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ESTIMATES OF BREEDING FEMALES & ADULT HERD SIZE AND ANALYSES OF DEMOGRAPHICS FOR THE BATHURST HERD OF BARREN-GROUND CARIBOU: 2018 CALVING GROUND PHOTOGRAPHIC SURVEY

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ABSTRACT

This report describes the results of a calving ground photo survey of the Bathurst caribou herd conducted in June of 2018 near Bathurst Inlet in Nunavut (NU). The main objectives were to estimate the numbers of breeding females, adult females, and adults in the herd, to compare with results of previous calving ground surveys of this herd, the last of them in 2015.

We flew a systematic reconnaissance survey with transects at ten km intervals over an area defined primarily by locations of collared female caribou. Adjacent areas were also flown to ensure that the distribution of females was fully defined. The results were used to assess how far calving had progressed, allocate survey effort to geographic strata of similar caribou density, and time the aerial photography to coincide with the peak of calving. Based on average daily movement rates of collared females falling below a threshold of 5 km/day on June 8, and observed proportions of cows with calves from fixed-wing flying, it appeared that the peak of calving would occur on or soon after June 8. The photo plane survey was flown with excellent field conditions (blue skies) on June 8. We delineated one photographic stratum where most of the cows were seen and which contained 12 of the 17 active cow collars, west of Bathurst Inlet. On June 8 and 9 we also conducted visual surveys of two other strata with lower densities of female caribou and five collared cows, on either side of Bathurst Inlet.

Snow cover was patchy in much of the survey area, which made caribou more difficult to see. For the visual surveys, we used a double observer method to estimate and correct for sightability of caribou. A double observer method was also used to estimate and correct for sightability of caribou on the aerial photographs. In addition, extra time was taken by the contract staff who counted the aerial photos to make sure that a very high percentage of caribou were found.

The estimate of 1+ year old caribou on the core calving ground was 6,919 (95% confidence interval (CI) =5,415-8,843) caribou. Combining these numbers with the results of the

composition survey, the estimate of breeding females was 3,636 (CI=2,709-4,880). This estimate was reasonably precise with a coefficient of variation (CV) of 13.9%. The estimate of adult females in the survey area was 5,162 (CI=3,935-6,771). The proportion of adult females classified as breeding was higher (70.4%) than in 2015 (60.9%). Herd size was estimated as the number of adult females on the survey area divided by the proportion of females in the herd from a 2017 fall composition survey, thus accounting for the bulls in the herd. The resulting estimate of Bathurst herd size in 2018 was 8,207 caribou at least two years old (CI=6,218-10,831), compared to 19,769 (CI=12,349-27,189) in 2015.

Reductions from 2015-2018 in estimates of breeding females were 55.0%, in adult females 61.0% and in overall herd size 58.5%. The reduction in herd size indicates an annual rate of decline of 25.5% 2015-2018. This decline could not be attributed to issues with survey methods. Demographic analysis indicates that adult female survival rates (estimated at 0.82 for 2017-2018 using a Bayesian demographic model) had improved from 2015 but continued to be below levels associated with stable populations (0.84-0.90). Overall calf productivity (the product of fecundity and calf survival) prior to 1997 averaged 0.46 while the average for 2011-2018 was 0.25 and was well below levels associated with stable populations. These low vital rates likely account for much of the decline 2015-2018.

Assessment of movement of collared females between the Bathurst and neighbouring Bluenose-East and Beverly calving grounds 2010-2017 showed minimal movement of cows to or from neighbouring herds. However, the Bathurst herd was heavily mixed throughout winter 2017-2018 with the much larger Beverly herd that calves in the coastal lowlands along the Queen Maud Gulf, and was outnumbered by that herd by a ratio of about 12:1 in 2018. Of 11 Bathurst collared cows that were known to have calved on the Bathurst calving ground in June 2017, three moved in the spring of 2018 to the coastal calving ground along the Queen Maud Gulf and did not return later in the year. This is a limited sample and should be interpreted cautiously, but it suggests that a portion (27%) of the herd's cows may have emigrated and joined the Beverly herd while 73% remained on the main Bathurst calving ground. In addition, the Bayesian demographic model was used to project the herd's likely size in 2018 based on its demographics, including or not including the 2018 survey results.

This suggested that about 31% of the cows might have emigrated to the Queen Maud Gulf coastal calving area and about 69% remained on the main Bathurst calving ground. The two estimates suggest that roughly 70% of the Bathurst cows remained on the Bathurst calving ground that the herd has used since 1996 in 2018, but this is based on limited data and model projections, and should be interpreted with caution. In June 2019, three of 17 (17.6%) collared cows that were on the Bathurst calving ground in June 2018 moved well east of Bathurst Inlet with Beverly collared females, suggesting that some eastward emigration of Bathurst cows had continued.

We suggest close monitoring of the herd in the next few years, including population surveys every two years, annual monitoring of cow survival, calf productivity and calf survival for this herd, and increased collar numbers for monitoring and management.

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INTRODUCTION

The Bathurst herd's calving grounds have been found since 1996 west of Bathurst Inlet (Figure 1). The herd's summer range includes the calving ground as well as areas south of it. The winter range is primarily in the Northwest Territories (NWT) and in some years has extended as far south as Saskatchewan.

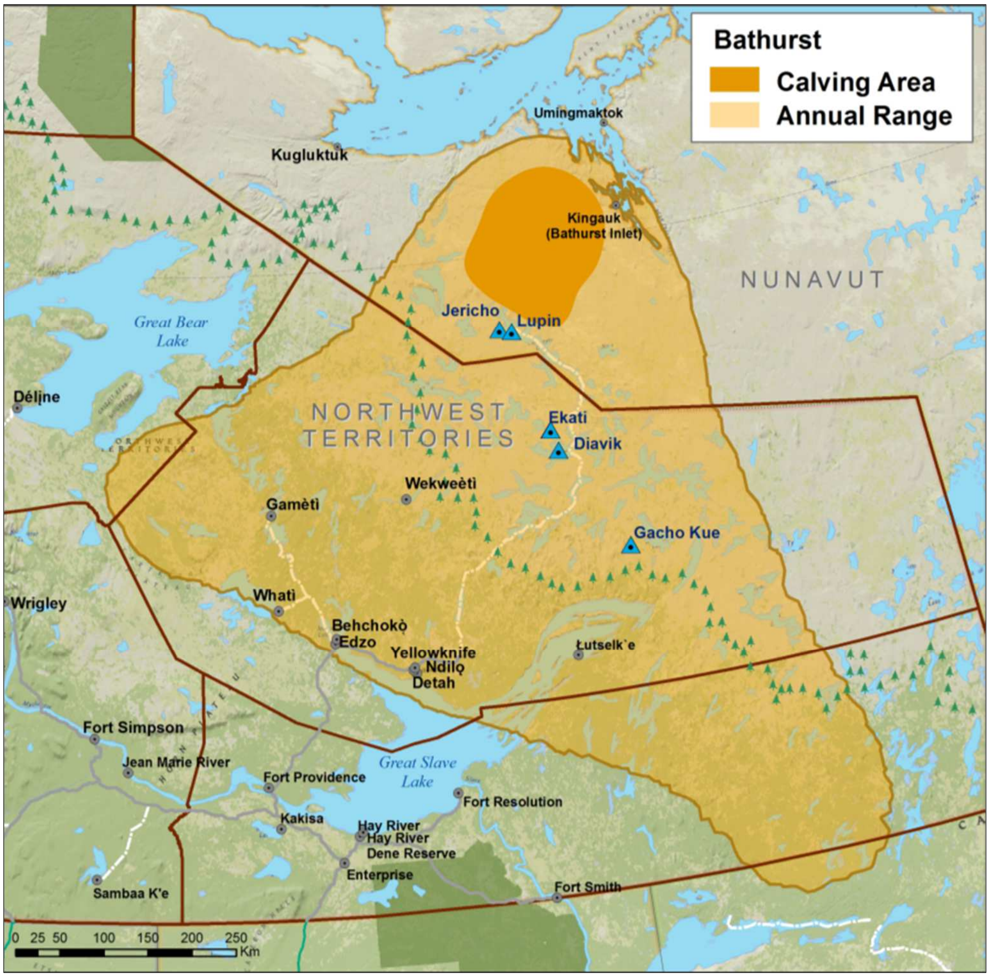

Figure 3: Annual range and calving grounds for the Bathurst herd, 1996-2009, based on accumulated radio collar locations of cows (Nagy et al. 2011). The calving area and a portion of the summer range are in Nunavut (NU) and the rest of the range is mostly in the NWT. At high numbers the herd has occasionally wintered as far south as Saskatchewan. The Gahcho Kué, Ekati and Diavik mines were in active production in 2018 and the Jericho and Lupin mine-sites were under care and maintenance with minimal maintenance staff.

In recent years (2009-2018) the herd's range has contracted as the herd has declined to low numbers, and the herd has wintered near tree-line or on the tundra since 2014. This herd has long been a key country food and cultural resource for Indigenous cultures in the NWT (e.g. Legat et al. 2014, Jacobsen et al. 2016), and the decline and associated harvest restrictions (e.g. WRRB 2016) have resulted in hardships in several communities. In addition, this herd was harvested by big-game outfitters and by NWT resident hunters until 2010 (Adamczewski et al. 2009, Boulanger et al. 2011).

This report describes results of a calving ground photo-survey of the Bathurst caribou herd conducted during June of 2018. A survey of the Bluenose-East herd's calving grounds west of Kugluktuk (Figure 2) was carried out at the same time and the results are reported separately (Boulanger et al. 2019). A survey of the Beverly calving grounds in the Queen Maud Gulf area was also carried out by biologists with the Government of NU (GN) in June 2018 and those results will also be reported separately (Campbell et al. 2019). The Beverly systematic survey transects began next to the Bathurst survey transects east of Bathurst Inlet, and transects were also flown between the Bathurst and Bluenose-East calving grounds, resulting in continuous coverage of the three calving grounds and areas between them.

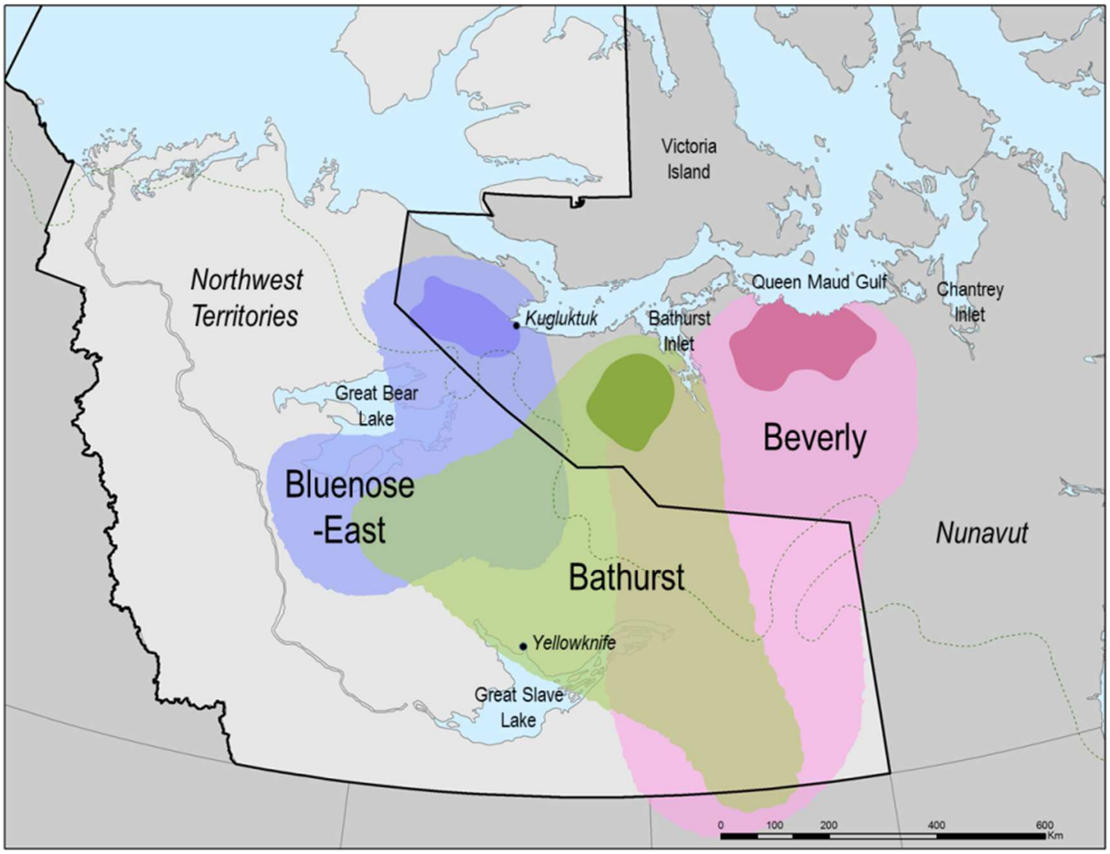

Figure 2: Annual ranges and calving grounds of the Bluenose-East, Bathurst, and Beverly [1] herds, based on accumulated radio collar locations of cows (Nagy et al. 2011). Other herd ranges west and east of these three herds were omitted for simplicity.

Calving ground photo surveys of the Bathurst herd have been carried out since the 1980s and the herd reached peak numbers estimated at 472,000 in 1986 (Figure 3). Surveys have been carried out at 3-year intervals since 2003 when a substantial decline in the herd was detected. The herd initially declined slowly in the 1990s and then at a more rapid pace after 2003. The most rapid decline was between 2006 and 2009 when the herd decreased from over 100,000 to just 32,000 in three years. A demographic evaluation of the herd's decline until 2009, including the role of harvest in the accelerated decline 2006-2009, was carried

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

out by Boulanger et al. (2011). The last calving photo survey of the Bathurst herd in 2015 was described by Boulanger et al. (2017).

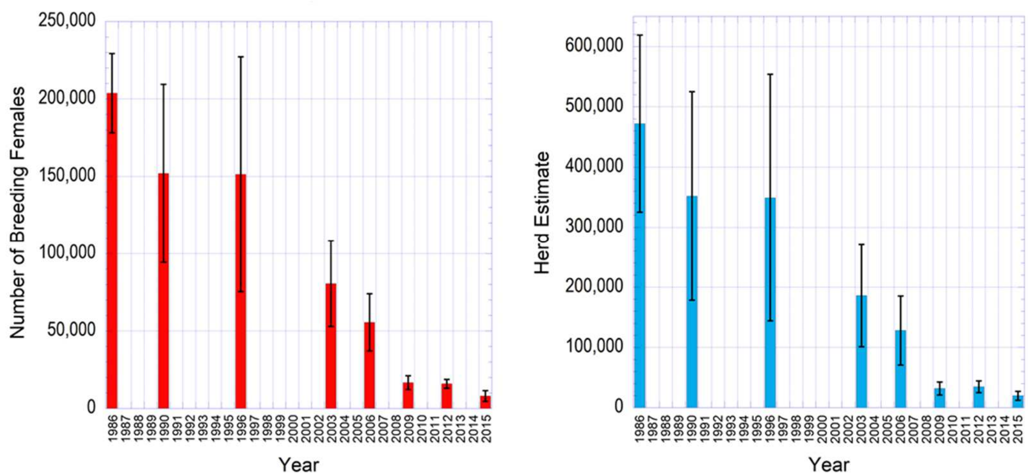

Figure 3: Estimates of breeding females on the left (red) and extrapolated herd size on the right (blue) from 1986-2015, based on calving ground photo surveys of the Bathurst caribou herd. Estimates are shown with 95% Confidence Intervals.

METHODS

Basic Methodology

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

1. Locations of collared female caribou and prior surveys of this herd's calving grounds were used to define the main area for the survey. Outlying adjacent areas were also flown.

2. A systematic reconnaissance survey was carried out before the peak of calving with transects spaced at 10 km intervals. The same 10 km grid system used to locate transects has been used since 2009. These allowed us to delineate areas where breeding and non-breeding females, bulls and yearlings were found on or near the calving ground. Timing of calving was assessed by evaluating the relative proportion of cows with newborn calves seen during the reconnaissance survey, and from reduced movement rates of collared cows associated with calving.

3. Using information on caribou density and composition derived from the reconnaissance survey, we defined strata (or survey blocks) that would be surveyed again at higher rates of coverage by photographic or visual transects. We allocated aerial photography to one stratum with the highest densities of breeding cows and the bulk of the collared cows. Two visual strata with lower densities of cows were also defined and flown east and west of Bathurst Inlet.

4. We initiated the helicopter-based composition survey soon after the photographic and visual surveys of the calving area. The composition survey crew classified larger groups (i.e. more than about 30-50 caribou) on the ground and classified smaller groups primarily from the air. Groups of caribou in each stratum were classified to determine the proportions of breeding and non-breeding cows, as well as bulls and yearlings.

5. We derived an estimate of breeding females using the estimates of total caribou at least one year old within each stratum, and the proportion of breeding females within that stratum. The total number of adult females was estimated from the proportion of females and the estimate of caribou at least one year old in the survey area.

6. The adult female estimate was used to extrapolate the total size of the Bathurst herd (caribou at least two years old) by accounting for males, using an estimate of the bull:cow ratio from a fall composition survey flown in October 2017.

7. Demographic data for the herd, the new estimates and collar movement data were used in trend analyses and population modeling to further evaluate population changes from 2015-2018 and their likely causes.

Analysis of Collared Caribou Data

Twenty-four collared female caribou were initially considered during the Bathurst June 2018 survey. Two of these reported rarely or erratically and were not considered in survey planning. A further two collars were well south of the survey area in June and not associated with any calving ground, and were also not considered in survey planning. Of the remaining 20 collars, three moved in May-June to the Queen Maud Gulf coastal calving ground with collared Beverly cows, and did not return. This left 17 active cow collars in the Bathurst Inlet area in June 2018. Of these 17, 12 were found within the eventual high density photo block, four in the eventual visual east block and one was just south of the eventual visual west block. Movement rates of these collared caribou females were monitored daily to help identify the timing of the peak of calving. Previous experience (e.g. Gunn et al. 2005, Boulanger et al. 2019) had shown that average daily movement rates of collared cows dropping below 5 km/day were a reliable indicator of the peak of calving.

Systematic Reconnaissance Survey to Delineate Strata

Kugluktuk was the main survey base of operations with two Cessna Caravans dedicated mostly to the Bluenose-East survey and to support the Bathurst survey; a third Cessna Caravan was based at the Ekati diamond mine (Figure 1). The Ekati Caravan flew most of the Bathurst reconnaissance survey and the visual strata, because the Caravans in Kugluktuk were grounded June 2-5 by poor weather. One of the two Caravans based at Kugluktuk flew part of the Bathurst visual survey strata.

Based on a systematic 10 km grid, reconnaissance transects were spaced at 10 km intervals to provide 8% coverage across the main calving area and in adjacent areas. 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/hour at an average altitude of 120 m above the ground to ensure that the strip width of the plane remained relatively constant.

Transects were spaced at 5 km intervals across the concentrated calving area to provide a more fine-grained assessment of the distribution and density of caribou. The initial focus was on delineating the annual concentrated calving area based primarily on the distribution of collared caribou cows. Once the main calving area had been covered, additional survey transects were flown adjacent to the concentrated calving area (north, west and south) to make sure that no substantial numbers of female caribou were missed. Using the systematic 10 km grid, transects were extended at least one 10 km segment past the last caribou seen.

The GN Beverly caribou survey started on June 5 and coverage started east of Bathurst Inlet and immediately adjacent to our systematic reconnaissance survey of the Bathurst calving ground (Campbell et al. 2019). We communicated daily with the GN survey crew during the Bathurst calving ground survey. We also flew survey transects west of the main Bathurst survey area at 20 km spacing to extend coverage to the Bluenose-East systematic survey area near Kugluktuk (Boulanger et al. 2019).

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. 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). Double observer methods have been used on other recent Bathurst calving ground photographic surveys (e.g. Boulanger et al. 2017). The two observers on the same side communicated to ensure that groups of caribou were not double counted.

On the reconnaissance survey, caribou groups were classified by whether they contained breeding females. Breeding females were cows with hard antlers or cows with newborn calves. A mature female with hard antlers is an indicator that the female has yet to give birth or has just given birth, as cows usually shed their antlers within a week after birth (Whitten 1995). Caribou groups were classified as non-breeders based on the absence of breeding females and newborn calves, and substantial representation of yearlings (identified by a short face and a small body), bulls (identified by thick, dark antlers in velvet and a large body), and non-antlered or females with short antlers in velvet. The speed of the fixed-wing aircraft and observer experience did not allow all caribou to be classified. Thus, the focus was on identifying breeding cows if they were present, and otherwise on the most common types of caribou present. In most cases, each group was recorded individually, but in some cases groups were combined if the numbers were larger and distribution was more continuous. Data were recorded on Trimble YUMA 2 tablets (Figure 4).

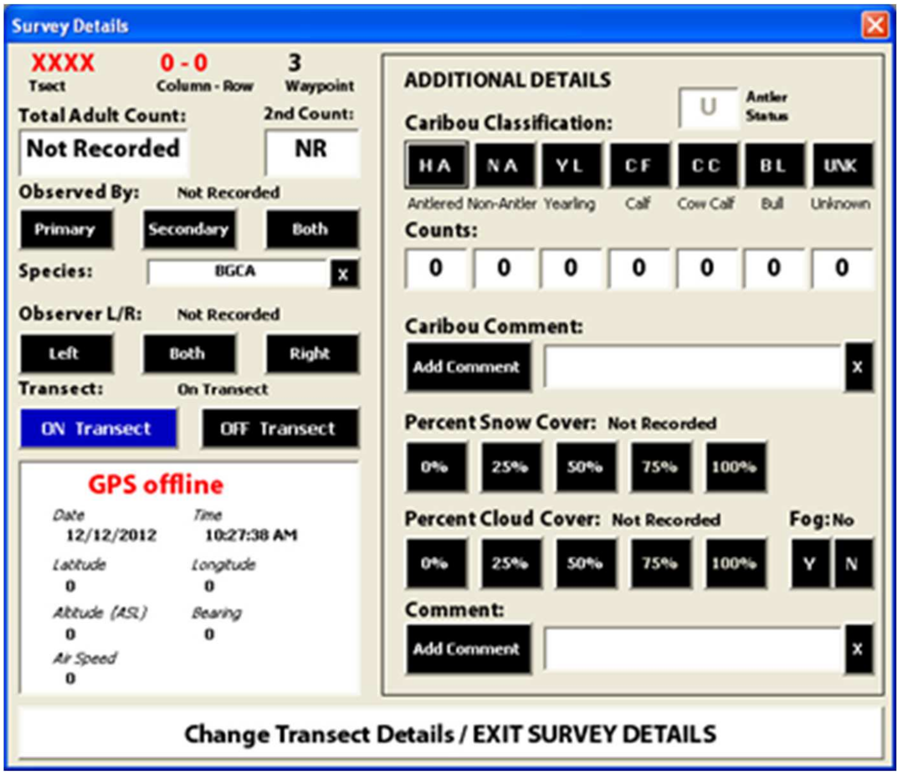

Figure 4: The tablet data entry screen used during reconnaissance and visual survey flying on the Bathurst June 2018 survey. A GPS waypoint was recorded for each observation. The unique segment unit number was also assigned by the software for each observation to summarize caribou density and composition along transect lines.

As each data point was entered, a real-time GPS waypoint was generated, allowing geo-referencing of the survey observations. Other large animals like moose, muskoxen and carnivores were also recorded with a GPS location.

North-south oriented transects were divided into 10 km segments to summarize the density and distribution of geo-referenced caribou counts. The density of each segment was estimated by dividing the count of caribou by the survey area of the segment (0.8 km strip width x 10 km = 8 km^2). The segment was classified as a breeder segment if at least one breeding female caribou or newborn calf was identified. Segments were then displayed spatially and used to delineate strata within the annual concentrated calving area based on the composition and density of the segments. During the survey, daily weather briefings were provided by Dr. Max Dupilka (Beaumont, AB) to assess current and future survey conditions.

Stratification and allocation of survey effort for photographic and visual estimates

The main objectives of the survey were to obtain precise and accurate estimates of breeding and adult female caribou on the calving ground, and to estimate overall adult herd size. To achieve this, the survey area was stratified using the results of the systematic reconnaissance survey, which is a process of grouping areas with similar densities into discrete strata. The stratum with the greatest caribou density was surveyed by the photo plane, with lower-density areas designated for visual surveys using a double observer method.

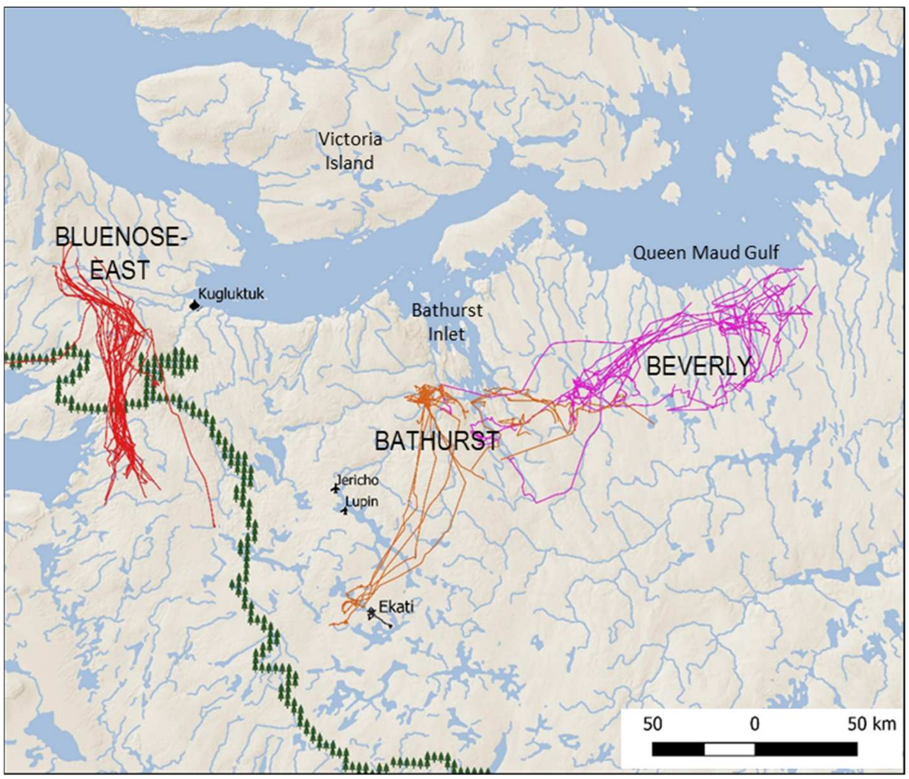

Figure 5: The northward paths of collared females (May 15 - June 11, 2018) from the Bluenose-East (red), Bathurst (orange), and Beverly (violet) caribou herds to their 2018 calving grounds.

In this survey, one photo stratum was defined west of Bathurst Inlet where most of the cows and most of the collared females (12 of 17) were observed. This was similar in size and location to the photo stratum in the June 2015 calving ground survey (Boulanger et al. 2017).

Five of the collared Bathurst female caribou showed an unusual movement in the spring that included a northward movement east of Bathurst Inlet and then a westward shift towards the Inlet and west of it at the beginning of June (Figure 5). As a result, a few Bathurst collared cows were found east and west of Bathurst Inlet at the time of the survey. The reconnaissance survey showed low numbers of caribou just west and east of Bathurst Inlet, with a majority of the caribou east of the Inlet being bulls and yearlings. We defined two low-density visual survey blocks, one east of Bathurst Inlet and one west of it.

Once the three survey strata were defined, an estimate of caribou numbers (animals at least 1+ year old) was derived from the reconnaissance data (Jolly 1969). The relative caribou numbers (and estimated variances) in each stratum were used to allocate survey effort and determine the numbers of transects to sample within each stratum.

Two approaches for allocation were considered for the aerial survey. First, optimal allocation was used to assign more effort to strata with higher densities, given that the amount of variation in counts is proportional to the relative density of caribou within the stratum. Optimal allocation was estimated using estimates of population size and variance for each stratum.

If strata were small, allocation was adjusted to ensure an adequate number of transect lines. For example, empirical results of previous surveys suggested that there should be a minimum of 10 transects per stratum to have good survey precision; in comparison, about 20 transects has been optimal for higher density areas. In general, coverage should be at least 15% with higher levels of coverage for higher density strata, for adequate precision. As populations become more clustered, a higher number of transect lines is required to achieve adequate precision (Thompson 1992, Krebs 1998).

Photographic Survey of High-density Stratum

GeodesyGroup Inc. aerial survey company (Calgary, AB) was contracted for the aerial photography in the 2018 June surveys. They used two survey aircraft, a Piper PA46-310P Jet-prop and a Piper PA31 Panther (Figure 6), each with a digital camera mounted in the belly of the aircraft. 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. To ensure timely completion, both aircraft were used for the Bathurst photo block and all photos (Bathurst and Bluenose-East) were taken on June 8 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.

Figure 6. Piper PA31 Panther aircraft used on Bathurst photo survey in June 2018 by GeodesyGroup Inc.

Caribou on the aerial photos were counted by a team of photo interpreters and supervised by Derek Fisher, president of GreenLink Forestry Inc., (Edmonton, AB) using specialized software and glasses that allowed three dimensional (3D) viewing of photographic images. Two of the authors (J. Boulanger and J. Adamczewski) visited the GreenLink office in Edmonton to gain greater familiarity with this process in fall 2018. The number of caribou counted was tallied by stratum and transect.

The exact survey strip width of photo transects was determined using the geo-referenced digital photos by GreenLink Forestry. Due to differences in topography, the actual strip width varied slightly for each transect flown. Population size (number of caribou at least one year old) within a stratum is usually estimated as the product of the total area of the stratum (A) and the mean density ($\overline{D}$) of caribou observed within the strata ($\widehat{N} = \overline{D}A$) where density is estimated as the sum of all caribou counted on transect divided by the total area of transect sampling ($\overline{D}$=caribou counted/total transect area). An equivalent estimate of mean density can be derived by first estimating transect-specific densities of caribou ($\widehat{D}_i = caribou_i/area_i$) where $caribou_i$ is the number of caribou counted in each transect and $area_i$ is the transect area (as estimated by transect length X strip width). Each transect density is then weighted by the relative length of each transect line (w_i) to estimate mean density ($\overline{D}$) for the stratum. More exactly, $\overline{D} = \sum_i^n \widehat{D}_i w_i / \sum_i^n w_i$ where the weight (w_i) is the ratio of the length of each transect line (l_i) to the mean length of all transect lines($w_i = l_i/\overline{l_i}$) and n is the total number of transects sampled. Using this weighting term accommodates for different lengths of transect lines within the stratum, ensuring that each transect line contributed to the estimate in proportion to its length. Population size is then estimated using the standard formula ($\widehat{N} = \overline{D}A$) (Norton-Griffiths 1978).

When survey aircraft first flew north to Kugluktuk on June 1, snow cover on the survey area was 90% or greater, and in some areas nearly 100%. Over the following ten days, however, snow melted rapidly and in many areas on June 8, snow cover was highly variable and patchy. This made spotting caribou by observers in the Caravans challenging, and also made complete counting of 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. Two approaches were used to address this with the aerial photos: (1) observers took extra time to search all photos carefully, approximately doubling the time these counts usually take, 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 used was to systematically resample a subset of photos to estimate overall sightability in the stratum using a second independent photo interpreter. This 2-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). The basic principle was to systematically resample the photo transects to allow an unbiased estimate of sightability from a subset of photos that were sampled by two independent observers. 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 sample with caribou being "marked" in the original count and then "re-marked" in the second count for each photo resampled. Using 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[2] was considered the most parsimonious, thus 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 Surveys of Low-density Strata

Visual surveys were conducted in two low density strata, one west of Bathurst Inlet and one east of it. The Caravans were used with two observers and a recorder on each side of the aircraft. The numbers of caribou sighted by observers were entered into the Trimble YUMA 2 tablet computers and summarized by transect and stratum.

A double observer method was used to estimate the sighting probability of caribou during visual surveys. The double observer method involves one primary observer who sits in the

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

front seat of the plane, a secondary observer who sits behind the primary observer, and a recorder on the same side of the plane. Analysis of the caribou seen by each of the two observers in each pair allows for an assessment of caribou that were likely missed, and how sighting probabilities are affected by snow cover, cloud condition and the abilities of individual observers. A detailed description of the double observer methods, analyses and results is given in Appendix 1. The methods have also been described in detail in other calving photo survey reports (e.g. Boulanger et al. 2019). The results were used to estimate the proportions of caribou that were likely missed, and numbers of caribou estimated on the two visual survey blocks east and west of Bathurst Inlet were corrected accordingly.

Composition Survey of Caribou on the Calving Ground

The composition survey was carried out June 13-16. Caribou were classified in strata that contained significant numbers of breeding females (based on the reconnaissance transects) to estimate proportions of breeding females and other sex and age classes. This survey was based on aerial and ground-based observations of caribou groups, which provided a more accurate and representative sampling procedure for caribou composition compared to the coarse classification criteria applied to caribou groups observed during the reconnaissance survey. For the composition survey, a helicopter (Aerospatiale A-Star 350 BA) was used to systematically sample groups of caribou throughout the photographic stratum and the two visual strata.

Search effort (i.e. helicopter flight hours) was allocated primarily to the high-density photographic stratum and was distributed within the stratum by developing a predetermined flight route that systematically covered the stratum, and which was subsequently loaded in to a portable GPS unit. Caribou groups encountered during the flight route were classified and their locations stored. The most recent caribou collar locations were also stored as waypoints in the GPS unit, which permitted the navigator/observer to ensure that those general areas were searched. By comparing the actual flight track to the planned route and collar locations, the navigator/observer maintained a systematic search pattern through the stratum and ensured that a caribou group was classified only once. Search effort was also distributed within the visual survey strata in a similar manner, but fewer hours were flown within those two strata.

Caribou groups that comprised ~<50 individuals were classified from the air by a front-seat observer using motion-stabilized binoculars. Classified caribou counts were called out to a rear-seat data recorder who entered the data into a computer tablet. Caribou groups that were generally greater than 50-100 animals were classified on the ground to minimize potential disturbance. The pilot landed the helicopter a few hundred meters from the main group of caribou, upon which the survey team would walk to a suitable position to observe and sample the animals. Using binoculars or a spotting scope, the observer scanned across the group(s) to avoid double counting and called out classified caribou to the data recorder. In larger groups, classification did not include the entire group; the focus was on a representative sample of each group and on limiting disturbance to caribou.

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

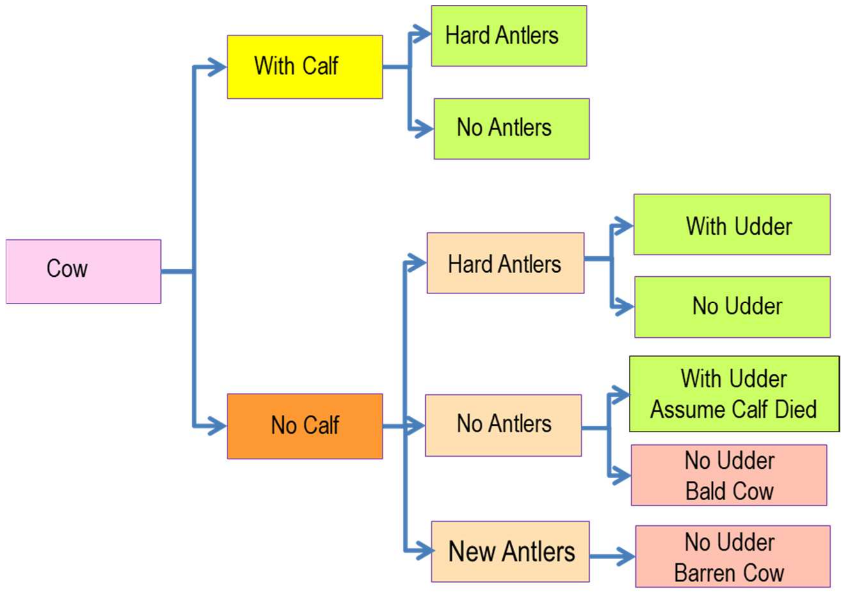

Figure 7: Classification of females used in composition survey of Bathurst caribou in June 2018. Green-shaded boxes were all classified as breeding females (diagram adapted from Gunn et al. 1997). Udder observation refers to a distended udder in a cow that has given birth. Hard antlers are from the previous year, and are distinct from new antlers growing in velvet.

The number of caribou in each group was summed 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 (SEs) and percentile-based confidence limits for the proportion of breeding caribou.

Estimation of Breeding Females and Adult Females

The numbers of breeding females were estimated by multiplying the estimate of total (at least one year old) caribou 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 was estimated by multiplying the estimate of total (at least one year old) caribou 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.

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).

Estimation of Adult Herd Size

Total herd size was estimated using two approaches. The first approach, which had been used in earlier calving ground surveys, assumed a fixed pregnancy rate for adult females, whereas the second approach avoided this assumption.

Estimation of Herd Size Assuming Fixed Pregnancy Rate and Estimated Sex Ratio

As a first step, the total number of adult females (at least two years old) in the herd was estimated by dividing the estimate of breeding females on the calving ground by an assumed pregnancy rate of 72% (Dauphiné 1976, Heard and Williams 1991). This pregnancy rate was based on a large sample of several hundred Qamanirjuaq caribou in the 1960s (Dauphiné 1976). The estimate of total females was then divided by the estimated proportion of females in the herd based on a bull:cow ratio from a fall composition survey conducted in October of 2017, to provide an estimate of total adult caribou in the herd (original methods described in Heard 1985, Heard and Williams 1991). This accounts for the bulls in the herd, very few of which are on the calving grounds in June. This estimator assumes that all breeding females were within survey strata areas during the calving ground survey and that the pregnancy rate of Bathurst caribou was 72% for 2017-2018. Note that this estimate corresponds to adult caribou at least two years old and does not include yearlings because yearling female caribou are not considered sexually mature.

Estimation of Herd Size Based on Estimates of Adult Females and Estimated Sex Ratio

An alternative extrapolated herd size estimator was developed to account for the effect of variable pregnancy rates as part of the 2014 Qamanirjuaq caribou herd survey (Campbell et al. 2015), and has been used in other recent calving photo surveys for the Bathurst herd (Boulanger et al. 2017), as well as the Bluenose-East herd (Adamczewski et al. 2017, Boulanger et al. 2019). This estimator first uses data from the composition survey to estimate the total proportion of adult females (breeding and non-breeding) and the numbers of adult females in each of the survey strata. The estimate of total adult females is then divided by the proportion of adult females (cows) in the herd from one or more fall composition surveys. This accounts for the bulls in the herd, very few of which are on the calving grounds in June. Using this approach, the fixed pregnancy rate is eliminated from the estimation procedure. Pregnancy rates do vary depending on cow condition (Cameron et al. 1993, Russell et al. 1998). This estimate assumes that all adult females (breeding and non-breeding) were within the photographic and visual survey strata during the calving ground survey. It makes no assumption about the pregnancy rate of the females and does not include the yearlings.

In calving ground photographic surveys since the 2014 Qamanirjuaq survey (Campbell et al. 2015), the estimate of females based on total adult females on the calving ground survey area, and adjusted for the bull:cow ratio from a recent fall survey, has become the preferred way for Government of the NWT (GNWT) Department of Environment and Natural Resources (ENR) of estimating herd size from these surveys. With the current sample of collared cows and extensive flying, it has become possible to reliably define the full distribution of the females in the Bathurst herd. Using survey-specific estimates of breeding and non-breeding cows, together with a recent estimate of herd sex ratio, is considered a more robust method of extrapolating to herd size, rather than assuming a constant pregnancy rate that ignores this source of variation. This method also increases the precision of the overall herd estimate.

Trends in Numbers of Breeding and Adult Females

As an initial step, a comparison of the estimates from the 2015 and 2018 surveys was made using a t-test (Heard and Williams 1990), with gross and annual rates of changes estimated from the ratio of estimates.

Longer term trends 2010-2018 were estimated using Bayesian state space models, which are similar to previously used regression methods (Ordinary Least Squares, OLS, as described in Boulanger et al. 2011). However, hierarchical Bayesian models allow more flexible modeling of variation in trend through the use of random effects (Humbert et al.

2009, Kery and Royle 2016). This general approach is described further in the demographic model analysis in the next section. An underlying exponential rate of change was assumed with estimates of λ (where $\lambda = N_{t+1}/N_t$). If λ=1 then a population is stable; values > or <1 indicate increasing and declining populations. The rate of decline was also estimated as 1-λ.

Survival Rate Analyses from Collared Cows

Collar data for female caribou 1996-2018 were compiled for the Bathurst caribou herd by GNWT ENR staff. 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 then summarized by month as live or dead caribou. Caribou whose collars failed or were scheduled to drop off were censored 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.

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

One of the most important questions for the Bathurst herd was whether the adult female segment of the population had declined since the last survey in 2015. The most direct measure that indicates the status of breeding females is their survival rate, which is the proportion of breeding females that survive from one year to the next. This metric, along with productivity (proportion of calves produced per adult female each year that survive their first year of life) largely determines the overall population trend. For example, if breeding female survival is high then productivity in previous years can be relatively low and the overall trend in breeding females can be stable. Alternatively, if calf productivity is consistently high, then slight reductions in adult survival rate can be tolerated. The interaction of these various indicators can be difficult to interpret and a population model can help increase understanding of herd demography.

We used a Bayesian state space IPM (Buckland et al. 2004, Kery and Schaub 2012) based upon the original (OLS) model (White and Lubow 2002) developed for the Bathurst herd (Boulanger et al. 2011) to further explore demographic trends for the Bathurst herd. This work was in collaboration with a Bayesian statistician/modeller (Joe Thorley-Poisson Consulting) (Thorley 2017, Ramey et al. 2018, Thorley and Boulanger 2019). We note that the underlying demographic model used for the hierarchical Bayesian state space model 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. Appendix 2 provides details on the Bayesian IPM state space modeling, including the base R code used in the analysis.

We used breeding female estimates, as well as calf-cow ratios, bull-cow ratios (Cluff et al. 2016, Cluff unpublished data), estimates of the proportion of breeding females, and adult female survival rates from collared caribou to estimate the most likely adult female survival values that would result in the observed trends in all of the demographic indicators for the Bathurst herd. Calf-cow ratios were recorded during fall (late October) and spring (late March - April) composition surveys whereas proportion of breeding females was measured during June composition surveys conducted on the calving ground. Proportion of females breeding was estimated as the ratio of breeding females to adult females from each calving ground survey.

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); this structure is identical to the OLS modeling (Boulanger et al. 2011) used previously on the Bathurst and Bluenose-East herds.

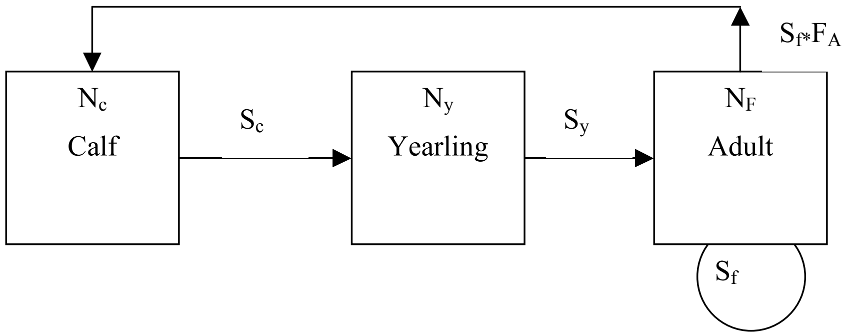

Figure 8: Underlying stage matrix life history diagram for the caribou demographic model used for Bathurst caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates 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.

We used the entire Bathurst demographic data set that started in the 1980s (Boulanger et al. 2011, Boulanger 2015) for the analysis but focused modeling efforts and inference on the more recent years, i.e., since 2014. The timeline of recruitment relative to survey years is illustrated in Table 1. It was assumed that a calf born in 2010 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). It was considered a non-breeder until 2013. Calves born in 2014 and 2015 had the most direct bearing on the number of new breeding females on the 2018 calving ground that were not accounted for in the 2015 breeding female estimate.

Table 1: A schematic of the assumed timeline 2011-2018 in the Bayesian IPM analysis of Bathurst caribou in which calves born are recruited into the breeding female segment (green boxes) of the population. Calves born prior to 2013 were counted as breeding females in the 2013 and 2015 surveys. Calves born in 2014 and 2015 recruited to become breeding females in the 2018 survey.

Calf Born	**Survey years 2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
2010	yearling	non-breeder	breeder	breeder	breeder	breeder	breeder	breeder
2011	calf	yearling	non-breeder	breeder	breeder	breeder	breeder	breeder
2012		calf	yearling	non-breeder	breeder	breeder	breeder	breeder
2013			calf	yearling	non-breeder	breeder	breeder	breeder
2014				calf	yearling	non-breeder	breeder	breeder
2015					calf	yearling	non-breeder	breeder
2016						calf	yearling	non-breeder

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 estimate cow and bull abundance each year. Figure 9 shows the rates used which show an increasing harvest rate up to 2010, when harvest was reduced significantly. The harvest numbers, estimated cow and bull population sizes are given in Appendix 2.

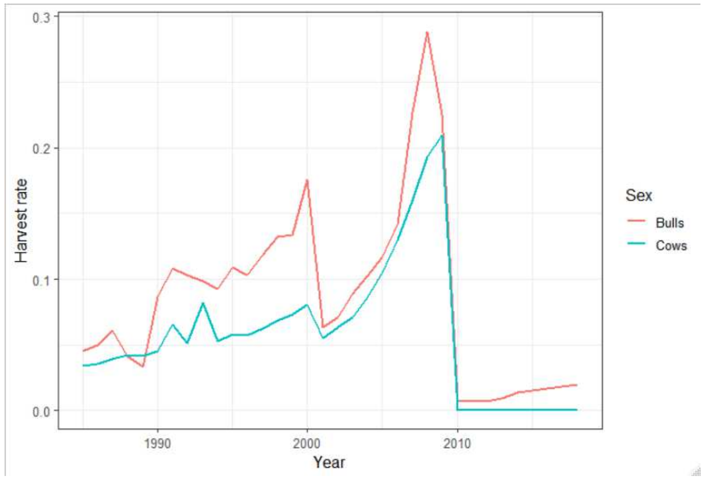

Figure 9: Harvest rates used as inputs into the demographic model. See Appendix 2 for actual harvest numbers and rates used in the model.

In 2018, three of 11 known Bathurst cow collars calved on the Queen Maud Gulf/Beverly calving ground which likely reduced the estimates of Bathurst breeding females used as an input of the model. The demographic model defines the Bathurst caribou herd as the population of caribou that utilized the Bathurst calving ground in the previous year (i.e. 2017). Collared caribou are included in the survival analysis if they utilized the Bathurst calving ground previously or if they were collared in 2018 in the vicinity of known Bathurst cows. In this context, the estimated survival rates from the demographic model are potentially influenced by emigration to the Queen Maud Gulf of adult cows. More precisely, the observed survival of cows is a function of both true survival and fidelity of cows to the calving ground. Low sample sizes of known Bathurst collared cows (11 in 2018) as well as high historic fidelity of caribou to the Bathurst calving ground challenged modeling of cow fidelity. We conducted a sensitivity analysis where the demographic model was run with and without the 2018 estimate to determine how much the 2018 emigration event might have affected demographic parameters. Of most interest was the estimate of cow survival, however of additional interest was the resulting estimate of adult cows when the 2018 estimate and emigration event were not part of the input data set, as described in the next section. As discussed later, more elaborate methods to model fidelity of caribou will be considered in future modeling efforts.

Estimation of Bathurst herd, including caribou that emigrated to Queen Maud Gulf

The estimates of adult females and herd size for the Bathurst herd in 2018 were influenced by movement of known Bathurst cows to the Queen Maud Gulf/Beverly calving ground. Of interest was the potential size of the Bathurst herd if this emigration event had not occurred. We used three approaches to initially assess how emigration of Bathurst cows to the Queen Maud Gulf coastal calving area may have influenced the Bathurst herd estimate.

1) The ratio of known Bathurst collared caribou calving in the Bathurst Inlet calving ground to total known Bathurst collars (8/11=0.727) provides a simple estimate of fidelity to the calving ground. Dividing the adult female estimate for the Bathurst calving ground by fidelity is therefore one estimate of total Bathurst adult females, including those occurring in the Queen Maud Gulf.

2) The Lincoln-Petersen mark-recapture estimator (N_{LP}) has been applied using proportion of collars in the survey area to estimate herd size for the Dolphin Union herd (Dumond and Lee 2013). The Lincoln-Petersen formula is N_{LP}= (((M+1)*(C+1))/(R+1))-1. In this case, M equals the number of known female collared caribou (11), R equals the number of known collared female caribou detected in the calving ground area (8), and C equals 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 collars and the adult female estimate ($var(N_{LP}) = N_{LP}^2(CV^2(p_{LP}) + CV^2(N_{AF}))$ where CV^2=(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). This estimator is a variation on the first estimator above.

3) The Lincoln-Petersen estimator of adult females was challenged by the low sample size of known Bathurst herd collared caribou (11) and therefore results should be interpreted cautiously. An alternative estimate of caribou was derived using the demographic model with the 2018 breeding female estimate not included in the input

data set. This amounts to a projection of likely herd size if no emigration had occurred and all Bathurst cows calved on the traditional Bathurst calving ground. In this case an extrapolated herd estimate was only influenced by collar survival rates, previous survey estimates, and composition survey results, thus the estimate was not influenced by emigration of adult cows to the Queen Maud Gulf coastal calving area. This estimate was compared to the demographic model's projected 2018 estimate of cows.

RESULTS

Survey conditions

Weather conditions were challenging due to the late spring with higher than normal snow cover in most of the annual concentrated calving area (Figure 10). At the beginning of the survey on June 1, snow cover was more than 90% in most areas but snow melted rapidly during the first 10 days of June. On June 8 and 9, snow cover varied between ten and 80%. Most areas had about 50% snow cover and much of it was a "salt-and-pepper" patchy mosaic. This made caribou more difficult to see. We reasoned, however, that aerial photo coverage of the one main concentration of calving cows would still provide an accurate estimate that would account for at least 80% of the female caribou in the survey area. The rationale was that caribou would still be reliably seen on high-resolution photos that could be searched carefully and repeatedly with a 3D projection. In addition, the sightability of caribou on photos could be estimated using independent observers.

Figure 10: Photos of variable Bathurst survey conditions during visual surveys near Bathurst Inlet on June 9, 2018, the day after photo surveys were conducted (photos J. Adamczewski). Snow cover in most areas was patchy and ranged from about 80% (top right) to about 10% (bottom right). A view of Bathurst Inlet is shown at top left.

Movement Rates of Collared Female Caribou

The locations of 17 collared female caribou that occurred in or around the Bathurst survey area were monitored throughout the June survey to assess movement rates. The peak of calving is considered close when the majority of collared female caribou exhibit movement rates of less than 5 km/day (Gunn and Russell 2008). Using this parameter, we surmised that the peak of calving was near on June 8, when mean daily movement rates were on average below 5 km for the radio collared caribou (Figure 11). Movement rates remained below 5 km/day for the next week. The peak of calving was further verified from observations of substantial numbers of cows with calves from the visual survey flying on June 8 and 9.

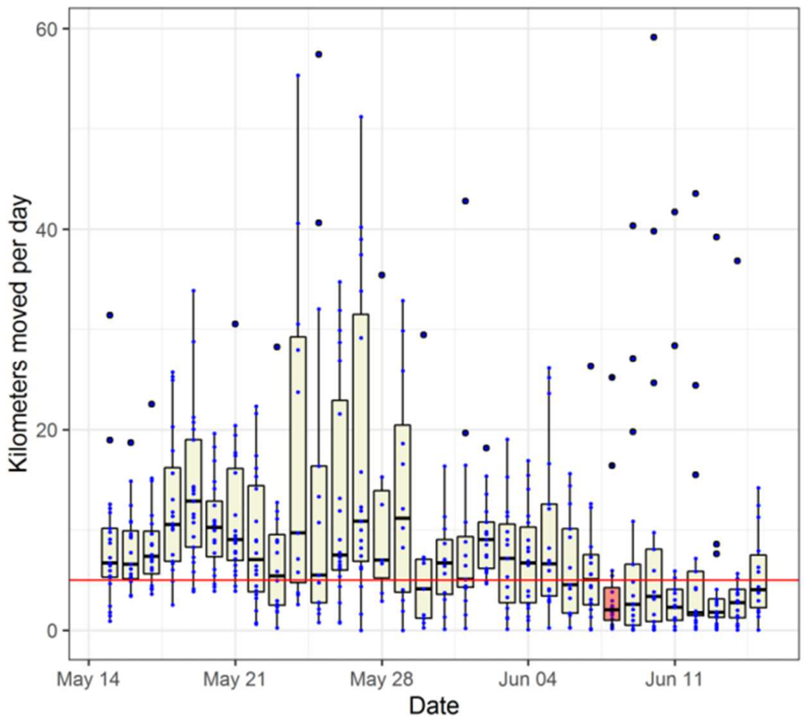

Figure 11: Movement rates of female collared caribou (n=17) on or around the Bathurst calving ground before and during calving in June 2018. The boxplots contain the 25th and 75th percentile of the data with the median shown by the central bar in each plot. The ranges up to the 95th percentile are depicted by the lines with outlier points shown as larger dots. The red line indicates a movement rate of 5 km/day. The movement rates of collared cows on June 8, the date of the photo survey, are highlighted in red. Visual strata were surveyed on June 8 and 9.

Collared Caribou Movements Leading up to June 2018 Survey

Our objectives for the reconnaissance survey were to map the distribution of adult and breeding females and define the concentrated calving area for the Bathurst herd. Collar movements and initial reconnaissance flying demonstrated an unusual distribution of caribou in the Bathurst Inlet area, which affected the way in which the Bathurst survey was designed and flown. An explanation of these collar movements with a sequence of maps is given here to explain the survey design.

In most years, Bathurst collared cows are largely moving northward from wintering areas, and by early June the Bathurst cows are well separated from Bluenose-East cows that calve west of Kugluktuk and Beverly cows that calve well east of Bathurst Inlet (Figure 12). In 2015 and 2016 the Bathurst herd showed these typical patterns. In 2017 the Bathurst herd was well mixed with the Bluenose-East herd, as shown by the southern ends of the collar trails that diverged in May and June, but cows separated well by the beginning of June. There was also substantial winter mixing of the Bathurst collared cows with Beverly collared cows, most Bathurst cows wintered on the tundra, and some wintered east of Bathurst Inlet. In spring 2017, 5 collared Bathurst cows whose 2016 June locations were on the usual Bathurst calving ground were initially east of Bathurst Inlet, but all 5 cows moved west of Bathurst Inlet in early June 2017 (Figure 13).

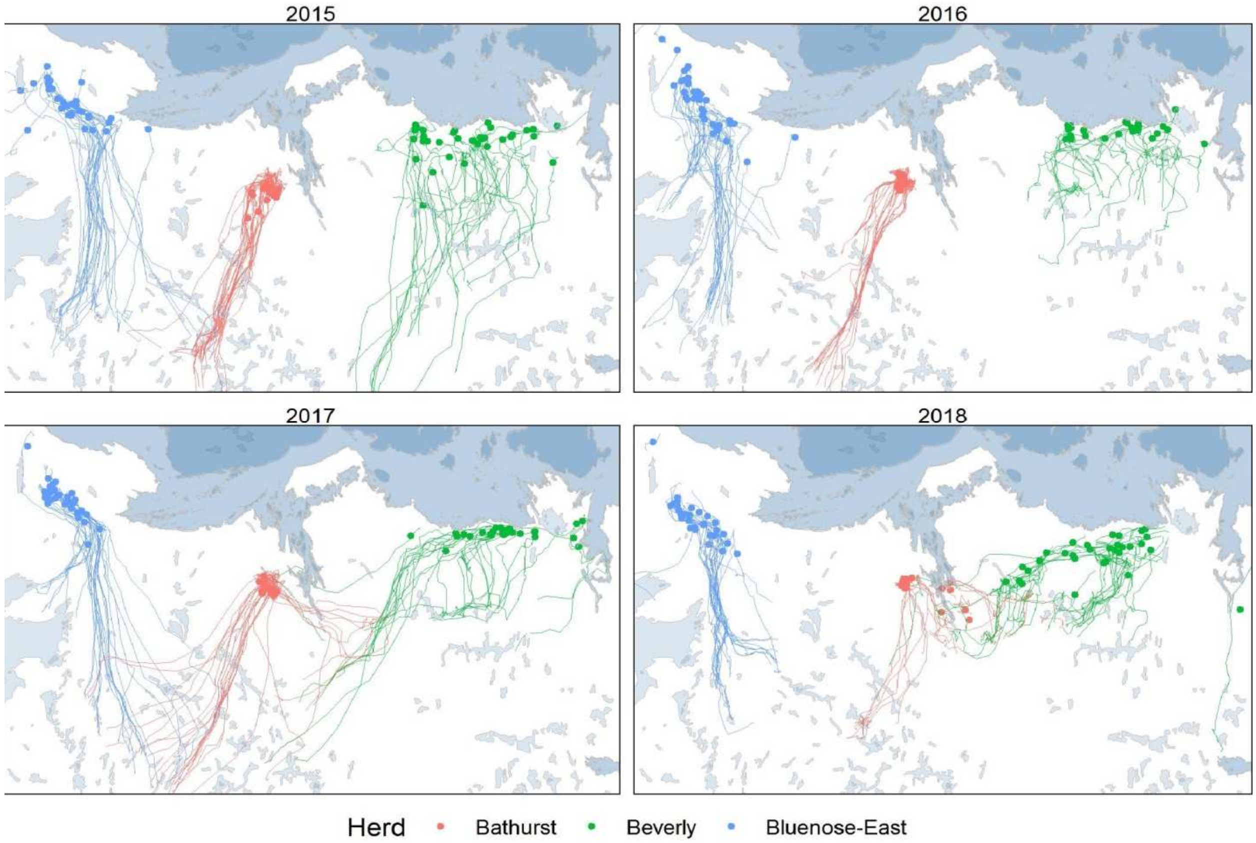

Figure 12: Spring migration paths of collared females from the Bluenose-East (blue), Bathurst (red) and Beverly (green) herds in 2015, 2016, 2017 and 2018 May 1 - June 10 of each year. The circles represent mean collared locations in the first two weeks of June for each year. Note that in June 2018 three of the known Bathurst collars (red dots) were in the main cluster of Beverly collars (blue dots); these are more easily seen in Figure 15b. Collar data are from GNWT and GN.

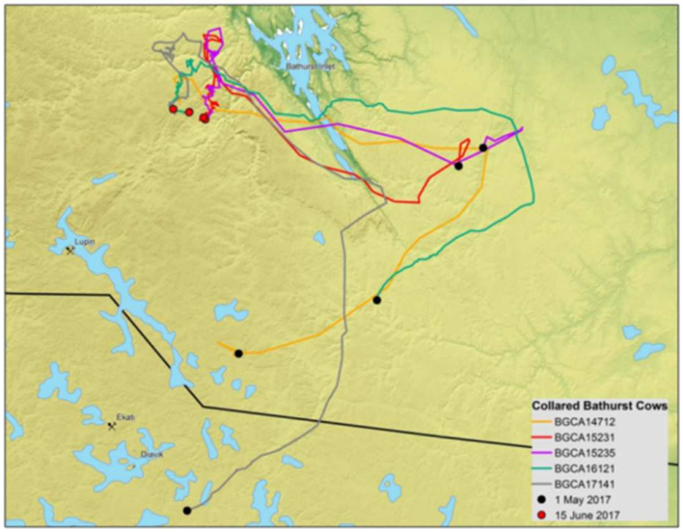

Figure 13: Spring migration paths of five collared Bathurst cows May 1 - June 15, 2017. All five cows were known to have been on the traditional Bathurst calving ground in June 2016. All wintered on the tundra and three wintered south or east of Bathurst Inlet with Beverly collared cows. Beverly collars are omitted for clarity.

In winter 2017-2018, collared Bluenose-East caribou wintered well separated from the Bathurst herd but Bathurst collared cows and bulls were well mixed with Beverly cows and bulls all winter (Figure 14). Bathurst collared cows all wintered on the tundra and some were east of Bathurst Inlet through the winter. In the spring, migration paths of Bathurst and Beverly collared cows showed continued mixing, with some Bathurst cows moving north into the main Beverly calving area (Figures 15a and 15b). Further south, collared Bathurst and Beverly bulls in the spring of 2018 also showed continued mixing and some movement into the Queen Maud Gulf area (Figure 16).

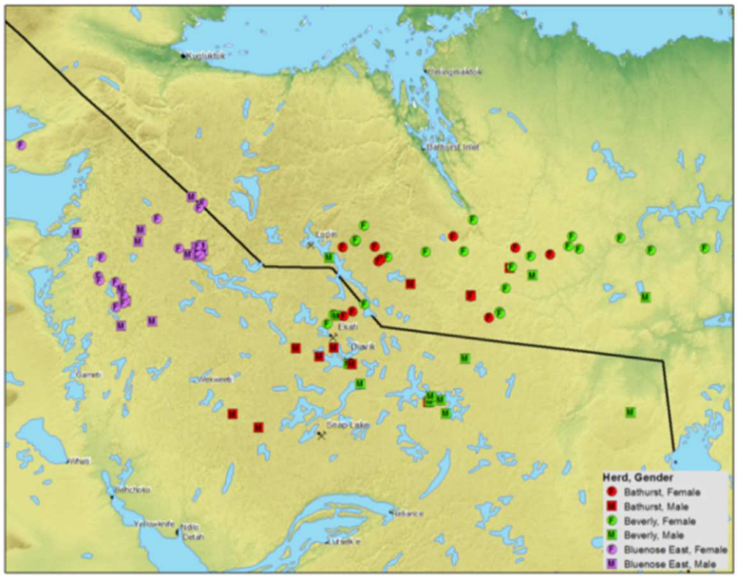

Figure 14: Winter locations (March 15, 2018) of Bluenose-East collared cows (18) and bulls (18) in purple, Bathurst cows (10) and bulls (10) in red, and Beverly cows (23) and bulls (12). The Bathurst and Beverly herds were mixed throughout winter 2017-2018.

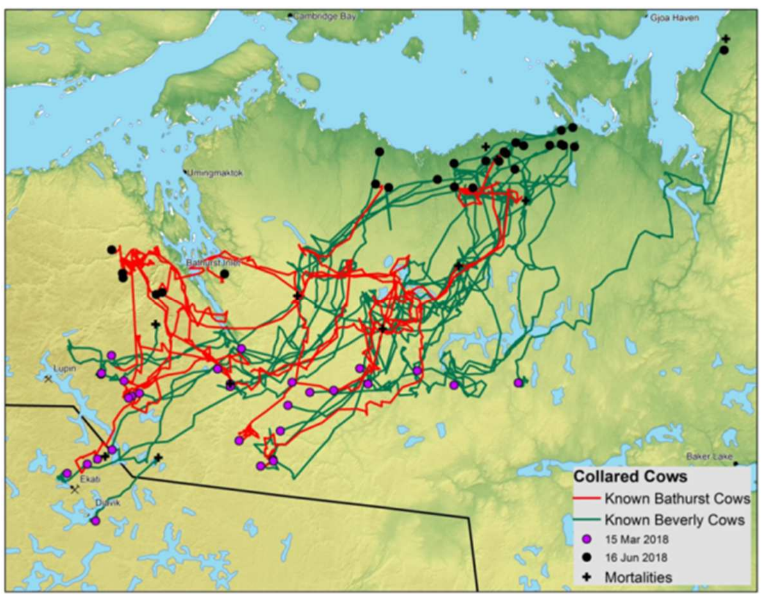

Figure 15a: Spring migration paths northward March 15 - June 16, 2018 of 11 known Bathurst collared cows (red) and 19 known Beverly cows (green). Purple dots are March 15 locations and indicative of wintering areas; black dots are June 16 locations.

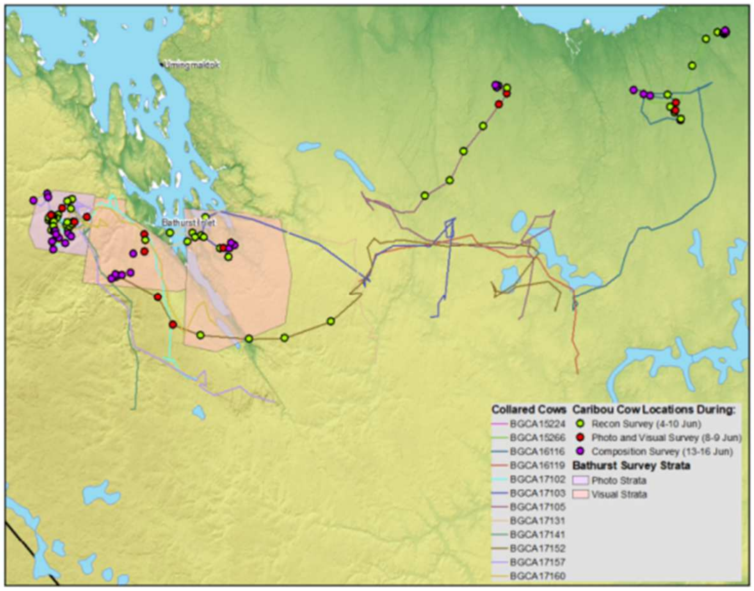

Figure 15b: Spring migration paths May 1 - June 16, 2018 of 11 known Bathurst collared cows, in relation to June 2018 Bathurst calving ground survey area. Eight collared Bathurst cows were within the Bathurst strata during the survey, while three were in the Queen Maud Gulf coastal calving area. Beverly collars are omitted for clarity. Light green dots were during the June 4-10 reconnaissance survey, red dots were at time of photo and visual flying, and purple dots were during the composition survey June 13-16.

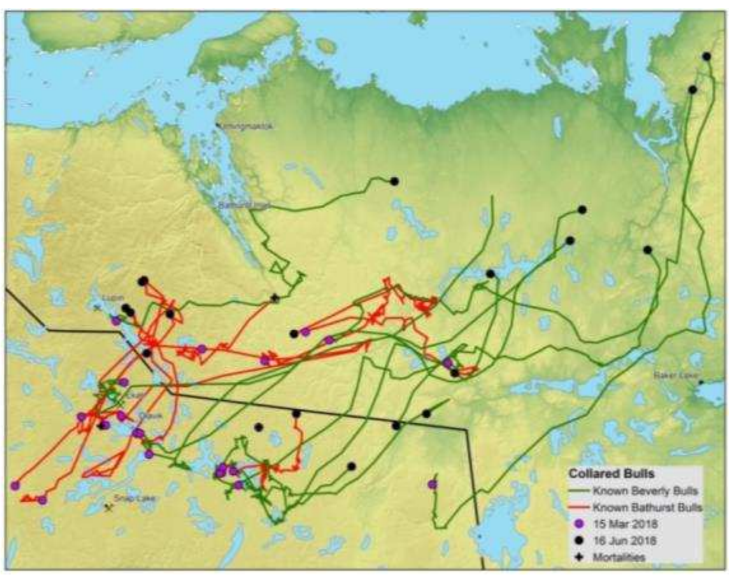

Figure 16: Spring movements (March 15 - June 16) of eight known Bathurst collared bulls and 11 known Beverly collared bulls in 2018.

For clarity, the movements of the 11 known Bathurst collared females are shown separately (Figure 15b). Of the 11 collared cows that were known to have calved on the Bathurst calving ground in 2017 or earlier, three moved well east of Bathurst Inlet and into the main calving area of the Beverly herd based on collared cows and the GN survey in June 2018. These three did not return to the calving ground that the Bathurst herd has used consistently since 1996, in June or thereafter. The remaining eight known collars were either west of Bathurst Inlet in the area the herd has calved in since 1996, or in the Bathurst Inlet area during the June survey period. There were an additional nine newly collared cows (collared winter 2017-2018) that were in the Bathurst Inlet area, thus 17 collared cows total in the Bathurst Inlet area. Of these 17, 12 were west of Bathurst Inlet in the traditional Bathurst calving area and five were east and west of the Inlet on June 8 (the day of the photo survey). These five showed a general westward movement during the initial two weeks of June (Figure 15b).

A further consideration in designing the Bathurst survey area was the observations from GN biologist M. Campbell and NU Tunngavik Incorporated (NTI) biologist D. Lee (pers. comm.) east of Bathurst Inlet, that showed consistent caribou trails in the snow from their first two survey lines with those trails moving westward. Further east, by contrast, all the caribou trails were more heavily used and led in a northeast direction, which followed the movements of the known Beverly cows to the central and eastern Queen Maud Gulf coastal calving area (Figure 15a).

Reconnaissance Survey to Delineate Strata

One Caravan based at the Ekati diamond mine flew the entire Bathurst reconnaissance survey June 4-10, 2018. The initial focus was on the areas with collared cows, and thereafter outlying areas were flown. Two other Caravans were based in Kugluktuk but these aircraft were unable to fly June 2-5 due to fog and low cloud in the Kugluktuk area. June 6-8 these two Caravans were primarily occupied with the Bluenose-East survey. A single day of clear weather with blue skies occurred on June 8, and on this day the Bathurst (one) and Bluenose-East photo blocks (two) were flown. The two Bathurst visual strata were surveyed on June 8 and 9, with one of the Kugluktuk Caravans assisting with covering the Visual East stratum. A summary of the fixed-wing flying on the Bathurst June 2018 survey is given in Table 2.

Table 2: Summary of reconnaissance and visual survey flying on the June 2018 Bathurst calving ground survey.

Date	Caravan 1 (Ekati)	Caravan 2 (Kugluktuk)
June 1	Arrive Ekati	Arrive Kugluktuk
June 4	Recon of core area at 10 km spacing	Grounded (weather)
June 5	Recon of core and surrounding area	Grounded (weather)
June 6	Recon of areas south and east of core area	Bluenose-East survey
June 7	Grounded (weather)	Grounded (weather)
June 8	Bathurst visual west block survey	Bluenose-East survey
June 9	Bathurst visual east block survey	Bathurst visual east block survey & lines between Bathurst and BNE
June 10	Recon lines to the west of Ekati & return to Yellowknife	Recon lines to the East of Kugluktuk & return to Yellowknife

Considering the collar movements of Bathurst and Beverly collared cows, the results of the Bathurst reconnaissance survey and the reconnaissance survey observations of the NU biologists, we reasoned that the Bathurst herd's main calving concentration as in past years was west of Bathurst Inlet with most of the collared Bathurst cows (12 of 17 in the Bathurst Inlet area) and that area should be the focus of the aerial photography. We reasoned further from the locations and movement patterns (generally westward) of the other 5 collared Bathurst cows just east and west of Bathurst Inlet, along with the westward-moving caribou trails reported by NU biologists, that a smaller portion of the Bathurst herd's cows were east and west of Bathurst Inlet, in much lower numbers, and these areas should be visual strata for the Bathurst survey. All known Beverly collared cows were by June 8 far east of Bathurst Inlet (Figure 15a), so it appeared there had been a separation of the two herds just east of Bathurst Inlet. The movement of three of the 11 known Bathurst cows to the main Beverly calving concentration in the Queen Maud Gulf, while based on a limited sample, suggested that a portion of the Bathurst herd's cows may have emigrated to join that herd (Figures 15a and 15b).

Reconnaissance flying included the areas west and east of Bathurst Inlet and all collared cows in the area (Figures 17a and 17b). Areas north, west and east were also flown extensively to make sure that no significant numbers of cows were missed. In the east, our reconnaissance lines adjoined the easternmost lines of the GN Beverly survey.

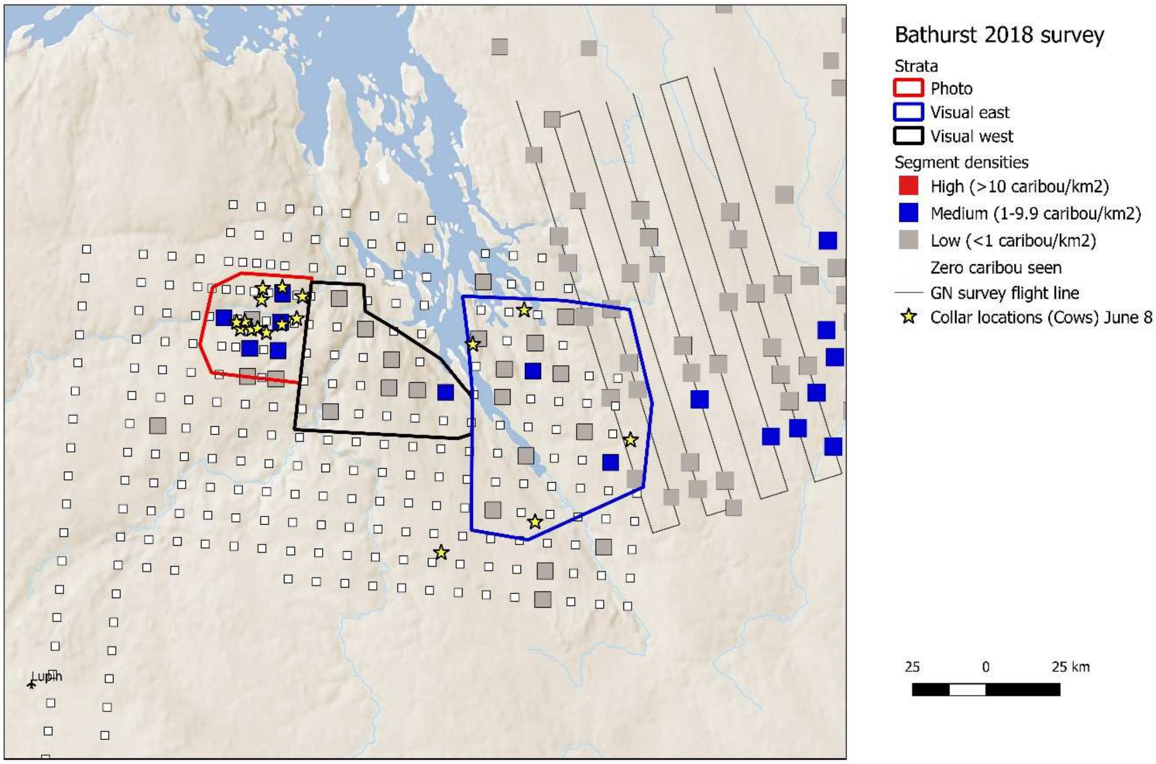

Figure 17a: Reconnaissance survey of the Bathurst calving ground in June 2018 with densities of caribou seen. White squares are from areas where no caribou were seen, grey squares are from low-density areas (< 1 caribou/km^2), and blue squares are from medium density areas (1-9.9 caribou/km^2). Gold stars show locations of collared female caribou on June 8. One caribou in the lower visual east did not return a location for June 8 and the June 7th location is shown. Full movement paths of collared caribou during the survey are shown in later sections of the report. Transects east of Bathurst Inlet were from the first day of flying on the GN Beverly survey in June 2018, courtesy of M. Campbell and D. Lee.

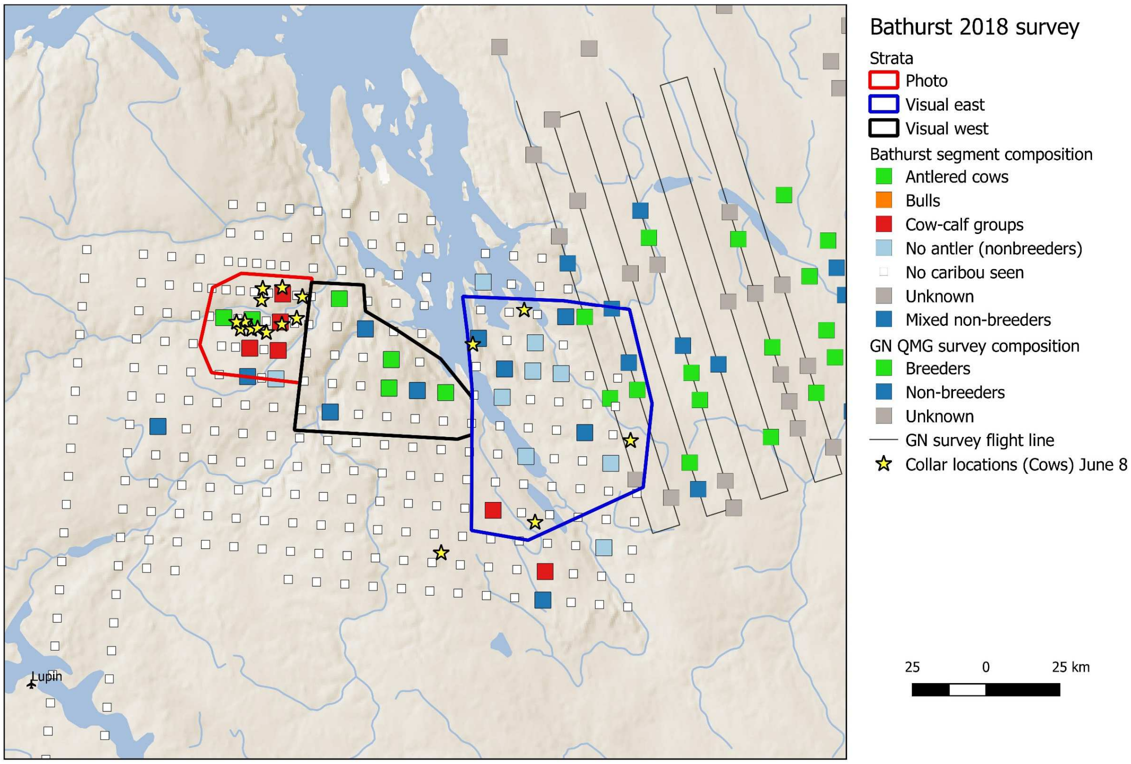

Figure 17b: Reconnaissance survey of the Bathurst calving ground in June 2018 with composition of caribou seen. Areas with cow-calf groups are red, areas with antlered cows are light green, and areas with non-breeders (non-breeding cows, bulls and yearlings) are blue. Gold stars are collared female caribou. Transects east of Bathurst Inlet were from the first day of flying on the GN Beverly survey in June 2018, courtesy of M. Campbell and D. Lee.

Stratification: Photo Stratum and Visual Strata

One photo stratum was defined for the Bathurst 2018 survey (Figures 17a and 17b), which included the majority of adult and breeding females and 12 of 17 collared cows in the survey area. This block was similar in size and location to the Bathurst photo block in June 2015 (Boulanger et al. 2017). Two lower density visual blocks were also defined: a Visual West block west of Bathurst Inlet and a Visual East block east of Bathurst Inlet.

Photo Stratum

With photo planes using high-resolution digital cameras, it is possible for the planes to fly at different altitudes. Flying at a higher altitude increases the strip width and reduces the number of pictures but also reduces the resolution of the pictures as indexed by ground sample distance (GSD). GSD is a term used in aerial photography to describe the distance between pixels on the ground for a photo sensor. In practical terms, the GSD for the aerial photos used in this survey translates into strip width and elevation AGL as follows (Table 3).

Table 3: GSD for photo sensor used on Bathurst June 2018 caribou survey, along with associated elevation AGL and photographed ground transect strip width. Typical elevation and strip width used in earlier film photo surveys are included for reference.

GSD (cm)	Elevation AGL (feet)	Strip width in m
4	2,187	692
5	2,734	866
6	3,281	1,039
7	3,828	1,212
8	4,374	1,385
9	4,921	1,558
10	5,468	1,731
Film Photos	2,000	914.3

With blue skies on June 8, the Bathurst photo stratum was flown at GSD 7 (average elevation 3,828 ft. (1,167 m) AGL) and a total of 1,715 photos were taken (Table 4, Figure 18).

Table 4: Stratum dimensions, transect dimensions, photo numbers and ground coverage for Bathurst photo survey block in June 2018. Actual coverage and photo numbers are in bold and underlined.

Photographic stratum dimensions				Photos at GSD (Elevation AGL in feet)			Coverage at GSD		
Area (km^2)	Average Transect Width (km)	Transects Sampled	Total transect length (km)	5 (2,734)	6 (3,281)	7 (3,828)	5	6	7
1,159	35	15	525	2,389	2,003	**<u>1,715</u>**	40%	48%	**<u>56%</u>**

Figure 18: Composite photo block west of Bathurst Inlet flown on June 8, 2018. The Hood River valley can be seen in an east-west direction in the upper half of the survey block.

Visual strata

The Bathurst reconnaissance survey was flown June 4-10 by a single plane based at Ekati. Given forecasted weather conditions for June 8 and 9, visual survey flying was designed to allow strata to be flown within two days, with one plane for the Visual West stratum and two planes for the Visual East stratum. Estimates of density from the reconnaissance data suggested that each stratum had relatively equal low densities of caribou (0.15 and 0.13 caribou/km^2 for west and east strata respectively) and therefore allocation of effort was similar for the two strata. Based on logistics 12 and 18 transects were flown in the west and east strata with resulting levels of coverage of 16 and 18% respectively. Dimensions of photo and visual strata are in Table 5.

Table 5: Final dimensions of photo and visual strata for the 2018 Bathurst calving photo survey.

Stratum	Total Transects Possible	# Sampled Transects	Area of stratum (km^2)	Average Strip width (km)	Transect area (km^2)	Coverage
Photo	27	15	1,227.3	1.29[A]	682.7	56%
West Visual	12	12	2,305.6	0.8	368.3	16%
East Visual	18	18	4,661.9	0.8	824.5	18%

Movements of collared caribou within and between reconnaissance and photo/visual blocks

As described earlier, 17 active cow collars were in the Bathurst Inlet area during the June 2018 survey, transmitted locations daily, and were used for survey planning. Twelve of these were in the photo stratum for the duration of the visual/photo survey (Figure 19). One collared cow moved from the Visual West to the Visual East stratum during the survey period, two were contained within the Visual East stratum and two moved out of the Visual East stratum during the visual survey. There was no location given for one of the caribou on June 8, however, it occurred in the stratum on June 7 but was out of the stratum on June 9. It was likely in the stratum during the survey based on the midpoint of the June 7 and June 9 locations (Figure 19). We note that reconnaissance flying to the south of the three survey blocks showed extremely low numbers of caribou present. Three additional collared cows had moved into the main Beverly calving ground far to the east and are not shown on this map.

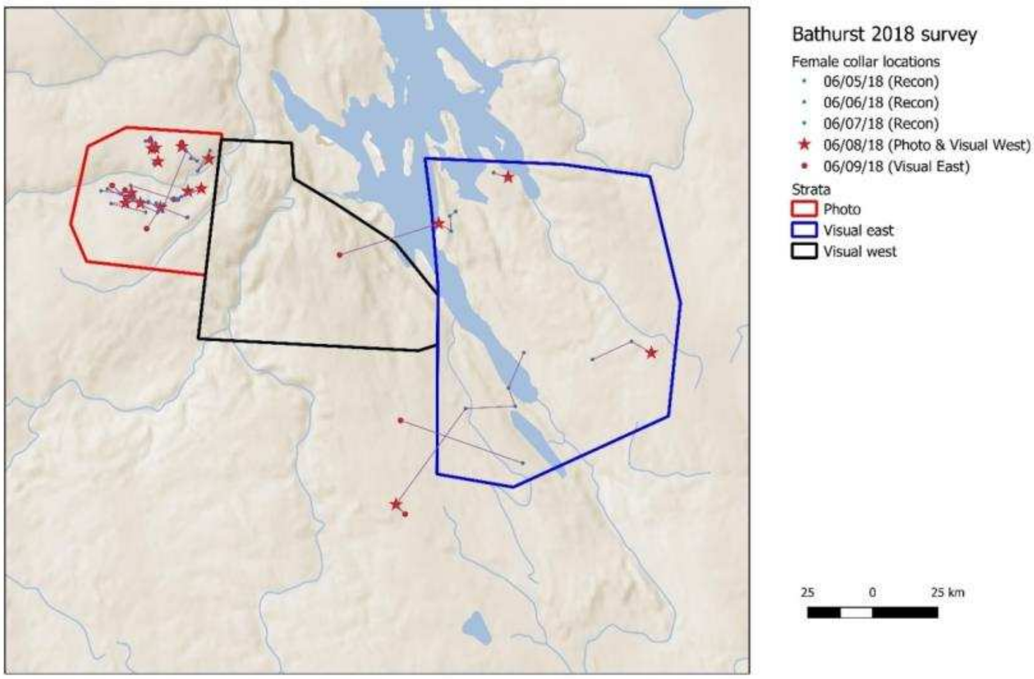

Figure 19: Locations of collared Bathurst female caribou and movements from the reconnaissance phase (June 5-7), photo survey (June 8th) and visual survey of the east stratum on June 9th. One collar near the south end of the Visual East block did not report a location on June 8, so no star is shown.

Collared caribou that had movement rates of greater than 5 km/day were mainly located within the central regions of strata, suggesting that the strata contained the range of caribou movements as indicated by collared caribou. The one collared cow south of the visual strata during the survey was in an area where almost no caribou were seen during the reconnaissance flying (see Figure 17).

In general, the observations of caribou in the Visual East and Visual West blocks confirmed the low numbers found during the reconnaissance survey (Figure 20).

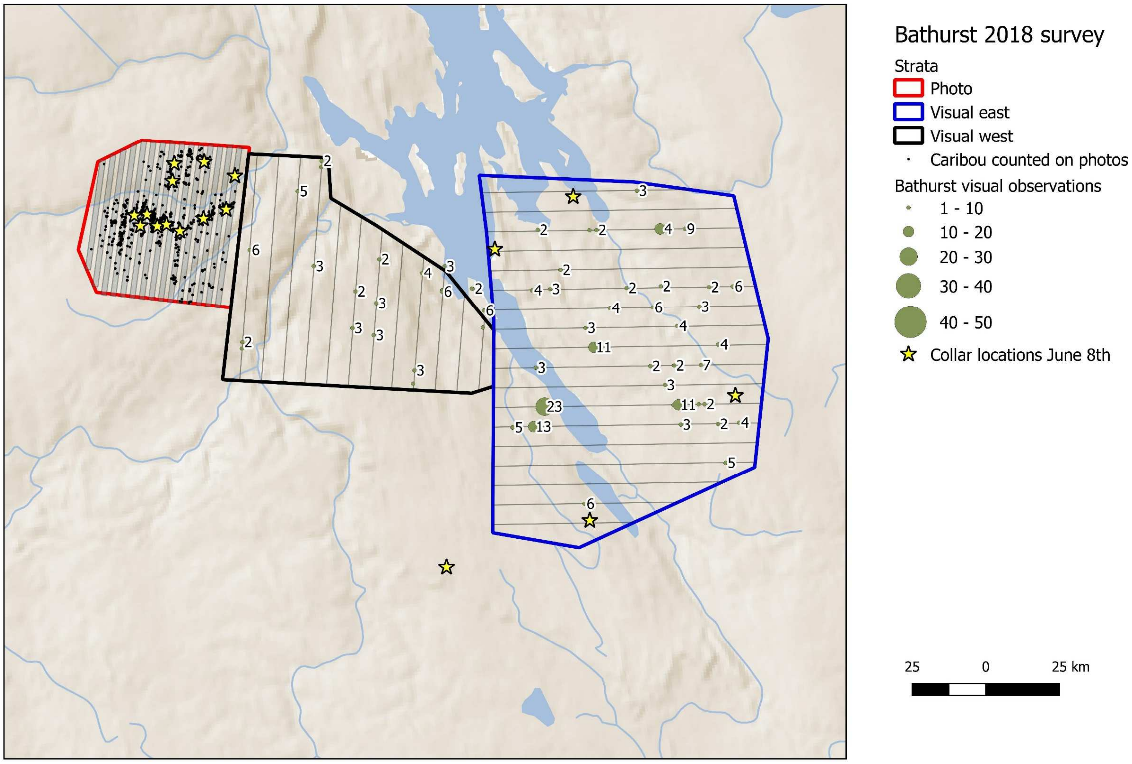

Figure 20: Map of Bathurst June 2018 survey blocks showing the locations of caribou groups seen in the photo block from photos and in the visual blocks from observations June 8 and 9. Relative group sizes for the visual blocks are shown as varying sizes of circles, but not for the groups seen in the photo block (too many).

Estimates of Caribou on Photo Stratum: Sightability

Photo interpreters found that the sightability of caribou on photos was influenced by snow cover. If the ground was bare caribou were readily visible (Figure 21), however, caribou were not as easy to see with patchy snow, particularly when caribou were at the edges of snow patches. Overall, it took nearly twice as long to count the 2018 aerial photos (Bathurst and Bluenose-East) as in the last photo surveys in 2015 when the ground was predominantly bare (D. Fisher, GreenLink Forestry Inc., pers. comm.), to allow for comprehensive searching of all photos.

Figure 21: A zoomed-in portion of one of the Bathurst aerial photos from June 2018 survey. Most caribou and their shadows are readily visible. A caribou on the edge of a snow patch in bottom left corner is less clearly visible. There are 23 caribou on this photo.

Initial quality control of photo counting was carried out by D. Fisher re-counting several hundred of the Bathurst and Bluenose-East photos counted by his staff. In addition, sightability of caribou on photos was estimated by having a 2nd observer from GreenLink Forestry independently re-count caribou on a subset of photos, without knowing what the first observer had found. The second observer was Derek Fisher, who is the most experienced observer of aerial photographs at the company.

The photo survey transect lines were resampled systematically using transects perpendicular to the original photo-plane transects. Two phases of sampling were conducted. In the first phase, transects were sampled regardless of whether caribou were detected in the original counts. In the second phase, photos closest to the first phase transect line that contained caribou in the first phase were resampled. Using this approach, we tested whether all caribou were detected on photos even when they were not detected originally. The second phase still was a systematic sample but increased the sample size of photos with caribou counts, which were most useful for cross validation purposes. Figure 22 shows the photo resampling design.

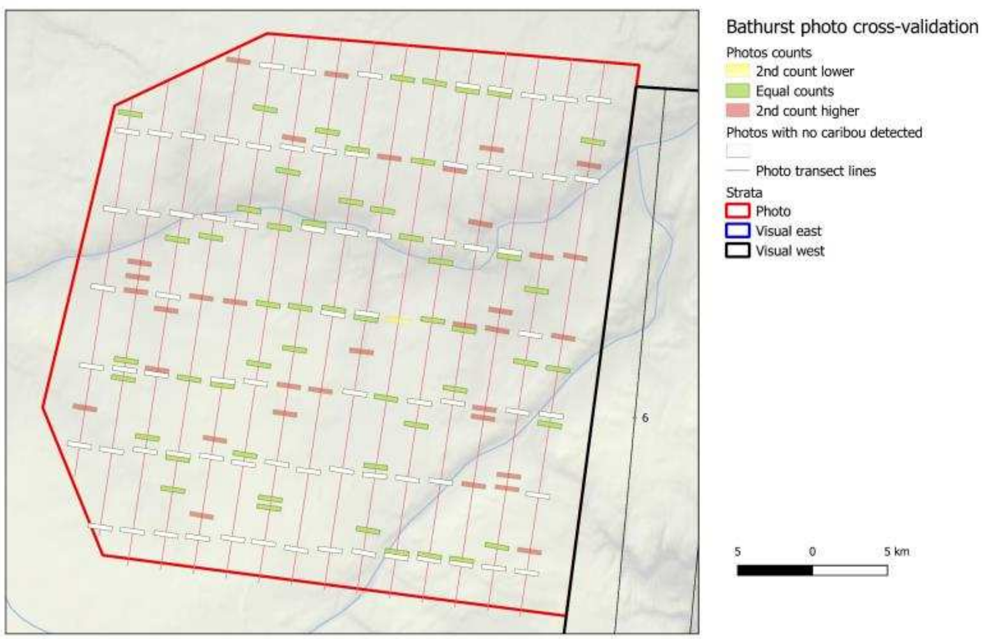

Figure 22: Systematic sampling design for cross validation of photos for the Bathurst June 2018 calving ground survey.

Overall, 161 photos were recounted, of which 87 contained caribou. Seventy-four additional caribou were counted in the second count, with a corresponding ratio of original to second count of 0.842 (Table 6). One assumption in this comparison is that the first and second counter were counting the same caribou on a given photo. To test this assumption the distances between points of counted caribou in the first and second count was measured in GIS to identify any counted caribou that were a further distance from the original counts.

This process did not identify any new caribou. One caribou was counted on a photo during the original counts but not counted in the second count. An additional 228 photos were re-sampled by similar means as part of the Bluenose-East June 2018 survey, with similar results (Boulanger et al. 2019).

Table 6: Summary of photo cross validation data set for Bathurst June 2018 aerial photos. The ratio of the original count to second count is an estimate of photo sightability.

Original count	Second count	New caribou counted in second count	Caribou not detected in second count	Original count/second count
393	467	74	1	0.842

This cross-validation process can be modeled as a two sample mark-recapture sample with caribou being "marked" in the original count and then be "re-marked" in the second count. Using 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 then used to estimate sightability. Table 7 below gives the results with the sightability from the first counter being very close to the ratio of the original to second count. The reason for this is that the second counter only missed one caribou not originally counted and therefore his sightability score was very high.

Table 7: Estimates of sightability for the first and second counters on the Bathurst June 2018 aerial photos, from the Huggins closed N model.

Counter	Estimate	SE	LCI	UCI	CV
First	0.841	0.017	0.805	0.872	2.01%
Second	0.997	0.003	0.982	1.000	0.25%

The variance estimate from program MARK assumes that all caribou counted are independent, which is likely violated given that in many cases caribou occurred in larger groups. The violation of this assumption leads to over-dispersion of binomial variances and a resulting negative bias. To confront this issue, we used a bootstrap method (Manly 1997) that bootstrapped based on caribou counted on photos. The assumption in this case is that counts of caribou on each photo are independent rather than all caribou counted being independent. The resulting estimate of SE was 0.042 with a coefficient of variation (CV) of 4.7% which is more realistic, and this was used for subsequent calculations. Future photo counting efforts should classify counted caribou in groups to allow more focused methods of estimating sightability variance.

Estimates of Total Caribou in Photo Stratum

Table 8 below gives the initial estimates of caribou in the photo stratum and the estimates adjusted for photo sightability. We also corrected the initial estimates for differential strip widths, as was done in the 2015 surveys. The photo-sightability estimate was calculated as the initial estimate divided by photo sightability. Variance for the photo sightability was calculated using the delta method (Buckland et al. 1993). The resulting estimate was about 800 caribou (16%) higher than the non-adjusted estimate.

Table 8: Initial estimates of abundance in survey strata, estimated photo sightability and corrected estimates of abundance with photo sightability for Bathurst June 2018 calving photo survey.

Initial estimate of N (not corrected)			Photo sightability			Photo-sightability corrected N estimate		
N	SE	CV	p	SE	CV	N	SE	CV
4,245.7	580.34	0.136	0.842	0.042	0.050	5,043.4	734.5	0.146

Double Observer Analysis and Estimates of Total Caribou in Visual Strata

Detailed descriptions of the double observer methods and results are provided in Appendix 1. Data from both the Bathurst and Bluenose-East surveys were combined as some survey crews flew portions of both surveys. Overall, double observer corrected estimates (using the MRDS R package) were about 5% higher than non-double observer estimates. Precision was lower than for uncorrected count-based estimates but still acceptable (Table 9).

Table 9: Standard strip transect and corrected double observer model estimates of caribou on Bathurst visual strata in 2018.

Stratum	Caribou	Standard estimate			Double observer corrected estimate				
	counted	Estimate	SE	CV	Estimate	SE	Confidence interval		CV
Visual West	88	551	132.1	24.0%	567	140.50	332	970	24.8%
Visual East	220	1,244	286.7	23.0%	1,309	332.70	773	2,216	25.4%
Total	369	1,795	151.7	17.6%	1,877	360.9	1,265	2,783	19.2%

Estimates of Total Caribou on the Calving Ground

The estimate of total caribou at least one year old on the calving ground (6,919) is given in Table 10 below. The CV was slightly high due to the aggregation of caribou (clumped distribution) in the photo stratum as well as the added variance from estimating sightability of caribou on the photos.

Table 10: Estimates of caribou numbers (at least one year old) in photo and visual Bathurst strata in June 2018. These are corrected for sightability.

Strata	N	SE N	Conf. Limit		CV	Density
Photo	5,043	734.5	3,696	6,881	0.146	4.11
West Visual	567	140.5	332	970	0.248	0.24
East Visual	1,309	332.7	773	2,216	0.254	0.27
Total	**6,919**	**818.5**	**5,415**	**8,843**	**0.118**	

Composition Survey in June 2018

A composition survey was conducted in the Bathurst survey area June 13-16, which was five to eight days after the photo and visual survey. Review of the locations of collared females suggested that minimal movement occurred during this time with collared females inside the photo stratum on June 8 remaining within it (Figure 23). One additional collared cow that was south of the photo stratum on June 8 moved into this stratum, thus the composition survey results were still representative of the distribution of Bathurst caribou females. In addition, daily movement rates for Bathurst collared cows were below 5km/day on June 8 and remained there the following week (Figure 11).

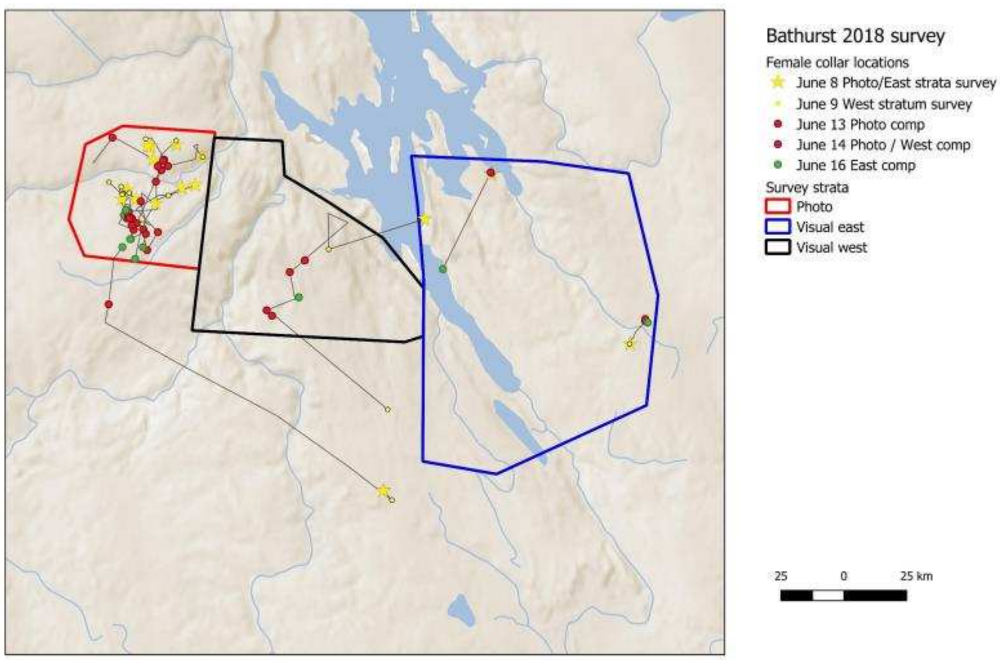

Figure 23: Locations of collared females between the dates of the Bathurst photo and visual strata flown June 8 and 9, and the composition survey flown June 13-16.

The composition survey systematically covered the photo stratum (Figure 24), which confirmed stratum boundaries and showed that most breeding cows were contained within this stratum. The Visual West block had some cow-calf groups and a higher proportion of non-breeding cows than the photo block. The Visual East stratum mainly contained bulls, yearlings and a few non-breeding cows. The numbers of breeding cows, non-breeding cows, yearlings and bulls within each stratum are listed in Table 11.

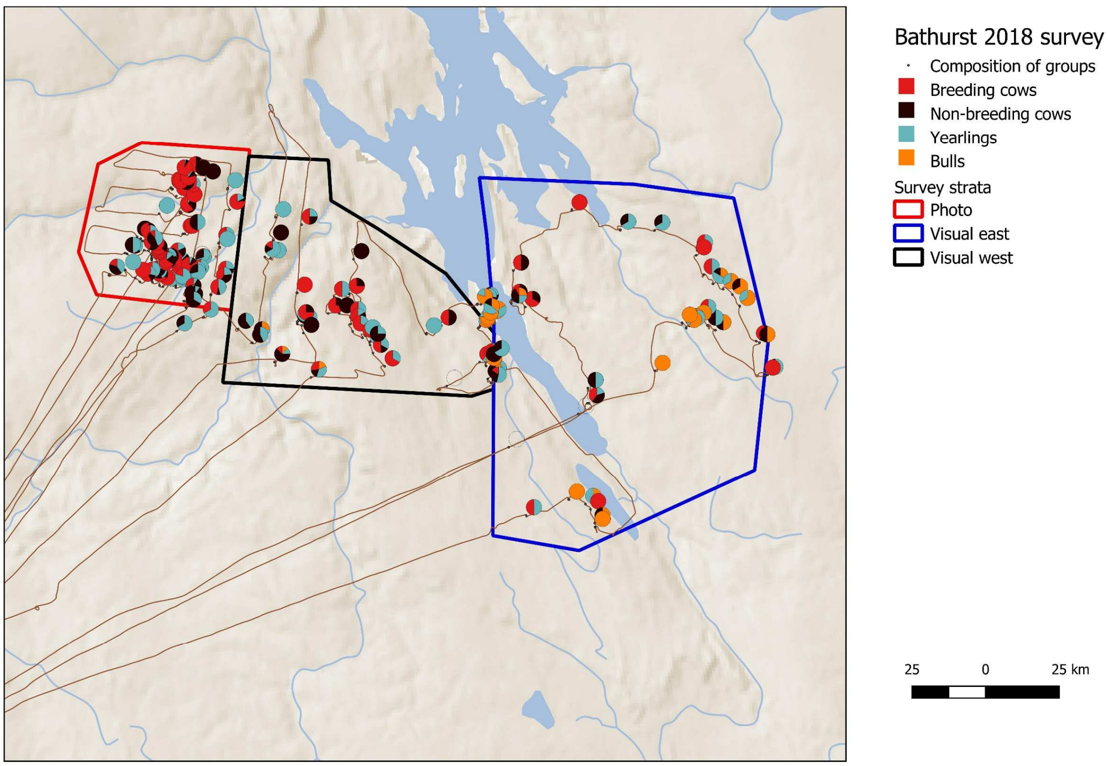

Figure 24: Helicopter flight paths and caribou groups classified during calving ground composition survey of Bathurst caribou, June 13-16, 2018. The size of the pie charts is proportionate to the number of caribou classified in a group. Proportions of age-sex classes make up the individual pie sections.

Table 11: Summary of composition survey results on Bathurst calving ground June 2018 in photo and visual strata.

Stratum	# groups	Adult females			Yearlings	Bulls	Total caribou (1 yr+)
		Total	breeding	non-breeding			
Photo	80	1,517	1,134	383	242	0	1,759
Visual East	38	46	20	26	33	36	115
Visual West	52	135	72	63	94	34	263

Estimates of the proportions of adult females and breeding females were then derived with variance and confidence limits estimated via bootstrap methods (Table 12).

Table 12: Proportions of breeding females and adult females from composition survey on Bathurst calving ground June 13-16, 2018. Proportions are expressed as percentages of caribou at least one year old.

Stratum	Estimated Proportion	SE	Confidence Limit (Upper and Lower)	
Breeding females				
Photo	0.645	0.029	0.581	0.695
Visual west	0.274	0.043	0.185	0.354
Visual east	0.174	0.044	0.098	0.266
Adult females				
Photo	0.862	0.020	0.814	0.896
Visual West	0.513	0.041	0.429	0.593
Visual East	0.400	0.059	0.284	0.524

Estimates of Breeding and Adult Female Caribou

Estimates of the numbers of breeding females (Table 13) were derived by the product of caribou at least one year old (Table 10) and the proportion of breeding females in each stratum (Table 12). Estimates of the numbers of adult females (Table 14) were similarly derived from the product of caribou at least one year old (Table 10) and the proportion of adult females in each stratum (Table 12).

Table 13: Estimates of number of breeding females based upon initial abundance estimates and composition surveys on Bathurst calving ground June 2018.

Stratum	Caribou		Proportion of breeding cows		Number of Breeding Females				
	N	CV.N	pb	CV	N	SE	Conf. Limit		CV
Photo	5,043	0.146	0.645	0.045	3,253	495.8	2,350	4,502	0.152
West Visual	567	0.248	0.274	0.157	155	45.6	82	292	0.294
East Visual	1,309	0.254	0.174	0.253	228	81.7	110	474	0.358
Total	**6,919**				**3,636**	**504.6**	**2,709**	**4,880**	**0.139**

Table 14: Estimates of numbers of adult females based upon initial abundance estimates and composition surveys on Bathurst calving ground June 2018.

Stratum	Caribou		Proportion of adult cows		Number of Adult Females				
	N	CV.N	pa	CV	N	SE	Conf. Limit		CV
Photo	5,043	0.146	0.862	0.023	4,347	641.1	3,174	5,954	0.147
West Visual	567	0.248	0.513	0.080	291	75.7	166	511	0.260
East Visual	1,309	0.254	0.400	0.148	524	153.9	286	960	0.294
Total	**6,919**				**5,162**	**663.7**	**3,935**	**6,771**	**0.129**

The ratio of breeding females to adult females was 70.4%, suggesting a fair-good proportion of pregnant females compared to previous survey years. The proportion of breeding females in June 2015 was lower (60.9%; Boulanger et al. 2017).

Fall Composition Survey October 2017

A composition survey was conducted 23-25 October 2017 to estimate the bull-cow ratio of the Bathurst herd. Overall there were 39 groups observed with totals of bulls, cows and calves summarized in Table 15. Bootstrap methods were used to obtain SEs on estimates (Table 16).

Table 15: Summary of observations from fall composition survey on Bathurst herd October 23-25, 2017.

Cows	Bulls	Calves	Groups
940	532	431	39

Table 16: Estimates of the bull-cow ratio, proportion cows, and calf-cow ratio from the fall composition survey on Bathurst herd October 2017.

Indicator	Estimate	SE	Conf. Limits		CV
Proportion cows	0.629	0.017	0.596	0.666	2.7%
Bull-cow ratio	0.592	0.044	0.501	0.678	7.4%
Calf-cow ratio	0.429	0.018	0.399	0.466	4.1%

Extrapolated Herd Estimates for Bathurst Herd

Estimates of adult herd size (caribou at least two years old) for the Bathurst herd in 2018 are presented in Table 17. The estimate based on an assumed fixed pregnancy rate uses a value of 0.72 (Dauphiné 1976) while the estimated proportion of breeding females in June 2018 was 0.704, which resulted in relatively similar extrapolated herd estimates (8,207 vs 8,029; Table 17). The preferred estimate uses the proportion of females, which is simply the estimate of adult females (5,162) divided by the proportion of cows in the herd (0.629) from the fall 2017 survey. Log-based confidence limits, which were used for other estimates as well as traditional symmetrical confidence limits (estimate ± *t**SE) are given. In most cases log-based limits give better representation of confidence estimates than traditional symmetrical methods because the distribution of estimates has a slight positive skew. However, previous analyses have used the symmetrical method. The actual difference in CI's is relatively minor.

Table 17: Extrapolated herd size estimates for the Bathurst herd in 2018 based on two estimators. The estimate based on proportion of adult females is the preferred one and has a smaller variance.

Method	N	SE	Log-based CI		Symmetric Traditional CI		CV
Proportion of adult females	8,207	1079.0	6,218	10,831	5,920	10,494	13.1%
Constant pregnancy rate (0.72)	8,029	1390.9	5,565	11,583	5,064	10,993	17.3%

Trends in Numbers of Breeding and Adult Females and Herd Size 2010-2018

Estimates of breeding cows, nonbreeding cows and (total) adult cows in the Bathurst herd are shown in Figure 25 for surveys 2009-2018. A roughly stable trend 2009-2012 was followed by significant declines to 2015 and 2018. Reductions from 2015 to 2018 in estimates of breeding females were 55.0%, in adult females 61.0% and in overall herd size 58.5%. The reduction in herd size indicates an annual rate of decline of 25.5% 2015-2018. These reductions consider only the numbers of caribou found on the June 2018 Bathurst survey area (and associated extrapolated herd sizes), and do not consider the apparent loss of some of the herd to the Queen Maud Gulf calving ground. The proportion of adult females classified as breeding was higher (70.4%) in 2018 than in 2015 (60.9%).

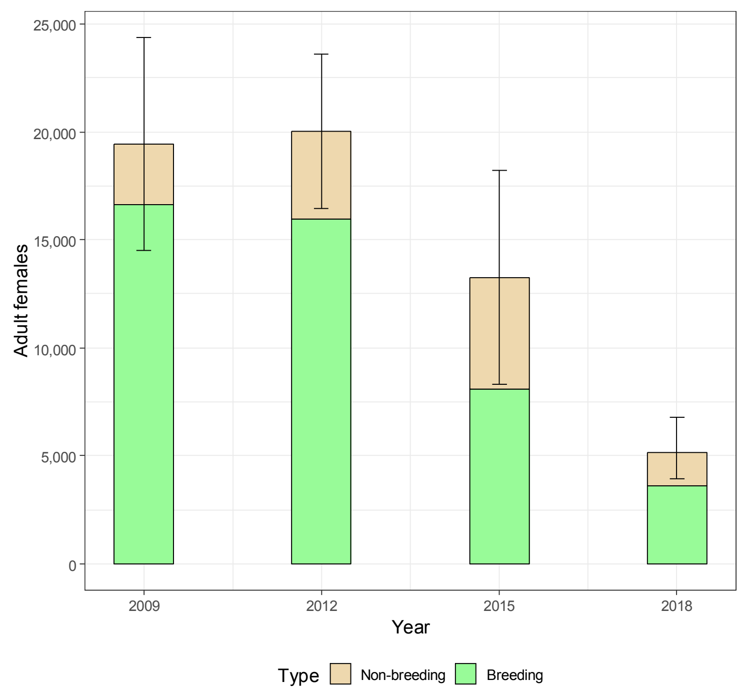

Figure 25: Estimates of the number of breeding females (green), non-breeding females (light brown) and adult females (summed bars) in the Bathurst herd 2010-2018.

Demographic Analysis of Trends in the Bathurst Herd

The Bayesian state space model (Humbert et al. 2009, Kery and Royle 2016) was used to estimate longer term trends in the Bathurst data set. For this analysis, trend (log λ) was modeled as a random effect, therefore allowing assessment of variation in λ in intervals between surveys.

For breeding females, overall trends were significant (p=0.025) with an overall λ estimate for the entire data set (1985-2018) of 0.88 (0.79-0.98) (Figure 26).

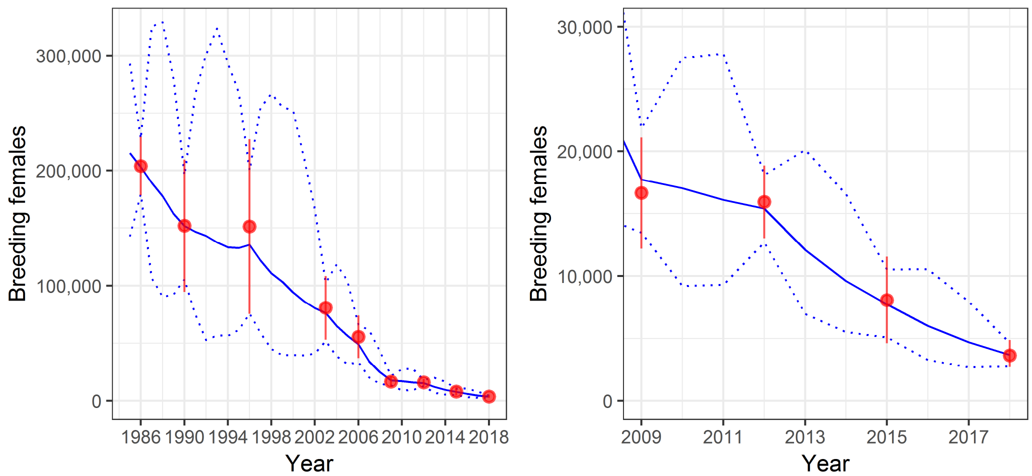

Figure 26: Trends in Bathurst breeding females 1986-2018, as estimated by the Bayesian state space model. The left graph is for the full extent of the data set and the right graph is zoomed into the period of 2009-2018. Field estimates are given as red dots (with confidence limits) and model predictions are shown as blue lines with confidence intervals as hashed lines.

Of greatest interest is trend since 2009, which suggested an initial increasing trend up to 2012, where the geometric mean of λ (3 year) was 0.95 (CI=0.87-1.06), before declining to 0.78 (CI=0.68-0.91) in 2018 (Figure 27). Trend of breeding females will be influenced both by abundance of adult females and pregnancy rate.

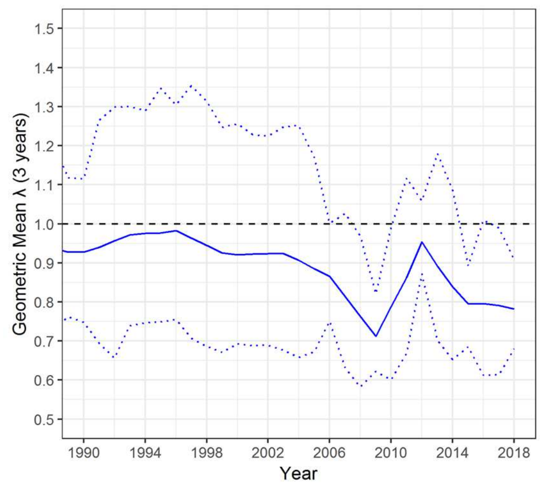

Figure 27: Estimate of λ for Bathurst breeding females 1989-2018, as estimated by the Bayesian space model analysis. Model predictions are shown as blue lines with confidence intervals as hashed lines. A λ of 1.0 indicates a stable population.

Trends in numbers of adult Bathurst females (Figure 28) were also significant for the entire data set (p=0.045) with an overall λ estimate of 0.88 (CI=0.80-0.99) for the entire (1985-2018) data set (Figure 29).

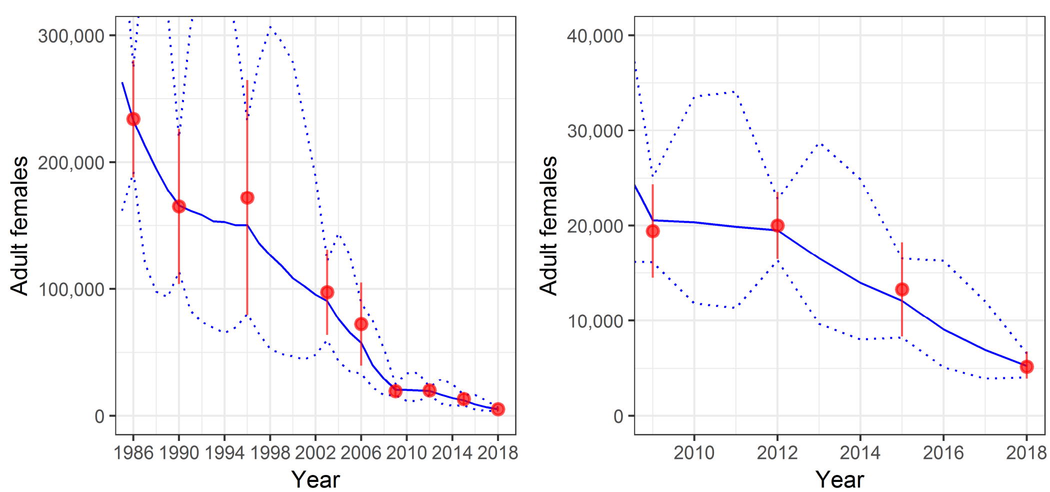

Figure 28: Trends in numbers of adult Bathurst females 1986-2018, as estimated by the Bayesian state space model. The left graph is for the full extent of the data set and the right graph is zoomed into the period of 2009-2018. Field estimates are given as red dots (with confidence limits) and model predictions are shown as blue lines with confidence intervals as hashed lines.

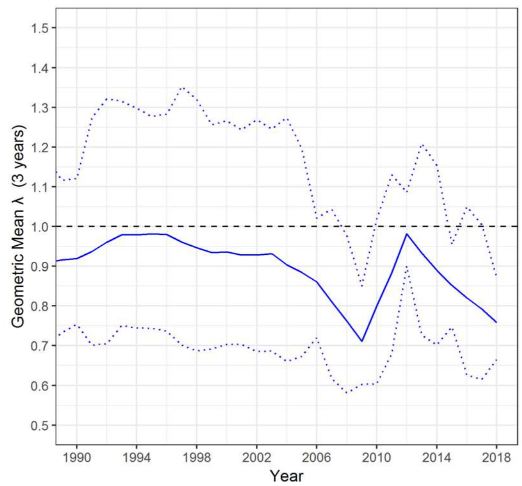

Figure 29: Estimates of λ for adult Bathurst females 1989-2018, as estimated by the Bayesian state space model. Model predictions are shown as blue lines with confidence intervals as hashed lines. A λ of 1.0 indicates a stable population.

Estimates of λ in adult Bathurst females were also relatively similar in trend to the breeding female estimates, with the exception of the 2012-2018 period where a trend of decreasing λ is evident, resulting in a three year geometric mean estimate of 0.76 (CI=0.66-0.7) in 2018 (Figure 29).

In general, densities of caribou in the core Bathurst area have decreased in parallel with overall trends since 2012. In 2012, densities in the core area did increase in unison with a smaller more aggregated core calving area. An analysis of trends in core calving ground area and related densities is given in Appendix 4.

Demographic analysis using multiple data sources

Survival analysis of collared cows

Collar data from adult Bathurst females were used to estimate annual survival rates 1996-2018. Of most interest was the interval 2009-2018 when management actions limited hunting mortality and collar sample sizes were increased after 2014. Estimates of monthly mortality, which is the ratio of collar mortalities to collars available, indicate higher mortality rates in the summer months of 2010-2014 followed by lower levels of mortality from 2014 to 2018 (Figure 30). A collar history plot that details individual collar fates is given in Appendix 2.

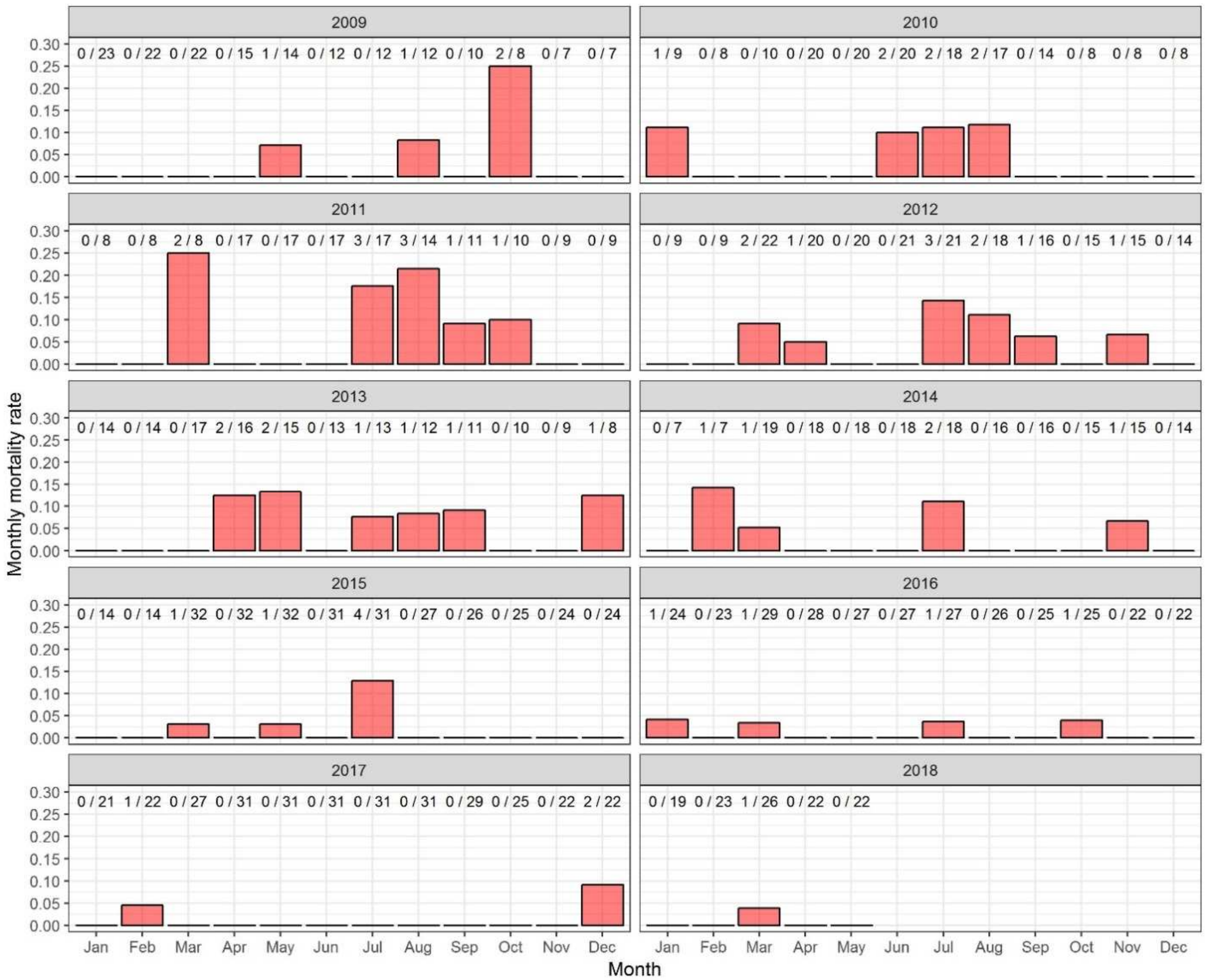

Figure 30: Summary of monthly collared cow mortality data for Bathurst herd 2009-2018. Individual collar histories for recent years (i.e. since 2016) are given in Appendix 2.

The total data set is summarized in Table 18 with corresponding cow survival rate estimates for each year. Initial collar sample sizes were very low in 1996 and 1997 (<10), then increased somewhat 1998-2014 (10-20) with an average of 25-26 in 2015-2017. As a result, annual survival estimates have a high variance and should be interpreted with caution.

Table 18: Summary of Bathurst collar sample sizes and survival estimates.

Caribou Year	Mortalities	Live collar sample sizes				Yearly survival estimates			
	Total	Collar months	Mean	Min	Max	Estimate	SE	Conf. Limit	
1996	2	101	8.4	7	10	0.79	0.13	0.44	0.95
1997	2	85	7.1	6	12	0.75	0.15	0.38	0.94
1998	7	174	14.5	5	21	0.52	0.14	0.27	0.76
1999	1	161	13.4	13	14	0.92	0.07	0.61	0.99
2000	3	158	13.2	12	15	0.79	0.11	0.51	0.93
2001	6	123	10.3	5	13	0.50	0.14	0.25	0.76
2002	2	136	11.3	9	15	0.86	0.09	0.58	0.97
2003	5	117	9.8	7	13	0.58	0.14	0.31	0.82
2004	4	136	11.3	6	22	0.66	0.14	0.35	0.87
2005	4	187	15.6	13	19	0.78	0.10	0.53	0.91
2006	3	199	16.6	15	22	0.85	0.08	0.62	0.95
2007	6	213	17.8	15	21	0.71	0.10	0.48	0.86
2008	2	210	17.5	12	23	0.87	0.09	0.59	0.97
2009	4	135	11.3	7	20	0.61	0.15	0.31	0.85
2010	8	151	12.6	8	20	0.53	0.13	0.29	0.76
2011	11	167	13.9	9	22	0.46	0.11	0.26	0.67
2012	11	196	16.3	14	21	0.51	0.10	0.31	0.70
2013	6	145	12.1	7	19	0.55	0.14	0.28	0.79
2014	5	236	19.7	14	32	0.78	0.09	0.55	0.91
2015	6	319	26.6	23	31	0.81	0.07	0.63	0.91
2016	3	306	25.5	21	31	0.88	0.06	0.69	0.96
2017	3	303	25.3	19	31	0.87	0.07	0.67	0.96

The annual cow survival rate estimates are plotted in Figure 31, which suggests an increasing trend in cow survival after 2014, albeit still with high variance due to limited collar numbers.

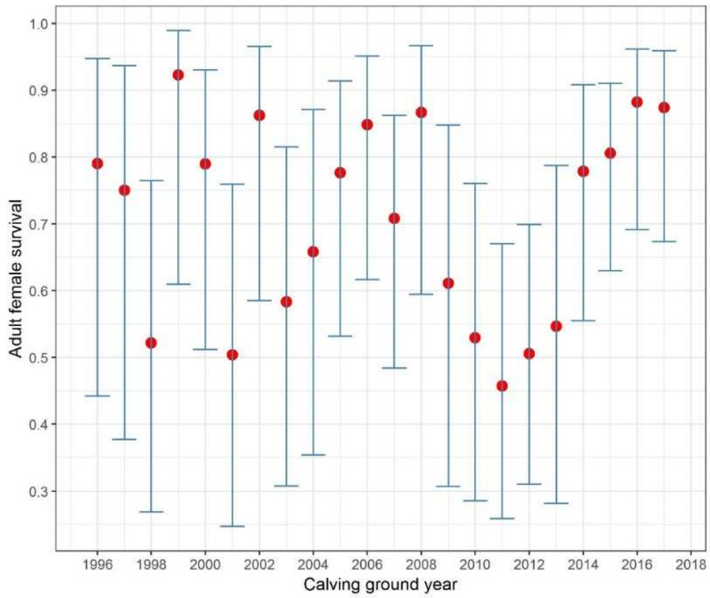

Figure 31: Annual survival rate estimates 1996-2018 for Bathurst adult females based on collared female caribou.

Bayesian state space integrated population model (Bayesian IPM)

The main objective of the Bayesian IPM was to provide refined estimates of demographic parameters using all available field data. For the Bathurst herd, temporal variation in main parameters (cow/yearling survival, calf survival) was modeled as random effects. A more detailed technical description of the model, including tests of model parameters and the associated *R* code, is given in Appendix 3.

The Bayesian IPM fit most field measurements adequately (Figure 32). The main exceptions were overestimates of cows and cows+bulls (compared to extrapolated estimates) in 2018, which is discussed later in the report. Also, in some cases the proportion of breeding females estimates did not align well with field estimates. Confidence in model predictions tended to be highest for the years in which there were field estimates.

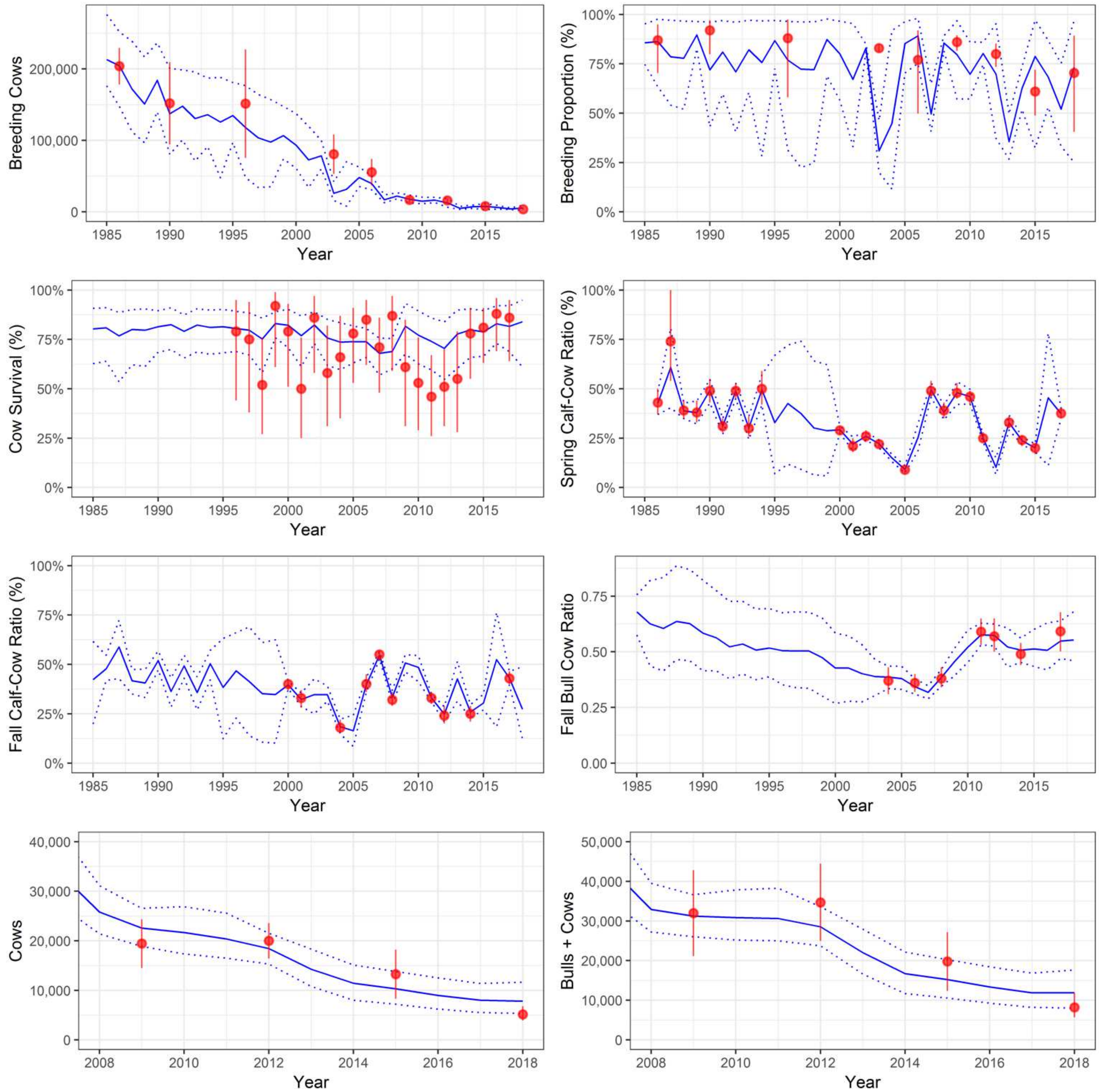

Figure 32: Predictions of demographic indicators from Bayesian model analysis compared to observed values, for Bathurst herd 1985-2018. The solid blue lines represent model predictions and confidence limits are shown as hashed blue lines. The red points are field estimates with associated confidence limits. Spring calf:cow ratios are flown in March or April and are also called late-winter surveys. Estimated numbers of cows and herd size (bulls+cows) show the more recent ten-year period to facilitate interpretation.

We modeled summer (June - late October) and winter (October - June) calf survival with the transition being the fall rut when fall composition surveys occur (Figure 33). This parameterization takes advantage of years where fall and spring calf cow surveys occur, therefore allowing assessment of change in proportion calves between June calving ground surveys, October fall surveys, and March/April late winter surveys and subsequent estimation of calf survival for each period. As found in previous studies (Gunn et al. 2005), summer survival is consistently lower than winter survival, when calves are larger. We note that the survival rates in the graphs below are expressed on the annual scale for comparison purposes. The actual rates will be different (slightly higher) given that summer or winter is shorter in time than a year.

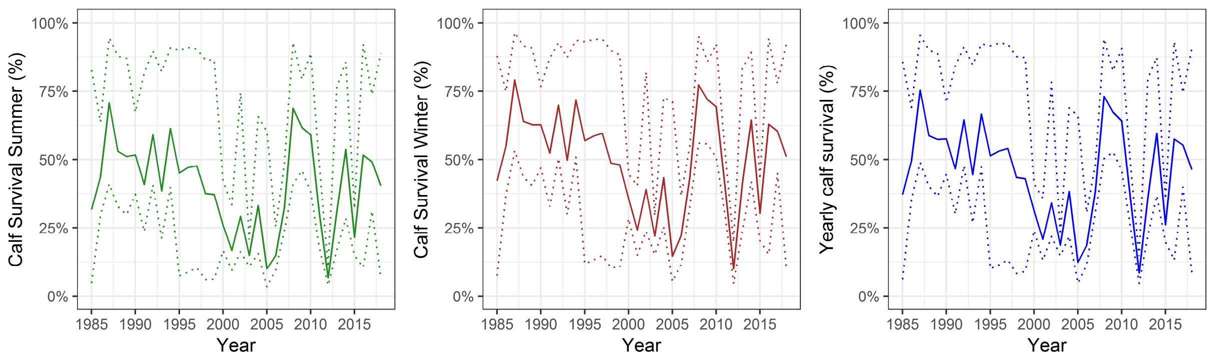

Figure 33: Trends in model-based summer and winter and overall calf survival for the Bathurst herd 1985-2018.

Overall calf productivity, which is basically the proportion of adult females that produce a calf that survives the first year of life, can be derived as the product of fecundity (from the previous caribou year) and calf survival (from the current year) (Figure 34). Estimates from Figure 34 suggest that productivity has not returned to levels observed prior to 1997 (mean productivity=0.46) in the 2011-2018 period (mean productivity=0.25). A potential negative trend in proportion of breeding females is evident as well as lower calf survival in the past ten years. As discussed later, environmental covariates and trend models will be used to further explore demographic trends and mechanisms affecting herd productivity.

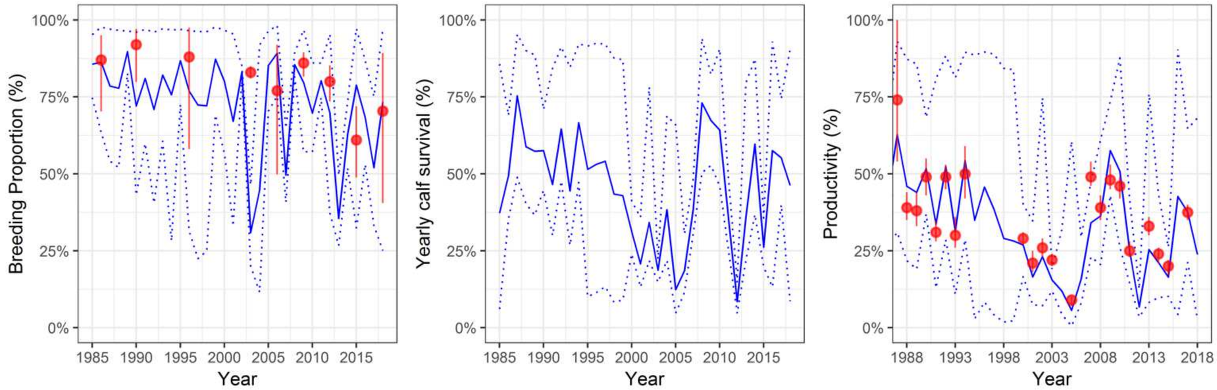

Figure 34: Trends in a) fecundity, b) annual calf survival and c) productivity (which is the product of the previous year's fecundity times the current year calf survival) for Bathurst herd 1985-2018. Spring calf cow ratios, which are lagged by one year, so that they correspond to the productivity/caribou year prediction of the model, are shown for reference purposes.

Spring calf-cow ratios, which are recorded in March or April, are overlaid in the productivity graph (Figure 34). Note that the spring calf-cow ratio is influenced by cow survival, calf survival as well as fecundity and therefore will not correspond directly to productivity. It will be greater than actual productivity because lower cow survival rates, which influence the count of cows in the spring, will inflate calf-cow ratios. The model predictions of spring calf-cow ratios, which account for cow survival, are shown in Figure 34. In addition, the model uses both calf cow ratios and proportion breeders (estimated during calving ground survey years) to estimate fecundity. In some cases, this results in poor model fit if calf cow ratios do not correspond well with the proportion of breeding cows estimated on the calving ground. In all cases the field estimates are within the confidence limits of the corresponding demographic model estimates.

One of the most important determinants of herd trend is adult cow survival since this directly influences the overall productivity of the herd. Collar-based point estimates and modeled annual and three-year average values for cow survival are shown in Figure 35. The dashed horizontal line indicates survival level needed for herd stability at mean productivity levels of 0.30 (2015-2018). The shaded region represents the range of cow survival levels needed for population stability across lowest observed levels of productivity (2015: 17%) to higher levels of productivity (2016:45%) during the 2015-2018 period (Figure 35). If productivity is at levels observed from 2015-2018 (0.31) then cow survival would need to be 0.88 for stability.

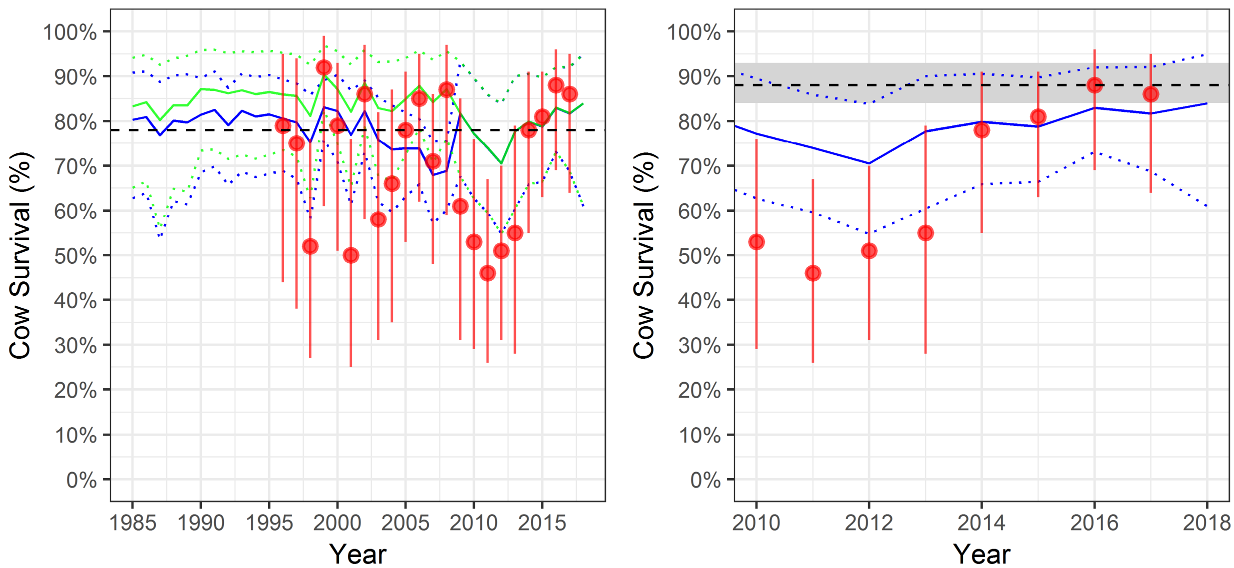

Figure 35: Trends in Bathurst cow survival 1985-2018 from Bayesian IPM analysis and collars. The solid blue lines represent model predictions and confidence limits are the hashed blue lines. A) The left graph shows the full time series with model estimates of survival denoted by blue lines, and "natural survival" with hunting mortality removed denoted by a green line. The red points are observed field estimates from collars with associated confidence limits. B) The right graph shows the empirical and modeled estimates of cow survival since 2010, when harvest restrictions were placed on the Bathurst herd. The dashed horizontal line indicates cow survival level needed (mean survival of 0.89) for herd stability at mean productivity levels of 0.30 (2015-2018). The shaded region represents the range of cow survival levels (0.85-0.93) needed for population stability across lowest observed levels of productivity (17%) to higher levels of productivity (45%) during the 2015-2018 period as shown in Figure 34c.

Model-based estimates of cow survival suggested an increasing trend in cow survival from 2012 to 2018 with a three-year average survival of 0.81 (CI=0.75-0.87) for the 2014-2017 calving year period. The model estimate of cow survival for the caribou year of 2017 (which spans from June 2017 to May 2018) was 0.82 (0.69-0.92). The estimate of cow survival in 2015 using the OLS model was 0.78 (CI=0.74-0.89) which compares to the Bayesian model estimate of 0.79 (CI=0.66-0.90) for 2015. While survival rates are potentially increasing, they still are below levels needed for herd stability as indicated by the grey zone in Figure 35.

Comparison of natural (green line) and observed survival rates (blue line) in Figure 35 illustrates the increasing impact of harvest on cow survival rates up to 2009 when harvest was reduced. In 2008, observed cow survival (including harvest) was 0.69 (CI=0,60-0.76) compared to a natural survival level of 0.87 (CI=0.76-0.96) during this time, assuming an annual cow harvest of 5,000. When harvest was reduced, observed and natural survival rates were similar. Future modeling will further consider variation in harvest rates and potential overall trends in natural survival when historic harvest is accounted for.

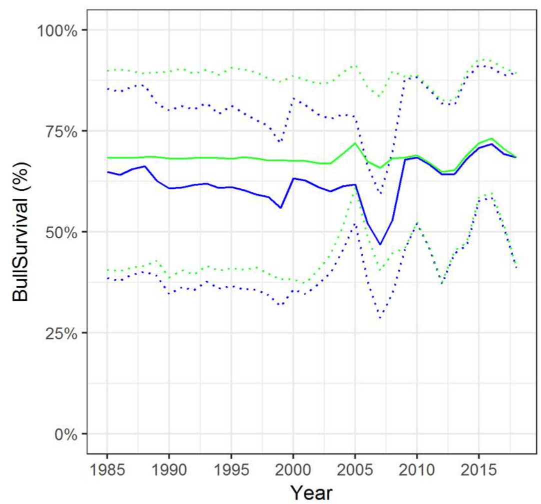

Figure 36: Estimates of bull survival for the Bathurst herd 1985-2018. The blue line represents observed survival whereas the green line represents natural survival with harvest mortality removed. Because harvest was very low 2010-2018, observed and natural mortality were similar.

Bull survival was estimated at 0.71 (0.52-0.91) in 2017 which is similar to the estimate in 2015 (0.72 (CI=0.59-0.92) (Figure 36).

Preliminary assessment of effects of emigration on estimate of Bathurst caribou

Population rates of change (λ) for cows suggest a rate of 0.92 (CI=0.83-0.99) 2015-2018 (Figure 37), which is higher than the rate indicated by adult cow estimates from the calving ground surveys of 0.76. The most likely reason for this difference is the direct impact of emigration of cows on the adult female calving ground survey estimate.

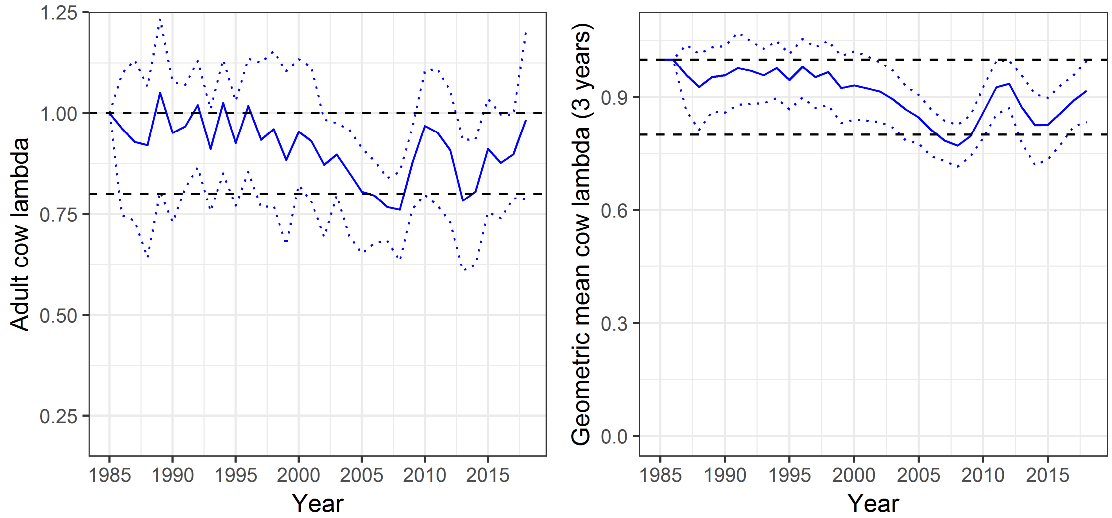

Figure 37: Overall trends (λ) in adult cows in the Bathurst herd 1985-2018 from the Bayesian model analysis. A value of 1.0 indicates stability.

Predicted numbers of breeding cows, adult cows, and bulls from the demographic model in 2018 were higher than calving ground estimates. For example, the estimate of breeding cows for the demographic model in 2018 was 5,551 (CI=1,935-9,591) compared to the calving ground-based estimate of 3,636 (CI=2,709-4,880). The demographic model estimate is 35% higher, although the confidence limits of the demographic model estimate overlap the field estimate. The likeliest reason for this is that the demographic information used in the model is based on caribou that were in the Bathurst herd up to the 2018 survey, and the 2018 breeding female estimate is only one of many data points used to inform the model. Basically, the model tolerates a slight lack of fit to the breeding female estimate in order to fit the other field estimates such as proportion breeding, calf-cow ratios, and cow survival rates. In this context, demographic predictions are less influenced by emigration of some Bathurst cows to the Queen Maud Gulf in 2018, which reduced breeding female estimates.

We conducted a sensitivity analysis of estimates to inclusion of the 2018 breeding female estimate, which was influenced by movements of cows to the Queen Maud Gulf. Estimates of cow survival when the 2018 adult female estimate were excluded were 0.85 (CI=0.74-0.93) for the 2017 calving ground year compared to 0.82 (CI=0.69-0.92) when the 2018 data point was included. The three-year average survival rate was 0.84 (CI=0.78-0.89) compared to 0.81 (CI=0.75-0.87) when the 2018 data point was included. Therefore, exclusion of the 2018 breeding female estimates boosted survival rates by 3%. Sensitivity analysis results for other parameters are given in Appendix 3.

The demographic model in this report will be further refined in the future. Potential refinements include more direct modeling of fidelity to the Bathurst calving ground using ratios of caribou that emigrate from the Bathurst calving ground. One of the challenges of this analysis is that we only had estimates of fidelity for collared cows with no estimates of fidelity for yearlings, calves, and bulls. It may be possible to partially estimate fidelity of bulls by proximity to calving grounds as well as get direct estimates of bull survival from the bull collars. In addition, harvest in the current version was modeled as a fixed rate which did not account for uncertainty in actual harvest particularly in the historic data set. Methods will be used to better incorporate uncertainty in harvest estimates which may help better refine estimates of natural survival. Finally, environment covariates will be used to model temporal trends in demographic parameters in unison with other trend models. The use of environmental covariates in previous demographic analyses up to 2016 (Boulanger and Adamczewski 2017) suggested possible linkages; however the recent 2017-2018 environmental data were not available for this analysis.

Estimation of Bathurst adult females, including emigration to the Queen Maud Gulf

The Lincoln-Petersen mark-recapture estimator (N_{LP}) based estimate of adult Bathurst cows that occurred both on the Bathurst calving ground and in the Queen Maud Gulf calving area was 7,098 (CI=4,432-11366, CV=23%), assuming that the proportion of known Bathurst collared cows (8/11) on the Bathurst calving ground was indicative of the overall distribution of cows in the entire herd. The corresponding estimate from the survey was 5,162 adult females in the Bathurst survey area, suggesting that 1,936 (CI=497-4,595) were in the Queen Maud Gulf coastal calving area. This estimate should be interpreted cautiously since it is based on only 11 collared caribou.

Estimates of adult females were generated using the demographic model for the Bathurst herd with and without the 2018 data point included (Figure 38). The demographic model attempted to balance the input from collared caribou, composition surveys, and previous survey estimates to estimate the number of adult females in 2018. The resulting estimate with the 2018 data point included was 7,833 adult females (CI=5,329-11,631, CV=21%), which was 35% higher than the corresponding observed estimate on the calving ground (5,162 CI=3,935-6,771, CV=13%). In addition, as discussed earlier, the demographic model estimate of adult females was less directly influenced by emigration of females to the Queen Maud Gulf coastal calving area in 2018 (which reduced the calving ground adult female estimate). Therefore, it would be expected that the demographic model estimate would be higher than the calving ground estimate, perhaps approaching the N_{LP} estimate of 7,098. Regardless, confidence intervals overlapped for the two estimates and therefore the difference could be expected by chance.

The demographic model was then run without the 2018 adult female estimate as part of the data set, therefore considering a scenario where all caribou occurred in the core Bathurst calving ground. The resulting estimate (11,423 CI=7,620-16,190) was 30% higher than when the 2018 adult female estimate was included in the demographic model run. The ratio of the estimates with and without the 2018 estimate included was 69% (CI=27-69%). This provides an alternative estimate of the proportion of Bathurst cows that remained on the traditional calving ground; this would mean that 31% of the cows had emigrated to the Queen Maud Gulf coastal calving area. This is relatively similar to the Lincoln-Petersen based estimates of 72% of the cows on the traditional Bathurst calving ground and 28% in the Queen Maud Gulf coastal calving area, based on collars. However, both estimates should be used with caution as one is based on model projections and the other on a limited number of collars.

The field and model-based estimates that include the Bathurst cows that appear to have emigrated to the east are still lower than the estimate of adult females on the calving ground in 2015 (13,264, CI=8,312-18,216) suggesting that substantial decline of the Bathurst herd has occurred even when emigration in 2018 to the Queen Maud Gulf/Beverly calving ground is considered. More exactly, the collar-based estimate (7,098, CI=4,432-11,366) was 46% of the 2015 adult cow estimate resulting in an annual rate of decline of 23%. The estimated annual rate of decline based on the demographic model estimate of 11,423 (CI=7,620-

16,190) was 5%, however, this estimate should be treated cautiously given limitations in directly comparing field estimates with demographic model estimates.

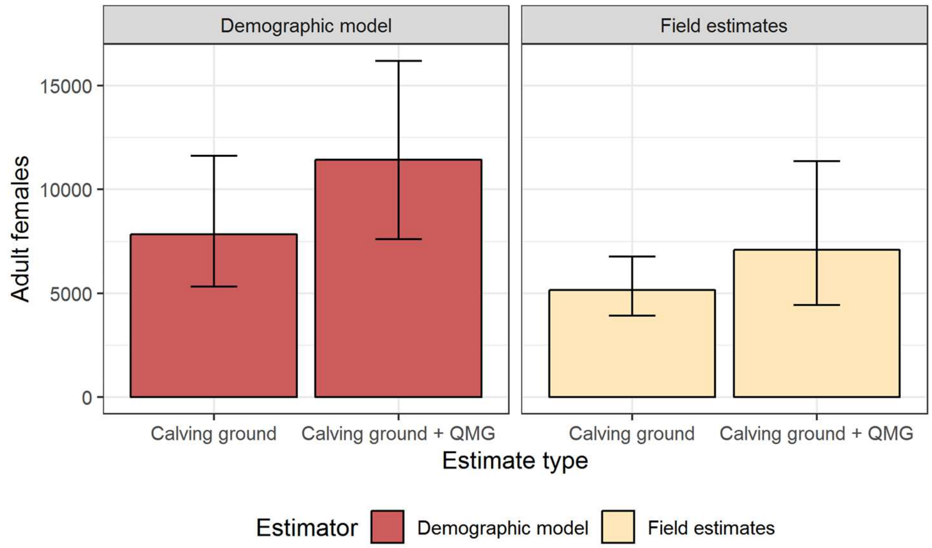

Figure 38: Field and model-based estimates of adult females on the Bathurst calving ground compared to estimates that were adjusted to include Bathurst females that calved on the Queen Maud Gulf coast calving area in 2018. Field estimates include the base estimate of adult females, and the base estimate of adult females divided by the proportion of collars that occurred on the Bathurst calving ground. Demographic model estimates include Bayesian IPM runs with the 2018 adult female estimate included and excluded.

Exploration of Potential Reasons for Decline in Herd Size

The apparent large decline in breeding and adult females in the Bathurst herd 2015-2018 could have resulted from (1) missing female caribou based on limited survey coverage or sightability, (2) movement of female caribou to adjacent calving grounds, and (3) demographic changes within the herd (low pregnancy rates, reduced calf survival, or reduced survival of adult caribou). We considered the likelihood of each factor contributing significantly to the estimated reduction in abundance.

Survey conditions and female caribou not occurring in strata

Survey conditions were challenging during the Bathurst 2018 survey; in particular, the snow conditions made caribou more difficult to see than on previous surveys with predominantly bare ground. It is possible that the counts from the two visual strata under-estimated true abundance due to poor sighting conditions. However, 96.9% of the estimated breeding females and 84.2% of the estimated adult females for the overall survey area were estimated from the photo stratum. The comparable figures in 2015 were a very similar 96.2% of breeding cows and 88.9% of adult females from the photo stratum (Boulanger et al. 2017). In the photo stratum for 2018, extra time spent counting caribou on photos and the double observer check on photos provided confidence that sightability was >84% and thus that caribou missed had been accounted for. In addition, the 17 active collared females in the Bathurst Inlet area were accounted for in the three survey strata. One collared cow was south of the visual and photo strata at the time of the aerial photography June 8-9, but reconnaissance flying in this area showed there were very few caribou in that area (see Figure 17). Extensive reconnaissance flying north, south and west of the three survey strata demonstrated that there were very few caribou in these areas.

There remains a possibility, based on very low densities of caribou observed by GN biologists (Figure 17) beyond the eastern boundary of the Bathurst East Visual block, that a few Bathurst cows were found further east. However, GN biologists observed caribou trails to the east of that block in the snow predominantly leading northeast to the main Beverly calving ground, and the Beverly collared cows continued to move north and east in the first and second weeks of June (M. Campbell, pers. comm.). The East Visual stratum contributed 6.3% of the estimated breeding females and 10.1% of the estimated adult females in the survey area; the photo stratum, as in previous Bathurst surveys, accounted for the vast majority of the female caribou. Overall, we believe that the June 2018 Bathurst estimates of breeding females, adult females and herd size are representative of the herd and that sightability and distribution issues had little influence on the survey outcome.

Movement to Adjacent Calving Grounds and Ranges

Figures 12-16 earlier in this report documented movements of collared Bathurst caribou in the vicinity of Bathurst Inlet in the spring of 2017 and particularly in the spring of 2018, as these collar movements affected the design of the survey and interpretation of the results.

In this section, collar fidelity is further assessed for 2018 with a comparison to previous years and neighbouring herds. Figure 39 displays movement in the mean location of calving for collared females that were monitored for successive years, for the Bathurst herd and its neighbours; annual fidelity is shown for 2009-2018. The head of the arrow is the mean location for the current year and the tail is the location for the previous year. In general, collared female caribou have shown reasonable fidelity to the Bathurst calving ground until 2018, when three collared caribou moved to the Beverly calving ground in the Queen Maud Gulf coastal calving area. Those three collared cows were monitored through the summer of 2018. One died in July and the other two continued to move with collared female Beverly caribou; i.e. there was no apparent return to the Bathurst herd.

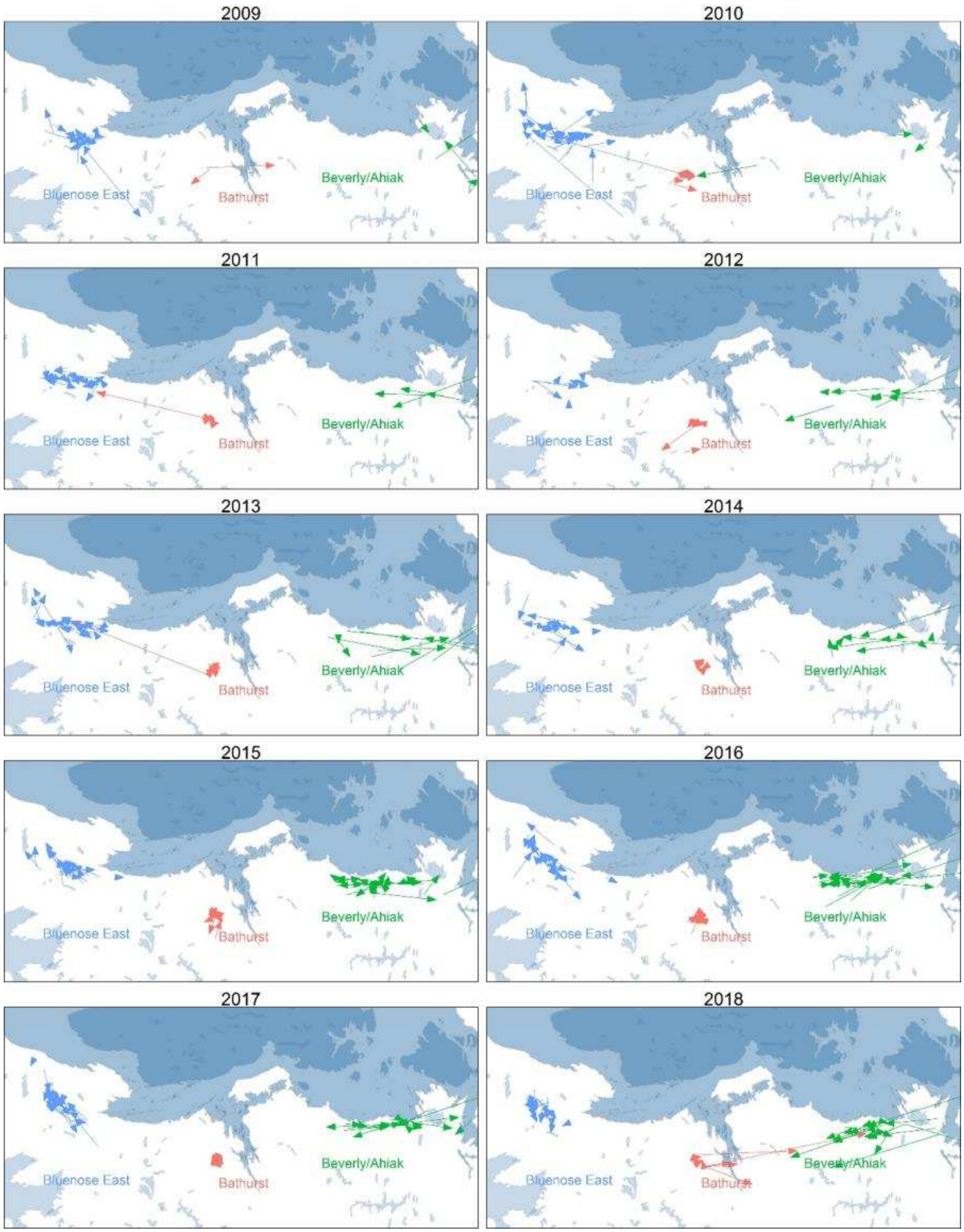

Figure 39: Yearly fidelity and movements to calving grounds in the Bluenose East (blue), Bathurst (red), and Beverly (green) herds 2009-2018. The head of the arrow indicates the current calving ground in the given year and the tail indicates the mean location from the previous year calving ground.

Frequencies of movement events between calving grounds for the Bathurst herd and neighbouring herds were assessed for collared female caribou monitored for consecutive years (Figure 40). A pair of consecutive June locations for a collared female was a single event or data point. Overall, the rates of switching were low 2010-2015 with 254 returns to the same calving ground and five switches for the three herds, indicating an overall 98% fidelity. Over the period 2016-2018, there were 174 returns to the same calving ground and three switches for the three herds, indicating again an overall fidelity of 98%. The low rate of switching of collared cows is consistent with previous estimates of about 3% switching and 97% fidelity in the Bathurst herd (Adamczewski et al. 2009) and similar fidelity in the Cape Bathurst, Bluenose-West and Bluenose-East herds (Davison et al. 2014). However, the only three switches between 2016 and 2018 were the three of 11 Bathurst collared females (27%) in June 2018. Movements of collared Bathurst bulls in spring 2018 (Figure 16) also suggested an unexpected degree of movement into the inland areas adjacent to the Queen Maud Gulf after collared males and females from the two herds were strongly mixed all winter (Figure 14).

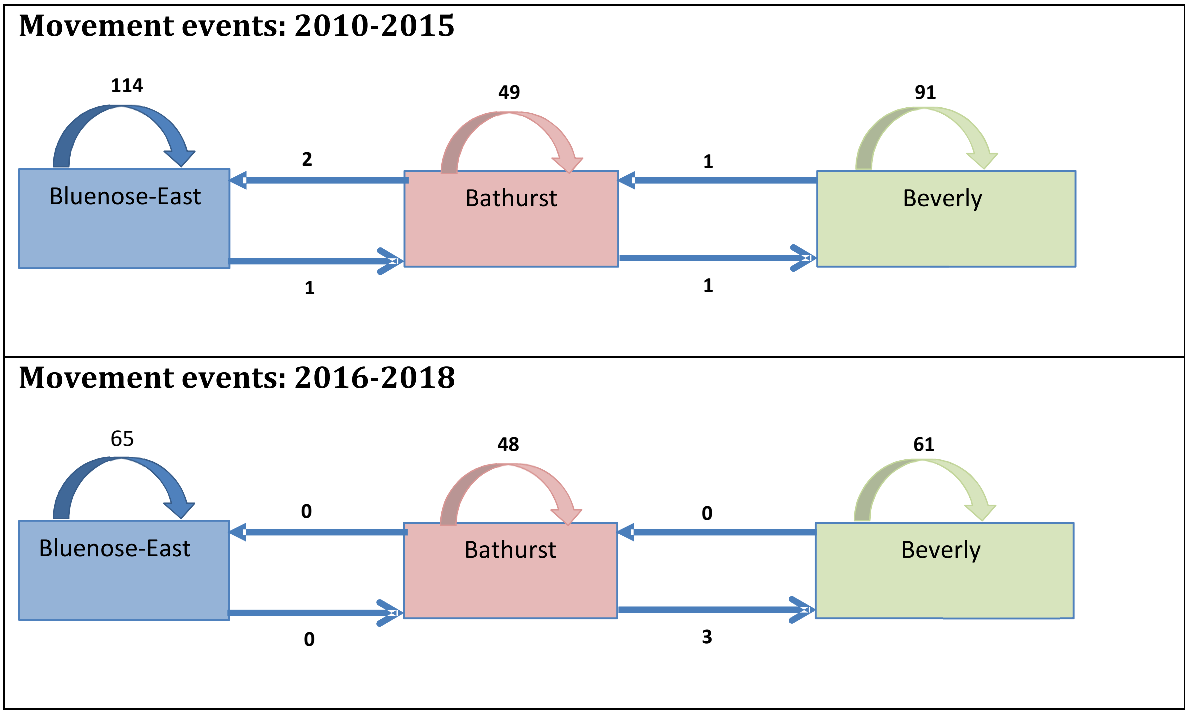

Figure 40: Frequencies of collared caribou movement events for the Bathurst and neighbouring Bluenose-East and Beverly herds 2010-2015 and 2016-2018 based on consecutive June locations. The curved arrows above the boxes indicated the number of times a caribou returned to the same calving ground in successive years. The straight arrows indicate movement of caribou to other calving grounds.

Demographic Change: Adult Survival, Calf Productivity and Calf Survival

Comparison of the 2015 and 2018 Bathurst June survey results shows declines by more than half in estimates of breeding females (55.0%), adult females (61.0%) and overall herd size (58.5%). Part of this decline is due to a proportion (approximately 27% based on three of 11 collared cows) of Bathurst cows calving on the Beverly/Queen Maud Gulf calving ground as discussed earlier (Figure 38). Demographic analysis described earlier indicates this decline is in part attributed to adult cow survival rates (estimated for 2017-2018 at 0.82) that have improved since 2015 (Figure 35) but continue to be below levels associated with stable populations (0.84 to 0.90). Calf survival has also been low overall in the past ten years (Figure 34). Overall calf productivity (the product of fecundity and one-year calf survival) in the 2011-2018 period (mean productivity of 0.25) was well below the levels observed prior to 1997 (mean productivity=0.46) and is well below levels associated with stable populations (Figure 34). Both productivity and cow survival would need to increase substantially to reach levels associated with a stable population. We note that demographic model estimates from a model that used the 2018 data point will be influenced by the emigration event in 2018. The three-year average survival rate was 0.84 (CI=0.78-0.89) with the 2018 adult female estimate excluded compared to 0.81 (CI=0.75-0.87) when the 2018 adult female estimate was included. Therefore, survival estimates are still on the lower level needed for herd recovery given current levels of productivity, regardless of model scenario considered.

Incidental Sightings of Other Wildlife

Sightings of other wildlife during the June 2018 calving ground surveys are listed in Table 19. Observations for both the Bathurst and the Bluenose-East surveys are included for convenience. Of particular interest are the sightings of wolves and grizzly bears as key predators of young caribou calves. There were 29 grizzly bear sightings and five wolf sightings on the Bathurst calving ground, and 44 grizzly bear sightings and eight wolf sightings on the Bluenose-East calving ground. In general this is consistent with previous calving ground surveys of these two herds, which have shown substantially more bears than wolves.

Table 19: Incidental sightings of other wildlife during June 2018 calving ground surveys from reconnaissance flying, visual blocks, and composition surveys. Note that some areas were flown more than once, thus some individuals may have been sighted more than once.

Species	**Bathurst calving ground**	**Bluenose-East calving ground**
Red fox	1	2
Arctic Fox	2	1
Eagles	4	2
Grizzly bears	29	44
Moose	4	4
Muskox	233	411
Wolverine	0	0
Wolves	5	8

DISCUSSION

Results from the Bathurst 2018 calving photo survey documented significant declines by more than half in estimates of breeding females (55.0%), adult females (61.0%) and overall herd size (58.5%) since 2015. The reduction in herd size indicates an annual rate of decline of 25.5% 2015-2018. The overall decline from peak numbers in 1986 of 470,000 is on the order of 98%. We suggest that the most recent decline cannot be attributed to poor survey methods or sampling. The caribou on the visual strata may have been under-estimated somewhat due to the patchy snow conditions and relatively low sightability, but 96.9% of the estimated breeding females and 84.2% of the estimated adult females for the overall survey area were estimated within the photo stratum, similar to the 2015 survey. Extra time spent searching photos and the double observer check suggested that a very high proportion of the caribou were found on the aerial photos.

An analysis of the herd's demography suggests that low calf survival rates and improved, but still low adult female survival rates both contributed to the continuing decline of the Bathurst herd. In 2018, fecundity of the Bathurst herd was relatively good, with 70.4% breeding females on the calving ground. However, by October 2018 the estimated calf:cow ratio of 21 calves: 100 cows (D. Cluff, unpublished data) indicated that calf survival through the first four to five months was poor and well below levels needed for a stable population.

An evaluation of spatial patterns of mortality in collared Bathurst cows resulted in two maps, one for 1996-2009 and one for 2010-2016 (Figure 41; Boulanger and Adamczewski 2017). Mortality risk for 1996-2009 was relatively dispersed, with some mortality on the winter range and some on the summer range. Some of the winter mortality in the winter may reflect hunter harvest, which over that period was not restricted. Mortality risk was lowest during calving 1996-2009. The overall geographic range of the Bathurst herd in the later period 2010-2016 was reduced, reflecting the herd's much reduced numbers. As in the earlier period, mortality risk was lowest during calving 2010-2016. This appears to support the longstanding view that caribou cows migrate to remote tundra calving grounds primarily to reduce predation risk (Bathurst herd: Heard et al. 1996; Porcupine herd: Griffith et al. 2002, Russell and McNeill 2005). In the later period, mortality risk was highest on the summer range. While this analysis did not include an assessment of the causes of mortality in collared caribou, the summer mortality of collared female caribou and the poor summer calf survival may point to predation on the summer range as contributing significantly to mortality of calves and adults. Summer mortality has decreased in the Bathurst herd from 2015 to 2017 resulting in an increased rate of cow survival (Figures 30, 31, and 35), however overall cow survival rates are still lower than needed for herd recovery, given current levels of productivity.

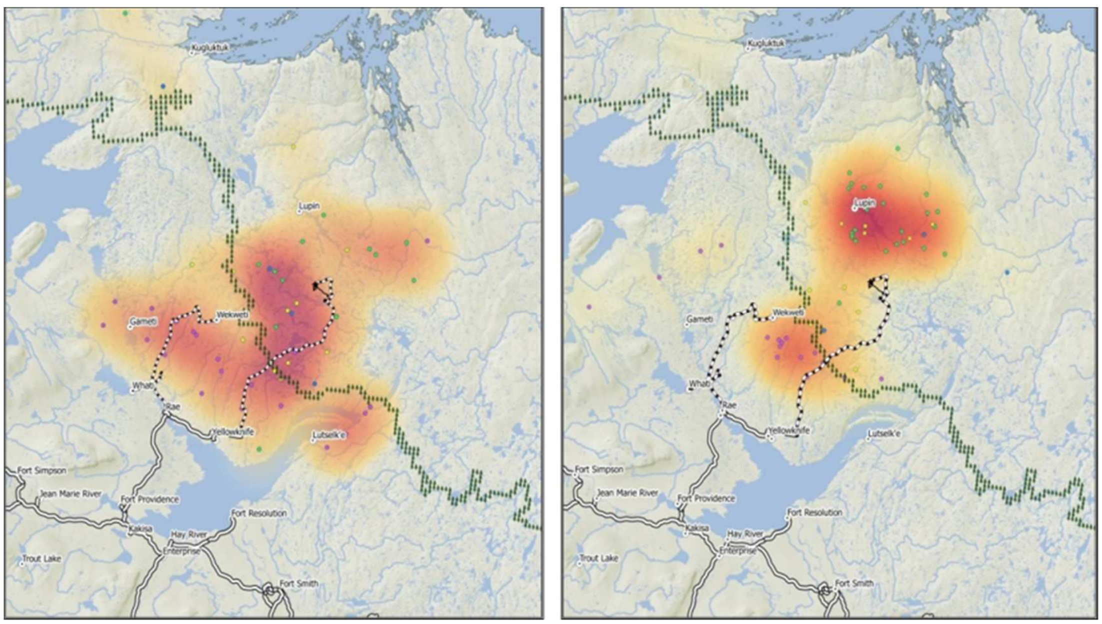

Figure 41: Relative likelihood of mortality in collared Bathurst female caribou shown as a "heat map" for 1996-2009 (left) and 2010-2016 (right). Darker colours (orange and red) indicate areas with an above-average probability of mortality, and lighter areas (yellow) indicate areas with a below-average probability of mortality. If mortalities were in proportion to live locations of collared caribou, all of the range would have the same colour. From Boulanger and Adamczewski (2017).

In 2018 some Bathurst collared cows were initially east of Bathurst Inlet and moved west across the Inlet at the time of the survey, but three of 11 (27%) Bathurst cows continued moving east into the Queen Maud Gulf coastal calving area with collared Beverly cows and remained there during the calving period. This is a limited sample and it is difficult to quantify the percentage of the herd that moved east with the three collared cows; assessment of collars and analyses through the demographic model suggest that roughly 30% of the herd's cows may have emigrated in 2018. Spring-time movements of collared Bathurst bulls (Figure 16) suggest that some of them also moved east into the Queen Maud Gulf area, south of the coastal calving grounds. These movements may in part reflect strong mixing of the Bathurst and Beverly herds in the winter of 2017-2018, as also happened in the winter of 2016-2017. There is a large disparity in size of the two herds. With the Bathurst estimate of 8,207 caribou (this survey) and the 2018 Beverly estimate of just over 100,000 (Campbell et al. 2019), the Beverly herd outnumbered the Bathurst by about 12:1. Caribou are gregarious animals and movement of collared Bathurst cows towards the calving grounds in the Queen Maud Gulf may indicate that they were drawn along by the northeast movement of the larger herd after sharing wintering ranges from November-December to April-May.

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. 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. Heavy overlap on the winter range with a larger herd, as in the Bathurst herd's recent substantial overlap in recent winters with the much larger herd calving in the Queen Maud Gulf coastal lowlands, may also act as a factor predisposing a smaller declining herd to joining a much larger herd.

The observed switching of three of 11 known Bathurst collared cows to the Queen Maud Gulf lowland calving ground during the 2018 calving season presents at least two possibilities. The first is that the switching observed for three Bathurst cows in June 2018 was an isolated occurrence and spatial fidelity to the Bathurst calving ground, which has generally been 97-98% based on collared cows, is maintained. The second is that observed rates of switching by known Bathurst cows to the Queen Maud Gulf lowland calving ground in 2018 will continue and possibly increase in subsequent calving periods, especially if the Bathurst herd continues to decline. In June 2019, three of 17 (17.6%) collared cows that were on the Bathurst calving ground in June 2018 moved well east of Bathurst Inlet with Beverly collared females, suggesting that some eastward emigration of Bathurst cows had continued (Adamczewski et al. 2019). There was evidence from 2006-2009 of several collared caribou females using the inland Beverly calving ground, then switching to the coastal Queen Maud Gulf calving ground in a following year (Adamczewski et al. 2015). The management implication of continued or increased calving ground switching by Bathurst cows is that a combination of numerical decline and emigration may further reduce the likelihood of recovery for the Bathurst herd.

Harvest of the Bathurst herd has been closed in the NWT since early 2015 (see WRRB 2016), with a Mobile Core Bathurst Caribou Conservation Area (MCBCCA) applied as a no-harvest zone. The MCBCCA (i.e. mobile zone) was developed as a minimum convex polygon around Bathurst collared caribou locations (males and females) with a spatial buffer ranging from 20-60 km, depending on the degree of overlap with adjacent herds and recommendations from a technical committee. Limited numbers of Bathurst collars in some winters may mean that the herd's distribution was not fully defined, potentially leading to a limited harvest of Bathurst caribou outside the mobile zone. However, the heavy mixing of Bathurst and Beverly collars in recent winters and the 12:1 ratio of Beverly:Bathurst caribou, in addition to the Beverly collars generally found south and east of the mobile zone, would mean that the harvest in areas bordering on the mobile zone was predominantly comprised of Beverly caribou.

Results of the Bayesian state space model analysis of the Bathurst herd confirm earlier results (Crête et al. 1996 and Boulanger et al. 2011) and suggest that cow survival levels of 0.84-0.92 are needed for stability, given the recent range of calf productivity levels observed for this herd. Low natural survival rates may reflect significant predation by wolves and bears (Haskell and Ballard 2007), and the spatial concentration of collared cow mortalities 2010-2016 (Figure 41) suggests that summer was the time of greatest predation risk.

Summer mortality as estimated by collared caribou has decreased in recent years (Figure 30).

Overall calf productivity in the 2011-2018 period (mean productivity of 0.25) was well below the levels observed prior to 1997 (mean productivity=0.46) and far below levels needed for a stable herd. Cyclical patterns in abundance of migratory caribou herds may also reflect the influence of large-scale weather patterns on vegetation and range conditions (Joly et al. 2011); declines of multiple NWT caribou herds from 2000 to 2006-2008 in part reflected late calving and sustained low calf recruitment (Adamczewski et al. 2009, Adamczewski et al. 2015).

Boulanger and Adamczewski (2017) suggested that high summer drought and warble fly indices on the Bathurst and BNE ranges may in part have contributed to poor female condition and low pregnancy rates in some years. For example, very high drought and warble fly indices for both herds in 2014 were followed by low percentages of breeding females in both herds in June 2015 (Boulanger et al. 2016, 2017). These results are further supported by the Bayesian IPM analysis that found correlations between warble fly indices and calf survival, and June temperature and cow survival based upon estimates between 2008 and 2016.

A concurrent calving ground survey of the Beverly herd (Campbell et al 2019) estimated 84,705 (CI=73,636-88,452) adult females and a total herd size of 103,372 (CI=93,684-114,061) in the survey area as defined by the caribou calving in the coastal lowland Queen Maud Gulf area and the Adelaide Peninsula. Comparison with abundance of caribou estimated in 2011 in the Queen Maud Gulf coastal calving area and re-analyzed to include the Adelaide Peninsula indicates that this herd has declined from an estimated 136,608 at that time. The comparison suggests an annual rate of decline of 4-5% from 2011 to 2018. If our evaluations of the proportion of Bathurst caribou that emigrated to the Queen Maud Gulf coastal calving area (about 30%) are correct and a similar proportion of bulls emigrated in 2018, then approximately 3,000 Bathurst caribou may have added to the estimate for the Beverly herd calving in the Queen Maud Gulf, a number that would have had a very limited effect on the GN Beverly herd estimate for 2018 and was well within the confidence limits of the estimate.

Monitoring Recommendations

As a result of the significant declines in the Bluenose-East (Boulanger et al. 2019) and Bathurst (this report) herds documented by 2018 calving photo surveys, the Tłı̨chǫ Government and GNWT ENR submitted joint management proposals for each herd to the Wek'èezhìi Renewable Resources Board (WRRB) in January 2019. While the WRRB has yet to determine what management actions and monitoring it will recommend, we include here the revised and increased monitoring and research included in the two proposals.

1. Calving photo surveys every two years, an increase in survey frequency from the three-year interval that has been used since about 2006. Population estimates from these surveys are key benchmarks for management decisions.
2. Annual composition surveys in June, October and late winter (March/April) to monitor initial calf productivity, survival through the first four to five months, and survival to nine to ten months in late winter. Results in 2018 suggested that initial fecundity was moderately high for the Bathurst herd (70% breeding females) but by late October the calf:cow ratio had dropped to 21 calves:100 cows, far below recruitment and productivity needed for a stable population. Annual fall surveys will also allow monitoring of the bull:cow ratio.
3. An increase in numbers of collars on the Bathurst and Bluenose-East herds from 50 (30 cows, 20 bulls) to 70 (50 cows, 20 bulls). This will improve estimation of annual cow survival rates and improve monitoring of herd distribution and harvest management, along with many other uses for collar information. Assessment of collar fate is essential to obtain unbiased survival estimates.
4. Suspension of reconnaissance surveys on the calving grounds. Although reconnaissance surveys on the calving grounds in years between photo surveys generally tracked abundance of cows on the calving grounds, the variance on these surveys has been high. In particular, results of the June 2017 reconnaissance survey on the Bluenose-East calving ground suggested that the herd's decline had ended and the herd had increased substantially, while the 2018 photo survey showed that in

reality the herd's steep decline had continued. As noted above, however, annual composition surveys on the calving grounds of the two herds are planned, and were carried out in June 2019 (Adamczewski et al. 2019).

5. Increased support for studies of predator abundance and predation rates, as well as studies of factors affecting range condition, caribou productivity and health.
6. Increased support for on-the-land traditional monitoring programs like the Tłı̨chǫ Boots-on-the-Ground program (Jacobsen and Santomauro 2017) that provide insights into caribou health and the influence of weather and other factors on caribou.

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Appendix 1: Double observer methods and results for visual survey strata

Methods and results described in this appendix include data from the Bathurst and Bluenose-East surveys in June 2018. One Cessna Caravan crew was based at the Ekati Mine and flew all of the Bathurst reconnaissance survey and most of the Bathurst two visual blocks. One Cessna Caravan based at Kugluktuk flew only on the Bluenose-East reconnaissance and two visual blocks, and the other Caravan based at Kugkuktuk flew primarily on the Bluenose-East survey but also flew part of the Bathurst visual survey. Snow conditions were generally similar across the two survey areas. Given the overlap in survey flying and the similar sightability conditions on both surveys, double observer data were combined in the analyses and results described in this appendix.

Visual surveys were conducted in two low density strata in June 2018 on the Bathurst survey, one west of Bathurst Inlet and one east of it. There were also two visual blocks in the Bluenose-East survey in June 2018, one north of the two photo blocks and one south of them. Each of the Caravans had two observers and a recorder on each side of the aircraft. The numbers of caribou sighted by observers were entered into the Trimble YUMA 2 tablet computers and summarized by transect and stratum.

A double observer method was used to estimate the sighting probability of caribou during visual surveys. The double observer method involves one primary observer who sits in the front seat of the plane and a secondary observer who sits behind the primary observer on the same side of the plane (Figure 1). The method followed five basic steps:

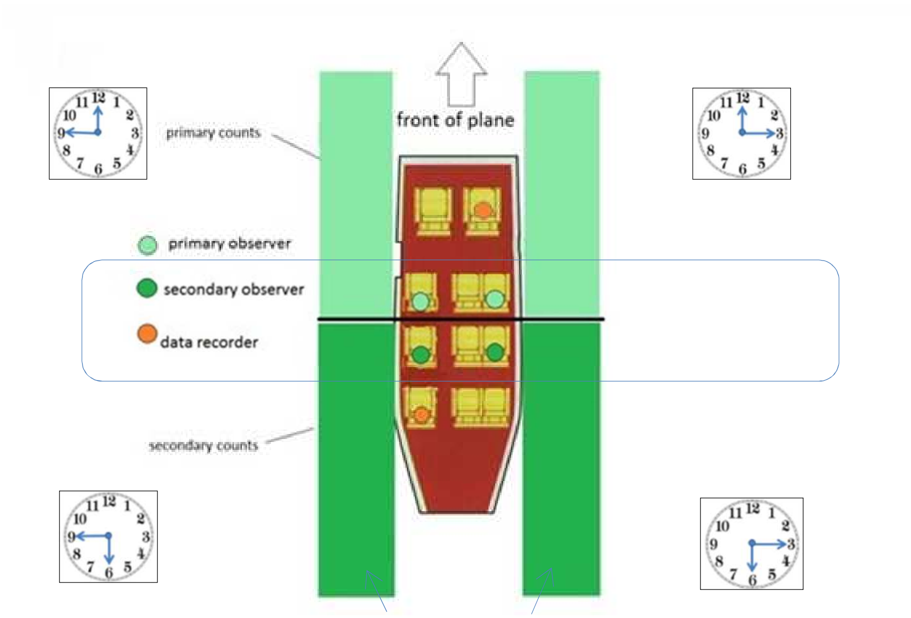
1 - The primary observer called out all groups of caribou (number of caribou and location) he/she saw within the 400 m wide strip transect before they passed about halfway between the primary and secondary observer. This included caribou groups that were between approximately 12 and 3 o'clock for right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

2 - The secondary observer called out whether he/she saw the caribou that the first observer saw and observations of any additional caribou groups. The secondary observer waited to call out caribou until the group observed passed about 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.



Counting strip (wheel to wing strut

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

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

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

The Huggins closed mark-recapture model (Huggins 1991) in program MARK (White and Burnham 1999) was used to estimate and model sighting probabilities. In this context, double observer sampling can be considered a two sample mark-recapture trial in which some caribou are seen ("marked") by the ("session 1") primary observer, and some of these are also seen by the second observer ("session 2"). The second observer may also see caribou that the first observer did not see. This process is analogous to mark-recapture except that caribou are sighted and re-sighted rather than marked and recaptured. In the context of dependent observer methods, the sighting probability of the second observer was not independent of the primary observer. To accommodate this removal, models were used which estimated p (the initial probability of sighting by the primary and secondary observer) and c (the probability of sighting by the second observer given that it had been already sighted by the primary observer). The removal model assumed that the initial sighting probability of the primary and secondary observers was equal. Observers were switched midway in each survey day (on most days there were two flights with a re-fueling stop between them), and covariates were used to account for any differences that were caused by unequal sighting probabilities of primary and secondary observers.

One assumption of the double observer method is that each caribou group seen has an equal probability of being sighted. To account for differences in sightability we also considered the following covariates in the MARK Huggins analysis (Table 1). Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. 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.

Table 1: Covariates used to model variation in sightability for double observer analysis for Bathurst caribou survey in June 2018.

Covariate	Acronym	Description
observer pair	obspair	each unique observer pair
observer order	obsorder	order of 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 most planes flew the visual surveys for both calving grounds. 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, Laake et al. 2008b) was used. This made it possible to derive double observer strip transect estimates. Strata-specific variance estimates were calculated using the formulas of (Innes et al. 2002). 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).

Double observer analysis

Data from both the reconnaissance and visual surveys were used in the double observer analysis, however, only the visual survey data was used to derive estimates of abundance for survey strata. Observers were grouped into pairs which were used for modeling the effect of observer on sightability. A full listing of observer pairs is given in Table 2. Frequencies of observations as a function of group size, survey, and phase suggested that approximately half of the single caribou were seen by both observers in most cases (Figure 2). In previous years approximately 70-80% of single caribou were seen by both observers. As group size increased the proportion of observations seen by both observers increased. This general pattern suggests low sightability compared to previous surveys, which generally had much less snow cover.

Table 2: Double observer pairings with associated summary statistics.

Observer information			Frequencies				Probabilities	
Pair No	Pooled Pair no.	notes	Secondary	Primary	Both	Total observations	Single ob p	Douple ob p
1	1	did not switch	5	6	14	25	0.80	0.96
2	2		6	3	16	25	0.76	0.94
3	2		0	0	1	1	1.00	1.00
4	3		1	4	11	16	0.94	1.00
5	3		6	10	16	32	0.81	0.96
6	4	did not switch	11	8	17	36	0.69	0.91
7	5	did not switch	14	17	48	79	0.82	0.97
8	6		18	19	46	83	0.78	0.95
9	6		17	20	38	75	0.77	0.95
10	7		16	4	23	43	0.63	0.86
11	7		5	6	8	19	0.74	0.93
12	8		0	2	3	5	1.00	1.00
13	8		20	3	20	43	0.53	0.78
14	9		5	1	7	13	0.62	0.85
15	9		20	18	42	80	0.75	0.94
16	9	pooled with 9	1	0	0	1	0.00	0.00
17	10		14	3	16	33	0.58	0.82
18	10		1	3	0	4	0.75	0.94
19	11	did not switch	10	9	41	60	0.83	0.97
20	12		0	0	1	1	1.00	1.00
21	12	pooled with 12	0	0	3	3	1.00	1.00
22	12		9	1	20	30	0.70	0.91

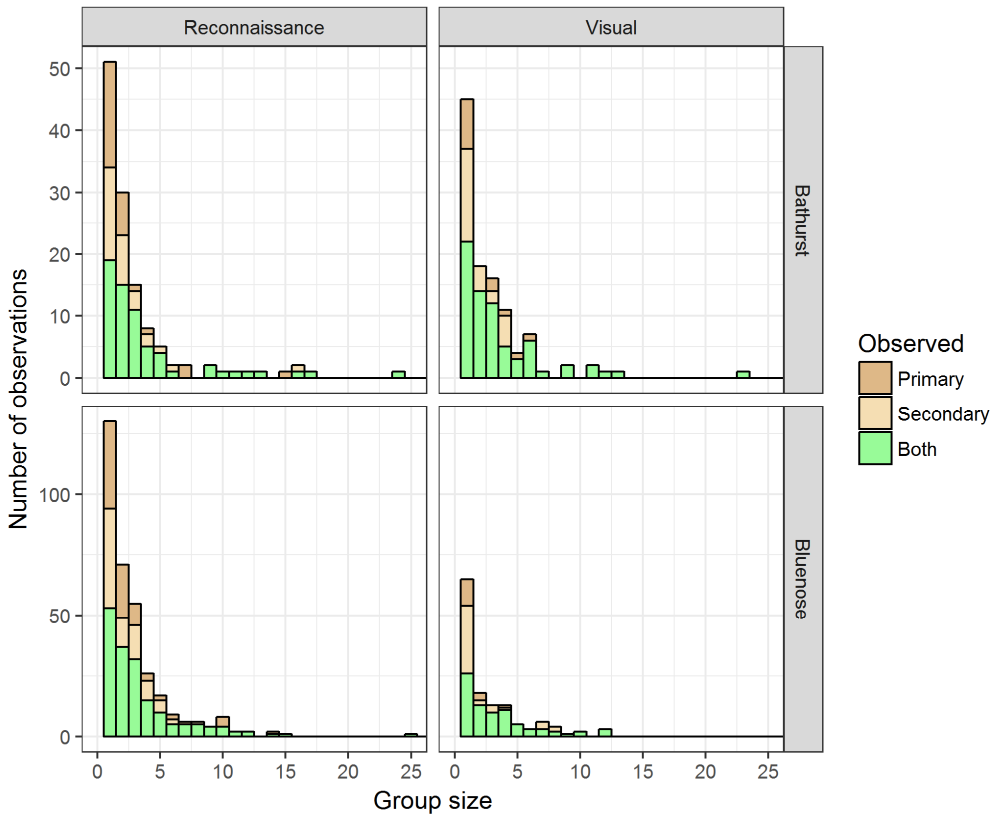


Figure 2: Frequencies of double observer observations by group size, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

Snow and cloud cover also influenced sightability, however, the pattern depended on survey phase and herd surveyed (Figure 3). The most noteworthy trends occurred for higher snow cover (75%) for the Bathurst and higher cloud cover. Snow cover was evident in all surveys with few observations of 0 snow cover and most within the 25-75% range. This range corresponds to the "salt and pepper" patchy snow cover where sightability is lower. The lack of "effect size" of snow cover (i.e minimal 0 and 100% snow cover observations) potentially made it problematic to model the effect of increasing snow cover on observations. Instead, sightability was lower (as modeled by an intercept term) due to the poor survey conditions.

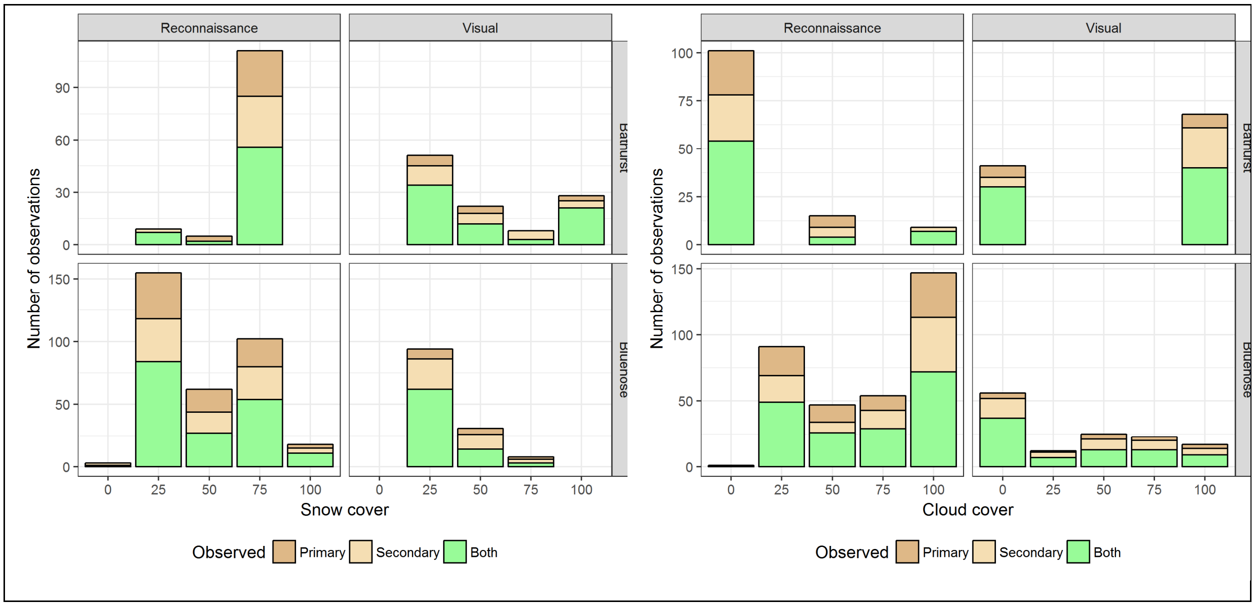


Figure 3: Frequencies of double observer observations by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation was categorized by whether it was observed by the primary, secondary, or both observers.

Snow cover was modeled as a continuous (snow) or categorical covariate (snow25, snow50, snow75) based on the categorical entries in the tablets. Model selection identified a strong effect of the log of group size, observers, snow cover and the interaction of snow and cloud cover (Table 3). An additional effect of snow cover at 75% for the Bathurst herd was evident. Observer pairs were reduced to the pairs to those that showed substantial differences from the mean level of sightability in the survey.

Table 3: Double observer model selection using Huggins mark-recapture models in program MARK for Bluenose-East and Bathurst June 2018 caribou surveys. Covariates follow Table 1 in the methods section of the report. Reduced observer pairs are denoted as red_A and red_B. 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.

No	Model	AICc	ΔAIC_c	wi	K	Dev
1	log(group size)+obs(red_A)+order+herd*snow75+cloud+snow*cloud	764.99	0.00	0.33	8	748.9
2	log(group size)+obs(red_B)+order+herd*snow75+cloud+snow*cloud	767.02	2.03	0.12	9	748.9
3	log(group size)+obs(red_B)+order+snow75+cloud+snow*cloud	768.15	3.16	0.07	8	752.1
4	log(group size)+obs(red_B)+order+herd*snow75+cloud+snow+snow*cloud	768.32	3.33	0.07	10	748.2
5	log(group size)+obs(red_B)+order+herd*snow75+cloud	768.63	3.63	0.06	8	752.5
6	log(group size)+obs(red_B)+order+snow+cloud +snow*cloud	770.75	5.75	0.02	9	752.6
7	log(group size)+obs(red_B)+order+snow25+log(group)*snow25	772.54	7.55	0.01	8	756.4
8	log(group size)+obs(red_B)+order+snow(categorical)	773.52	8.52	0.00	10	753.4
9	log(group size)+obs(red_B)+order+snow+$snow^2$+cloud+$cloud^2$+snow*cloud	774.15	9.15	0.00	11	752.0
10	log(group size)	781.88	16.89	0.00	2	777.9
11	log(group size)+snow +cloud	782.04	17.05	0.00	4	774.0
12	group size	783.22	18.22	0.00	2	779.2
13	log(group size)+snow25+cloud0	784.31	19.31	0.00	4	776.3
14	log(group size)+snow25+sno50+snow75+snow100	784.84	19.95	0.00	6	772.8
15	log(group size)+obs(all))	785.96	20.97	0.00	13	759.7
16	constant	802.05	37.06	0.00	1	800.0

Plots of single and double observation probabilities show lower probabilities for individual or smaller group sizes especially in moderate snow cover and higher cloud cover, for Bluenose-East and Bathurst June 2018 caribou surveys (Figure 4). The mean detection probability (across all groups) was 0.66 (CI=0.60-0.72). This compares to a mean probability of 0.91 (CI=0.88-0.92) for the 2015 Bluenose and Bathurst surveys.

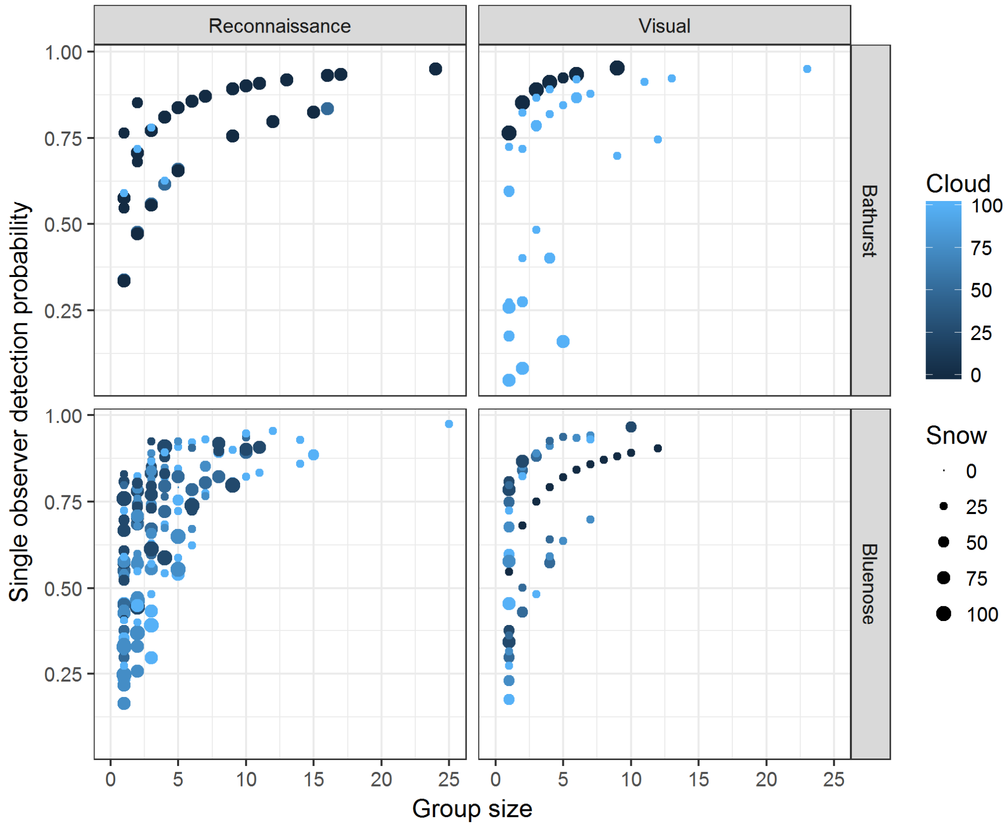


Figure 4: Estimated single observer probabilities from model 1 (Table 3) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

Double observer probabilities (the probability that at least one of the observers saw the caribou) were higher but still relatively low for single caribou especially for cases of higher cloud cover and snow cover (and for some observer pairs) (Figure 5).

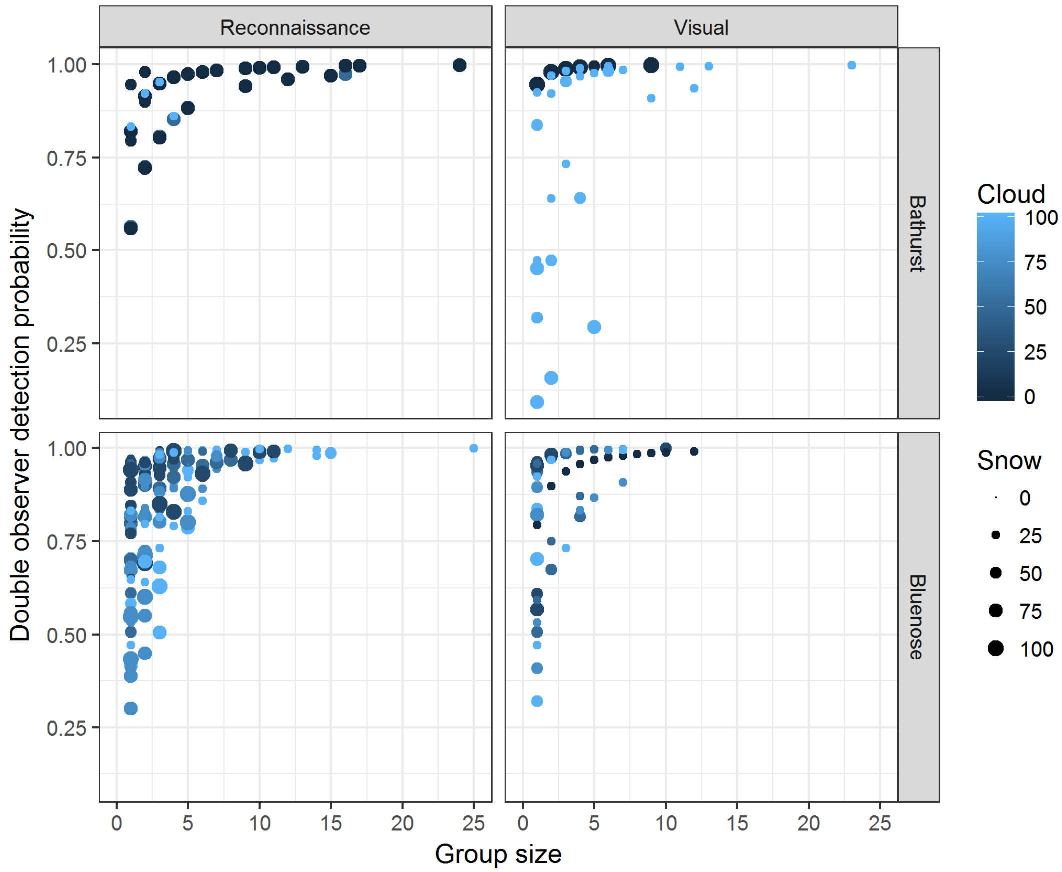


Figure 5: Estimated double observer probabilities from model 1 (Table 3) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

Estimates of total caribou in visual strata

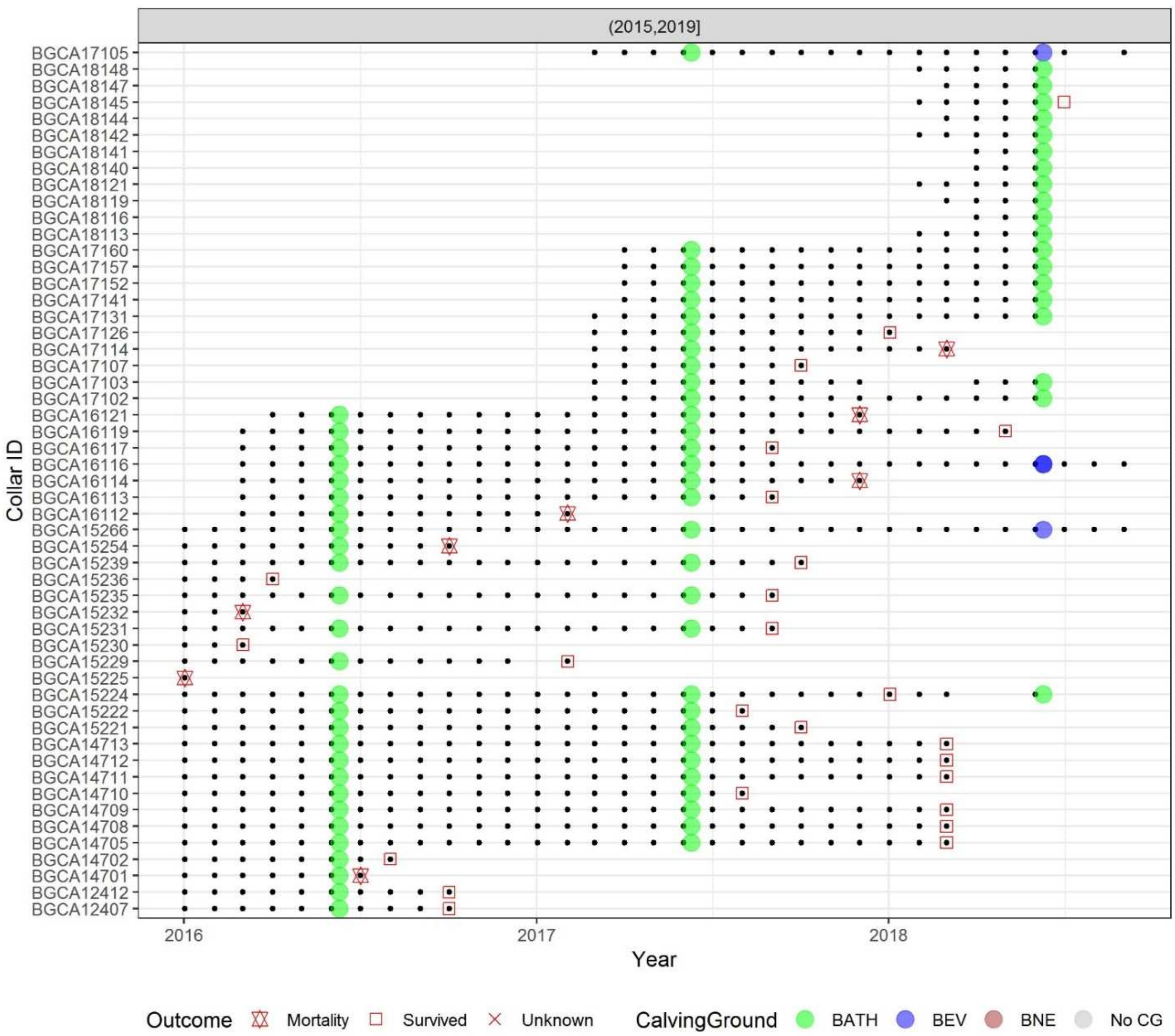
Double observer estimates (using the MRDS R package) were about 5% higher than non double observer estimates. Precision was lower than uncorrected count-based estimates but still acceptable (Table 4).

Table 4: Standard strip transect and double observer model estimates of caribou on Bathurst visual strata in 2018 from the MRDS package in R.

Strata	Caribou	Standard estimate			Double observer estimate				
	counted	Estimate	SE	CV	Estimate	SE	Confidence interval		CV
West	88	551	132.1	24.0%	567	140.50	332	970	24.8%
East	220	1,244	286.7	23.0%	1,309	332.70	773	2,216	25.4%
Total	369	1,795	151.7	17.6%	1,877	360.9	1,265	2,783	19.2%

Appendix 2: Bathurst collared female caribou histories 2016-2018

This figure presents the collar histories for each cow caribou from 2016 to 2018. Each black point represents a monthly fix of a live caribou. Color larger dots represent presence on delineated calving grounds. Fates of caribou are delineated by a square if the collar released with the caribou being alive whereas stars denote mortalities.



Appendix 3: Bayesian State space population model details

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). 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) which is an excellent introduction to Bayesian analysis.

Data Preparation

The estimates of key population statistics with SEs and lower and upper bounds were provided in the form of an csv spreadsheet and prepared for analysis using R version 3.5.2 (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 normal and uniform prior distributions that were vague in the sense that they did not constrain the posteriors (Kery and Schaub 2011, p. 36). 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, pp. 38–40). Model convergence was confirmed by ensuring that the split potential scale reduction factor $\hat{R} \leq 1.05$ (Kery and Schaub 2011, p. 40) and the effective sample size (Brooks et al. 2011) ESS ≥ 150 for each of the monitored parameters (Kery and Schaub 2011, p. 61). In addition, trace plots of Markov Chains and the posterior distributions were inspected to further check convergence and symmetry of estimated parameter distributions.

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

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, p 37 and 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 in the main body of the report 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 3.5.2 (R Core Team 2018) and the mbr family of packages.

Model Descriptions

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

Population

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

- Calving occurs on the 11th of June (with a year running from calving to calving)

- Cow natural survival from calving to the following year varies continually and randomly by year.
- Bull natural survival from calving to the following year varies randomly by year.
- Cow and bull natural survival is constant throughout the year.
- Harvest of cows and bulls occurs on the 15th of January.
- Yearling survival to the following year is the same as cow natural survival.
- Calf survival varies between the summer and winter seasons and randomly by year.
- The calf sex ratio is 1:1.
- The proportion of breeding cows is the fecundity the previous year.
- Fecundity varies randomly by year.
- Female yearlings are indistinguishable from cows in the fall and spring surveys.
- 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 standard deviation of 50,000.
- The number of cows in the initial year is the number of breeding cows in the intial year divided by the fecundity in a typical year.
- The number of bulls in the initial year is two thirds the number of cows in the initial year.
- The number of calves in the initial year is the number of breeding cows in the initial year.
- The number of yearlings in the initial year is the number of calves in the initial year multiplied the calf survival in a typical year.
- The uncertainty in each data point is normally distributed with a standard deviation equal to the provided SE.

Model Templates

The base R code used in the analysis is summarized below.

Population (R-code)

```
. 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)

 sSurvivalCowAnnual ~ dnorm(0, 1^-2) T(0,)
 sSurvivalBullAnnual ~ dnorm(0, 1^-2) T(0,)
 sFecundityAnnual ~ dnorm(0, 1^-2) T(0,)
 sSurvivalCalfAnnual ~ dnorm(0, 1^-2) T(0,)
 for(i in 1:nAnnual){
  bSurvivalCowAnnual[i] ~ dnorm(0, sSurvivalCowAnnual^-2)
  bSurvivalBullAnnual[i] ~ dnorm(0, sSurvivalBullAnnual^-2)
  bFecundityAnnual[i] ~ dnorm(0, sFecundityAnnual^-2)
  bSurvivalCalfAnnual[i] ~ dnorm(0, sSurvivalCalfAnnual^-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]
 }
 bBreedingCows1 ~ dnorm(200000, 50000^-2) T(0,)
 logit(eFecundity1) <- bFecundity
 logit(eSurvivalCalfSummerAnnual1) <- bSurvivalCalfSummerAnnual
 logit(eSurvivalCalfWinterAnnual1) <- bSurvivalCalfWinterAnnual

 bCows[1] <- bBreedingCows1 / eFecundity1
 bBulls[1]<- bCows[1] * 2 / 3
 bCalves[1] <- bBreedingCows1
 bYearlings[1] <- bCalves[1] * eSurvivalCalfWinterAnnual1^(154/365) *
eSurvivalCalfWinterAnnual1^(211/365)
 bSpringCalfCow[1] <- bCalves[1] / (bCows[1] + bYearlings[1] / 2)
 bCowHarvestRate[1] <- CowHarvestRate[2]
 bBullHarvestRate[1] <- BullHarvestRate[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]

   bCowHarvestRate[i] <- CowHarvestRate[i]
   bBullHarvestRate[i] <- BullHarvestRate[i]

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

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

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

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

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

  for(i in CowsAnnual) {
```

```
  BreedingProportion[i] ~ dnorm(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)
 }
..
```

Parameter estimates

The Bayesian model estimated principal parameters pertaining to the mean estimates of fecundity, bull survival, calf survival and cow survival. In addition, temporal variation in calf survival, bull survival, fecundity, and cow survival were estimated as random effects (Table 1).

Table 1: Bayesian IPM state space model coefficients. Parameters are given on the logit scale (which are then transformed to the probability scale using a logit transform). Parameter significance is determined by overlap of confidence limits with 0. The parameters are summarized in terms of the point *estimate*, standard deviation (*sd*), the *z-score*, *lower* and *upper* 95% CI/CLs and the *p-value* (Kery and Schaub 2011, p 37 and 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.

term	estimate	sd	zscore	lower	upper	pvalue
Main effects						
bFecundity	1.018	0.269	3.837	0.524	1.567	0.000
bSurvivalBull	0.785	0.173	4.685	0.531	1.242	0.000
bSurvivalCalfSummerAnnual	-0.388	0.323	-1.135	-0.937	0.332	0.258
bSurvivalCalfWinterAnnual	0.072	0.272	0.304	-0.450	0.621	0.759
bSurvivalCow	1.650	0.127	13.104	1.441	1.946	0.000
Random effects						
sFecundityAnnual	1.042	0.220	4.850	0.708	1.571	0.000
sSurvivalBullAnnual	0.421	0.327	1.447	0.035	1.250	0.000
sSurvivalCalfAnnual	1.081	0.218	5.053	0.752	1.609	0.000
sSurvivalCowAnnual	0.554	0.175	3.274	0.291	0.969	0.000

Model fit was judged using R-hat value which suggested adequate model convergence. In addition, the distribution of parameter estimates was inspected to assess model convergence (Table 2).

Table 2: Model summary. N is the number of parameters, nchains is the number of Markov Chains used, nthin is the number of Markov Chain samples that were thinned, ess is the effective sample size, R-hat is the R-hat convergence metric and convergence is the score based on effective sample size and number of parameters in the model.

n	K	nchains	niters	nthin	ess	R-hat	converged
34	10	3	1000	200	1473	1.002	TRUE

Unsplit R-hat values were used to assess if choice of prior distribution influenced the posterior distribution of parameter estimates (Table 3).

Table 3: Split R-hat values indicating sensitivity of posterior distributions to the choice of priors.

term	R-hat
bBreedingCows1	1.019
bFecundity	1.023
bSurvivalBull	1.009
bSurvivalCalfSummerAnnual	1.005
bSurvivalCalfWinterAnnual	1.002
bSurvivalCow	1.002
sFecundityAnnual	1.032
sSurvivalBullAnnual	1.027
sSurvivalCalfAnnual	1.006
sSurvivalCowAnnual	1.011
bBreedingCows1	1.019

The Bayesian model generated yearly estimates of demographic parameters as well as field measurements which were used in the fitting of the model. These estimates are detailed in Table 4. Most of the actual estimates are shown in Figures 9 to 14 of the main report.

Table 4: Parameter descriptions for estimates generated by the model. Parameter estimates are shown in Figures 31 to 35 in the main report.

Parameter	Description
Annual	The year as a factor
bCows1	The number of cows in the initial year
bFecundity	The proportion of cows breeding in a typical year
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 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
bSurvivalCalfAnnual[i]	The random effect of the i^{th} Annual on bSurvivalCalfSummerAnnual and bSurvivalCalfWinterAnnual
bSurvivalCalfSummerAnnual	The log-odds summer calf survival if it extended for one year
bSurvivalCalfWinterAnnual	The log-odds winter calf survival if it 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
BullHarvestRate[i]	The proportion of bulls harvested in January of the i^{th} year
CowHarvestRate[i]	The proportion of cows harvested in January of the i^{th} year
CowSurvival[i]	The data point for cow survival from the $i\text{-}1^{th}$ year to the i^{th} year
CowSurvivalSE[i]	The SE for CowSurvivalSE[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
FallCalfCowSE[i]	The SE for FallCalfCow[i]
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]
sSurvivalCalfAnnual	The SD of bSurvivalCalfAnnual
sSurvivalCowAnnual	The SD of bSurvivalCowAnnual

Figure 1 displays sensitivity of parameter estimates and trends in parameter estimates to inclusion of the 2018 breeding female estimate. It can be seen that inclusion or exclusion of this estimate affects both estimates of cows, breeding cows, and bull + cows, but also estimates of cow survival. In most cases, estimates of survival are lower as well as estimates of fecundity/productivity prior to the 2018 survey. In both cases reduction of these parameter values results in a lower estimate of caribou on the 2018 calving ground.

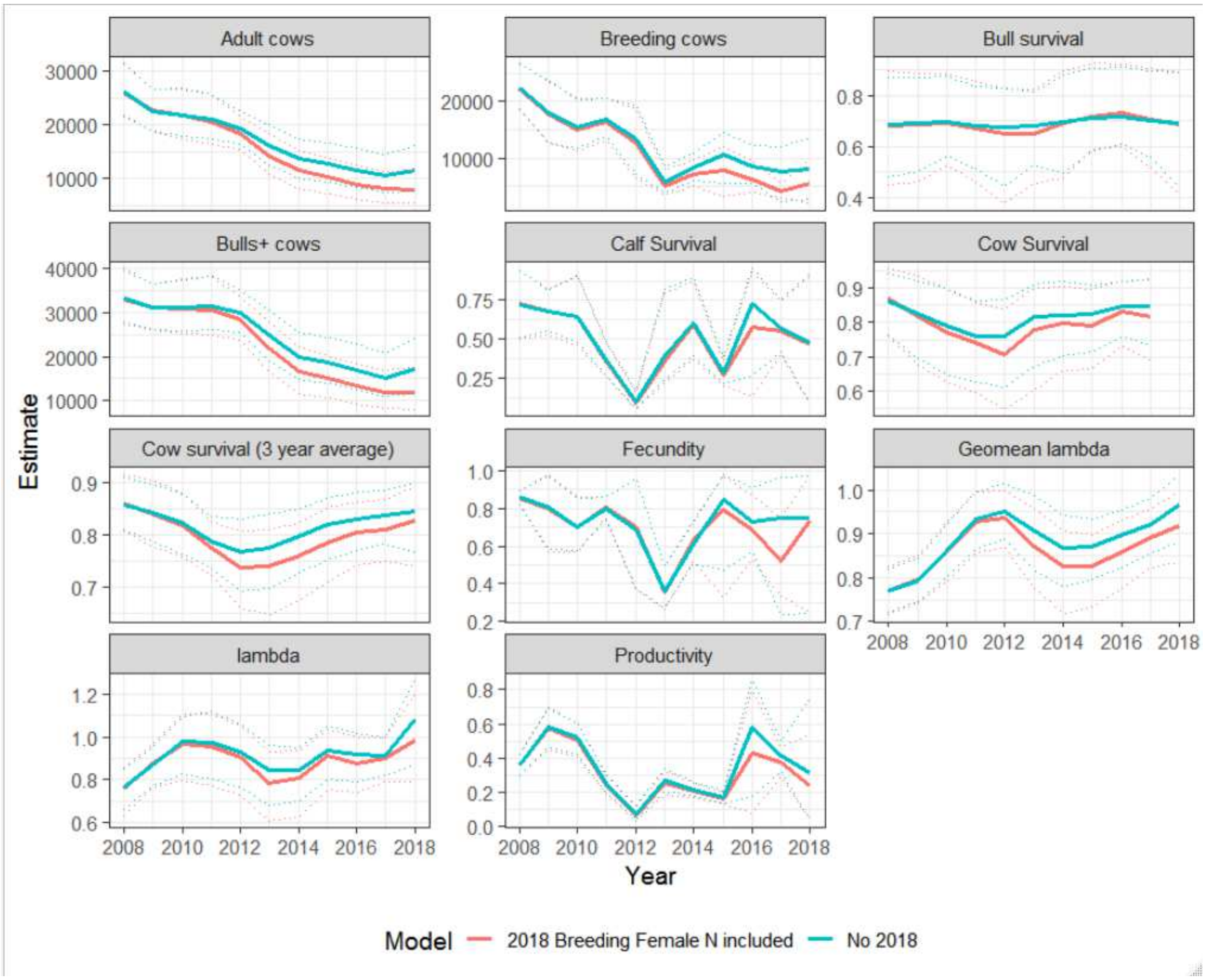


Figure 1: Estimates of principal demographic parameters from the IPM with the 2018 breeding female estimate included and excluded. Confidence limits are given as dashed lines around model predictions.

The harvest estimates used in the demographic model are given in Table 5.

Table 5: Harvest estimates and approximate harvest rates used in the demographic model. Rate is estimated harvest divided by estimate cow or bull abundance each year. Estimates based on Dogrib Harvest study, Boulanger et al. 2011, and approximate harvest levels estimated since 2010 (B. Croft, Unpublished).

Year	Harvest estimate		Harvest rate	
	cows	bulls	cows	bulls
1985	8380	7484	0.034	0.046
1986	8380	7484	0.036	0.050
1987	8380	7484	0.039	0.061
1988	8380	4606	0.043	0.042
1989	8380	3855	0.042	0.033
1990	8450	8970	0.045	0.086
1991	11626	10073	0.066	0.108
1992	9046	9685	0.051	0.103
1993	13107	7712	0.082	0.099
1994	8380	7484	0.053	0.092
1995	8380	7484	0.058	0.109
1996	8380	7484	0.058	0.103
1997	8380	7484	0.063	0.119
1998	8380	7484	0.068	0.132
1999	8380	7484	0.073	0.134
2000	8380	7484	0.081	0.176
2001	5000	2000	0.055	0.064
2002	5000	2000	0.064	0.071
2003	5000	2000	0.071	0.089
2004	5000	2000	0.086	0.102
2005	5000	2000	0.105	0.117
2006	5000	2000	0.130	0.142
2007	5000	2000	0.160	0.227
2008	5000	2000	0.193	0.289
2009	5000	2000	0.210	0.226
2010	5	70	0.000	0.008
2011	5	70	0.000	0.007
2012	5	70	0.000	0.007
2013	5	70	0.000	0.009
2014	5	70	0.000	0.014
2015	5	70	0.001	0.015
2016	5	70	0.001	0.017
2017	5	70	0.001	0.019
2018	5	70	0.001	0.019

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Appendix 4: Trends in Bathurst Calving Ground Size and Densities 2009-2018

Introduction

This document provides additional information on calving ground size, distribution of caribou on calving grounds, and core calving ground densities on the Bathurst herd calving grounds 2009-2018, based on reconnaissance survey and photo survey data. The core area has also been referred to as the "annual concentrated calving area" by Russel et al 2002. Information on the Bluenose-East herd's calving ground size and densities and spatial distribution of caribou was requested during the WRRB April 2019 Bluenose-East Caribou Hearing. A summary on the Bluenose-East herd's patterns 2010-2018 was included as an appendix in the 2018 survey report (Boulanger et al. 2019). Similar analyses were also carried out for the Bathurst herd 2009-2018 based on calving ground surveys, and the results are included here.

This document provides a summary of data from previous surveys as opposed to full documentation of methods used to define core calving areas. For full descriptions of survey methods and results, readers should refer to calving photo survey results for the Bathurst herd in 2009 (Nishi et al. 2010), 2012 (Boulanger et al. 2014), 2015 (Boulanger et al. 2017) and 2018 (main text of this report).

Methods

Trends in segment densities from reconnaissance surveys flown during calving photo surveys were initially assessed to infer distribution and aggregation of higher densities of caribou. Segments that were contained within core calving strata were included in the analysis. Data were plotted spatially and by segment density class. Core calving area was defined by the presence of breeding caribou in contiguous segments.

Estimates of density based on photo survey data and core calving ground size (based on the area of survey strata) were used to estimate numbers of adult and breeding females. One potential issue with this approach is that the degree of aggregation of adult and breeding females varies among years, and therefore changes in the core area will be due to both changes in abundance, aggregation, and survey coverage. For example, in years of high aggregation the core area might be surveyed primarily by photo survey methods whereas photo and visual survey methods would be used when aggregation is lower. Therefore, defining core areas as those just photo surveyed may not represent the true density and distribution of breeding females. To explore this issue, we derived a weighted core calving ground index based on the summation of the product of stratum areas and proportions of breeding and adult females. For example, if a 100 km^2 stratum had 20% breeding females, then the core calving ground index was estimated as 20 km^2. Each survey stratum area was scaled using this approach and summed for the survey year to provide the aggregate core calving ground index value. Density estimates using this approach will be more robust to differences in calving ground surveys where layout and types of strata (i.e., photographic and visual) would vary. For example, this approach avoids the subjective inclusion or exclusion of survey strata areas for estimation of core areas and uses all the survey strata to estimate core area. However, the actual core calving ground index will not directly pertain to a defined geographic area.

Results

Plots of segment densities for the Bathurst herd from calving ground surveys 2009-2018 suggest different levels of aggregation for each survey year, with the highest levels in 2012 (Figure 1). The core area in 2018 was reduced to only low and medium density segments with no high density segments. The annual concentrated calving area for the Bathurst herd in 2018 was to the west of Bathurst Inlet. Segments near Bathurst Inlet, which contained intermittent pockets of females, are shown for reference purposes. This pattern of low densities on either side of Bathurst Inlet included some collared caribou cows, and was not observed in previous years. Estimation of the core area based on the survey strata detailed in the next section provides further inference on the core area in 2018.

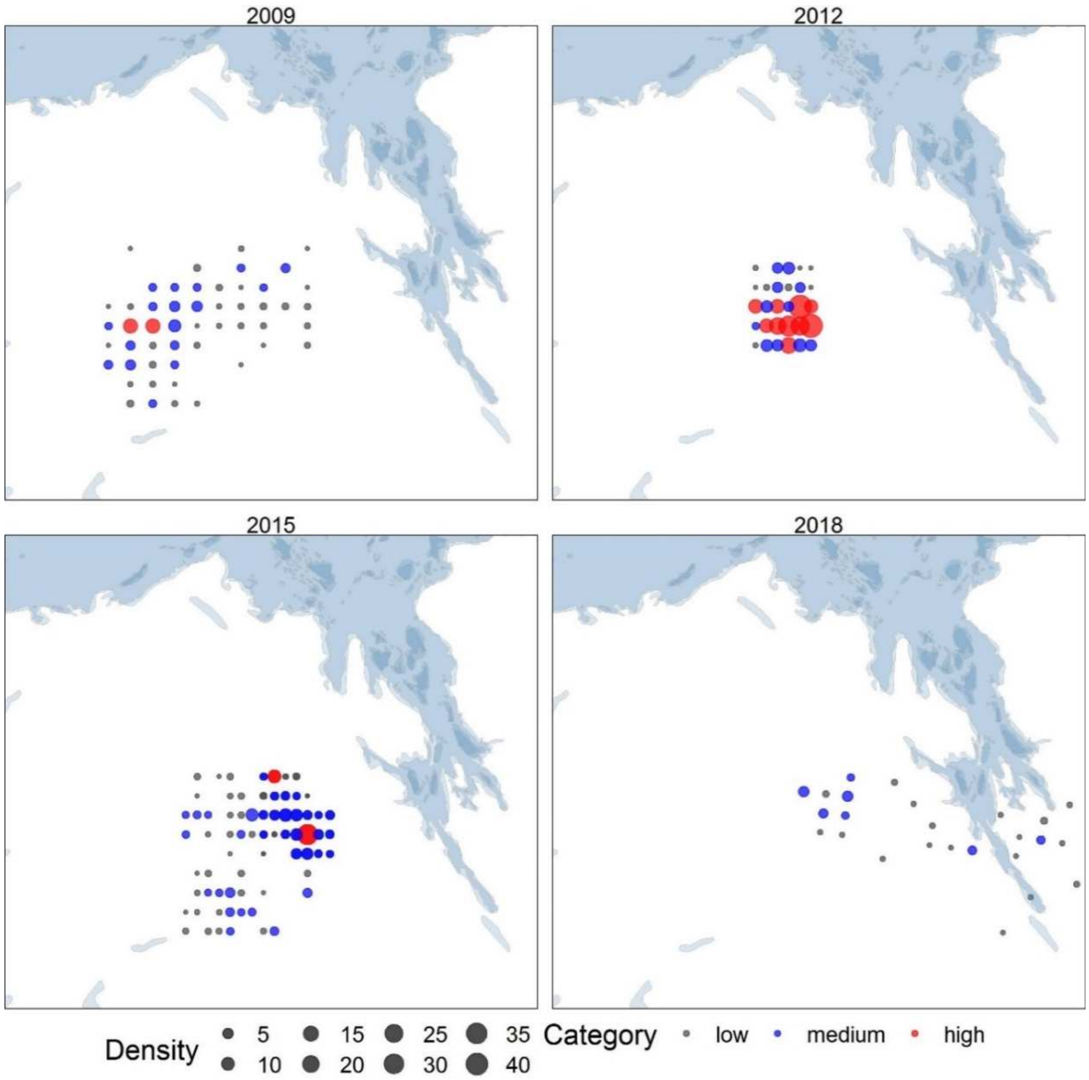

Figure 1: Maps of segment densities from reconnaissance surveys of the Bathurst caribou herd from calving ground surveys 2009-2018. Low density = <1 caribou/km^2, medium density = 1-9.9 caribou/km^2, and high density = at least 10 caribou/km^2.

Plots of segment densities also illustrate the higher level of aggregation in 2012 with fewer lower and medium density segments in comparison to high density segments (Figure 2).

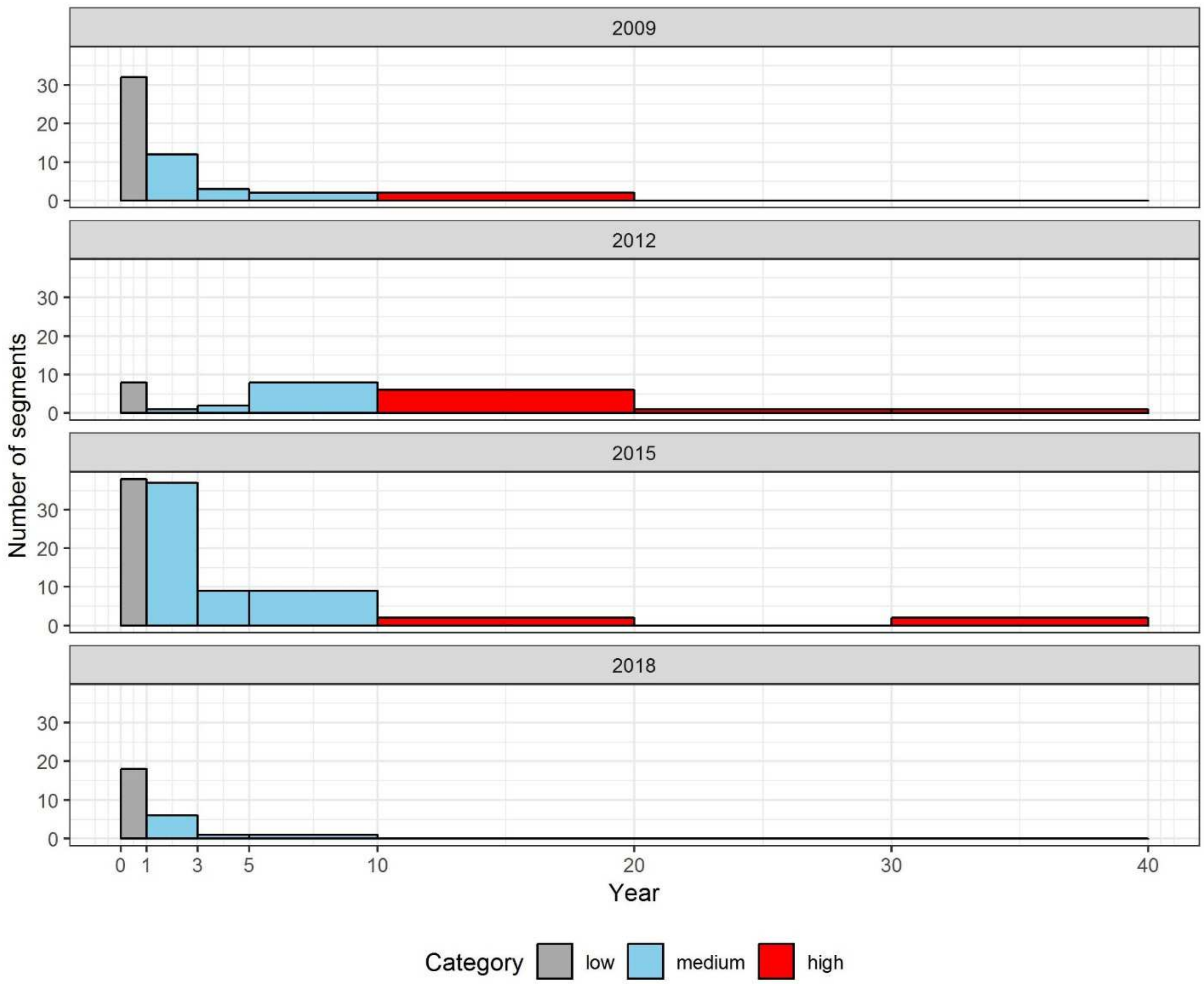

Figure 2: Segment densities in annual concentrated calving areas for the Bathurst caribou herd 2009-2018. Low density = <1 caribou/km^2, medium density = 1-9.9 caribou/km^2, and high density = at least 10 caribou/km^2.

Median segment densities were below 5 caribou per km^2 for all years except 2012 (Figure 3).

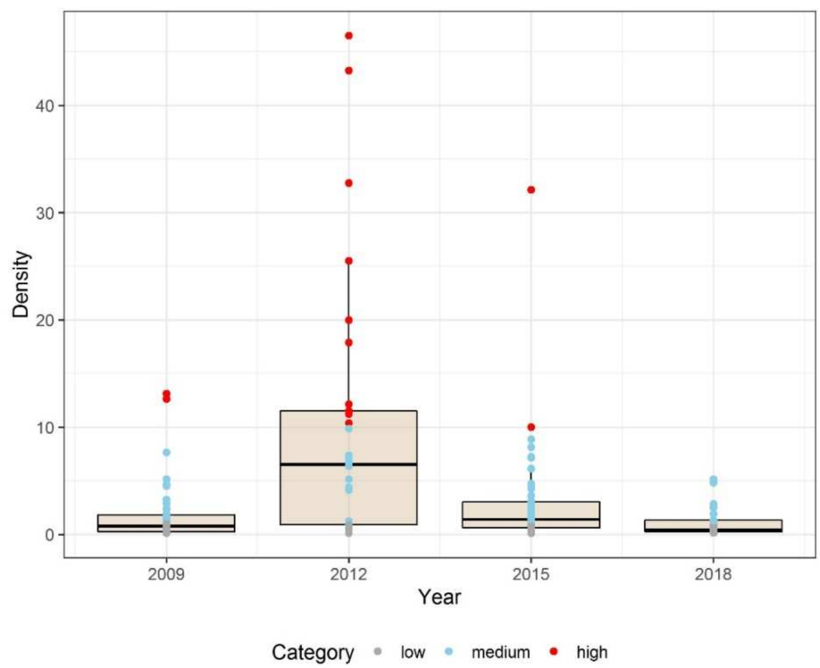

Figure 3: Boxplot of segment densities on calving ground surveys for the Bathurst herd 2009-2018.

A comparison of core areas further demonstrates the higher level of aggregation in 2012 with a smaller core area compared to other years (Figure 4).

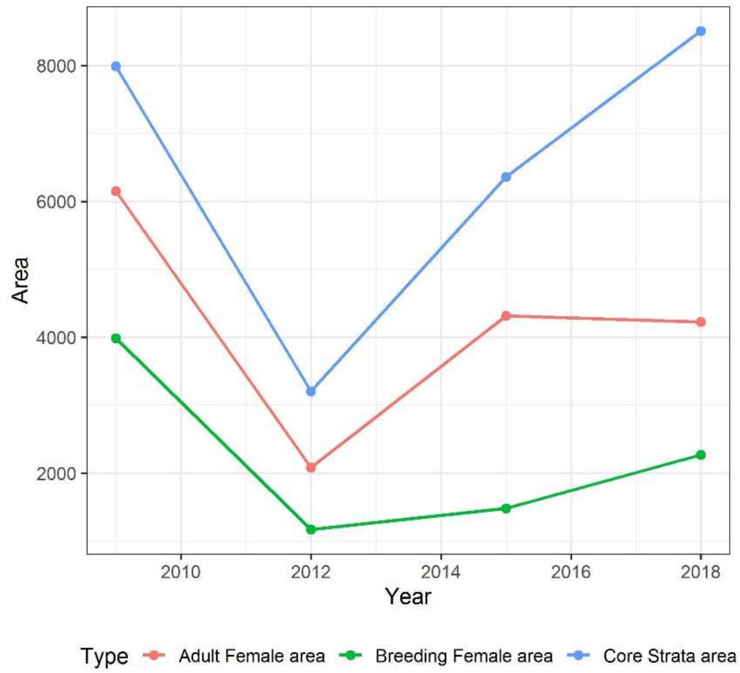

Figure 4: Area of core survey strata, area weighted by proportion of breeding females, and area weighted by proportion of adult females in survey strata by year for the Bathurst herd 2009-2018.

During this time, estimates of abundance of adult and breeding females stabilized from 2009-2012 followed by a decline from 2012-2018 (Figure 5).

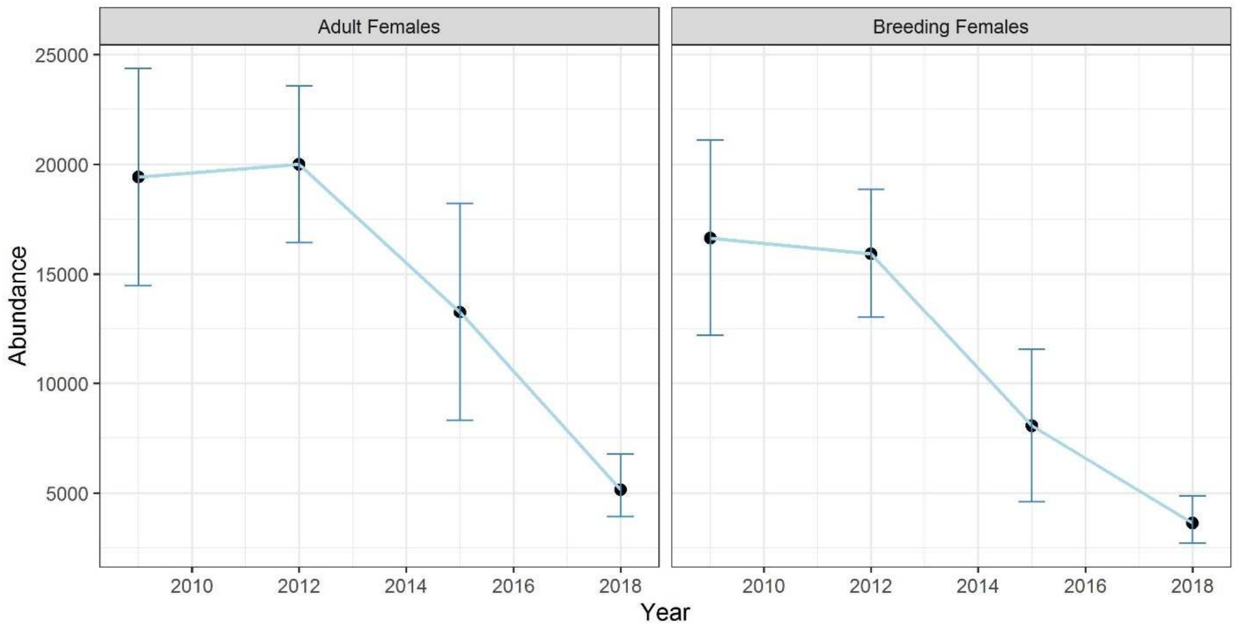

Figure 5: Estimates of abundance of adult and breeding females on core calving areas 2009-2018 for the Bathurst herd.

Density was estimated by dividing abundance (Figure 5) by core area (Figure 4). Plots of core densities suggest an increase from 2009-2012 followed by a decrease from 2012-2018 (Figure 5). The increase in density in 2012 was partially due to a decrease in core area of the calving ground rather than a substantive increase in overall abundance (Figure 6). Trends in density estimates using the core and weighted methods were reasonably similar.

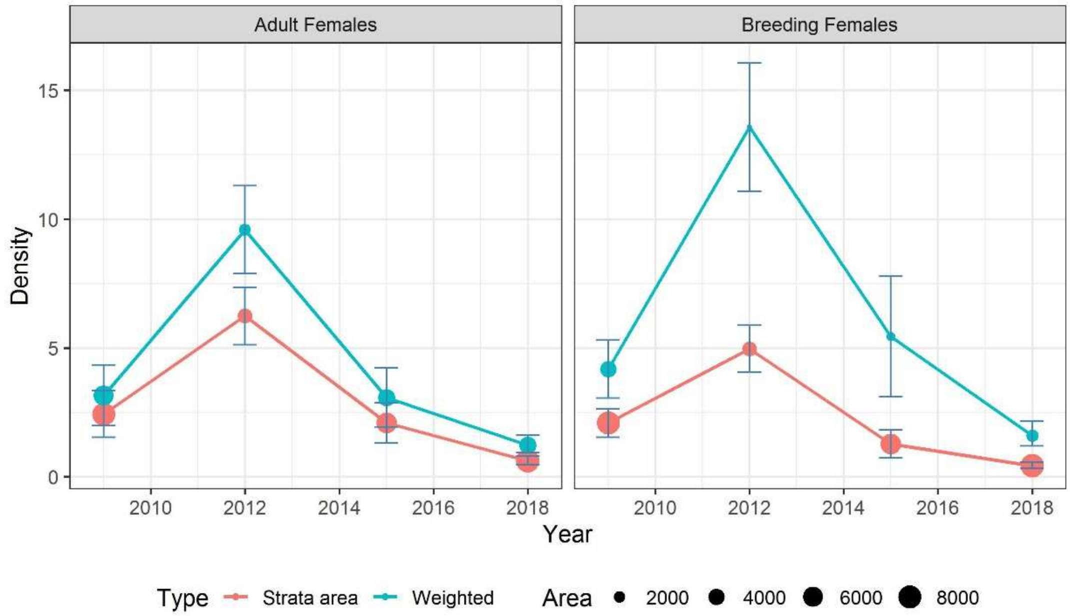

Figure 6: Densities (number/km^2) of adult females and breeding females in survey strata using total area (Strata area) and corresponding breeding female or adult female areas, for Bathurst calving ground 2009-2018. The size of symbols is proportional to the calving ground area used for density estimates.

Discussion

This report is based on Bathurst caribou calving photo surveys (2009-2018) and provides a summary of trends in caribou distribution, core calving ground area, and caribou densities in core calving ground areas. Defining the core calving area is challenging due to differences in levels of aggregation of caribou during each survey year. We describe a weighted method used to describe trends based on a calving ground core area index, which attempts to confront this issue by weighting the contribution of survey stratum to the overall estimate of core area by the proportion of adult and breeding females estimated in the given strata. The resulting core area index values are best used to infer trends rather than define an absolute area.

In general, aggregation of the Bathurst herd increased in 2012, as indicated by a reduced core calving ground area with increasing density, followed by a decline in density from 2012-2018 (Figure 6).

Alternative methods such as use of collared caribou locations could be used to further infer core areas. This type of analysis could be useful for the 2018 survey year when the core area was mainly defined in a single small area. This type of analysis is beyond the scope of this report but could be pursued in the future.

LITERATURE CITED – see main text