	36
6/04/21	91	35	75	44	1	9	36	291	65
6/08/21	18	10	0	0	0	70	7	105	7
6/09/21	181	21	42	25	4	4	25	302	80

Locations and classes of caribou recorded in a Husky on flight lines east of Bathurst Inlet on June 8 and 9, 2021 are shown in Figure 20. These lines were flown in large part to assess whether there was separation of Bathurst and Beverly caribou east of the Inlet. Combined with the composition survey results and visual survey results east of the Inlet, these results indicated that there was no separation of the two herds in that area.

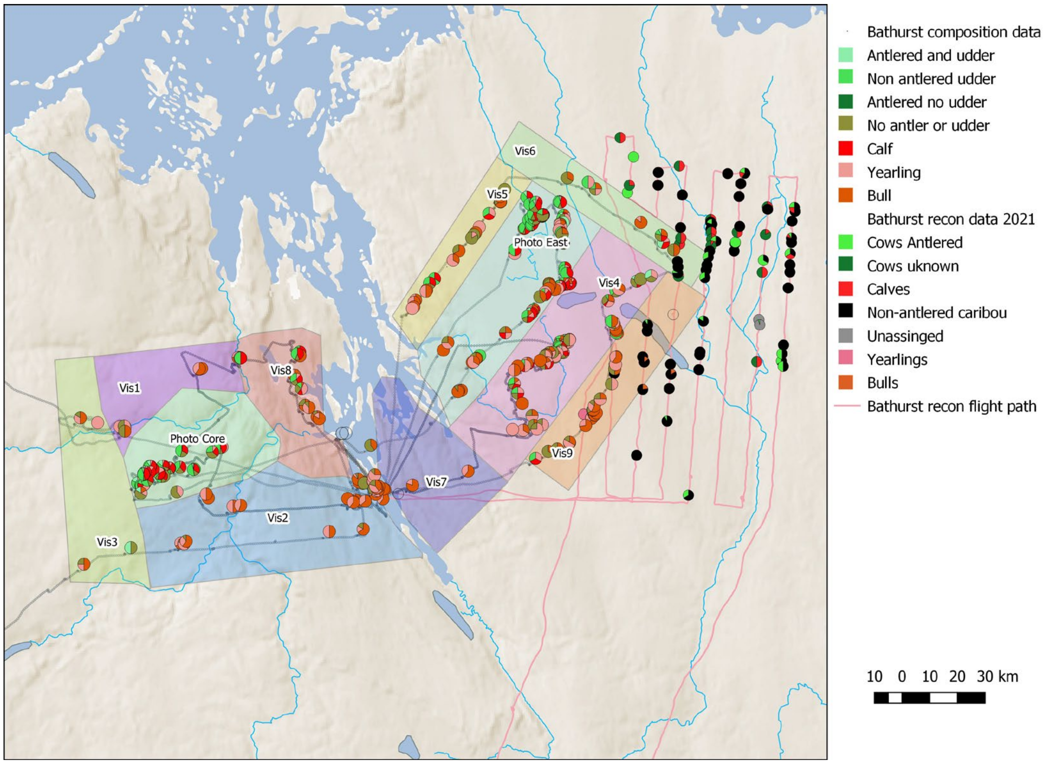

Figure 20. Flight lines and observations of caribou recorded in an Aviat Husky on June 8 and 9, 2021 east of Bathurst Inlet. Composition is also shown, although classes of caribou did not correspond exactly to the classes recorded during the helicopter-based composition survey. Composition recorded by the helicopter crew, shown previously in Figure 16, is included for comparison.

Fall 2020 Composition Survey Results

A composition survey was flown in late October 2020 near the peak of the breeding season to estimate bull:cow ratios and calf:cow ratios for the Bathurst and Bluenose-East herds (Adamczewski et al. 2022a). For the Bathurst herd, the survey resulted in an estimated ratio of 64.1 bulls:100 cows (95% CI 50.5-80.6), based on 1,843 caribou classified in 15 groups. Of the 38 collared cows and 12 collared bulls in the Bathurst herd at the time of the survey, 33 female and five male collared caribou (76% of total collars) were within areas surveyed. There were no collars from neighbouring herds within the areas surveyed. A further five female and seven male collared Bathurst caribou were far east of Contwoyto Lake and mixed with Beverly collared caribou, and out of flying range at the time. This bull:cow ratio was slightly higher than had been previously recorded for the herd, but was similar to the bull:cow ratio of 63.3 bulls:100 cows estimated in the Bluenose-East herd a few days later. A composition survey of the Bathurst herd was attempted in late October 2021 but was unsuccessful due to extensive mixing of the Bathurst and Beverly herds, based on collars. The fall 2020 sex ratio for the Bathurst herd was used in extrapolating the estimate of adult females to the estimated herd size. The fall 2020 bull:cow ratio and proportion of females in the herd are shown with variance in Table 8.

Table 8. Bull:cow ratio and proportion of cows in the herd estimated from fall 2020 composition survey of the Bathurst herd. SE = standard error, CI = 95% confidence interval, CV = coefficient of variation.

Metric	Mean	SE	CI Low	CI High	CV (%)
Bulls:100 cows	64.1	7.8	50.5	80.6	0.122
Proportion cows (%)	61.0	2.9	0.554	66.5	0.047

Visual Survey Block Estimates and Double Observer Correction

Estimates of adult caribou (at least one year old) on the nine visual survey blocks are given in Table 9, together with corrected estimates that incorporate double observer analyses, which are described in Appendix 1. Overall, the total number of caribou at least one year old was 9,323 as recorded during the survey and 9,549 as corrected from double observer calculations, an increase of 2.4%.

Table 9. Estimates of caribou in visual survey strata from double observer and strip transect estimates for the Bathurst herd, June 2021. Note these numbers include Beverly caribou east of the Inlet. N = estimate; SE = standard error; 95% CI = 95% confidence interval; CV = coefficient of variation.

Stratum	**Caribou seen**	**Corrected double observer estimates**					**Uncorrected transect estimates (as recorded in field)**		
		N	SE	95% CI		CV	N	SE	CV
Vis1	55	356	95.6	181	702	26.8%	351	91.3	26.0%
Vis2	162	1,195	319.5	652	2,190	26.7%	1,173	449.6	38.3%
Vis3	32	202	57.6	107	380	28.5%	198	91.7	46.3%
Vis4	437	3,024	306.3	2,407	3,800	10.1%	2,950	459.4	15.6%
Vis5	164	1,168	264.7	688	1,982	22.7%	1,134	287.0	25.3%
Vis6	77	556	123.2	336	921	22.1%	542	114.8	21.2%
Vis7	48	382	217.6	98	1,492	56.9%	372	174.3	46.8%
Vis8	132	655	217.2	311	1,379	33.1%	641	167.2	26.1%
Vis9	276	2,011	256.1	1,501	2,693	12.7%	1,963	286.7	14.6%
Total	1,383	9,549	675.3	8,285	11,005	7.1%	9,323	816.1	8.8%

Overall, the estimated numbers of caribou at least one year old in the visual blocks west of Bathurst Inlet (Vis 1, 2, 3 and 8) and in the block at the south end of Bathurst Inlet (Vis 7) were relatively low, and about as expected based on the few known collared Bathurst female caribou outside the Photo Core block. Estimated numbers of caribou in the visual strata are shown separately for the blocks west and east of the Inlet (Table 10).

Table 10. Estimates of caribou (at least one year old) in visual survey strata from double observer-corrected estimates for the Bathurst herd, June 2021, west and east of Bathurst Inlet. Note these numbers include Beverly caribou east of the Inlet. N = estimate; SE = standard error; 95% CI = 95% confidence interval; CV = coefficient of variation.

Stratum	Caribou counted	N	SE	95% CI		CV
West of Bathurst Inlet						
Vis1	55	356	95.6	181	702	26.8%
Vis2	162	1,195	319.5	652	2,190	26.7%
Vis3	32	202	57.6	107	380	28.5%
Vis8	132	655	217.2	311	1,379	33.1%
Total	381	2,408	402.2	1,695	3,421	16.7%
East of Bathurst Inlet						
Vis4	437	3,024	306.3	2,407	3,800	10.1%
Vis5	164	1,168	264.7	688	1,982	22.7%
Vis6	77	556	123.2	336	921	22.1%
Vis7	48	382	217.6	98	1,492	56.9%
Vis9	276	2,011	256.1	1,501	2,693	12.7%
Total	1,002	7,141	541.6	6,120	8,332	7.6%

The estimated numbers of caribou at least one year old in the blocks east of Bathurst Inlet (Vis 4, 5, 6, and 9) were much higher than expected based on a total of four known Bathurst collared cows, and particularly so in Vis 4, 5 and 9. The total number of caribou at least one year old in the four visual blocks west of the Inlet was estimated at 2,408, while the total number estimated east of the Inlet was about three times as large at 7,141 (Table 10). Visual Stratum 7 at the south end of Bathurst Inlet is included as east of the Inlet.

In combination with the composition survey results that showed large proportions of non-breeding cows, yearlings and bulls east of the Inlet (Figure 17) that continued east past the edge of the survey area (Figure 20), these results indicated that there were far too many caribou in this area to be only Bathurst. East of Bathurst Inlet, the caribou were most likely primarily Beverly caribou with smaller numbers of Bathurst caribou mixed in. The presence of substantial numbers of bulls and yearlings indicated that these caribou were in part made up of the "trailing edge" at the back end of the Beverly migration, where non-breeding cows, yearlings and bulls are commonly observed.

Photo Strata Estimates and Double Observer Correction

Characteristics of the two Bathurst photo strata in June 2021 are given in Table 11. There were 18 transects in each stratum and ground coverage was 46% in the Photo Core and 30% in the Photo East strata. The average strip width of photo strips was 1.43 km when geo-referencing was used to account for elevation change and resulting variation in strip width.

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

Stratum	Area (km^2)	Transect Number	Mean transect length (km)	Stratum length (km)	Area Surveyed (km^2)	Total survey lines possible	Coverage (%)	Caribou counted	Estimated number caribou N
CORE	1,690.0	18	30.37	55.6	784.20	38.9	46	1,590	3,427
EAST	2,443.4	18	28.19	86.7	723.80	60.5	30	1,950	6,583

Densities of caribou on the Photo Core transects were variable and most caribou were concentrated in the western end of the block, with few caribou in the eastern end (Figure 21). This resulted in a relatively high variance for this block and inflated the overall variance around estimates of females and adults. Only one transect had a density of more than 10 caribou/km^2. Densities of caribou were less variable in the Photo East block.

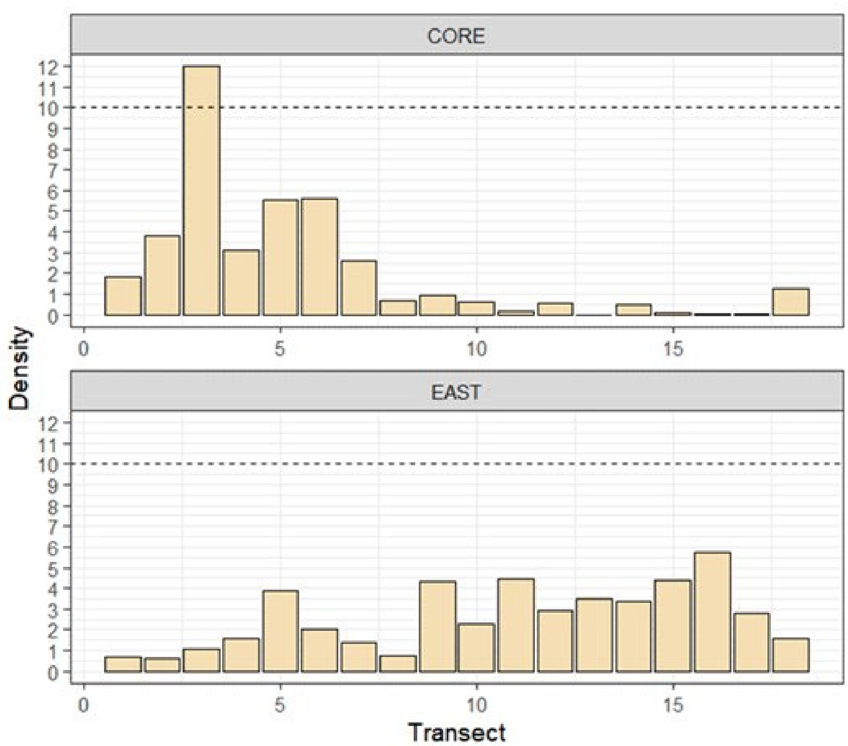

Figure 21. Transect densities (uncorrected) for the photo strata on the Bathurst June 2021 calving ground survey. The dotted line indicates a density of 10 caribou/km^2, a number that has in the past been used as a threshold of high density.

An example of a zoomed-in portion of an aerial photo from June 10, 2021 on the Bathurst calving ground survey area is shown in Figure 22.

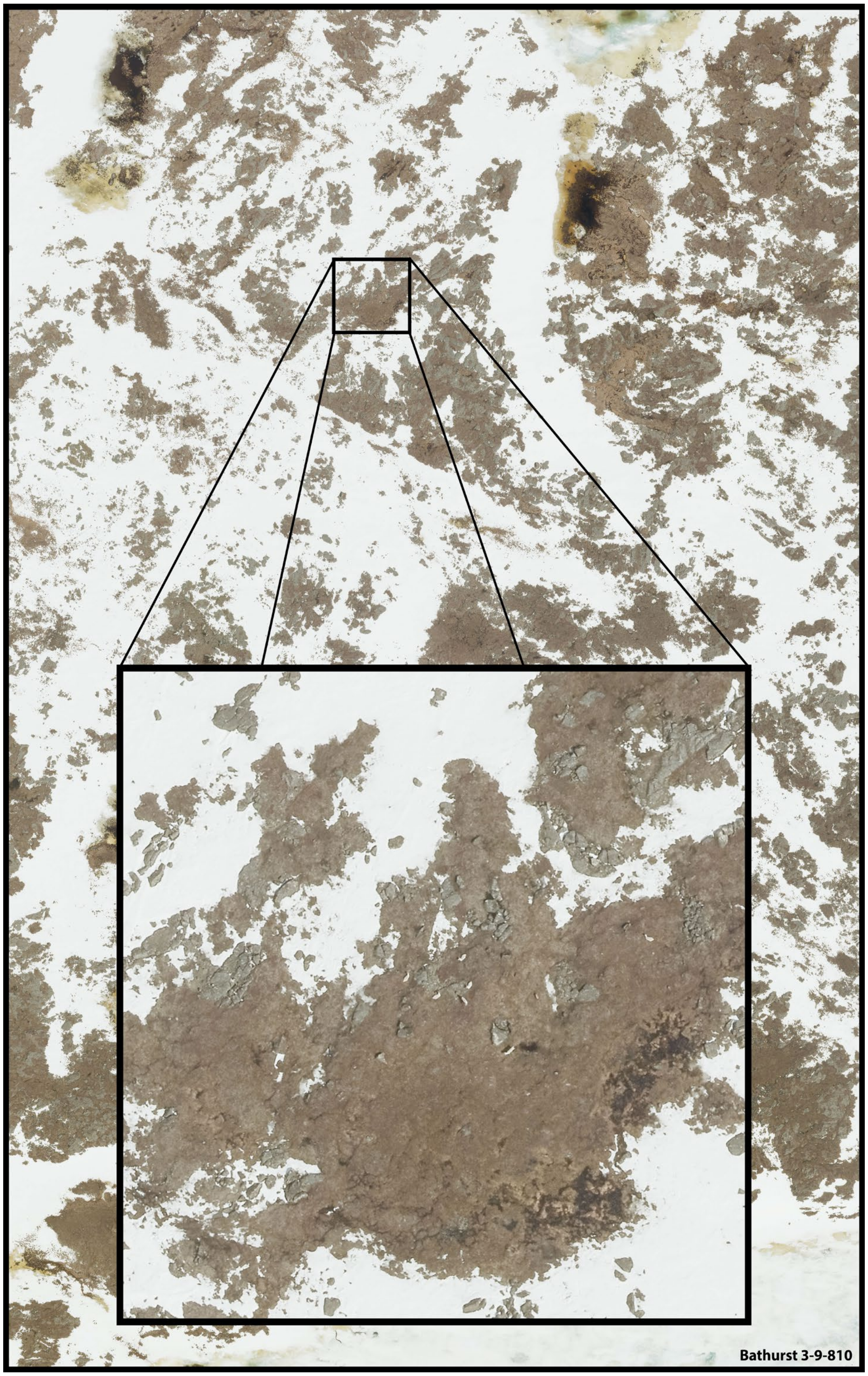

Figure 22. A zoomed-in part of one of the aerial photos taken over the Bathurst calving ground on June 10, 2021. Several caribou can be seen on the bare ground; most are bedded but two are standing, based on the shadows visible.

Composite photos strips making up the coverage on the Photo Core and Photo East blocks are shown in Figures 23a and b with groups of caribou marked as red dots. A composite map of the survey area showing locations of caribou groups is in Figure 24.

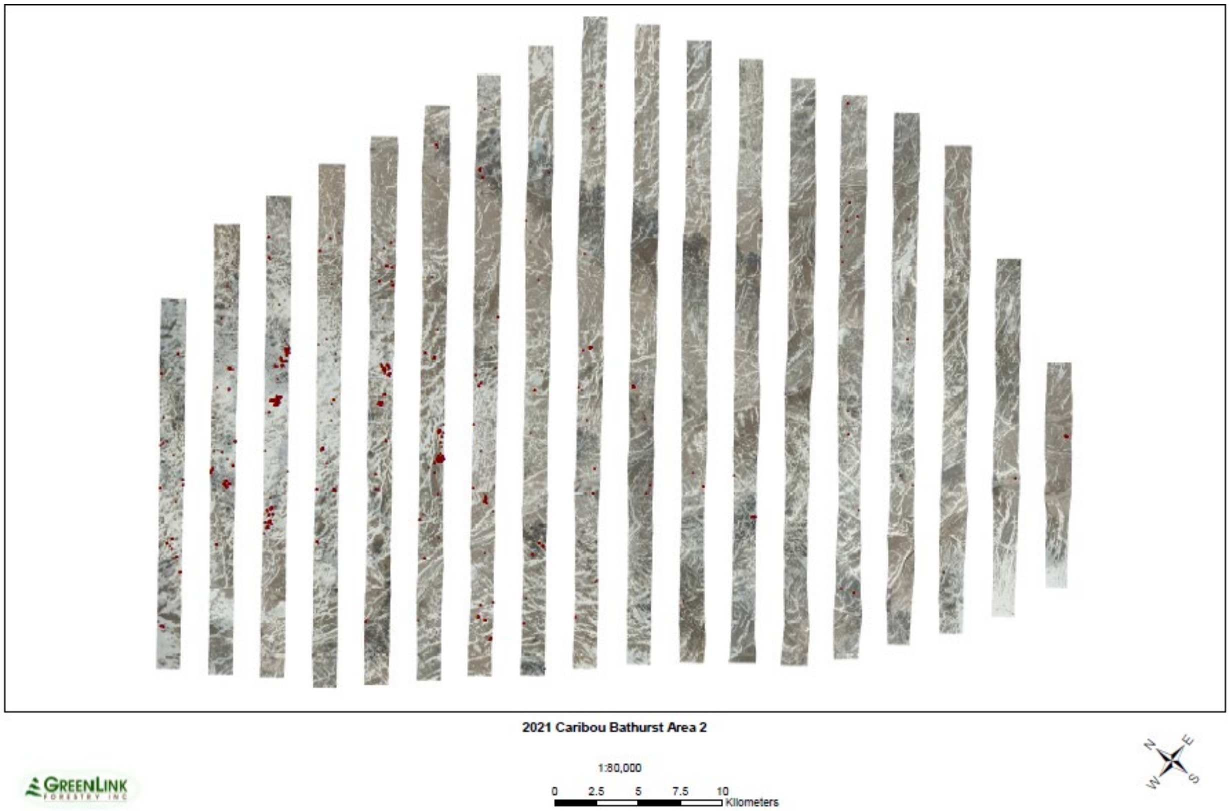

Figure 23a. A composite image of continuous aerial photo strips taken during the June 2021 Bathurst calving ground survey over the Photo Core block west of Bathurst Inlet. Red dots show locations of caribou recorded. Caribou were concentrated in the northwestern end of the block. Coverage was 46%.

Figure 23b. A composite image of continuous aerial photo strips taken during the June 2021 Bathurst calving ground survey over the Photo East block east of Bathurst Inlet. Red dots show locations of caribou recorded. Coverage was 30%.

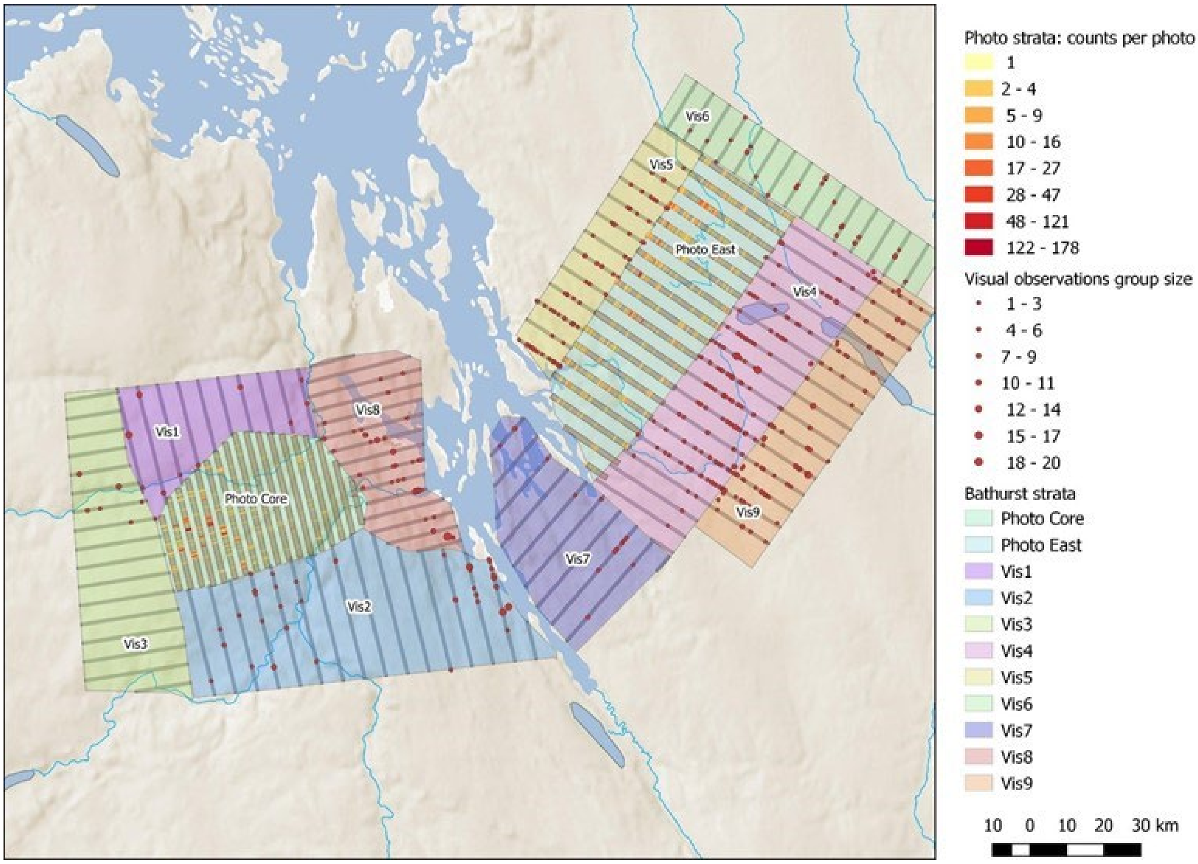

Figure 24. June 2021 Bathurst calving ground survey strata with groups of caribou seen on photo and visual transect lines. Group sizes on visual transects are shown as circles varying in size. Counts of caribou on aerial photos are shown as a colour gradation from lighter to darker (see legend).

The full Bathurst aerial photo set included 2,983 photos, of which 2,365 had no caribou. A total of 207 photos were re-counted, 150 of them with at least one caribou and 47 with no caribou. Details of the second independent count and analysis are in Appendix 2. The second observer for this analysis was Derek Fisher, president of Greenlink Forestry and the most experienced photo analyst at the company. A summary of the caribou counts for the two observers is in Table 12, and the uncorrected and corrected estimates of caribou at least one year old in the two photo strata are shown in Table 13. The net effect was an increase of 3.2% from 6,583 caribou estimated from the initial counts to 6,794 caribou estimated with the double-observer correction.

Table 12. First and second observer counts and detection rates of caribou at least one year old in the Photo Core and Photo East blocks from the Bathurst June 2021 survey, from a subsample of 207 photos.

Stratum	**Observer counts**			**Detection rates (Observer 1)**
	Observer 1	Observer 2	Total caribou	
Photo Core	396	423	424	0.93
Photo East	376	385	388	0.97
Total	772	808	352	0.96 (combined)

Table 13. Initial uncorrected estimates and corrected estimates of caribou at least one year old in the Photo Core and Photo East blocks of the Bathurst June 2021 calving ground survey. Corrections were based on the detection rates in Table 12. Note these numbers include Beverly caribou east of the Inlet. N = estimated number; SE = standard error; P = probability of detection; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation.

Stratum	**Strip-transect estimates of Numbers (uncorrected)**			**Detection Rate**			**Corrected estimates of Numbers**				
	N	SE	CV	P	SE	CV	N	SE	CIL	CIU	CV
Photo Core	3426.6	824.0	0.240	0.934	0.015	0.016	3670	884.5	2223	6059	0.241
Photo East	6582.8	700.4	0.106	0.969	0.011	0.011	6794	726.9	5425	8509	0.107

Estimates of Adult Females and Breeding Females for Bathurst Herd

Summaries of the numbers of adult caribou at least one year old, adult females, and breeding females in the survey area east and west of Bathurst Inlet are given in Tables 14 and 15. We note that these numbers do not all represent Bathurst caribou, as the caribou east of the Inlet were likely primarily Beverly caribou. In the east, the largest numbers of caribou were estimated in the Photo East block, but there were substantial numbers estimated for Visual Blocks 4, 5 and 9. In the west, the largest numbers of caribou were in the Photo Core block, with lesser numbers in the four visual blocks surrounding it.

Table 14. Numbers of adult caribou at least one year old and numbers of adult females estimated from the Bathurst June 2021 calving ground survey area. Note these numbers include all caribou in the survey area, including Beverly caribou. N = estimate; SE = standard error; pf = proportion (as fraction of 1.0); CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation.

Side of Bathurst Inlet	**Stratum**	**Adult caribou number (at least 1-year-old)**		**Proportion of adult females**		**Adult female number**				
		N	CV	pf	CV	N	SE	CIL	CIU	CV
East	Photo East	6,794	0.11	0.81	0.05	5,480	654.47	4,263	7,044	11.9%
East	Vis4	3,024	0.10	0.52	0.06	1,579	187.95	1,208	2,064	11.9%
East	Vis5	1,168	0.23	0.26	0.32	303	118.76	124	740	39.2%
East	Vis6	556	0.22	0.52	0.17	290	81.90	153	549	28.2%
East	Vis7	382	0.57	0.00		0	0.00			
East	Vis9	2,011	0.13	0.22	0.26	436	124.37	229	831	28.5%
West	Photo Core	3,670	0.24	0.91	0.01	3,342	806.95	2,023	5,522	24.1%
West	Vis1	356	0.27	0.09	0.74	32	24.96	5	188	78.0%
West	Vis2	1,195	0.27	0.12	0.28	143	55.66	60	340	38.9%
West	Vis3	202	0.29	0.19	0.60	37	24.79	9	147	67.0%
West	Vis8	655	0.33	0.39	0.23	254	102.80	103	624	40.5%
	Total	20,012	0.07			11,896	1079.82	9,826	14,402	18.3%

Table 15. Numbers of adult caribou at least one year old and numbers of breeding females estimated from the Bathurst June 2021 calving ground survey area. Note these numbers include all caribou in the survey area, including Beverly caribou. N = estimate; SE = standard error; pf = proportion (as fraction of 1.0); CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation.

Side of Bathurst Inlet	**Stratum**	**Adult caribou number**		**Proportion of breeding females**		**Breeding female number**				
		N	CV	pf	CV	N	SE	CIL	CIU	CV
East	Photo East	6,794	0.11	0.63	0.10	4294	615.0	3,179	5,800	14.3%
East	Vis4	3,024	0.10	0.19	0.19	578	124.2	358	934	21.5%
East	Vis5	1,168	0.23	0.07	0.56	87	51.9	24	321	59.6%
East	Vis6	556	0.22	0.28	0.30	157	58.0	69	358	36.9%
East	Vis7	382	0.57	0.00		0	0.0	0		
East	Vis9	2,011	0.13	0.00	0.00	0	0.0	0		
West	Photo Core	3,670	0.24	0.74	0.03	2726	662.3	1,645	4,518	24.3%
West	Vis1	356	0.27	0.02	1.37	8	11.1	1	114	138.5%
West	Vis2	1,195	0.27	0.01	1.02	17	18.3	2	128	107.5%
West	Vis3	202	0.29	0.04	1.61	7	12.2	0	101	174.5%
West	Vis8	655	0.33	0.18	0.43	120	65.0	37	387	54.2%
	Total	20,012	1,328.33			7,994	918.3	6,278	10,178	20.2%

A further summary of numbers of adult caribou at least one year old, adult females and breeding females east and west of the Inlet is given in Table 16. There were more than twice as many adult caribou on the east side of Bathurst Inlet as on the west side, and numbers of adult females and breeding females were also higher on the east side.

Table 16. Estimates of adult caribou at least one year old, adult females and breeding females east and west of Bathurst Inlet during June 2021 Bathurst calving ground survey. Note these numbers include all caribou in the survey area, including Beverly caribou. N = estimate; SE = standard error; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation.

Side of Bathurst Inlet	**Category of Caribou**	**N**	**SE**	**CIL**	**CIU**	**CV**
East	Adult caribou	13,935	905.8	12,140	15,995	6.5%
East	Adult females	8,088	707.1	6,727	9,724	8.7%
East	Breeding females	5,116	632.2	3,946	6,634	12.4%
West	Adult caribou	6,078	971.6	4,345	8,503	16.0%
West	Adult females	3,808	816.1	2,435	5,955	21.4%
West	Breeding females	2,878	666.0	1,778	4,660	23.1%

Because the survey blocks east of Bathurst Inlet contained Beverly caribou as well as Bathurst caribou, the proportion of Bathurst caribou (adult females and breeding females) was assumed to be 28/34 or 82.35% in the west and 6/34 or 17.65% in the east. Estimates of Bathurst adult females and breeding females in the west-only blocks and in the west and east blocks are given in Table 17. A secondary estimate of the Bathurst herd with and without emigration was generated as part of the IPM exercise in the next section of the report.

Table 17. Estimates of Bathurst adult females and breeding females west of Bathurst Inlet, west and estimated east (based on proportion of collars) during June 2021 Bathurst calving ground survey. N = Lincoln-Petersen estimate; SE = standard error; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation.

Bathurst caribou west of Bathurst Inlet				**Proportion of cow collars west**		**Bathurst caribou east and west of Bathurst Inlet**				
Group	N	SE	CV	Proportion (28/34)	CV	N	SE	CIL	CIU	CV
Adult females	3808	816.1	0.21	0.8235	0.078	4596	1049	2857	7392.48	0.23
Breeding females	2878	666.0	0.23	0.8235	0.078	3474	848.4	2090	5772.15	0.24

Estimates of Bathurst Herd Size in 2021 and Comparison with 2018 Estimates

Estimates of Bathurst adult herd size (caribou at least two years old) were generated by extrapolating from the adult female estimate using the fall 2020 sex ratio estimated for the herd. Estimates were generated from the adult female caribou estimate based on survey blocks west of the Inlet, and from the west and estimated east adult female caribou estimate (Table 18). The herd estimate based on west-only survey blocks assumes that male Bathurst caribou would have emigrated to the Beverly distribution in equal proportion to the female caribou, as documented from collared female caribou. Movement of Bathurst collared bulls will be evaluated further in future. By difference, the estimated numbers of Bathurst caribou on the east side of the Inlet were: 596 breeding cows, 788 adult cows, and 1,292 adult caribou (males and females).

Table 18. Estimates of Bathurst adult herd size in 2021, based on caribou west of Bathurst Inlet and west and estimated east (based on proportion of collars). N = estimate; SE = standard error; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation.

Portion of Survey Area	**N**	**SE**	**CIL**	**CIU**	**CV**
West	6,243	1370.4	3,950	9,134	0.22
West+East	7,535	1755.9	4,638	11,239	0.23

Comparisons of 2018 and 2021 estimates were made using the west-only numbers for 2021, as well as the west and estimated east numbers. The ratio of estimates was used to estimate gross change and yearly change (λ) and confidence limits were calculated assuming log-normal distributions of estimates. A comparison of Bathurst herd estimates 2009-2021 based on West-only and West and estimated East numbers is shown in Figure 25. In both cases, the rate of decline slowed between 2018 and 2021 from the rapid decline 2012-2018, with the West and estimated East herd estimate approaching stability. Variance on the 2021 estimates was relatively high, in part due to a large variation in transect counts in the Photo Core block and in Visual blocks.

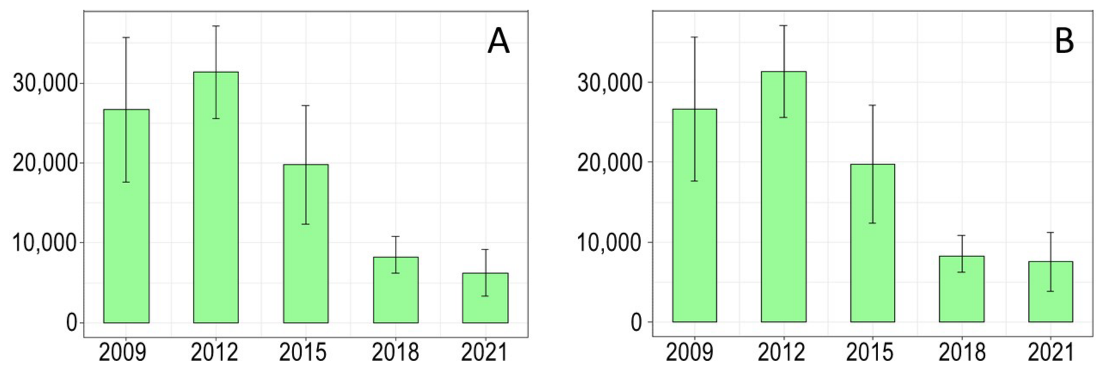

Figure 25. Estimated size of Bathurst herd 2009-2021 based on calving ground photo surveys: A (left) based on caribou west of Bathurst Inlet in June 2021 only, and B (right) based on caribou west and estimated east.

Estimates of caribou that include the likely number of Bathurst cows east of the Inlet in effect set aside possible emigration losses, reflecting the internal balance of mortalities and calf recruitment – what herd size might have been had there been no eastward movement. Yearly change ranged from 0.96 for adult females to 0.98 for breeding females (Table 19). In all cases (breeding females, adult females and adult herd size) confidence limits for yearly change overlapped 1, indicating that a significant change in estimates was not detected between 2018 and 2021.

Table 19. Comparison of Bathurst caribou estimates of adult females, breeding females, and adult herd size in 2018 and 2021, based on caribou west and estimated east (based on proportion of collars). N = estimate; SE = standard error; GC = gross change; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation; λ = lambda (rate of change).

Metric	**Estimates**				**Overall change 2018-2021**				**Yearly change**			
	N_{2018}	SE	N_{2021}	SE	GC	SE	CIL	CIU	λ	SE	CIL	CIU
Adult Females	5162	663.7	4596	1048.6	0.89	0.24	0.53	1.45	0.96	0.08	0.81	1.13
Breeding Females	3636	504.6	3474	848.4	0.96	0.28	0.54	1.62	0.98	0.09	0.82	1.17
Adult Herd Size	8207	1079	7535	1755.9	0.92	0.25	0.54	1.51	0.97	0.09	0.81	1.15

Estimates that were based only on Bathurst caribou west of Bathurst Inlet showed larger declines in estimates of breeding females, adult females and adult herd size from 2018-2021 (Table 20), with yearly change for adult females estimated at 0.90 and 0.93 for breeding females. Confidence intervals for yearly change again overlapped 1, indicating that a significant change in estimates was not detected. Our working assumption is that the caribou that moved to the Beverly herd in June/July will not return, thus these estimates are the ones that should be used for management purposes.

Table 20. Comparison of Bathurst caribou estimates of adult females, breeding females, and adult herd size in 2018 and 2021, based on caribou west of Bathurst Inlet only. N = estimate; SE = standard error; GC = gross change; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation; λ = lambda (rate of change).

Metric	**Estimates**				**Overall change 2018-2021**				**Yearly change**			
	N_{2018}	SE	N_{2021}	SE	GC	SE	CIL	CIU	λ	SE	CIL	CIU
Adult Females	5162	663.66	3808	816.13	0.74	0.19	0.45	1.18	0.90	0.07	0.76	1.06
Breeding Females	3636	504.56	2878	665.96	0.79	0.22	0.46	1.31	0.93	0.08	0.77	1.10
Adult Herd Size	8207	1079.00	6243	1370.44	0.76	0.20	0.46	1.23	0.91	0.08	0.77	1.07

Demographic Modeling of Bathurst Herd

In this section, field-based demographic indicators for the Bathurst herd 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. Thereafter, results of the integrated Bayesian population model are described.

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 26a). 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 at least 2-3 years.

Cow survival rates varied around the 0.8 or 80% level from about 2014 onward until the last three years, when IPM and collar-based estimates suggested higher levels 2018-2020 than, for example, 2009-2013 (Figure 26a). Collar-based cow survival was over 90% in 2018 and 2019 and estimated at 87% in 2020.

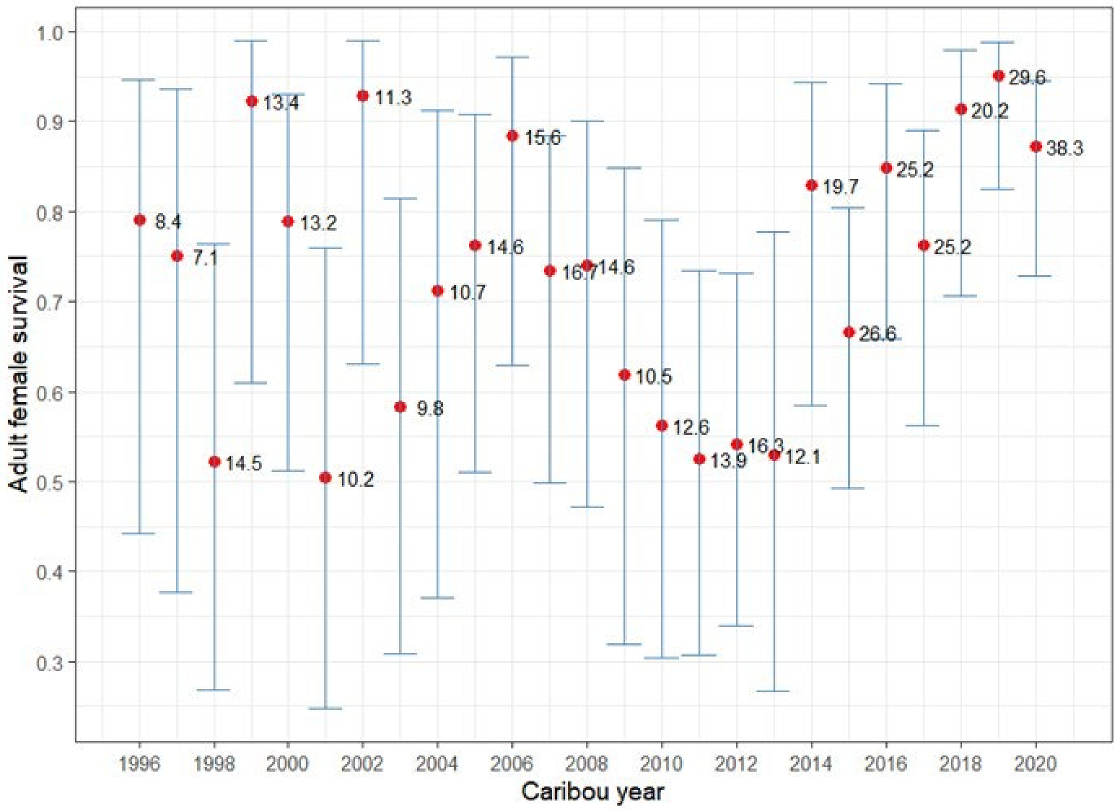

Figure 26a. Annual collar-based cow survival estimates for the Bathurst herd from 1996-2020. Red dots are the annual estimates, with 95% confidence intervals as blue bars. Numbers beside the red dots show the average number of collared females available for the estimate. Variance has been high, particularly 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 were also estimated for the spring-fall period (June - October) and early winter to spring migration (November - May) (Figure 26b); these showed relatively high cow survival in both seasonal periods in 2018 to 2020. Collared bull survival estimates have only become available recently and were relatively imprecise due to low collar numbers. However, these estimates provided a second point of inference to bull cow ratios.

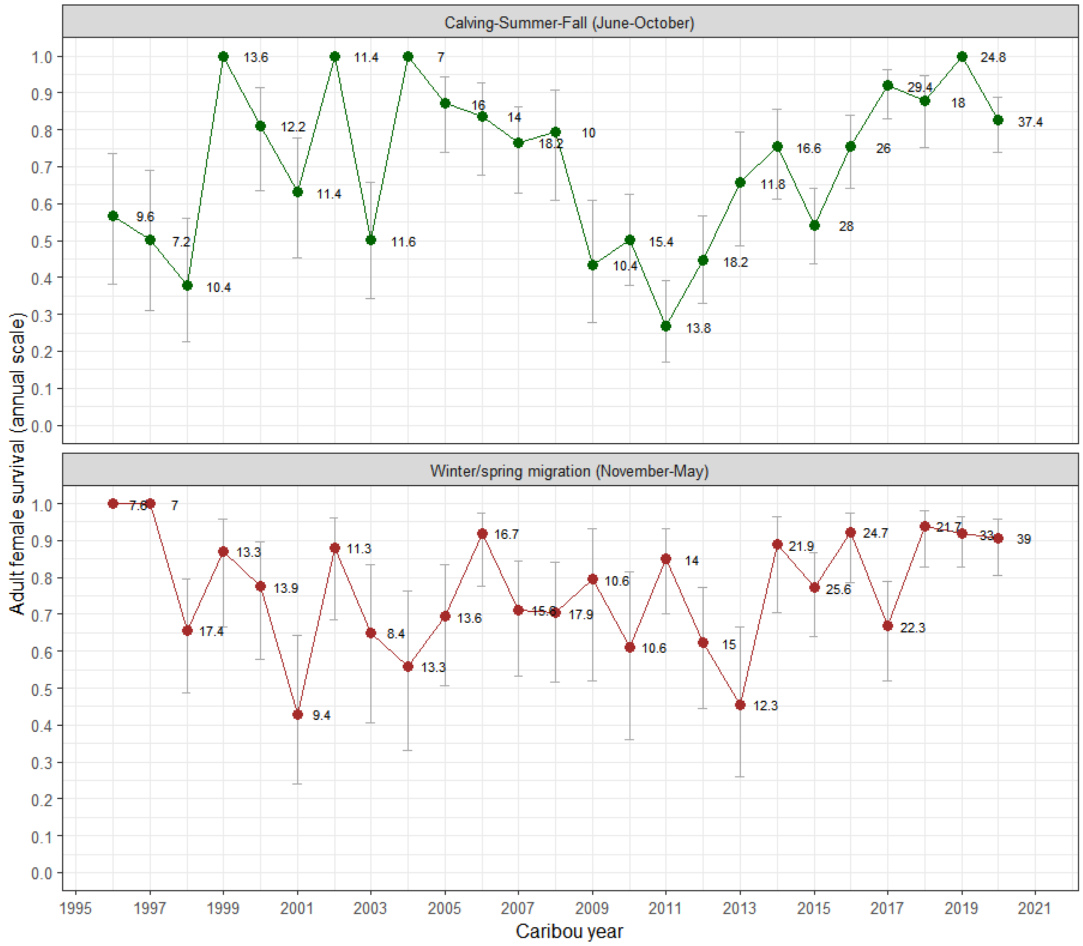

Figure 26b. Annual collar-based cow survival estimates for the Bathurst herd from 1996 to 2020 for two seasonal periods (June-October and November-May). Dots are the annual estimates, with 95% confidence intervals as blue bars. Numbers beside the dots show the average number of collared females available for the estimate.

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 at 60% in 2015, 86% in 2019 and about 75% in 2018 and 2021 (Figure 27). Some years had lower fecundity that was potentially associated with high drought conditions and severe insect harassment (Boulanger and Adamczewski unpublished). Ongoing analyses will explore the relationship between variation in climatic covariates and demographic parameters.

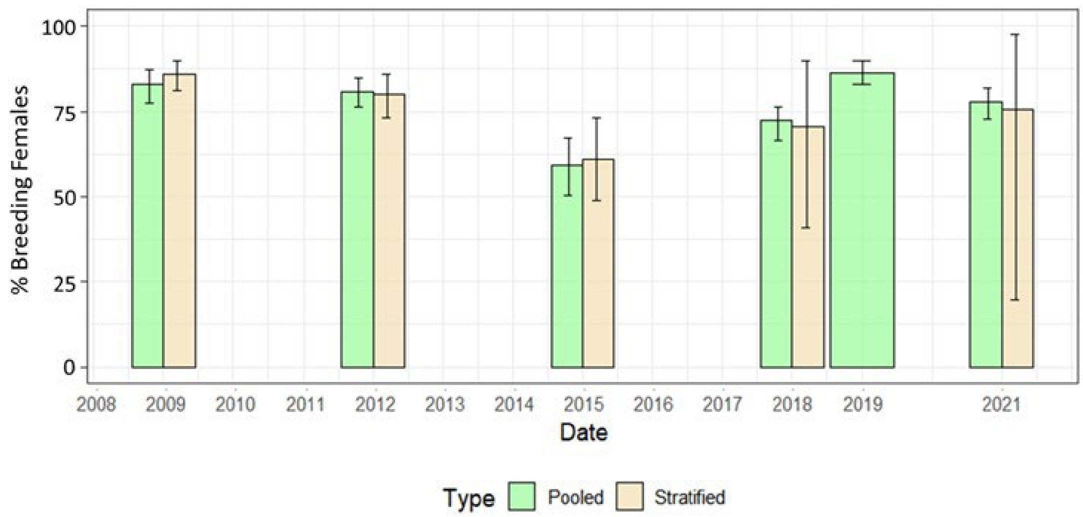

Figure 27. Proportion of breeding females on the Bathurst calving ground from composition surveys near the peak of calving, 2009-2021. All surveys except 2019 were part of calving photo surveys. Stratified estimates consider relative numbers of caribou in individual survey blocks, while pooled estimates do not. The 2019 composition survey was a stand-alone survey with no survey blocks defined. Comparison of pooled and stratified estimates suggests there is little difference in estimates.

Fall composition surveys usually conducted in late October in the middle of the breeding season provide two useful demographic indicators: a calf:cow ratio and a bull:cow ratio. The fall calf:cow ratio is an index of calf survival to 4 ½ months of age, although it is also affected by initial calf productivity in June. The fall bull:cow ratio is an index of bull survival rates, which are consistently lower than cow survival rates. In October, the fall calf:cow ratio for the Bathurst herd showed an increasing trend from 2018 to 2020 (Figure 28). The fall bull:cow ratio has varied since 2006 ranging between 30 and 59 bulls:100 cows; the highest bull:cow ratio recorded between 2006 and 2020 was 64 bulls: 100 cows in October 2020 (Figure 28). A fall survey was attempted in October 2021 but was unsuccessful due to extensive mixing of the Bathurst herd with the much larger Beverly herd.

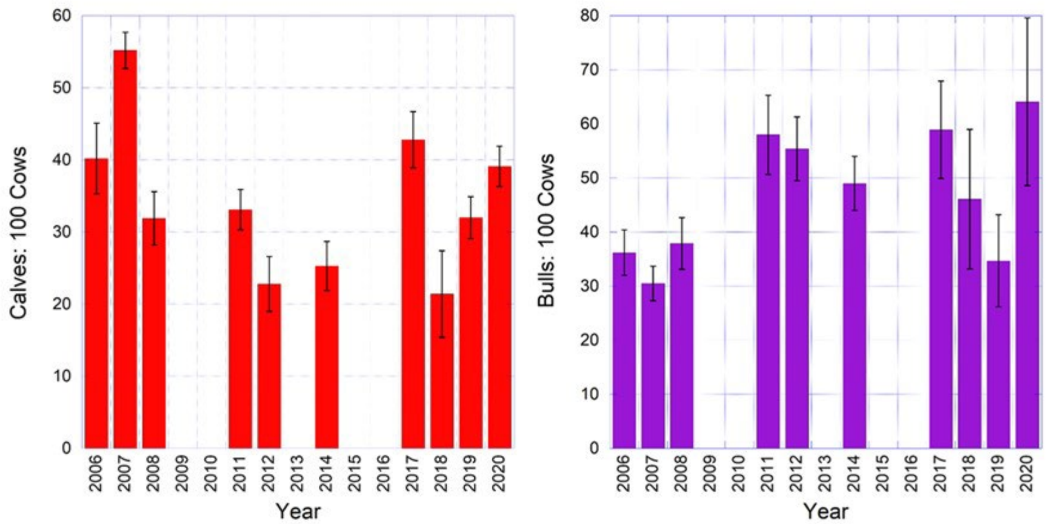

Figure 28. Calf:cow ratios recorded for the Bathurst in the fall breeding season 2006-2020 (left) and bull:cow ratios from the same surveys (right). Error bars are 95% confidence intervals.

The random effects IPM was then fitted to the survey, composition, and survival data to provide overall inference on demography using all field indicators. Figure 29 shows field estimates and the fit of the IPM to cow and bull survival, fall and spring calf:cow ratios, fecundity, fidelity to calving grounds, fall bull:cow ratios, estimated numbers of breeding cows, and estimated numbers of adult cows and bulls. Overall fit was reasonable for all indicators as shown by overlap of modeled values (blue) with results recorded in the field or from collar data (red).

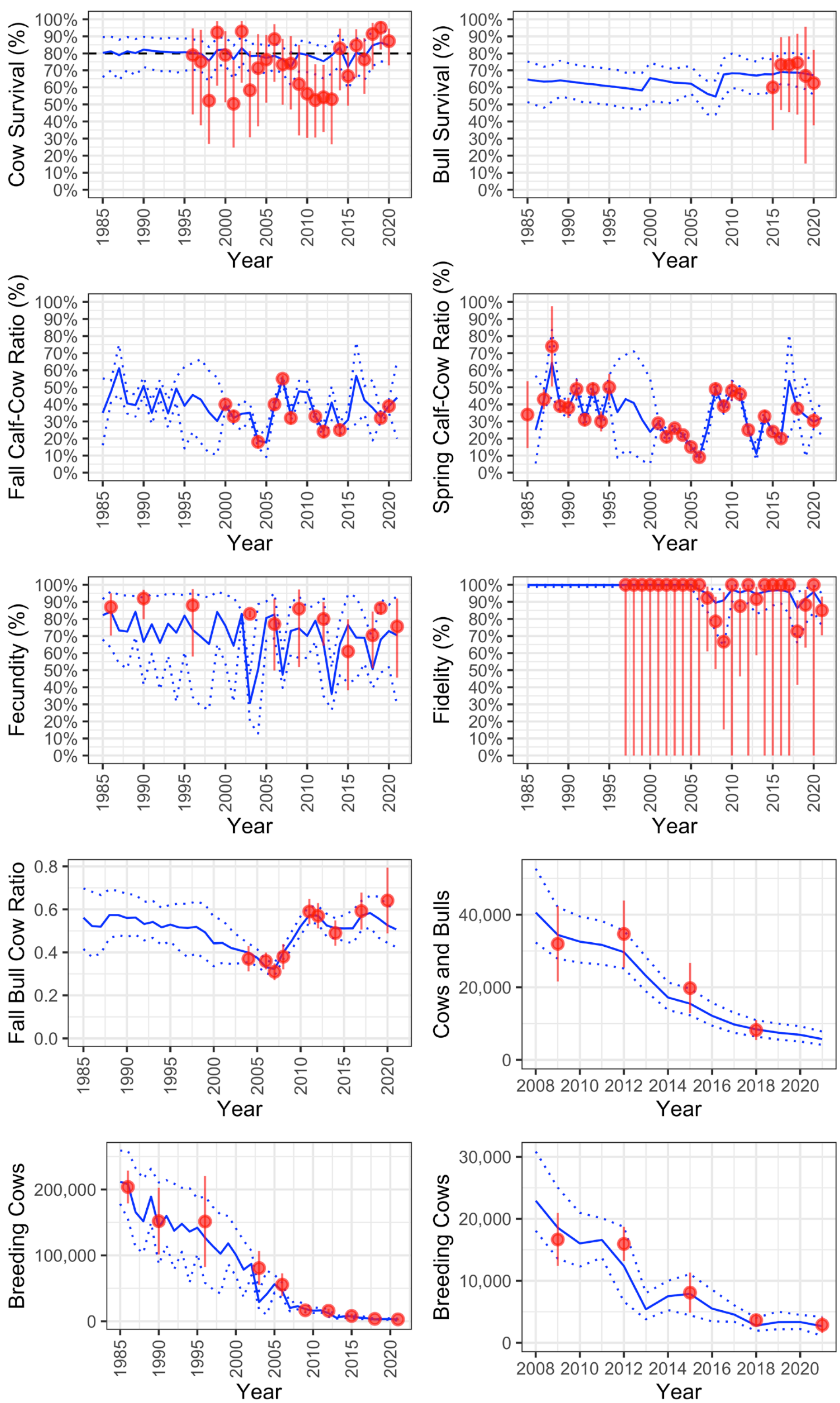

Figure 29. The fit of the IPM to estimates of survival, calf:cow ratios, fecundity, fidelity, bull:cow ratios and numbers of breeding females for the Bathurst herd 1985-2021. The blue lines are model-based with variance as a dotted blue line, and the red dots are estimates from field surveys or collar data, with variance as red bars.

Estimates of the Bathurst herd using the west-only survey data were used in the IPM. Fidelity defined as the proportion of known Bathurst cows returning to the Bathurst calving ground west of Bathurst Inlet each year was used to inform the model of emigration events. By doing this the model was able to account for emigration while still assessing overall demographic status. For this model run it was assumed that a similar proportion of bulls emigrated to the Beverly herd as cows. This assumption will be assessed further based on fall and winter herd affiliations of bull caribou.

One of the main additional inputs into the IPM was survival rates from collared cows. Cow survival is the most sensitive of demographic indicators of population trend. IPM estimates were more precise than field estimates and varied below 0.8, which is the absolute lower limit for herd stability, up to 2016 when an increasing trend is suggested (Figure 30). The IPM estimate of cow survival for the 2020-2021 caribou year was 0.85 (CI=0.76-0.92) which was similar to the collar-based survival estimate of 0.87 (CI=0.73-0.95). Confidence limits were tighter on the IPM estimate. Given that the IPM model used all data sources available, the IPM survival estimate was likely more robust than the collar-based estimate that was based on a limited sample size of caribou (mean collars per month=38; Figure 26a).

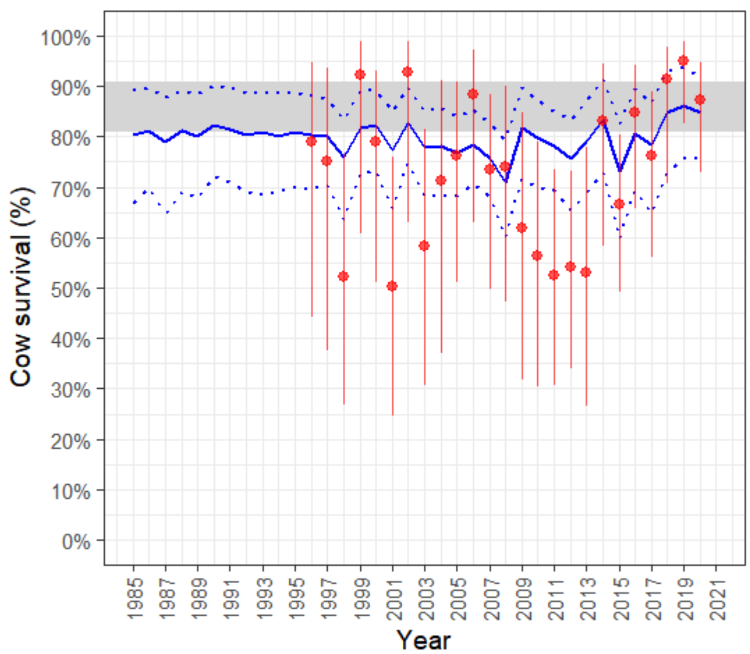

Figure 30. Trends in Bathurst cow survival 1985-2021 from Bayesian IPM analysis and collars. The solid blue lines represent model predictions and confidence limits are the hashed blue lines. The red points are observed field estimates from collars with associated confidence limits. The shaded region represents the range of cow survival levels (0.81-0.91) needed for population stability across the range of productivity values observed for the Bathurst herd (Boulanger et al 2011).

The estimated levels of adult cow survival suggest stability of the herd but are still low to ensure recovery. Previous analysis of demographic data (Boulanger et al 2011) suggests that for the range of productivity levels of the Bathurst herd, cow survival should be at least 0.81 to ensure stability. Levels of up to 0.91 would be needed for recovery if productivity is low. In this context, recent estimates are within range for herd stability but further increases in female survival would be needed for recovery.

Of interest in terms of possible predation effects was calf survival, which is a derived parameter of the IPM (Figure 31). Calf survival rates were variable; however, recent estimates (2018-2020) indicate levels above 0.5, suggesting a potential increase in calf survival. Trends in calf survival and the effect of covariates on survival will be tested in future model runs. Overall herd productivity can also be estimated as the product of fecundity times calf survival which is an estimate of recruitment of yearlings to the subadult age class. Estimates of productivity suggest a generally increasing trend from 2013 to 2021 with substantial year to year variability in model values and field estimates (Figure 31). Spring calf-cow ratios, which are a field-based estimate of productivity, are overlaid with productivity and fall calf-cow ratios shown in Figure 28. Previous experience with the Bathurst herd and other herds has shown that March calf:cow ratios often show a sawtooth pattern of alternating higher and lower values (e.g. Figure 31 right), and year-to-year variation is common. We note that productivity corresponds to the end of the caribou year (late May) whereas spring calf-cow ratios are estimated in March. The spring calf-cow ratio will index productivity if cow and calf survival rates are relatively similar from March to late May.1

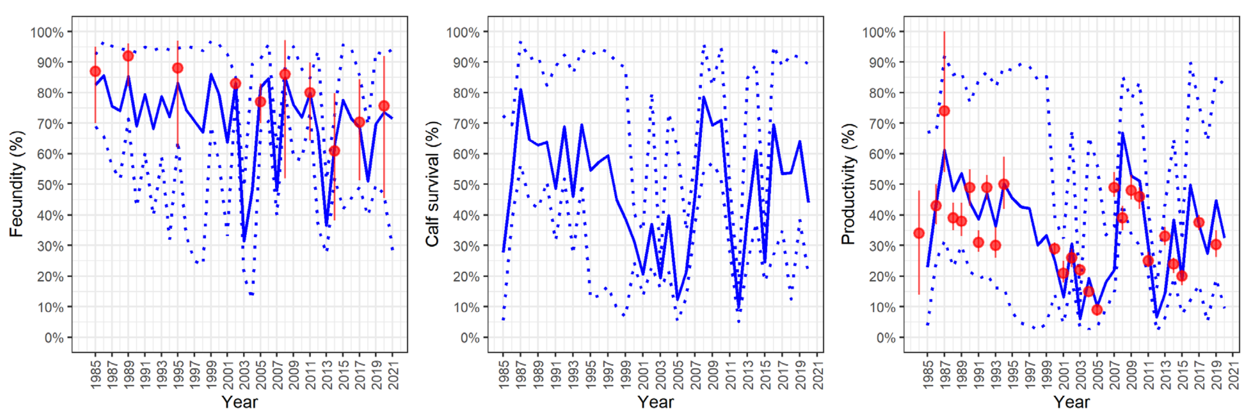

Figure 31. Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for the Bathurst herd 1985-2020. Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year prediction of the model), are shown for reference purposes.

Estimates of fidelity were close to 1 in most years (Figure 29). Field estimates of fidelity were imprecise due to the low sample size of known Bathurst cows used for estimates.

There were <20 known Bathurst cows used for fidelity estimates for all years up to 2021, when there were 34 known Bathurst cows. IPM estimates of fidelity were close to 1 for most years suggesting that the underlying demography primarily explained population trends rather than emigration events.

We generated overall estimates of trend (yearly change in adult female numbers) with emigration to the Beverly herd in 2021 included and excluded (Figure 32).

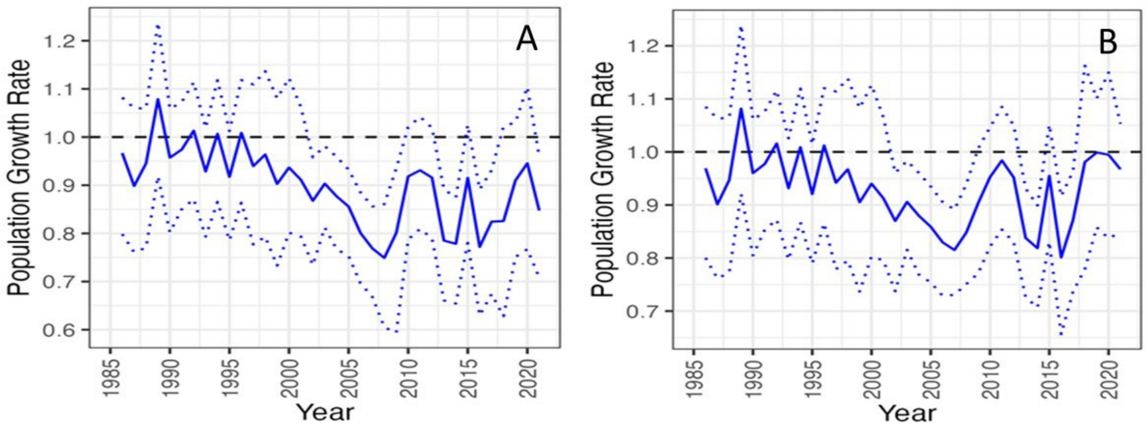

Figure 32. Estimates of trend in the Bathurst herd's growth rate ($\lambda=N_{year+1}/N_{year}$) 1995-2020 with emigration events included and excluded. The graph on the left (A) includes emigration to the Beverly herd, and the graph on the right (B) excludes emigration. The dotted line shows a growth rate of 1.0, which is a stable population.

For this model run the base model was fitted to data that included emigration. Estimates of trend in adult cow numbers were then generated under a scenario with and without emigration each year, to provide an overall sensitivity analysis of emigration events on the herd from 1985 to 2021. Estimates with emigration included (Figure 32 left) suggest a significant decrease in herd size (with confidence limits not overlapping 1), while estimates with emigration excluded (Figure 32 right) suggest the herd is approaching overall stability with point estimates of λ close to 1 (with confidence limits symmetrical around 1 from 2018 to 2021). This analysis suggests that the Bathurst herd might have been stabilizing 2018-2021 based on the balance between mortalities and recruitment of young, but not if the emigration events are included. However, even with yearly emigration events excluded, population growth rate estimates were <1 for most years from 1995 to 2018.

Estimates of numbers of adult cows with and without emigration were also generated from the emigration simulation runs. The estimate of adult cows with fidelity=1 in 2021 was 4,394 (CI=3,085-6,105) compared to 3,826 (CI=2,701-5,473) with emigration included. These estimates lined up well with field (survey) estimates of 4,596 (CI=2,857-7,392) cows with emigration accounted for based on collar proportions, and estimates of the Bathurst herd west of Bathurst Inlet of 3,803 (CI=2,435-5,955) cows representing the herd minus emigration. Both estimates suggest a relatively small portion of the Bathurst cows calved east of Bathurst Inlet. Similarity of estimates with emigration excluded from the IPM (3,826) and the field-based estimate of 3,803 also demonstrate relatively good fit of the IPM model.

In the past five years emigration events where Bathurst collared cows were located on the Beverly calving ground have challenged assessment of population trends in the Bathurst herd. To assess management actions, estimates that are not confounded by movements to other herds are useful. In addition, it would be useful to forecast when emigration events might occur based on herd overlap prior to calving.

To explore overlap and fidelity to calving grounds, we estimated monthly herd ranges for the Bathurst and neighbouring herds using a kernel estimator; overlap was high in 2018, 2019 and 2021 (Figure 33). We estimated monthly overlap using the Bhattacharyya's affinity index (Fieberg and Kochanny 2005) using the *adehabitat* R package (Calenge 2015). This index considers the overlap of utilization distributions from the Kernel home range/utilization distribution estimator with values ranging from 0 (0 overlap) to 1 (complete overlap).

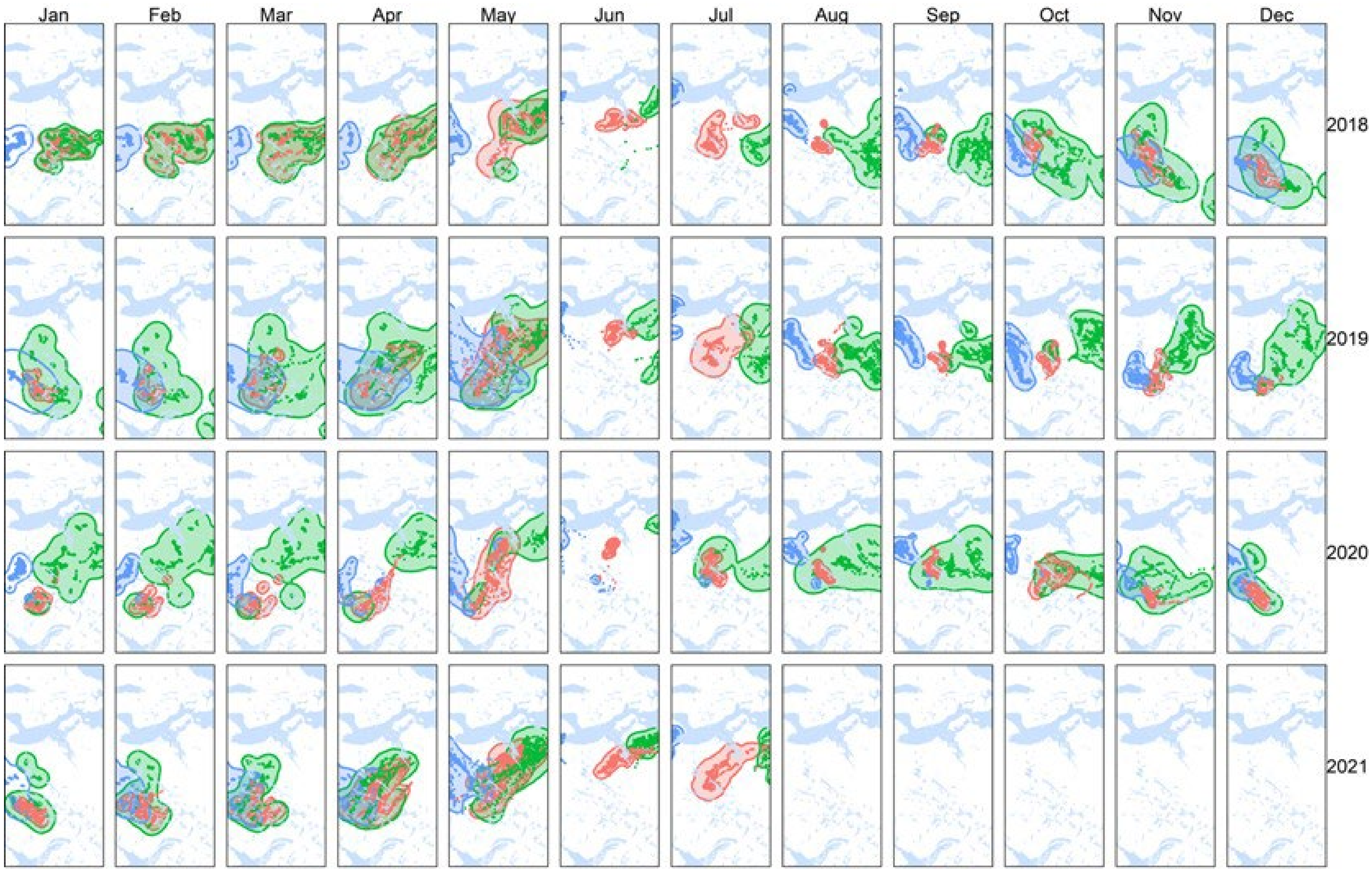

Figure 33. Monthly kernel-based home ranges of the Bluenose-East (blue), Bathurst (red) and Beverly (green) caribou herds in 2018, 2019, 2020 and 2021.

A regression analysis was then undertaken where monthly overlap between December and March (the winter preceding spring migration north) was regressed against switching (proportion of cows emigrating to the Beverly calving ground) in the following June calving period. Assessment of slopes suggested similar trends starting in December up to April of the following year. Figure 34 shows a plot using pooled overlap scores from December to March, however, the general slope became evident using data from December of the preceding year. Overlap was highest in 2018, 2019 and 2021 (and lower in 2020) and associated with a higher likelihood of calving ground switching by collared female caribou.

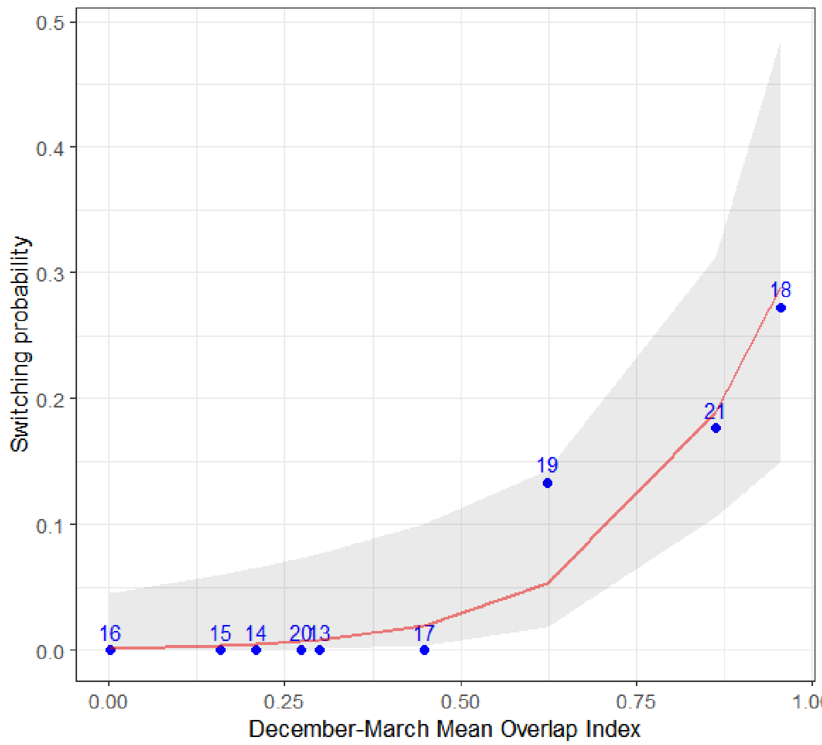

Figure 34. Estimates of spatial overlap between Bathurst and Beverly caribou herds in winter (December-March) using Bhattacharyya's affinity index 2012-2021, in relation to probability of caribou cows switching calving grounds. A GAM model regression trend line with shaded confidence limits is also shown. The abbreviated year for the data point (year-2000) is shown next to each data point. Years 2020 and 2013 are directly beside each other.

The relationship between herd overlap (Bathurst with Beverly) and fidelity should make it possible to better forecast and model potential emigration events. We note that there is a large size disparity between the two herds, the Beverly outnumbering the Bathurst by more than 12:1 based on 2018 population estimates. Emigration from the smaller to the larger herd may be facilitated by this disparity. Using the fidelity term in the IPM allows assessment of both retrospective (prior to switching) and prospective (current status) of herds. Therefore, it is possible to assess herd trend in response to management actions while accounting for emigration events.

DISCUSSION

Survey Considerations

The June 2021 calving ground photo survey of the Bathurst herd was carried out following methods consistent with several previous surveys on the herd since 1986. We acknowledge that the lack of an initial reconnaissance survey to estimate caribou densities is a departure from previous Bathurst calving ground surveys, however we believe that design of the survey area west of Bathurst Inlet, with a core area that had most of the calving cows and lower-density visual blocks surrounding it, was effective. There were 28 known collared Bathurst female caribou and a further ten unassigned female collared caribou in the survey blocks west of the Inlet at the time of the June 2021 survey. Based on movements during and after the survey period, those ten unassigned collared cows were assigned as Bathurst. The number of Bathurst cow collars, substantially higher than during any previous calving ground photo surveys, gave us confidence that a high proportion of the cows in the calving distribution had been included in the survey blocks west of the Inlet.

We suggest that it remains preferable to carry out a reconnaissance survey prior to defining photo and visual survey blocks on calving ground surveys where possible, as the reconnaissance survey provides useful information on distribution, relative abundance and approximate composition of caribou in the main calving and surrounding areas. The reconnaissance survey provides empirical data to design survey blocks and minimize variance, especially when collar sample sizes limit the ability to assess overall variation in density of caribou on the calving ground.

The mixing of Bathurst and Beverly caribou east of Bathurst Inlet created a challenging situation in estimating the numbers of Bathurst caribou in that area. One of the key assumptions in estimating abundance of breeding female caribou from calving ground photo surveys is that the calving grounds are separate and distinct for each herd (Gunn and Miller 1986). This assumption held for the June 2021 Bathurst survey area west of the Inlet but did not hold for the survey area east of the Inlet. Reconnaissance flying, more intensive photographic coverage, or additional visual flying east of the Inlet would not have resolved this issue or enabled a reliable quantitative estimate of the Bathurst caribou east of the Inlet. Assuming that the Bathurst herd females east of the Inlet were in proportion to known Bathurst cow collars (6 of 34) is a reasonable assumption that is based on distribution of collared caribou.

The relatively low numbers of Beverly collared caribou (ten known females and eight known males) in a herd estimated at 103,000 in 2018 (Campbell et al. 2019) did not allow for robust quantitative estimation of Beverly caribou numbers within the survey area east of the Inlet. There was one Beverly collared bull in the survey area east of the Inlet and one Beverly collared cow just north of it. The presence of abundant bulls, yearlings and non-breeding cows east of the Inlet indicated that many of the caribou there were part of the "trailing edge" of the Beverly herd moving eastward toward the main Beverly calving distribution in the Queen Maud Gulf lowlands. Some Beverly females also apparently calved in the study area east of the Inlet, given the overall numbers of cows with calves.

The mixing of Bathurst and Beverly caribou east of the Inlet leaves some uncertainty as to the numbers of Bathurst caribou east of the Inlet in June 2021, and likewise some uncertainty as to the overall numbers of breeding females and adult females in the Bathurst herd in June 2021.

There is also uncertainty as to the numbers of Bathurst bulls that may have switched herd ranges in 2021. Using the October 2020 sex ratio in the extrapolation from adult females to herd size implicitly assumes that an equal proportion of Bathurst bulls (as among cows) shifted to the Beverly distribution. However, the October 2020 sex ratio was estimated prior to the June 2021 emigration of collared Bathurst cows. It is possible that the extent of emigration documented in Bathurst cows in June-July 2021 was not matched by equivalent emigration of Bathurst bulls. A detailed analysis of bull fidelity and movements should be considered to test this assumption. These analyses further highlight the need for adequate sample sizes of collared cows and bulls in both the Beverly and Bathurst herds to better understand and estimate movements between the two herds. Annual targets for additional collars have been up to 70 (50 cows, 20 bulls) on the Bathurst herd and up to 50 (30 cows, 20 bulls) on the Beverly herd, as recommended by the WRRB in 2019. In practice, finding Bathurst cows and bulls to place collars on in March has been challenging due to their low numbers and extensive mixing with the much larger Beverly herd.

Further information on mixing of Bathurst and Beverly caribou herds is provided in Appendix 3, which shows the locations of Bathurst and Beverly collared cows and bulls at the time of the breeding season in October 2021, including the six Bathurst collared cows that moved east to the Beverly herd range in June-July. No clear pattern is apparent in October, as Bathurst and Beverly collared caribou (including those that switched ranges) were extensively mixed across their ranges. We also include a series of collar location maps for the Bathurst, Beverly and Bluenose-East herds from February 2021 to February 2022 in Appendix 4. Overall, mixing of Bathurst and Beverly collared caribou was greater in 2021-2022 than in any previous year. The Bathurst and Beverly collars were relatively separate in July 2021, but by August mixing had begun and continued through the fall rut into winter 2021-2022.

Confidence intervals around the estimates of breeding females, adult females and adult herd size for the Bathurst herd in June 2021 were relatively large, which suggests some uncertainty in these estimates. A portion of this high variance stems from uneven distribution of caribou in the Photo Core block west of the Inlet, with few caribou in the eastern portion of the block and most of the caribou near the western edge. Distribution of caribou in the visual blocks was also variable and uneven, and composition of caribou in the photo and visual blocks was variable. However, coverage of the Photo Core block was 46%, which should produce an accurate estimate of caribou in that block even if the precision was relatively low. High variability in numbers and composition of caribou among survey blocks likely added to the overall survey variance but appeared to reflect real biological variability.

Demographics, Trend and Indicators

The estimates of Bathurst breeding females, adult females, and herd size that included caribou west of the Inlet and estimated east of the Inlet were numerically lower (though not significantly so) than in 2018, however the rate of decline (about 3%/year) was substantially lower than observed between 2012 and 2018. A rate of decline in herd size of about 8%/year from 2018 to 2021 results if the west-only Bathurst caribou are considered, i.e., if assumed emigration of Bathurst caribou east of the Inlet is included. This is still a much lower rate of decline than the annual decline of about 25%/year between 2015 and 2018. We note that a portion of the decline between 2015 and 2018 resulted from emigration in June 2018: three of 11 known Bathurst collared cows (27.2%; albeit a limited collar sample) were found that year on the Beverly calving ground, and demographic modeling suggested that a loss of about 30% of the herd's cows to emigration in 2018 was consistent with the herd's demography (Adamczewski et al. 2019).

A number of demographic indicators suggest that the balance of deaths and recruitment of young in the Bathurst herd improved over the period 2018 to 2021 compared to 2015 to 2018. Population rate of change in caribou herds is very sensitive to adult cow survival rate, with values of 83-87% generally associated with stable herds (Crête et al. 1996, Haskell and Ballard 2007, Boulanger et al. 2011). Collar-based Bathurst cow survival estimates were 92% in 2018, 95% in 2019, and 87% in 2020, with a generally increasing trend from 2014 to 2020 (Figure 26a). IPM-based cow survival estimates were more modest but also showed an increasing trend 2018-2020 (see Figures 29 and 30) with estimated survival at 0.85 (CI=0.75-0.92) in 2020. Fecundity has been moderate to good based on June composition surveys (Figure 27) and IPM estimates (Figure 31). Calf survival as estimated from the IPM (Figure 31) suggested increased levels from 2018 to 2020 and fall calf:cow ratios from 2018 to 2020 were moderate to good (Figure 28). Further details on the demographic modeling, including the R code used, are in Appendix 5.

Recent bull:cow ratios in the herd suggested an increasing trend and the estimate for 2020 was the highest recorded since 2006 (Figure 28). A more detailed assessment of increased bull:cow ratios in the Bathurst and Bluenose-East herds is included in Appendix 6. Overall, these indicators are generally consistent with improving population demographics in the herd during the period 2018 to 2021 when compared to 2015 to 2018, excluding losses to emigration. Improved demographic indicators in the neighbouring Bluenose-East herd were associated with a stabilizing trend in that herd 2018 to 2021 (Boulanger et al. 2022) and were generally more positive than in the Bathurst herd.

Observations from the Tłı̨chǫ Government Ekwǫ̀ Nàxoèhdee K'è summer/fall monitoring of Bathurst caribou provide additional context on caribou condition, calf abundance, weather and habitat over the six years of the program (2016-2021; Figure 35; from GNWT and Tłı̨chǫ Government 2022). This ground-based monitoring has been carried out near Contwoyto Lake in the center of the Bathurst herd's summer range from July into September (see Jacobsen and Santomauro 2017).

Indicators Over Time

	2016	2017	2018	2019	2020	2021
Weather and Vegetation	Warm, Dry	Mix Dry/Wet	Wet, Windy	Wet, Windy	Wet, Windy	Cool, Windy
Caribou Health	Normal, Many Injured	Normal	Early Fat, Bulls Healthy	Early Fat, Bulls Healthy	Healthy, Fat Animals	Healthy, Fat Animals
Calf Abundance	Normal, High	Normal, High	Normal, Low	Low	Low	Low
Wolves Observed	1	18	16	31	0	13

Figure 35. Summary table of Ekwǫ̀ Nàxoèhdee K'è Bathurst caribou monitoring observations near Contwoyto Lake 2016-2021 (from GNWT and Tłı̨chǫ Government 2022, with permission).

Among the trends reported by Tłı̨chǫ observers, the summer weather on the Bathurst range shifted from warm and dry in 2016 to wet, windy and cool conditions more recently, which meant limited insect harassment and good feeding conditions for caribou. Caribou observed in 2018, 2019, 2020 and 2021 were generally healthy and fat, with bulls building fat reserves in July. However, calf abundance was relatively low in the summers of 2019, 2020 and 2021; the calf:cow ratios reported for these three years in mid-late summer from the Ekwǫ̀ Nàxoèhdee K'è program were 31, 29, and 39.2 calves:100 cows (GNWT and Tłı̨chǫ Government 2022). The relatively low calf:cow ratios reported in these three summers by Tłı̨chǫ observers may be indicative of relatively low summer calf survival in the Bathurst herd.

Results from the June 2021 Bathurst calving ground composition survey suggest that a significant portion of the early calf mortality in the Bathurst herd occurred in the first week: the calf:cow ratio in the Photo Core block for breeding cows was 62 calves:100 cows June 11-14, just a week after the estimated peak of calving of June 3-6. This would suggest that about 38 of 100 pregnant Bathurst cows might have already lost their calves 7-10 days after calving. By contrast, the calf:cow ratios for breeding cows for the Photo North and Photo South survey blocks in the Bluenose-East composition survey were 93 and 90 calves:100 cows, respectively, over the same period of June 11-15 (Boulanger et al. 2022). The peak of calving estimated for the Bluenose-East herd (June 6-9) was slightly later than for the Bathurst herd (June 3-6), which could have affected these calf:cow ratios (more days between peak of calving and composition survey calf:cow ratio for Bathurst than Bluenose-East). Nonetheless, this comparison does suggest that early calf mortality has been more of an issue for the Bathurst herd in recent years than for the Bluenose-East herd.

Incidental sightings of other wildlife species recorded during the visual and composition surveys of the Bathurst June 2021 calving ground are included in Appendix 7. There were nine grizzly bears and two wolves sighted during the composition survey, recognizing that sighting rates from caribou surveys of relatively rare species like wolves and grizzly bears are highly variable. This continues a trend of grizzly bear sightings outnumbering wolf sightings on the Bathurst calving ground surveys (Adamczewski et al. 2019) as well as the Bluenose-East calving ground surveys (Boulanger et al. 2019, 2022).

Apparent Emigration and Mixing with the Beverly Herd

The apparent emigration of six of 34 known Bathurst collared cows (17.6%) to the Beverly calving and post-calving distribution in June and July 2021 continued a trend from 2018 (three of 11, 27.3%) and 2019 (three of 17, 17.6%) of similar unidirectional movements from the Bathurst calving range to the Beverly calving range. There were no Beverly-to-Bathurst collared cow switches during these years. Prior to 2018, fidelity of Bathurst collared cows to their calving ground was about 98% from 2010 to 2018 (Adamczewski et al. 2019), and 97% up to 2009 (Adamczewski et al. 2020) with occasional switches to and from the two neighbouring herds' calving grounds. Similar estimates of collared cow fidelity were found for the Tuktoyaktuk Peninsula, Cape Bathurst, Bluenose-West and Bluenose-East herds (Davison et al. 2014). In the winters before each of the Bathurst emigration events (2017-2018, 2018-2019, and 2020-2021), mixing of Bathurst and Beverly collared caribou was extensive (Figures 33 and 34), with the Beverly caribou outnumbering the Bathurst by at least 12:1 based on 2018 population estimates for the two herds (Adamczewski et al. 2019, Campbell et al. 2019). These conditions may have facilitated the spring movements of small numbers of Bathurst caribou in the company of much larger numbers of Beverly caribou to the Beverly herd's calving grounds in the Queen Maud Gulf lowlands.

As described by Gunn et al. (2012), gregariousness of female caribou during calving is a strategy for reducing predation risk and is a principal reason for high densities of breeding females on a calving ground (Heard et al. 1996). For the Porcupine herd, Griffith et al. (2002) demonstrated that newborn calves on the interior of large calving aggregations on the calving ground had higher survival rates than calves on the periphery of these aggregations. However, as a population of migratory barren-ground caribou declines below a small threshold size, spatial fidelity to a calving area may start to break down, resulting in a partial or complete shift in use of a calving area (Gunn et al. 2012). High spatial overlap on the winter range with a larger herd, as in the Bathurst herd's recent substantial overlap with the much larger Beverly herd, may act as a factor predisposing a smaller declining herd to joining a much larger herd. Bathurst-Beverly overlap was much more limited in winter 2019-2020 (see Figures 33 and 34) than in 2018, 2019 and 2021 and no collar-based Bathurst emigration was found in June 2020.

Shifting of a portion of Bathurst cows to the Beverly calving and post-calving distribution may have adaptive value in terms of cows giving birth on a calving ground with larger numbers of calving cows, reducing predation risk and increasing survival rates both for the cows and their newborn calves. This adaptive advantage could extend into other times of year. However, those advantages could be offset by "switchers" having to adapt to less familiar environments. Assessing cow survival rates is possible with an adequate number of collared cows (see Adamczewski and Boulanger 2016 for details) and can also be assessed through demographic modeling. For the Bathurst herd, collar-based cow survival rates between 2018 and 2020 were high (Figure 26) and the demographic model also suggested an increasing recent trend in cow survival (Figure 30). A summary of fates of collared Bathurst cows that switched to the Beverly distribution in 2018 (3), 2019 (3) and 2021 (6) is provided in Appendix 8; however, the limited numbers of collared cows and the limited length of collar life for these few individuals do not allow for an assessment of survival rates in Bathurst cows that switched to the Beverly distribution.

While we recognize there are conflicting views as to the fate of the inland-calving Beverly herd between 2006 and 2010 (Nagy et al. 2011, Adamczewski et al. 2015), the recent emigration from the Bathurst herd to the Beverly herd (defined as calving in the central and eastern Queen Maud Gulf lowlands) has several parallels to the switching of low numbers of inland-calving Beverly caribou to the coastal Queen Maud Gulf calving ground used by much larger numbers of Ahiak caribou between 2006 and 2010 (Adamczewski et al. 2015). With the improving internal demographics of the Bathurst herd 2018-2021, emigration is an important factor that needs to be monitored to assess its impact on the size and persistence of the Bathurst herd as a distinct population on the landscape.

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

necessary in 2021 and we look forward to having full participation of Nunavut observers and Government of Nunavut staff in future surveys.

Figure 36. Cessna Caravan C-GZIZ survey crew (left to right): Dylan Reid (pilot), Jan Adamczewski, Robin Abernethy, Judy Williams, Peter Crookedhand, Aimée Guile, Karin Clark and Earl Evans.

Figure 37. Cessna Caravan C-GDLC survey crew (left to right): Stefan Goodman, Roy Judas, Randi Jennings, Dean Cluff, Kevin Chan, Jess Hurtubise and Fred Martin (pilot).

Figure 38. Acasta Heliflight C-FGSC survey crew: Geoff Furniss (pilot), Judy Williams and Stefan Goodman.

Figure 39. Great Slave Helicopters C-FYZF survey crew: Tom Frith (pilot), Jan Adamczewski and Dean Cluff.

Figure 40. Irene and Kerry Horn, owners of the Coppermine Inn and our hosts in Kugluktuk. They celebrated their 50th wedding anniversary in June 2021.

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

Introduction

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

Methods

The double observer method involves one primary observer who sits in the front seat of the plane and a secondary observer who sits behind the primary observer on the same side of the plane (Figure 41). The method followed five basic steps:

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

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

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

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

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

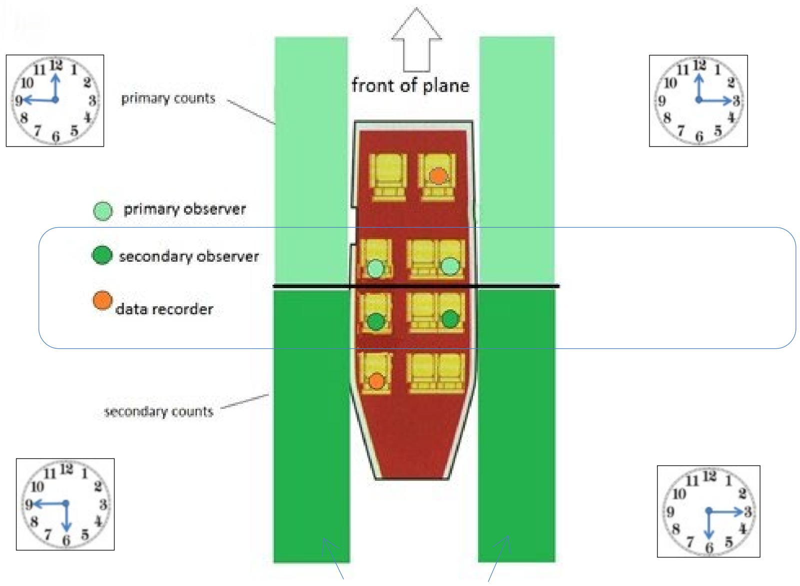

Figure 41. Observer and recorder positions for double observer methods on June 2021 caribou surveys of Bathurst and Bluenose-East caribou. The secondary observer confirmed or called caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can be used to reference relative locations of caribou groups (e.g. “caribou group at 1 o’clock”). The recorder was seated behind the two observers on the left side, or with the pilot in the front seat. On the right side the recorder was seated at the front of the aircraft and was also responsible for navigating in partnership with the pilot.

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

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

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

One assumption of the double observer method is that each caribou group seen has an equal probability of being sighted. To account for differences in sightability the covariates listed in Table 21 were also considered in the analysis. Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. An observer order covariate was modeled to account for variation caused by observers switching order. If sighting probabilities were equal between the two observers, it would be expected that order of observers would not matter and therefore the confidence limits for this covariate would overlap 0. This covariate was modeled using an incremental process in which all observer pairs were tested followed by a reduced model where only the beta parameters whose confidence limits did not overlap 0, were retained. Snow and cloud cover were modeled as a continuous (snow or cloud) or categorical covariate (snow_factor or cloud_factor) based on the categorical entries in the tablets.

Table 21. Covariates used to model variation in sightability for double observer analysis for Bathurst and Bluenose-East caribou surveys in June 2021.

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

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

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

Estimates of herd size and associated variance were estimated using the mark-recapture distance sampling (MRDS) package (Laake et al. 2012) in program R program (R Development Core Team 2009). In MRDS, a full independence removal estimator which models sightability using only double observer information (Laake et al. 2008a, b) was used. This made it possible to derive double observer strip transect estimates. Strata-specific variance estimates were calculated using the formulas of (Innes et al. 2002). SEs 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 2015, 2020).

Results

Unlike previous surveys there was no reconnaissance survey in 2021 for either herd, therefore only data from the visual surveys were used in the analysis. Observers were grouped into pairs which were used for modeling the effect of observer on sightability. The relatively small size of the crews resulted in four primary pairs of observers, all of whom switched places during the survey (Table 22). The probabilities of sighting (1-secondary/total sightings) were remarkably similar between pairs, compared to previous years (Figure 42).

Table 22. Double observer pairings with associated summary statistics. Single observer probabilities are estimated as (1-secondary/total sightings) and double observer probabilities are estimates as 1-(1-single p)^2.

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

Frequencies of observations as a function of group size, survey, and phase suggested that approximately 70% of the single caribou were seen by both observers in most cases (Figure 42). As group size increased the proportion of observations seen by both observers increased.

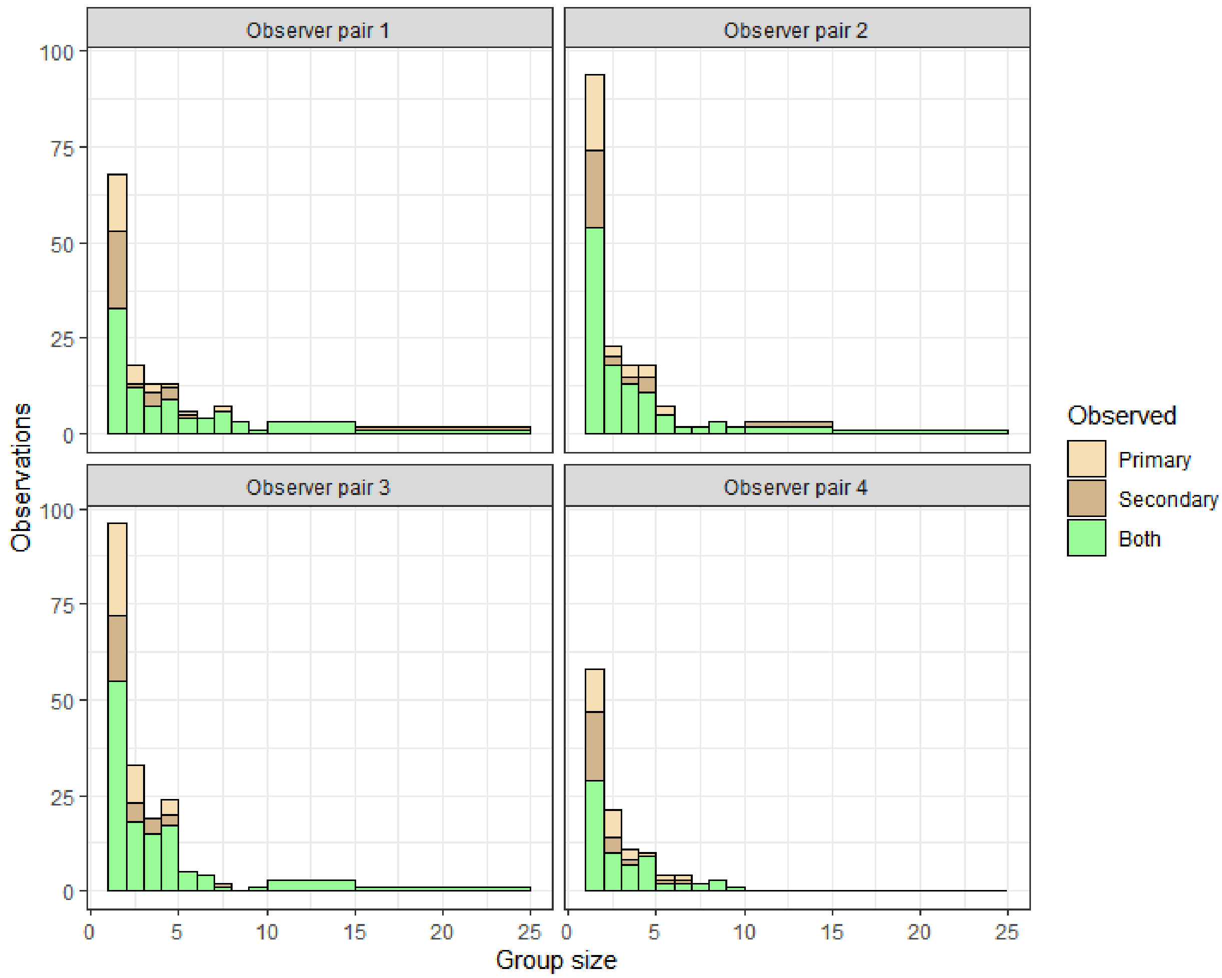

Figure 42. Frequencies of double observer observations by group size, survey phase and survey for Bluenose-East and Bathurst 2021 calving ground surveys. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

The percentage of snow observed during surveys ranged between 25 and 75% with a suggestion of lower sightability at higher snow levels, as determined by the relative proportion of groups seen by both observers for each binned category (Figure 43). We note that the tablet computers limited snow cover categories to 0, 25, 50, 75 or 100%, whereas actual snow cover ranged from 1-5% to 95% (Figure 43).

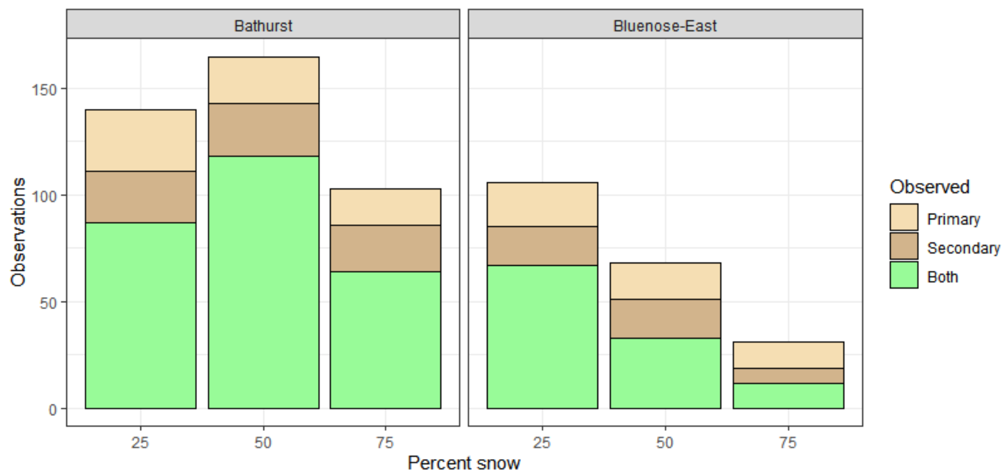

Figure 43. Percentage snow cover on Bathurst and Bluenose-East calving grounds during visual survey flying June 8-11, 2021.

Cloud cover ranged from 0 to 75% with a small amount of 100% cloud cover on the Bluenose-East calving ground (Figure 44). There was minimal suggestion of cloud cover affecting sightability. We note that the tablet entries limited cloud cover categories to 1, 25, 50, 75, and 100%, whereas actual cloud cover included finer-scale categories.

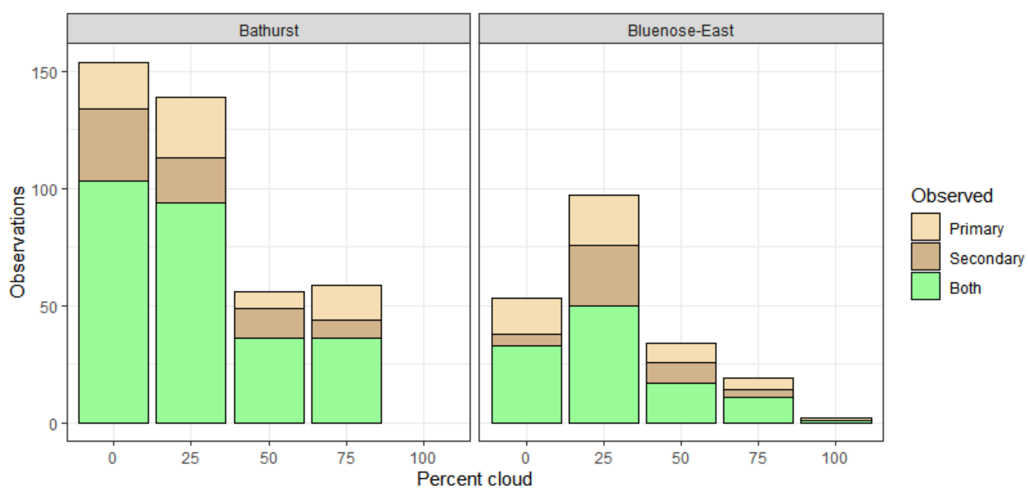

Figure 44. Percentage cloud cover over Bathurst and Bluenose-East calving grounds June 8-11, 2021 during visual survey flying.

Model selection identified a strong effect of the log of group size with less influence of other covariates (Model 1: Table 23). The effect of snow as an additive effect to the log of group size also had some support as indicated by a ΔAIC_c of 0.86. The effect of herd (calving ground) was weak (model 3). The interaction of herd (calving ground) and snow cover was also tested (models 4 and 5) with lower support. Other factor such as observers (model 23), cloud cover (models 6, 9, 11) and the interaction of cloud and snow cover (model 8) showed little support. Consistency of observations among observers was suggested by similarity of detection probabilities for observer pairs (Table 22) and similarity of double observer sighting probabilities (Figure 45).

Plots of single and double observation probabilities from model 2 showed lower probabilities for individual or smaller group sizes, especially in higher snow cover (Figure 45). Detection probabilities for both observers combined are above 0.9 for all group sizes. The mean detection probability (across all groups) was 0.78 (CI=0.76-0.80) for 2021 compared to 0.66 (CI=0.60-0.72) and 0.91 (CI=0.88-0.92) for the 2018 and 2015 Bluenose-East and Bathurst calving ground surveys.

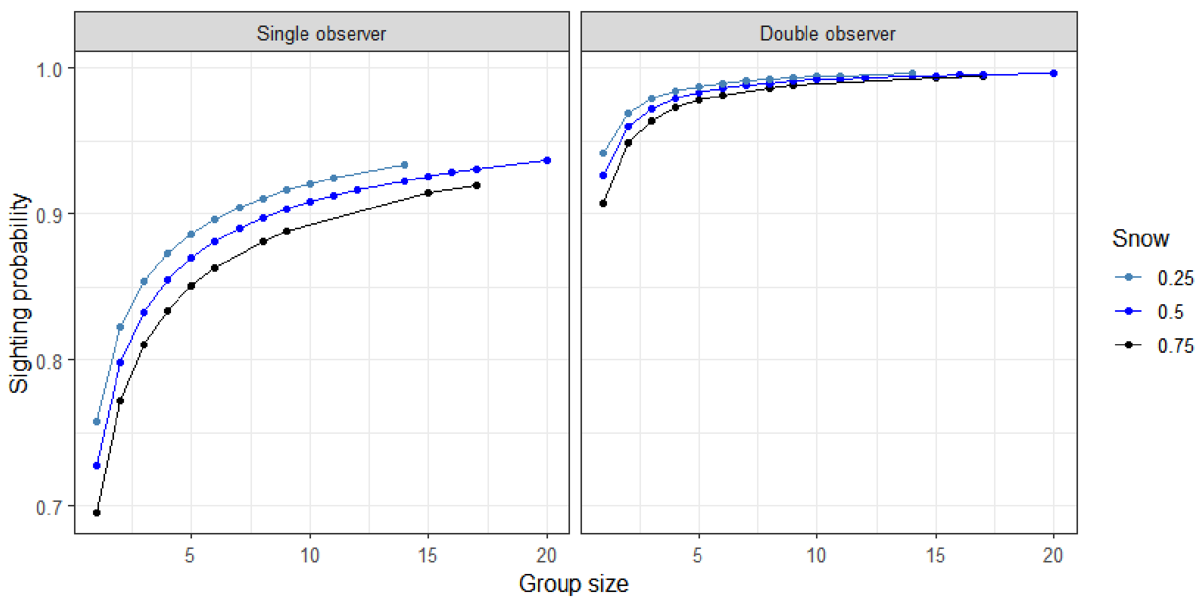

Figure 45. Estimated double observer probabilities from model 2 (Table 23) by snow cover, from Bathurst and Bluenose-East calving ground survey flying June 8-11, 2021.

Estimates from model 1 (Table 23; sighting probabilities influenced by the log of group size) were used for abundance estimates. Estimates from model 2 (logsize and snow) which displayed lower support were very close (9,557 compared to 9,449) suggesting minimal change in estimates due to inclusion of snow as a covariate (Table 24). Double observer estimates (using the MRDS R package) were 2.4 % higher than the uncorrected standard strip transect estimates. Precision for the double observer estimate was higher which was due to the use of the S2 variance estimator that takes into account similarity in distributions of caribou on adjacent transects (Fewster 2011). If the non-systematic variance estimator is used (as is for the standard strip transect estimator) then the CV increases to 9.4% which is higher than the standard strip transect estimator. Overall precision of the estimates was good with a CV of 7.1%.

Table 23. Double observer model selection using Huggins mark-recapture models in program MARK for Bluenose-East and Bathurst June 2021 caribou surveys. Covariates follow Table 1 in the methods section of the report. AIC_c, the difference in AIC_c values between the *i*th and most supported model 1 (ΔAIC_c), Akaike weights (w_i), and number of parameters (*K*), and deviance (Dev) are presented.

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

Table 24. Estimates of caribou in visual survey strata from double observer (model 1, Table 23) and strip transect estimates for the Bathurst herd, June 2021. Note this includes all caribou in the survey area, including Beverly caribou east of the Inlet. N = estimate; SE = standard error; 95% CI = 95% confidence interval; CV = coefficient of variation.

Stratum	Caribou seen	Corrected double observer estimates					Uncorrected transect estimates (as recorded in field)		
		N	SE	95% CI		CV	N	SE	CV
Vis1	55	356	95.6	181	702	26.8%	351	91.3	26.0%
Vis2	162	1,195	319.5	652	2,190	26.7%	1,173	449.6	38.3%
Vis3	32	202	57.6	107	380	28.5%	198	91.7	46.3%
Vis4	437	3,024	306.3	2,407	3,800	10.1%	2,950	459.4	15.6%
Vis5	164	1,168	264.7	688	1,982	22.7%	1,134	287.0	25.3%
Vis6	77	556	123.2	336	921	22.1%	542	114.8	21.2%
Vis7	48	382	217.6	98	1,492	56.9%	372	174.3	46.8%
Vis8	132	655	217.2	311	1,379	33.1%	641	167.2	26.1%
Vis9	276	2,011	256.1	1,501	2,693	12.7%	1,963	286.7	14.6%
Total	1,383	9,549	675.3	8,285	11,005	7.1%	9,323	816.1	8.8%

The total number of caribou at least one year old in the four Visual Blocks west of the Inlet was estimated at 2,408, while the total estimated east of the Inlet was about three times as large at 7,141 (Table 25). Visual Stratum 7 at the south end of Bathurst Inlet is included as east of the Inlet.

Table 25. Estimates of caribou (at least one year old) in visual survey strata from double observer-corrected estimates for the Bathurst herd, June 2021, west and east of Bathurst Inlet. Note this includes all caribou in the survey area, including Beverly caribou east of the Inlet. N = estimate; SE = standard error; 95% CI = 95% confidence interval; CV = coefficient of variation

Stratum	**Caribou counted**	**N**	**SE**	**95% CI**		**CV**
West of Bathurst Inlet						
Vis1	55	356	95.6	181	702	26.8%
Vis2	162	1,195	319.5	652	2,190	26.7%
Vis3	32	202	57.6	107	380	28.5%
Vis8	132	655	217.2	311	1,379	33.1%
	381	2,408	402.2	1,695	3,421	16.7%
East of Bathurst Inlet						
Vis4	437	3,024	306.3	2,407	3,800	10.1%
Vis5	164	1,168	264.7	688	1,982	22.7%
Vis6	77	556	123.2	336	921	22.1%
Vis7	48	382	217.6	98	1,492	56.9%
Vis9	276	2,011	256.1	1,501	2,693	12.7%
	1,002	7,141	541.6	6,120	8,332	7.6%

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

As with the June 2018 Bathurst calving ground photo survey (Adamczewski et al. 2019), we subsampled approximately 200 aerial photos to assess the accuracy of caribou counts on the photos. This analysis was carried out due to the variable and often patchy snow cover during the survey, which made caribou more difficult to identify.

To do this required a systematic sample of ground conditions and photos. Of most interest for the analysis were photos that had caribou on them, since these could be used in the analysis; however, it was also important to subsample photos that did not have caribou detected on them. The full photo data set contained 2,963 photos of which 2,365 had no caribou detected on them (80%).

Using total km of transect as a guide, we overlaid a grid with 5 km spacing to systematically sample approximately 200 photos from the two photo blocks. The initial grid is shown for the Photo Core block in Figure 46. This grid intersected 238 photos. Of these photos, 180 of the 238 had no caribou.

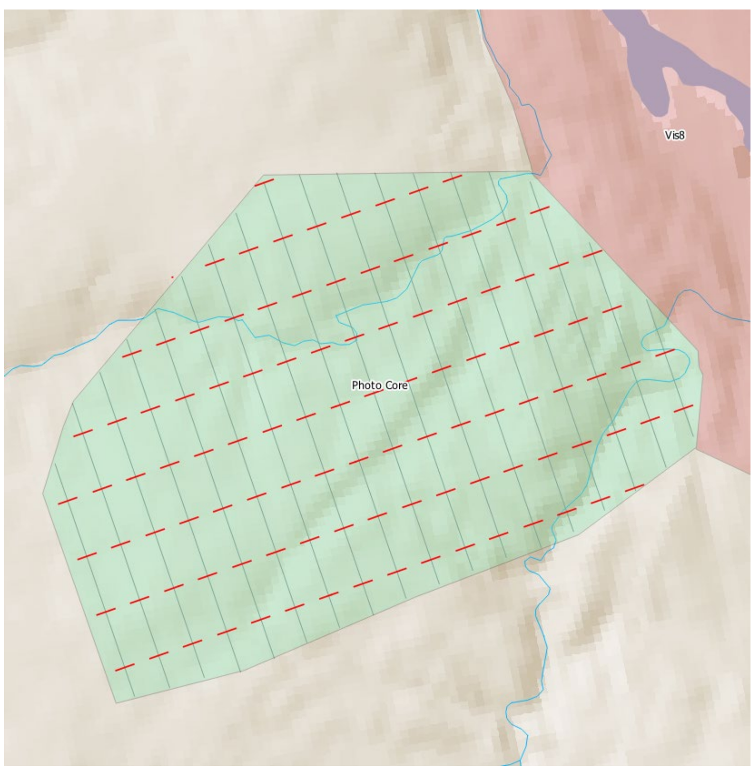

Figure 46. Initial Bathurst photo subsample layout for Photo Core survey block from the June 2021 Bathurst caribou survey.

To increase the number of photos with caribou, we then employed a sampling system where the nearest photo that had a caribou that was less than half the spacing between grid points (<2.5 km) was chosen if the systematic grid cell had no caribou detected. If no cells had caribou within 2.5 km then the cell with 0 caribou was chosen. This resulted in 48 of 207 cells having no caribou (23%) ensuring that 159 cells with at least one caribou were available for the cross-validation analysis. Figure 47 shows the counts of caribou from the 107 photos in the Photo Core block. Most caribou were in the western part of the block and numbers in the eastern part were generally low. Figure 48 shows the counts of caribou from the counts of caribou from 100 photos in the Photo East block. Caribou were more evenly distributed in this stratum.

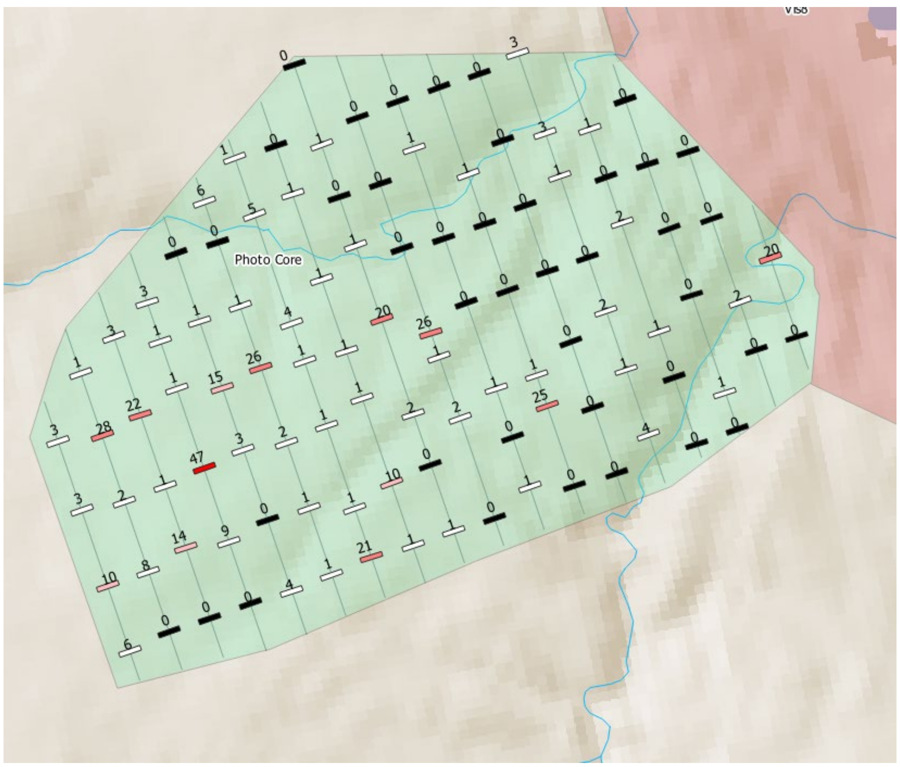

Figure 47. Grid of 107 aerial photos chosen for a second count from the Photo Core block of the Bathurst June 2021 survey. Dark bars show photos with no caribou found, white bars had low numbers of caribou and red bars had higher numbers of caribou.

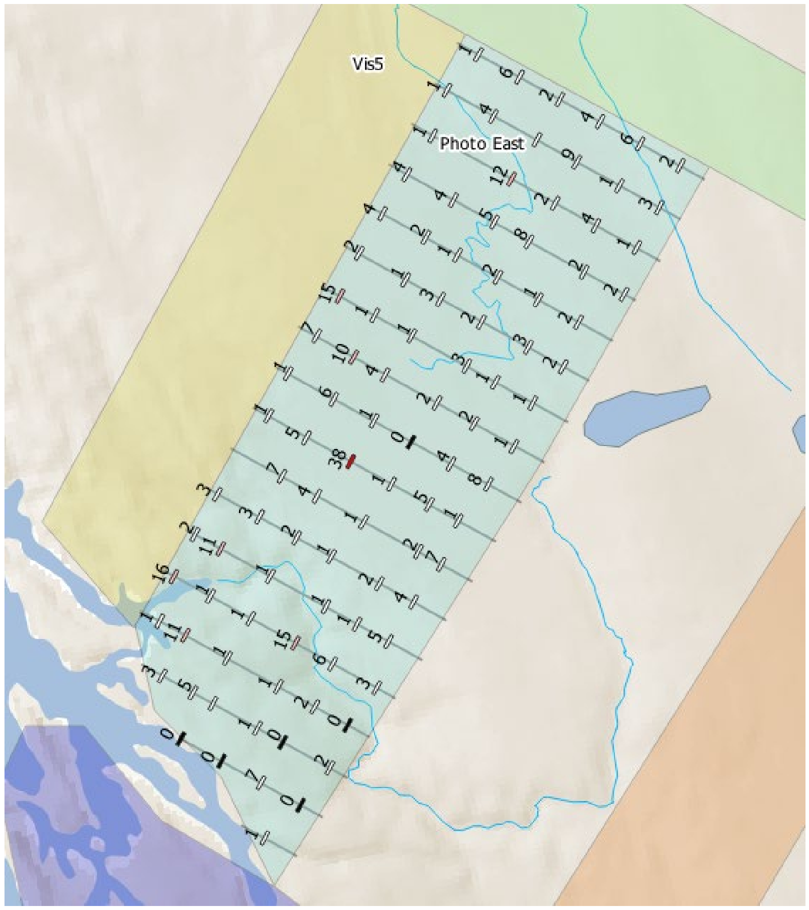

Figure 48. Grid of 100 aerial photos chosen for a second count from the Photo East block of the Bathurst 2021 calving ground survey. Dark bars show photos with no caribou found, white bars had low numbers of caribou and pink/red bars had higher numbers of caribou.

Counts of caribou by observers 1 and 2 on these 207 aerial photos are shown in Table 26. Detection rates were 0.93 in the Photo Block and 0.97 in the Photo East block, for a combined detection rate of 0.96. Bootstrapping was used to obtain a SE for the observed estimates (0.96) of 0.0117 with a 95% confidence interval (CI) of 0.93-0.98. The binomial based estimate of SE was 0.007. Dividing these two estimates gave an estimate of over dispersion of counts of 1.54. This c-hat value was then used in Mark analysis. Mark analysis suggested different detection by strata for the initial observer 1 with similar sighting for the 2nd observer (Table 27).

Table 26. First and second observer counts and detection rates (sightability) of caribou at least one year old in the Photo Core and Photo East blocks from the Bathurst 2021 calving ground survey, from a subsample of 207 photos.

Stratum	Observer counts			Detection rates
	Observer 1	Observer 2	Total caribou	
Photo Core	396	423	424	0.934
Photo East	376	385	388	0.969
Total	772	808	352	0.96 (combined)

Table 27. MARK closed model selection for photo cross-validation from Bathurst 2021 calving photo survey.

Model	QAICc	Delta QAICc	QAICc Weights	Num. Par	QDeviance
Observer 1 X stratum	243.55	0.00	0.50	3.00	5325.99
Observers (1,2) X stratum	244.80	1.25	0.27	4.00	5325.23
Observers	245.14	1.59	0.23	2.00	5329.58
All equal	265.48	21.93	0.00	1.00	5351.93

The resulting estimates of photo sightability are given below from the MARK analysis (Table 28).

Table 28. Estimates of photo sightability (detection rate) used to correct counts on subsample of aerial photos from 2021 Bathurst calving ground survey. SE = standard error; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval.

Stratum	Sightability	SE	CIL	CIU
Photo Core	0.934	0.015	0.898	0.958
Photo East	0.969	0.011	0.939	0.984

Estimates of caribou at least one year old from photo strata were adjusted by dividing the strip-transect estimate by photo sightability (detection rate) for each stratum (Table 29). The net effect was an increase of 3.2 % from 6,583 caribou estimated from the initial counts to 6,794 caribou estimated with the double observer correction.

Table 29. Initial uncorrected estimates and corrected estimates of caribou at least one year old in the Photo Core and Photo East blocks of the Bathurst 2021 calving ground survey. Corrections were based on the detection rates in Table 3. N = estimated number; SE = standard error; P = probability of detection; CIL = lower 95% confidence interval; CIU = 95% upper confidence interval; CV = coefficient of variation.

Stratum	Strip-transect estimates of Numbers (uncorrected)			Detection Rate			Corrected estimates of Numbers				
	N	SE	CV	p	SE	CV	N	SE	CIL	CIU	CV
Photo Core	3426.6	824.0	0.240	0.934	0.015	0.016	3670	884.5	2223	6059	0.241
Photo East	6582.8	700.4	0.106	0.969	0.011	0.011	6794	726.9	5425	8509	0.107

Appendix 3. Schematics of Bathurst and Beverly Collared Caribou Locations in Fall 2021

In June 2021, six of 34 known Bathurst female collared caribou were found east of Bathurst Inlet. Two of these were east of the survey area on June 10 and were assumed to be emigrants to the Beverly herd's calving distribution. The other four were within the survey area east of Bathurst Inlet, then in late June moved further eastward to the Beverly calving distribution (Figures 12, 13). In recent years, collared bulls have usually been assigned to a herd in July as bulls from different herds appear to be most separate at that time. Mixing of Bathurst and Beverly collared caribou was extensive in late summer and into the fall breeding season 2021, as shown in Appendix 4.

At the time of the fall breeding season in late October 2021, all Bathurst collared cows and bulls were mixed with Beverly collars (Figure 49).

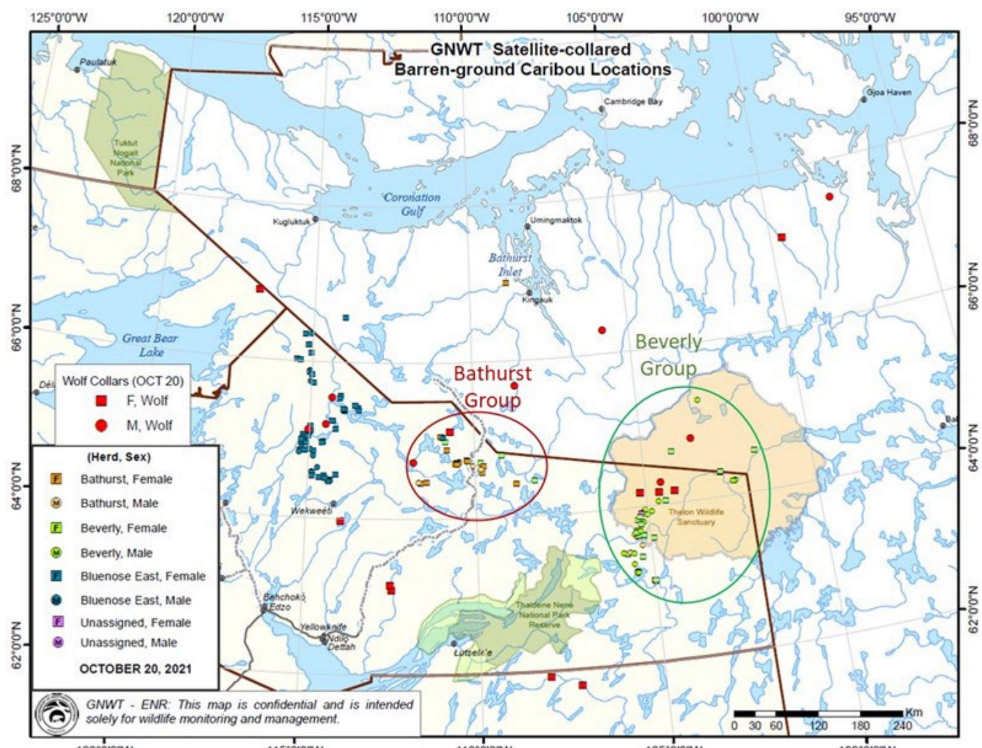

Figure 49. Locations of Bluenose-East, Bathurst and Beverly collared caribou on October 20, 2021. Most of the Bathurst collared caribou were in the western Bathurst group, and most of the Beverly collars were in the eastern Beverly group.

Most of the Beverly collars were mixed with a few Bathurst collars in an eastern group, and most of the Bathurst collars were in a western group with a few Beverly collars. Schematics of the collared Bathurst and Beverly collars with their June/July history are shown in Figures 50-53 below. The extent of mixing of Bathurst and Beverly collared caribou in

2021-2022 was greater than in any previous years. In the fall of 2020 during the breeding season, most Bathurst collared caribou were in a single cluster with no other collared caribou nearby, although about ¼ of the Bathurst collared caribou were mixed with Beverly collars further to the east. The locations of the Bathurst-Beverly "switchers" do not show any clearly defined trends.

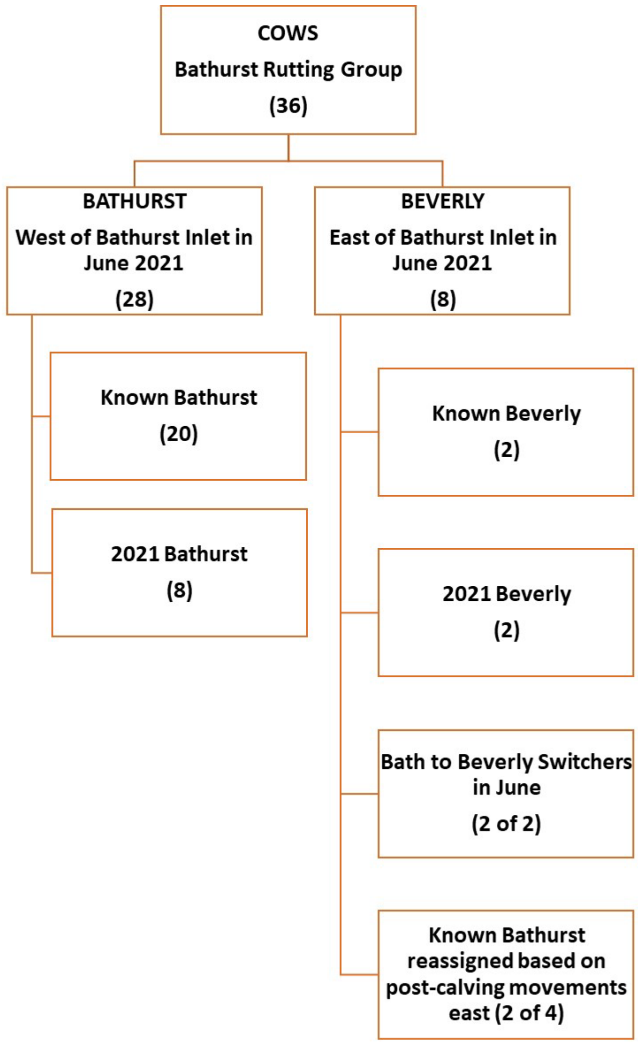

Figure 50. Collared Bathurst and Beverly caribou females in the (western) Bathurst rutting group in October 2021. They are identified as categories of caribou based on their locations in June/July 2021 during and after the surveys.

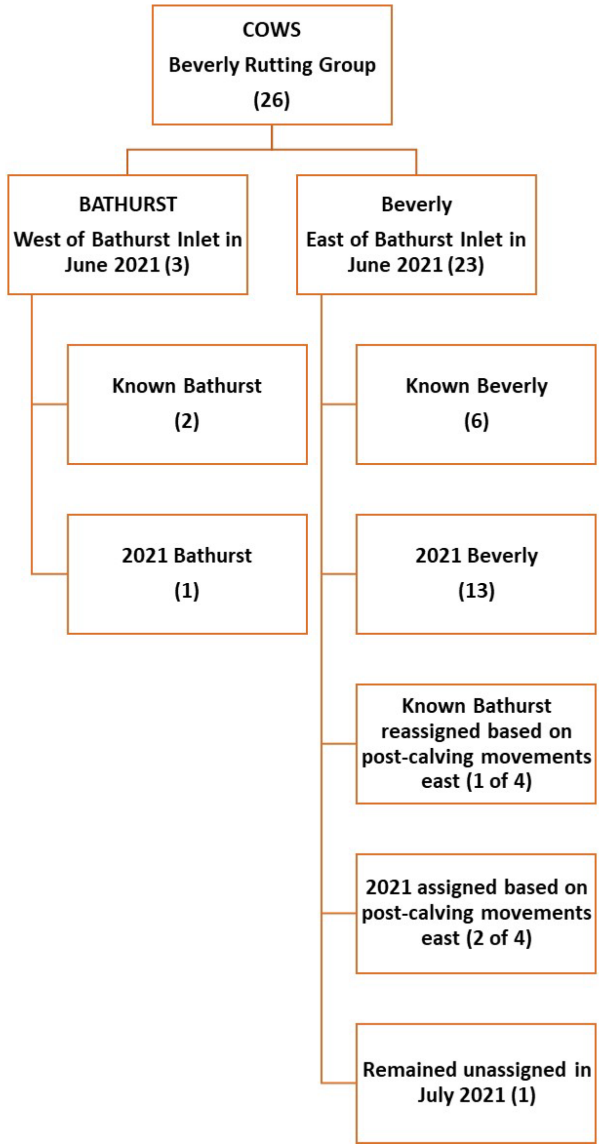

Figure 51. Collared Bathurst and Beverly caribou females in the (eastern) Beverly rutting group in October 2021. They are identified as categories of caribou based on their locations in June/July 2021 during and after the surveys.

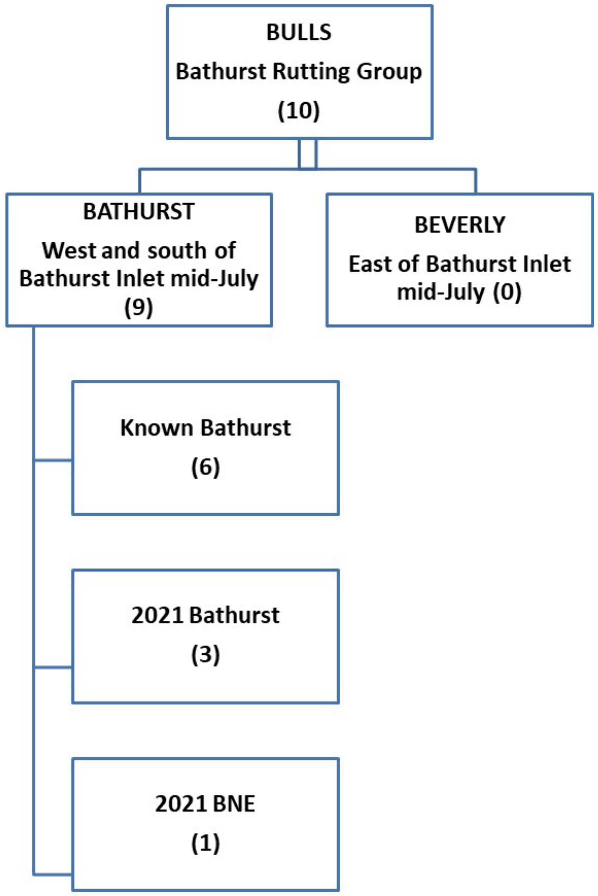

Figure 52. Collared Bathurst and Beverly caribou males in the (western) Bathurst rutting group in October 2021. They are identified as categories of caribou based on their locations in July 2021.

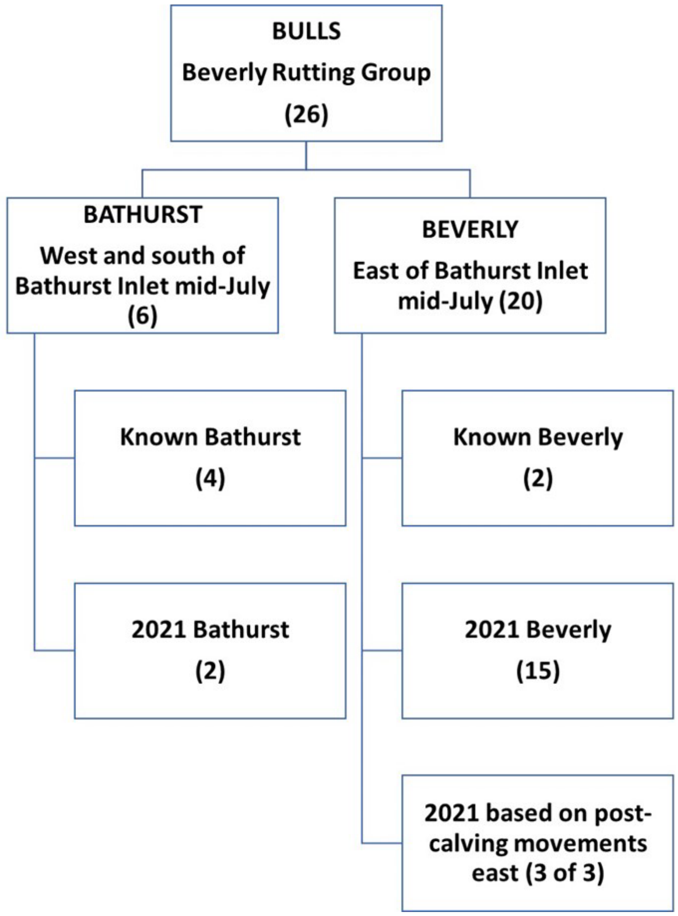

Figure 53. Collared Bathurst and Beverly caribou males in the (eastern) Beverly rutting group in October 2021. They are identified as categories of caribou based on their locations in July 2021.

Appendix 4. Locations and Movements of Bathurst, Beverly and Bluenose-East Collared Caribou February 2021 to February 2022

Movements of collared Bathurst and Beverly caribou showed a high degree of mixing in the winter of 2020-2021 and some continued mixing into and after the calving period in June of 2021 (Figures 12, 13). Mixing was also evident in the late summer of 2021 and by the time of the fall rut in October, mixing of Bathurst and Beverly caribou was extensive. In this appendix, a series of maps is included that begin on February 15, 2021 and continue until February 15, 2022, to provide a spatial context for the degree of herd mixing and seasonal movements. The maps include Bathurst, Bluenose-East and Beverly collared caribou, as there was some mixing of all three herds during the winters of 2020-2021 and 2021-2022 (Figures 54-67).

We note that the maps from February 15 to June 15, 2021 include the known collared caribou, not the caribou newly collared in March 2021. In this context, "known" means that their locations and herd affiliations in June or July 2020 were known. The newly collared caribou were considered as unassigned until calving in June for females and July for males. The degree of herd mixing in the winter of 2020-2021 meant that there was substantial uncertainty as to the herd affiliation of many of the newly collared caribou. The newly collared caribou are first shown on a separate map (Figure 60) for July 15, 2021 while the caribou collared in 2020 or earlier (known) are shown in Figure 59 for the same date. Beginning with the August 15, 2021 map (Figure 61), all the collared caribou are shown on the same maps. On the June 15, 2021 map, six known collared Bathurst cows that were east of the Inlet and then moved further east toward the Beverly calving distribution are shown in a distinct colour (violet) in Figure 58; thereafter, those six collared caribou are shown as Beverly collars, having been re-assigned in July 2021.

The first maps from February 15 and March 15, 2021 (Figures 54, 55) demonstrate the degree of herd mixing in the winter of 2020-2021. Bathurst and Beverly collars were extensively mixed through the winter of 2020-2021. At the western end of their distribution, some Bathurst collars were mixed with Bluenose-East collars. The Beverly collars were extensively mixed with Bathurst collars and there were a few Beverly collars mixed with Bluenose-East collars. About half the Bluenose-East collars were on their own in an area east and southeast of Great Bear Lake. Mixing of Bathurst and Beverly collared caribou had been common in preceding winters, but mixing of Beverly collared caribou with Bluenose-East collared caribou had not been seen prior to 2020-2021.

By April 15, 2021, there was movement northeast of most Beverly and Bathurst cow collars; six Beverly cow collars and one Bathurst collar were nearing the south end of Bathurst Inlet (Figure 56). A few Bluenose-East collars that were mixed with Bathurst and

Beverly collars also showed some northeast movement, while the Bluenose-East collars that were not mixed with Bathurst or Beverly collars showed little movement. By May 15, 2021, nearly all the cow collars were moving northward (Figure 57). Many of the Bathurst cow collars were already on site in the area west of Bathurst Inlet where the herd has calved since 1996. Most of the Beverly cow collars were east or south of Bathurst Inlet, along with a few Bathurst collared cows. There was some northward movement of collared bulls from the three herds, but their movements generally lagged well behind the collared cows.

On June 15, 2021, just after the end of the Bathurst and Bluenose-East calving ground surveys, most of the Bathurst cows were west of Bathurst Inlet in the main calving area (Figure 58). Most of the Bathurst bull collars were south and west in the Contwoyto Lake area. The distribution of Beverly collared cows extended from just east of Bathurst Inlet to the eastern Queen Maud Gulf lowlands, with most Beverly bulls to the south and moving eastward. The Bluenose-East collared cows were on the main calving ground survey area, with most of the bulls south and east on the east side of the Coppermine River.

The July 15, 2021 map (Figure 59) shows the greatest overall separation of the Bathurst, Bluenose-East and Beverly herds in 2020-2021, with tight clustering of Bluenose-East collared caribou possibly suggesting post-calving aggregation. By August 15, 2021, the Bluenose-East collars remained separate from the other two herds with the exception of two bull collars (Figure 61). Most of the Beverly collars had moved west toward the main traditional Bathurst summer range near Contwoyto Lake and mixing of Bathurst and Beverly collars had begun.

By mid-September 2021 (Figure 62), all three herds had moved southward and mixing of Bathurst and Beverly collars increased. The Bluenose-East collars were relatively separate and there were two main clusters of collared Bathurst and Beverly caribou, with most of the Bathurst collars and a few Beverly collars in a western cluster and most of the Beverly collars and a few Bathurst collars in an eastern cluster in or near the Thelon Wildlife Sanctuary. By October 15, 2021, just before the estimated peak of the breeding season, most of the Bluenose-East collars were moving south and distributed north of Wekweètì, and the two clusters of mostly Bathurst collars and mostly Beverly collars were moving southward (Figure 63). In mid-November, the main cluster of Bluenose-East collars near Wekweètì overlapped with a cluster of most of the Bathurst collars mixed with some Beverly collars, while the main cluster of Beverly collars had moved west and south into the Thaidene Nëné area (Figure 64).

In December 2021 and January 2022, the main Bluenose-East and Bathurst collar distributions were relatively continuous with an area of overlap and some Beverly collars mixed in; there was a wider distribution of Beverly collars to the east, with a few Bathurst collars mixed in (Figures 65, 66). The Beverly collars showed a substantial degree of movement in December and January, first east and then west, at a time when barren-ground caribou normally have settled into their mid-winter distributions and show limited directional movement. In the last of this map series, February 15, 2022, distribution had changed relatively little from January (Figure 67).

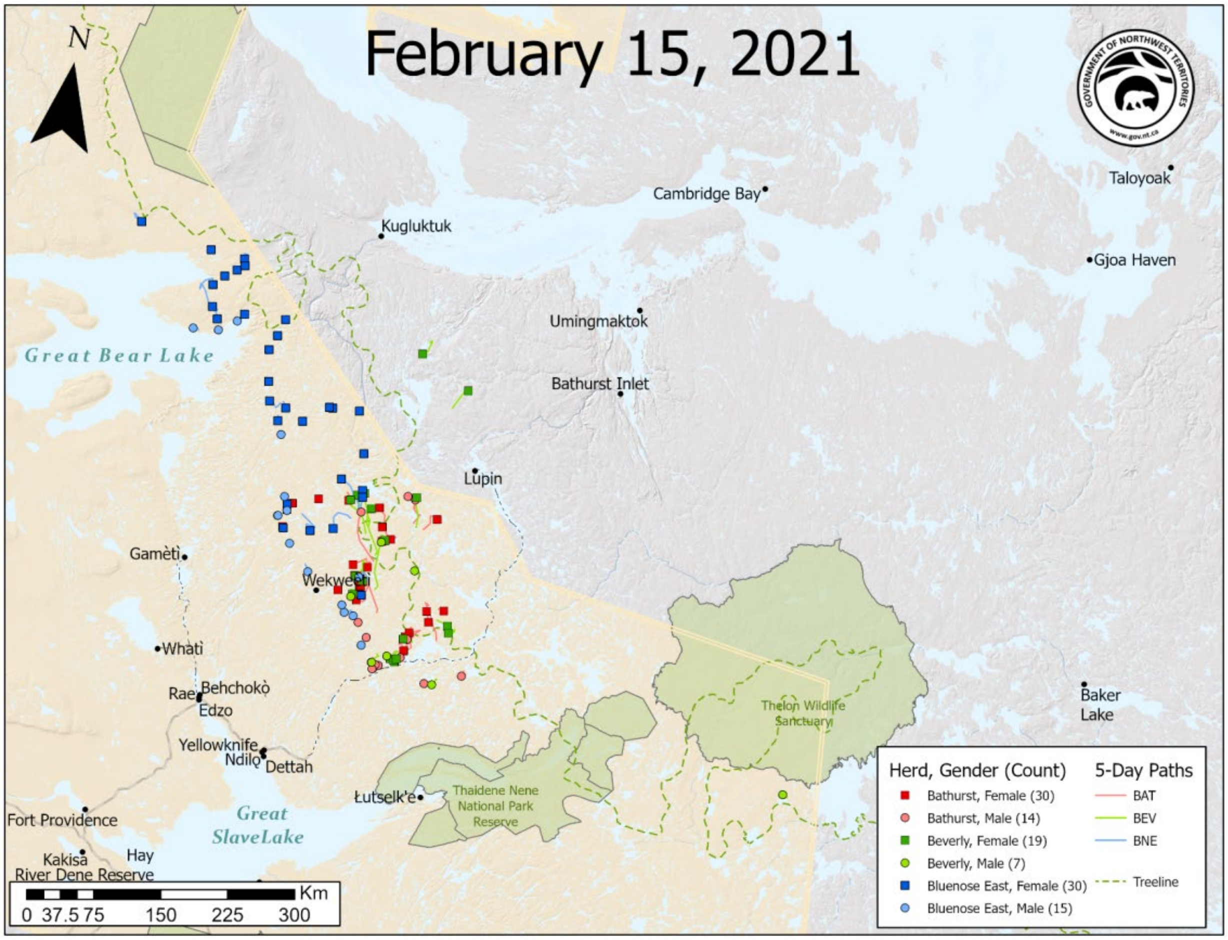

Figure 54. Locations of collared Bathurst, Bluenose-East and Beverly caribou on February 15, 2021.

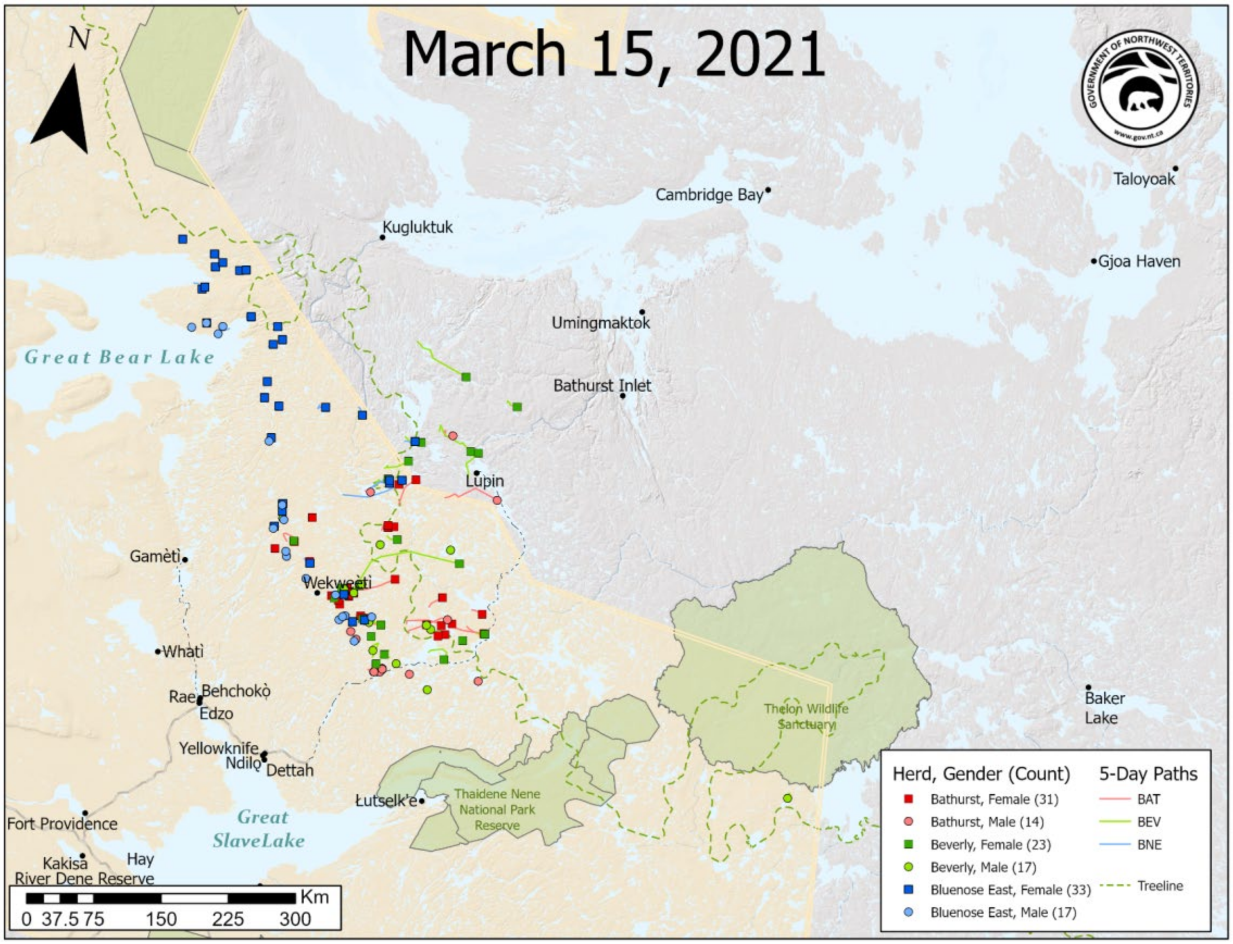

Figure 55. Locations of collared Bathurst, Bluenose-East and Beverly caribou on March 15, 2021.

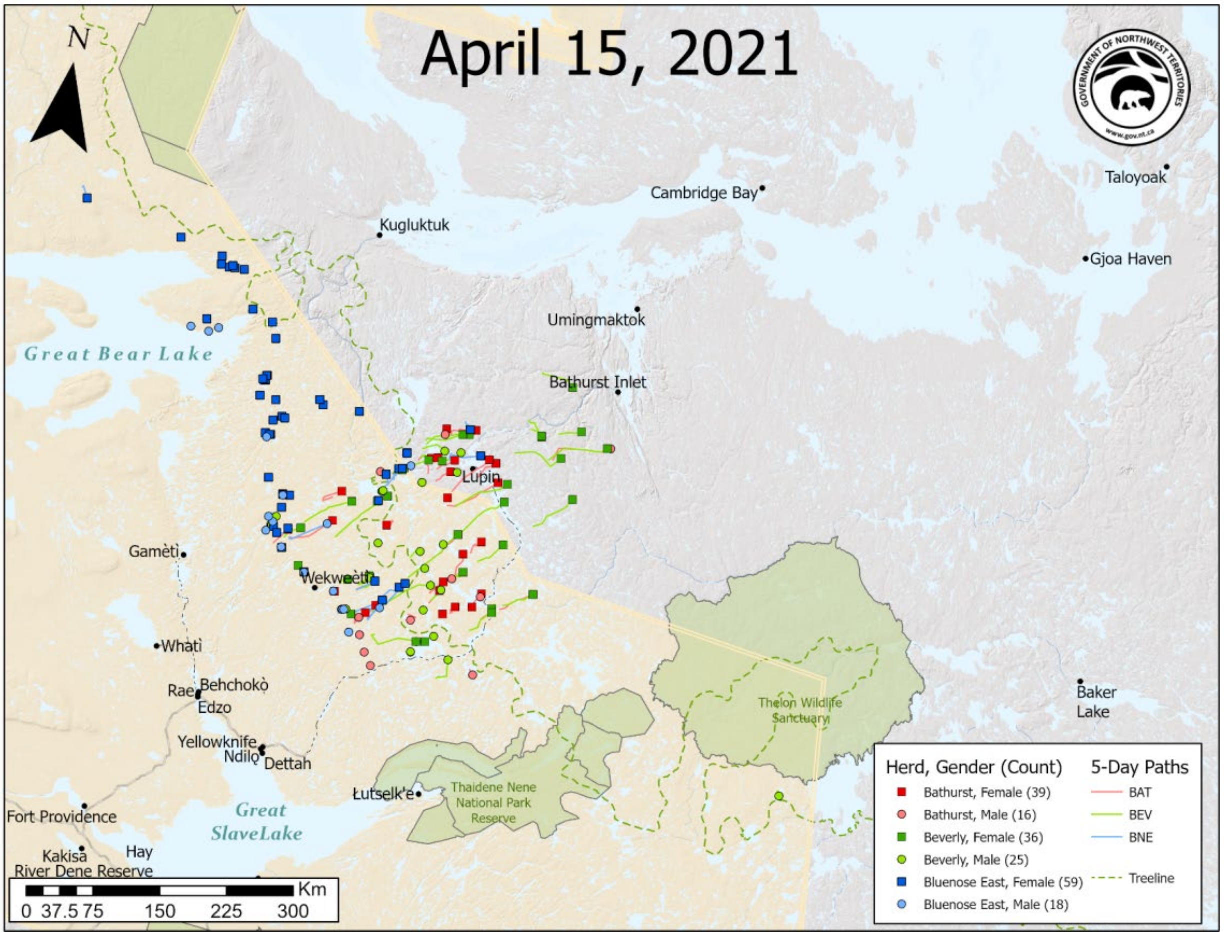

Figure 56. Locations of collared Bathurst, Bluenose-East and Beverly caribou on April 15, 2021.

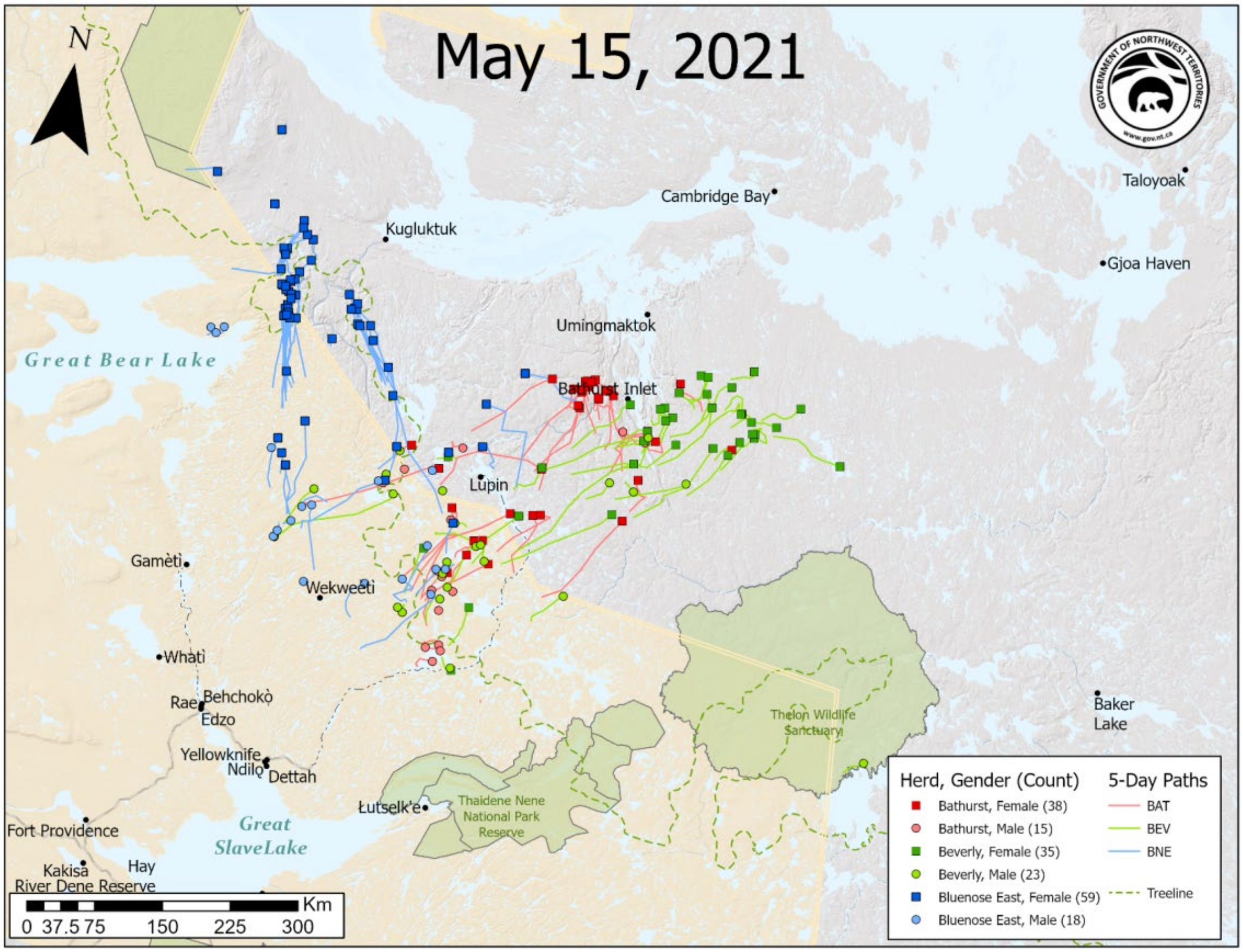

Figure 57. Locations of collared Bathurst, Bluenose-East and Beverly caribou on May 15, 2021.

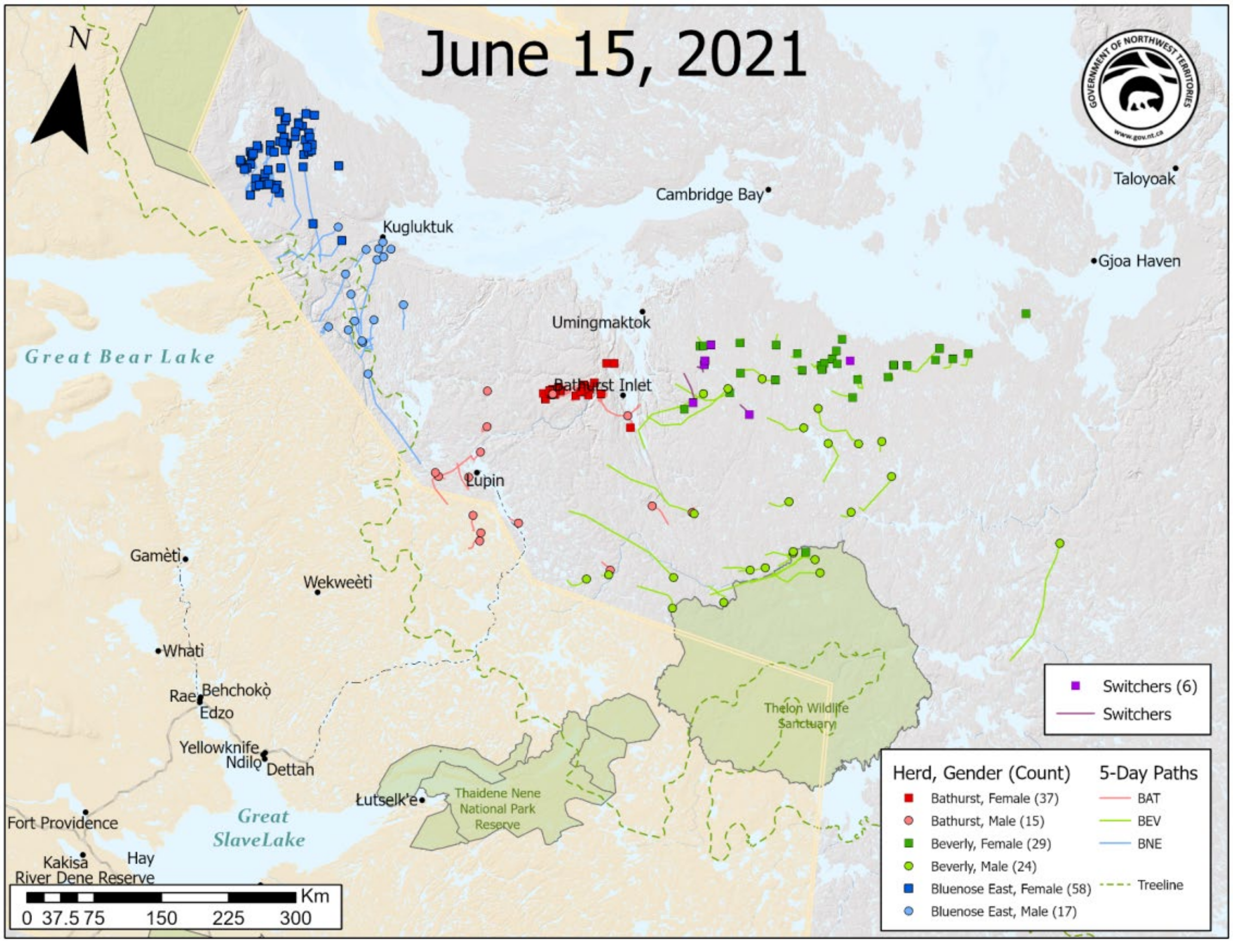

Figure 58. Locations of collared Bathurst, Bluenose-East and Beverly caribou on June 15, 2021. Six known Bathurst collared cows that switched to the Beverly distribution are included in violet.

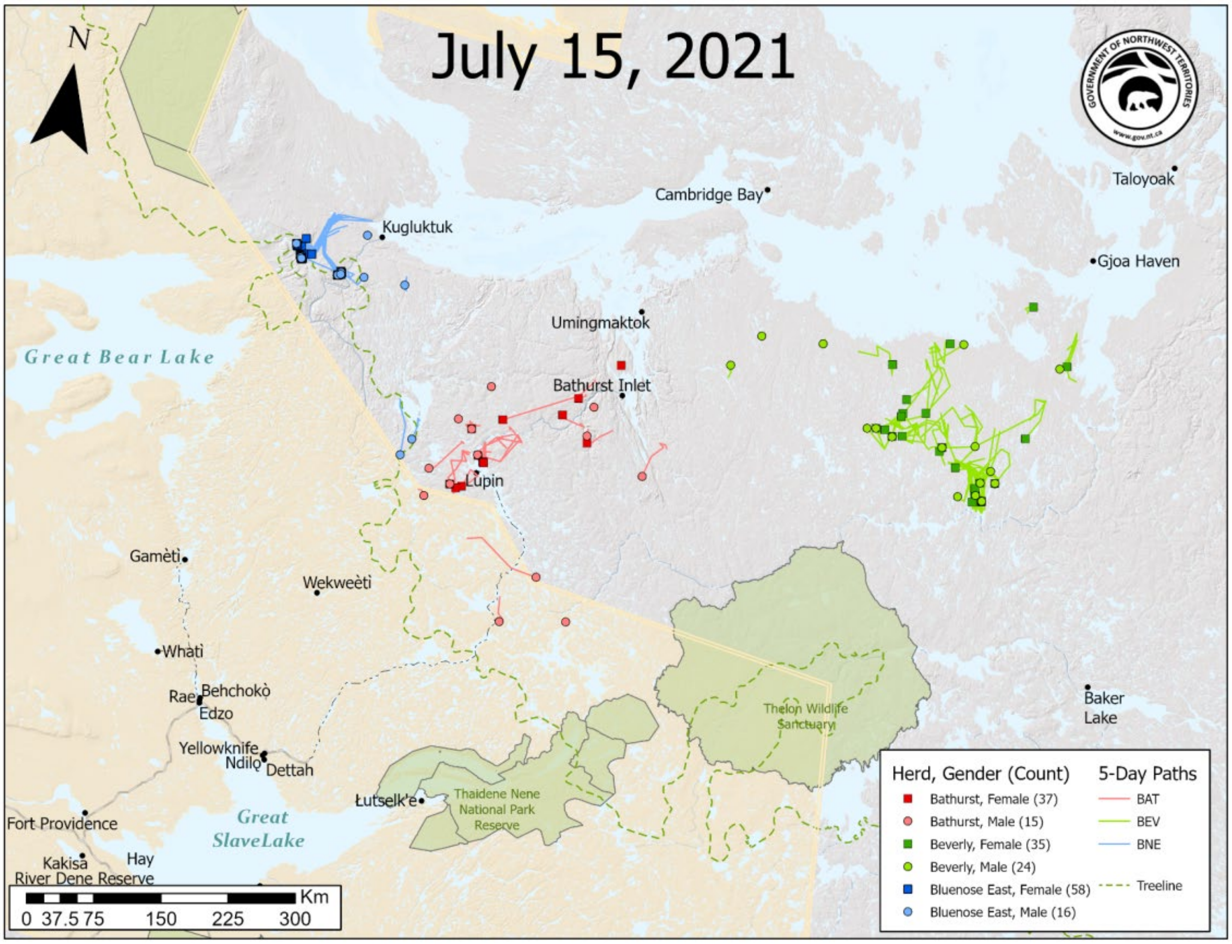

Figure 59. Locations of known collared Bathurst, Bluenose-East and Beverly caribou on July 15, 2021.

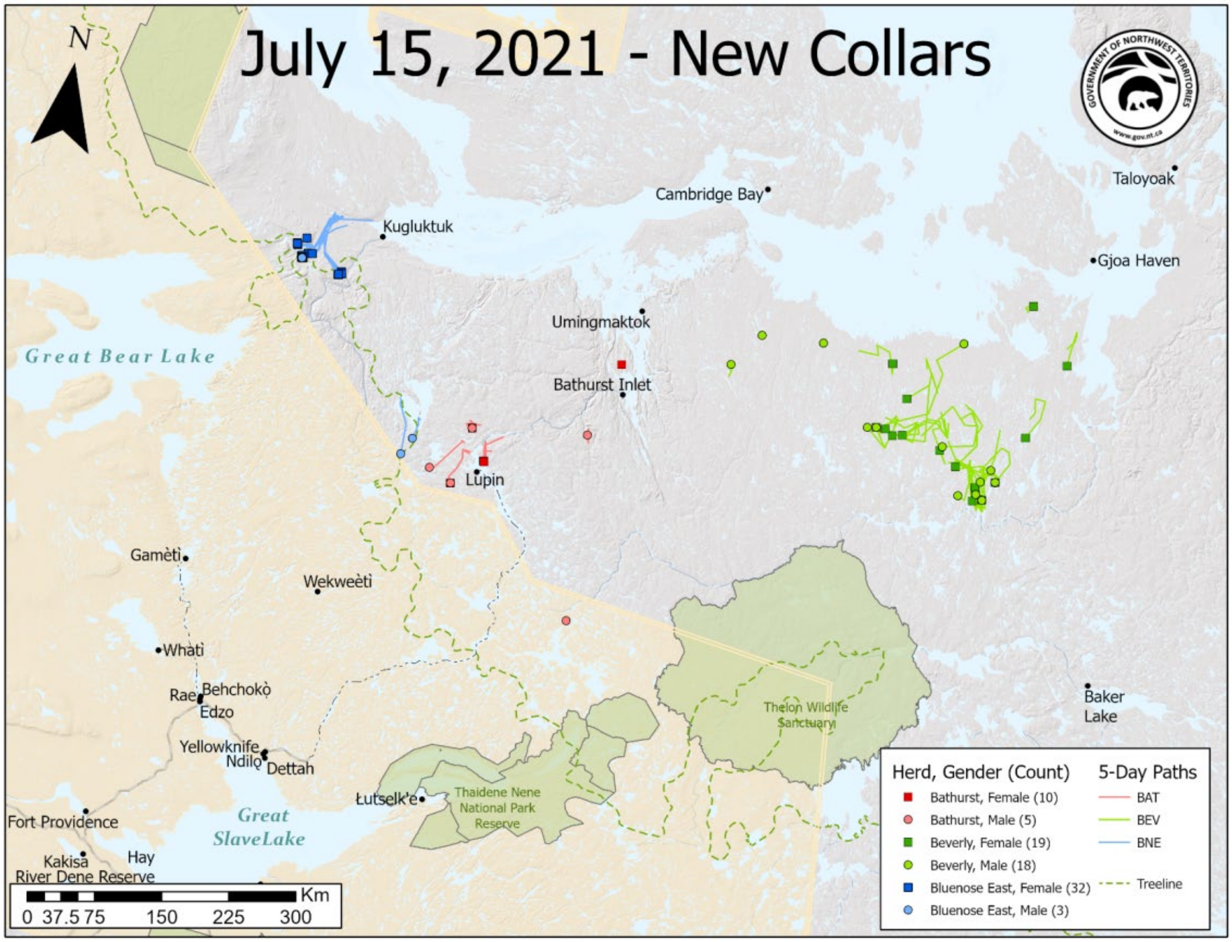

Figure 60. Locations of newly collared Bathurst, Bluenose-East and Beverly caribou on July 15, 2021. New collars were placed in March 2021 and assigned to herd in June (females) and July (males).

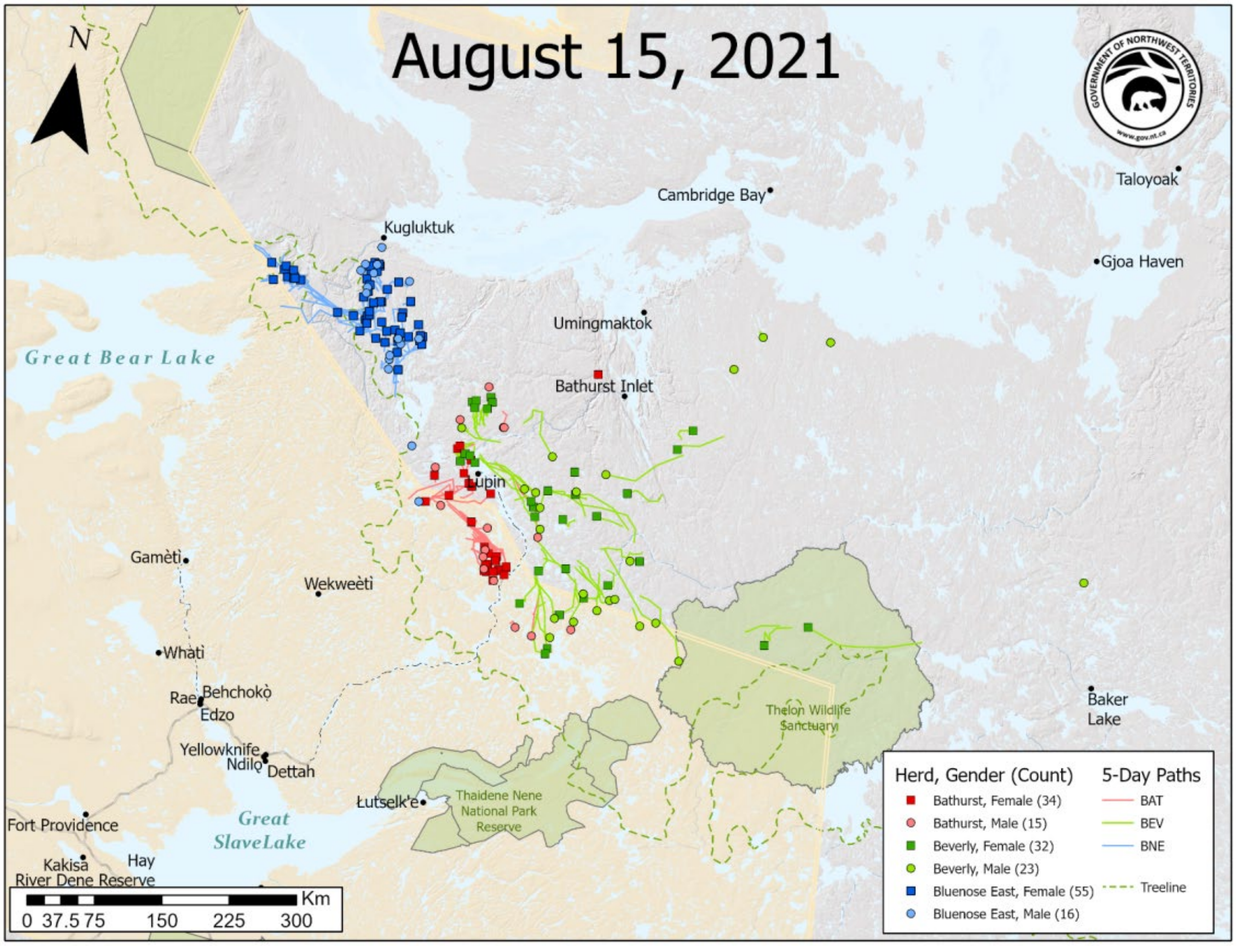

Figure 61. Locations of collared Bathurst, Bluenose-East and Beverly caribou August 15, 2021, including known and new collars.

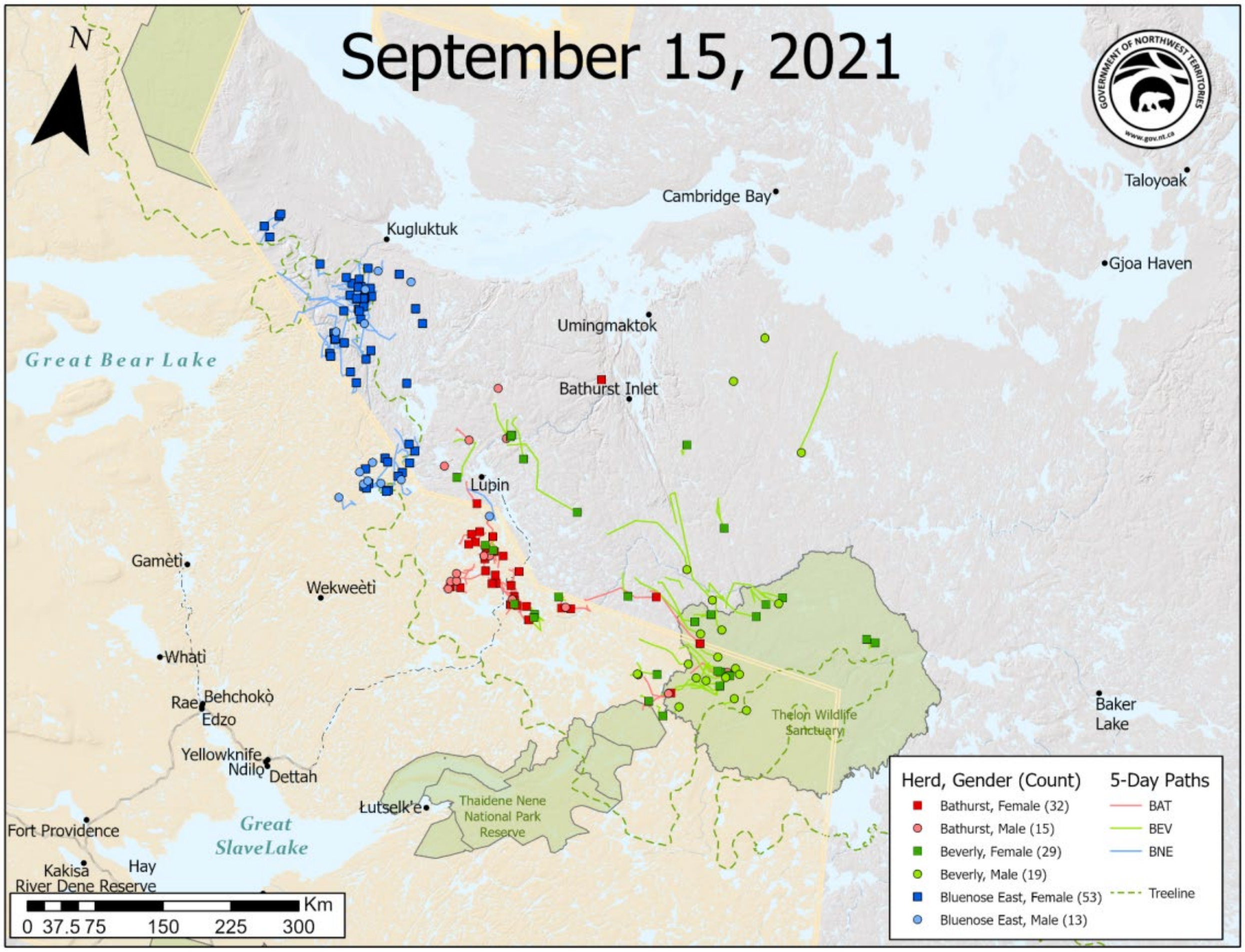

Figure 62. Locations of collared Bathurst, Bluenose-East and Beverly caribou September 15, 2021.

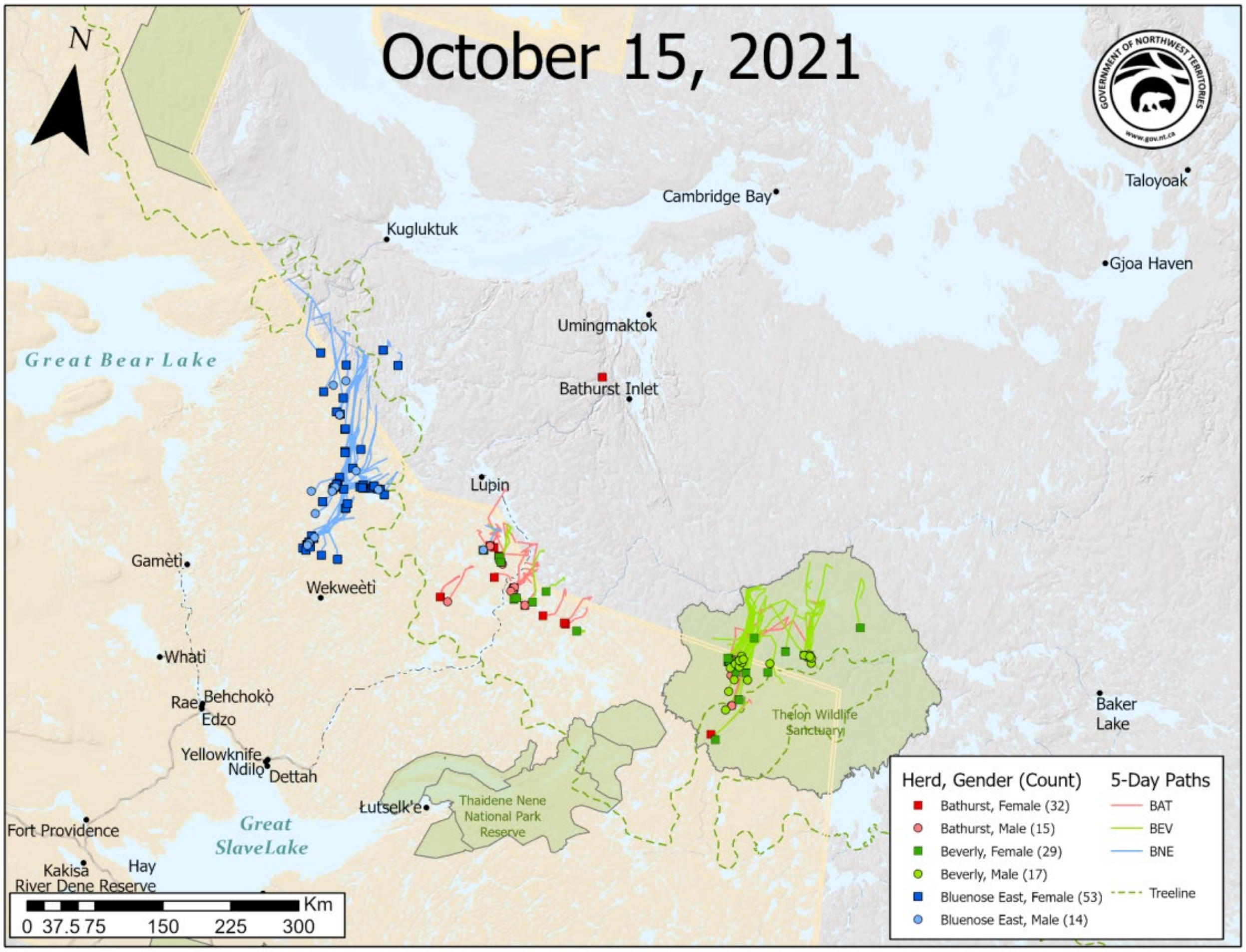

Figure 63. Locations of collared Bathurst, Bluenose-East and Beverly caribou October 15, 2021.

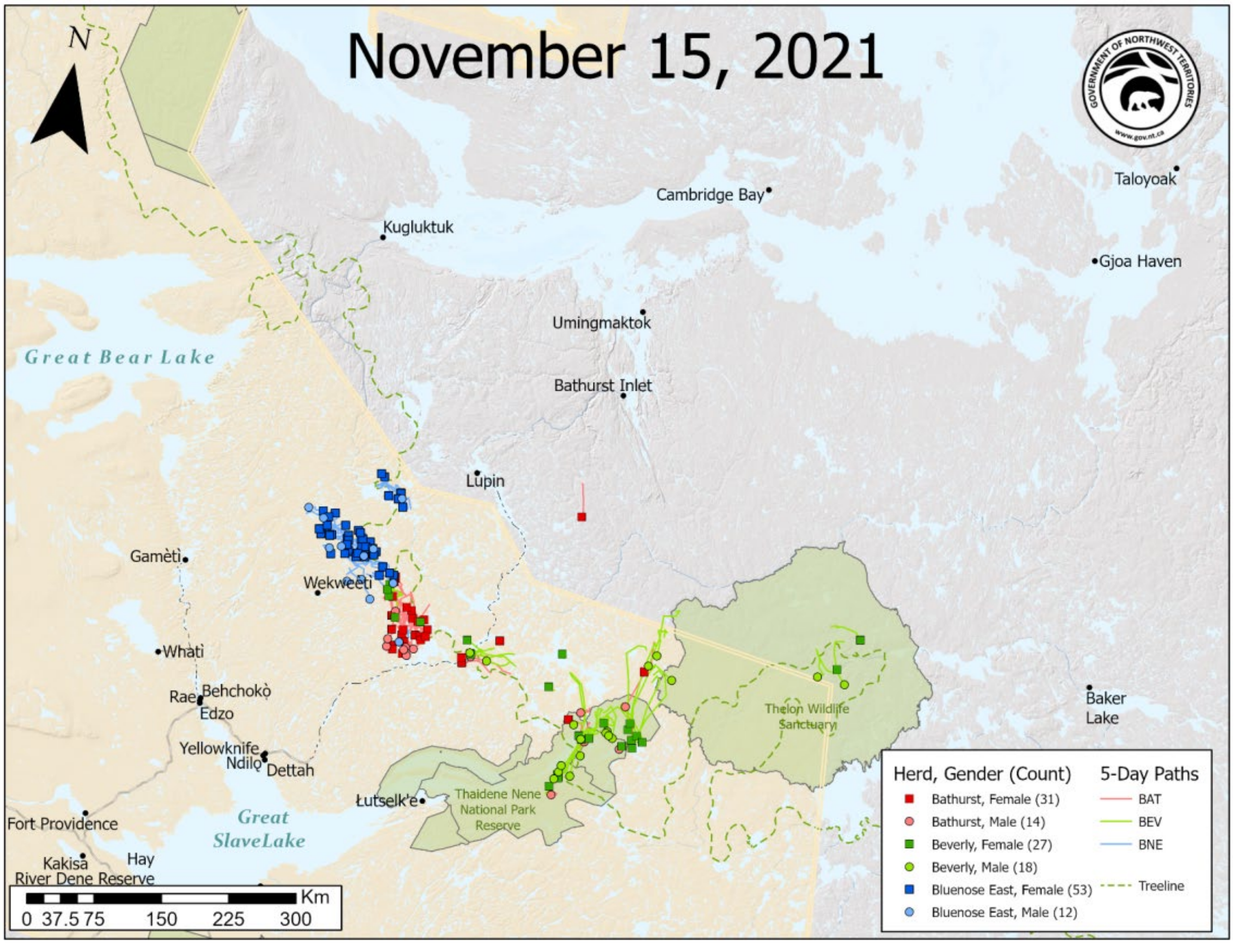

Figure 64. Locations of collared Bathurst, Bluenose-East and Beverly caribou November 15, 2021.

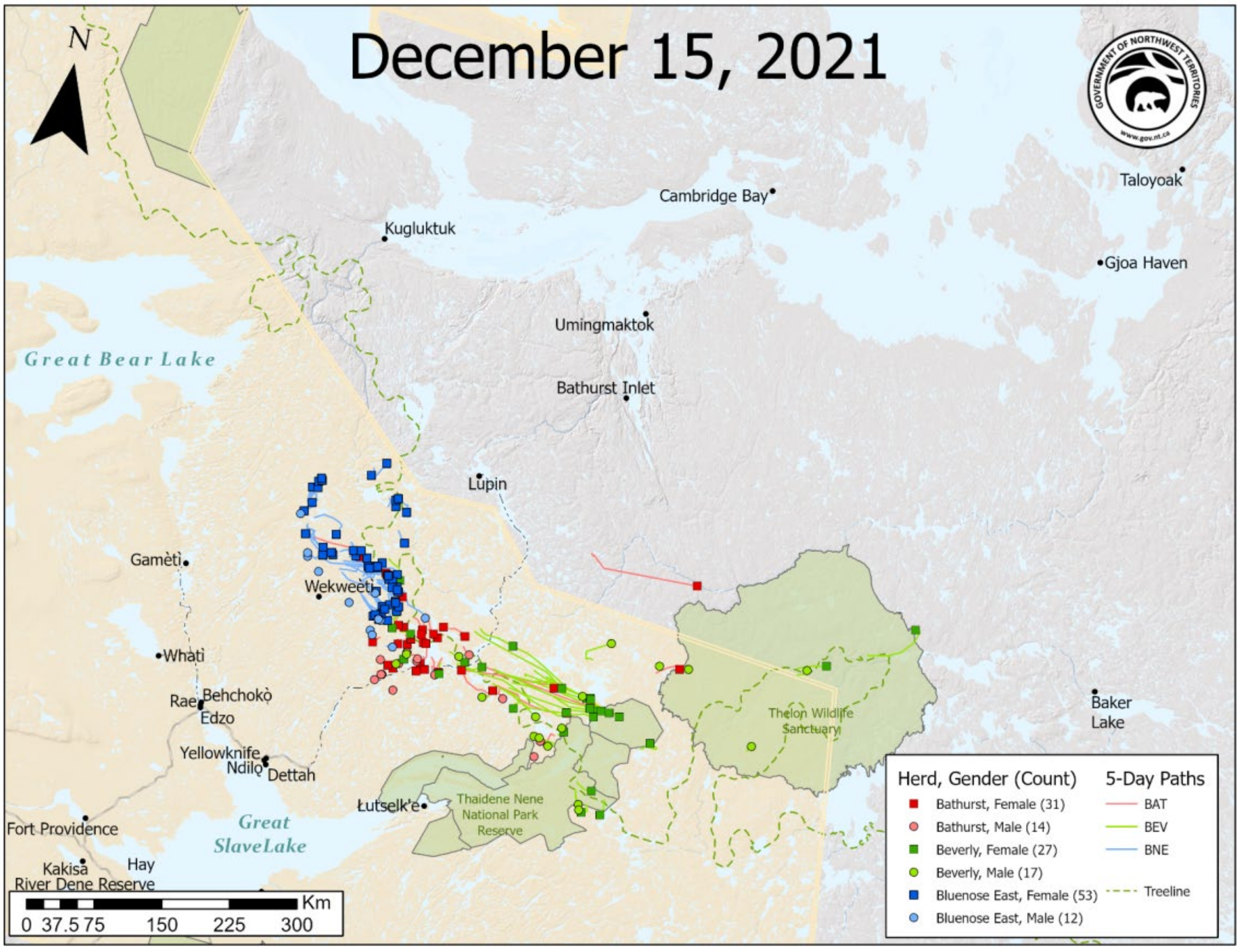

Figure 65. Locations of collared Bathurst, Bluenose-East and Beverly caribou December 15, 2021.

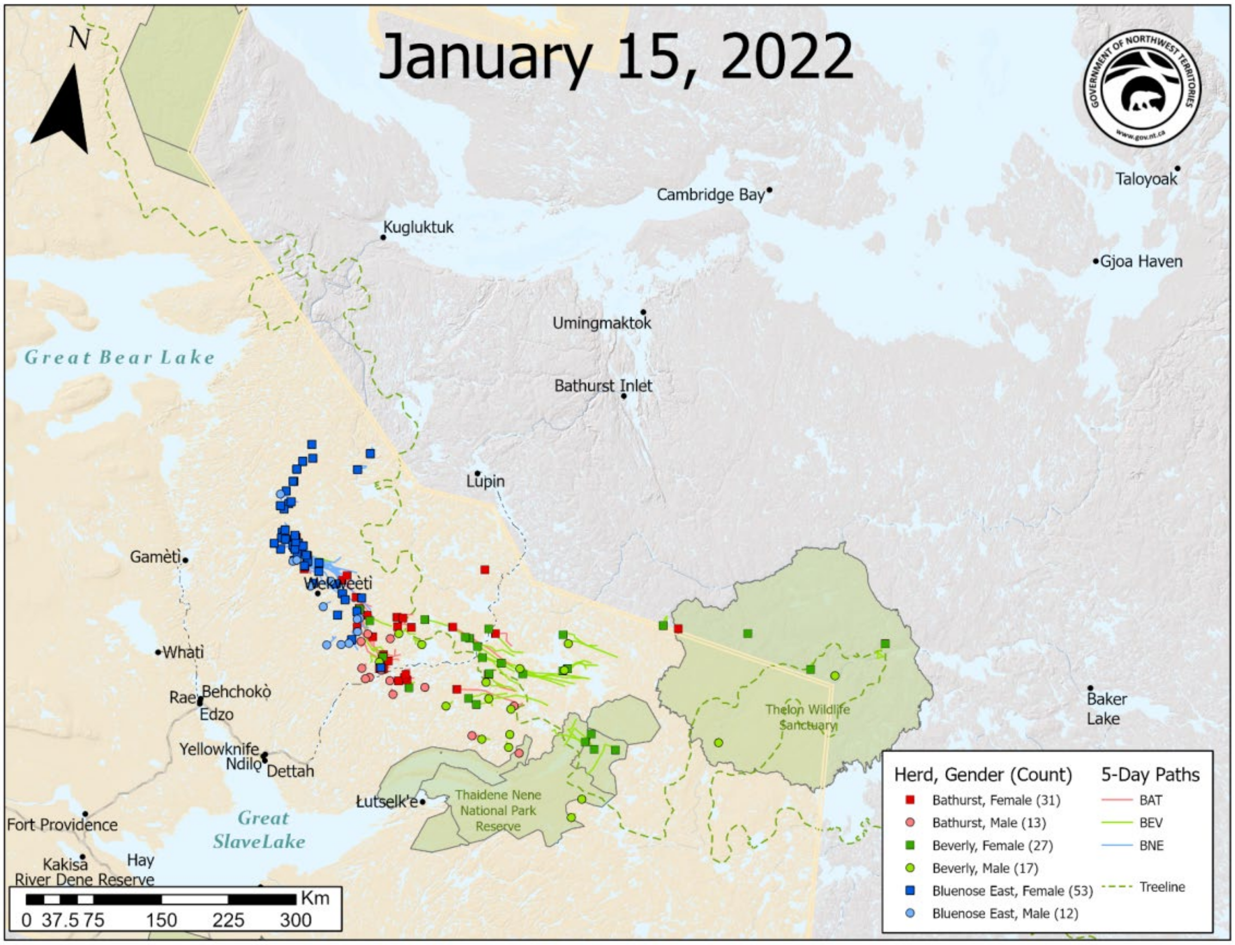

Figure 66. Locations of collared Bathurst, Bluenose-East and Beverly caribou January 15, 2022.

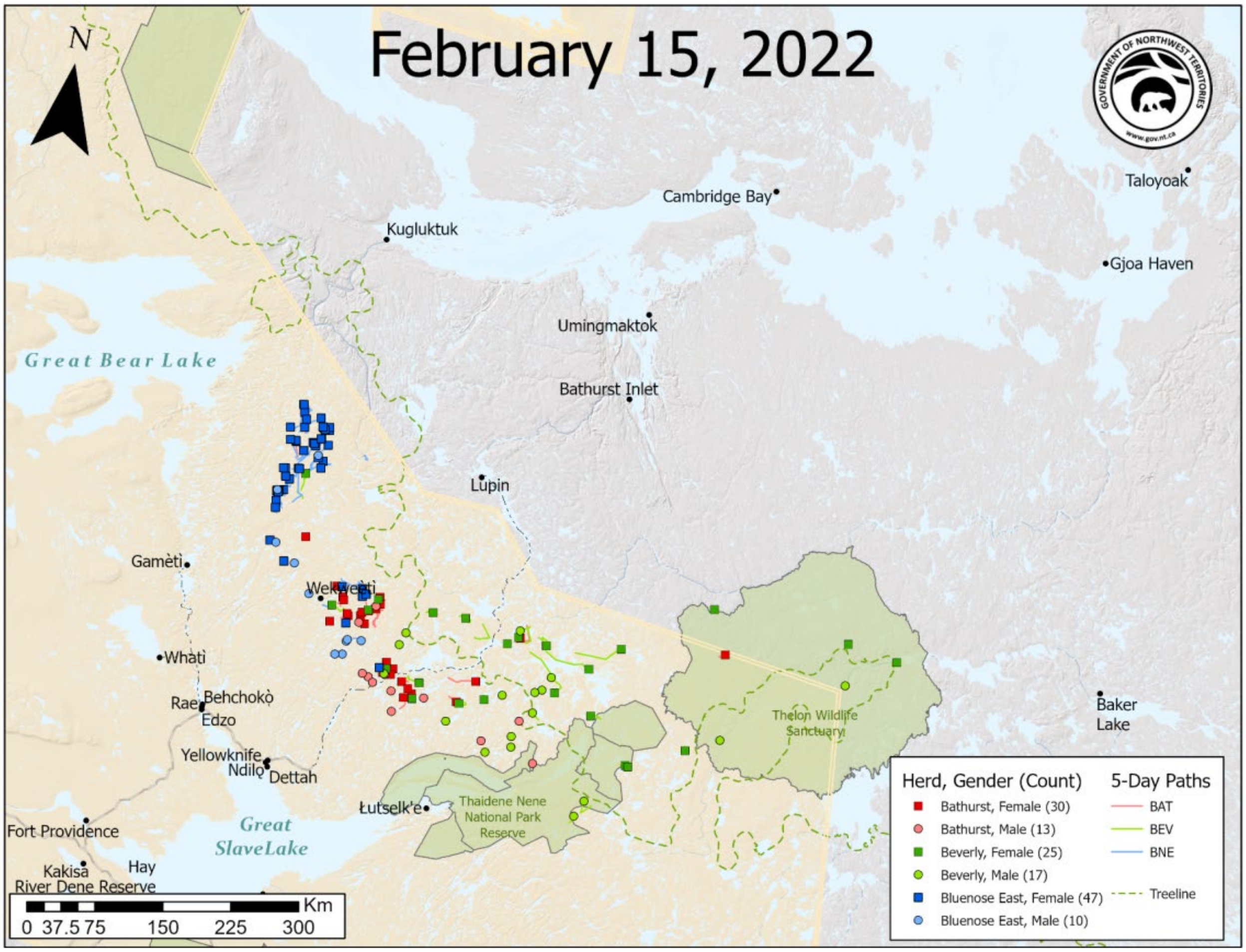

Figure 67. Locations of collared Bathurst, Bluenose-East and Beverly caribou February 15, 2022.

Appendix 5. Bathurst Demographic Analysis with IPM Model in R Code

This appendix details the development of the Bayesian IPM state space model. The primary state space model R coding was developed by Joe Thorley (Poisson Consulting, poissonconsulting.ca) in collaboration with John Boulanger (Thorley and Boulanger 2019; also see Ramey et al. 2018 and Thorley and Andrusak 2017). The demographic model used was similar to the previous OLS model used in previous analyses. The primary development was to evolve model fitting to a more robust Bayesian state space approach. The objective of this appendix is to provide a brief description of the model used in the analysis rather than a complete description of the Bayesian model approach. Readers interested in the Bayesian modeling approach should consult Kery and Schaub (2011) and Schaub and Kery (2022) which are excellent introductions to Bayesian analysis and Integrated Population Models.

Data Preparation

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

Statistical Analysis

Model parameters were estimated using Bayesian methods. The Bayesian estimates were produced using JAGS (Plummer 2015). For additional information on Bayesian estimation the reader is referred to McElreath (2016).

Unless indicated otherwise, the Bayesian analyses used weakly informative normal prior distributions (Gelman, Simpson, and Betancourt 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 split potential scale reduction factor $\hat{R} \leq 1.05$ (Kery and Schaub 2011, 40) and the effective sample size (Brooks et al. 2011) ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, 61).`

The parameters are summarized in terms of the point *estimate*, standard deviation (*sd*), the *z-score*, *lower* and *upper* 95% confidence/credible limits (CLs) and the *p-value* (Kery and Schaub 2011, 37, 42). The estimate is the median (50th percentile) of the MCMC samples, the z-score is mean/sd and the 95% CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95% CL is 0.

The results are displayed graphically by plotting the modeled relationships between particular variables and the response(s) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively, while random variables are held constant at their typical values (expected values of the underlying hyperdistributions) (Kery and Schaub 2011, 77–82). When informative the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% confidence/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 4.1.2 (R Core Team 2018; and see Pebesma 2018) and the mbr family of packages.

Model Descriptions

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

Population

The cow and bull harvest, fecundity, breeding cow abundance, cow survival, bull survival, fall bull to cow, fall calf to cow and spring calf to cow ratio data complete with SEs 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).
- Natural survival of cows from calving to the following year varies continually and randomly by year.
- Natural survival of bulls from calving to the following year varies randomly by year.
- Cow and bull natural survival is constant throughout the year in any given year.
- Harvest of cows and bulls occurs on the 15th of January.
- Harvest rate varies by harvest period (the second harvest period occurs from 2001-2009) and continually by year by harvest period.
- Yearling survival to the following year is the same as cow natural survival.
- Calf survival varies between the summer and winter seasons and randomly by year.
- Calf sex ratio is 1:1.
- Proportion of breeding cows is the fecundity 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 positively truncated normal distribution with a mean of 200,000 and a SD of 50,000.
- The number of cows in the initial year is the number of breeding cows in the initial year divided by the fecundity in a typical year.
- The prior for the bull to cow ratio in the initial year is a normal distribution with a mean of 0.5 and SD 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 SE is normally distributed with a SD equal to the provided SE.

Prediction

The model was used to predict the number of breeding cows one year into the future assuming herd fidelity of 100% and typical levels for all other parameters. To predict the number of breeding cows at a herd fidelity of 50% simply multiply the predictions by 0.5.

Model Templates

R code is listed below and parameters are in Table 30.

Population

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

  for(i in 1:nFidelityPeriod) {
    bFidelity[i] ~ dnorm(5, 2^-2)
  }

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

  sSurvivalCowAnnual ~ dnorm(0, 1^-2) T(0,)
  sSurvivalBullAnnual ~ dnorm(0, 1^-2) T(0,)
  sSurvivalCalfAnnual ~ dnorm(0, 1^-2) T(0,)
  sFecundityAnnual ~ dnorm(0, 1^-2) T(0,)
```

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

   logit(eSurvivalCow[i]) <- bSurvivalCow + bSurvivalCowAnnual[i]
   logit(eSurvivalBull[i]) <- bSurvivalBull + bSurvivalBullAnnual[i]
   logit(eFecundity[i]) <- bFecundity + bFecundityAnnual[i]
   logit(eSurvivalCalfSummerAnnual[i]) <- bSurvivalCalfSummerAnnual + bSurvivalCalfAnnual[i]
   logit(eSurvivalCalfWinterAnnual[i]) <- bSurvivalCalfWinterAnnual + bSurvivalCalfAnnual[i]
   logit(eFidelity[i]) <- bFidelity[FidelityPeriod[i]] + bFidelityAnnual[i] * equals(FidelityPeriod[i], 2)
   logit(eHarvestRateCow[i]) <- bHarvestRateCow[HarvestPeriod[i]] + bHarvestRateCowYear[HarvestPeriod[
i]] * Annual[i]
   logit(eHarvestRateBull[i]) <- bHarvestRateBull[HarvestPeriod[i]] + bHarvestRateBullYear[HarvestPeriod[i]
] * Annual[i]
 }
 bBreedingCows1 ~ dnorm(200000, 50000^-2) T(0,)
 bBullsCows1 ~ dnorm(0.5, 0.15^-2) T(0.3, 0.7)

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

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

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

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

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

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

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

   eSpringCows[i] <- eJanCows[i] * (1 - eHarvestRateCow[i]) * eSurvivalCow[i-1]^eJanToSpringCor[i]
```

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

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

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

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

 for(i in 1:nAnnual) {
  CollarsFidelity[i] ~ dbin(eFidelity[i], CollarsTotal[i])
 }

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

 for(i in CowSurvivalAnnual) {
  CowSurvival[i] ~ dnorm(logit(eSurvivalCow[i] * (1 - eHarvestRateCow[i+1])), CowSurvivalSE[i]^-2)
 }

 for(i in BullSurvivalAnnual) {
  BullSurvival[i] ~ dnorm(logit(eSurvivalBull[i] * (1 - eHarvestRateBull[i+1])), BullSurvivalSE[i]^-2)
 }

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

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

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

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

Block 1. The model description.

Results

Tables

Population

Table 30. Parameter descriptions.

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

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

Table 31. Model coefficients.

term	estimate	sd	zscore	lower	upper	pvalue
bBullsCows1	0.5137539	0.0977879	5.2183057	0.3245445	0.6809841	0.0006662
bFecundity	0.9284114	0.2341378	3.9906833	0.4916535	1.4303373	0.0006662
bFidelity[1]	6.4266195	1.3867078	4.7220899	4.2080459	9.7030439	0.0006662
bFidelity[2]	3.0665827	0.5629504	5.5908669	2.2996825	4.5843085	0.0006662
bHarvestRateBull[1]	-3.0469928	0.3548491	-8.5590719	-3.7193437	-2.3551459	0.0006662
bHarvestRateBull[2]	-6.9056917	1.1370806	-6.0467031	-9.0906645	-4.5563244	0.0006662
bHarvestRateBull[3]	-4.2251964	0.8689380	-4.8681068	-5.8800527	-2.5249470	0.0006662
bHarvestRateBullYear[1]	0.0801588	0.0333748	2.3967476	0.0129534	0.1434852	0.0206529
bHarvestRateBullYear[2]	0.2220199	0.0539107	4.0884722	0.1099127	0.3258455	0.0006662
bHarvestRateBullYear[3]	-0.0090796	0.0281988	-0.3041471	-0.0628982	0.0456463	0.7734843
bHarvestRateCow[1]	-3.3231613	0.2355312	-14.1677179	-3.8380536	-2.9124734	0.0006662
bHarvestRateCow[2]	-6.2827491	0.9369411	-6.7014112	-8.1244370	-4.4741652	0.0006662
bHarvestRateCow[3]	-7.3115823	0.9885595	-7.4116542	-9.3897204	-5.3457411	0.0006662
bHarvestRateCowYear[1]	0.0366739	0.0226658	1.6563777	-0.0056759	0.0832956	0.0886076
bHarvestRateCowYear[2]	0.1792897	0.0444536	3.9898704	0.0923230	0.2612761	0.0006662
bHarvestRateCowYear[3]	-0.0307976	0.0328733	-0.9541158	-0.1003436	0.0360456	0.3057961
bSurvivalBull	0.7869795	0.0808718	9.7559547	0.6482516	0.9653100	0.0006662
bSurvivalCalfSummerAnnual	-0.3180072	0.3654620	-0.7581329	-0.8697023	0.5249081	0.4003997
bSurvivalCalfWinterAnnual	0.2659098	0.2918479	0.9659561	-0.2664838	0.9143597	0.3031312
bSurvivalCow	1.6170073	0.1044283	15.5618619	1.4367667	1.8544866	0.0006662
sFecundityAnnual	0.8906905	0.1836496	5.0158598	0.6304483	1.3682014	0.0006662
sFidelityAnnual	1.0916820	0.6049159	1.9462634	0.1602219	2.6512610	0.0006662
sSurvivalBullAnnual	0.1710316	0.1519230	1.3323236	0.0091253	0.5539258	0.0006662
sSurvivalCalfAnnual	1.1245238	0.2309119	5.0317539	0.7988910	1.6835643	0.0006662
sSurvivalCowAnnual	0.4246591	0.1281806	3.3914575	0.2183711	0.7164536	0.0006662

Table 32. Model summary.

n	K	nchains	niters	nthin	ess	rhat	converged
37	26	3	500	200	392	1.006	TRUE

Appendix 6. Increased Fall Bull:Cow Ratios in the Bathurst and Bluenose-East Caribou Herds 2020-2021

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

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

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

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

(2) Spatial variation and adequacy of sampling: Regional bull:cow ratios in the Bluenose-East survey in October 2020 varied widely from 52.3:100 in the North area to

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

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

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

(4) **A real increase in bull:cow ratios in both herds:** Demographic indicators in the Bathurst and Bluenose-East caribou herds have shown improving trends 2018-2021, particularly in the Bluenose-East herd, as detailed in the 2021 calving ground photo surveys for the two herds. Improved bull:cow ratios in the Bathurst and Bluenose-East herds in 2020 and 2021 may be a further indicator of improving demographics in the two

herds. The last period of widespread growth in NWT mainland barren-ground caribou herds was in the early 1980s. The average bull:cow ratio recorded during six fall composition surveys during this period was 66 bulls:100 cows (in Gunn et al. 1997, p. 35).

(5) **Insights on bull:cow ratios and bull survival from demographic modeling:** Demographic modeling of the Bathurst and Bluenose-East described in the main text of the 2021 calving ground survey reports also suggests an increase in bull numbers and bull:cow ratios. Below is a synopsis of findings related to bull-cow ratios.

For the Bathurst herd, a moderate increase in field estimates of bull to cow ratios occurred from 2014 to 2020 in comparison to a larger increase from 2008 to 2010 (Figure 68). We note that compared to the Bluenose-East the increase from 2018 to 2020 was moderate with overlap of confidence limits of the estimates. The integrated population model (the blue line in the figure below) predicted stability of the bull cow ratio from 2015 to 2020.

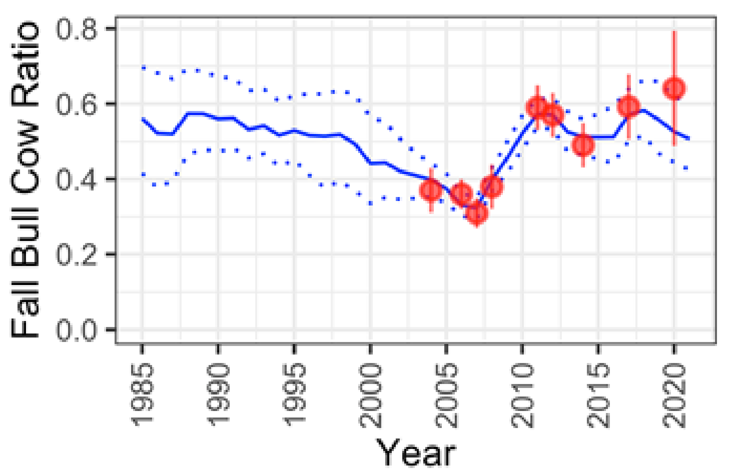

Figure 68. IPM estimates of bull-cow ratio for the Bathurst herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

Changes in bull-cow ratios can be due to differential changes in bull and cow survival. Estimates of bull and cow survival from collared caribou (with IPM predictions in blue) suggest a potential increasing trend in cow survival with stable bull survival (Figure 69). Low precision of bull collar survival data limits interpretation of bull survival trends.

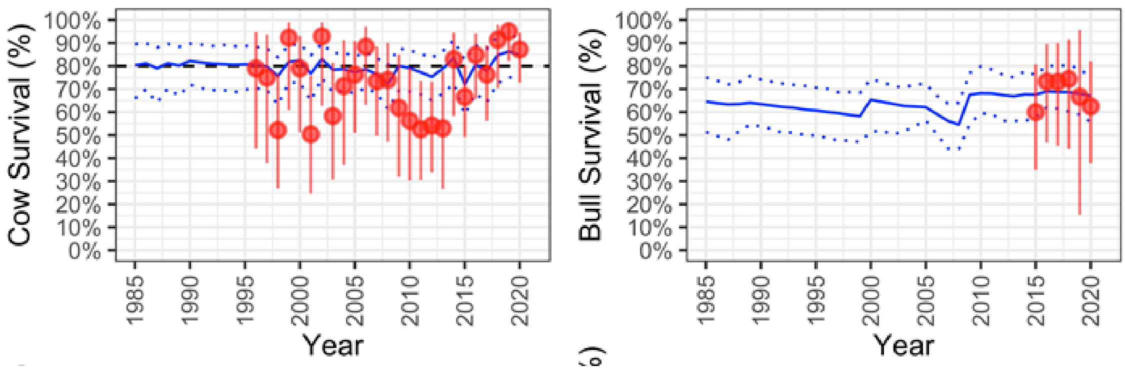

Figure 69. IPM estimates of cow and bull survival for the Bathurst herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

Increases in bull-cow ratios can also be related to increases in productivity; birth ratios of about 50:50 males:females and a large calf cohort or cohorts will increase the male:female ratio in young caribou, which offsets higher mortality rates of bulls and increases the overall bull:cow ratio. The IPM uses estimates of fecundity (proportion of females pregnant) and calf survival (a derived parameter) to estimate productivity which is the product of the previous year's fecundity times calf survival. Comparison of productivity with bull cow ratios does suggest some correspondence between increases in productivity and increases in bull cow ratio (Figure 70). For example, productivity was higher from 2008 to 2011 which corresponds to an increase in bull:cow ratios in 2012. Productivity then dropped to lower/moderate levels with a slight increasing trend from 2013 to 2020, which corresponds to a slight increase in bull cow ratios. Therefore, the slight increase in bull cow ratios is partially supported by increases in productivity.

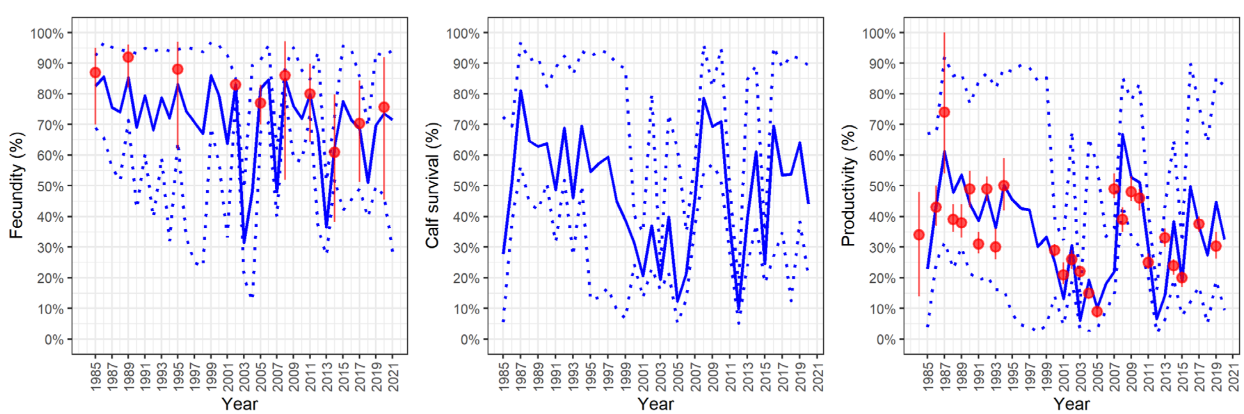

Figure 70. Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for the Bathurst herd 1985-2020. Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year prediction of the model), are shown for reference purposes.

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

The Bluenose-East herd did display a marked increase in the bull-cow ratios recorded in the fall in 2020 and 2021 (Figure 71).

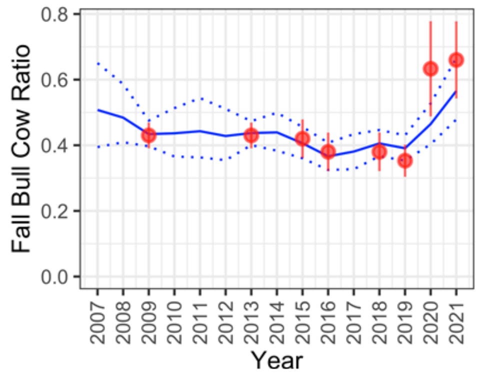

Figure 71. IPM estimates of bull-cow ratios for the Bluenose-East herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

During this time cow survival was relatively constant, however, collar-based and IPM estimates of bull survival did suggest an increase which supports the increase in bull:cow ratios (Figure 72).

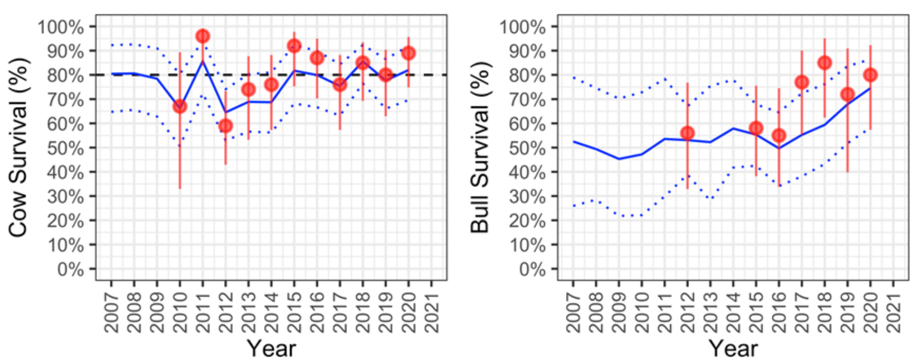

Figure 72. IPM estimates of cow and bull survival for the Bluenose-East herd (blue line) and corresponding field estimates (red dots). Confidence limits are indicated by dashed lines (IPM) or red lines (field estimates).

There was also an increase in productivity of calves from 2018 to 2020 (Figure 73), which would also increase the bull cow ratio as discussed for the Bathurst herd (initial male:female ratio of 50:50 in large calf cohorts leading to more young males and an increased bull:cow ratio).

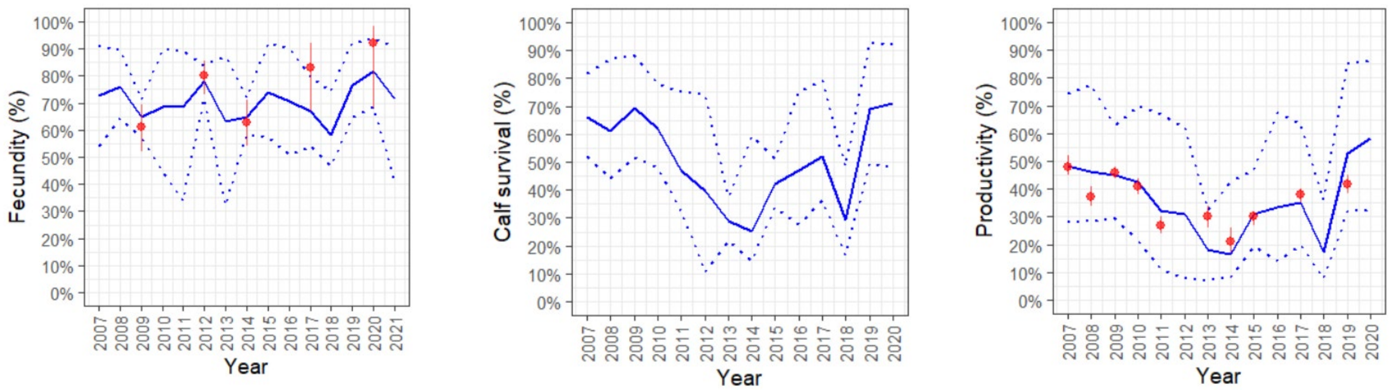

Figure 73. Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for Bluenose-East herd 2007-2021. Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year prediction of the model), are shown for reference purposes.

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

A Comparison with Bull:cow Ratios in the Western Arctic Herd, Alaska

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

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

The graph below is from Dau (2015) and shows bull:cow ratios in the WAH from the 1970s to 2014 (Figure 74). This herd was increasing in the 1980s and early 1990s, at high numbers of over 400,000 1993-2003, and has had a declining trend since about 2003. The overall range in bull:cow ratios in this herd has varied between 1991 and 2015 from a high of more than 60:100 in 1991, when the herd was still increasing, to a low of 38-40:100 in 2001 and 2014. The overall range in sex ratios is similar to the range reported for the Bathurst and Bluenose-East herds 2006-2020, although somewhat lower ratios were recorded for the Bathurst herd 2006-2008 during a period of rapid decline. Bull:cow ratios were higher during periods of herd increase and lower during periods of decline in the WAH.

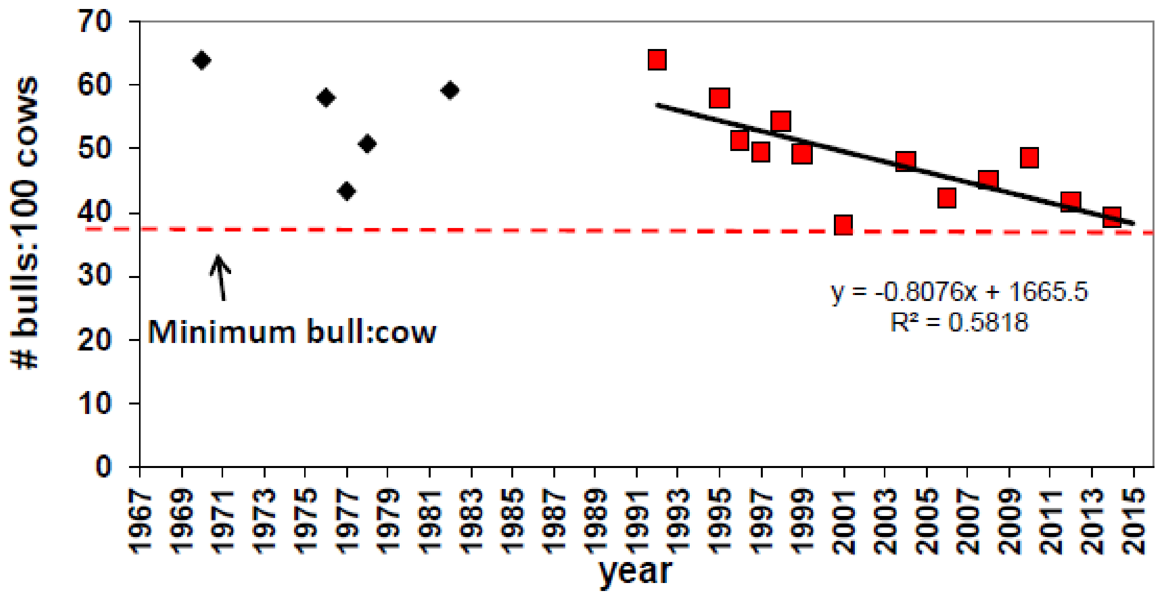

Figure 74. Fall bull:cow ratios, WAH, 1976-2014. No trend line shown for 1970-1982 because yearly survey methods varied. (Originally Figure 27 in Dau 2015; figure caption as presented in that report).

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

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

Emigration in collared bulls is more difficult to assess than in collared cows. Distribution of collared bulls in June is spatially more variable than in cows; some bulls may still be on the wintering ranges while other bulls may be near the calving grounds or just south of them. Herd affiliation of some bull collars in June is not easy to define. In addition, bull collar numbers are usually much lower than cow collar numbers, creating a more limited sample. In 2021-2022, the only month when bull collars in the Bathurst, Bluenose-East and Beverly herds were clearly separated was July (Figure 59). Newly placed bull collars were assigned to herds at that time because of that separation. However, by August, mixing of Bathurst and Beverly collared caribou had begun and continued through the fall of 2021 and winter 2021-2022 (Appendix 4).

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

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

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

Appendix 7. Incidental Sightings of Other Large Mammals and Eagles on Bathurst 2021 Calving Ground Survey

Incidental sightings of large carnivores and eagles during the visual and composition survey portions of the 2021 Bathurst calving ground surveys are listed in Table 33. The surveys are not designed to estimate abundance of relatively rare species like bears, wolves and wolverines and variability of sightings is high, thus these sightings should be considered broad indices of relative abundance only. Of particular interest are sightings of grizzly bears and wolves on the calving grounds, as they are considered effective predators of young caribou calves. Nine grizzly bears and two wolves were seen during the Bathurst June 2021 calving ground composition survey, which continues a trend of bear sightings outnumbering wolf sightings on the Bathurst calving ground surveys (Adamczewski et al. 2019).

Table 33. Incidental sightings of other wildlife species on Bathurst calving ground survey June 2021. Hours flown on survey and on ferry flights by Caravan or helicopter are included.

Species/Metric	Visual Flying Total	Visual Flying Notes	Composition Survey Total	Composition Survey Notes
Bald Eagle	0		2	1,1
Golden Eagle	5		2	1,1
Grizzly Bear	2		9	4x1,1+2,2
Moose	4		11	3x1,3x2,1+1
Muskox	183	20 groups	67	2,30,35
Wolverine	1		1	1
Wolf	2		2	1,1
Survey Hours	32.9		14.0	
Ferry Hours	4.6		13.7	
Total Hours	37.5		27.7	

Appendix 8. Fates of Collared Bathurst Females that Switched to Beverly Herd

A history of collared Bathurst caribou females that switched from calving on the Bathurst calving ground to the Beverly calving ground in 2018, 2019 and 2021 is in Table 34. There were no Bathurst-to-Beverly switchers in 2020. There were no Beverly-to-Bathurst switchers over this period. In most cases, collar transmission after switching was limited in duration by mortality or timed collar release, limiting interpretation of trends.

Table 34. History and fate of collared Bathurst caribou cows that switched from Bathurst calving distribution to Beverly in 2018, 2019, and, 2021 to March 30, 2022. One collared Bluenose-East cow switched to the Bathurst calving ground in 2019 and is included.

Year	Caribou ID	Switched From:	Switched To:	Year Deployed	End Date Locations	Fate	Notes
2018	BGCA15266	Bathurst	Beverly	2015	29-Sep-18	Mortality	
2018	BGCA16116	Bathurst	Beverly	2016	01-Mar-19	Released	
2018	BGCA17105	Bathurst	Beverly	2017	01-Jul-18	Unknown	Stationary; presumed dead; not retrieved yet
2019	BGCA18144	Bathurst	Beverly	2018	15-Apr-21	Released	Stayed with Beverly after switching
2019	BGCA17157	Bathurst	Beverly	2017	01-Aug-19	Released	
2019	BGCA17103	Bathurst	Beverly	2017	30-Aug-19	Released	
2019	BGCA18129	Bluenose East	Bathurst	2018	01-Apr-20	Released	
2021	BGCA19370	Bathurst	Beverly	2019		Alive	East of Bathurst Inlet, east of survey area June 10; tried re-collar March 2022; could not find
2021	BGCA19374	Bathurst	Beverly	2019	18-Oct-21	Unknown	East of Bathurst Inlet, east of survey area June 10; stationary; presumed dead; not retrieved yet
2021	BGCA20105	Bathurst	Beverly	2020		Alive	East of Bathurst Inlet in survey area June 10, then moved east
2021	BGCA20135	Bathurst	Beverly	2020		Alive	East of Bathurst Inlet in survey area June 10, then moved east
2021	BGCA20139	Bathurst	Beverly	2020	23-Jul-21	Mortality	East of Bathurst Inlet in survey area June 10, then moved east
2021	BGCA20237	Bathurst	Beverly	2020		Alive	East of Bathurst Inlet in survey area June 10, then moved east