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

**John Boulanger¹, Jan Adamczewski², John Nishi³, Dean Cluff²,
Judy Williams², Heather Sayine-Crawford², and Lisa Marie LeClerc⁴**

¹ Integrated Ecological Research, Nelson, BC

² Environment and Natural Resources, Government of Northwest Territories

³ EcoBorealis Consulting Inc., Millarville, AB

⁴ Department of Environment, Government of Nunavut

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The contents of this report are the sole responsibility of the authors.

ABSTRACT

This report describes the results of a calving ground photo survey of the Bluenose-East caribou herd conducted in June of 2018 west of Kugluktuk, Nunavut (NU). The survey objective was to estimate abundance of breeding females and overall herd size that could be compared to results of previous calving ground surveys done in 2010, 2013 and 2015.

We used collared caribou locations and flew systematic reconnaissance survey transects at 10 kilometer (km) intervals over the calving ground and adjacent areas to delineate the annual concentrated calving area, assess calving status, allocate survey effort to geographic strata of similar caribou density, and time the aerial photography to coincide with the peak of calving. Based on collar movements and observed proportions of calves, it appeared that the peak of calving would occur soon after June 8 and the photo plane survey was flown with excellent field conditions (blue skies) on June 8. We delineated two relatively large photographic strata in the higher density areas, in part because we were concerned that patchy snow would reduce sightability of caribou and we thought that aerial photography would provide better accuracy and precision compared to visual counts under these conditions. On June 8 we also conducted visual surveys of two other strata with lower densities of breeding caribou. 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 sightability of caribou on the aerial photographs as some caribou (on or on the edges of snow patches) required extra effort to identify.

The estimate of 1+year old caribou on the core calving ground was 19,161 (95 percent Confidence Interval (CI) =16,512-22,233) caribou. Combining these numbers with the results of the composition survey, the estimate of breeding females was 11,675 (CI=9,971-13,670). This estimate was precise with a coefficient of variation (CV) of 7.7 percent. The estimate of adult females in the survey area was 13,988 (CI=12,042-16,249). The proportion of adult females classified as breeding was higher in 2018 (83 percent) than in 2015 (63 percent). 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 2018 fall composition survey. The resulting estimate of Bluenose-East herd size in 2018 was 19,294 caribou at least two years old (CI=16,527-22,524). Comparison of 2015 and 2018 adult female numbers and overall trend 2010-2018 indicated an annual rate of decline of 20 percent (CI=13-27 percent) and a herd reduction of 50 percent between 2015 and 2018. This decline could not be attributed to issues with survey methods. Assessment of movement of collared females between the Bluenose-East and neighbouring Bluenose-West and Bathurst calving grounds from 2010-2018 showed minimal movement of cows to or from neighbouring herds. Demographic modeling that used composition, collared caribou, and survey data estimated that the cow survival rate was low in 2018 (0.72, CI=0.60-0.83) and calf survival has declined

since 2010. We suggest population surveys every two years, and annual monitoring of cow survival, calf productivity and calf survival for this herd in the future.

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INTRODUCTION

This report describes results of a calving ground photo-survey of the Bluenose-East caribou herd conducted during June of 2018. This herd's extent of calving area (Russell et al. 2002) has been found in recent years west of Kugluktuk, and the summer range includes the calving ground as well as areas south and east of it. The winter range is primarily south, southeast and east of Great Bear Lake (Figure 1).

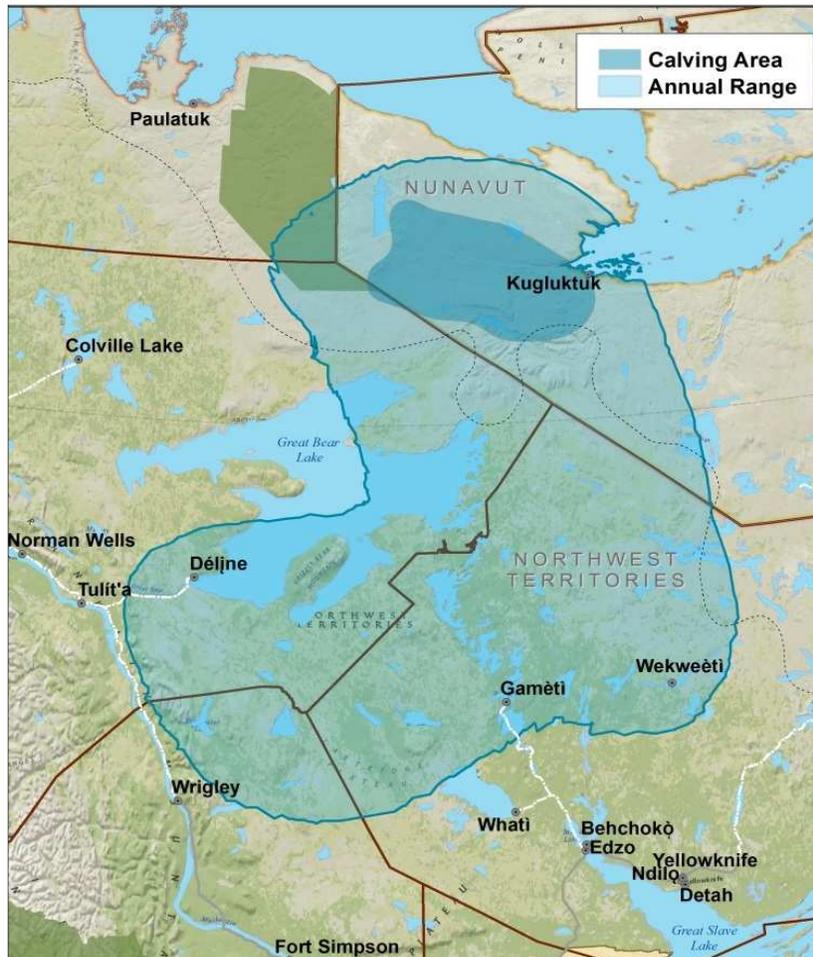


Figure 1: Annual range and extent of calving for the Bluenose-East herd, 1996-2009, based on accumulated radio collar locations of cows (Nagy et al. 2011). The calving area and a portion of the summer range are in Nunavut (NU) and the rest of the range is in the Northwest Territories (NWT).

The Bluenose-East survey was conducted concurrently with a survey of the Bathurst calving ground; results of the Bathurst caribou survey are reported separately. Figure 2 shows paths of collared caribou cows between May 15 and June 8 to the Bluenose-West, Bluenose-East, and Bathurst calving grounds.

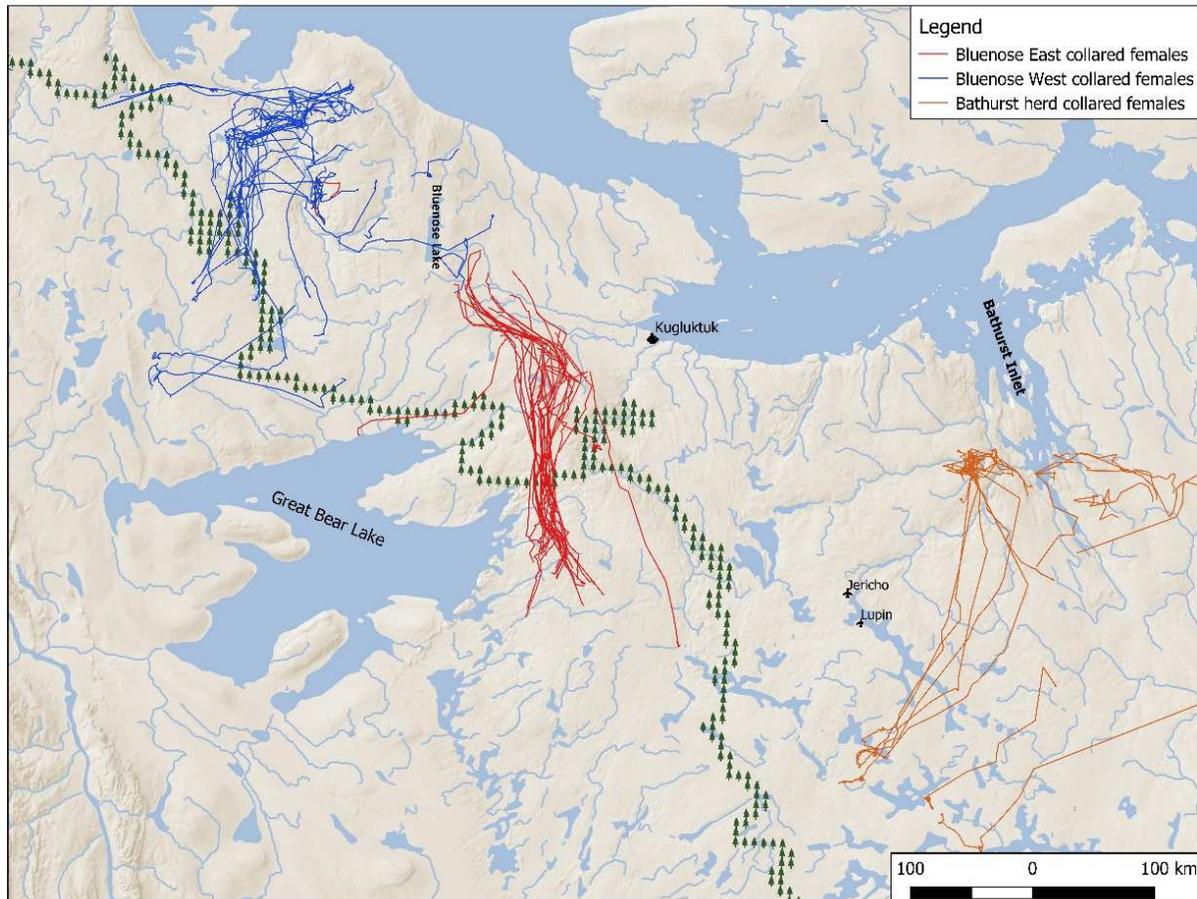


Figure 2: Spring migration paths of satellite collared Bluenose-West (blue), Bluenose-East (red) and Bathurst (orange) cows from May 15 - June 8, 2018.

In earlier years (2000-2010), post-calving surveys were used for this herd (Patterson et al. 2004, Adamczewski et al. 2009) but surveys were challenged by the lack of consistent formation of the tightly packed caribou groups this survey depends on. Since aggregation of caribou into large, compact groups is a behavioural response to reduce harassment by blood-sucking insects, the observed pattern of aggregation varies with insect abundance and environmental conditions. Insect harassment generally increases with temperature and decreases with wind (Patterson et al. 2004). Thus, success of post-calving surveys is contingent on suitable summer weather and aggregation patterns of caribou, which are highly variable within and between post-calving survey windows.

The Bluenose-East herd was surveyed in 2010 using both a calving ground photo-survey and a post-calving survey (Adamczewski et al. 2017, Boulanger et al. 2018). Both the calving and post-calving surveys in 2010 indicated that the herd was over 120,000 adult caribou. Additional calving photo surveys followed in 2013 (Boulanger et al. 2014b) and 2015 (Boulanger et al. 2016). Based on these surveys, the herd was declining at an approximate rate of 20 percent per year 2010-2015, based on adult female estimates (Figure 3).

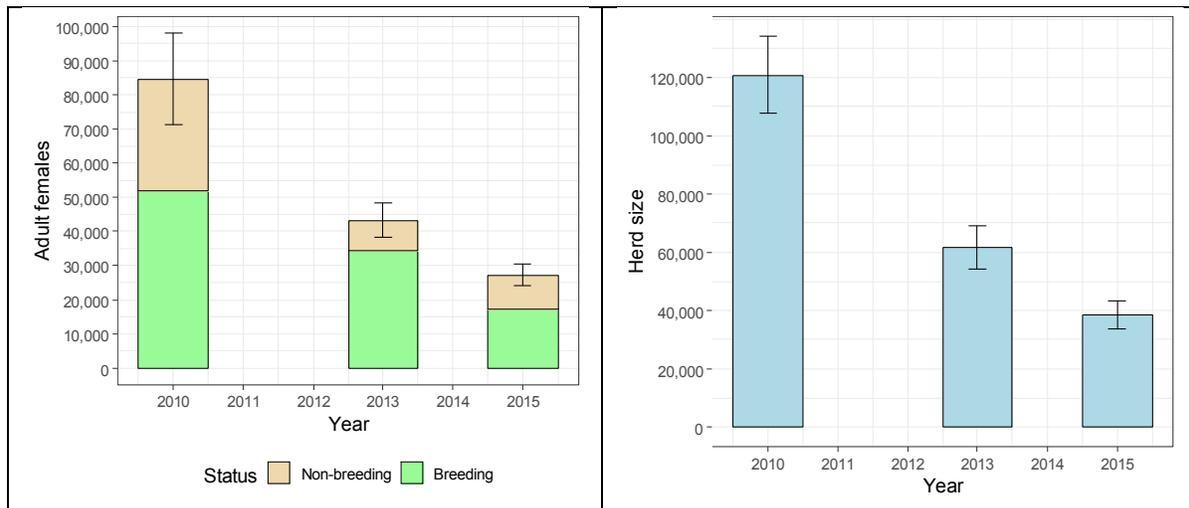


Figure 3: Estimates of adult females (subdivided by breeding status) on the left and extrapolated herd size on the right, from 2010, 2013, and 2015 calving ground surveys of the Bluenose-East caribou herd.

METHODS

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

1. Locations from collared caribou, historic records of calving ground use, and systematic aerial reconnaissance surveys of the Bluenose-East calving area were used to identify the extent of calving between Kugluktuk and Bluenose Lake in NU in June 2018.
2. The systematic aerial reconnaissance survey was conducted before the peak of calving, where 800 m strip transects were flown at 10 km intervals to determine areas where breeding females were concentrated on the calving ground, as well as locations of bulls, yearlings, and non-breeding cows on or near the calving ground. Timing of the peak of calving was assessed by (a) observers who estimated the proportion of cows with newborn calves from survey flying, and (b) from a pattern of reduced movement rates of collared cows which was used as an indication of calving when average daily movement declined to ≤ 5 km/day.
3. Using data from the reconnaissance survey, geographic areas called strata (or survey blocks) were delineated for the more intensive survey, either by the photo plane or visually. We allocated photographic sampling effort to areas with the highest densities of breeding cows. Two photo blocks were delineated based on higher relative densities of breeding cows and were surveyed with photo-planes. Two visual blocks were delineated based on lower relative densities of adult female caribou and were surveyed by human observers in fixed-wing aircraft. The aerial survey was conducted with the photo-plane and by visual survey.
4. We initiated the helicopter-based composition survey at the same time of the photographic and visual surveys of the calving area. The composition survey crew classified larger groups (i.e. $> \sim 50$ -100 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, yearlings, and newborn calves.
5. The estimate of breeding females was derived using the estimates of total 1+year old caribou 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 1+year-old caribou in the survey area.
6. The adult female estimate was then used to extrapolate the total size of the Bluenose-East 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 2018.
7. Demographic data for the herd and the new estimates 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

Locations of 32 collared female caribou were monitored to assess movement rates and pathways and serve as a geographic guide for overall survey coverage. Of these, 17 were known Bluenose-East cows that had occurred on the Bluenose-East calving ground in June 2017 and 15 were collared during the winter of 2017-2018. Four were most likely Bluenose-West cows based on collaring locations in winter and June locations during calving. In addition, changes in daily movement rates of collared cows were assessed to determine the timing of calving. Usually, movement rates of parturient female caribou are reduced to <5 km/day during the peak of calving and for a few days after calving (Gunn et al. 1997, Nishi et al. 2007, Gunn et al. 2008, Gunn and Russell 2008, Nishi et al. 2010).

Reconnaissance Surveys to delineate Strata

Reconnaissance transect lines were systematically spaced at 10 km intervals (i.e. eight percent coverage) across the extent of calving and in adjacent areas. The initial focus was on delineating the annual concentrated calving area based on observations of caribou density and composition and the distribution of collared caribou cows. Once the extent of the calving area had been covered, additional survey transects were flown adjacent to the annual concentrated calving area to make sure that no large aggregations of female caribou were missed. Transect lines were generally extended at least 10 km past the last caribou seen, with the exception of the southern trailing edge where composition was increasingly comprised of bulls, yearlings and non-breeding females.

Kugluktuk was the base of operations for the Bluenose-East survey (Figure 1). Two Cessna Caravans were used for the systematic reconnaissance surveys and visual blocks. During visual surveys, caribou were counted within a 400 meter (m) strip on each side of the survey plane (800 m total, Gunn and Russell 2008). For each side of the plane, strip width was defined by the wheel of the airplane on the inside, and a single thin rope attached to the wing strut, that became horizontal during flight, served as the outside strip marker. Planes were flown at an average survey speed of 160 km/hr. at an average altitude of 120 m (by monitoring a radar altimeter) above the ground to ensure that the strip width of the plane remained relatively constant.

Two observers (one seated in front of the other) and a recorder were used on each side of the airplane to minimize the chance of missing caribou. Previous research (Boulanger et al. 2010) demonstrated that this method increases sightability compared to single observers. The two observers on the same side communicated to ensure that groups of caribou were not double counted.

Caribou groups were classified by whether they contained breeding females. Breeding caribou were defined as female caribou with hard antlers or a newborn calf at heel. A mature female with hard antlers is a general indicator that the caribou had yet to give 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 the predominance of yearlings (as indicated by a short face and a small body), bulls (as indicated by thick, dark antlers in velvet and a large body), and non-antlered females or females with short antlers in velvet. The speed of the aircraft did not allow all caribou to be classified; 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). 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 ($0.8 \text{ km strip width} \times 10 \text{ km} = 8 \text{ km}^2$). 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.

Figure 4: The tablet data entry screen used during reconnaissance and visual survey flying on Bathurst and Bluenose-East June surveys in 2018. A GPS waypoint was obtained for each observation, allowing efficient entry and management of survey data. In addition, the unique segment unit number was also assigned by the software for each observation to summarize caribou density and composition along the transect lines.

Stratification and Allocation of Survey Effort

The main objective of the survey was to obtain a precise and accurate estimate of breeding female caribou on the calving ground. To achieve this, the survey area was stratified using the results of the systematic reconnaissance survey, a procedure of grouping areas with similar densities into contiguous blocks. Areas of higher caribou densities were considered for survey by the photo plane, with lower-density areas designated for visual surveys with two observers on each side. In this survey, two relatively large photo blocks were defined. We delineated the large photo strata because we were concerned that patchy snow conditions would reduce visual sightability of caribou (particularly single animals or small groups) and that aerial photography would provide a more consistent and reliable method for detecting and counting caribou in the area where most breeding females occurred. We thought that caribou would still be found reliably on the high-resolution aerial photos, which could be searched slowly and repeatedly using multiple counters. Two other relatively small strata were designated for visual survey, one north of the photo blocks and one south of them. Given that a key objective of the survey was to estimate breeding females, areas that contained breeding females were given priority, but all areas with collared female caribou were also surveyed.

Once the survey strata were delineated, an estimate of caribou numbers (animals at least 1+year-old) was derived from the reconnaissance data (Jolly 1969). The relative population size of each stratum and the degree of variation in caribou numbers of each block were used to allocate survey effort and a suitable number of transects to each stratum.

We used two approaches for allocating survey effort. First, optimal allocation of survey effort was considered based on sampling theory (Heard 1987, Thompson 1992, Krebs 1998). Optimal allocation basically assigned more effort to strata with higher densities, given that the amount of variation in counts is proportional to the relative density of caribou within the stratum. Optimal allocation was estimated using estimates of population size for each stratum and survey variance.

Secondly, based on relative sizes of delineated strata, we adjusted optimal allocation estimates to ensure an adequate number of transects. Based on previous surveys, we considered 10 transects per stratum to be a minimum level of coverage, with closer to 20 transects being optimal for higher density areas. In general, we considered 15 percent coverage as a minimum to achieve adequate precision, and allocated higher levels of coverage for higher density strata. In the context of sampling, increasing the number of transects in a stratum is “insurance” because it minimizes the influence of any one transect on estimate precision. As populations become more clustered, a higher number of transects is required to achieve adequate precision (Thompson 1992, Krebs 1998).

Estimation of Caribou on the Calving Ground

Photo Surveys of High-density Strata

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, each with a digital camera mounted in the belly of the aircraft. Survey height to be flown for photos was determined at the time of stratification based on cloud ceilings and desired ground coverage. Both aircraft were used for the two Bluenose-East photo blocks. Coverage on each photo transect was continuous and overlapping so that stereoscopic viewing of the photographed areas was possible.

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 3D glasses that allowed three-dimensional viewing of photographic images. Two of the authors (J. Boulanger and J. Adamczewski) visited the GreenLink office in Edmonton and tested the photo-counting equipment 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 (\hat{N} : 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 (\bar{D}) of caribou observed within the strata ($\hat{N} = \bar{D}A$) where density is estimated as the sum of all caribou counted on transect divided by the total area of transect sampling ($\bar{D} = \text{caribou counted} / \text{total transect area}$). An equivalent estimate of mean density can be derived by first estimating transect-specific densities of caribou ($\hat{D}_i = \text{caribou}_i / \text{area}_i$) 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 (\bar{D}) for the stratum. More exactly, $\bar{D} = \sum_i^n \hat{D}_i w_i / \sum_i^n w_i$ 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 ($w_i = l_i / \bar{l}_i$) 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 ($\hat{N} = \bar{D}A$) (Norton-Griffiths 1978).

When survey aircraft first flew north to Kugluktuk on June 1, snow cover on the survey area was 90 percent or greater, and in some areas 100 percent. Over the following 10 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 than usual. 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: (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.

For the double observer method, we systematically resampled a subset of photos to estimate overall sightability for each stratum. For these photos, a second photo interpreter provided an independent count of caribou. This two-stage approach to estimation, where one stage is used to estimate detection rates that are then used to correct estimates in the second stage, has been applied to a variety of wildlife species (Thompson 1992, Barker 2008, Peters et al. 2014). 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 2nd count for each photo resampled. Using this approach avoids the assumption that the 2nd 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. 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 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).

Non-independence of caribou counted in photos most likely caused over-dispersion of binomial variances. The over-dispersion parameter (\hat{c}) 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 in Low-density Strata

Visual surveys were conducted in two low density strata, one north of the photo blocks and one south of them. For visual surveys, the Caravans were used with double observers and a recorder on each side of the aircraft. The numbers of caribou sighted by observers were then 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 5). 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 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 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.

- 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 (Boulanger et al. 2010, Buckland et al. 2010, Boulanger et al. 2014a).

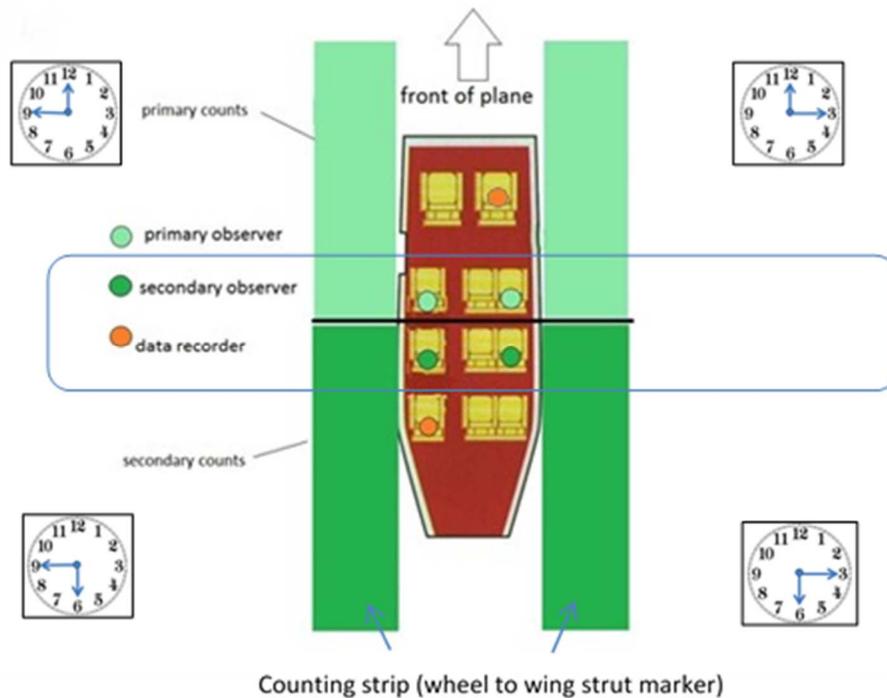


Figure 5: Observer and recorder positions for double observer methods on June 2018 caribou survey of Bluenose-East caribou. The secondary observer confirmed or called caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can be used to reference relative locations of caribou groups (e.g. “caribou group at 1 o’clock”). The recorder was seated behind the two observers on the left side, with the pilot in the front seat. On the right side the recorder was seated at the front of the aircraft and was also responsible for navigating in partnership with the pilot.

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 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 Bluenose-East 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 calving ground 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. Appendix 1 provides more details on estimation using double observer methods.

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 (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 with GIS maps being produced in QGIS software (QGIS Foundation 2015).

Composition Survey of Breeding and Non-breeding Caribou on the Calving Ground

The composition survey was initiated in the survey strata at the same time of the photo and visual surveys on June 8. 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 allowed more detailed and accurate classification than the relatively broad classification applied during the reconnaissance survey. For this, a helicopter (initially a Long Ranger, later replaced by an A-Star) was used to systematically survey groups of caribou. Caribou groups that comprised $\sim <50$ individuals were classified from the air by a front-seat observer using motion-stabilized binoculars (Canon 10X42L IS WP). Classified caribou counts were called out to a rear-seat data recorder who entered the data into a computer tablet.

Caribou were classified following the methods of Gunn et al. (1997) (and see Whitten 1995) where antler status, presence/absence of an udder, and presence of a calf are used to categorize breeding status of females. Newborn calves, yearlings and bulls were also classified (Figure 6). 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.

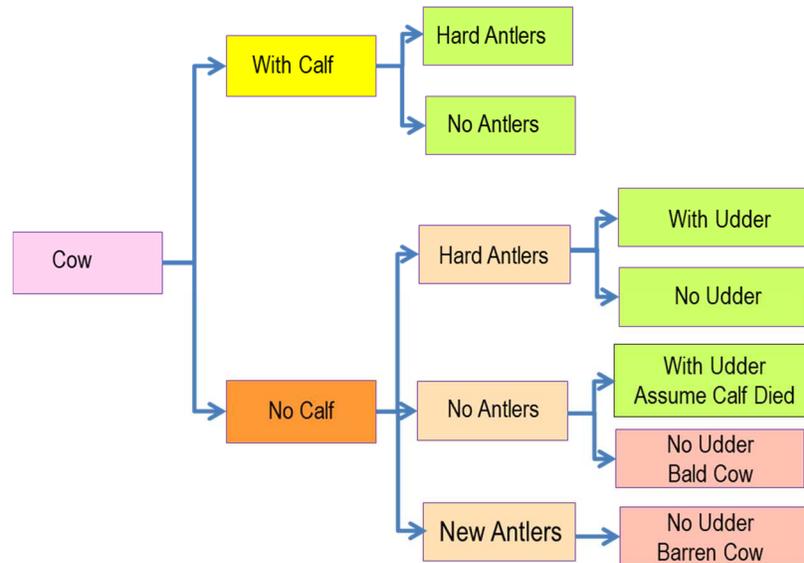


Figure 6: Classification of breeding females used in composition survey of Bluenose-East caribou in June 2018. Shaded boxes were classified as breeding females (diagram adapted from Gunn et al. (2005b)). Udder observation refers to a distended udder in a cow that has given birth, and antler observation is a hard antler distinct from new antlers growing in velvet.

The number of each group was totaled 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 (SE) 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 (1+year old) caribou on each stratum by the estimated proportion of breeding females in each stratum from composition surveys. 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 (1+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

As a first step, the total number of adult (2+year old) females in the herd was estimated by dividing the estimate of breeding females on the calving ground by an assumed pregnancy rate of 0.72 (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 2018, to provide an estimate of total adult caribou in the herd (methods described in Heard and Williams 1991). This estimator assumes that all breeding females were within survey strata areas during the calving ground survey and that the pregnancy rate of caribou was 0.72 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.

Estimate of Herd Size Based upon Estimates of Adult Females

An alternative extrapolated herd size estimator was developed to explore the effect of variable pregnancy rates as part of the 2014 Qamanirjuaq caribou herd survey (Campbell et al. 2016) and has been used in other calving photo surveys for the Bluenose-East herd (Boulanger et al. 2016, Adamczewski et al. 2017). This estimator first uses data from the composition survey to estimate the total proportion of adult females, and 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. Using this approach, the fixed pregnancy rate is eliminated from the estimation procedure. This estimate assumes that all adult females (breeding and non-breeding) were within the 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 photo surveys since the 2014 Qamanirjuaq survey (Campbell et al. 2016), the estimate of females based on total adult females on the calving ground survey area has become the preferred way (for the Department of Environment and Natural Resources (ENR)) of estimating this number, and herd estimates based on this method are the ones graphed in Figure 3. With sufficient numbers of collared cows and extensive systematic reconnaissance surveys, it has become possible to define the full distribution of the females in the herd reliably. Pregnancy rates do vary depending on cow condition (Cameron et al. 1993, Russell et al. 1998). We found that the proportion of breeding females on the Bluenose-East calving grounds in 2010, 2013, 2015 and 2018 has been quite variable. Using survey-specific estimates of breeding and non-breeding cows is a more robust method of extrapolating to herd size, rather than assuming a constant

deterministic pregnancy rate that ignores this source of variation. This method also increases the precision of the overall herd estimate.

Trends in 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. However, Bayesian models allow more flexible modeling of variation in trend through the use of random effects models (Humbert et al. 2009). This general approach is described further in the demographic model analysis in the next section. The population size was log transformed to partially account for the exponential nature of population change (Thompson et al. 1998). The rate of change could then be estimated as the exponent of the slope term in the regression model (r). The per capita growth rate can be related to the population rate of change (λ) using the equation $\lambda = e^r = N_{t+1}/N_t$. If $\lambda = 1$ then a population is stable; values $>$ or < 1 indicate increasing and declining populations. The rate of decline was also estimated as $1 - \lambda$.

Demographic Analyses

Survival Rate Analyses

Collar data for female caribou 2010-2018 were compiled for the Bluenose-East caribou herd by the Government of the Northwest Territories (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 Model Analyses

One of the most important questions for the Bluenose-East herd was whether the breeding 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 (recruitment of yearlings to adult breeding females) 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 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 Integrated Population Model (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 Bluenose-East herd. A state space model is basically a model that allows separate modeling of field sampling estimates and demographic processes. 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 used the 2010, 2013, 2015 and 2018 breeding female estimates, as well as calf-cow ratios, bull-cow ratios (Cluff et al. 2016), 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 Bluenose-East 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 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 model is a stage based model that divides caribou into three age-classes, with survival rates determining the proportion of each age class that makes it into the next age class (Figure 7); this structure is identical to the OLS modeling done previously on the Bathurst and Bluenose-East herds.

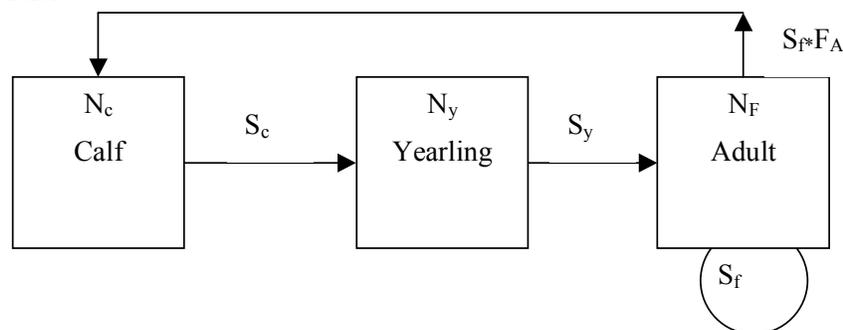


Figure 7: Underlying stage matrix life history diagram for the caribou demographic model used for Bluenose-East and Bathurst caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected 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 restricted the data set for this exercise to composition and survey results between 2008 and 2018, which covered the time period in which calving ground photographic surveys had been conducted on the Bluenose-East herd. In addition, this interval basically covered potential recruitment into the breeding female class since any surviving female calf born from 2008-2010 would be a breeding female by 2013, and breeding females recruited prior to 2008 were accounted for by the 2010 calving ground estimate of breeding females (Table 2). 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 2: A schematic of the assumed timeline 2011-2018 in the Bayesian IPM analysis of Bluenose-East 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

We note that the underlying demographic model used for the 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 modeling to model temporal variation in demographic parameters. For random effects models, it is assumed that there is a central mean value for a parameter (i.e. Cow survival) with a distribution of values created over time based on temporal variation. 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 3 provides details on the Bayesian IPM state space modeling, including the base R code used in the analysis.

RESULTS

Survey Conditions

Weather conditions were challenging due to the late spring with higher than normal snow cover in most of the core calving ground area (Figure 8). On June 8, snow cover varied from nearly 100 percent at the north end of Bluenose Lake to nearly 0 percent at the south end near the Coppermine River. Most areas had about 50 percent snow cover and much of it was a “salt-and-pepper” patchy mosaic. This reduced sightability of caribou and we decided to photo-survey the majority of the core calving ground area to offset this potential issue. The rationale was that caribou would still be reliably seen on high-resolution photos that could be searched carefully and repeatedly with a three-dimensional projection. We expected that 80-90 percent of the female caribou found would be in the photo blocks. In addition, the sightability of caribou on photos could be tested further using independent observers.



Figure 8: Photos of variable Bluenose-East survey conditions on June 8, 2018 when the visual and photo surveys were conducted (photos J. Adamczewski). Snow cover ranged from 95 percent or more at the north end near Bluenose Lake (bottom right) to nearly bare ground near the Coppermine River (bottom left).

Movement Rates of Collared Caribou

The locations of 30 adult female caribou that occurred in or around the Bluenose-East 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 <5 km/day (Gunn and Russell 2008). Using this parameter, we surmised that the peak of calving was near starting on June 8, when mean daily movement rates were 5 km or less for half of the radio

collared caribou (Figure 9). The peak of calving was further verified from observations of substantial numbers of cows with calves from the composition and visual survey flying on June 8.

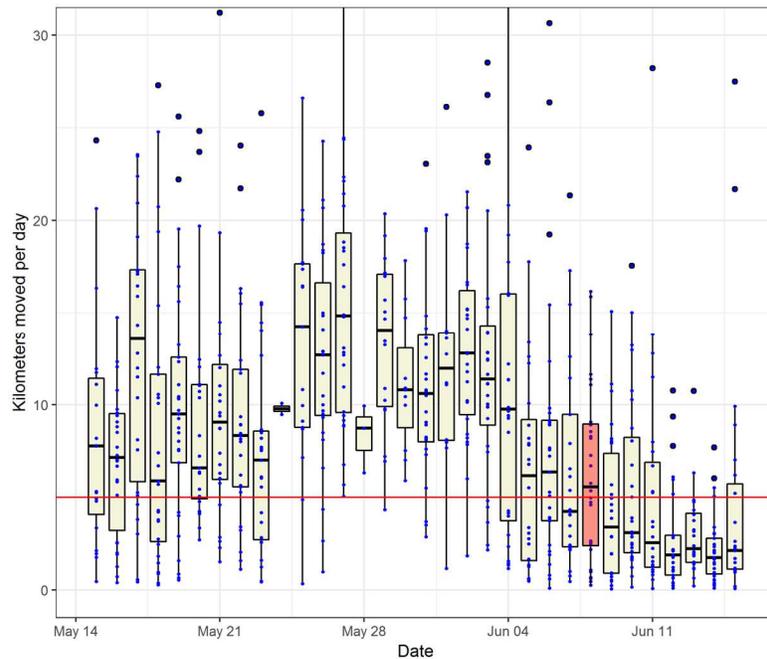


Figure 9: Movement rates of female collared caribou on or around the Bluenose-East calving ground before and during calving in 2018. The boxplots contain the 25th and 75th percentile of the data with the median shown by the central bar in each plot. The ranges up to the 95th percentile are depicted by the lines with outlier points shown as larger dots. The movement rates of collared cows on June 8, the date of the visual and photo surveys are highlighted in red.

Reconnaissance Surveys to Delineate Strata

An initial exploratory survey was conducted on June 1st to assess the breeding status of caribou. This survey focused on collared caribou and determined that calving was in the very early stages (very few cows with calves). Low ceilings and ground fog delayed subsequent flying until June 6 and 7 when full days of reconnaissance flying were conducted. A single day of clear weather with blue skies occurred on June 8, and on this day the two photo blocks and two visual blocks were surveyed (Table 3).

Table 3: Summary of reconnaissance and visual survey flying on the June 2018 Bluenose-East calving ground survey

Date	Caravan 1	Caravan 2
June 1	Arrive in Kugluktuk/recon of calving area with collared cows	Arrived in Kugluktuk
June 2-5	Grounded due to fog	Grounded due to fog
June 6	Recon of core calving ground	Recon of core calving ground
June 7	Recon of Northern area	Recon of areas SE of Kugluktuk
June 8	Visual surveys and areas to SE of Kugluktuk	Visual surveys and extra recon on northern edges of strata
June 9	Bathurst survey	Bathurst survey and lines in between Bathurst and BNE
June 10	Recon lines to the East of Kugluktuk & return to Yellowknife	Recon lines to the East of Kugluktuk & return to Yellowknife

Our objectives for the reconnaissance survey were to map the distribution of adult and breeding females and define the concentrated calving area for the Bluenose-East herd. As with the previous survey in 2015, the highest densities of breeding females were to the west of Kugluktuk with lower densities of antlered female caribou and non-breeders to the south. No collared females were found east of the Coppermine River. The distribution of caribou based on reconnaissance surveys and collared females suggested the highest concentrations of breeding caribou along the Rae River up to the east of Bluenose Lake (Figure 10).

The distribution and relative density of hard-antlered female caribou, together with the movement patterns of collared females and recent tracks in the snow, clearly showed that most breeding females were moving in a northwestern direction within a wide corridor along the headwaters of the Rae and Richardson River valleys and northward along the eastern slopes of the Melville Hills east of Bluenose Lake. The leading edge of breeding females in the northern part of the survey area was conspicuous because the density of caribou dropped markedly along the northern boundary. The leading edge and associated distribution of breeding females was included within the visual north stratum (Figure 10).

Within the observed distribution of breeding females mapped during the systematic reconnaissance, relatively consistent densities and distribution of breeding females were observed in the western reaches of the Rae and Richardson River valleys. Based on reconnaissance surveys and distribution of collared cows, we delineated the photo north stratum to encompass what we considered was a majority of breeding females. The photo south stratum was delineated directly adjacent to the photo north strata, and included remaining collared cows and observations of smaller groups with breeding females. Based on the reconnaissance survey, we delineated the photo south stratum to include the mapped distribution of breeding females but

observed and expected this stratum to include more non-breeders as it included the trailing edge of the north-western migratory push of breeding females.

We added the visual south stratum as a smaller adjacent area that extended to tree-line to cover what we observed to be a dispersed trailing edge of caribou at medium densities but with no sightings of hard-antler cows and calves during the systematic reconnaissance survey. Observations of bulls and yearlings were predominant in this stratum. The southern edge of this stratum aligned with the bend of the Coppermine River and included the Coppermine Mountains. A trailing edge towards the south, increasingly composed of bulls and yearlings, is characteristic of this herd, based on previous June surveys (Boulanger et al. 2016, Adamczewski et al. 2017).

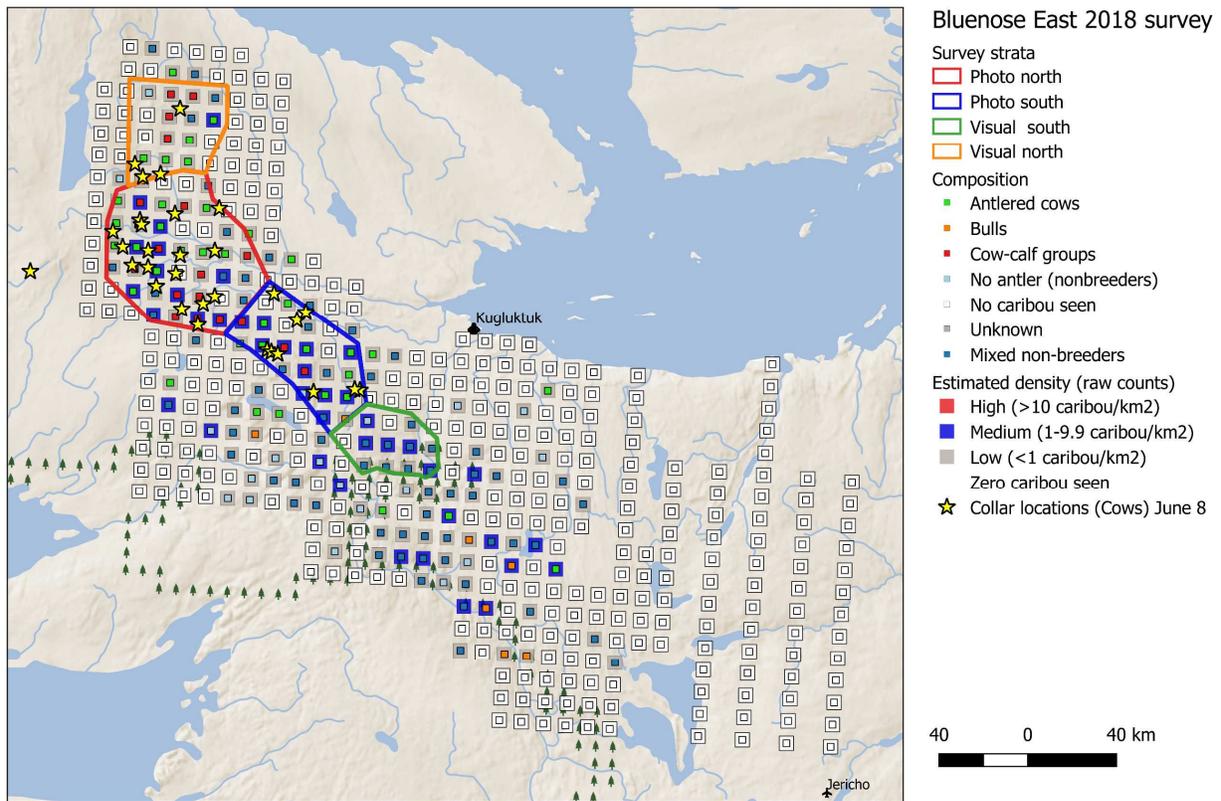


Figure 10: Reconnaissance survey coverage for the June 2018 Bluenose-East calving ground survey. The two photo blocks are shown in red and blue outlines and the two visual blocks are shown to the north and south in orange and green. Outer squares show density of the caribou found (high, medium and low), and inner squares show the kind of caribou seen. Gold stars show locations of collared female caribou, of which 30 occurred in the survey strata. The collared female south of Bluenose Lake was from the Bluenose-West herd. There was also a single caribou to the north of the survey strata from the Bluenose-West herd as shown in Figure 13.

Stratification and Allocation of Survey Effort

Photo Strata

Two photo strata were defined for the Bluenose-East 2018 survey (Figures 10, 11), which included the majority of adult and breeding females and almost all the collared cows. Based on reconnaissance data, relative abundance and density were estimated for the two strata, with higher densities suggested for the south. However, observation of the kinds of caribou recorded in segments suggested that the proportion of breeding caribou was higher in the northern stratum, which argued for higher coverage for this stratum. As a result, roughly equal coverage was given to each stratum.

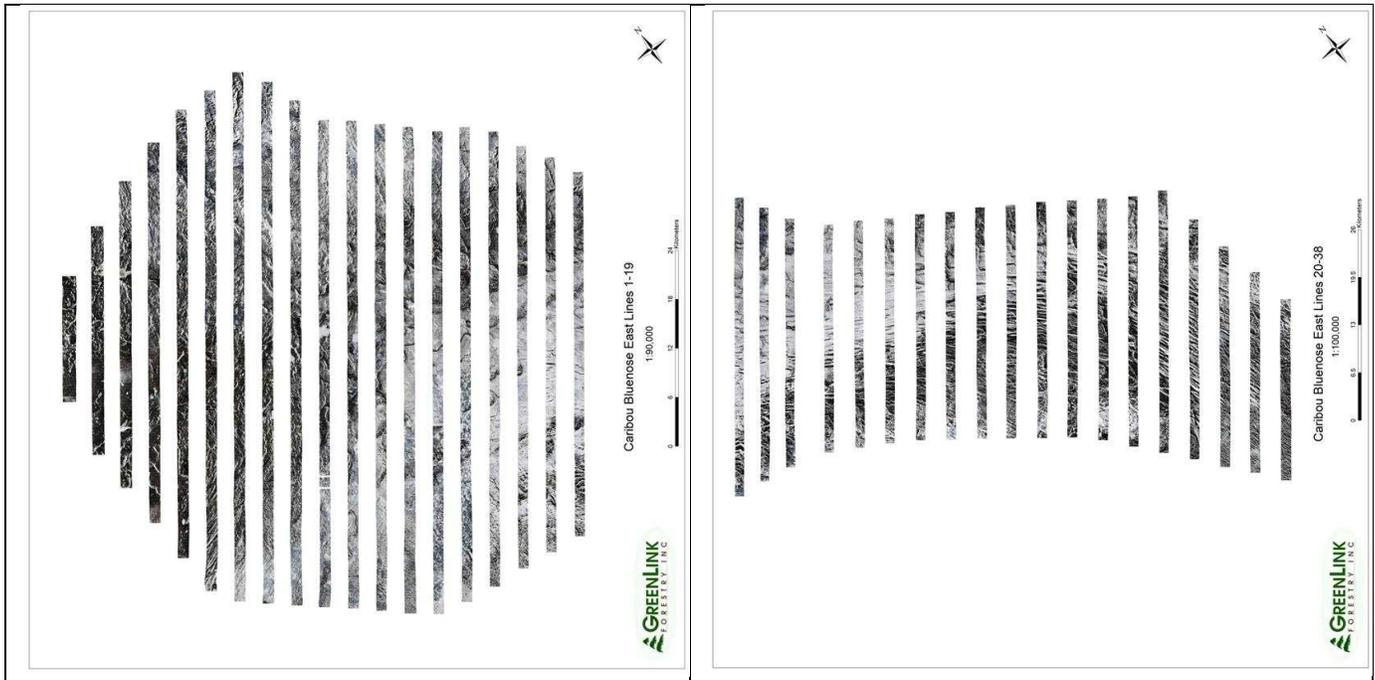


Figure 11: Composite photos of the Bluenose-East North and South photo strata.

Table 4 provides the stratum dimensions for the photo strata.

Table 4: Stratum dimensions and reconnaissance-based estimates of density for the Bluenose-East photo strata in June 2018. Average transect (the average length of a transect), baseline (length of longest axis; transects are flown perpendicular to the baseline), area surveyed, and preliminary estimates of density and abundance (N) based on reconnaissance surveys are given.

Stratum	Area (km ²)	Avg. transect (km)	Baseline (km)	Caribou counted	Area surveyed (km ²)	Density Caribou/km ²	N	SE (N)	CV
North	3,787.8	49.8	76	221	296	0.75	2,828	442.2	0.15
South	2,051.5	34.0	68	207	208	0.99	2,042	261.9	0.13

With photo planes using high-resolution digital cameras, it is possible for the plane 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 particular photo sensor. In practical terms, the GSD for the aerial photos used in this survey translates into strip width and elevation above ground level (AGL) as follows (Table 5).

Table 5: GSD for photo sensor used on Bluenose-East June 2018 caribou survey, along with associated elevation AGL and photographed ground strip width. Typical elevation and strip width used in earlier analog photo surveys are included for reference.

GSD (cm)	Elevation AGL (feet)	Strip width (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
Analog Photos	2,000	914.3

The coverage of photos for the Bluenose-East survey was based upon the approximate total number of photos budgeted for the Bluenose-East and Bathurst surveys occurring at the same time (6,000) and corresponding levels of coverage across a range of likely altitudes (Table 6). When viewed in this context, GSD levels of 5 were not feasible for the Bluenose-East survey with GSD levels of at least 6 needed to keep within 2,000 photos of the budgeted number of 6,000.

Table 6: Stratum dimensions and photos required for various levels of survey coverage for the Bathurst and Bluenose-East photo strata in June 2018. The GSD/photos levels used are underlined and bold.

Strata	Stratum Dimensions				Approximate No. of Photos at GSD				Estimated % Coverage at GSD			
	Stratum Area (km ²)	Average Transect Length (km)	No. Transects	Total Transect Length (km)	5	6	7	8	5	6	7	8
<u>Bathurst</u>	1,159	35.0	15	525	2,389	2,003	<u>1,715</u>	1,458	40%	48%	<u>56%</u>	74%
<u>Bluenose-East</u>												
North	3,788	49.8	22	1,096	4,852	4,046	3,426	<u>3,046</u>	25%	30%	34%	<u>45%</u>
South	2,052	34.0	16	544	2,407	2,007	1,700	<u>1,511</u>	23%	27%	31%	<u>41%</u>
Total photos					7,259	6,053	5,126	4,557				
Total photos					9,648	8,056	6,841	6,015				

In the June 2018 surveys, the Bathurst photo stratum was flown at GSD 7 (average elevation 3,828 feet (1,167 m) above ground) and the Bluenose-East photo strata were flown at GSD 8 (average

elevation 4,374 feet (1,333 m) above ground) with a resulting total of 6,170 photos. Of these, 4,455 were taken in the Bluenose-East calving ground survey and 1,715 were taken in the Bathurst survey. There was only one relatively small higher-density area on the Bathurst calving ground, while the Bluenose-East calving ground, similar to past surveys, has tended to be larger in area with calving caribou more dispersed. Ground coverage on the Bluenose-East North photo block was 37.0 percent and 30.3 percent on the South photo block.

Visual Strata

The Bluenose-East north and south visual strata were relatively small and were flown on June 8, the same day as the aerial photography. These strata had lower densities of caribou (0.36 and 0.88 caribou/km for the north and south stratum respectively). As with the Bathurst surveys, coverage was determined so that each stratum could be completed in one survey flight and each stratum had a minimum of 10 flight lines for acceptable precision. The resulting levels of coverage were 22 percent and 20 percent for the north and south visual strata (Table 7).

Table 7: Final dimensions of strata surveyed for the 2018 Bluenose-East caribou survey.

Stratum	Total Transects Possible	Sampled Transects	Area of Stratum (km ²)	Strip Width (km)	Transect Area (km ²)	Coverage
North Photo	60	22	3,787.8	1.31 ^A	1,402.4	37.0%
South Photo	54	16	2,051.5	1.28 ^A	621.3	30.3%
North Visual	51	12	1,746.9	0.8	378.5	21.7%
South Visual	40	10	1,085.4	0.8	214.9	19.8%

^A Mean strip width for stratum-transect width varied by transect.

Movements of collared caribou from reconnaissance to photo/visual surveys.

Thirty-two collared females were within or around the Bluenose-East calving ground (Figure 12). Of these, 30 occurred in survey strata (Photo North 18, Photo South 8, Visual North 4, Visual South 0). One caribou moved from the south to the north photo stratum between June 7th and 8th. The general movement paths of caribou also occurred within survey strata. Collared caribou that had movement rates of >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 (Figure 12).

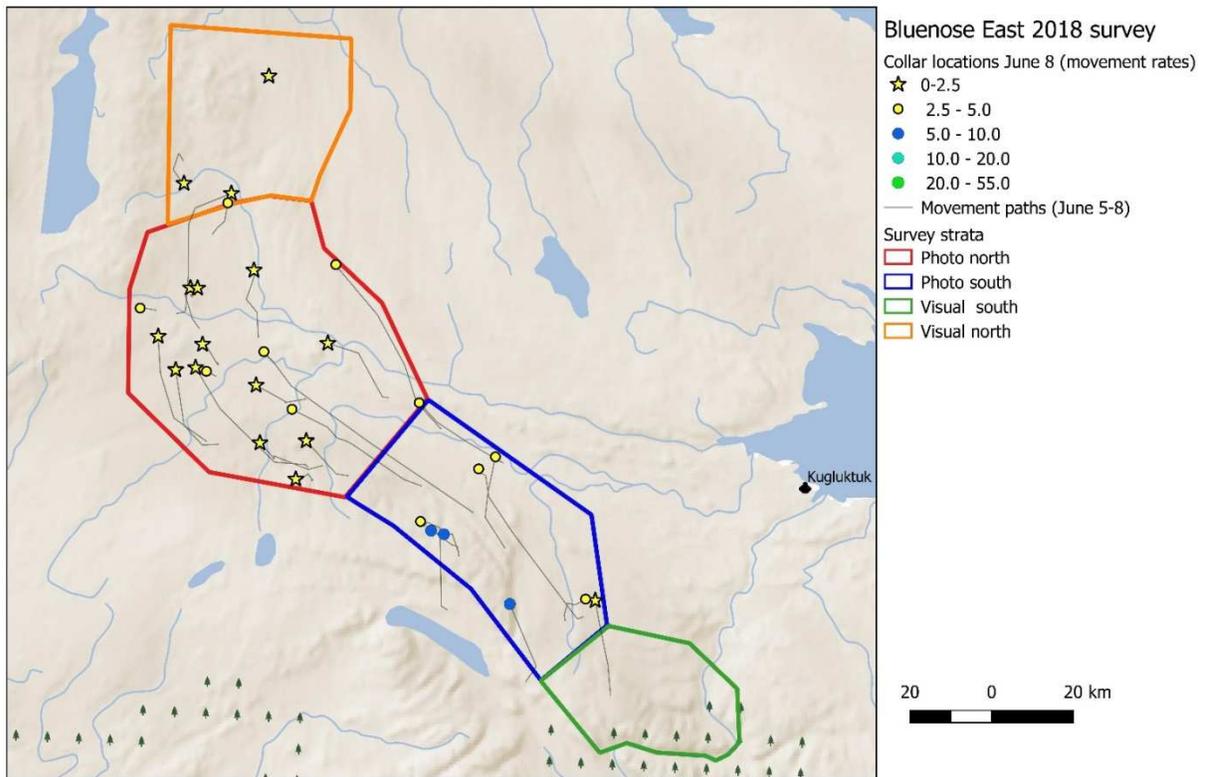


Figure 12: Locations of collared Bluenose-East female caribou and movements up to and during June 8, 2018 when the photo and visual surveys occurred.

Figure 13 displays the distribution of caribou on photos as indicated by points of caribou counted on photos. Dots with color delineating group size illustrate distribution on visual surveys. Two collared cows were north and south of Bluenose Lake and were identified as Bluenose-West females.

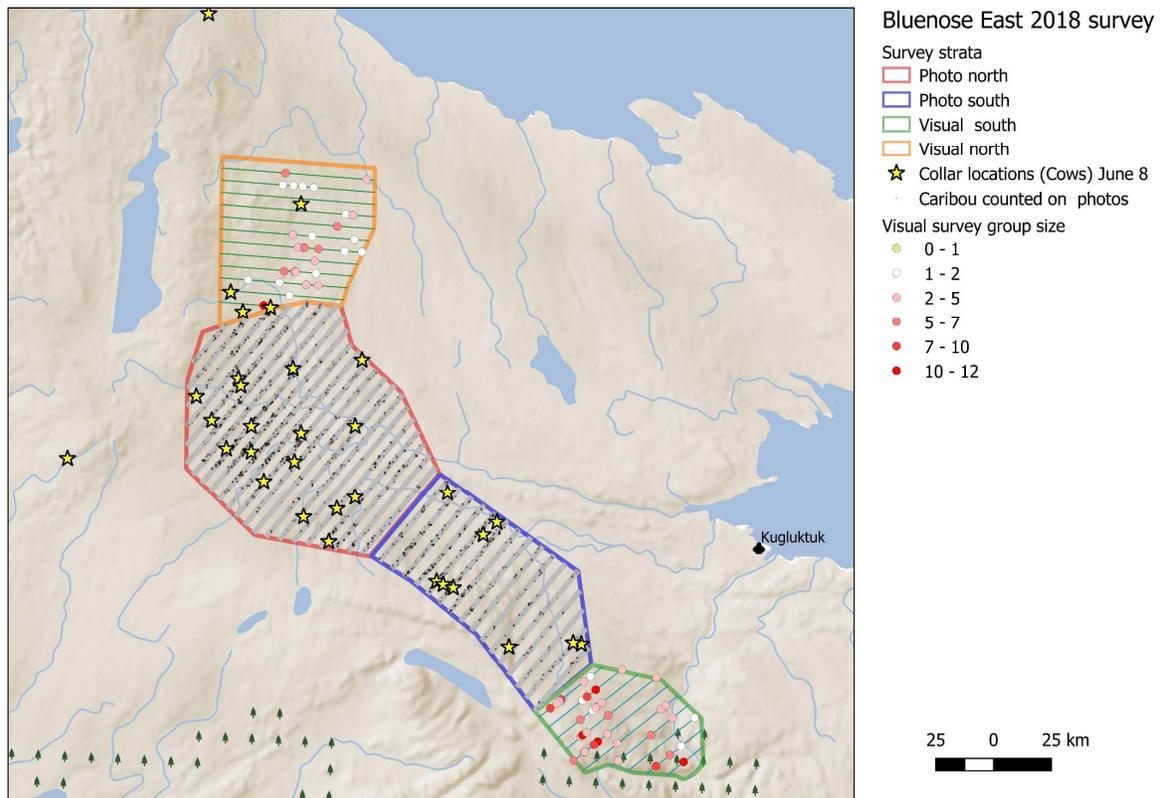


Figure 13: A plot of the Bluenose-East photo data counts and visual survey results with collar locations on June 8, 2018 when surveys occurred. Collared caribou south and north of Bluenose Lake were Bluenose-West females.

Estimates of Caribou on Photo Strata

Photo Sightability Estimation

Photo interpreters found that the sightability of caribou on photos was influenced by snow cover. If the ground was bare caribou were readily visible, however, sightability decreased with snow cover especially in cases of intermittent snow and bare ground at the edges of snow patches (Figure 14).



Figure 14: Close-up view of one zoomed-in portion of an aerial photo on Bluenose-East survey on June 8, 2018. Among others, three caribou are visible in the upper left corner, and a cow and calf can be seen walking (along with their shadows) across the snow-patch in the middle of the photo. Caribou in areas without snow are readily visible. There is also one caribou on the edge of the snow-patch at bottom right, which is less obvious.

Sightability of caribou on photos was estimated by having a second observer from GreenLink Forestry independently re-count caribou on a subset of photos (i.e. 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. A design that sampled the closest photo to the transect line in which at least one caribou was detected, was used to select photos for resampling. This systematic resampling approach ensured an adequate sample size of photos with caribou on them (Figure 15).

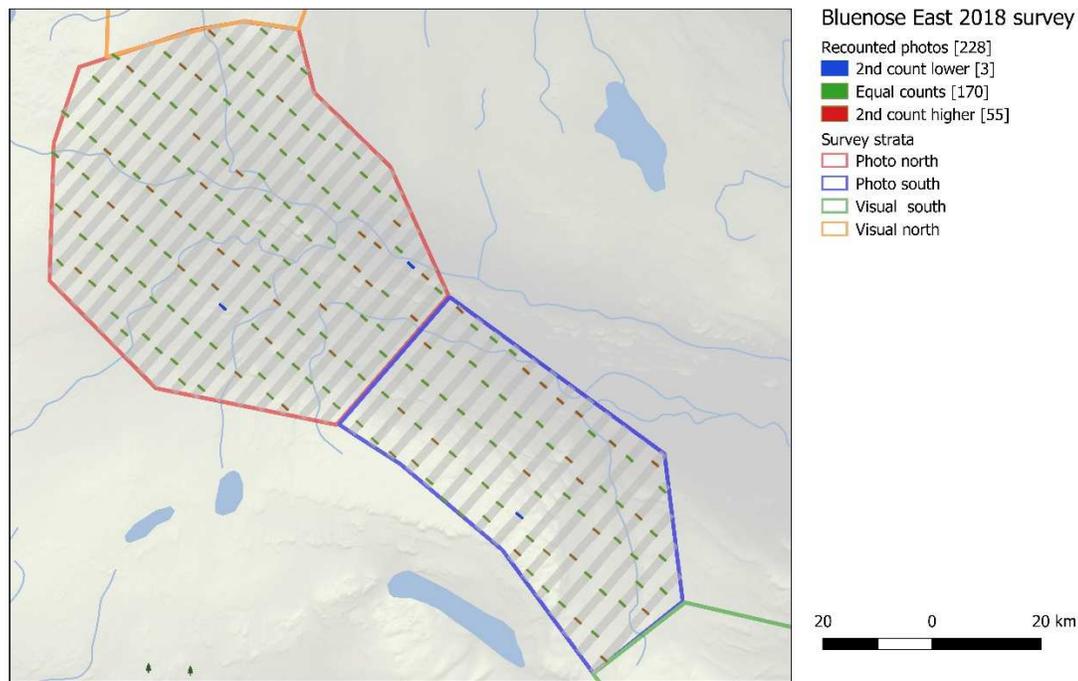


Figure 15: Systematic sampling design for cross validation of photos for the Bluenose-East June 2018 calving ground survey.

Overall, 228 photos were resampled in the North and South photo strata (Table 8). Ratios of second to original count suggested higher photo sightability in the North stratum. One assumption in this comparison is that the first and second counters 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 further distant from the original counts. This process did not identify any new caribou.

Table 8: Summary of photo cross validation data set for Bluenose-East June 2018 caribou survey photo blocks. The ratio of the original count to second count is an estimate of photo sightability.

Strata	Photos Resampled	Original Count	Second Count	New Caribou Counted in Second Count	Caribou not Detected in Second Count	Ratio of Original Count/Second Count
North	158	447	490	43	2	0.91
South	70	257	301	44	1	0.85

This cross-validation process was 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 (Table 9). Model selection suggested that the difference in sightability between strata was supported even when

over-dispersion was accounted for. Therefore, strata-specific sightability estimates were used for subsequent estimates.

Table 9: Model selection of photo sightability cross validation data set for Bluenose-East June 2018 caribou survey using Huggins closed models in program MARK. Quasi Akaike Information Criterion (QAIC_c), the difference in QAIC_c between the most supported model and given model Δ QAIC_c, the model weight (w_i), number of parameters (K) and quasi-Deviance (QDeviance) is given.

Model		Model Selection				
First Count	Second Count	QAIC _c	Δ QAIC _c	w_i	K	QDeviance
Strata	Constant	269.90	0.00	0.50	3	3,609.0
Constant	Constant	270.77	0.87	0.32	2	3,611.9
Strata	Strata	271.91	2.00	0.18	4	3,609.0

The estimates of sightability are given below along with the bootstrap-based estimates of SE, CV and confidence limits, CI (Table 10). The bootstrap estimates, which use caribou counted on each photo as the sample unit, were used for subsequent variance estimates.

Table 10: Estimates of sightability from the most supported Huggins model for Bluenose-East June 2018 caribou survey.

Count-stratum	Sightability Estimate	Binomial SE	Binomial CV	Bootstrap SE	Bootstrap CV	Bootstrap (95% CI)	
1 st count-North stratum	0.912	0.013	0.014	0.015	0.016	0.884	0.941
1 st count -South stratum	0.853	0.020	0.024	0.035	0.040	0.782	0.919
2 nd count-Both stratum	0.996	0.002	0.002				

Estimates of Total Caribou in Photo Strata

The standard Jolly 2 estimator (Jolly 1969, Norton-Griffiths 1978) was used to obtain estimates of caribou on the calving ground from the transect data. Consistent with the 2015 Bluenose-East survey (Boulanger et al. 2016), transect densities were weighted to ensure equal representation of transects with varying strip widths (Table 11). The initial estimate was divided by photo sightability to obtain the sightability-corrected abundance estimate. Overall, sightability-corrected estimates were 12 percent higher than initial estimates.

Table 11: Initial estimates of abundance in photo survey strata, estimated photo sightability and estimates of abundance with photo sightability for Bluenose-East June 2018 caribou survey.

Strata	Initial Estimate of N			Photo Sightability			Photo-sightability N Estimate		
	N	SE	CV	p	SE	CV	N	SE	CV
North	9,887	849.5	0.086	0.912	0.015	0.016	10,841	948.4	0.087
South	5,488	837.0	0.154	0.853	0.035	0.041	6,426	1,014.8	0.158

Overall, densities of caribou were lower on transects compared to previous years with all densities below the 10 caribou/km² level (Figure 16).

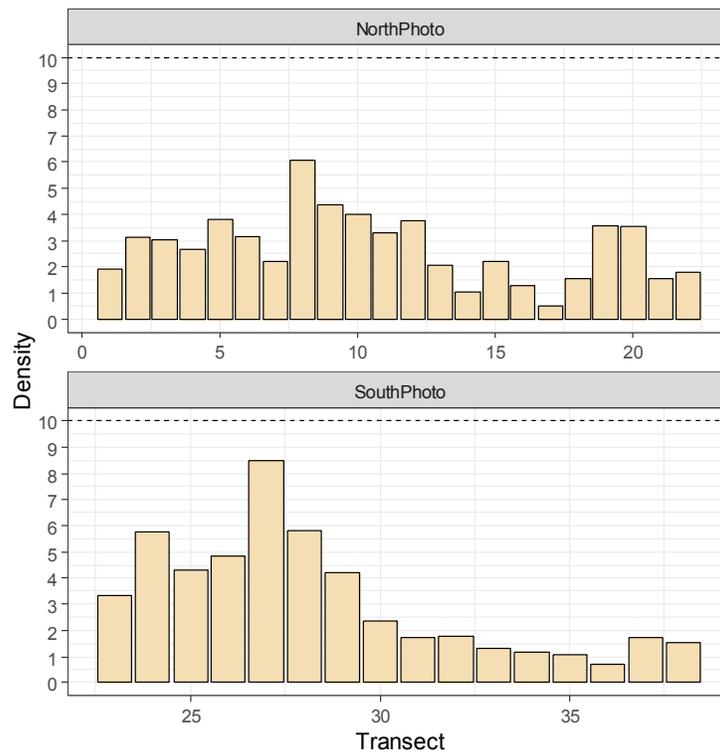


Figure 16: Transect-specific densities for the Bluenose-East photo blocks in June 2018. Transects go from west to east. Sightability was accounted for in density estimates.

Estimates of Total Caribou in Visual Strata

Double Observer Analysis

Data from both the reconnaissance and visual surveys were used in the double observer analysis, however, only the visual survey data were 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 Appendix 1. 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 17). In previous years approximately 70-80 percent 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.

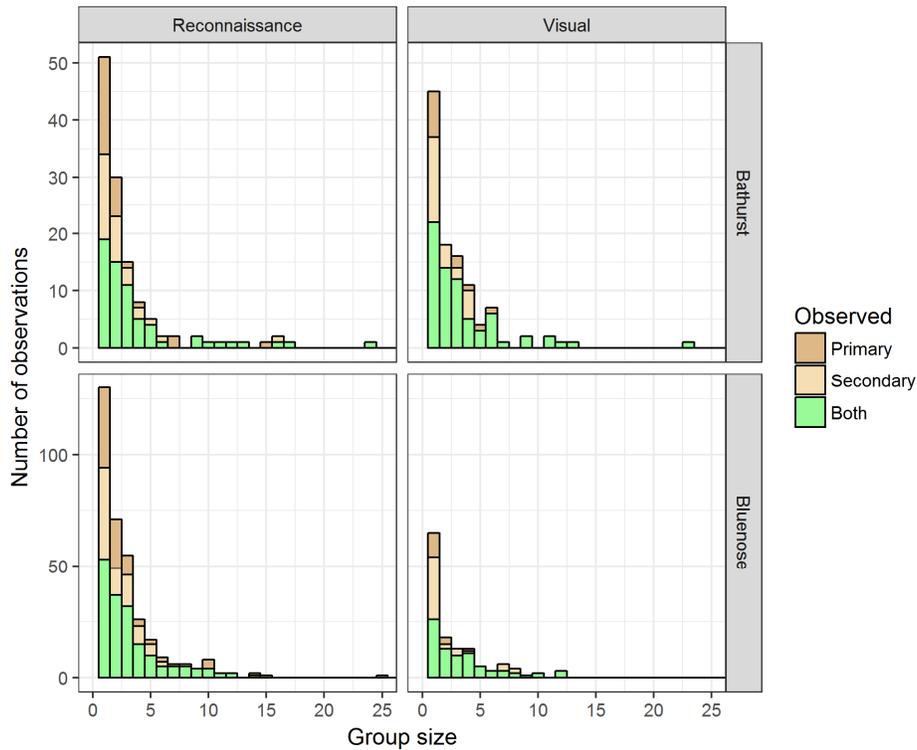


Figure 17: Frequencies of double observer observations by group size, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

Snow and cloud cover also influenced sightability, however, the pattern depended on survey phase and herd surveyed (Figure 18). The most noteworthy trends occurred for higher snow cover (75 percent) 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 percent 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 percent 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.

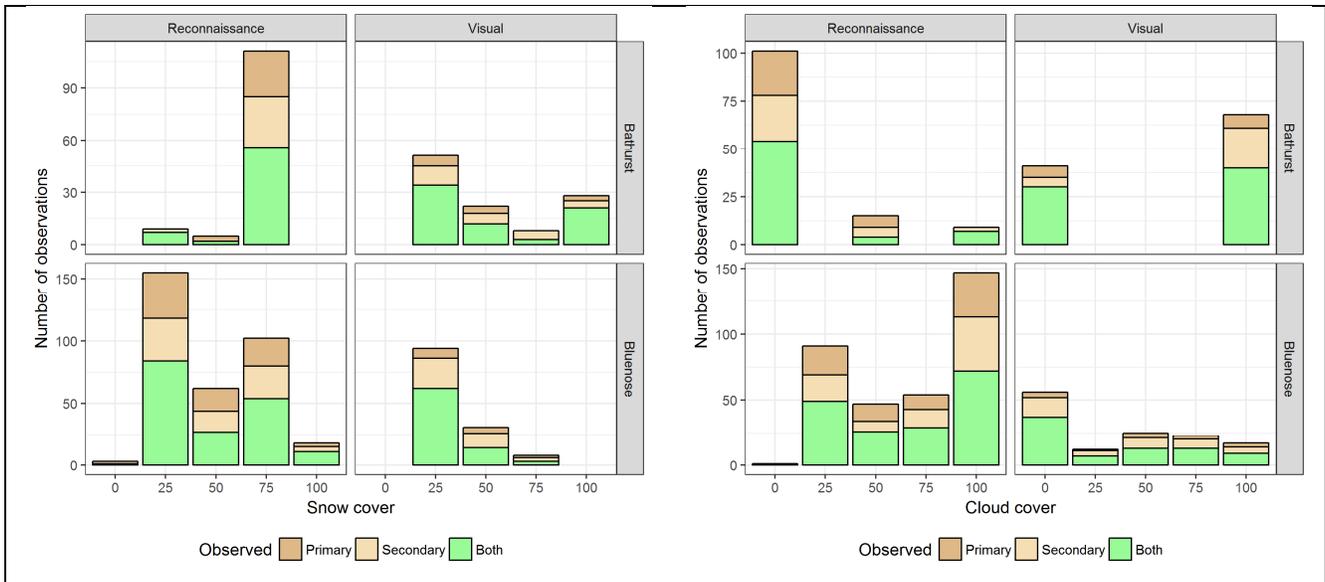


Figure 18: Frequencies of double observer observations by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation was categorized by whether it was observed by the primary, secondary, or both observers.

Snow cover was modeled as a continuous (snow) or categorical covariate (snow 25, snow 50, snow 75) 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 12). An additional effect of snow cover at 75 percent 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 12: 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 K, and deviance (Dev) are presented.

No	Model	AIC _c	ΔAIC_c	w_i	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 19). 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.

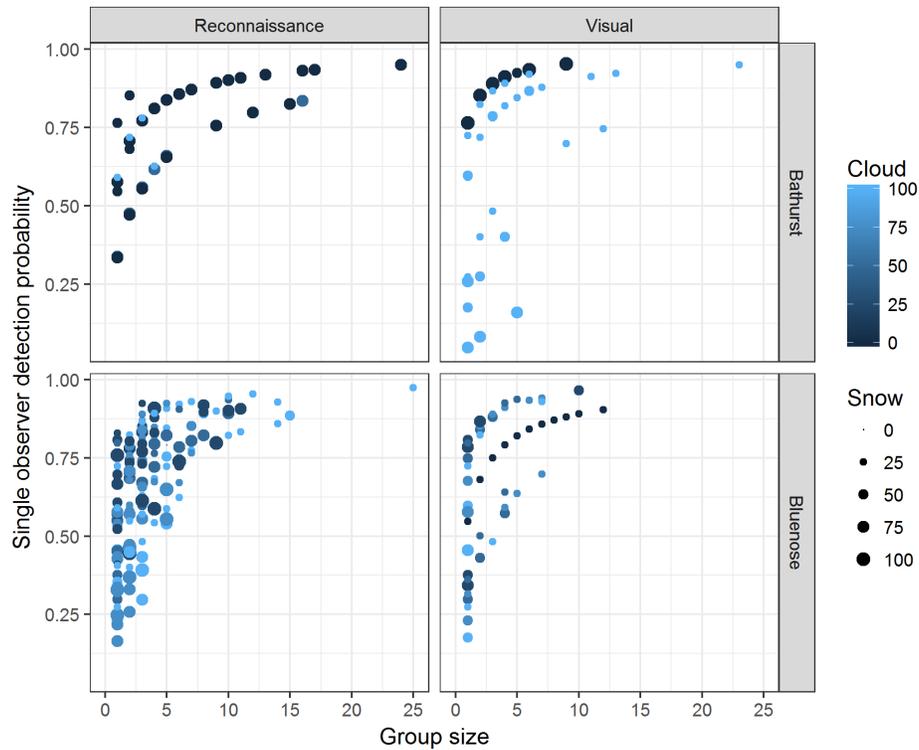


Figure 19: Estimated single observer probabilities from model 1 (Table 12) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

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 20).

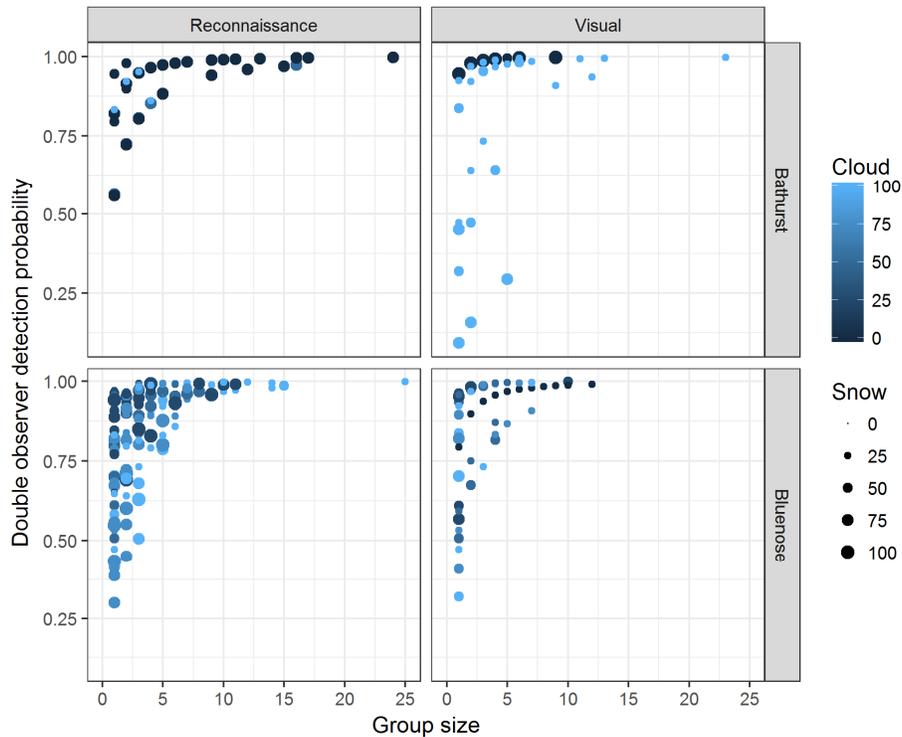


Figure 20: Estimated double observer probabilities from model 1 (Table 12) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

Estimates of Total Caribou in Visual Strata

Double observer estimates (using the MRDS R package) were about 6 percent higher than non-double observer estimates. Precision was lower than uncorrected count-based estimates but still acceptable (Table 13).

Table 13: Standard strip transect (two observers per side with no estimation of sightability) and double observer model estimates (with sightability accounted for) of caribou on Bluenose-East visual strata in 2018 from the MRDS package in R.

Strata	Caribou	Standard Estimate			Double Observer Estimate				
	Counted	Estimate	SE	CV	Estimate	SE	CI	CV	
North	159	734	100.4	13.7%	788	140.4	541	1,149	17.8%
South	210	1,061	113.7	10.7%	1,106	173.5	778	1,571	15.7%
Total	369	1,795	151.7	8.5%	1,894	223.1	1,482	2,419	11.8%

An estimate where there was only one observer per side of plane without the estimation of sightability was also run to assess the importance of having double observers on each side of the plane during surveys. This data set was created by only using observations from the front

observer (excluding caribou groups only seen by the rear observer). This resulted in an overall estimate of 1,397 caribou which was 23 percent lower than the standard double observer estimate and 26 percent lower than the double observer estimate with sightability correction. The lower single observer estimate demonstrates the need for double observers on each side of the plane to ensure higher sightability of caribou and reliable estimates.

Estimation of Total Caribou on the Calving Ground

The photo data (corrected for double observer analysis) were combined with visual data (corrected for double observer analysis) to obtain a total estimate of caribou on the calving ground of 19,161 caribou at least one year old (Table 14). This total applies to strata with corresponding composition survey data. Overall, the photo strata accounted for 90.1% of caribou.

Table 14: Estimates of caribou abundance on all survey strata (photo and visual) for Bluenose-East herd in 2018.

Strata	N	SE	Conf. Limit		CV
North Visual	788	140.4	541	1,149	17.8%
North Photo	10,841	948.4	9,041	13,000	8.7%
South Photo	6,426	1,014.8	4,599	8,979	15.8%
South Visual	1,106	173.5	778	1,571	15.7%
Total	19,161	1,406.8	16,512	22,233	7.3%

Composition Survey

A composition survey was conducted June 8-10 in the photo strata and June 10-11 in the visual strata. During the composition survey, caribou were relatively stationary as there were few caribou groups observed outside stratum boundaries relative to search effort and flight-lines (Figure 21). Observations of the pattern of distribution, abundance, and composition of caribou during the composition survey were consistent with the delineated visual and photographic strata, which in turn provided additional confidence in representativeness of the overall survey design. The photo north and visual north blocks had high proportions of breeding cows, while the photo south block had increasing proportions of yearlings and non-breeding cows toward the south end. The visual south block had substantial proportions of bulls and yearlings and few cows.

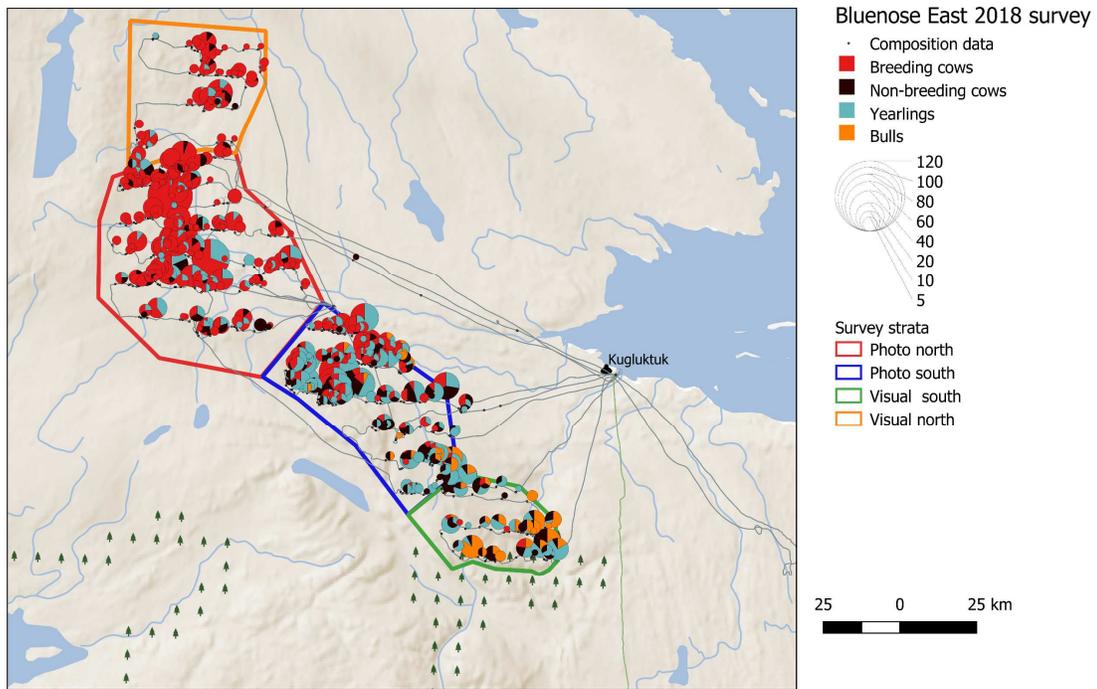


Figure 21: Helicopter flight paths and pie charts of groups classified during calving ground composition survey of Bluenose-East caribou in 2018. The size of pie charts is proportional to the number of caribou in each classification group as indicated by the scale diagram. Proportions of age-sex classes make up the individual pie sections.

Individual caribou were classified in each group based on physical characteristics as well as presence of a calf, hard antler(s) or distended udder (for breeding females) and are summarized in Table 15.

Table 15: Summary of composition survey on Bluenose-East calving ground June 2018 in photo and visual strata.

Strata	# Groups	Total	Adult Females		Yearlings	Bulls	Total Caribou (1 yr+)
			Breeding	Non-breeding			
North Visual	59	158	147	11	16	0	174
North Photo	189	726	677	49	104	0	830
South Photo	166	490	300	190	388	30	908
South Visual	39	53	7	46	71	61	185

Estimates of adult females and breeding females were then derived with variance and confidence limits estimated via bootstrap methods (Table 16).

Table 16: Proportions of breeding females and adult females from composition survey on Bluenose-East calving ground June 2018

Strata	Estimate	SE	Conf. Limit	
<u>Breeding females=breeding females/caribou 1 yr+</u>				
North Visual	0.845	0.027	0.786	0.892
North Photo	0.816	0.020	0.774	0.853
South Photo	0.330	0.033	0.269	0.396
South Visual	0.038	0.016	0.012	0.072
<u>Adult females=Adult females/caribou 1 yr+</u>				
North Visual	0.908	0.024	0.861	0.951
North Photo	0.875	0.016	0.841	0.903
South Photo	0.540	0.027	0.491	0.595
South Visual	0.286	0.042	0.213	0.380

Estimates of Adult and Breeding Females

Estimates of breeding females were derived by the product of caribou and the proportion of breeding females in each stratum (Table 17).

Table 17: Estimates of breeding females based upon initial abundance estimates and composition surveys on Bluenose-East calving ground June 2018.

Strata	Caribou		Proportion Breeders		Breeding Females				
	N	CV.N	pb	CV	N	SE	Conf. Limit		CV
North Visual	788	0.178	0.845	0.032	666	120.5	454	976	18.1%
North Photo	10,841	0.087	0.816	0.025	8,846	803.7	7,326	10,681	9.1%
South Photo	6,426	0.158	0.330	0.100	2,121	396.4	1,429	3,148	18.7%
South Visual	1,106	0.157	0.038	0.421	42	18.9	16	110	45.0%
Total	19,161				11,675	904.4	9,971	13,670	7.7%

Estimates of adult females are given in Table 18.

Table 18: Estimates of adult females based upon initial abundance estimates and composition surveys on Bluenose-East calving ground June 2018.

Strata	Caribou		Prop. Adult Females		Adult Females				
	N	CV.N	pf	CV	N	SE	Conf. Limit		CV
North Visual	788	0.178	0.908	0.026	716	128.9	489	1,048	18.0%
North Photo	10,841	0.087	0.875	0.018	9,486	847.7	7,880	11,419	8.9%
South Photo	6,426	0.158	0.540	0.050	3,470	574.8	2,444	4,928	16.6%
South Visual	1,106	0.157	0.286	0.147	316	68.0	196	510	21.5%
Total	19,161				13,988	1,034.6	12,042	16,249	7.4%

The ratio of breeding females to adult females suggests a relatively high proportion of pregnant females of 83 percent compared to previous years.

Extrapolated Herd Estimates for Bluenose-East Herd

A composition survey was conducted October 23-25, 2018 to estimate the bull-cow ratio of the Bluenose-East herd. Overall there were 115 groups observed with totals of bulls, cows and calves summarized in Table 19.

Table 19: Summary of observations from fall composition survey on Bluenose-East herd October 23-25, 2018

Cows	Bulls	Calves	Groups Observed
1,542	586	396	115

Bootstrap methods were used to obtain SEs on estimates (Table 20).

Table 20: Estimates of the bull-cow ratio, proportion cows, and calf-cow ratio from the fall composition survey on Bluenose-East herd October 2018.

Indicator	Estimate	SE	Conf. Limit	CV
Bull cow ratio	0.380	0.027	0.333 0.437	7.0%
Proportion cows	0.725	0.014	0.697 0.750	1.9%
Calf-cow ratio	0.257	0.016	0.229 0.291	6.1%

Comparison of bull:cow ratios from composition surveys 2009-2018 suggest a slowly decreasing bull cow ratio (Table 21).

Table 21: Estimates of proportion of cows and the bull cow ratio from fall surveys on the Bluenose-East herd 2009-2018.

Year	Proportion Cows				Bull-cow Ratio			
	Estimate	SE	Conf. Limit	CV	Estimate	SE	Conf. Limit	
2009	0.700	0.008	0.684 0.716	1.1%	0.429	0.017	0.396 0.463	
2013	0.701	0.009	0.685 0.720	1.3%	0.426	0.019	0.389 0.461	
2015	0.706	0.014	0.678 0.734	2.0%	0.417	0.029	0.367 0.479	
2018	0.725	0.014	0.697 0.750	1.9%	0.380	0.026	0.332 0.437	

Estimates of adult herd size (caribou at least two years old) for the Bluenose-East herd in 2018 are presented in Table 22. The estimate based on an assumed fixed pregnancy rate estimate is higher since it assumes a constant pregnancy rate of 0.72, which is lower than that observed in 2018 (0.83), thereby inflating the estimate. The preferred estimate uses the proportion of females, which is simply the estimate of adult females (13,988), divided by the proportion of cows in the herd (0.725) from the October 2018 survey. Log-based confidence limits, which were used for other estimates as well as traditional symmetrical confidence limits (estimate $\pm t^*SE$) 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 22: Extrapolated herd size estimates for the Bluenose-East herd in 2018 based on two estimators

Method	N	SE	Log-based CI		Symmetric Traditional CI		CV
Proportion of adult females	19,294	1,474.7	16,527	22,524	16,303	22,285	7.6%
Constant pregnancy rate (0.72)	22,366	2,861.8	17,247	29,004	16,530	28,202	12.8%

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

Comparison of 2015 and 2018 Estimates

Comparison of 2015 and 2018 estimates suggests a gross reduction of 49 percent in adult females, which translates into a mean annual rate of decline of 20 percent in the 2015-2018 interval (Figure 22). In contrast, breeding females had a gross reduction of 32.9 percent which translates to an annual rate of change of -13 percent in the interval since 2015. The difference in gross and annual changes of breeding and adult females was due to an increase in proportion of breeding females in 2018 compared to 2015. Using a t-test the gross reduction in estimates is significant for adult females ($t=-7.35$, $df=42$, $p<0.0001$) and breeding females ($t=-3.9$, $df=47$, $p=0.002$).

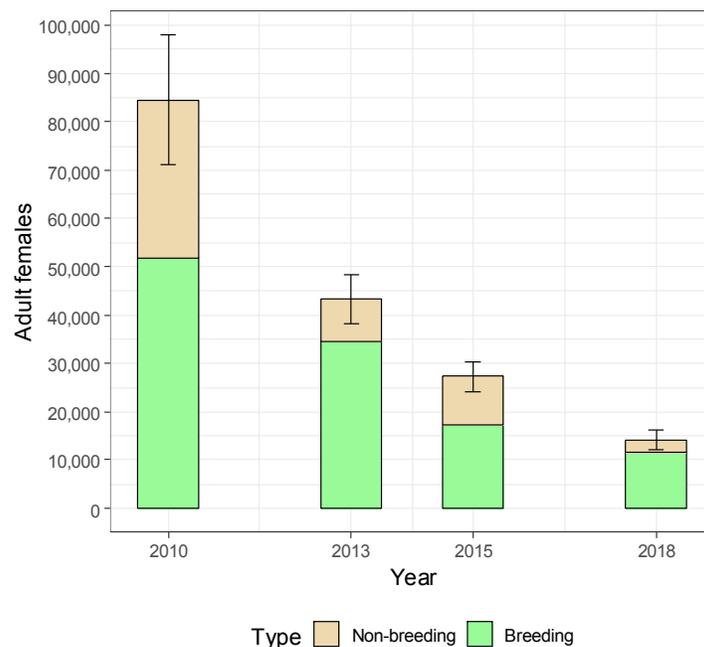


Figure 22: Estimates of total adult females in the Bluenose-East herd from 2010-2018 dichotomized shown by breeding and non-breeding females status from 2010-2018.

Overall Trends 2010-2018

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

For breeding females, yearly trends in breeding females were marginally significant ($p=0.071$) with estimates of λ overlapping 1 for some years between 2010 and 2018. The mean estimate of λ for breeding females was 0.81 (CI=0.62-1.04). Variation in λ for breeding females was presumably due to the influence of variable pregnancy rate on estimates of breeding females (Figure 23).

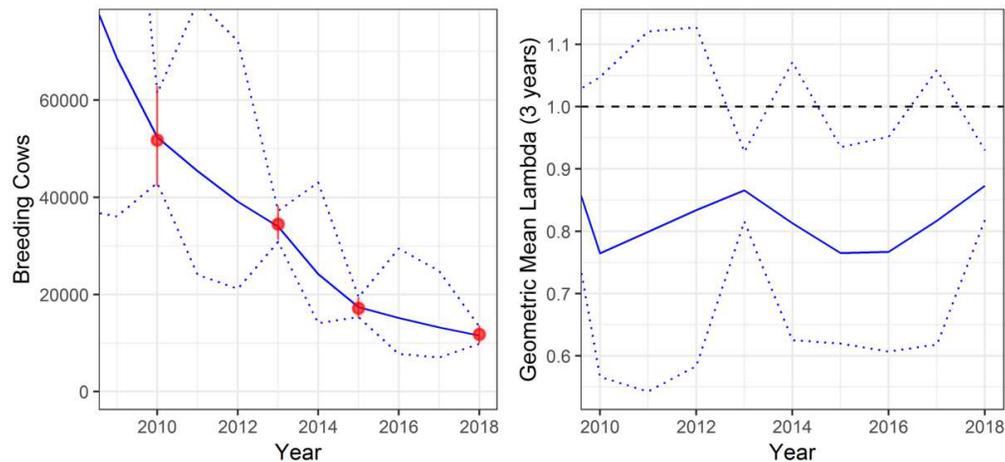


Figure 23: Estimates of breeding cows and λ (geometric mean of three previous years) in the Bluenose-East herd 2010-2018 from Bayesian state space model analysis.

In contrast, trends in adult females were significant ($p=.0087$) with minimal yearly variation in λ and no overlap of λ estimates with one in any of the years considered (Figure 24). The mean estimate of λ was 0.8 (CI=0.73-0.87) which translates into an annual rate of decline of 20 percent (CI=13-27percent).

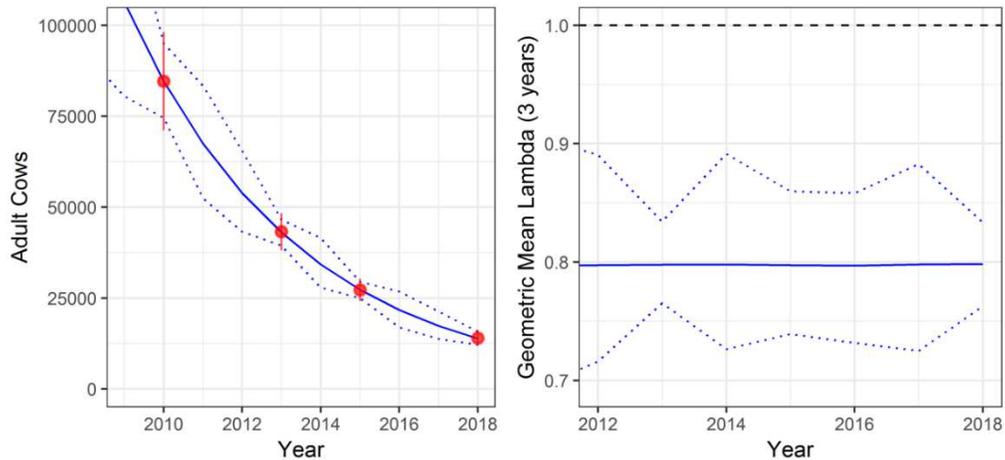


Figure 24: Estimates of adult cows and λ (geometric mean of three previous years) in the Bluenose-East herd 2010-2018 from state space model analysis.

Overall Bluenose-East herd size followed the general trend in adult and breeding females (Figure 25).

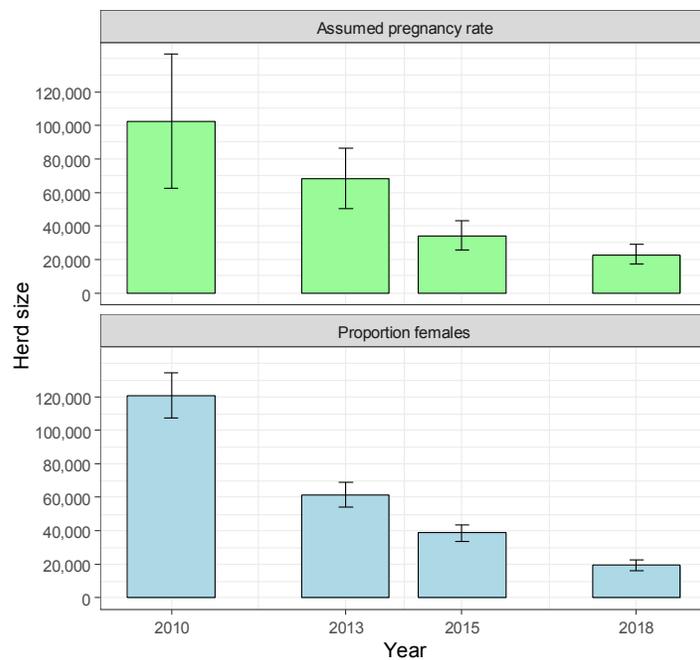


Figure 25: Estimates of Bluenose-East herd size (adults at least two years old) using the constant pregnancy rate of 0.72 and proportion of females method from 2010-2018. We suggest the estimates based on proportion of females (bottom) are more reliable.

The core calving ground area as well as densities of adult female caribou have both declined 2010-2018 suggesting that the degree of aggregation of caribou on the calving ground has not changed substantially. A full analysis of trends in core calving ground area and densities of females on the calving ground is presented in Appendix 5.

Exploration of Potential Reasons for Decline in Herd Size

Potential contributing factors to the apparent large numerical decline in breeding females on the Bluenose-East calving ground 2015-2018 could include (a) a portion of female caribou may have been missed based on limited survey coverage, (b) some female caribou may have moved to adjacent calving grounds, and (c) demographic factors including reduced survival of adult caribou, reduced pregnancy rates, and reduced calf survival. We considered the likelihood of each factor contributing significantly to the estimated reduction in abundance.

Breeding and Adult Females not Occurring on Survey Strata

One potential reason for lower estimates would have been female caribou occurring outside survey strata. We note first that extensive additional reconnaissance flying to the north, west and east of the main concentrations of calving caribou resulted in almost no caribou observations (see blank squares on Figure 27), suggesting that the herd's distribution had been well defined in those areas. Only at the southern trailing edge were there any substantive numbers of caribou seen on reconnaissance flying outside the survey strata.

All 30 Bluenose-East collared female caribou that were monitored occurred within the survey strata, and none of them were in the south visual block (Figure 13). Two collared females, which were most likely from the Bluenose-West herd, occurred to the north and south of the central study area. The south visual block contributed just 42 of 11,675 breeding females (0.3 percent) (Table 17) and 316 of 13,988 adult females (2.2 percent) (Table 18) in the survey area. The composition survey showed that the south visual block had substantial numbers of yearlings and bulls, and progressively higher proportions of them at the southern end (Figure 21). In addition, a map of the movements of 15 Bluenose-East collared bulls in May-June 2018 (Figure 26) demonstrates that most of the herd's bulls were at the southern fringe of the south visual block and south of it in the two reconnaissance-based strata. Our observations suggest that areas further south of the south visual block were likely to have mostly bulls and yearlings, a few non-breeding cows and virtually no breeding cows.

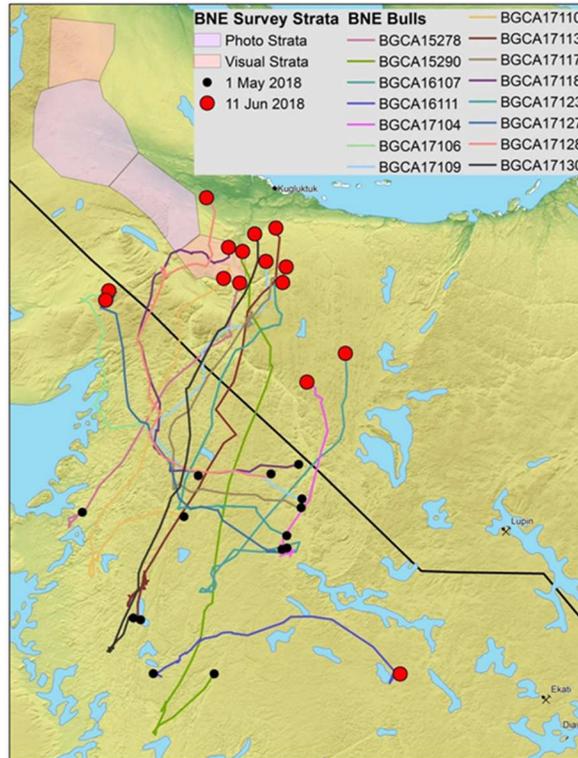


Figure 26: Spring movements (May 1 - June 11) of 15 Bluenose-East collared bulls in 2018 in relation to the survey area. Most bulls were concentrated at the south end of the survey area and some were scattered far to the south.

We added two post-hoc reconnaissance-based strata to the area south of the survey strata to assess the relative sensitivity of estimates to inclusion of these areas (Figure 27). No composition surveys were conducted for these areas, making estimates of breeding females and adult females problematic, but these areas most likely were dominated by bulls and yearlings.

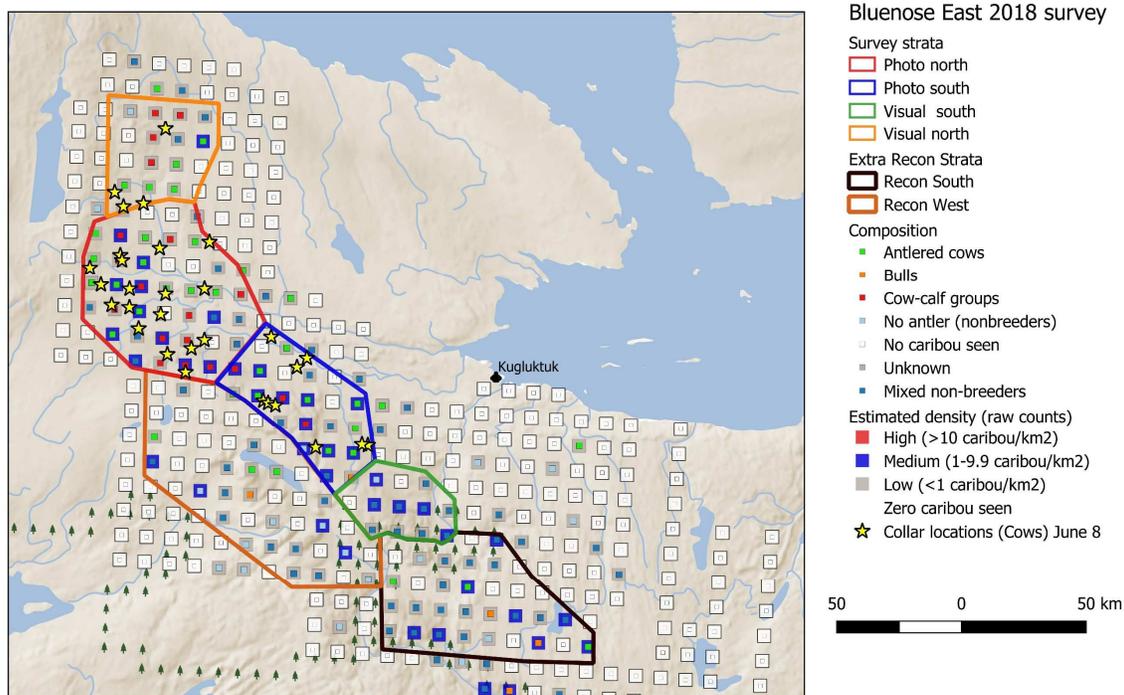


Figure 27: Bluenose-East June 2018 survey area with extra (post-hoc) reconnaissance-based strata at bottom in black and brown outlines.

The resulting estimate of total caribou was 22,425 caribou (Table 23), which is higher than the extrapolated herd estimate of 19,294 caribou at least 1-year-old for the survey area with two photo and two visual blocks (Table 22). However, the estimate of 22,425 caribou (Table 23) *includes* yearlings (calves from 2017) whereas the extrapolated herd estimate includes adult caribou and *excludes* yearlings. An estimate of yearlings in 2018 of 6,594 (CI=5,590-7,782) was derived from the demographic model (described in the next section) which suggests that the difference in extrapolated herd estimates (19,294) and total caribou on the calving ground (22,245) can largely be explained by the presence of yearlings in the total caribou on the calving ground estimate.

Table 23: Estimates of total caribou at least one year old on Bluenose-East June 2018 calving ground survey area with two supplemental reconnaissance strata (as delineated in Figure 27).

Strata	N	SE	Conf. Limit	CV	
North Visual	788	140.4	541	1,149	17.8%
North Photo	10,841	948.4	9,041	13,000	8.7%
South Photo	6,426	1,014.8	4,599	8,979	15.8%
South Visual	1,106	173.5	778	1,571	15.7%
Recon South	2,117	250.2	1,616	2,773	11.8%
Recon West	1,147	285.0	661	1,991	24.8%
Total	22,425	1,457.0	19,669	25,565	6.5%

Movement to Adjacent Calving Grounds

Figure 28 displays movement in the mean location of calving for collared females that were monitored for successive years. The head of the arrow is the mean location for the current year and the tail is the location for the previous year. From this it can be seen that in general caribou have shown reasonable fidelity to the Bluenose-West, Bluenose-East and Bathurst calving grounds 2010-2018. Some unusual June 2018 movements of collared Bathurst cows are considered in the survey report for that herd.

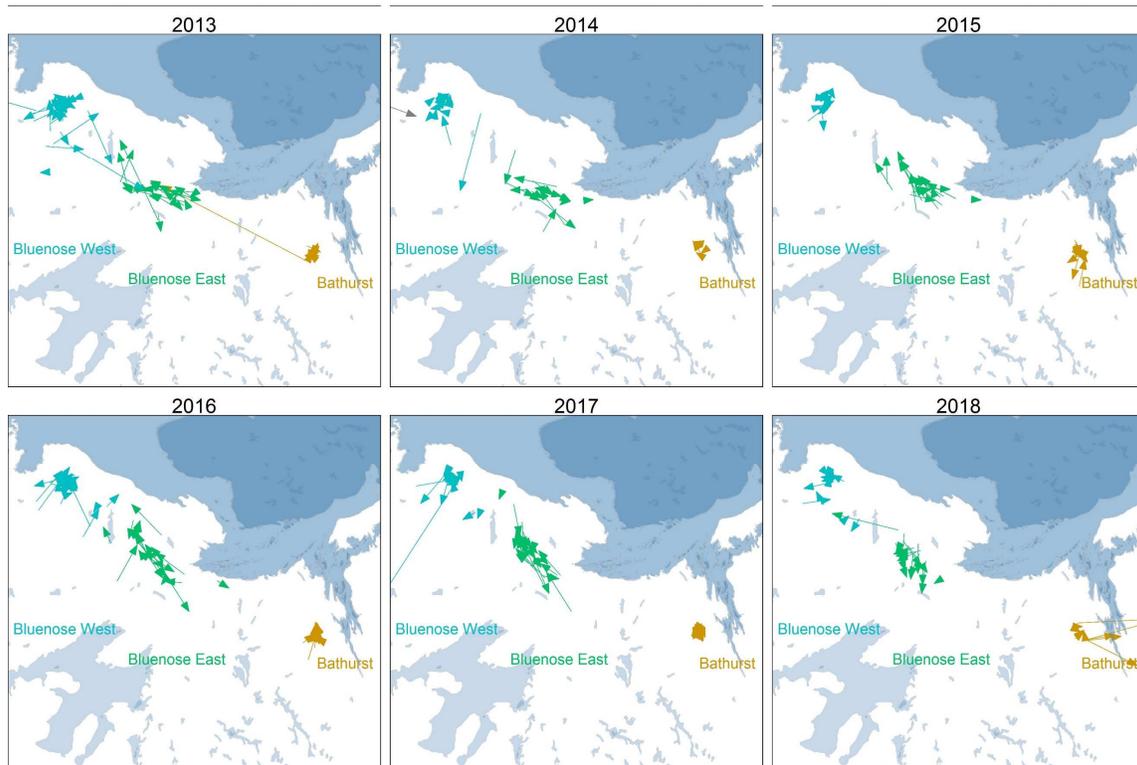


Figure 28: Yearly fidelity and movements to calving grounds in the Bluenose-West, Bluenose-East and Bathurst herds 2013-2018. The head of the arrow indicates the current calving ground in the given year and the tail indicates the mean location from the previous year calving ground.

Frequencies of movement events were assessed for collared female caribou monitored for consecutive years and tabulated (Figure 29). Overall, the rates of switching between the Bluenose-East and neighbouring Bluenose-West and Bathurst calving grounds were low for both 2010-2015 and 2016-2018. The low rate of switching of collared cows is consistent with previous estimates of about 3 percent switching and 97 percent 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). This factor was not likely responsible for the decline in Bluenose-East females, as there were very few switches between calving grounds and they occurred in both directions about equally.

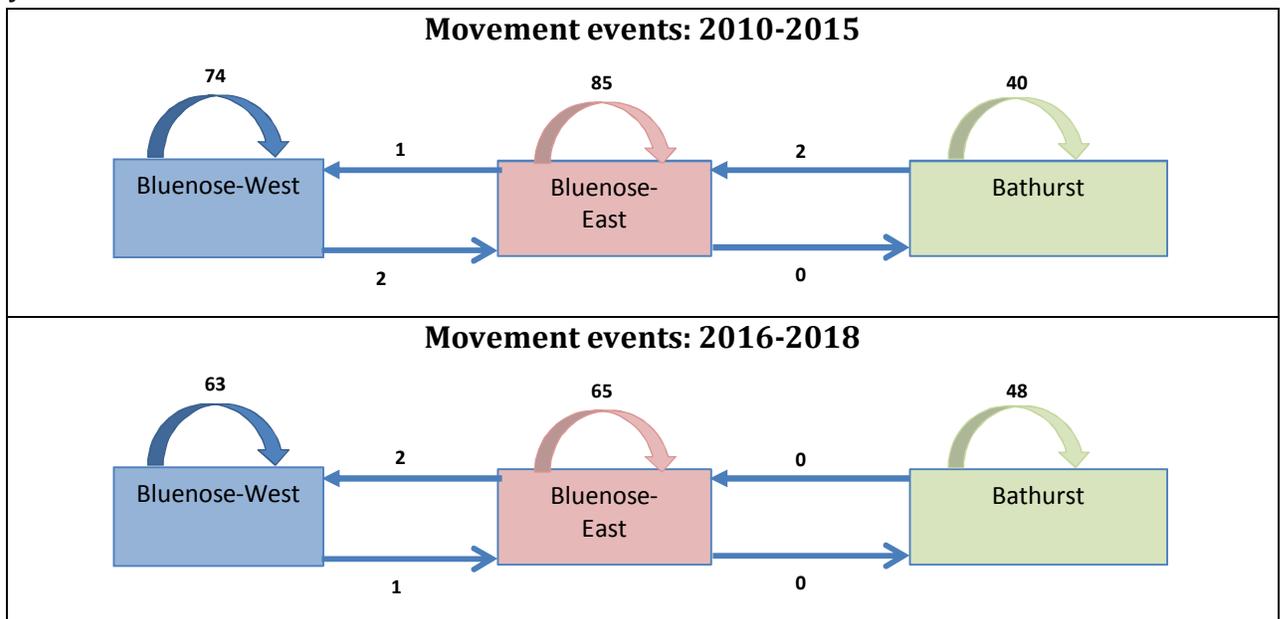


Figure 29: Frequencies of caribou movement events for the Bluenose-East and neighbouring Bluenose-West and Bathurst herds from 2010-2015 and 2016-2018 based on consecutive June locations of collared females on calving grounds. The curved arrows above the boxes indicated the number of times a caribou returned to each calving ground for successive years. The straight arrows indicate movement of caribou to other calving grounds.

Demographic Analysis using Multiple Data Sources

Survival Analysis of Collared Cows

The monthly collar data used in the Bluenose-East survival analysis are shown in Figure 30, which estimates monthly mortality rates as the ratio of the number of collared caribou mortalities divided by the number of collars monitored each month. The actual analysis was based on calving ground year which begins in June of each year. Sample sizes were in the range of 30 collars per month with the exception of 2010 and 2011 when collar sample sizes were lower. A gap in collars monitored occurred in late 2011 and early 2012 before re-deployment of collars in the spring of 2012. Survival estimates were scaled to account for this interval. Collared caribou mortalities occurred mostly in summer periods for 2016 and 2017 compared to earlier years.

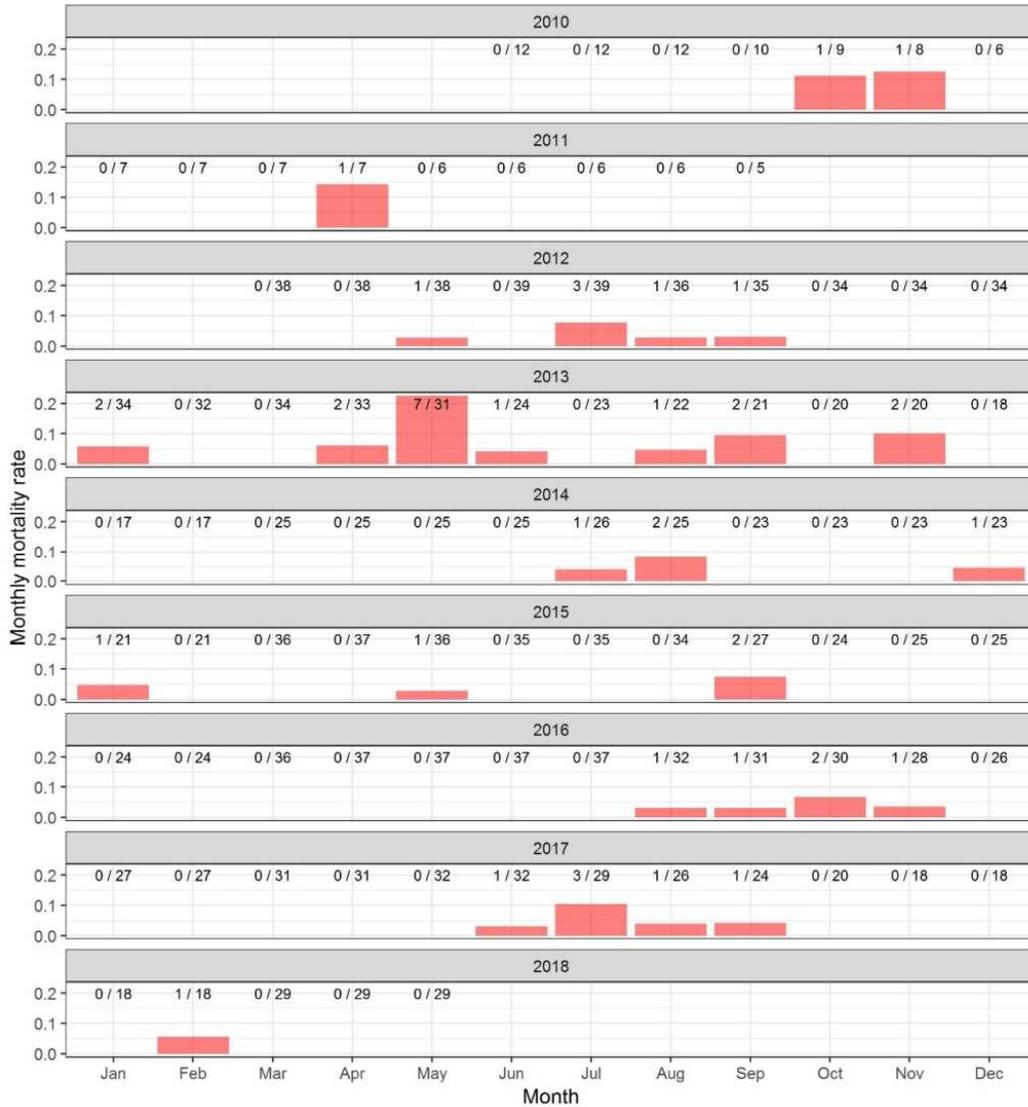


Figure 30: Summary of monthly mortality rates for the Bluenose-East herd by calendar year. The mortality rate, which is the ratio of number of collar mortalities/number of available collars, is given above each bar. The analysis is based on calving ground year which begins at June of each year and ends at May the following year.

Table 24 shows the Bluenose-East collar-based cow survival data defined by caribou year (the year begins on the calving ground each year in June and ends the following May) along with summary statistics for each year. Mortalities are broken down by known and stationary (assumed mortality). The data set ends in caribou year 2017 which goes up to May 2018, the month before the 2018 calving ground survey.

Table 24: Summary of Bluenose-East collared female data used for survival analysis 2010-2018. Caribou year starts June of the caribou year and ends in May of the next year.

Caribou Year	Annual Mortalities		Live Caribou Sample Sizes			
	Known	Stationary Collar	Collar Months	Mean Alive	Min	Max
2010	3	0	103	8.6	6	12
2011	0	1	137	11.4	0	38
2012	4	12	415	34.6	31	39
2013	0	6	257	21.4	17	25
2014	0	6	319	26.6	21	37
2015	0	2	363	30.3	24	37
2016	0	5	369	30.8	26	37
2017	2	5	290	24.2	18	32
Total	9	37				

Figure 31 displays the Bluenose-East collar-based female survival estimates based on the current data set 2010-2017 using the Kaplan-Meier estimator (Pollock et al. 1989). In general, the earlier estimates had high variance due to limited numbers of collars. The overall mean number of live collared cows was 23.5 for this period, and the average annual survival rate for collared cows over the eight years was 0.79 (Table 24) with no clear trend 2010-2017. The trend 2015-2018 was a decline with the last year's survival (2017-2018) estimated at 0.76. Survival estimates were further explored and refined using information from all data sources using the Bayesian IPM model described in the next section. One concern was that the 2011 survival estimate was influenced by lack of sampling of winter months during this year. A sensitivity analysis was conducted with this estimate not included in the 2011 to assess the relative influence of this data point on overall IPM model estimates.

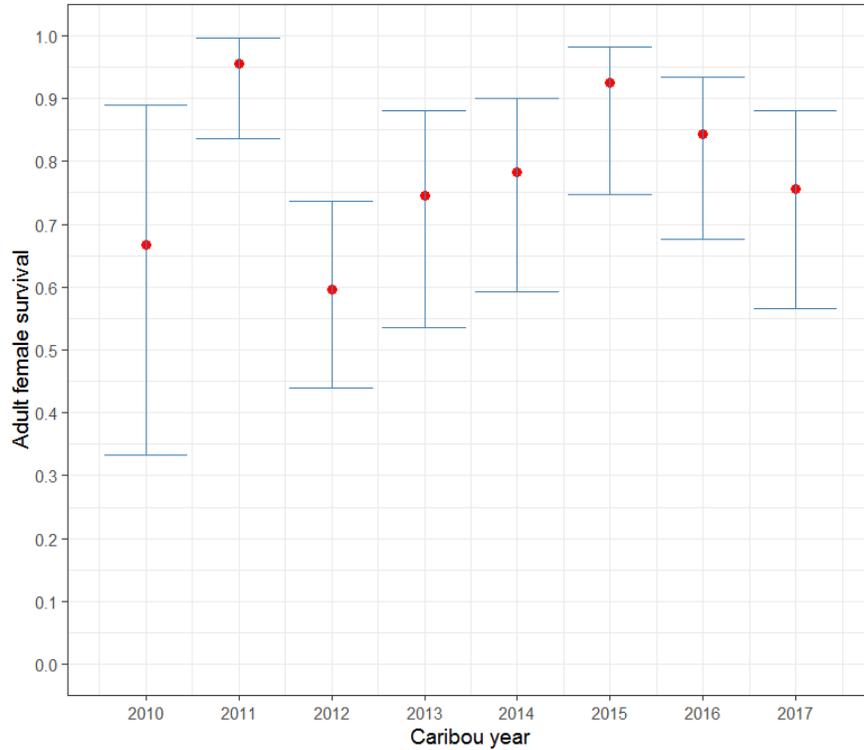


Figure 31: Annual Kaplan-Meier estimates of survival from collared Bluenose-East female caribou for caribou years 2010-2017, based on collar data in Table 24.

Table 25 provides the survival rate estimates for calving ground years (June 1 - May 31), which are also shown in Figure 31. Years begin at calving in June and extend to the following May. Note that all estimates of survival include hunting mortality.

Table 25: Estimates of yearly survival rate for the Bluenose-East herd 2010-2018 from Kaplan-Meier survival rate estimator.

Caribou Year	Survival	SE	Conf. Limit	
2010	0.67	0.16	0.33	0.89
2011	0.96	0.03	0.84	1.00
2012	0.60	0.08	0.45	0.74
2013	0.74	0.09	0.54	0.88
2014	0.78	0.08	0.59	0.90
2015	0.93	0.04	0.77	0.98
2016	0.84	0.07	0.67	0.93
2017	0.76	0.08	0.57	0.88

Bayesian Integrated Population Demographic Model

The main objective of the Bayesian IPM was to provide refined estimates of demographic parameters using all of the field data sources available. For the Bluenose-East model, temporal

variation in main parameters (cow/yearling survival, calf survival) was modeled as random effects. Sparse data prevented modeling fecundity and bull survival as a random effect and therefore these parameters were held constant. A technical description of the model including tests of model parameters and the associated *R* code is given in Appendix 3.

The IPM fit most field measurements adequately (Figure 32). The main exceptions were a slight overestimate of cows and cows+bulls (compared to extrapolated estimates) in 2018. Also, since fecundity was fixed (estimated at 0.69, CI=0.64-0.75), the model did not capture variation in proportion of breeding females, however model predictions did intersect the confidence limits of field estimates in all cases. Confidence in model predictions tended to be highest for the years in which there were field estimates.

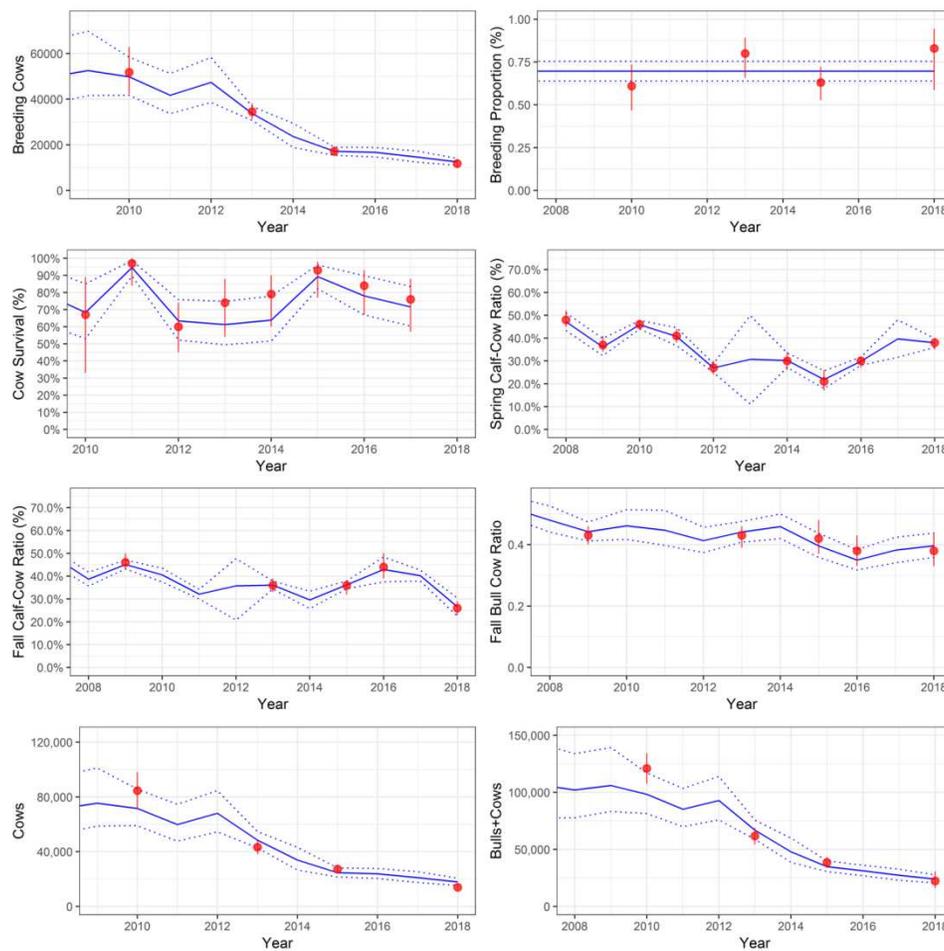


Figure 32: Predictions of demographic indicators from Bayesian IPM analysis compared to observed values, for Bluenose-East herd 2010-2018. The solid blue lines represent model predictions and confidence limits are shown as hashed blue lines. The red points are field estimates with associated confidence limits. Spring calf:cow ratios are flown in March or April and are also called late-winter surveys.

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 calving ground, fall surveys, and late winter surveys and subsequent estimation of calf survival for each period. As found in previous studies (Gunn et al. 2005a), summer survival is 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.

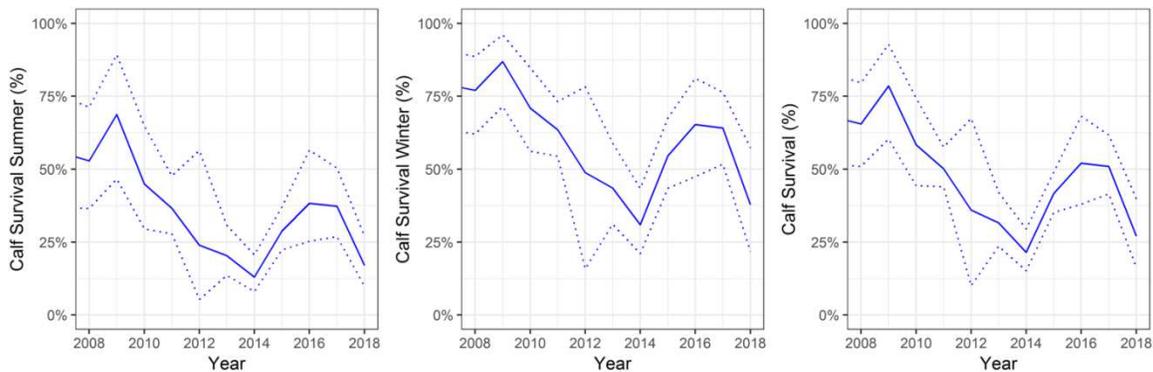


Figure 33: Trends in summer and winter and overall calf survival for the Bluenose-East herd 2010-2018 from the IPM analysis.

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). Calf productivity estimates suggest a negative trend in productivity 2008-2018 which was influenced by decreasing calf survival. An additional model run was conducted to test for a negative trend in calf survival which was found to be significant ($p=0.02$). Calf productivity is predicted to be lower in the caribou year of 2018 (June 2018 - June 2019) than 2017 due to a low calf-cow ratio in the fall 2018 survey (Figure 32). Future analyses will explore calf survival trends as well as linkages in calf survival and other demographic parameters with environmental covariates.

Spring calf-cow ratios, which are recorded in March or April, are overlaid in the productivity graph (Figure 34) and similarly suggest an overall negative trend 2008-2018. Note that the spring calf-cow ratio is influenced by cow survival, calf survival as well as fecundity and therefore will not directly 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 32.

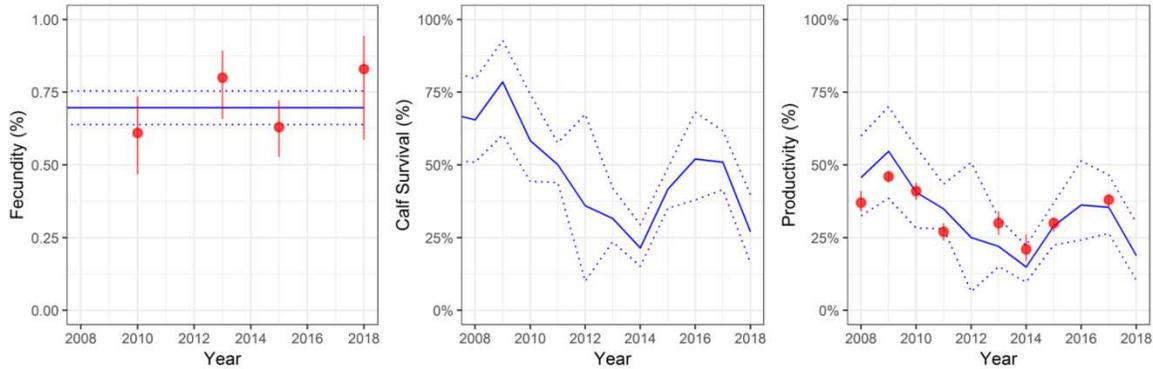


Figure 34: Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for Bluenose-East herd 2010-2018. Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year prediction of the model), are shown for reference purposes.

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. A grey box indicates the range of cow survival needed for the herd population size to stabilize (as assessed using a stage-based matrix model described in Appendix 4) across the range of observed levels of productivity (Figure 34). The lower level is a cow survival of 0.84 which is the minimum level needed for herd recovery at a higher productivity level of 0.46, which is like that observed in 2009. The upper level is a cow survival of 0.92 which is the level required for stability if productivity remains low at the 0.19 observed in 2018. If productivity is at levels observed from 2015-2018 (0.30) then cow survival would need to be 0.88 for stability. The lower hashed line is 0.71 which was the mean level (for 2010-2015) estimated in the previous demographic analysis conducted after the 2015 calving ground survey (Boulanger et al. 2016).

Estimates of cow survival suggest an increasing trend in cow survival from 2015 to 2018 with a three-year average survival of 0.79 (CI=0.71-0.84) for the 2015-2018 period. However, this estimate should be interpreted cautiously since both the collar-based and IPM estimates suggest a decreasing trend in cow survival from 2015-2018. The IPM estimate of cow survival for the caribou year of 2017 (which spans from June 2017 - June 2018) is 0.716 (0.60-0.83). We suggest this average value for cow survival be used for prospective harvest modeling purposes. All estimates of survival include harvest mortality. Harvest pressure was low from 2015 to 2018 and targeted bulls, as detailed in the next section, and therefore it is likely that that harvest had minimal effect on survival rates from 2015 to 2018.

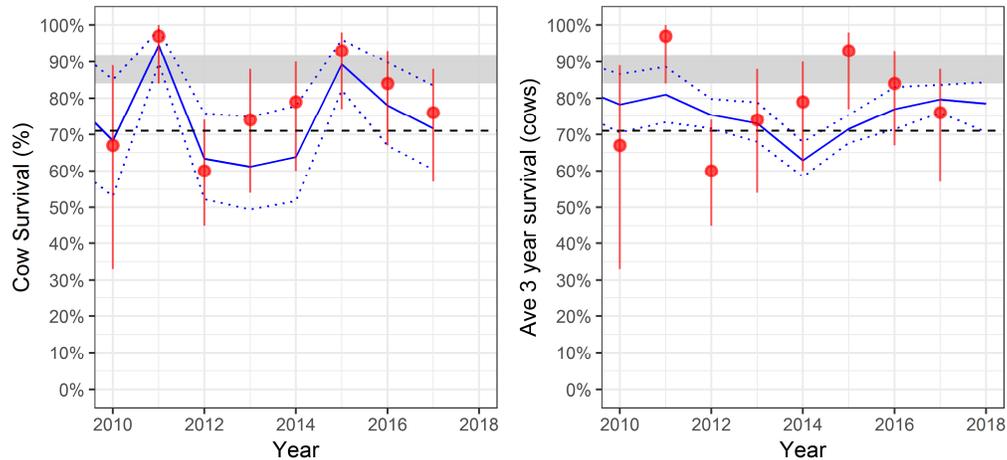


Figure 35: Trends in Bluenose-East cow survival 2010-2018 from IPM analysis. The solid blue lines represent model predictions and confidence limits are the hashed blue lines. The right graph represents a three-year moving average. The red points are field estimates from collars with associated Confidence Limit. The dashed horizontal lines indicate previous estimates of mean cow survival in 2015 (0.71). The shaded region represents the range of cow survival levels needed for population stability across lowest observed levels of productivity (19 percent) to higher levels of productivity (46 percent) as shown in Figure 34.

Bull survival was estimated at 0.52 (CI=0.48-0.57) from 2010 to 2018 which was lower than the estimate in 2015 (0.58; CI=0.55-0.60). This was presumably due to the slight decrease in bull cow ratios in fall surveys (Table 21) as well as changes in productivity. The demographic model basically estimates bull survival as the level needed to produce the observed bull-cow ratios based on levels of recruitment to the adult bull class and estimated cow survival. One potential enhancement to the model that will be considered is direct estimates of bull survival from collared bulls to further verify bull survival estimates.

Population rates of change (λ) for cows suggests a rate of 0.80 (as also indicated by regression analysis of calving ground survey estimates) up to 2015 followed by a slight increase in λ from 2015-2018 up to 0.90 (CI=0.85-0.94) (Figure 36). However, point estimates of λ decrease from 2015-2018 so that the λ estimate for 2018 is 0.85 (CI=0.71-0.99). We suggest the point estimate for 2018 be considered given the decreasing trend in λ from 2015-2018.

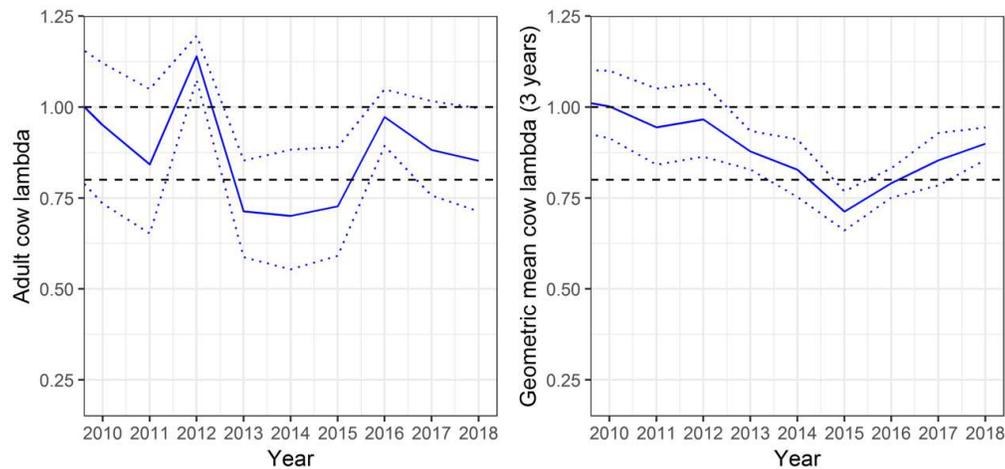


Figure 36: Overall trends in Bluenose-East adult female trend (λ) 2010-2018 from the IPM analysis. A value of 1.0 indicates stability.

Overall, the demographic model suggests that cow survival rates, which are one of the main determinants of overall herd trend, are still at lower values than needed for herd recovery (Figure 35). Low cow survival levels and an apparent negative trend in calf survival (Figure 33) both contributed to the overall decline in herd size. Overall trend estimates (three year λ) suggest a slightly less negative trend in adult cow numbers (0.90), however, there is an overall negative trend in cow survival and λ and therefore this result should be interpreted cautiously.

Sensitivity analyses were conducted to the effect of directional calf survival trends (by including a calf survival trend in the model) and the 2011 cow survival data point which may have been influenced by lower collar coverage (Figure 30), by running the model without this data point. In both cases, estimates were minimally affected. Of most interest was the 2018 cow survival estimate which was 0.72 (CI=0.62-0.83) if the 2011 cow survival data point was removed and 0.70 (CI=0.60-0.82) if a declining calf survival trend is assumed. This contrasts with the estimate of 0.72 (0.60-0.83) from the main model used in the analysis. More details are provided on this analysis including a plot of all model predictions from alternative models in Appendix 4.

Future analyses will further refine demographic predictions using environmental covariates to model temporal trends in parameters. Preliminary analysis of a limited environmental covariate data set (2008-2016) using remote sensing covariates (Russell et al. 2013) suggest negative correlations between IPM estimates of cow survival (Figure 35) and June temperature (Pearson ρ = -0.829, CI = 0.96 to -0.37, t = -3.95, df = 7, p = 0.005) as well as negative correlation between estimated calf survival (Figure 33) and Oesterid (warble and bot fly) indices for the summer after calving (Pearson ρ = -0.831, CI = -0.96 to 0.37, df = 7, p = 0.0056). Once the full temporal data set is available (up to 2018) these covariates will be used to further refine estimates and explore mechanisms causing temporal variation in demographic parameters. Analyses that further explore seasonal

survival estimates with the effect of hunting mortality (on earlier data points) will also be considered at this time.

Hunter Harvest of Bluenose-East Caribou 2016-2018

In 2016, three co-management boards – the Wek’èezhìi and Sahtú Renewable Resource Boards (WRRB and SRRB) in the NWT and the NU Wildlife Management Board (NWMB) in NU – held formal hearings on management of the Bluenose-East caribou herd. The WRRB determined a total allowable harvest (TAH) for Wek’èezhìi of 750 bulls and recommended that this be the harvest limit herd-wide, recognizing that the board has no jurisdiction outside Wek’èezhìi. The SRRB endorsed a community-based caribou management plan from Délìñę (*Belare Wíle Gots’ç Æekwç*, the Délìñę caribou plan), which included a harvest limit of 150 caribou and 80 percent bulls. The NWMB endorsed a similar plan from the Kugluktuk Hunters and Trappers Organization for the Bluenose-East herd, called an Integrated Community Caribou Management Plan or ICCMP (the Kugluktuk caribou plan); this included a harvest limit of 340 caribou (no gender specified). Since that time, actual estimated/reported harvest of Bluenose-East caribou has been below the limits in the three plans (Table 26). Overall totals were 373 caribou in 2016-2017 and 323 caribou in 2017-2018, with a substantial number of these being bulls; however, the harvest recorded for Kugluktuk is the largest part of the harvest for these two years and gender of harvested caribou was not specified. In 2017-2018, particularly, the herd was relatively inaccessible to hunters for a large part of the year. This harvest was less than 1 percent of the herd’s estimated size in 2015 (38,592). These harvest numbers suggest that harvest contributed relatively little to the herd’s most recent decline, in contrast to the situation prior to 2015 (Boulanger et al. 2016).

Table 26: Reported/estimated harvest of Bluenose-East caribou in harvest seasons 2016-2017 and 2017-2018.

Harvest Season	North Slave Region NWT (including Wek’èezhìi)	Délìñę, NWT	Kugluktuk, NU	Total	Notes
2016-2017	15 bulls	93 bulls, 33 cows	232 caribou	373 caribou	Most N. Slave hunters harvested Beverly caribou in east
Source	ENR wildlife officers	Délìñę RRC	GN wildlife staff		
2017-2018	142 bulls	7 caribou	174 caribou	323 caribou	Most N. Slave hunters harvested Beverly caribou in east; Délìñę harvest possibly boreal caribou
Source	Tłıchọ Government	Délìñę RRC	GN wildlife staff		

Hunter Harvest Modeling of Bluenose-East Caribou 2018-2021

To assist in preparation of a joint management proposal for Bluenose-East caribou (Tłı̨chǫ Government (TG) and ENR) that was submitted to the WRRB in Jan. 2019, a limited set of harvest modeling runs was carried out to assess how harvest might affect the herd's likely numbers in 2021, three years after the 2018 survey. The full results are included in Appendix 4 of this report. We include a selection of results here as they build on the Bayesian modeling described in preceding pages.

The methodology used for simulations followed the original generic harvest model approach (Boulanger and Adamczewski 2016). In review, the harvest model assumes that harvest mortality is additive to natural mortality each year. It assumes that harvest occurs in the new year (January) for both bulls and cows with mortality of cows not affecting calf survival in the year the cow is shot (it basically assumes that the calf has weaned at that point).

We note that the main objective of simulations was to provide an assessment of relative risk of accelerated decline of the herd at various harvest levels as opposed to firm predictions of herd status in 2021. It is challenging to assess future demographic rates and therefore we suggest that the results of simulations be used with ongoing demographic monitoring to assess herd status and response to harvest.

The following simulations were considered. Simulations with estimated cow survival levels in 2018 (minimal harvest, female survival (S_f)=0.716: CI=0.6-0.83) were considered across a range of calf productivity levels. This estimate of cow survival assumes low harvest pressure from 2017-2018 so that the difference in natural and harvest-influenced survival is minimal. This assumption is reasonable since harvest levels were relatively low (2015-2016, \approx 800 caribou, 2016-2017 \approx 300 caribou, 2017-2018 \approx 200 caribou) in the 2015-2018 interval.

Variation in productivity was simulated by varying calf survival while keeping fecundity constant. This scenario most closely follows the results of the IPM analysis where fecundity was held constant with yearly variation in calf survival estimated using a random effects model (Figures 33 and 34). The values of calf survival and productivity simulated followed the range of values estimated from the 2008-2018 data sets. We based the average productivity scenario on the last three years given that this level of productivity will have the higher influence on future herd size of the Bluenose-East herd. We note that the assumption of constant fecundity in the IPM analysis was due partially to data constraints ($n=4$ breeding proportion measurements) rather than lack of biological variation in pregnancy rates.

Estimates of demographic parameters in 2018 were relatively similar to those from 2015. The estimate of cow survival in 2018 of 0.716 was similar to that estimated from the 2015 analysis of 0.708. The mean cow survival rate 2015-2018 was 0.76; however the overall trend suggested a

declining recent trend in cow survival 2015-2018 and therefore the 2018 estimate was used for simulations. The average level of calf productivity (0.30) from 2015-2018 was slightly higher than the previous average calf productivity of 0.26 (from 2013-2015). The lower calf productivity scenario (0.187) was based on the 2018 estimate of calf productivity. Bull survival in 2018 was estimated at 0.52, which was lower than the estimate of 0.59 in 2015. Simulations were also run at the 2015 bull survival level of 0.59 to assess the sensitivity of estimates of bull cow ratio to this change in bull survival, as detailed in Appendix 4.

Table 27: Demographic scenarios considered in harvest simulations for the Bluenose-East caribou herd in 2018. S_f = cow survival rate; S_c = calf survival rate; S_m = bull survival rate; S_y = yearling survival rate; $F_a * S_c$ = calf productivity as the product of pregnancy and calf survival rates. Results of all simulations are detailed in Appendix 4.

Scenario	Productivity		Survival			Pregnancy Rate	λ	Stable Age Distribution Proportions at 2018		
	$F_a * S_c$	Cow (S_f)	Calf (S_c)	Bull (S_m)	Yearling (S_y)	F_a	(Cows Only)	Calves	Yearlings	Cows
High productivity (95 th percentile)	0.455	0.716	0.655	0.523	0.716	0.694	0.870	0.190	0.143	0.666
Average productivity (2015-2018)	0.301	0.716	0.433	0.523	0.716	0.694	0.828	0.206	0.108	0.686
Low productivity (2018)	0.187	0.716	0.270	0.523	0.716	0.694	0.793	0.221	0.075	0.704

As an initial cross check, demographic parameters for the female segment of the population were analyzed using a stage-based matrix model to determine stable age distributions as well as estimate the resulting lambda from the matrix model. The average productivity scenario resulted in a rate of decline (deterministic $\lambda=0.83$ from a stage-based matrix model of the female segment of the population) which is slightly higher than that observed by comparison of the 2015 and 2018 adult female calving ground survey estimates ($\lambda=0.80$). Estimates of trend from the demographic model were slightly higher than the observed difference between calving ground survey estimates, which accounts for this difference. The low productivity (2018) scenario resulted in a λ of 0.79 which is closer to the observed difference in adult female survey estimates.

The herd size estimate for 2018 (19,294) was used as the starting point for simulations with bull and cow numbers based on the fall bull cow ratio of 2018 (0.38). A stable age distribution was assumed. Harvest levels of 0-950 were considered with an additional harvest level of 2,000 to demonstrate the effects of a large-scale harvest. Simulations were kept to a short interval of three years (2018-2021) as the herd's demography has changed dynamically since 2010. In addition, population surveys have been carried out on a three-year interval in recent years.

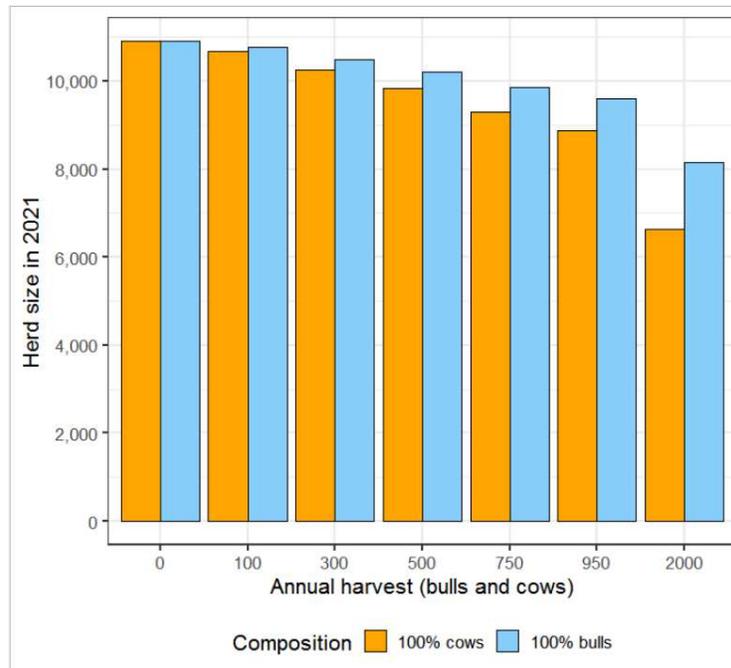


Figure 37: Projected herd size of the Bluenose-East herd in 2021 with various levels of harvest and harvest sex ratio of 100 percent bulls and 100 percent cows. Key assumptions: cow survival rate of 0.716 and average calf productivity of 0.301 (Table 27). Further simulations conducted across the range of observed productivity levels are given in Appendix 4.

Figure 37 shows projected herd size in 2021 (y-axis) across a range of harvest levels from 0-2,000 caribou/year (x-axis) and with harvest either 100 percent cows or 100 percent bulls in the harvest. Projections suggest that the herd would almost be halved again in 2021 to about 11,000 caribou with moderate productivity and 0 harvest, if recent demographic indicators stay the same. At low harvest levels of 100-300, incremental effects of harvest on herd size are limited because the scale of the harvest is small in relation to herd size (100 is 0.5 percent of the herd of 19,300 and 300 is 1.6 percent of this herd size). As the harvest level increases, the effect on herd size in 2021 increases. At the highest harvest level of 2,000 caribou/year and 100 percent cows, projected herd size in 2021 approaches 6,000-8,000 caribou or 30-40 percent the size of the 2018 estimate. The effects of a cow-focused harvest vs. a bull-focused harvest are most pronounced at higher harvest levels and they increase with time.

A more detailed description of the model and predictions is given in Appendix 4. This includes simulations across a full range of observed levels of productivity.

DISCUSSION

Results from the Bluenose-East 2018 calving photo survey documented a significant decline in adult and breeding females and an overall decline in the herd since the 2015 calving ground survey, and a continuing decline since 2010 at an annual rate of decline of about 20 percent. We suggest that this decline is not attributed to poor survey methods or sampling. The caribou counted on the visual blocks may have under-estimated caribou in those blocks somewhat due to the patchy snow conditions and relatively low sightability, but 90 percent of the caribou estimated on the survey area were from the two photo blocks, where extra time spent searching photos and the double observer check suggested that a very high proportion of the caribou were found. An analysis of the herd's demography using multiple data sources suggests that low calf productivity in 2018 (Figure 34) as indicated by declining calf survival rates and pregnancy rates, combined with low adult female survival rates (Figure 35) both contributed to the continuing decline of the Bluenose-East herd. Harvest as estimated/reported for 2016-2017 and 2017-2018 was relatively small and likely contributed little to the most recent decline. Based on available data, the switching of collared female caribou between the Bluenose-East and neighbouring calving grounds was very low (Figure 29) and therefore changes in abundance are not attributable to movement to other calving grounds.

The decline in breeding females, coupled with the low estimated survival rates and low recent calf:cow ratios is cause for serious concern. In general, barren-ground caribou herds have a high probability of declining, if cow survival rates are below 80-85 percent (Crête et al. 1996, Boulanger et al. 2011); results of the IPM analysis in this study suggest that survival levels of 0.84-0.92 are needed (Figure 35) for stability given the range of productivity levels observed for the Bluenose-East herd (Figure 34). Low natural survival rates may reflect significant predation by wolves and bears (Haskell and Ballard 2007). 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 2,000 to 2006-2008 in part reflected late calving and sustained low calf recruitment (Adamczewski et al. 2009, Adamczewski et al. 2015). A recent study (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 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. These results are further supported by the Bayesian analysis that found correlations between warble fly indices and calf survival, and June temperature and cow survival based upon estimates between 2008 and 2016.

Monitoring Recommendations

As a result of the significant declines in the Bluenose-East and Bathurst herds documented by 2018 calving photo surveys, the TG and GNWT ENR submitted joint management proposals for each herd to the 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 high for the BNE herd (83 percent breeding females) but by late October the calf:cow ratio had dropped to 25 calves:100 cows, far below recruitment and productivity needed for a stable population. Annual fall surveys will also allow close monitoring of the bull:cow ratio that has been decreasing in this herd.
3. An increase in numbers of collars on the BNE herd (and the Bathurst herd) 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 BNE 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.
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 Tłı̨chʔ Boots-on-the-Ground program (Tłı̨chʔ Research and Training Institute 2017) that provide insights into caribou health and the influence of weather and other factors on caribou.

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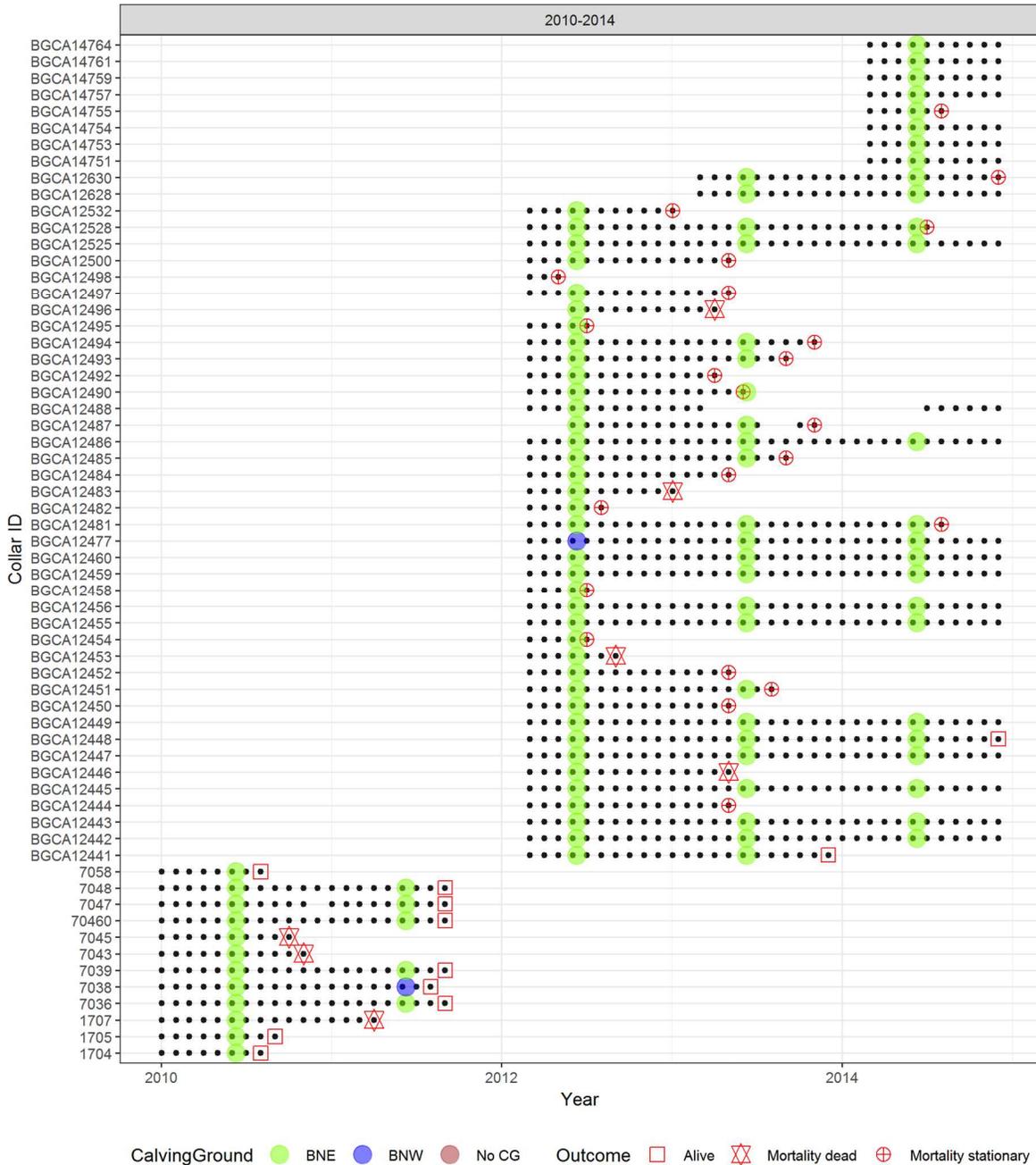
Appendix 1: Double observer visual model observer pairings

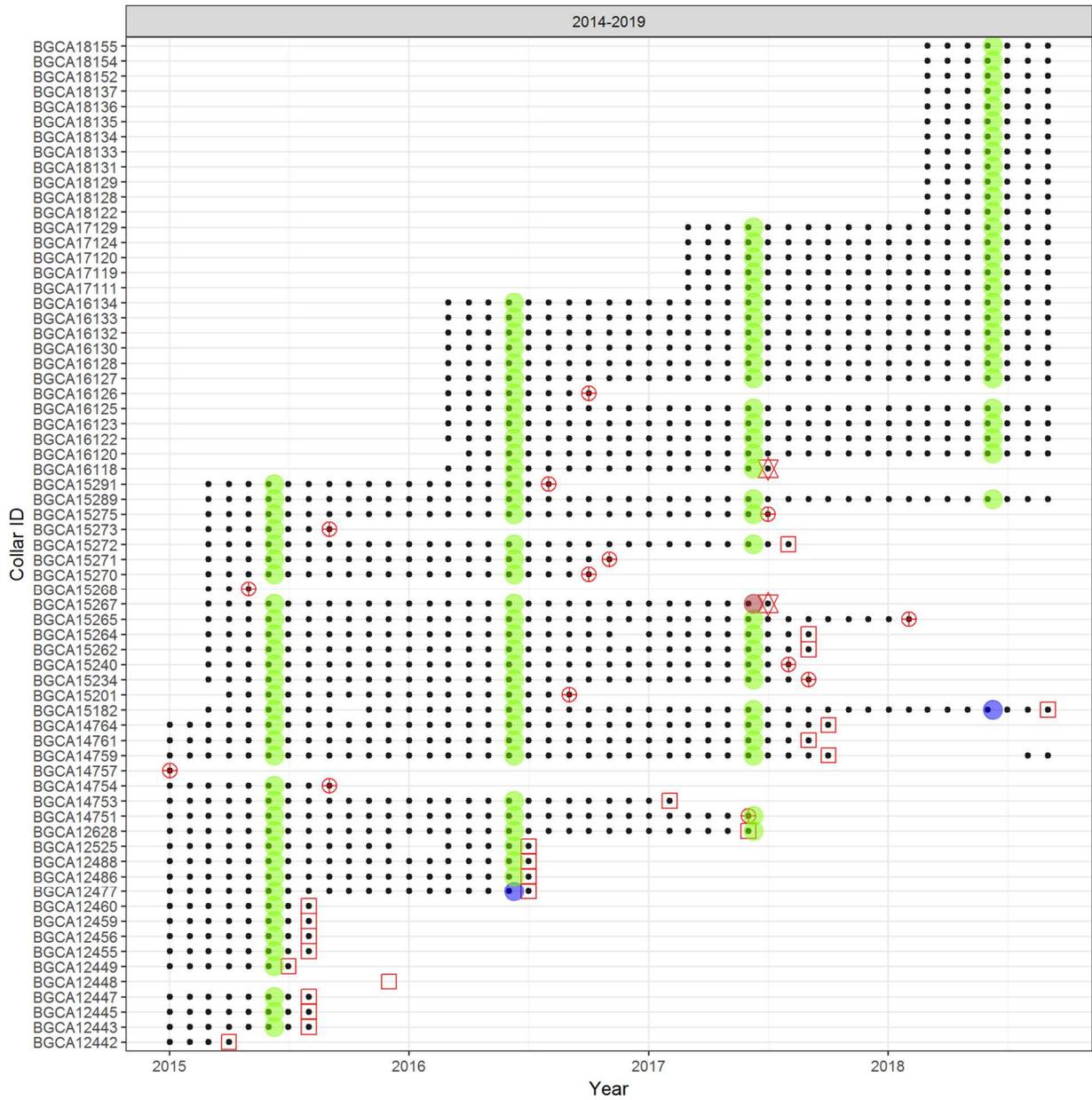
Double observer pairings with associated summary statistics.

Observer Information			Frequencies				Probabilities	
Pair No	Pooled Pair no.	Notes	Secondary	Primary	Both	Total observations	Single ob p	Double 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

Appendix 2: Bluenose-East Collared Female Collar Histories

The following charts detail the histories of collared caribou in the Bluenose-East herd including monthly locations (black dots), presence on calving grounds (as indicated by mean location on June 15), and fate. Fates include alive releases (collar released when caribou was alive and therefore the record was censored at the last location), known dead (stationary collar was directly determined to be a mortality due to harvest or other factors) and stationary dead (collar became stationary before its end date and a mortality was inferred).





CalvingGround ● BNE ● BNW ● No CG Outcome □ Alive ☒ Mortality dead ⊕ Mortality stationary

Appendix 3: Bayesian IPM Details

This appendix details the development of the Bayesian IPM analysis. The primary IPM R coding was developed by Joe Thorley (Poisson Consulting, poissonconsulting.ca) in collaboration with John Boulanger (Thorley and Boulanger 2019). The underlying demographic model used was similar to the OLS model used in previous analyses (Boulanger et al 2011). The primary development was to evolve model fitting to a more robust Bayesian IPM state space approach. The objective of this appendix is to provide a brief description of the model used in the analysis rather than a complete description of the Bayesian model approach. Readers interested in the Bayesian 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 a 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 1,500 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) $ESS \geq 150$ 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 (*sd*) 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*, *sd*, the *z-score*, *lower* and *upper* 95 percent 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 percent CLs are the 2.5th and 97.5th percentiles. A *p-value* of 0.05 indicates that the lower or upper 95 percent CL is 0.

The results are displayed graphically in the main body of the report with 95 percent confidence/credible intervals (CIs, Bradford, Korman, and Higgins 2005). Data are indicated by points (with lower and upper bounds indicated by vertical bars) and estimates are indicated by solid lines (with CIs indicated by dotted lines).

The analyses were implemented using R version 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 survival from calving to the following year varies randomly by year.
- Cow and bull survival is constant throughout the year.
- Calf survival to the following year (when they become yearlings) varies by season and randomly by year.
- Yearling survival to the following year is the same as cow survival.
- The sex ratio is 1:1.
- The proportion of breeding cows is the fecundity the previous year.
- Female yearlings are indistinguishable from cows in the fall and spring surveys.
- The number of calves in the initial year is the number of cows in the initial year multiplied by the product of the fecundity and cow survival in a typical year.
- The number of yearlings in the initial year is the product of the number of calves in the initial year and the calf survival in a typical year.
- The data are normally distributed with *sd* equal to their SEs.

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

    logit(eSurvivalCow[i]) <- bSurvivalCow + bSurvivalCowAnnual[i]
    logit(eSurvivalBull[i]) <- bSurvivalBull
    logit(eFecundity[i]) <- bFecundity
    logit(eSurvivalCalfSummerAnnual[i]) <- bSurvivalCalfSummerAnnual + bSurvivalCalfAnnual[i]
    logit(eSurvivalCalfWinterAnnual[i]) <- bSurvivalCalfWinterAnnual + bSurvivalCalfAnnual[i]
  }
  bBreedingCows1 ~ dnorm(50000, 10000^-2) T(0,)
  logit(eFecundity1) <- bFecundity
  logit(eSurvivalCalfSummerAnnual1) <- bSurvivalCalfSummerAnnual
  logit(eSurvivalCalfWinterAnnual1) <- bSurvivalCalfWinterAnnual

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

  bSpringCalfCow[1] <- bCalves[1] / (bCows[1] + bYearlings[1] / 2)

  for(i in 2:nAnnual){
    bCows[i] <- (bCows[i-1] + bYearlings[i-1] / 2) * eSurvivalCow[i-1]
    bBulls[i] <- bBulls[i-1] * eSurvivalBull[i-1] + (bYearlings[i-1] / 2) * eSurvivalCow[i-1]
    bCalves[i] <- bCows[i-1] * eSurvivalCow[i-1] * eFecundity[i-1]
    bYearlings[i] <- bCalves[i-1] * eSurvivalCalfSummerAnnual[i-1]^(154/365) *
    eSurvivalCalfWinterAnnual[i-1]^(211/365)
  }
}
```

```

}

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

  eFallCows[i] <- (bCows[i] + bYearlings[i] / 2) * eSurvivalCow[i]^eFallCor[i]
  eFallBulls[i] <- (bYearlings[i] / 2) * eSurvivalCow[i]^eFallCor[i] + bBulls[i] * eSurvivalBull[i]^eFallCor[i]
  eFallCalves[i] <- bCalves[i] * eSurvivalCalfSummerAnnual[i]^eFallCor[i]

  bFallBullCow[i] <- eFallBulls[i] / eFallCows[i]
  bFallCalfCow[i] <- eFallCalves[i] / eFallCows[i]
}

for(i in 2:nAnnual) {
  eSpringCows[i] <- (bCows[i-1] + bYearlings[i-1] / 2) * eSurvivalCow[i-1]^(SpringCalfCowDays[i] / 365)
  eSpringCalves[i] <- bCalves[i-1] * eSurvivalCalfSummerAnnual[i-1]^(154/365) *
eSurvivalCalfWinterAnnual[i-1]^((SpringCalfCowDays[i] - 154) / 365)

  bSpringCalfCow[i] <- eSpringCalves[i] / eSpringCows[i]
}

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

for(i in CowsAnnual) {
  BreedingProportion[i] ~ dnorm(eFecundity[i], BreedingProportionSE[i]^(-2))
  eBreedingCows[i] <- bCows[i] * eFecundity[i]
  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 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 is 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*, *sd*, the *z-score*, *lower* and *upper* 95 percent 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 percent CLs are the 2.5th and 97.5th percentiles. A p-value of 0.05 indicates that the lower or upper 95 percent CL is 0.

Term	Estimate	sd	zscore	lower	upper	pvalue
<u>Main effects</u>						
bFecundity	0.831	0.141	5.931	0.571	1.126	0.000
bSurvivalBull	0.092	0.095	0.955	-0.100	0.272	0.337
bSurvivalCalfSummerAnnual	-0.683	0.354	-1.913	-1.380	0.041	0.062
bSurvivalCalfWinterAnnual	0.421	0.362	1.177	-0.275	1.162	0.228
bSurvivalCow	1.377	0.317	4.393	0.800	2.068	0.000
<u>Random effects</u>						
sSurvivalCalfAnnual	0.887	0.250	3.704	0.557	1.526	0.000
sSurvivalCowAnnual	0.932	0.286	3.407	0.547	1.661	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. 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, rhat is the rhat 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	rhat	converged
12	8	3	3000	300	5328	1.00	TRUE

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

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

Term	rhat
bBreedingCows1	1.005
bFecundity	1.001
bSurvivalBull	1.004
bSurvivalCalfSummerAnnual	1.000
bSurvivalCalfWinterAnnual	1.002
bSurvivalCow	1.019
sSurvivalCalfAnnual	1.030
sSurvivalCowAnnual	1.041

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 32-36 of the main report.

Table 4. Parameter descriptions for estimates generated by the model.

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
CowSurvival[i]	The data point for cow survival from the $i-1^{\text{th}}$ 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

A sensitivity analysis was conducted to determine the effect of a declining calf survival trend and the including of the 2011 caribou year survival estimate which was higher than other estimates which may have been influenced by lack of collars for the winter months of 2011-2012 (Figure 30). In general, estimates were minimally affected by either of these alternative model runs (Figure 1) demonstrating the robustness of random effect models to smaller scale underlying trends in the model (calf survival) or individual historic data points (the 2011 survival rate estimate).

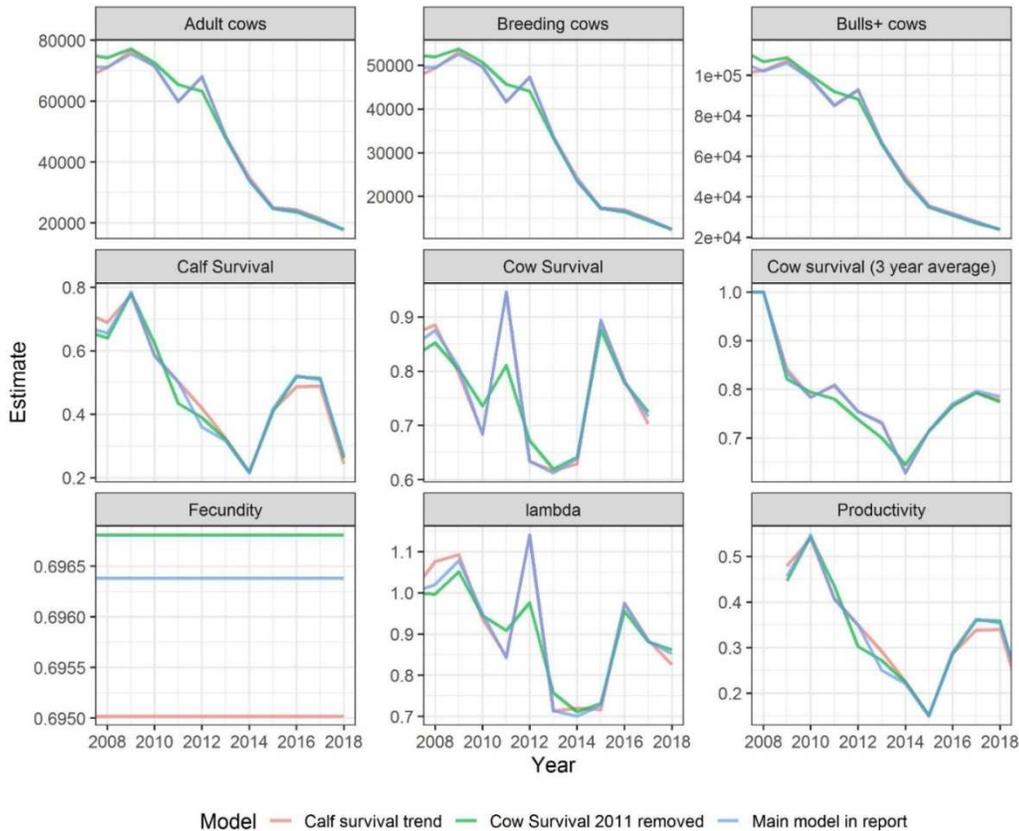


Figure 1: Comparison of model predictions of the main model used in report to a model with calf survival trends and the main model run without the 2011 collared cow survival data point.

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Appendix 4: Updated Harvest Simulations for the Bluenose-East Herd

This appendix briefly summarizes harvest simulations for the Bluenose-East herd carried out in winter 2018-2019 following the June 2018 calving photo survey for this herd. A previous version was dated January 2, 2019. The present summary uses direct estimates from the demographic model analyses described in the main body of this survey report, which were finalized after the initial harvest simulations had been completed. Harvest modeling outcomes are very similar between the January 2, 2019 summary and this version; there are slight changes in a few parameters. We suggest that readers review the original harvest simulation report with a broad range of modeling scenarios (Boulanger and Adamczewski 2016), the 2015 Bluenose-East calving ground survey report (Boulanger et al. 2016), the original Bathurst herd demographic model paper (Boulanger et al. 2011) and the section on demographic modeling of the current report, for more details on the approach used in simulations.

The IPM analysis detailed in the main report was used to produce updated estimates of demographic parameters based on the recent calving ground survey results, recent collar data and other demographic indicators. In addition, harvest pressure was reduced between 2015 and 2018 from levels 2010-2014, thus it is likely that herd decline was less influenced by harvest during the more recent interval. Updated parameter estimates were used in this updated harvest modeling.

The methodology used for simulations followed the original generic harvest model approach (Boulanger and Adamczewski 2016). In review, the harvest model assumes that harvest mortality is additive to natural mortality each year. It assumes that harvest occurs in the new year (January) for both bulls and cows with mortality of cows not affecting calf survival in the year the cow is shot (it basically assumes that the calf has weaned at that point).

We note that the main objective of simulations is to provide an assessment of relative risk of accelerated decline of the herd at various harvest levels as opposed to firm predictions of herd status in 2021. It is challenging to assess future demographic rates and therefore we suggest that the results of simulations be used with ongoing demographic monitoring to assess herd status and response to harvest.

The following simulations were considered. Simulations with estimated cow survival levels in 2018 (minimal harvest, female survival ($S_f=0.716$: $CI=0.6-0.83$) were considered across a range of calf productivity levels. This estimate of cow survival assumes low harvest pressure from 2017-2018 so that the difference in natural and harvest-influenced survival is minimal. This assumption is reasonable since harvest levels were relatively low (2015-2016, ≈ 800 caribou, 2016-2017 ≈ 300 caribou, 2017-2018 ≈ 200 caribou) in the 2015-2018 interval.

Variation in productivity was simulated by varying calf survival while keeping fecundity constant. This scenario most closely follows the results of the IPM analysis where fecundity was held constant with yearly variation in calf survival estimated using a random effects model (Figures 33 and 34 in main report). The values of calf survival simulated, and levels of productivity simulated follow the range of values estimated from the 2008-2018 data set. We based the average productivity scenario on the last three years given that this level of productivity will have the higher influence on future herd size of the Bluenose-East herd. We note that the assumption of constant fecundity is based partially on restrictions of the data set (n=4 estimates of proportion females breeding-Figure 32 in main report).

Estimates of demographic parameters in 2018 were relatively similar to those from 2015. The estimate of cow survival in 2018 of 0.716 was similar to that estimated from the 2015 analysis of 0.708. The mean cow survival rate 2015-2018 was 0.76, however the overall trend suggested a declining recent trend in cow survival 2015-2018 and therefore the 2018 estimate was used for simulations. The average level of calf productivity (0.30) from 2015-2018 was slightly higher than the previous average calf productivity of 0.26 (from 2013-2015). The lower calf productivity scenario (0.187) was based on the 2018 estimate of calf productivity. Bull survival in 2018 was estimated at 0.523, which was lower than the estimate of 0.58 in 2015. Simulations were also run at the 2015 bull survival level of 0.58 to assess the sensitivity of estimates of bull cow ratio to this change in bull survival.

Table 1: Demographic scenarios considered in harvest simulations for the Bluenose-East caribou herd in 2018. S_f = cow survival rate; S_c = calf survival rate; S_m = bull survival rate; S_y = yearling survival rate; $F_a * S_c$ = calf productivity as the product of pregnancy and calf survival rates.

Scenario	Productivity		Survival			Pregnancy Rate F_a	λ (cows only)	Stable Age Distribution Proportions at 2018		
	$F_a * S_c$	Cow (S_f)	Calf (S_c)	Bull (S_m)	Yearling (S_y)			Calves	Yearlings	Cows
High productivity (95 th percentile)	0.455	0.716	0.655	0.523	0.716	0.694	0.870	0.190	0.143	0.666
Average productivity (2015-2018)	0.301	0.716	0.433	0.523	0.716	0.694	0.828	0.206	0.108	0.686
Low productivity (2018)	0.187	0.716	0.270	0.523	0.716	0.694	0.793	0.221	0.075	0.704

As an initial cross check, demographic parameters for the female segment of the population were analyzed using a stage-based matrix model to determine stable age distributions as well as estimate the resulting λ from the matrix model. The average productivity scenario resulted in a rate of decline (deterministic $\lambda=0.83$ from a stage-based matrix model of the female segment of the population) which is slightly higher than that observed by comparison of the 2015 and 2018 adult female calving ground survey estimates ($\lambda=0.80$). Estimates of trend from the demographic model

were slightly higher than the observed difference between calving ground survey estimates, which accounts for this difference. The low productivity (2018) scenario resulted in a λ of 0.79 which is closer to the observed difference in adult female survey estimates.

The herd size estimate for 2018 (19,294) was used as the starting point for simulations with bull and cow numbers based on the fall bull cow ratio of 2018 (0.38). A stable age distribution was assumed. Harvest levels of 0-950 were considered with an additional harvest level of 2,000 to demonstrate the effects of a large-scale harvest. Simulations were kept to a short interval of three years (2018-2021) as the herd's demography has changed dynamically since 2010; In addition, population surveys have been carried out on a three-year interval in recent years. Results of the simulations are shown graphically.

Figure 1 shows projected herd size in 2021 across a range of harvest levels (x-axis) and percent bulls in the harvest. Projections suggest that the herd would almost be halved again in 2021 (top dashed line) to about 10,000 caribou with moderate productivity and 0 harvest, if recent demographic indicators stay the same. As the harvest level increases, the effect on herd size in 2021 increases. At the highest harvest level of 2,000 caribou/year, projected herd size in 2021 approaches 5,000 caribou or about one quarter the size of the 2018 estimate (the second dashed line). A harvest of primarily bulls offsets the effect of harvest to an extent; however, productivity needs to be higher to offset low cow survival rates regardless. The effects of a cow-focused harvest vs. a bull-focused harvest are most evident at higher harvest levels and they increase with time.

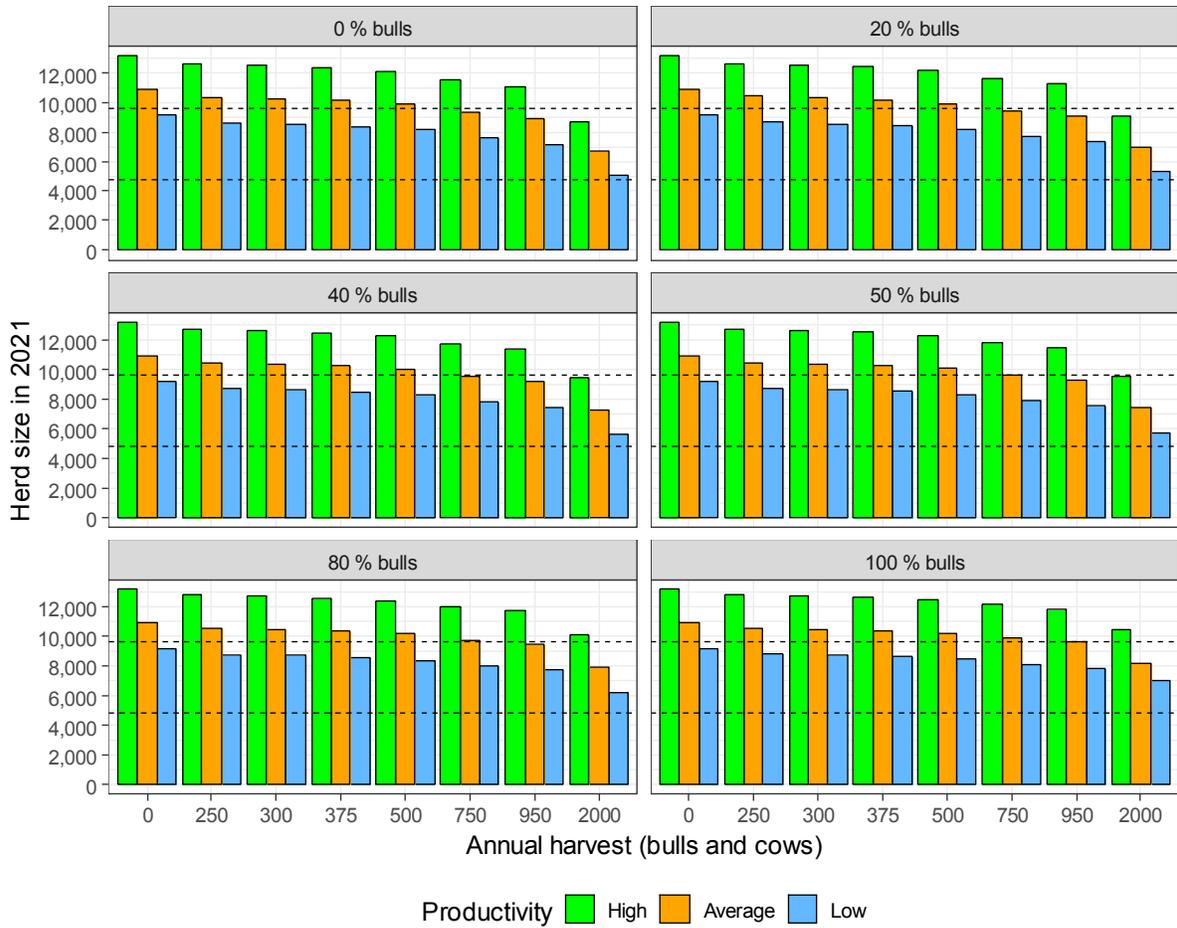


Figure 1: Projected Bluenose-East herd size in 2021, assuming a cow survival of 0.716 and three levels of calf productivity, across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

Figure 2 shows herd trajectories from 2018-2021 for each productivity scenario.

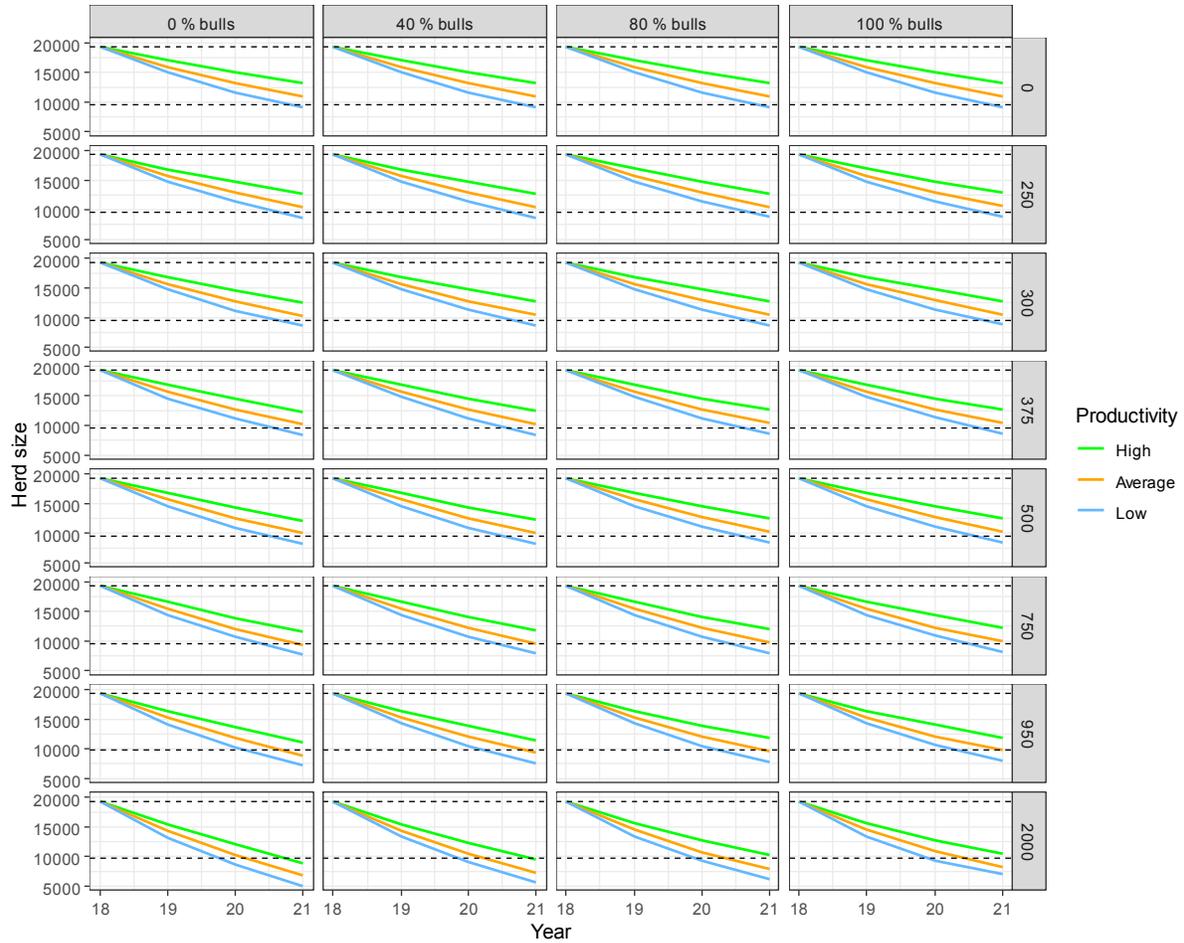


Figure 2: Projected herd trajectories for the Bluenose-East herd 2018-2021 assuming cow survival of 0.716 and three levels of calf productivity across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

One important point to consider with bull-dominated harvest is the effect on the bull-cow ratio. Figure 3 demonstrates the quick decline in bull-cow ratio at higher harvest levels when bulls are primarily harvested. The red line in this graph is a bull-cow ratio of 0.23 which is considered a preferred lower limit based roughly on other studies (Mysterud et al. 2002), although it is likely that all females would be bred even if the sex ratio was reduced further (Mysterud et al. 2002). At a harvest level of 300/year, the bull-cow ratio stays between the 2018 level and the lower limit regardless of productivity. When harvest is 2,000 per year, the modeled bull population in essence goes to 0 in 2020 with lower to moderate productivity. The bull cow ratio is inflated due to the decrease in cow numbers if cows are primarily harvested at higher harvest levels; ratios depend on the number in the denominator as well as the number in the numerator. In any case, it is unlikely that harvest of the herd after 2018 will be anywhere near this scale of bull or cow harvest, and increased monitoring proposed for the herd includes frequent (potentially annual) fall composition surveys that will monitor the bull:cow ratio.

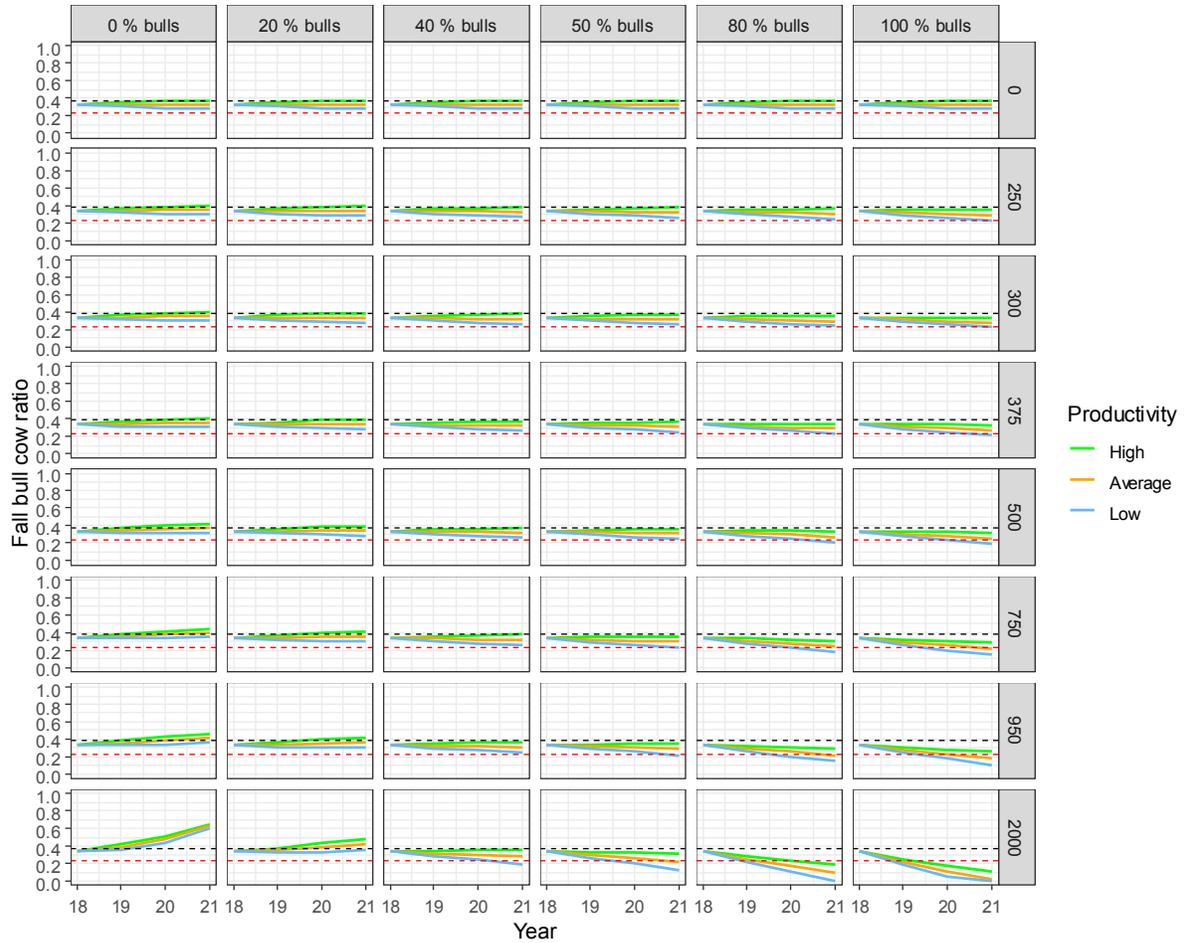


Figure 3: Projected bull-cow ratios in the Bluenose-East herd 2018-2021 assuming cow survival of 0.716 and bull survival of 0.523 and three levels of calf productivity, across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

Figure 4 shows predicted bull cow ratios in 2021 for the BNE herd; these are essentially the endpoints of the changing ratios shown in Figure 3. Unless calf productivity is high, a reduction in bull cow ratio is projected due to the lower estimate of bull survival (0.523).

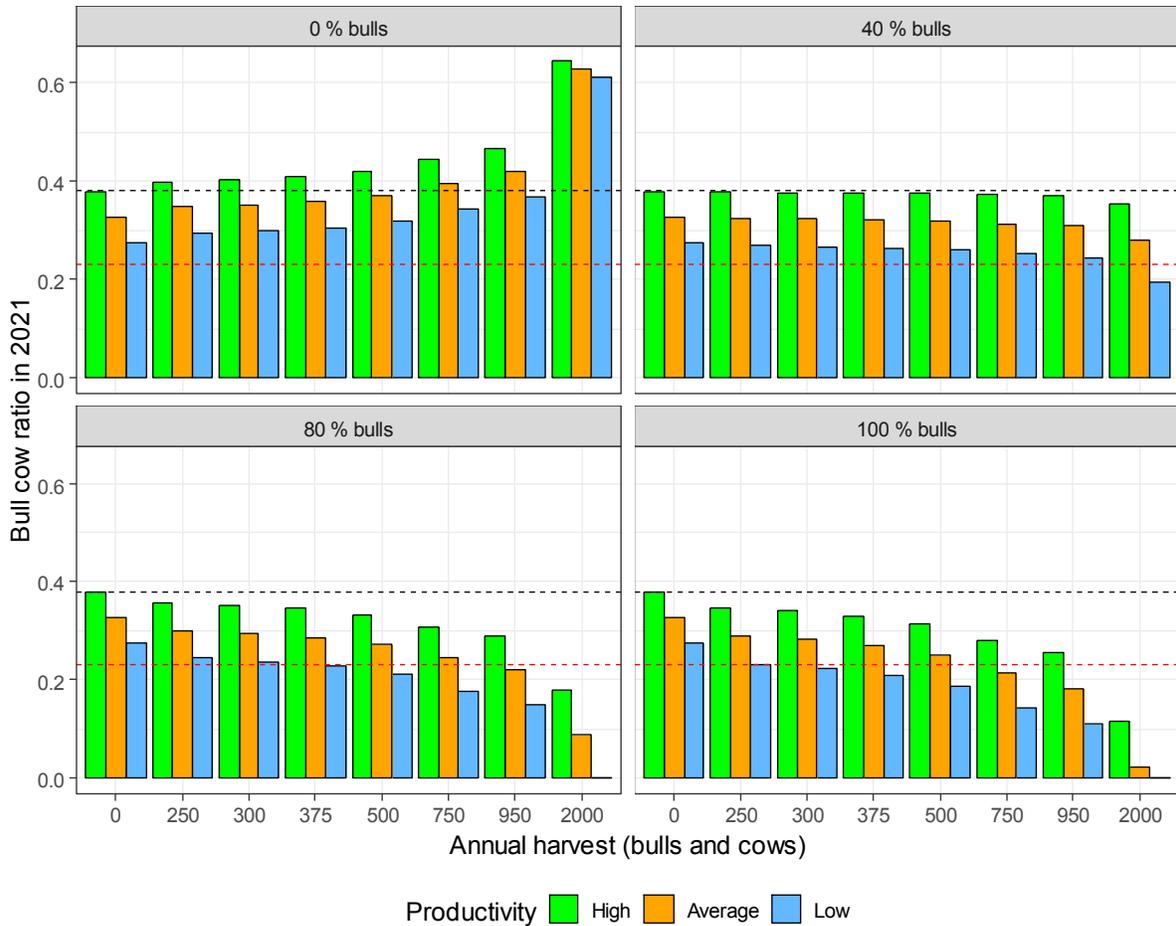


Figure 4: Projected bull-cow ratios in the Bluenose-East herd in 2021 assuming cow survival of 0.716 and bull survival of 0.523 and three levels of calf productivity, across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

Simulations with the previous slightly higher bull survival estimate of 0.58 from 2015 were also run to assess the sensitivity of harvest model predictions of bull cow ratio to bull survival, to compare results of projections at a bull survival of 0.523. It can be seen that in these simulations the projected bull cow ratios remain similar in 2021 to those observed in 2018 under the no harvest scenario.

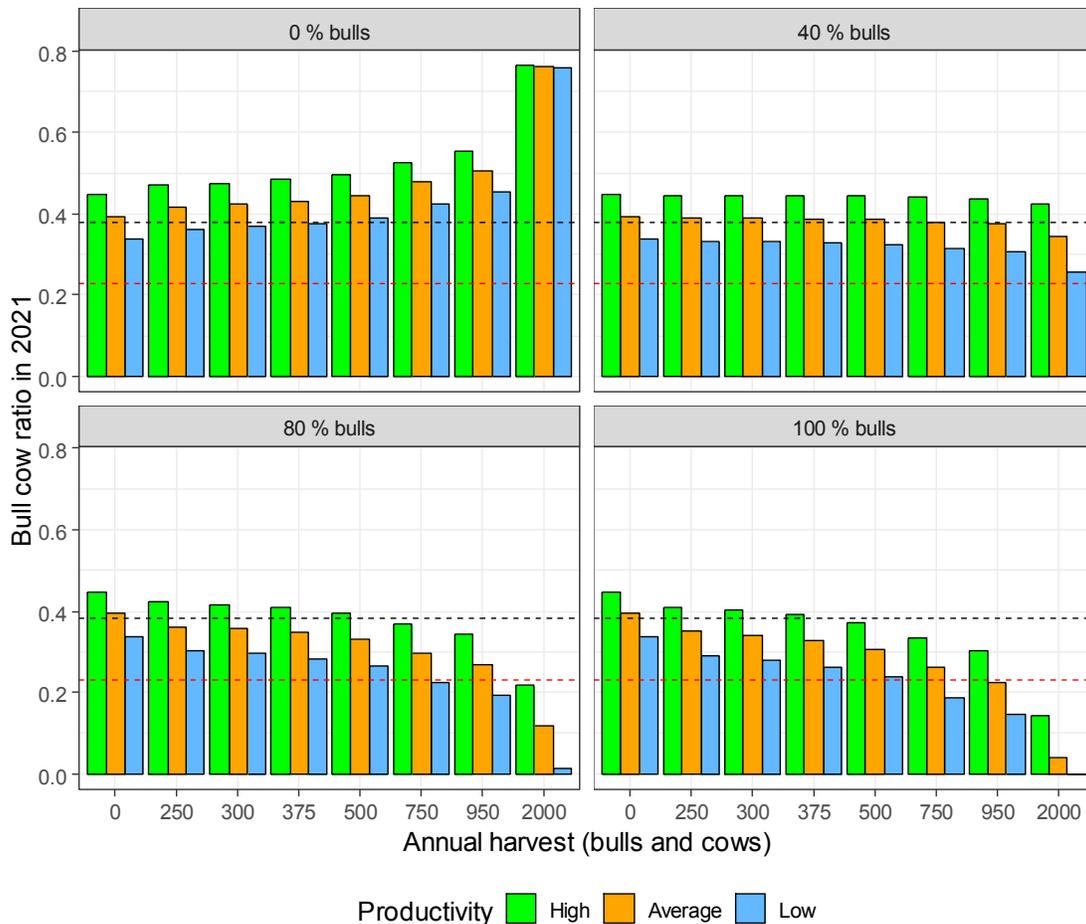


Figure 5: Projected bull cow ratios in the Bluenose-East herd in 2021, assuming cow survival of 0.716 and three levels of calf productivity and a bull survival of 0.58 (value from 2015 demographic model analysis). See Table 1 for the parameterization of each productivity level.

Why Do Low Harvest Levels have Minimal Effect on Herd Trajectories?

One question that has come up is the seemingly minimal effect of lower harvest levels on population trend. The main reason for this is that at these levels a relatively small proportion of the herd is being harvested as demonstrated in Figure 6, and thus harvest accounts for only a small proportion of the herd and mortality rates are predominantly natural. Once harvest level becomes higher (950 or higher) the proportion of the herd harvested increases as the herd declines. If the harvest remains at a constant number of caribou/year and the herd continues to decline, then the incremental effect of the harvest harvest-caused mortality keeps increasing and can lead to a downward acceleration. Then harvest adds substantially to the natural mortality rates. This effect was shown for the Bathurst herd in 2006-2009 (Boulanger et al. 2011), when harvest levels remained at 4,000-6,000/year as the herd declined rapidly. Although all harvest adds to decline if a herd is declining naturally, small-scale harvest rates have small incremental effects on a declining trend.

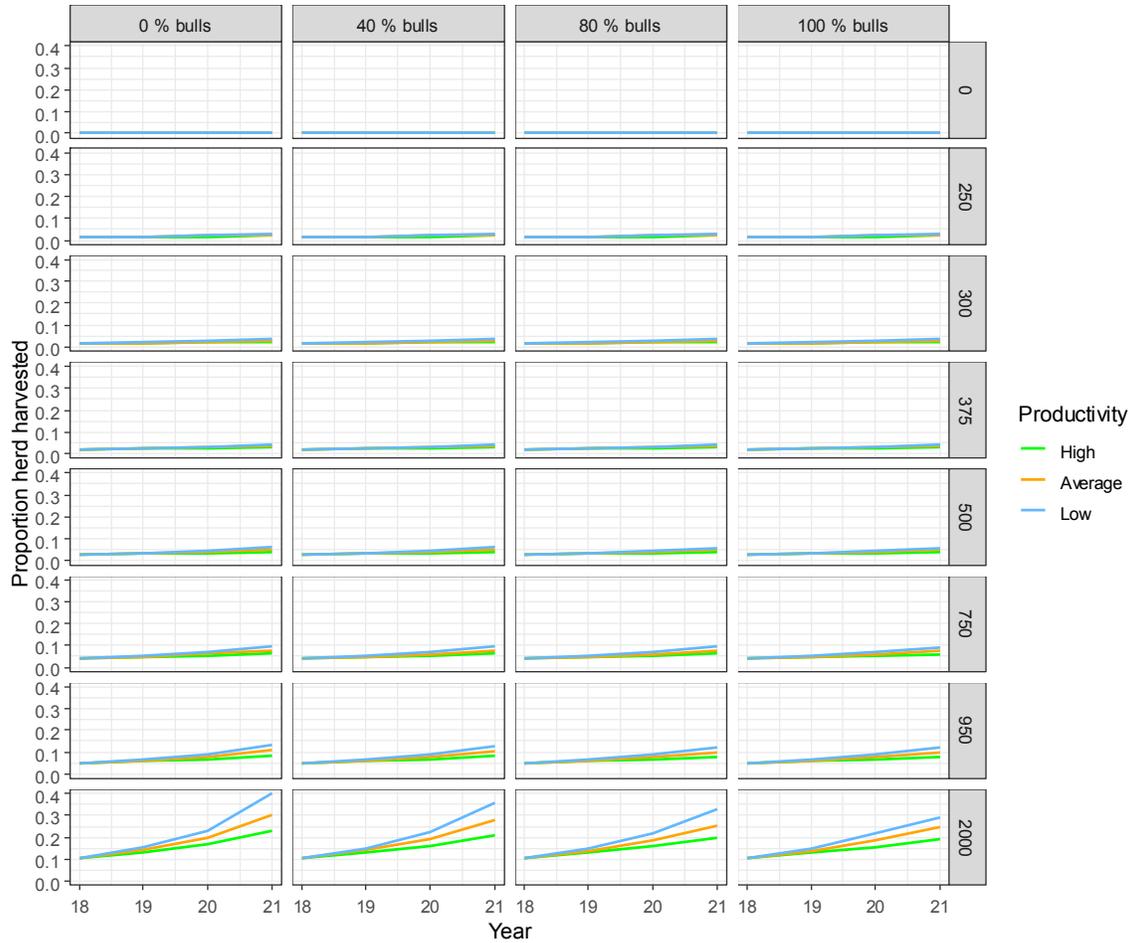


Figure 6: Proportion of the Bluenose-East herd harvested through 2021 across a range of harvest levels and proportion of the bulls in the harvest. See Table 1 for the parameterization of each productivity level.

In Figure 6 it can be seen that the proportion of herd harvested increases at a greater rate when the harvest is primarily cows. The reason for this is that harvest of cows reduces longer-term productivity of the herd through the reduction of future calves each cow would produce. For this reason, it is important to track proportion of cows (cow harvested/total cows) and proportion of bulls harvested (bulls harvested/total bulls) each year rather than just total harvest. Figure 7 provides total herd estimates subdivided by bulls and cows to further illustrate this point. It can be seen that at higher harvest levels (>750) a bull dominated harvest can adversely impact the bull population especially if productivity is low. This impact is also demonstrated by a substantial decrease in bull-cow ratios (Figures 3, 4) when bull harvest is higher.

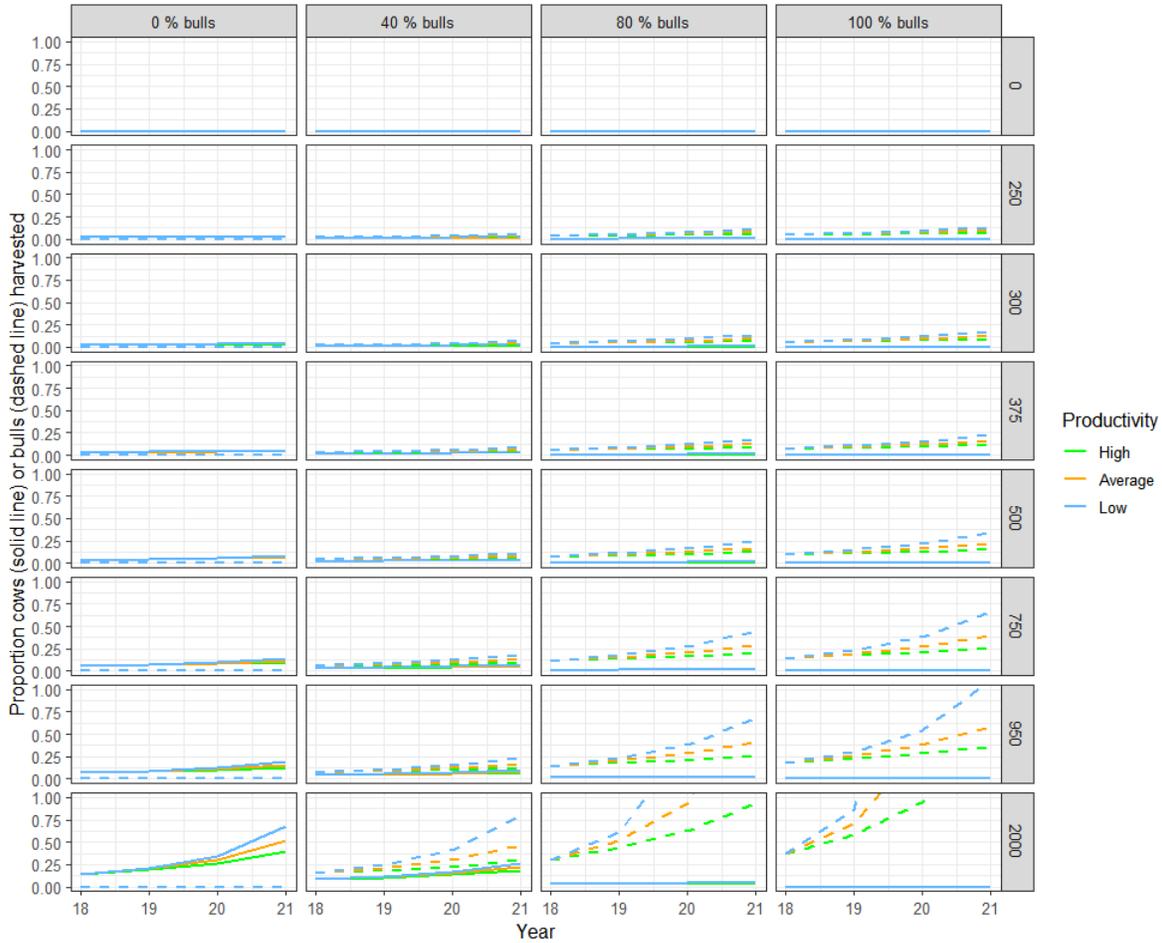


Figure 7: Proportion of bulls and cows harvested for each harvest and productivity scenario. This figure basically summarizes proportion harvested in Figure 6 by bulls and cows. See Table 1 for the parameterization of each productivity level.

Potential Future Analyses

These simulations illustrate the sensitivity of the bull cow ratio estimates to assumed bull survival. Estimates of bull survival from the demographic model are based on bull-cow ratios from fall surveys and are therefore indirect in nature. Collar-based estimates of bull survival could be used to further verify the indirect estimates from the IPM analysis.

Simulations with demographic variation could also be used to generate estimates of herd size in 2021 with confidence limits.

Literature cited (see main survey report).

Appendix 5: Trends in Calving Ground Size and Core Densities

This appendix provides additional information calving ground size, distribution of caribou on calving ground, and core calving ground densities in the Bluenose-East and Bathurst herd calving grounds based on reconnaissance survey and photo survey data. This appendix provides a summary of data from previous surveys as opposed to full documentation of methods used to define core calving areas. Readers should consult previous calving ground survey reports for the Bluenose-East (Adamczewski et al. 2014, Boulanger et al. 2014b, Boulanger et al. 2016, Adamczewski et al. 2017) for more details on each survey.

Methods

Trends in segment densities from reconnaissance surveys that occurred during 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 was plotted spatially and by segment density class.

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. To explore this issue, a scaled estimate of core calving ground size based on the summation of the product of stratum areas and proportions of breeding and adult females was also considered as an index of core calving area. For example, if a 100 km² stratum had 20 percent breeding females, then its core area was estimated as 20 km². Each survey stratum area was estimated using this approach and summed for the survey year. Density estimates using this approach will be more robust to strata layout and composition each year. 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 weighted density estimate will not directly pertain to a defined geographic area.

Results

Figure 1 displays reconnaissance segments that defined the core calving areas for the Bluenose-East herd during years that calving ground surveys were conducted (2010, 2013, 2015 and 2018). The distribution of higher density segments showed a trend toward shifting to the northwest over these years. There was also a strong trend toward fewer high density segments (at least 10 caribou/km²) from 2010-2015, and none in 2018. The high density segments in 2010 to the south

of Kugluktuk were partially influenced by higher densities of non-breeding cows, bulls and yearlings in this area.

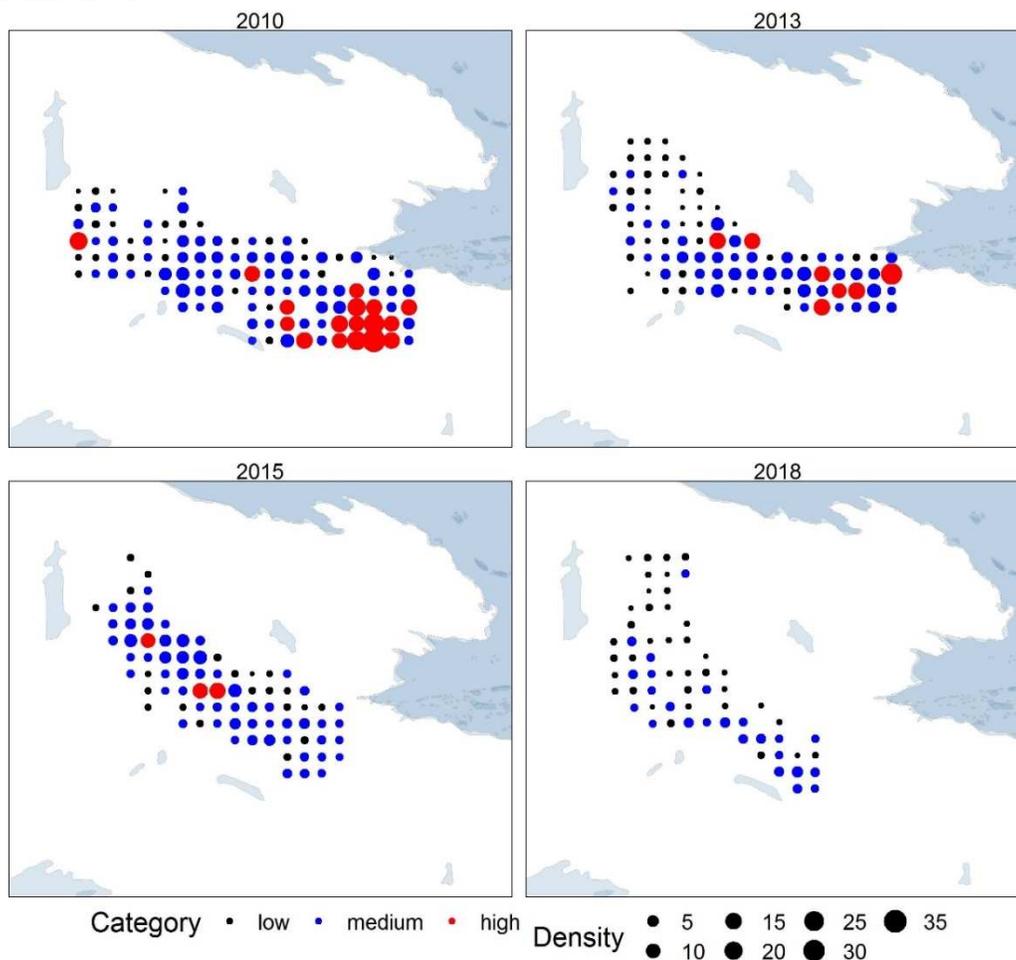


Figure 1: Segment densities in core calving areas for the Bluenose-East caribou herd 2010-2018 from calving photo surveys. Low density = <math><1</math> caribou/km², medium density = 1-9.9 caribou/km², and high density = at least 10 caribou/km².

Figure 2 provides a histogram of segment densities from the same Bluenose-East calving ground surveys, further demonstrating the shift to lower density segments.

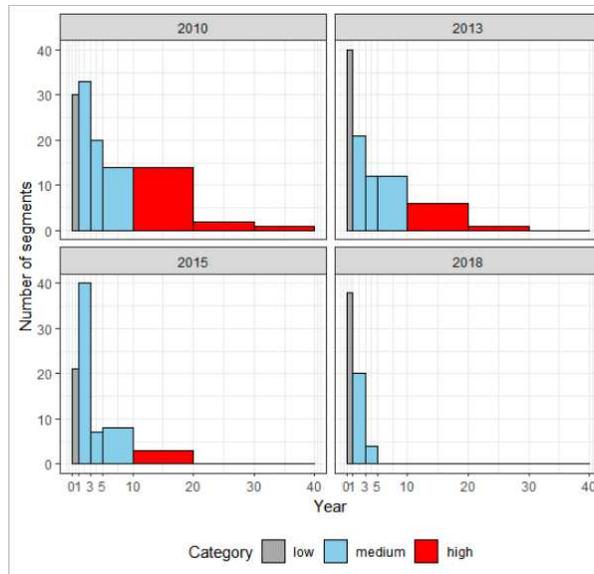


Figure 2: Segment densities in core calving areas for the Bluenose-East caribou herd 2010-2018. Low density = <1 caribou/km², medium density = 1-9.9 caribou/km², and high density = at least 10 caribou/km².

A boxplot of the Bluenose-East segment data set shows that the median segment densities were generally <5 caribou per km² with the majority of segments being in the medium density category (Figure 3). In 2018 a substantial proportion of the segments were in the low density category of <1 caribou/km².

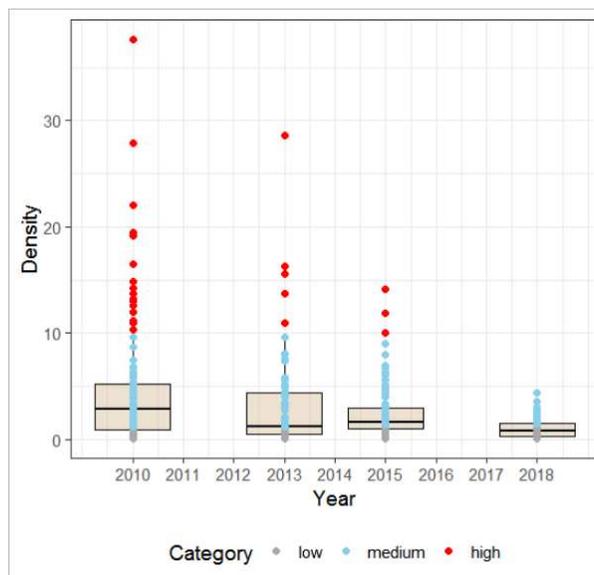


Figure 3: Boxplot of segment densities for the Bluenose-East herd 2010-2018.

Figure 4 shows the total areas of core strata for each year and the weighted area for breeding females and adult females. The weighted area in this case is simply the summation of the product

of each stratum area times the proportion breeding females or adult females. Trends estimated using this approach should be less sensitive to differences in survey strata layout and yearly differences in aggregation of females.

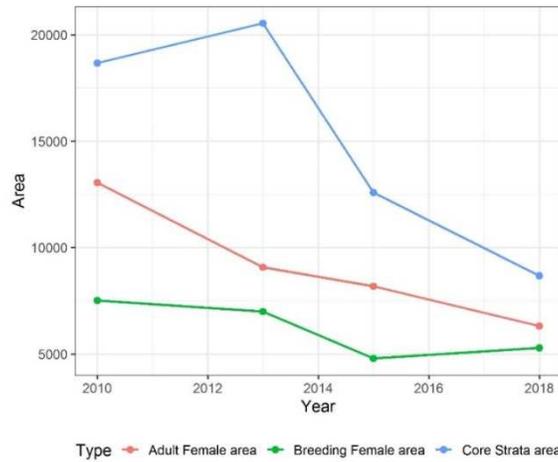


Figure 4: Estimated area of core survey strata, area weighted by proportion of breeding females, and proportion adult females in survey strata for the Bluenose-East caribou herd 2010-2018.

Comparison of the 2010 and 2018 area estimates suggests an overall decrease in area of 46 percent, 48 percent and 70 percent for core strata area, adult female, and breeding female areas. This translates to an annual decrease of 9 percent for core and adult female area and 4 percent for breeding female area. It could be argued that the breeding female area, which will be most affiliated with core densities, is most applicable to overall trends in core calving ground area. Abundance of adult and breeding females decreased at an approximate rate of 20 percent per year (Figure 5) from 2010-2018.

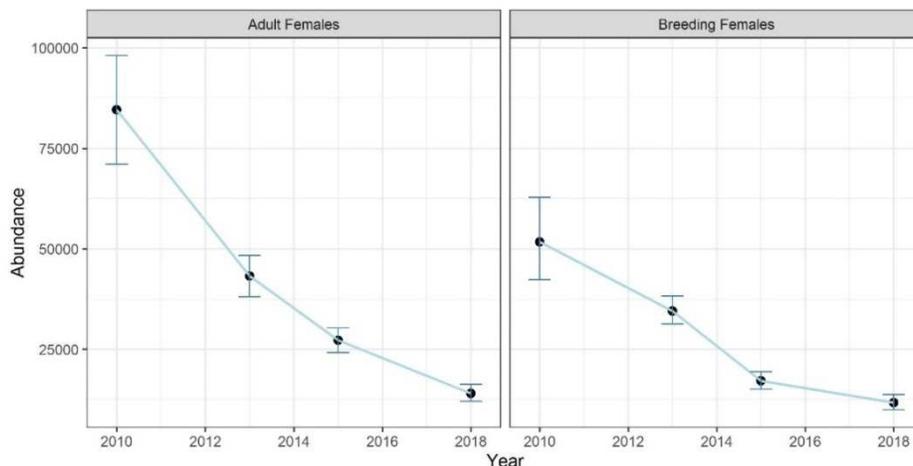


Figure 5: Estimate of abundance of adult and breeding females on core calving areas from 2010-2018 for the Bluenose East herd.

Density was estimated using abundance estimates for adult and breeding females (Figure 5) divided by the associated calving ground area (Figure 4). Comparison of 2010 and 2018 density estimates suggests a gross change in densities of 36 percent and 49 percent for adult and breeding females using strata area (Figure 6). Using weighted areas, the gross change is 34 percent and 32 percent for adult and breeding females. These rates of change translate to annual decreases that range from 9 percent (breeding females using core area) and 13 percent (breeding females using weighted area).

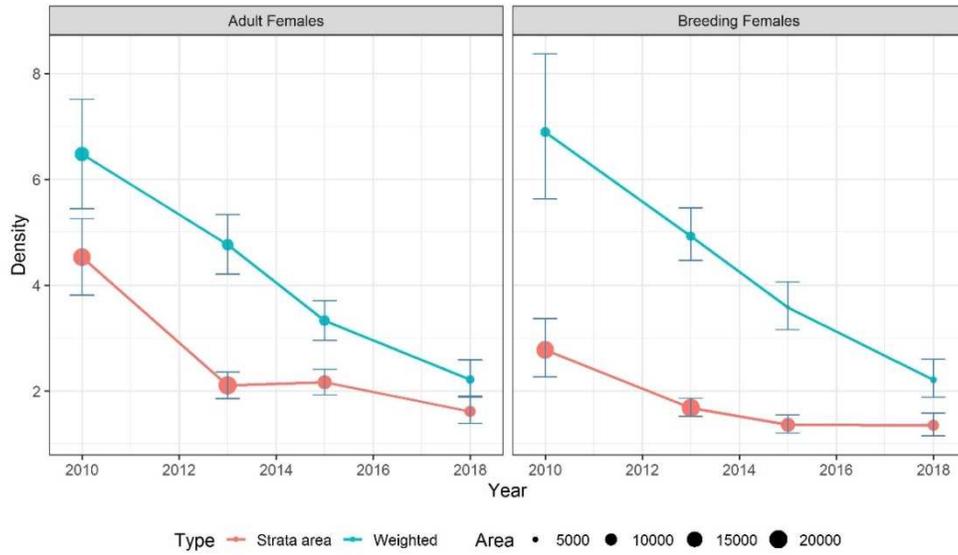


Figure 6: Density (number/km²) of adult females and breeding females in survey strata using total area (Strata area) and corresponding breeding female or adult female areas, for the Bluenose-East caribou calving grounds 2010-2018. The symbol size is proportional to the calving ground area used to estimate density.

Discussion

Defining the core calving area is challenging due to differences in levels of aggregation of caribou during each survey year. The weighted method used to infer trends in core area 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 area estimates are best used to infer trends rather than define an absolute area.

In general, the Bluenose-East herd has not aggregated substantially as the herd size has declined as indicated by similar trends in calving ground area and density (Figure 6). Using breeding females as an indicator, the breeding female weighted core area decreased annually by 4 percent with densities decreasing by 9 percent. This general trend suggests that caribou are not aggregating into smaller areas to maintain higher densities as observed with the Bathurst herd in 2012 (Boulanger et al. 2014c).

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 survey report).



Kugluktuk Angoniatit Association • Anguniaktit imalu Nanirgiaktukpaktunik Katimayit
PO Titikivvia 309, Kugluktuk NU X0B 0E0 • Hivayaut: (867) 982-4908 Hivayaut Tuyuutunik
Titikgakhimayunik: (867) 982-5912 Titikivvia Karitauyakgutunik: kugluktuk@krwb.ca

**HIVULIUYUNIK TUNYAKGAIKHIMAYUNIK TAHAPKUNUNGA NUNAVUT ANGUHIKIYIT
HAVAKATIGIKPAKTUNIK
KAKUNGUKGANGUT KATIMADJUTAUVAKTUNIK #004/2019
UBLUIKVIANI UVANI 4, 2019**

MIKHARUT

TUKIHIGIAGUTINIK: XX

TIKUAUKTAUYUKHANIK:

Ahiak Kivatani Tuktu

Aah tutkikhakhimayunik havakhimayunik Tamatkiumayunik Angunnahuaktautaktunik Angunnahuaknikmun ima 340 nik angunnahuaktautaaktunik havakhikhimayunik uvani 2017 nirgitinik Ahiak Kivatani Tuktunik ammihuakyunit tahapkunani nunalingni Kugluktuk.

Tahapkuat Kavamait talvani Nunatsiami Tunungani talvanituniklu Nunavut iniktikpakhimayunik aah kufiutilanginik nallautakgutaUVaktunik uvani 2018 havakhikhimayunik naunaitkutainit pikaktunik 19,294 nik nirgitinik, aah ikiklivalliavaktunik uvani 2015 ihiviukhinikmun naunaiyainikmun naunaitkutakanik pihimayunik havagiyauvaktunik ammihuakyuuknianik uvuna 38,592.

Havagiyauyunik upalungaiyaktuayunik mikharut katimadjutikhanik pilingnik Havakvit talvani Nunalikiyit, tahapkuat Kugluktuk Angoniaktit imalu Nanirgiaktukpaktunik Katimayit havagivakgainik aah ipiknakpaiktunik nunalingnik katimadjutaUVaktunik uvani Nikilikiviani 28, 2019. Tahamangnikmiutanik Kugluktuk havakhimayut aah hivungkiktukhanik mikharut 250 nik nirgitinik havakhiklutik havakhimayunik malikgakanik aah 1:1 atauhikaklugit avaatingnukpaktunik unguhulluk/unghulluk nallautakgutaUVaktunik hila malikhugu pinikmun angunahuaknikmun. Kanukgilidjutivaktunik nunalingni tahapkunani Angoniaktit Nanirgiaktukpaktunik Katimayit (HTO) pihimayunik ilihimaliktunik kauhimagjutaUVaktunik ikiklivalliavaliktunik tahapkunani Ahiak Kivatani tuktuttainik ammihuakyuiniklu, angunnahuaknikmun pidjutaUVaktuk huli nikikhakhiukpaktunik imalu amikhaakhiukpaktuniklu kakhakhiukpaktunik.

Talvani Kugluktuk Angoniatit Katimayit pivakhimayunik katimakatigikattaUVaktunik tahapkunani Kavamat Nunavut uvani Hikutilikvia 2, 2019 piyukhanik ukautiggiyauyukhanik ublumimut uvunalu hivunikgiyakhainiklu Tamatkiumayunik Angunnahuaktautaktunik Angunnahuaknikmun tuktutainik Ahiak Kivatani ammihuakyutainik. Tahapkuat Kavamat Nunavut pilutik havagiyaulutik uktutauyukhanik aah ikikliyumiklugit uvuna 340 nik nirgitinik tutkikhakhimayunik kangiktaulimaitunik ima 107 nik pungniiknik angunnahuaktaulutik kihimi tahapkununga pitkuihimayunik katimagamik tahapkuvalu NWMB uvani Ubluikvia 2019 katimadjutaUVayunik.

107 nik pungniiknik angunnahuaktaulutik kihimi hila maliklugu angunnahuaknikmun nirgitnik, takungnakhivaktunik kihimi ukiakhami nuyyukgaktinnagitlu. Ukallautigiyauvaktunik talvuna Hikutilikviani uvani 2 katimadjutauvaktunik mikharut angunnahuaknikmun tamangnik angnulluk imalu unguhulluk pidjutautaktunik pilugit angunnahuaktautaktunik, taimainakmut inungni ihaagiangnakmut nikitianik nikigivaktainik tamakpangangnut ukiumi; pidjutivakgainiklu havagivakgait huli amiit mikharut anurakhanik imalu kakhaniklu.

Tahapkuat HTO nipliutigihimayainik ihumalutigiyauvaktunik kanukgitunik havakhikhimayunik ikiikliyahimayunik atuktauvaktunik Ahiakmiutanik Kivatani tuktutainik TAH pilakilutik alauyuniklu ammihuakyuinik tuktunik alauyunitlu nirgitinik talvani Kugluktuk nunainilu (ilidjuhinitlu: Taryumi Kikiiktautainiklu tuktutainik; taktuuvak). Kanukgiliukpaktunik huli alauyunik nirgitinik angunnahuaktauvaktunik Kanukgiliukgutauvaktuniklu nirgitinik angunnahuaktaullakuyauvaktunik pidjutiyukhanik naudjutiyukhanik ikayutauyukhanik tuktutainik BNE taktu, kanukgilidjutihimayunik TAH pivakhimayunik 340; aah ikiikliyahimayunik TAH pidjutitaktunik aahikpaktiugit alauyunik nirgitiniklu.

Aah ammgaitunik tikuaktauvaktunik avaatingnukpaktunik nikikhakhiukpaktunik nirgitinik nirgitit havagiyauvaktukhanik. Tadja nunalingni havakatauvaktunik mikharut amagoit niakuinik katitiktavaktunik manikhakhautigiplugit havagiyauvaktunik tadja tahapkunanga Havakvit Nunalikiyit. Talvanganit tahapkunani havagiyauliktunik uvani ukiumi 2018/19, 101 nik amagonik angunnahuaktauvaktunik. Tahapkununa kufiutilanginik kilaminuak ammigaikhimayunik pidjutaugumik havakhikhimagumik \$300/ihiviuktauyukhanik. Angunnahuakpaktunik ukaalukhimayunik mikharut akikhautikhanik piyauyukhanik akittukyumiayuyukhanik, tahapkuatlu pidjutivakniaktugulluit angunnahuakpaktukhauyugulluit amagokhiukpakniakgulluaktutlu pidjutivakhimayut taimani 101 nik angunnahuaktauvakhimayunik pidjutivaktukhanik angunnahuaktauvaktukhaniklu.

Atuktauvaktunik pitkuhiktukpaktunik huli ilihimadjutiugit mikharut akhaait ammgaiyumivaliktunik, pivaktunik ammgaitunik takuvaktunik akhaanik akhaakgiaktunik, akhaakgiakpaktunik imalu talimanik akhaakalikpaktuniklu, ilanginik aktikikyukilikpaktunik maamainit.

Tahapkununa Ahiak Kivatani Tuktunik Munakgiyauyukhanik Havagiyauyukhanik Pangnattauyunik pihimayunik ilihimayauvaktunik tuniyauvaktunik uvani Imakguktiviani 2019; pihimayunik aah kiuyauvaktunik piyukhanik havakatigiktukhanik panaarinitlu havaktukhanik nutanguktigiyukhanik pangnattauyukhanik havakatigiktiaklutiklu. Talvanganit talvuna, tahapkuat HTO pidjutivakhimayunik katimakatauvaktunik tahapkunani Kavamat Nunavut ammgaitukhutik havakatigikpaktunik imalu pivalialiktunik tutkikhaivalialiktunik kanuk angiutauvaktunik.

Tahapkuat HTO havakhimakpaktunik huli havakatigivakgait tahapkuanik Havakvit Nunalikiyit mikharut munakgiyauyukhanik havagiyauyukhanik imalu ihiviukhinikmun naunaiyainikmun naunaitkutakhanik katitiktavaktunik.

Ikiikliyahimayunik havakhikhimayunik tahapkununa TAH taimailiukgumayunik 107 nik pangniiknik kihimi pipkaihunguyuk pilaakilutinilu aah ayuuknakhihunguyuk ihuigutivalialutik nauvalliavaktunik huli inugiangnianik nunalingni. Inuyunik ihaagiahutiggivakgaat atuktaulluakpaktuk kihimi nikigilluakpagaat nikitianik, pidjutitkiyumikpaktuk kihimi inuhikgingnaktuk nirgiyaulluakpaktunik.

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THANK YOU
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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

Jan Adamczewski¹, John Boulanger², Heather Sayine-Crawford¹, John Nishi³, Dean Cluff¹,
Judy Williams¹, and Lisa-Marie LeClerc⁴

¹ Environment and Natural Resources, Government of Northwest Territories

² Integrated Ecological Research, Nelson, BC

³ EcoBorealis Consulting Inc., Millarville, AB

⁴ Department of Environment, Government of Nunavut

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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 Gachokù, 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.

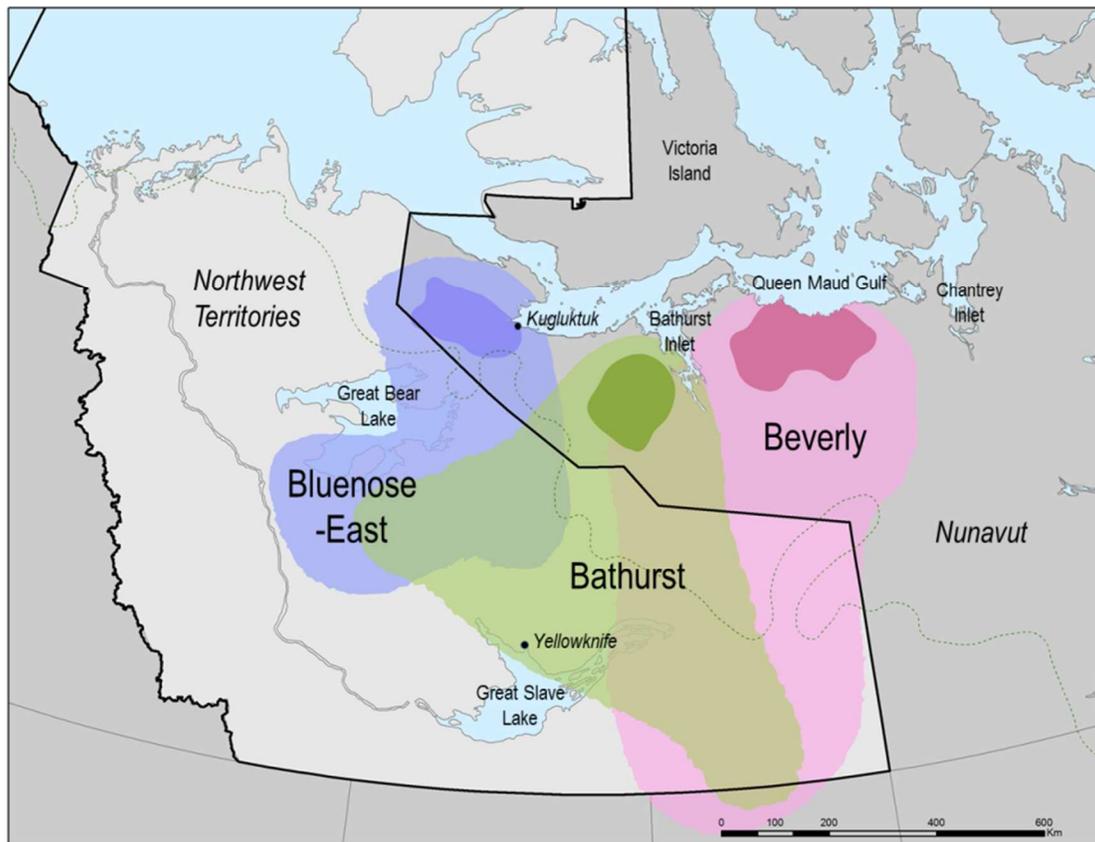


Figure 2: Annual ranges and calving grounds of the Bluenose-East, Bathurst, and Beverly¹ herds, based on accumulated radio collar locations of cows (Nagy et al. 2011). Other herd ranges west and east of these three herds were omitted for simplicity.

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).

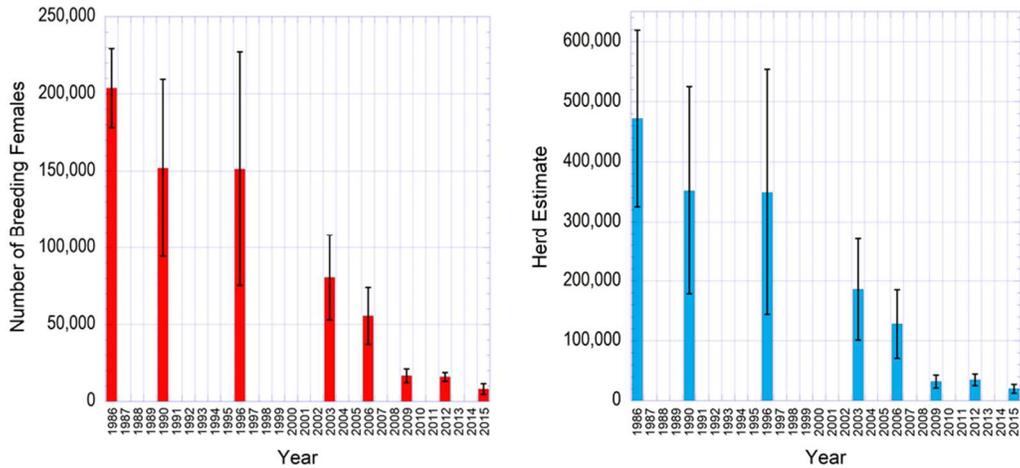


Figure 3: Estimates of breeding females on the left (red) and extrapolated herd size on the right (blue) from 1986-2015, based on calving ground photo surveys of the Bathurst caribou herd. Estimates are shown with 95% Confidence Intervals.

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).

Survey Details

XXXX 0-0 3
Tsect Column-Row Waypoint

Total Adult Count: Not Recorded 2nd Count: NR

Observed By: Not Recorded
Primary Secondary Both

Species: BGCA X

Observer L/R: Not Recorded
Left Both Right

Transect: On Transect
ON Transect OFF Transect

GPS offline

Date	Time
12/12/2012	10:27:38 AM
Latitude	Longitude
0	0
Altitude (ASL)	Bearing
0	0
Air Speed	
0	

ADDITIONAL DETAILS

Caribou Classification: U Antler Status

HA NA YL CF CC BL UNK
Antlered Non-Antler Yearling Calf Cow Calf Bull Unknown

Counts: 0 0 0 0 0 0 0

Caribou Comment: Add Comment X

Percent Snow Cover: Not Recorded
0% 25% 50% 75% 100%

Percent Cloud Cover: Not Recorded Fog: No
0% 25% 50% 75% 100% Y N

Comment: Add Comment X

Change Transect Details / EXIT SURVEY DETAILS

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 km²). 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.

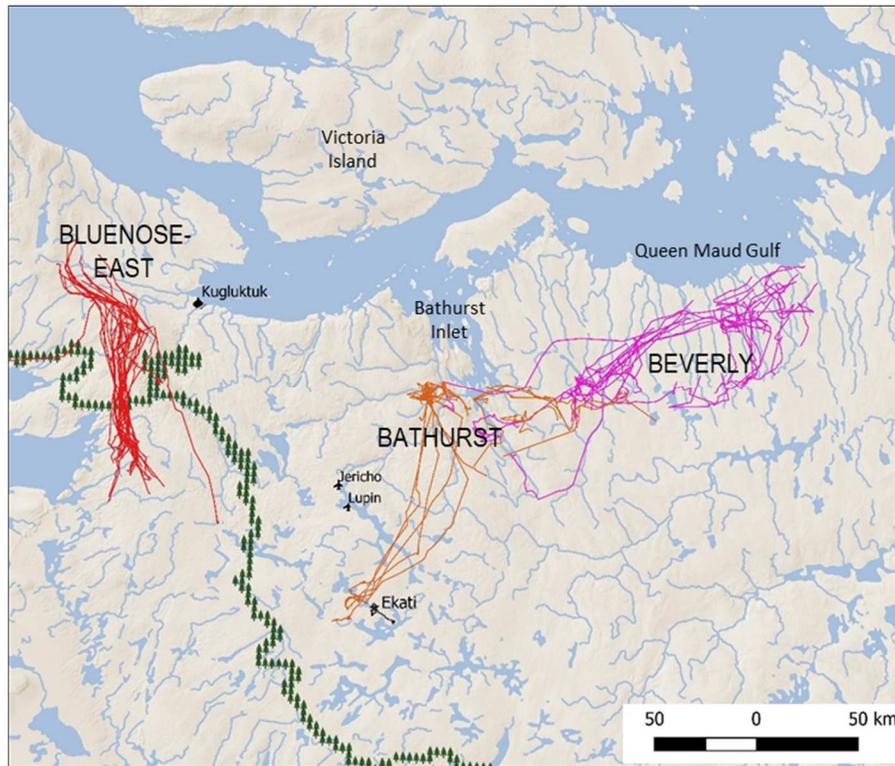


Figure 5: The northward paths of collared females (May 15 - June 11, 2018) from the Bluenose-East (red), Bathurst (orange), and Beverly (violet) caribou herds to their 2018 calving grounds.

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 (\bar{D}) of caribou observed within the strata ($\hat{N} = \bar{D}A$) where density is estimated as the sum of all caribou counted on transect divided by the total area of transect

sampling (\bar{D} =caribou counted/total transect area). An equivalent estimate of mean density can be derived by first estimating transect-specific densities of caribou ($\hat{D}_i = \text{caribou}_i / \text{area}_i$) 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 (\bar{D}) for the stratum. More exactly, $\bar{D} = \sum_i^n \hat{D}_i w_i / \sum_i^n w_i$ 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 ($w_i = l_i / \bar{l}_i$) 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 ($\hat{N} = \bar{D}A$) (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 score² 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 (\hat{c}) 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 $\sim < 50$ 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.

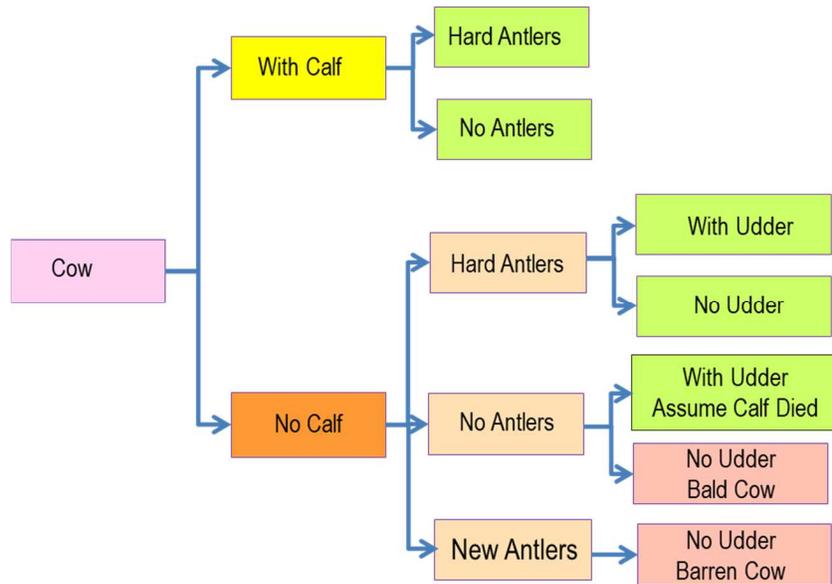


Figure 7: Classification of females used in composition survey of Bathurst caribou in June 2018. Green-shaded boxes were all classified as breeding females (diagram adapted from Gunn et al. 1997). Udder observation refers to a distended udder in a cow that has given birth. Hard antlers are from the previous 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 $\lambda=1$ then a population is stable; values $>$ or <1 indicate increasing and declining populations. The rate of decline was also estimated as $1-\lambda$.

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.

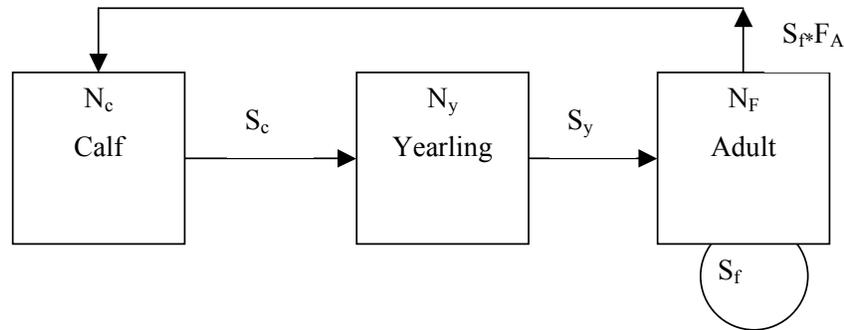


Figure 8: Underlying stage matrix life history diagram for the caribou demographic model used for Bathurst caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates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

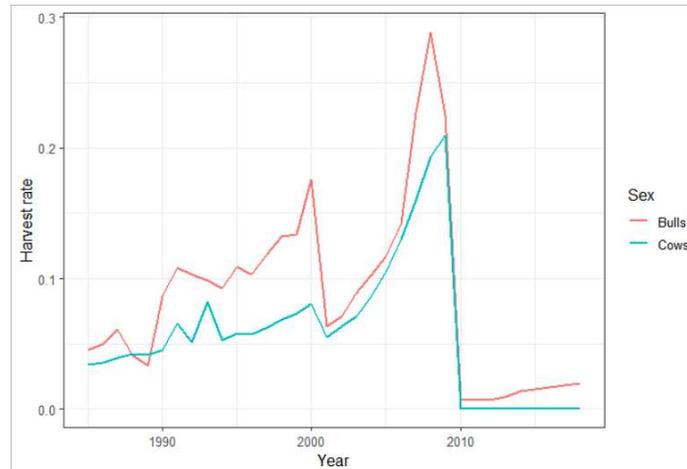


Figure 9: Harvest rates used as inputs into the demographic model. See Appendix 2 for actual harvest numbers and rates used in the model.

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.

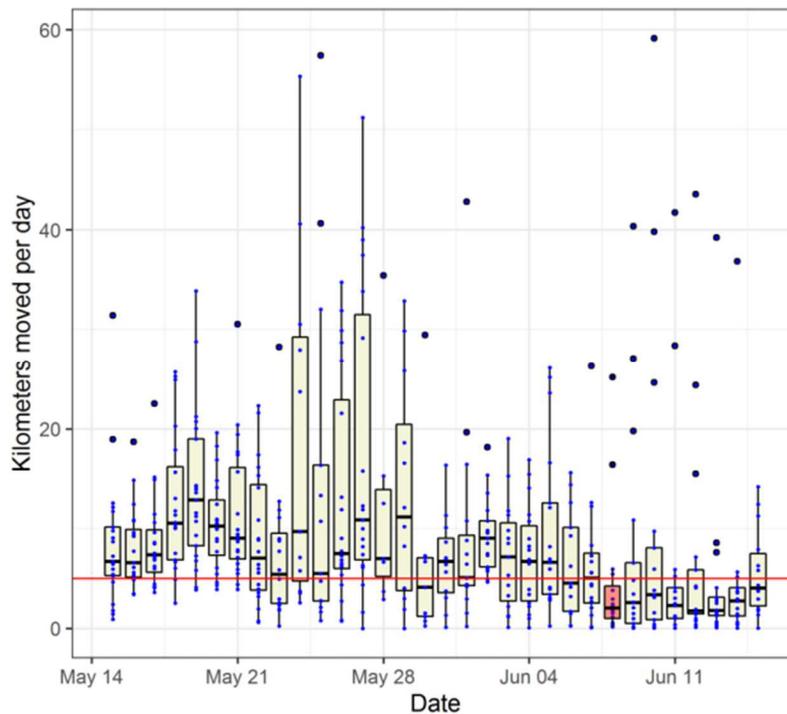


Figure 11: Movement rates of female collared caribou (n=17) on or around the Bathurst calving ground before and during calving in June 2018. The boxplots contain the 25th and 75th percentile of the data with the median shown by the central bar in each plot. The ranges up to the 95th percentile are depicted 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).

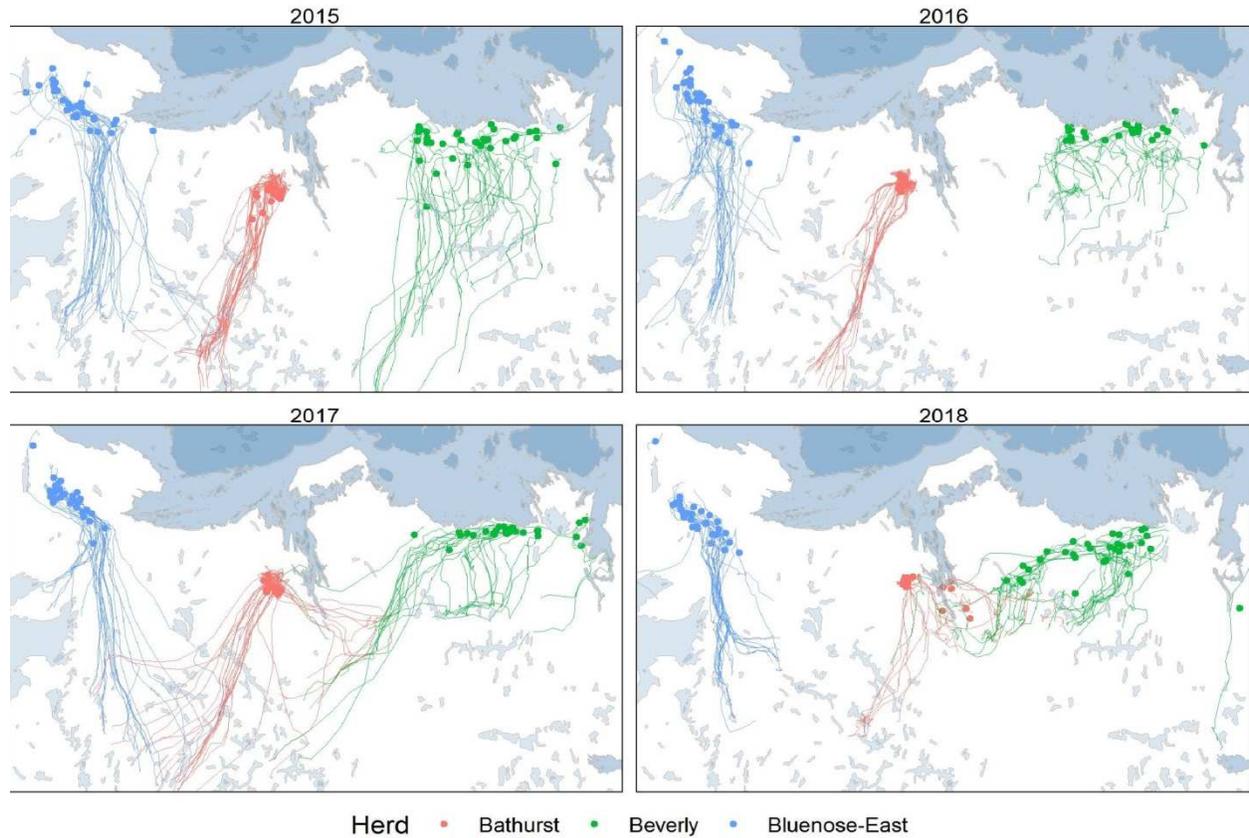


Figure 12: Spring migration paths of collared females from the Bluenose-East (blue), Bathurst (red) and Beverly (green) herds in 2015, 2016, 2017 and 2018 May 1 - June 10 of each year. The circles represent mean collared locations in the first two weeks of June for each year. Note that in June 2018 three 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.

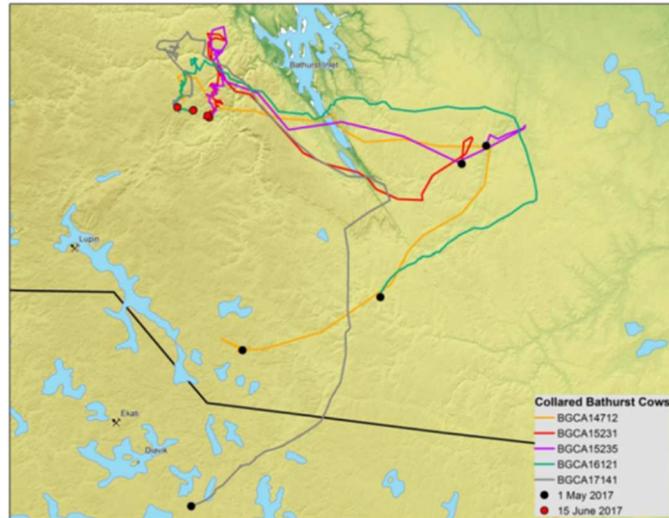


Figure 13: Spring migration paths of five collared Bathurst cows May 1 - June 15, 2017. All five cows were known to have been on the traditional Bathurst calving ground in June 2016. All wintered on the tundra and three wintered south or east of Bathurst Inlet with Beverly collared cows. Beverly collars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

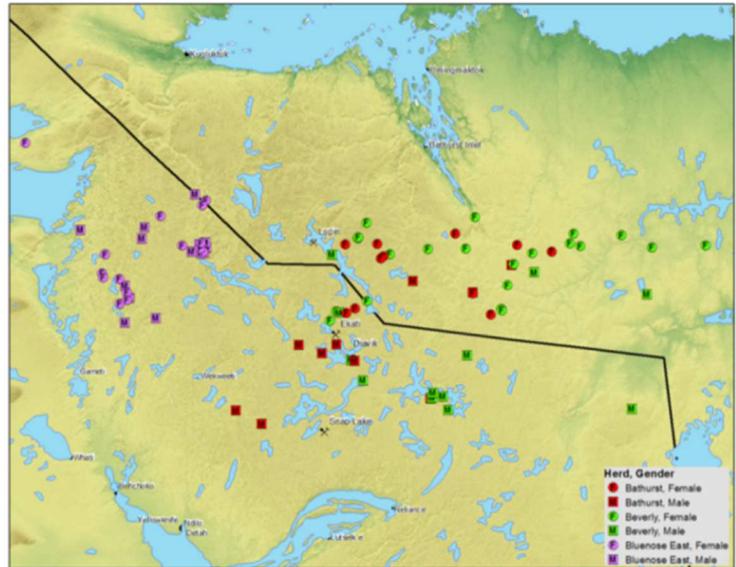


Figure 14: Winter locations (March 15, 2018) of Bluenose-East collared cows (18) and bulls (18) in purple, Bathurst cows (10) and bulls (10) in red, and Beverly cows (23) and bulls (12). The Bathurst and Beverly herds were mixed throughout winter 2017-2018.

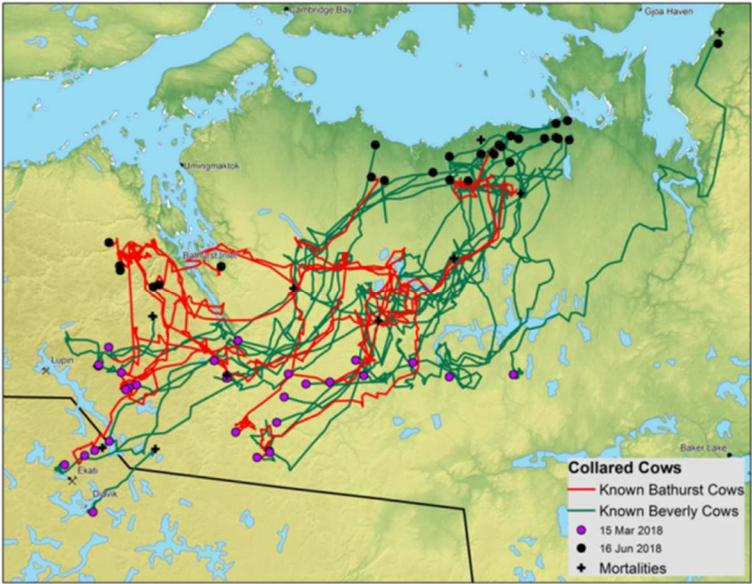


Figure 15a: Spring migration paths northward March 15 - June 16, 2018 of 11 known Bathurst collared cows (red) and 19 known Beverly cows (green). Purple dots are March 15 locations and indicative of wintering areas; black dots are June 16 locations.

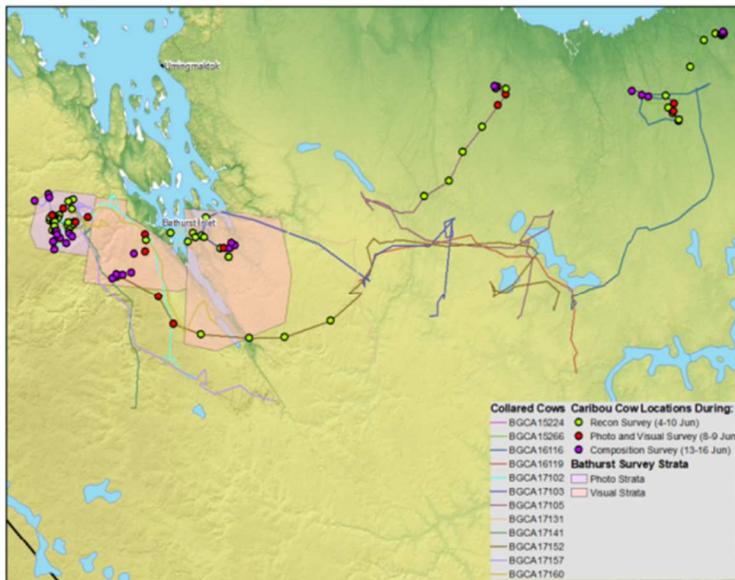


Figure 15b: Spring migration paths May 1 - June 16, 2018 of 11 known Bathurst collared cows, in relation to June 2018 Bathurst calving ground survey area. Eight collared Bathurst cows were within the Bathurst strata during the survey, while three were in the Queen Maud Gulf coastal calving area. Beverly 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.

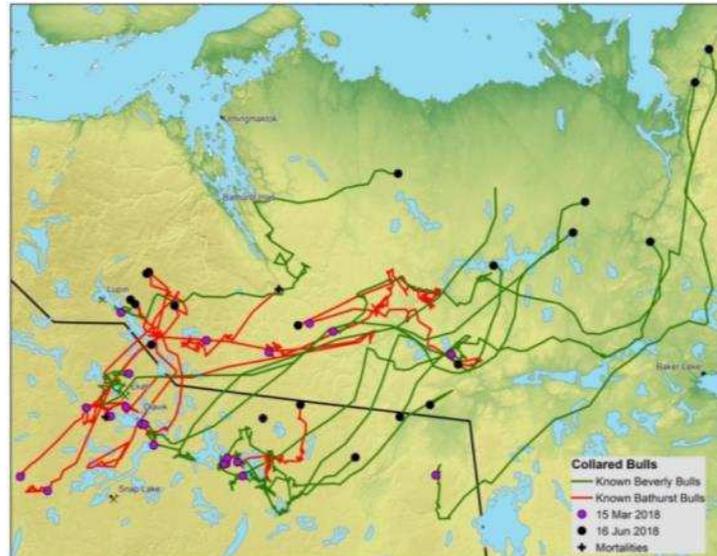


Figure 16: Spring movements (March 15 - June 16) of eight known Bathurst collared bulls and 11 known Beverly collared bulls in 2018.

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.

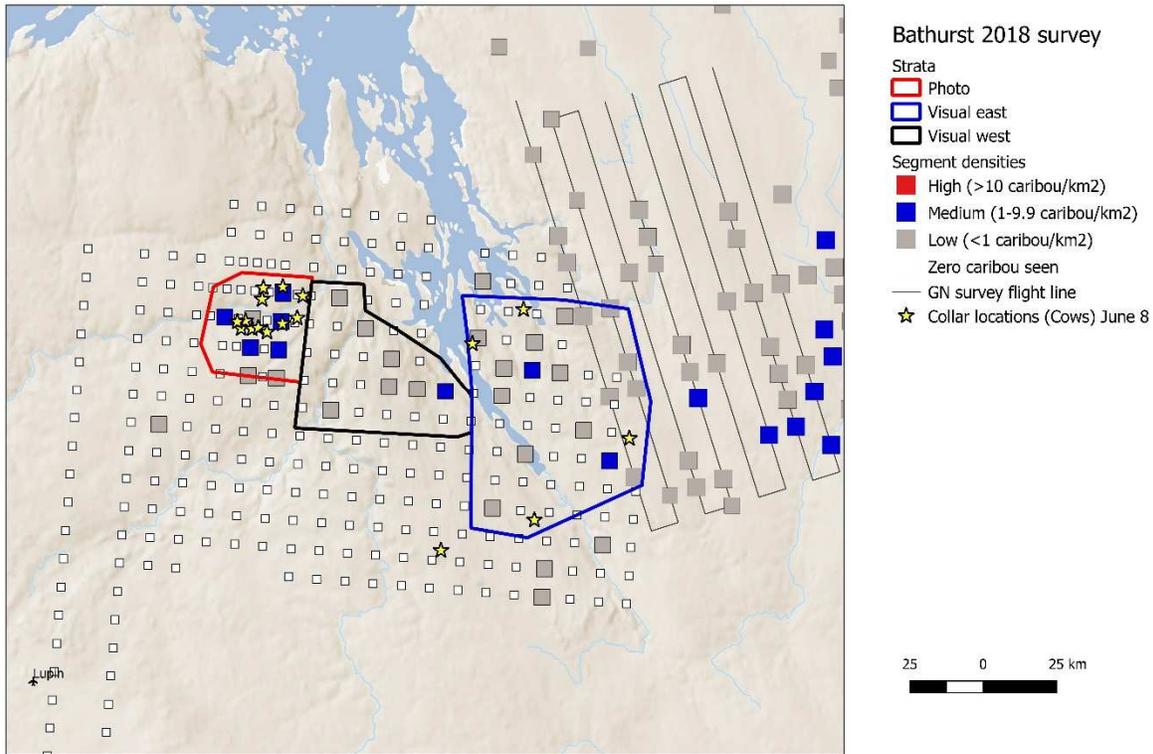


Figure 17a: Reconnaissance survey of the Bathurst calving ground in June 2018 with densities of caribou seen. White squares are from areas where no caribou were seen, grey squares are from low-density areas (< 1 caribou/km²), and blue squares are from medium density areas (1-9.9 caribou/km²). Gold stars 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.

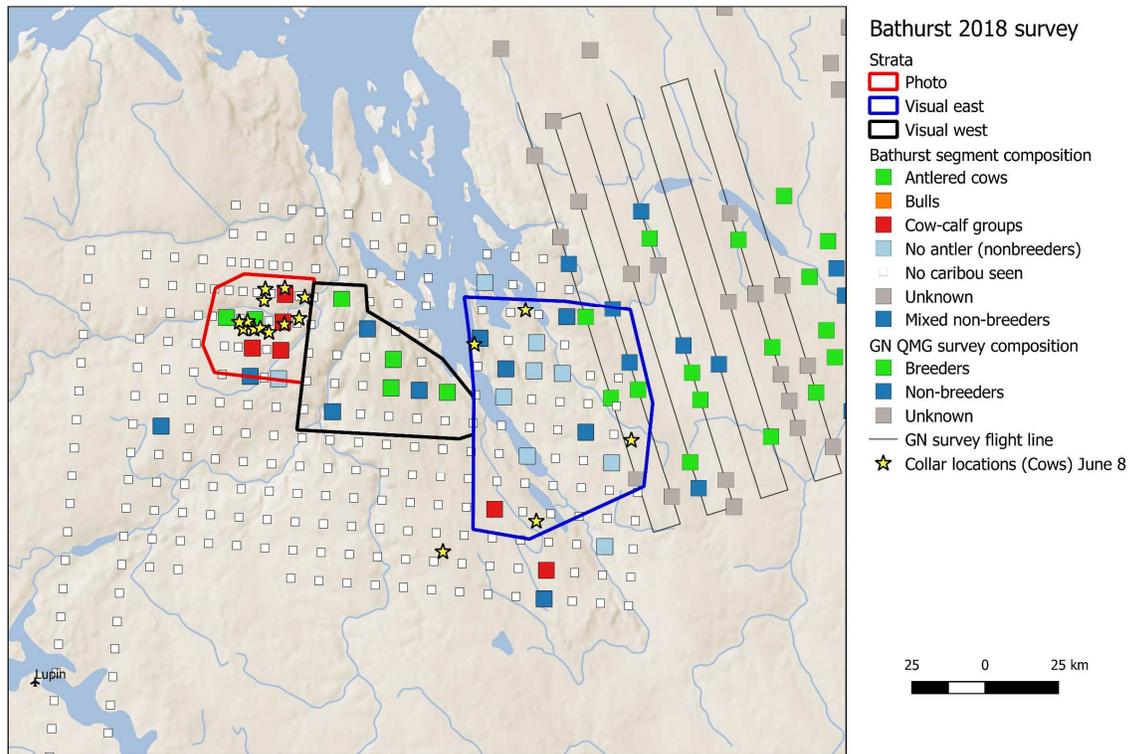


Figure 17b: Reconnaissance survey of the Bathurst calving ground in June 2018 with composition of caribou seen. Areas with cow-calf groups are red, areas with antlered cows are light green, and areas with non-breeders (non-breeding cows, bulls and yearlings) are blue. Gold stars are collared female caribou. 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/km² 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 (km²)	Average Strip width (km)	Transect area (km²)	Coverage
Photo	27	15	1,227.3	1.29 ^A	682.7	56%
West	12	12	2,305.6	0.8	368.3	16%
Visual						
East	18	18	4,661.9	0.8	824.5	18%
Visual						

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.

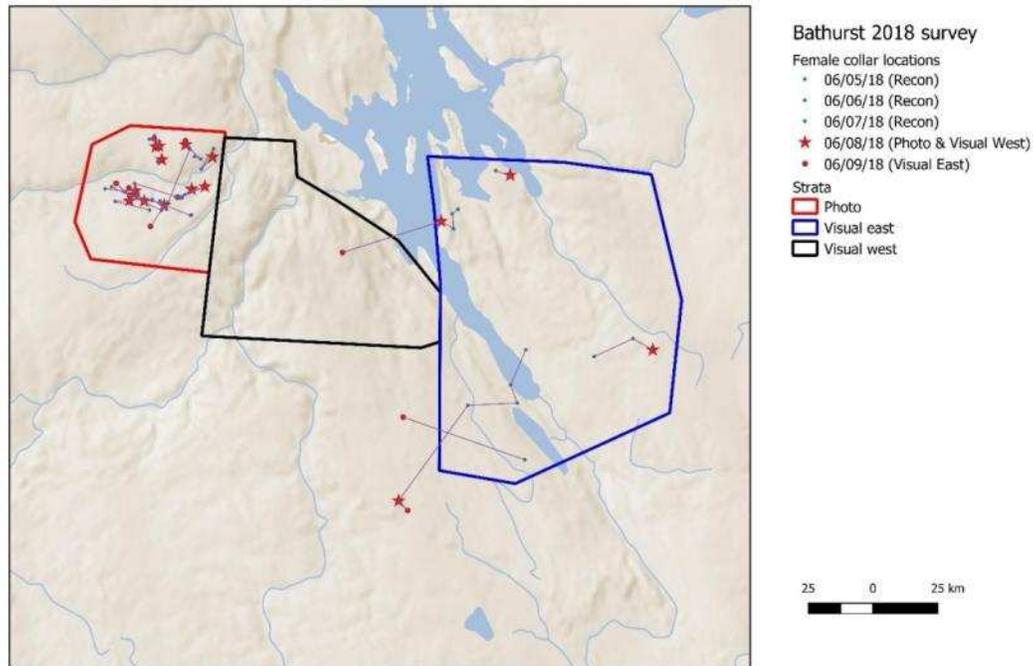


Figure 19: Locations of collared Bathurst female caribou and movements from the reconnaissance phase (June 5-7), photo survey (June 8th) and visual survey of the east stratum on June 9th. One collar near the south end of the Visual East block did not report a location on June 8, so no star is shown.

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).

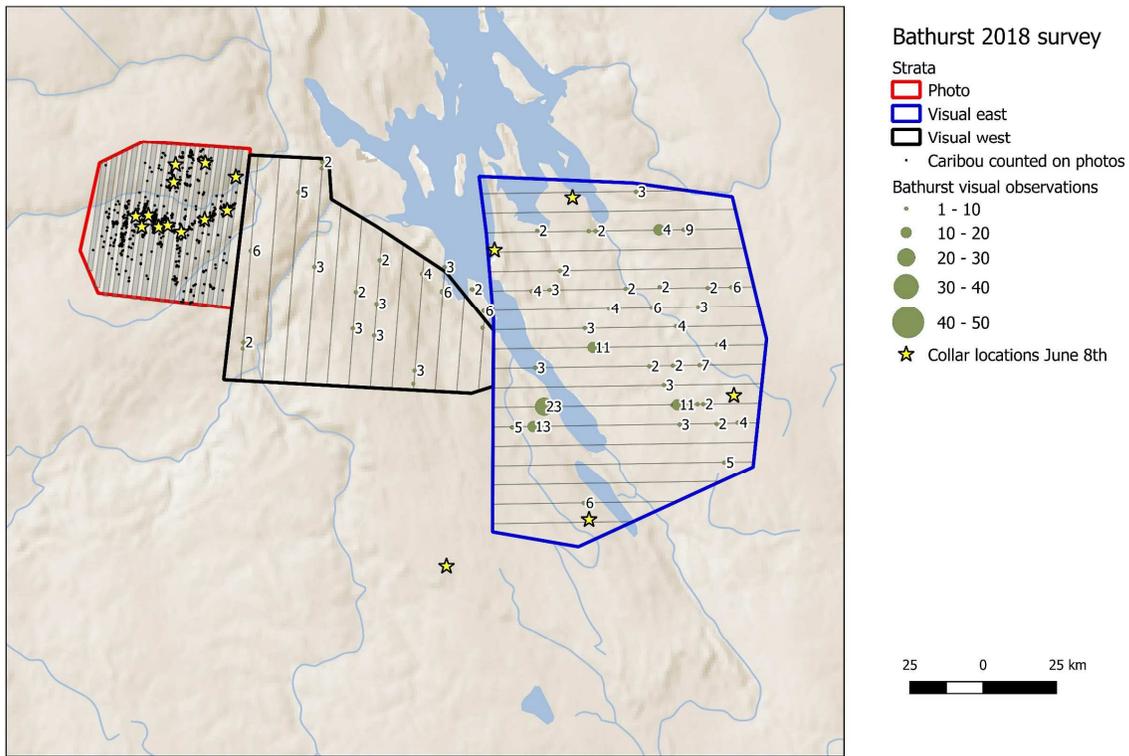


Figure 20: Map of Bathurst June 2018 survey blocks showing the locations of caribou groups seen in the photo block from photos and in the visual blocks from observations June 8 and 9. Relative group sizes for the visual blocks are shown as varying sizes of circles, but not for the groups seen in the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

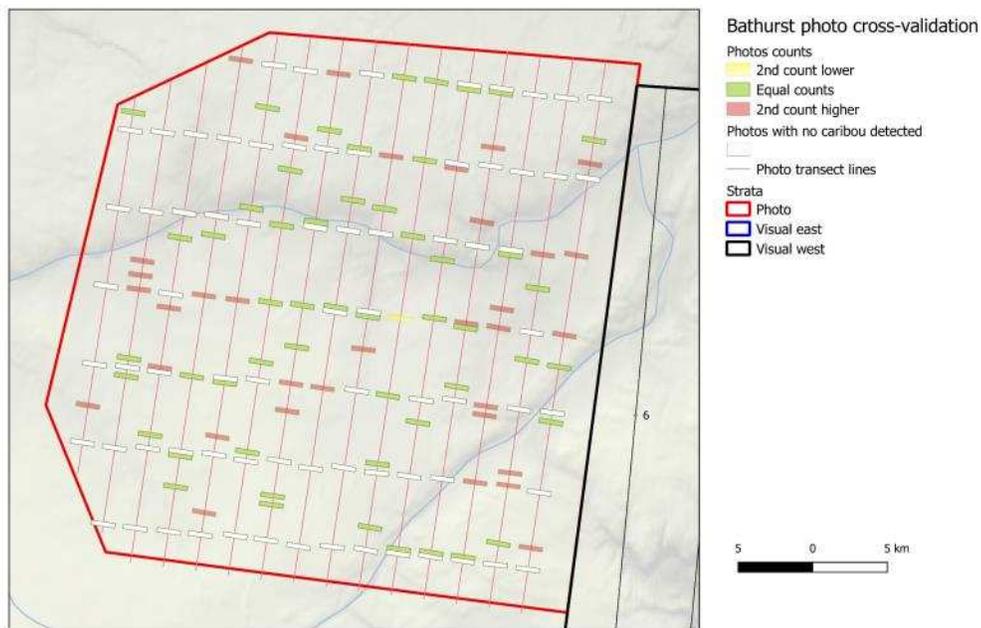


Figure 22: Systematic sampling design for cross validation of photos for the Bathurst June 2018 calving ground survey.

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 counted	Standard estimate			Double observer corrected estimate				
		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).

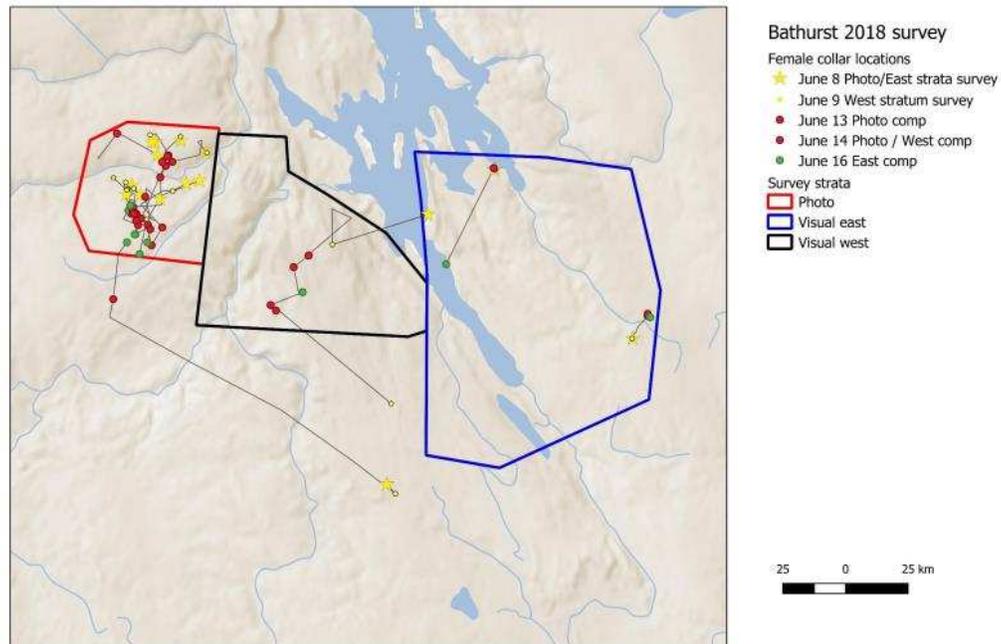


Figure 23: Locations of collared females between the dates of the Bathurst photo and visual strata flown June 8 and 9, and the composition survey flown June 13-16.

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.

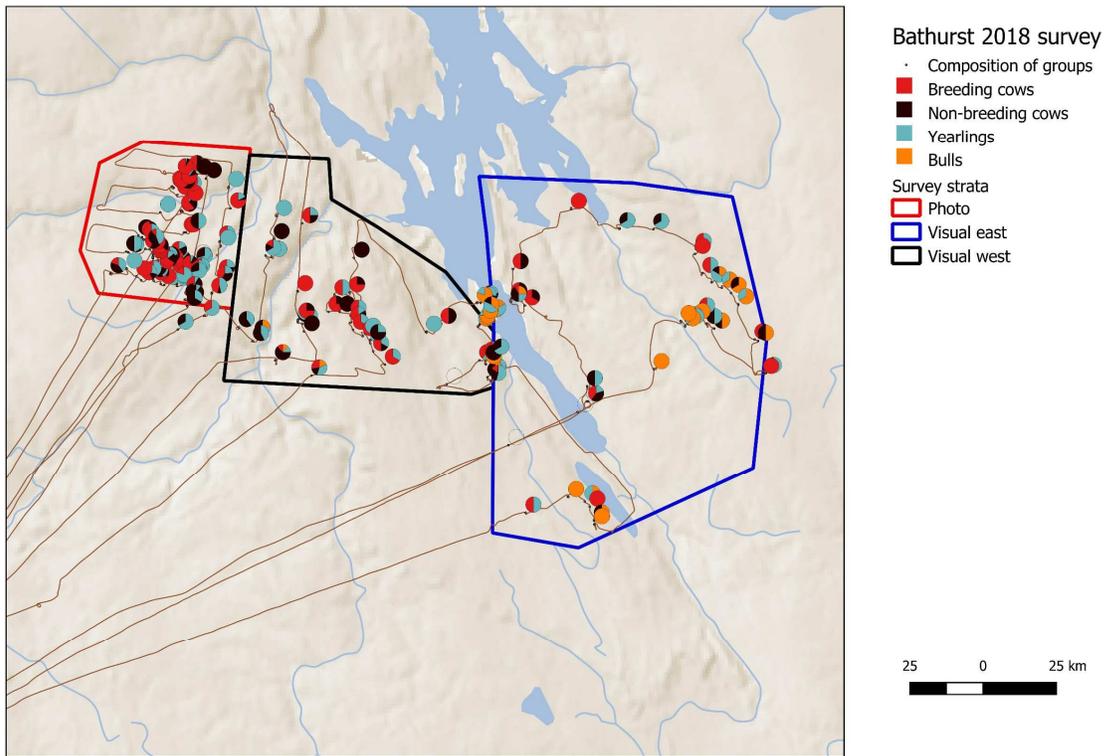


Figure 24: Helicopter flight paths and caribou groups classified during calving ground composition survey of Bathurst caribou, June 13-16, 2018. The size of the pie charts is proportionate to the number of caribou classified in a group. Proportions of age-sex classes make up the individual pie sections.

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 $\pm t^*SE$) 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		CV	
				Traditional CI			
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%).

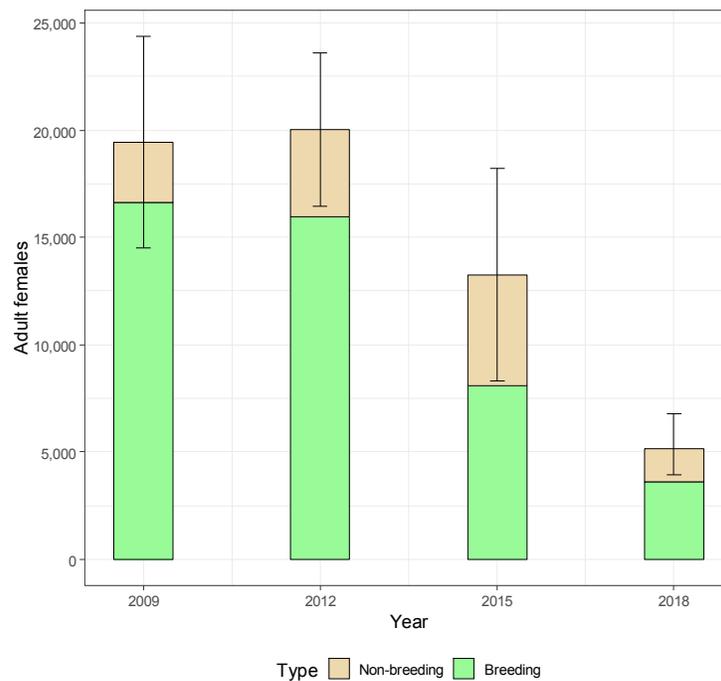


Figure 25: Estimates of the number of breeding females (green), non-breeding females (light brown) and adult females (summed bars) in the Bathurst herd 2010-2018.

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 ($\log \lambda$) 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).

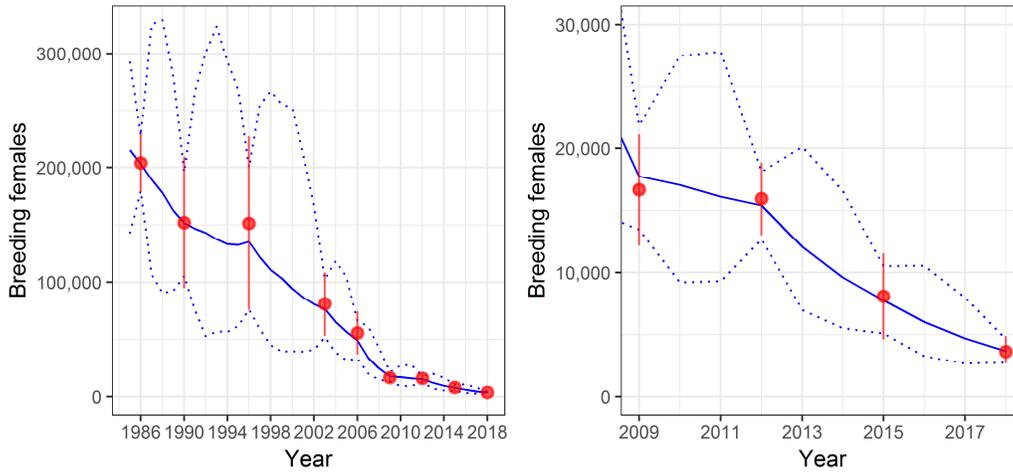


Figure 26: Trends in Bathurst breeding females 1986-2018, as estimated by the Bayesian state space model. The left graph is for the full extent of the data set and the right graph is zoomed into the period of 2009-2018. Field estimates are given as red dots (with confidence limits) and model predictions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

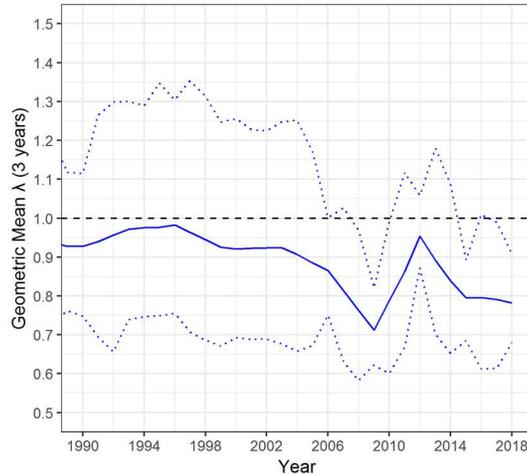


Figure 27: Estimate of λ for Bathurst breeding females 1989-2018, as estimated by the Bayesian space model analysis. Model predictions are shown as blue lines with confidence intervals as hashed lines. A λ of 1.0 indicates a stable population.

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).

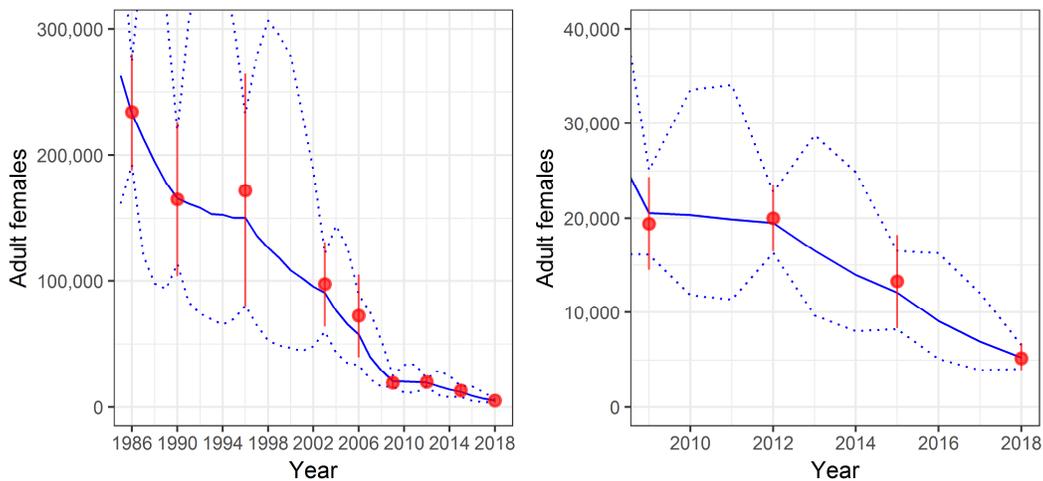


Figure 28: Trends in numbers of adult Bathurst females 1986-2018, as estimated by the Bayesian state space model. The left graph is for the full extent of the data set and the right graph is zoomed into the period of 2009-2018. Field estimates are given as red dots (with confidence limits) and model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

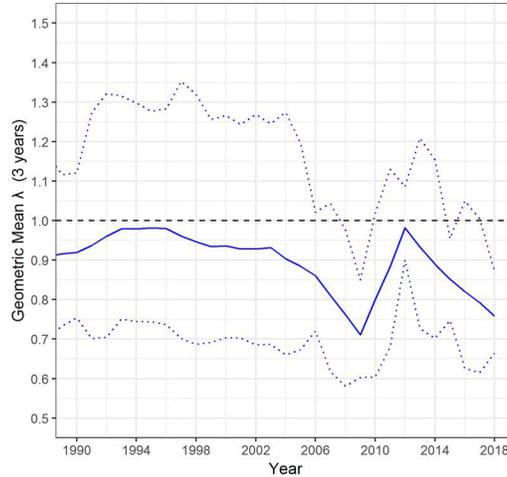


Figure 29: Estimates of λ for adult Bathurst females 1989-2018, as estimated by the Bayesian state space model. Model predictions are shown as blue lines with confidence intervals as hashed lines. A λ of 1.0 indicates a stable population.

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.

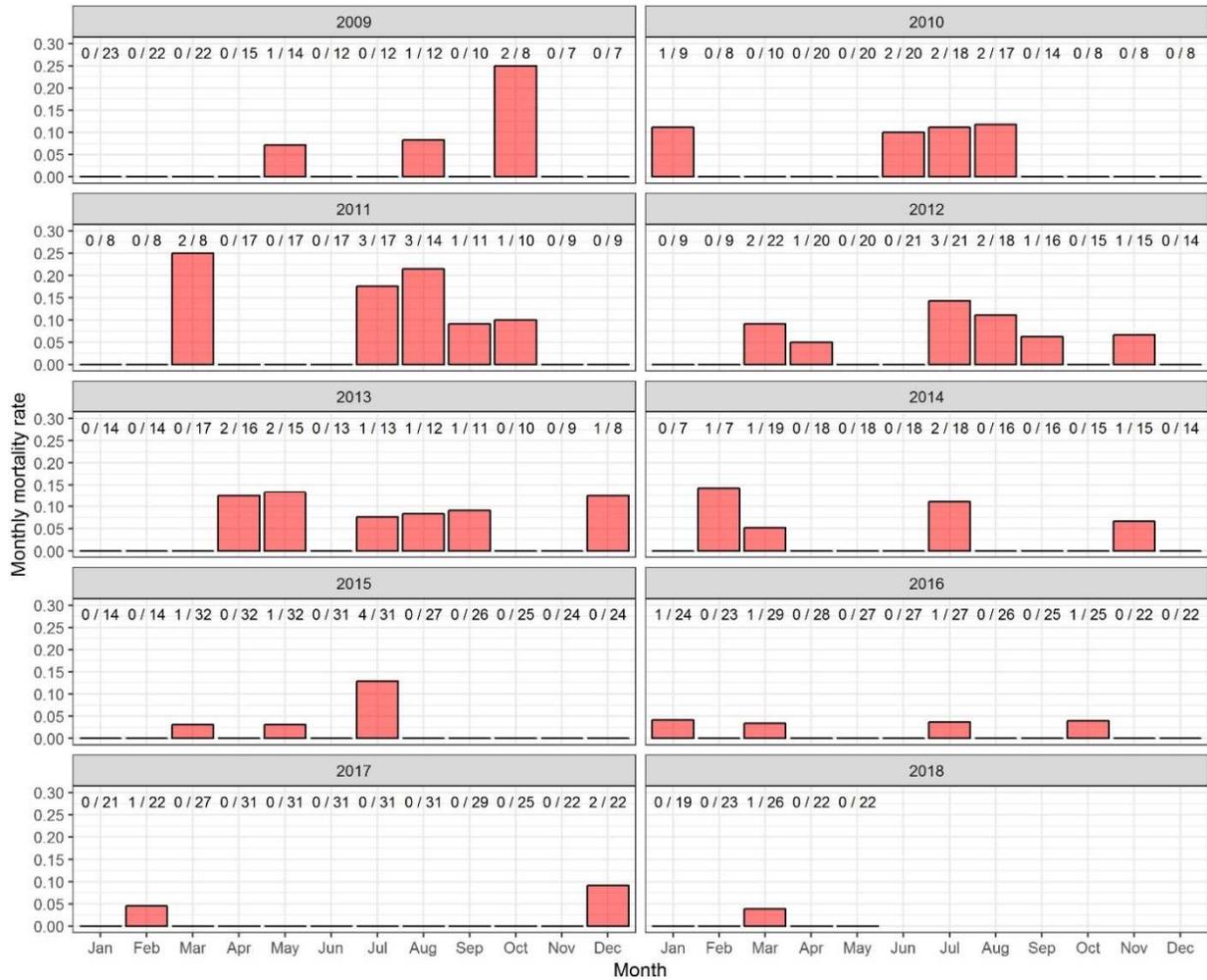


Figure 30: Summary of monthly collared cow mortality data for Bathurst herd 2009-2018. Individual collar histories for recent years (i.e. since 2016) are given in Appendix 2.

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.

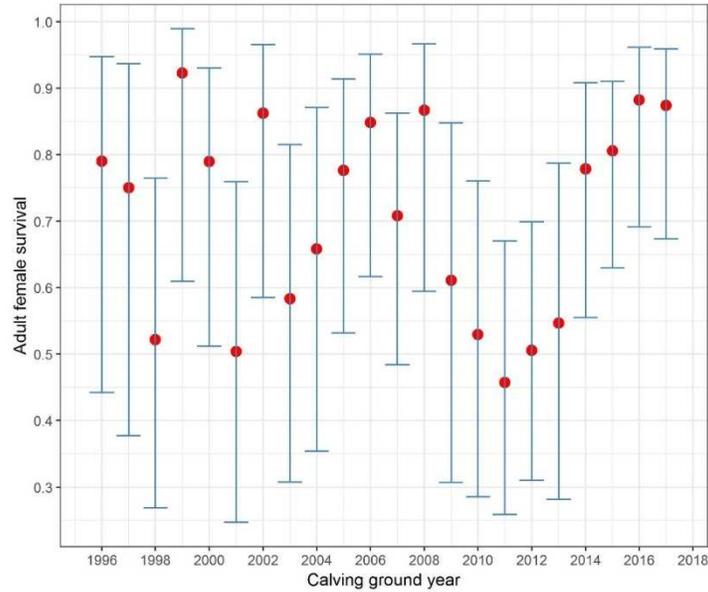


Figure 31: Annual survival rate estimates 1996-2018 for Bathurst adult females based on collared female caribou.

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.

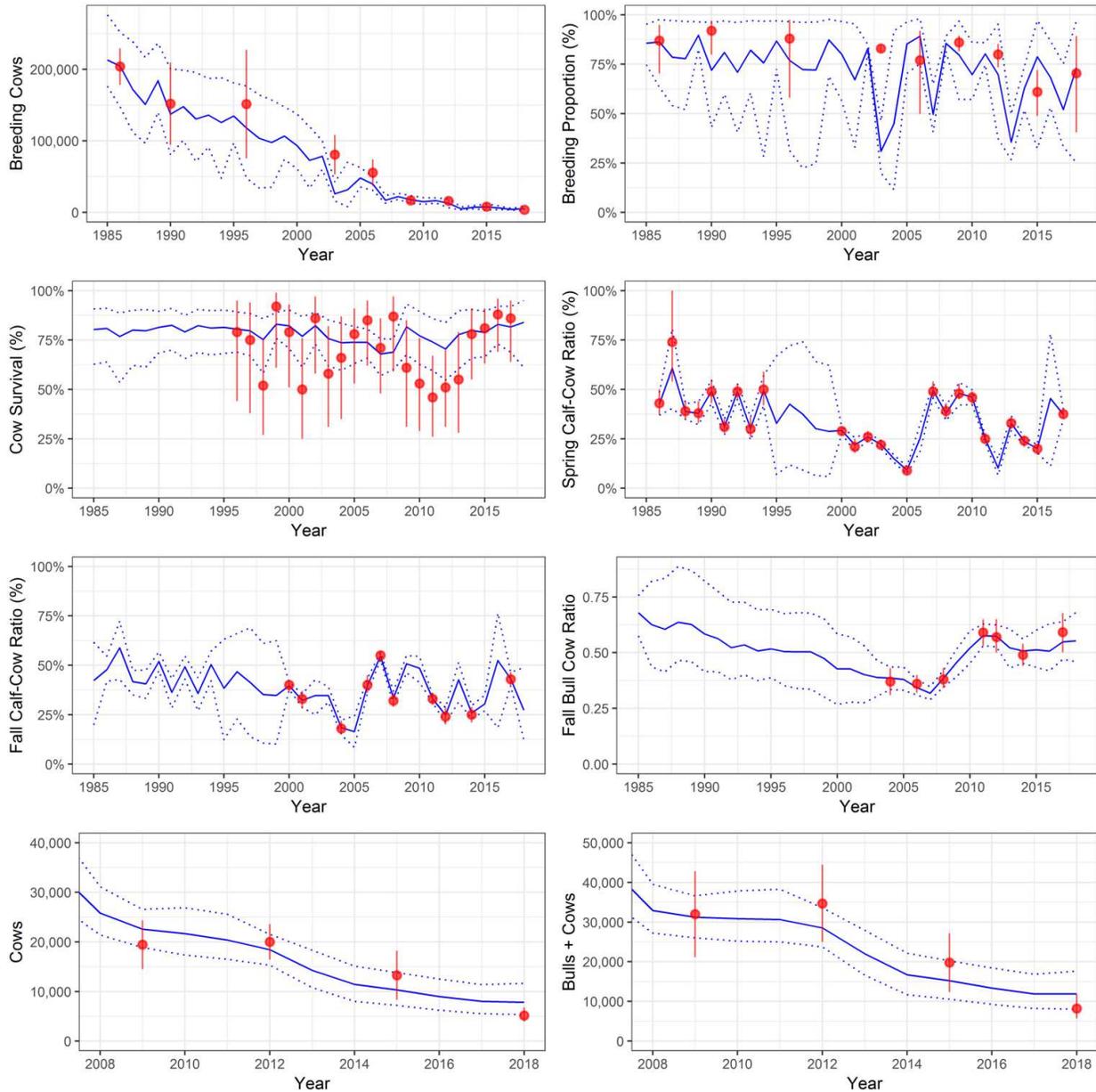


Figure 32: Predictions of demographic indicators from Bayesian model analysis compared to observed values, for Bathurst herd 1985-2018. The solid blue lines represent model predictions and confidence limits are shown as hashed blue lines. The red points are field estimates with associated confidence 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.

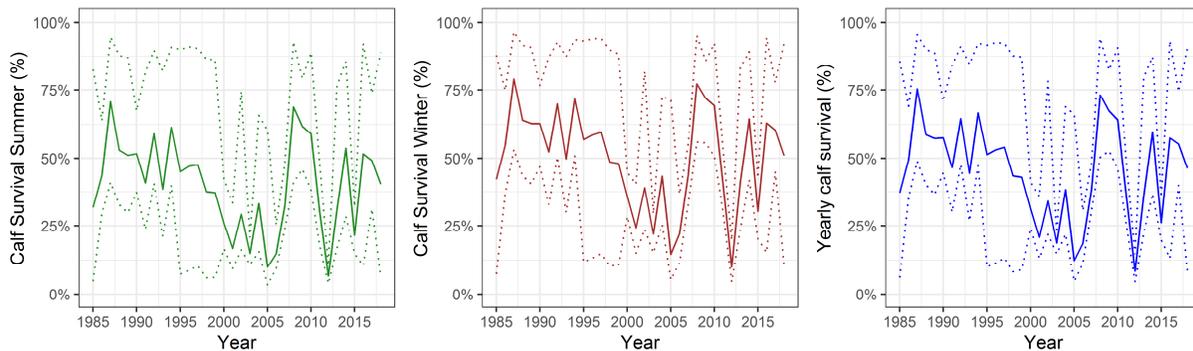


Figure 33: Trends in model-based summer and winter and overall calf survival for the Bathurst herd 1985-2018.

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.

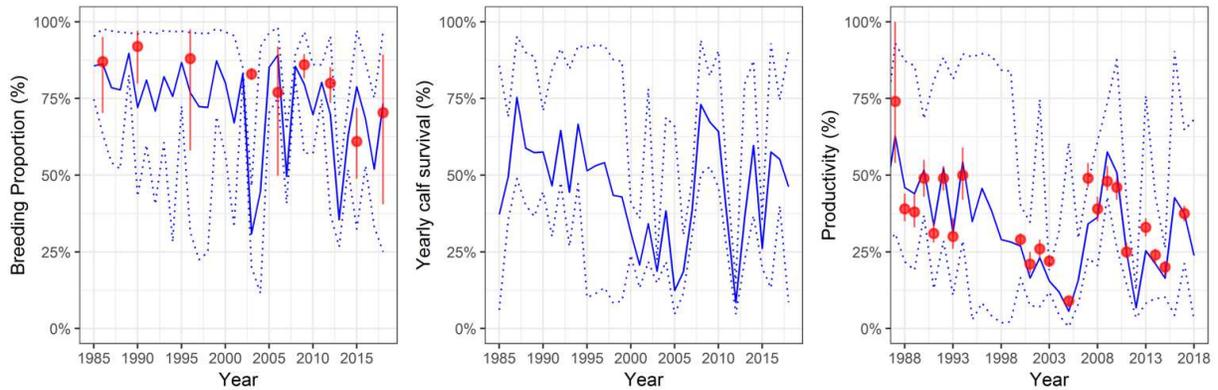


Figure 34: Trends in a) fecundity, b) annual calf survival and c) productivity (which is the product of the previous year’s fecundity times the current year calf survival) for Bathurst herd 1985-2018. Spring calf cow ratios, which are lagged by one year, so that they correspond to the productivity/caribou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

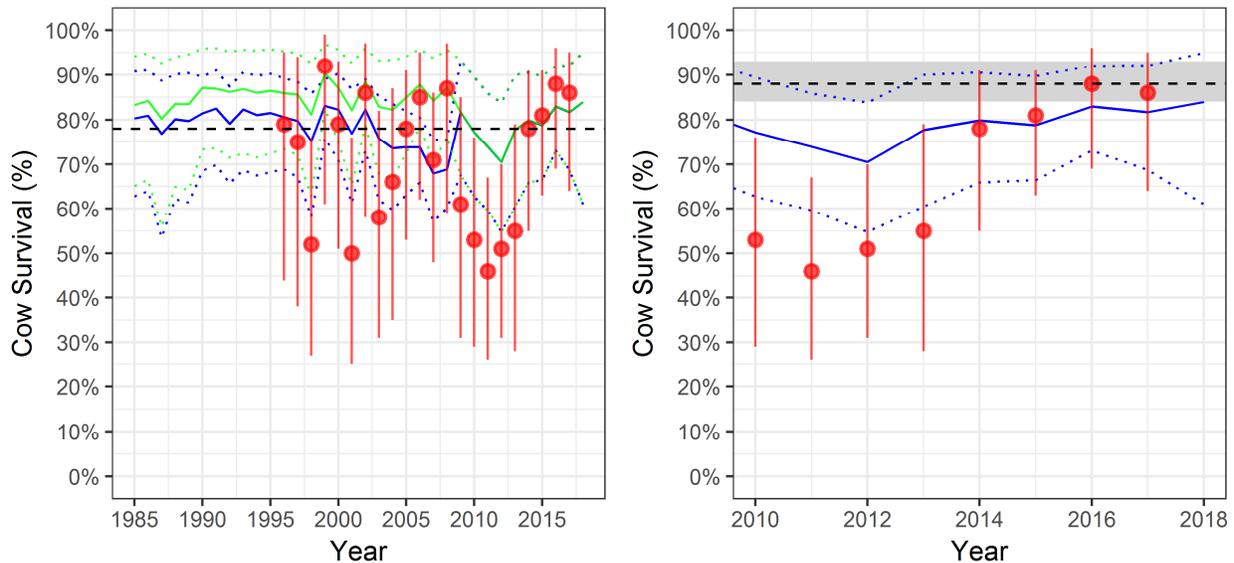


Figure 35: Trends in Bathurst cow survival 1985-2018 from Bayesian IPM analysis and collars. The solid blue lines represent model predictions and confidence limits are the hashed blue lines. A) The left graph shows the full time series with model estimates of survival denoted by blue lines, and “natural 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.

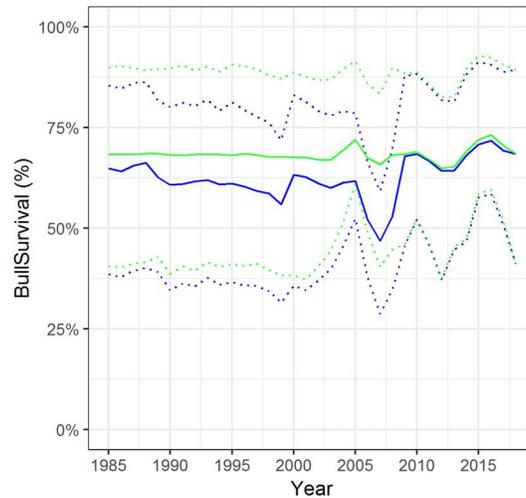


Figure 36: Estimates of bull survival for the Bathurst herd 1985-2018. The blue line represents observed survival whereas the green line represents natural survival with harvest mortality removed. Because harvest was very low 2010-2018, observed and natural mortality were similar.

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.

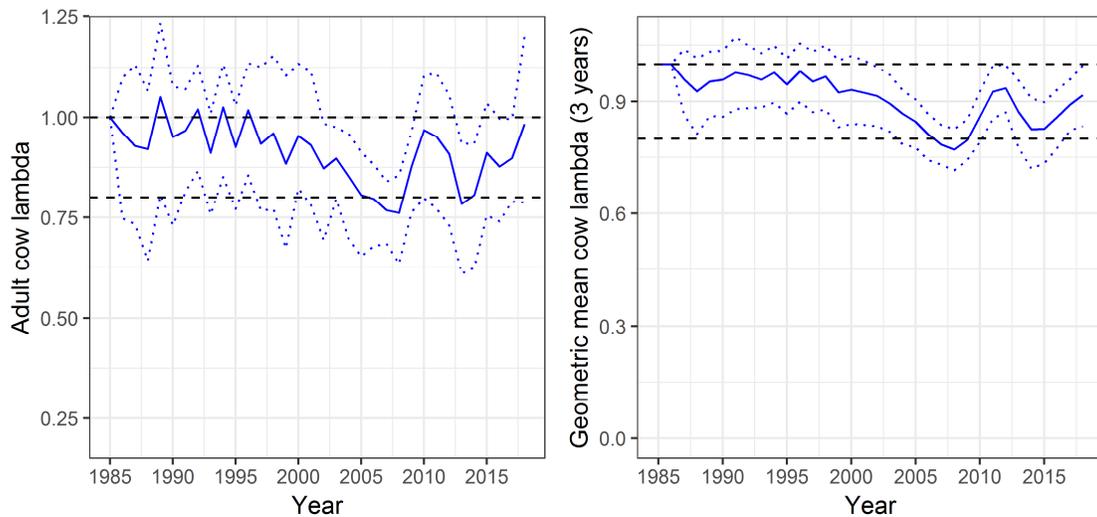


Figure 37: Overall trends (λ) in adult cows in the Bathurst herd 1985-2018 from the Bayesian model analysis. A value of 1.0 indicates stability.

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.

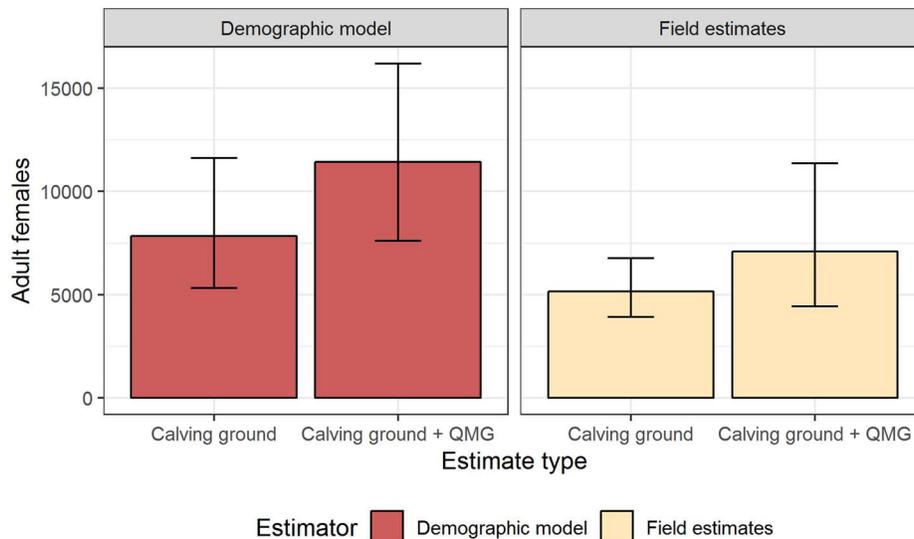


Figure 38: Field and model-based estimates of adult females on the Bathurst calving ground compared to estimates that were adjusted to include Bathurst females that calved on the Queen Maud Gulf coast calving area in 2018. Field estimates include the base estimate of adult females, and the base estimate 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.

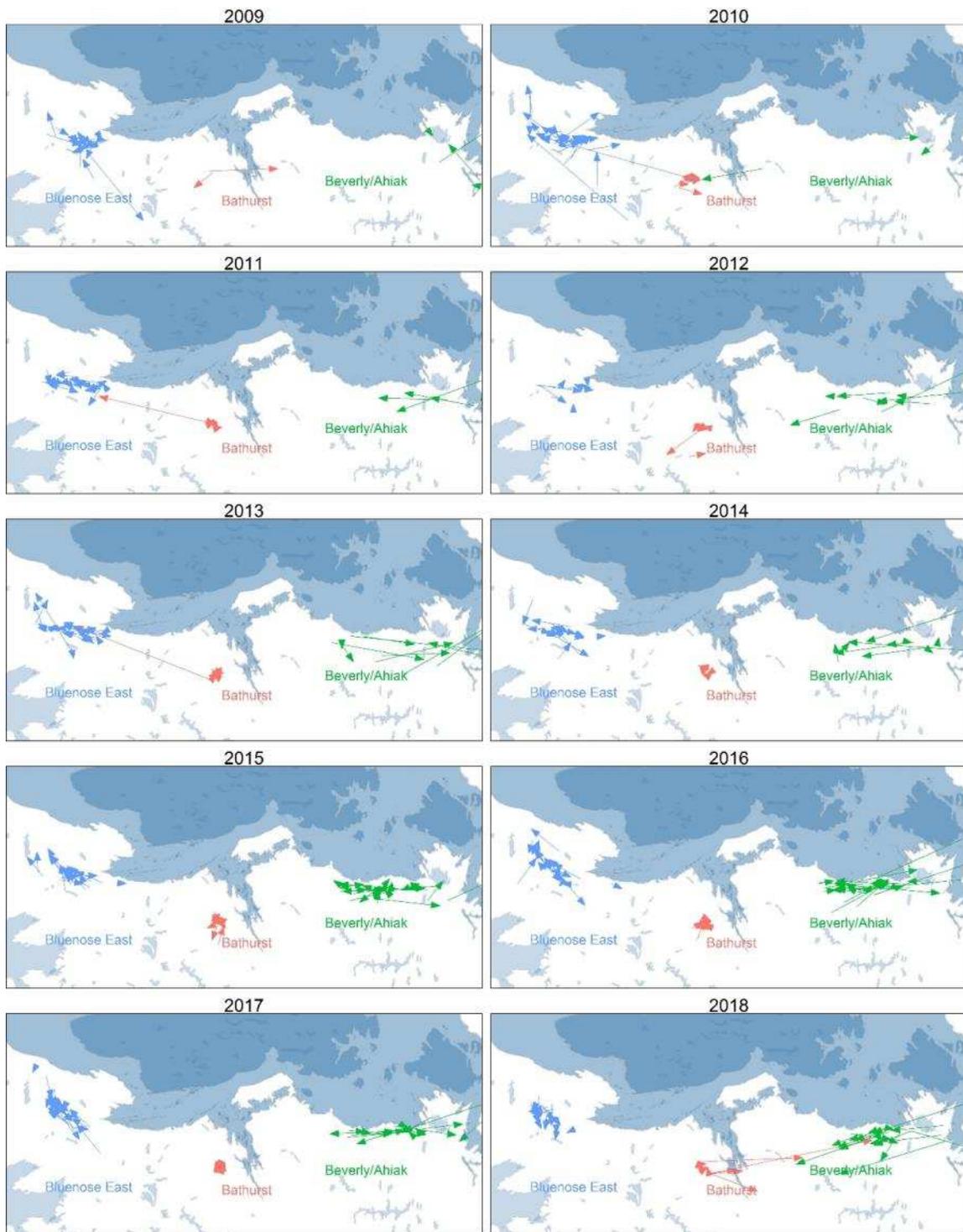


Figure 39: Yearly fidelity and movements to calving grounds in the Bluenose East (blue), Bathurst (red), and Beverly (green) herds 2009-2018. The head of the arrow indicates the current calving ground in the given year and the tail indicates the mean location from the previous year calving ground.

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).

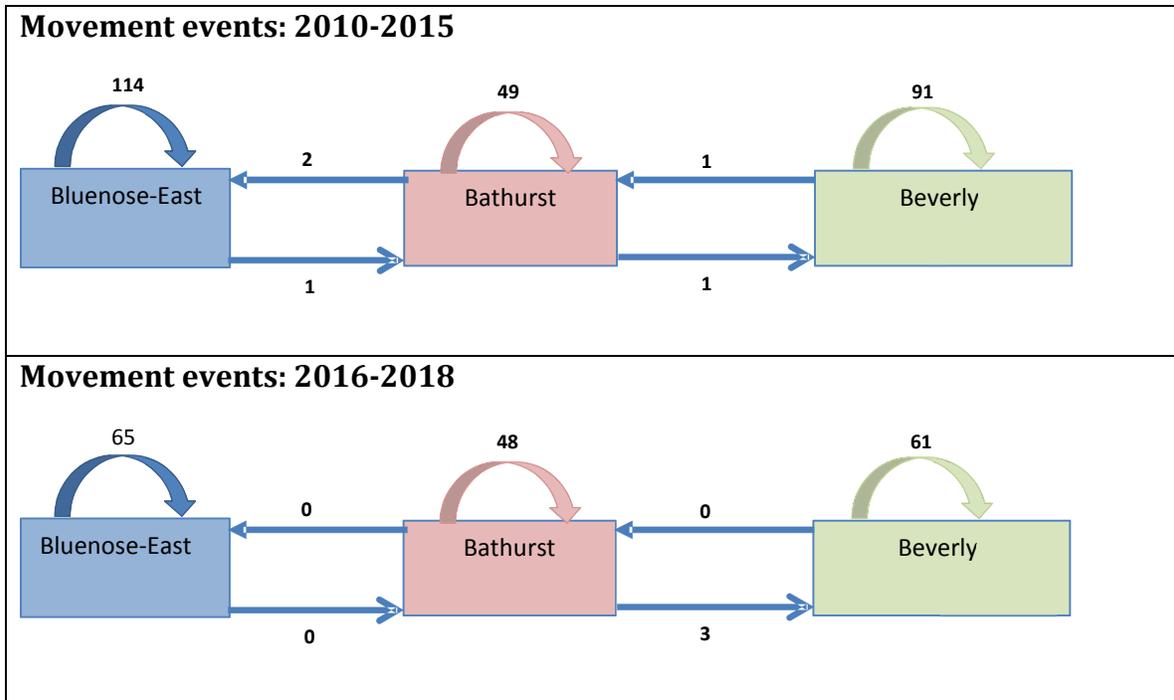


Figure 40: Frequencies of collared caribou movement events for the Bathurst and neighbouring Bluenose-East and Beverly herds 2010-2015 and 2016-2018 based on consecutive June locations. The curved arrows above the boxes indicated the number of times a caribou returned to the same calving ground in successive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

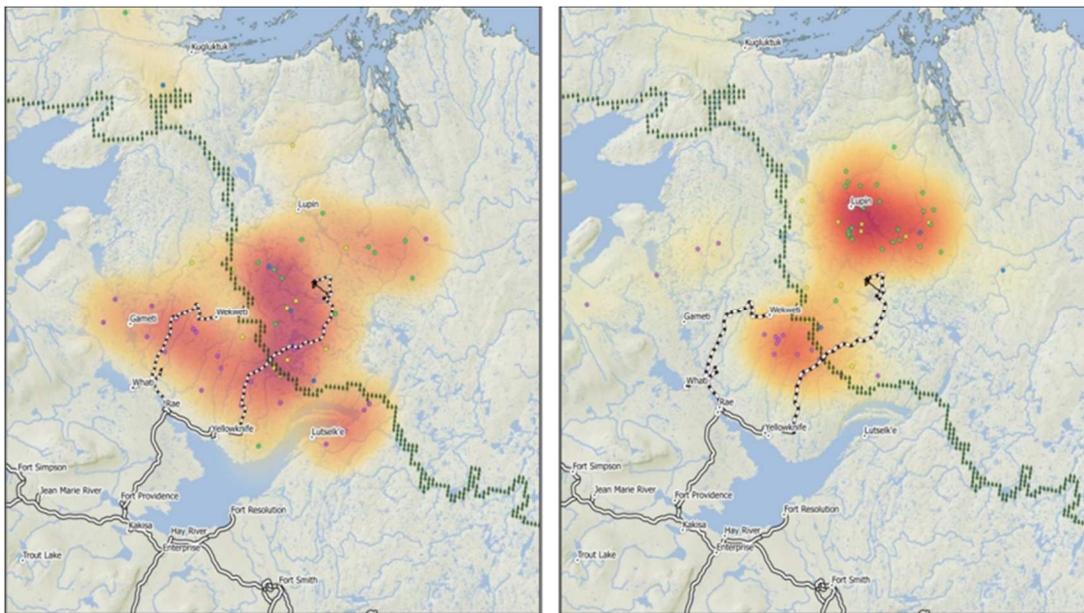


Figure 41: Relative likelihood of mortality in collared Bathurst female caribou shown as a “heat map” for 1996-2009 (left) and 2010-2016 (right). Darker colours (orange and red) indicate areas with an above-average probability of mortality, and lighter areas (yellow) indicate areas with a below-average 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 Tłıchǫ Government and GNWT ENR submitted joint management proposals for each herd to the Wek'èezhì 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 Tłıchǫ 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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PERSONAL COMMUNICATIONS

Mitch Campbell, Regional Biologist, Government of Nunavut, Department of Environment, Arviat, NU.

Derek Fisher, President, Greenlink Forestry Inc., Edmonton, AB.

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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 Kugluktuk 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.

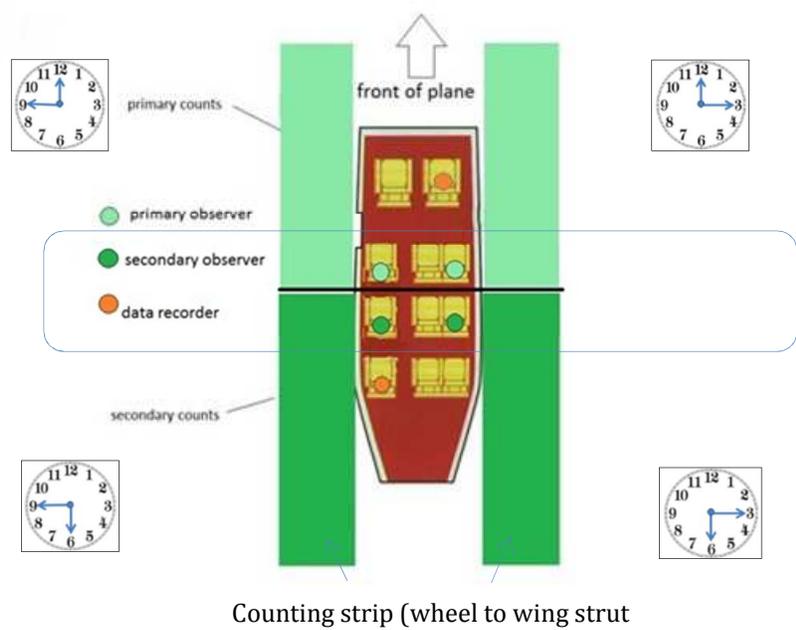


Figure 1: Observer and recorder positions for double observer methods on June 2018 caribou survey of Bathurst caribou. The secondary observer confirmed or called caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can 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
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	1	8	17	36	0.69	0.91
7	5	did not switch	1	17	48	79	0.82	0.97
8	6		1	19	46	83	0.78	0.95
9	6		1	20	38	75	0.77	0.95
10	7		1	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		2	3	20	43	0.53	0.78
14	9		5	1	7	13	0.62	0.85
15	9		2	18	42	80	0.75	0.94
16	9	pooled with 9	1	0	0	1	0.00	0.00
17	10		1	3	16	33	0.58	0.82
18	10		1	3	0	4	0.75	0.94
19	11	did not switch	1	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

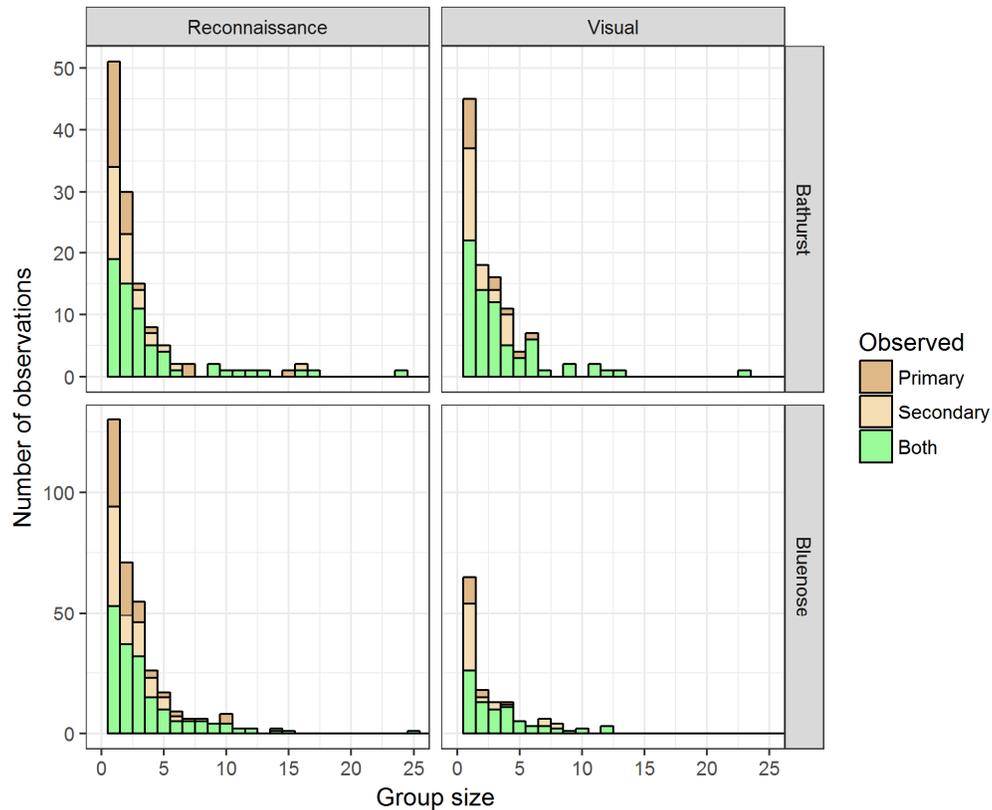


Figure 2: Frequencies of double observer observations by group size, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

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.

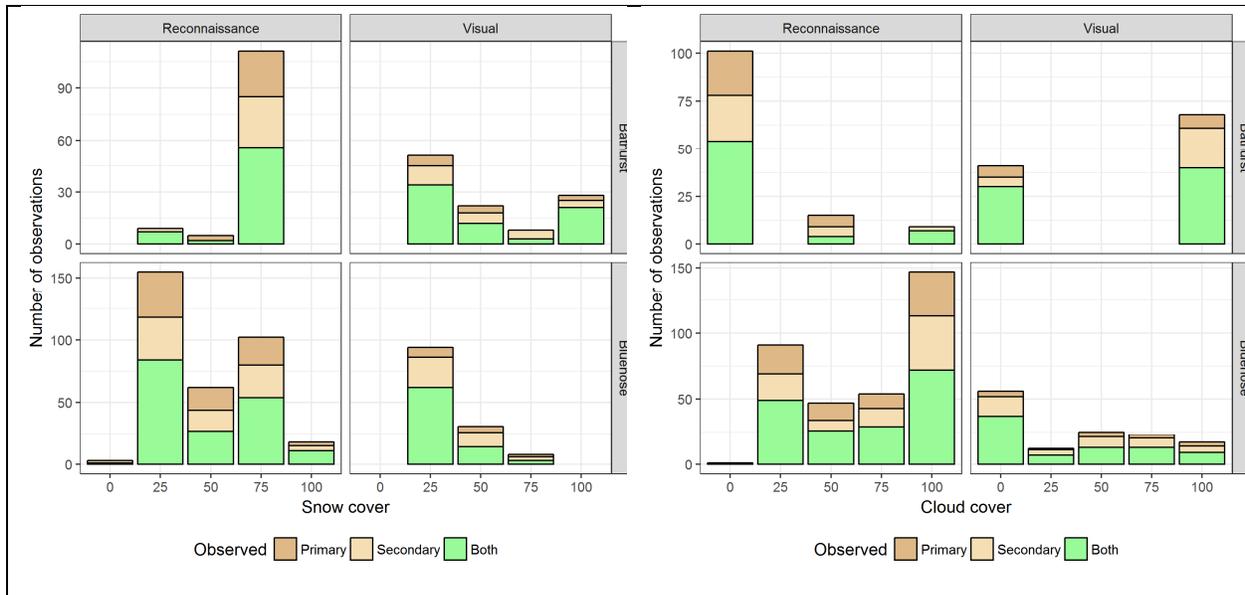


Figure 3: Frequencies of double observer observations by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation was categorized by whether it was observed by the primary, secondary, or both observers.

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	AIC _c	ΔAIC_c	w_i	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.

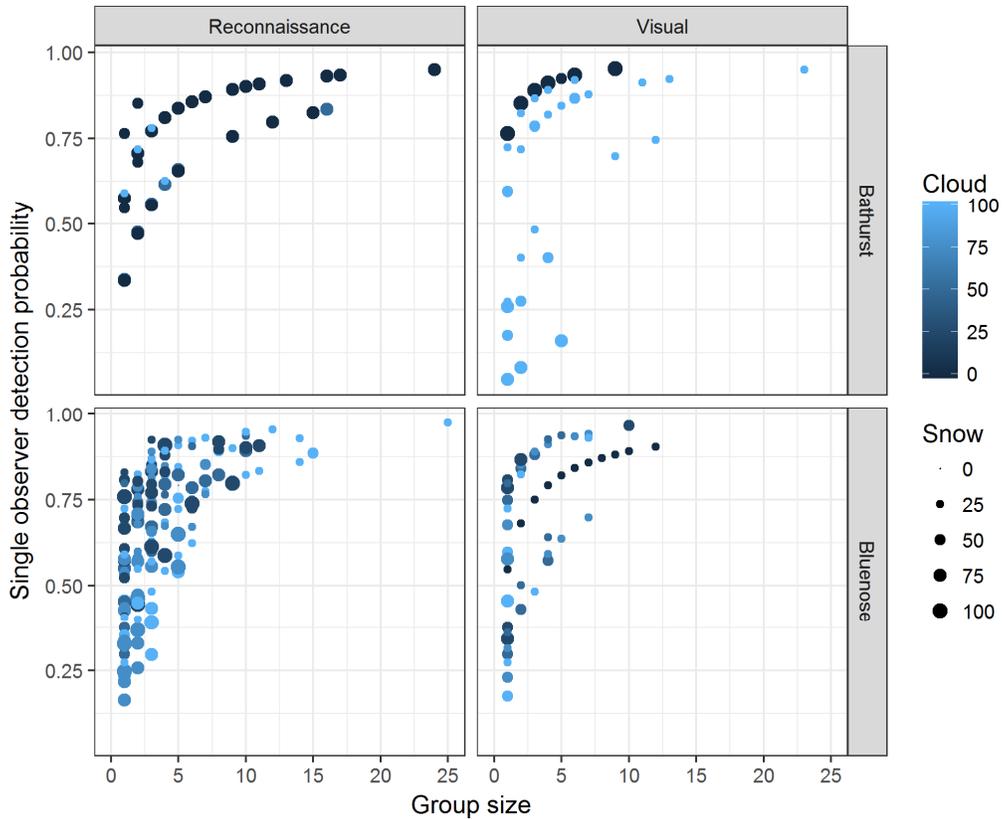


Figure 4: Estimated single observer probabilities from model 1 (Table 3) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

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).

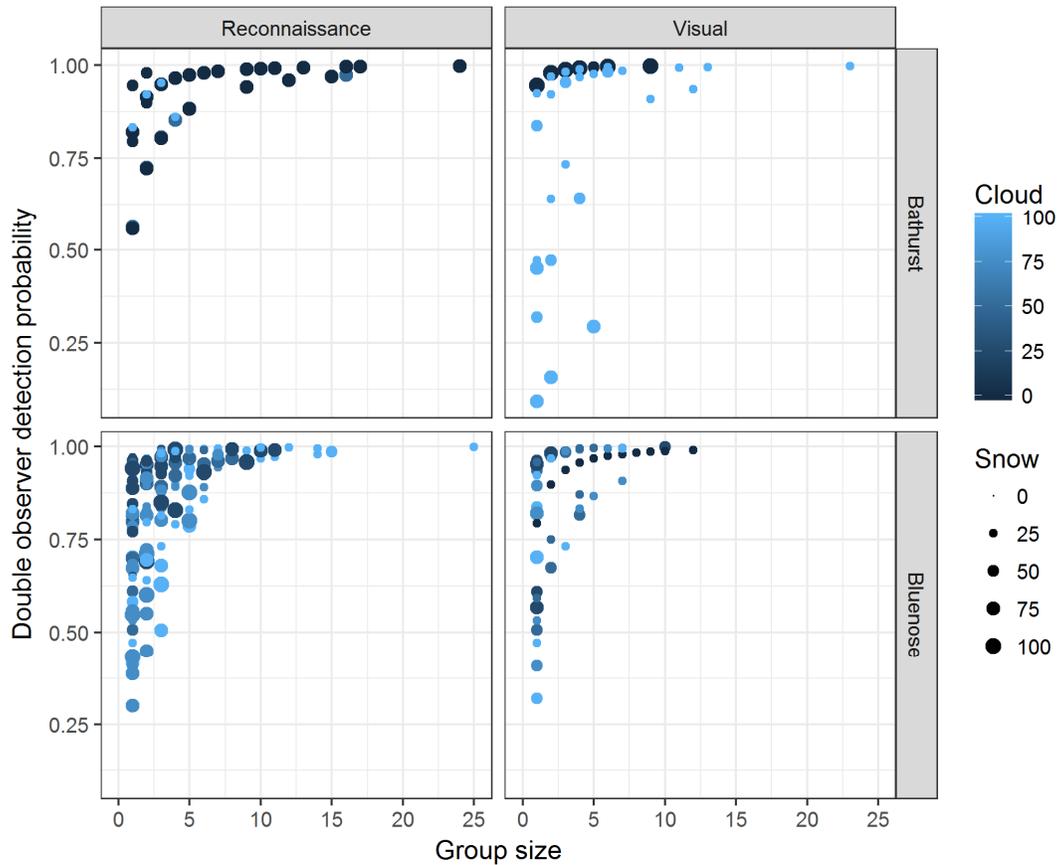


Figure 5: Estimated double observer probabilities from model 1 (Table 3) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

Estimates of total caribou in visual strata

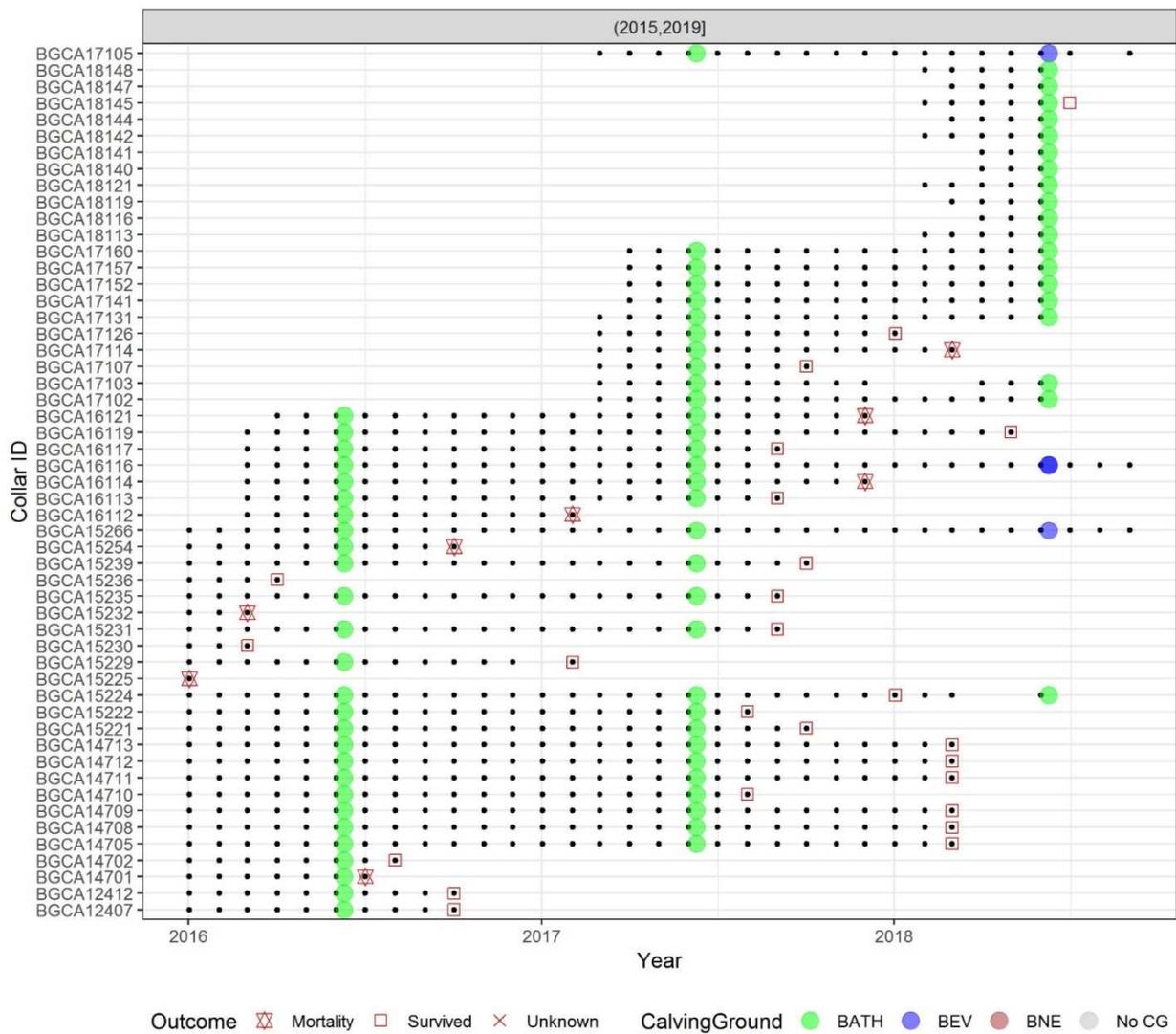
Double observer estimates (using the MRDS R package) were about 5% higher than non double observer estimates. Precision was lower than uncorrected count-based estimates but still acceptable (Table 4).

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 counted	Standard estimate			Double observer estimate				
		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) $ESS \geq 150$ 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 initial 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
<u>Main effects</u>						
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
<u>Random effects</u>						
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 $i-1^{\text{th}}$ 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.

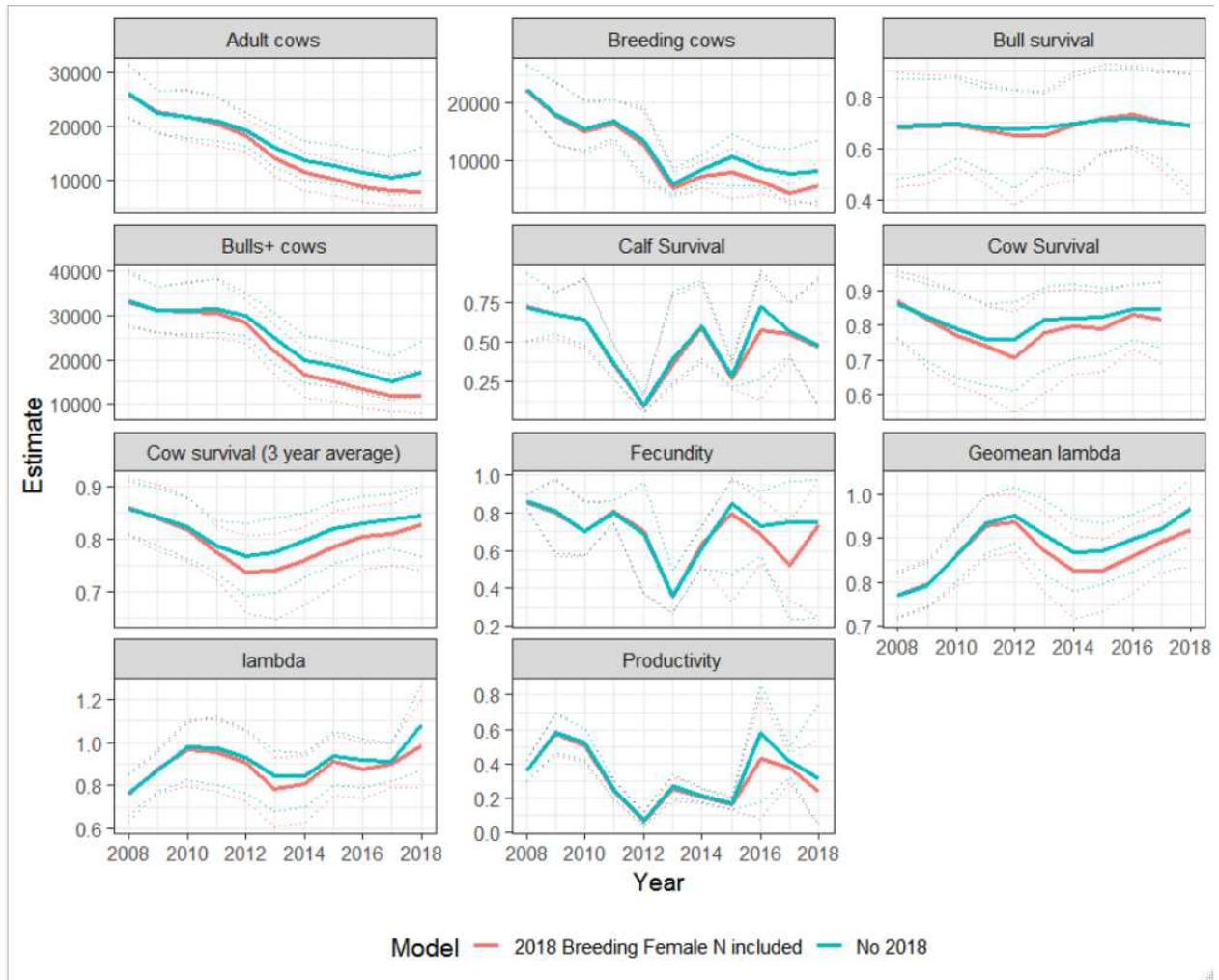


Figure 1: Estimates of principal demographic parameters from the IPM with the 2018 breeding female estimate included and excluded. Confidence limits are given as dashed lines around model predictions.

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 km² stratum had 20% breeding females, then the core calving ground index was estimated as 20 km². 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.

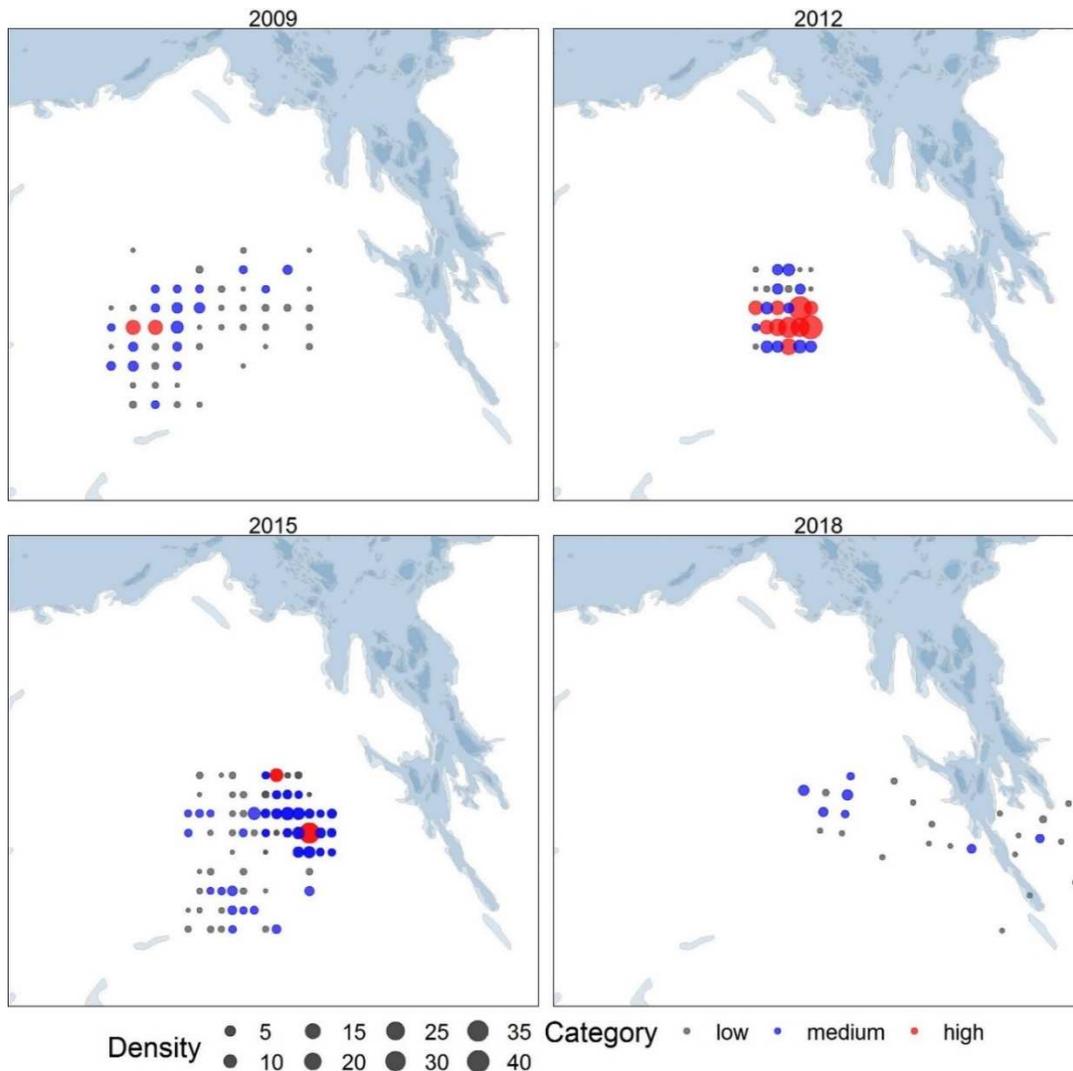


Figure 1: Maps of segment densities from reconnaissance surveys of the Bathurst caribou herd from calving ground surveys 2009-2018. Low density = <1 caribou/km², medium density = 1-9.9 caribou/km², and high density = at least 10 caribou/km².

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).

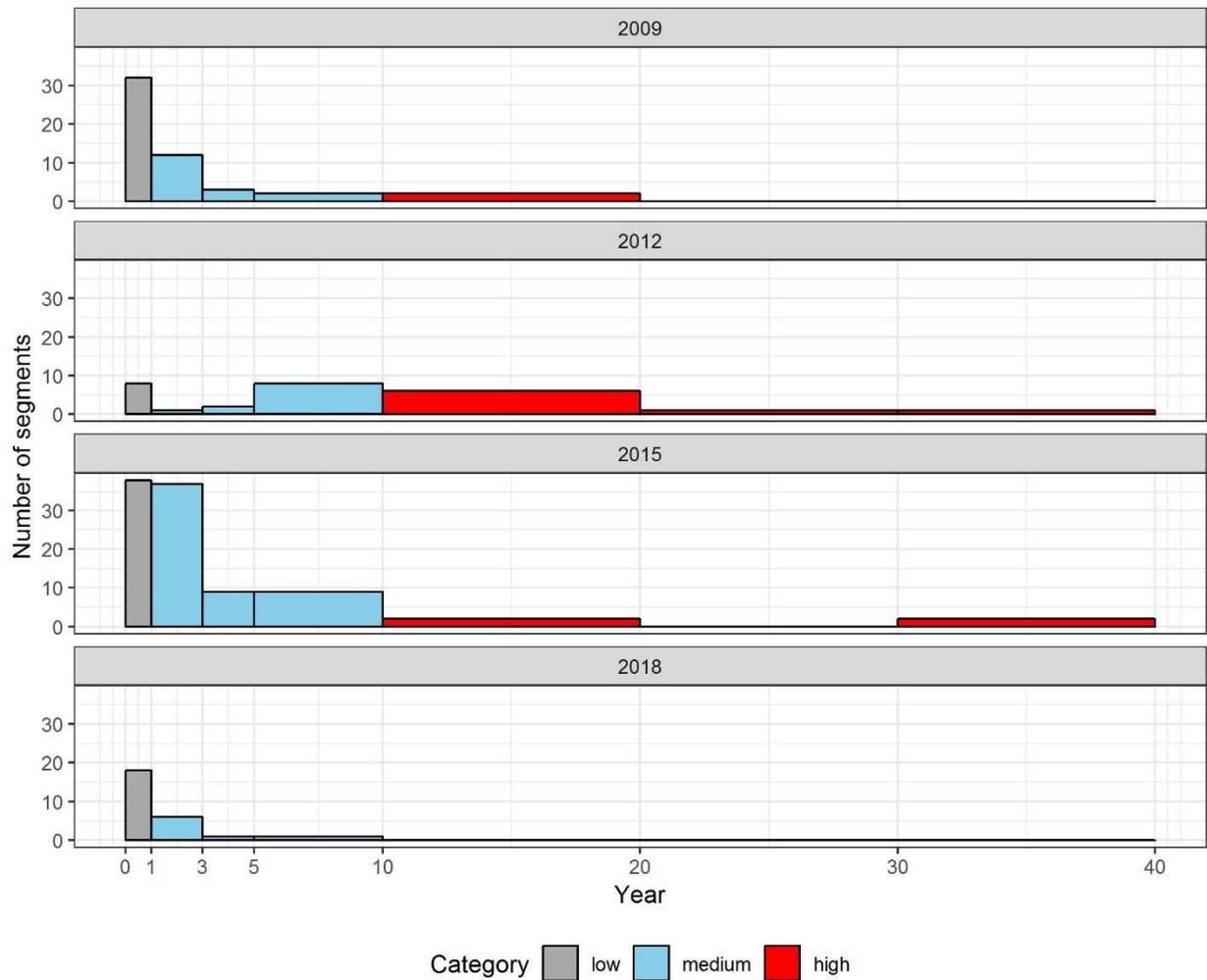


Figure 2: Segment densities in annual concentrated calving areas for the Bathurst caribou herd 2009-2018. Low density = <1 caribou/km², medium density = 1-9.9 caribou/km², and high density = at least 10 caribou/km².

Median segment densities were below 5 caribou per km² for all years except 2012 (Figure 3).

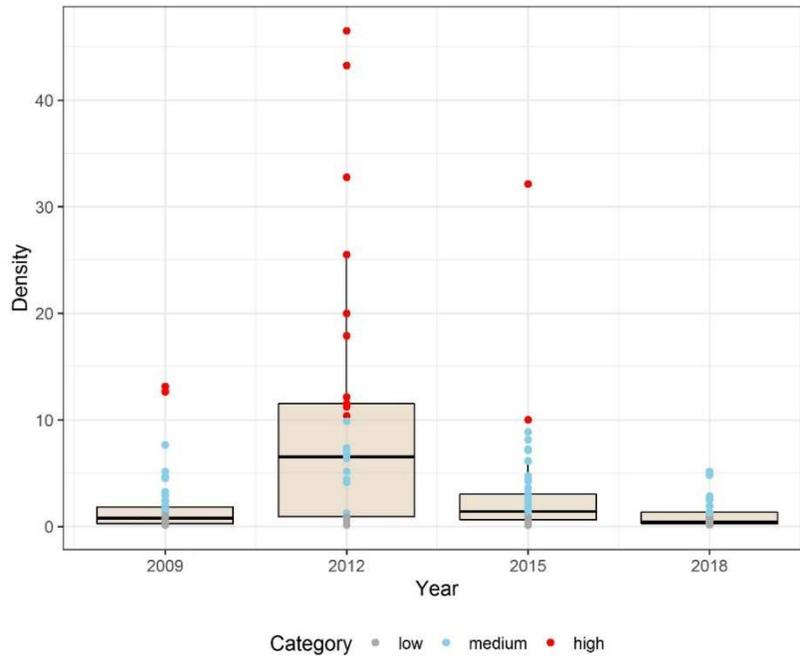


Figure 3: Boxplot of segment densities on calving ground surveys for the Bathurst herd 2009-2018.

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).

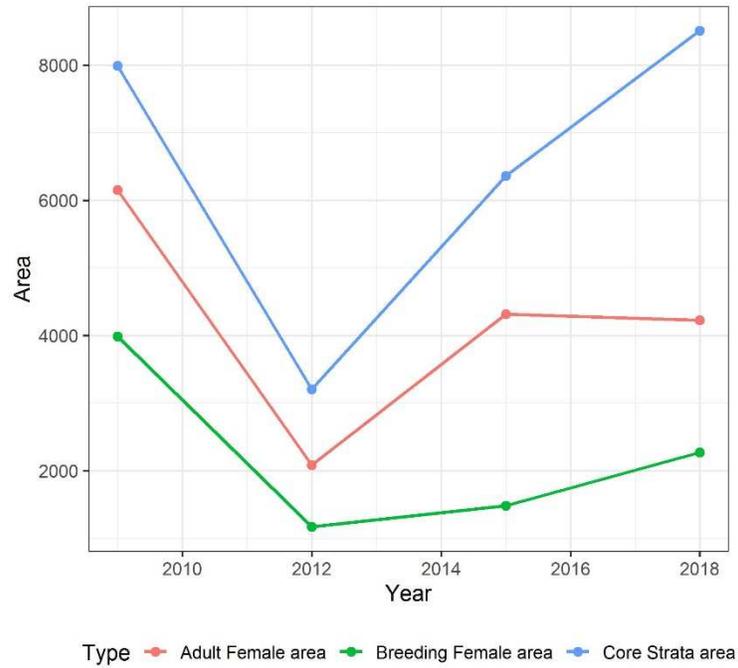


Figure 4: Area of core survey strata, area weighted by proportion of breeding females, and area weighted by proportion of adult females in survey strata by year for the Bathurst herd 2009-2018.

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

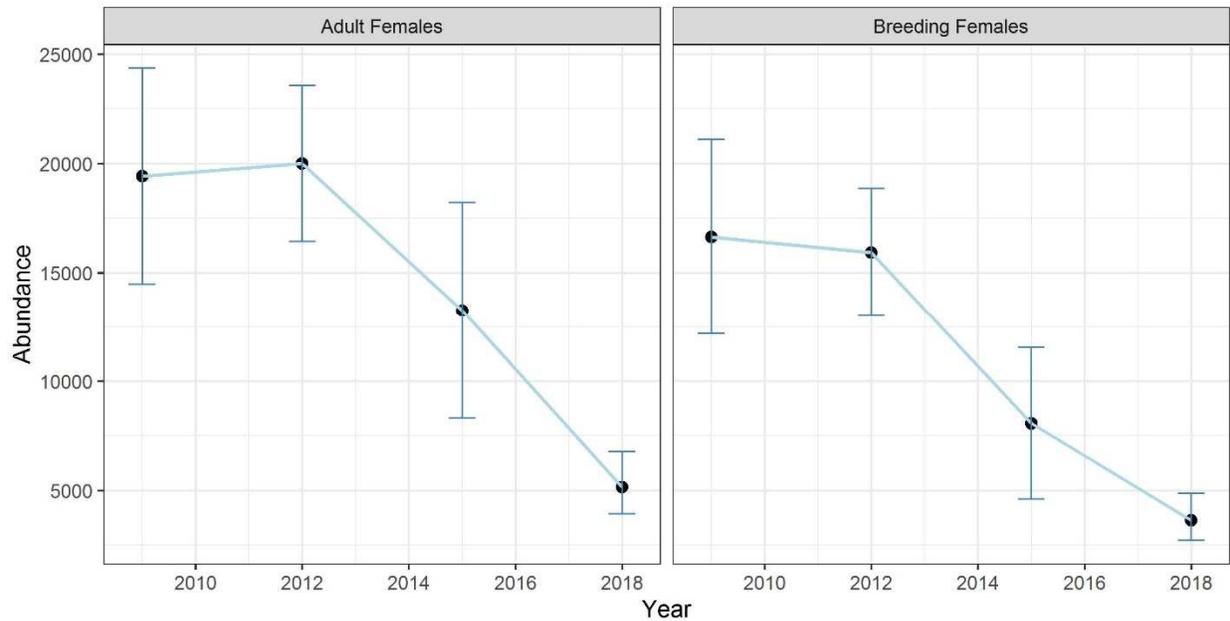


Figure 5: Estimates of abundance of adult and breeding females on core calving areas 2009-2018 for the Bathurst herd.

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.

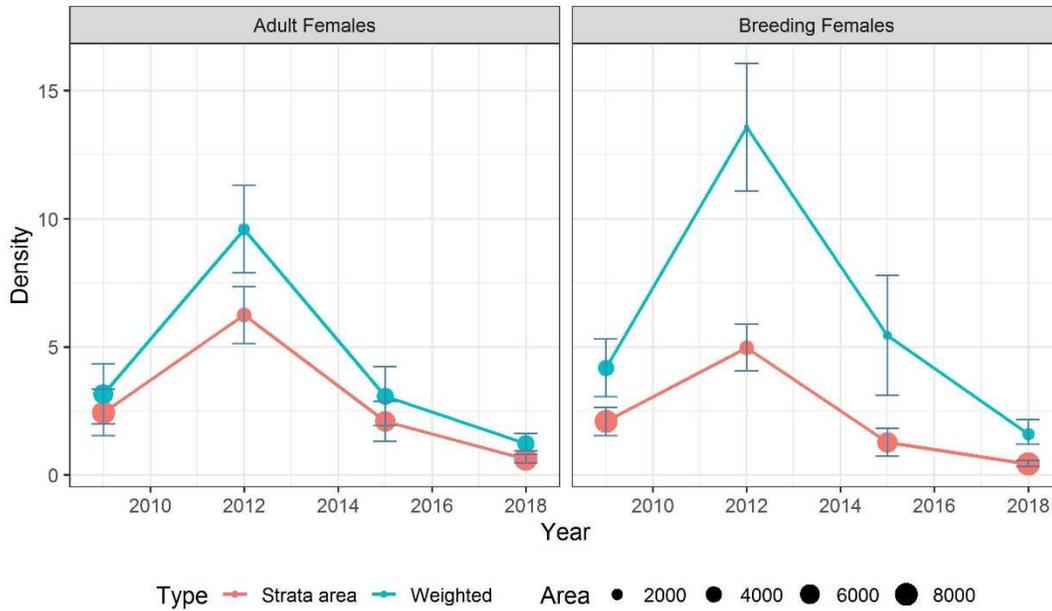


Figure 6: Densities (number/km²) of adult females and breeding females in survey strata using total area (Strata area) and corresponding breeding female or adult female areas, for Bathurst calving ground 2009-2018. The size of symbols is proportional to the calving ground area used for density estimates.

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



Kugluktuk Angoniaktit Katimayit • Angoniaktit imalu Nanirgiaktukpaktunik Katimayit
PO Titikikvia 309, Kugluktuk NU X0B 0E0 • Hivayaut: (867) 982-4908 Hivayaut Tuyuutunik
Titikgakhimayunik: (867) 982-5912
Titikikvia Karitauyakugutinik: kugluktuk@krwb.ca

**HIVULIUYUNIK TUNYAKGAIKHIMAYUNIK TAHAPKUNUNGA NUNAVUT ANGUHIKIYIT
HAVAKATIGIKPAKTUNIK
KAKUNGUKGANGUT KATIMADJUTAUVAKTUNIK #004/2019
UBLUIKVIANI UVANI 4, 2019**

MIKHARUT

TUKIHIGIARUTINIK: XX

TIKUAKTAUYUKHANIK:

Kingaokmiutanik Tuktu

Aah Tamatkiumayunik Angunahuaktautaaktunik Anguyaulutik 30 nik tuktunik havakhikhimayunik malikgaxhanik uvani 2017 mi tuktutainik Kingaokmiutanik Tuktutainik ammihuakyuunik talvanitunik Kitikmeot Nunatuttukanik. Kitikmeot Nunatuttukat Anguhikiyit Katimayit tutkikhaahimayunik tahapkungana 30 nik pihimayunik malikgaxhanik: Kugluktuk 10; Omingmaktok 10; Kingaok 10. Tahapkuat Kugluktuk Angoniaktit imalu Nanirgiaktukpaktunik Katimayit (HTO) tutkikhahimayunik tahapkungana nanaitkutaavaktunik atukgiaktunik tuktunuut nungudjutilingnik ubluunik atugaxhanik atuknianut tahapkungana ilaagiktunik nunagivaktunik ukiukpakgulluakhuni aihikpaanitpaktunik nunamiuplutik talvani Tahikyoak.

Tahapkuat Kavamat Nunatsiami Tunungani talvanilu Nunavut iniktikpakhimayunik havagiplugit aah kufiutilanginik nallautakgutauvaktunik uvani 2018 uvunalu nallautakgutauvaktunik mikharut uvuna 8,200 nirgitinik, aah ikiklivaliayunik talvanganit 2015 ihiviukhinikmun naunaiyainikmun naunaitkutaxhanik uvuna 20,000 nirgitinik.

Tahapkuat Kavamat talvani Nunavut, Havakvit talvani Nunalikiyit katimakatigivakgaait tahapkunani tutkikhakhikariaktunik talvanilu Kitikmeot HTOs uvani Hikutilikvia 7, 2019 talvani Ikaluktutiak. Tahapkuat havakvit Nunalikiyit pinnahuat uktukniaklutik aullaktikgutikxhanik mikhilaaktauyukxhanik uvanga uvunga 30 nik nirgitnik pilugit 0 nik paaiktaulutik hungnaamiklugit.

Aah ammigaitunik tikuaktaavaktunik avaatingnukpaktunik nikikhakhiukpaktunik nirgitinik nirgitit havagiyauvaktukxhanik. Tadjja nunalingni havakataavaktunik mikharut amagoit niakuunik katitiktavaktunik manikhakhautigiplugit havagiyauvaktunik tadjja tahapkungana Havakvit Nunalikiyit. Talvanganit tahapkunani havagiyauliktunik uvani ukiumi 2018/19, 101 nik amagonik angunnahuaktaavaktunik. Tahapkununa kufiutilanginik kilaminuak ammigaikhimayunik pidjutaugumik havakhikhimagumik \$300/ihiviuktauyukxhanik. Angunnahuakpaktunik ukaalukximayunik mikharut akikhautikxhanik piyauyukxhanik akittukyumiayuyukxhanik, tahapkuatlu pidjutivakniaktugulluit angunnahuakpaktukhauyugulluit amagokhiukpakniakgulluaktutlu pidjutivakhimayut taimani 101 nik angunnahuaktaavakhimayunik pidjutivaktukxhanik angunnahuaktaavaktukxhaniklu.

Tahapkuat HTO apikhukhimayunik tahapkuat Kavamat talvani Nunavut aah kufiuyunik apikuutauvaktunik talvanitunik uvani Hikutilikvia 7 katimadjutauvaktunik. Ilauhimayuniklu kanukgitunik havagiyauvaktukhaniklu Kavamat talvani Nunavutmi pilutik havagiplugit aahikuknikmunlu mikhitivaktunik tahapkununa TAH ima 0 nik paaiktaulutik hungnaamiklugit tahapkununalu aah amagonik havagiyauvaktunik havakhautikhanik, pinnahuaknikmun ungniguutinakpaktukhanik nauvulliafaakpaktukhaniklu nirgitinik, pihimayunik kiudjutinik havakhimayukhanik kiudjutaitunik havakhimayunik. Tahapkunani apikhuktauhimayut kanuktun tahapkuat Kavamani Nunavutmi kinauyunit havaginiagulluakihiggit mikharut ilingaituukhanik ammihuakyunik. Havagiyaulimaitunik pilimaituniklu. Tahapkuat HTO pihimayut apikhukhimayunik kanuktun ihuigutivaktunit havakhikhimayunik aah TAH talvunalu 100 nik naliak 30 nik naliak 0 nik paaiktaulutik hungnaamiklugit pilakilutiklu tahapkunani ammihuakyunik uvunalu havagiyauyuitkumik taakuyauyuitkumik upikgiyaulimaituniklu.

Ikiikliyahimayunik havakhikhimayunik tahapkununa TAH taimailiukgumayunik 0 nik paaiktaulutik hungnaamiklugit pipkaihunguyuk pilaakilutinilu aah ayuuknakhihunguyuk ihuikgutilutiklu tahapkunani ilaagiktunik nunagivaktunik ukiukpakgulluakhuni aihikpaanitpaktunik nunamiuplutik talvani Tahikyoak, mikharutlu pitkuhiktukpaktunik atukhugit havagiplugit nikikhakhiuknikmun huli ublumimuut atukhugit.

Good afternoon Denis,

The Burnside HTO, the Umingmaktok HTO, Boyd Warner, and myself at Adventure Northwest put together a little film we would like to show at the upcoming December 4th meeting. I understand today is the deadline for a submission. Its a short film highlighting the importance of the caribou tags for the HTO's that are hunting the Bathurst Caribou herd.

Here is the link to the video taken this fall at our Contwoyto Lake camp. I am not a very tech savvy guy so please let me know if the link does not work.

<https://drive.google.com/file/d/1gjwFyqRCm5zWbgRKvQcvQ-D4a8x5IB3c/view?usp=sharing>

▷▷ΔΔΔΔ 1: ΔΔΔΔΔΔΔΔΔΔ ΔΔΔΔΔ:



September 27, 2019

Mitch Campbell
Department of Environment
P.O. Box 120
Arviat, Nunavut
X0C 0E0

Dear: Mr. Campbell,

Increasement of Musk Ox Tags; MX-13

The Arviat Hunters and Trappers Organization held their regular meeting on Tuesday, September 24, 2019 and the board of directors would like to inform you that you have been approved for the letter of support.

This letter is written to state that we, the Arviat Hunters and Trappers Organization Board of Directors have discussed and are in support of increasing Status Quo MX-13; Musk Ox Tags by 5 from 90 to 95 and keep the other management the same from all other wildlife; (MX-10)

If you have any questions, comments or concerns, please contact the Arviat HTO. Thank you.

Sincerely,

Thomas Alikaswa
Arviat HTO Chairperson

***Re-evaluation of the Northern Kivalliq Muskoxen
(Ovibos moschatus) Distribution, Abundance and Total
Allowable Harvests in muskox management unit MX-10***

Final Technical Report

Government of Nunavut, Department of Environment

Arviat, Nunavut, Canada.

For submission to the Nunavut Wildlife Management Board
2019

Prepared by:

Mitch W Campbell¹ and David S. Lee²

¹Nunavut Department of Environment, Arviat, Nunavut.

²Nunavut Tunngavik Inc.



Introduction / Summary

Prior to the enactment of protection in 1917 (Burch, 1977), muskox subpopulations throughout the central Arctic were hunted to near extirpation. Muskox populations within Nunavut are currently re-colonizing much of their historical range (Fournier and Gunn, 1998; Campbell, 2017), but there remain gaps in information on the status of muskox subpopulations in the area collectively known as the Northeastern Mainland north of the Thelon River, Baker Lake, and Chesterfield Inlet where the Northern Kivalliq Muskox subpopulation (NKMX) resides, within the MX-10 muskox management unit (**Figure 1**). This subpopulation is part of a greater population in Kivalliq which also includes the subpopulation south of MX-10, the Central Kivalliq Muskox (CKMX) in management unit MX-13.

At its greatest extent, the distribution of muskox in the Kivalliq region of Nunavut occurred within an area extending south of 66° latitude, west to the Northwest Territories (NWT)/Thelon Game Sanctuary boundaries, east to the Hudson Bay coast line and south to the Manitoba border (Barr, 1991). Survey work conducted within the last 20 years has indicated a range expansion of Kivalliq muskox subpopulations to the northeast, east, and south of their historical range (Campbell, 2017) (**Figure 2**).

Prior to 2010, Kivalliq muskox subpopulations were estimated using fixed-width line transect surveys in July of 1985, July 1986, July 1991, July 1999 and July 2000 (Campbell and Settington, 2006; Fournier and Gunn, 1998; Case and Graf 1986; Graff et al. 1989; Mulders and Bradley 1991). Surveys were generally flown in July when muskox are distributed more evenly across the landscape, as compared with the winter season when groups can often coalesce due to limited forage accessibility due to snow and ice (Banfield, 1974). The history and reasons behind fluctuations in muskox numbers for the NKMX subpopulation are poorly understood. The first abundance survey of this subpopulation was undertaken in July 1999 within the southern extents of the MX-10 management zone, formerly known as the MX-20 management zone. This July 1999 survey resulted in an estimated population size of 1,522 (95% CI = 679; CV = 0.22) adult and yearling muskox (Campbell and Settington, 2006) for the NKMX in MX-10.

In the five years following the July 1999 survey estimates, local hunters from Arviat, Whale Cove, Rankin Inlet, Chesterfield Inlet and Baker Lake reported increased muskox abundance in MX-10 and a continued expansion of muskox into previously unoccupied range. Motivated by this local knowledge, the Government of Nunavut Department of Environment (GN DOE) met with the Kivalliq Wildlife Board (KWB) to discuss an increase in the Total Allowable Harvest (TAH), and the removal of the seasonal Non-Quota limitations (NQL), based on a new population assessment of both the CKMX and NKMX subpopulations.

By the fall of 2008, a new TAH was established for both the CKMX and NKMX subpopulations. All parties agreed to increase the TAH from 3%, to 5% of the lower confidence intervals of the 1999 survey estimates, with the understanding that aerial surveys to confirm hunter observations of increased muskox numbers would be flown as soon as possible. Additionally, all NQLs were removed for both the CKMX and NKMX subpopulations.

A re-evaluation of Kivalliq muskox subpopulations was undertaken in July 2010, and again in 2016, for the CKMX subpopulation, and in July 2012 for the NKMX subpopulation. Using the Jolly (1969) method for unequal sample sizes to analyze survey observations, the 2010 CKMX survey suggested continued growth from the estimated 2,143 (95% CI = 396; CV = 0.09) adults and yearlings in MX-13 in July 1999 to an estimated 4,506 (95% CI = 948; CV = 0.11) adult and yearling muskox in MX-13 by July 2010. The most recent survey of the CKMX subpopulation flown in July 2016, resulted in an abundance estimate of 4,437 (95% CI = 1,054; CV = 0.12) adult and yearling muskox, suggesting that the muskox population had remained stable between survey periods.

The July 2012 NKMX subpopulation abundance survey estimated 2,341 (95% CI = 545; CV = 0.12) adult and yearling muskox, an increase from the July 1999 survey estimate of 1,522 (95% CI = 679; CV = 0.22) adult and yearling muskox (Campbell and Settington, 2006). The results of this survey suggested strong growth within the NKMX subpopulation. Additionally, range expansion to the south and east for the CKMX subpopulation, and eastward for the NKMX subpopulation was evident (Campbell and Lee, 2013) (**Figure 2**). The following report provides a re-assessment of the NKMX subpopulation and summer range.

To date, there are no indications of disease within the herd. Research into the distribution of the lungworm (*Omingmakstrongylus pallikuukensis*) amongst mainland muskox has included samples from the NKMX subpopulation, but no evidence of the disease had been found (Kutz et al., 2002; Gunn and Wobeser, 1993). Similarly, no evidence of Yersiniosis has been discovered in muskox within the Kivalliq region, though no screening has occurred for Kivillaq muskox in recent years (Blake et al., 1991). Despite the lack of evidence of prevalent disease within Kivalliq muskox subpopulations, continued screening of suspect samples provided by hunters is strongly recommended.

From the late 1980s to present, hunters have been reporting increased observations of muskox closer to their communities both south and east of previously known distributions (Mulders and Bradley, 1991; Rankin Inlet (HTO pers. comm.; Baker Lake HTO pers. comm.; Arviat HTO pers. comm.; Chesterfield Inlet HTO pers. comm.; Repulse Bay HTO pers. comm.; Coral Harbour HTO, pers. comm.; Whale Cove HTO, pers. comm. 2008). Ideally, communities in the Kivalliq region would like to have access to healthy muskox populations. Both population estimates and distribution observations discussed herein will provide information that will enable Regional Wildlife Organizations (RWOs), local Hunters and Trappers Organizations (HTOs), and biologists to

determine the potential long-term effects of current harvest regimes on muskox populations in the Kivalliq, while also providing information on the continued expansion of muskox into their historical range.

At present, the Government of Nunavut continues to use aerial surveys and strip transect quantitative methods to estimate both CKMX and NKMX subpopulation numbers, and uses these estimates to re-assess the TAH for both management units (Heard, 1985; Heard, 1987; Jolly, 1969). The TAH for Kivalliq muskox subpopulations is currently based on 5% of the estimated lower 95% Confidence Interval (CI) of the mean population estimate. At present there is a TAH of 182 muskoxen for the CKMX subpopulation (MX-13) and a TAH of 90 for the northern Kivalliq muskox subpopulation (southern extents of MX-10) (**Figure 1**). There are no NQLs established for either subpopulation.

In this report we provide the detailed analysis of the results of our 2017 abundance survey for the NKMX subpopulation, and discuss management recommendations for both the NKMX and CKMX subpopulations, who are likely related by exchange.

The abundance survey of MX-10 in July 2017 resulted in an estimated 3,239 adult and yearling muskox in July 2017 and significant range expansion within the management unit. While further analysis is still pending, as a result of high variance from the analysis of data from the dependent double observer pair method, but preliminary estimates have been generated and consulted in October, 2018 with the Kivalliq Wildlife Board and representatives from Arviat, Whale Cove, Rankin Inlet, Baker Lake, Chesterfield Inlet, Repulse Bay, and Coral Harbour.

A slight increase in TAH is recommended for the subpopulation of muskox in MX10 from 90 to 95 animals, given the slight detected increase in abundance, and potential for this additional amount to generate income or enhance food security for communities which subsist from this muskox subpopulation.

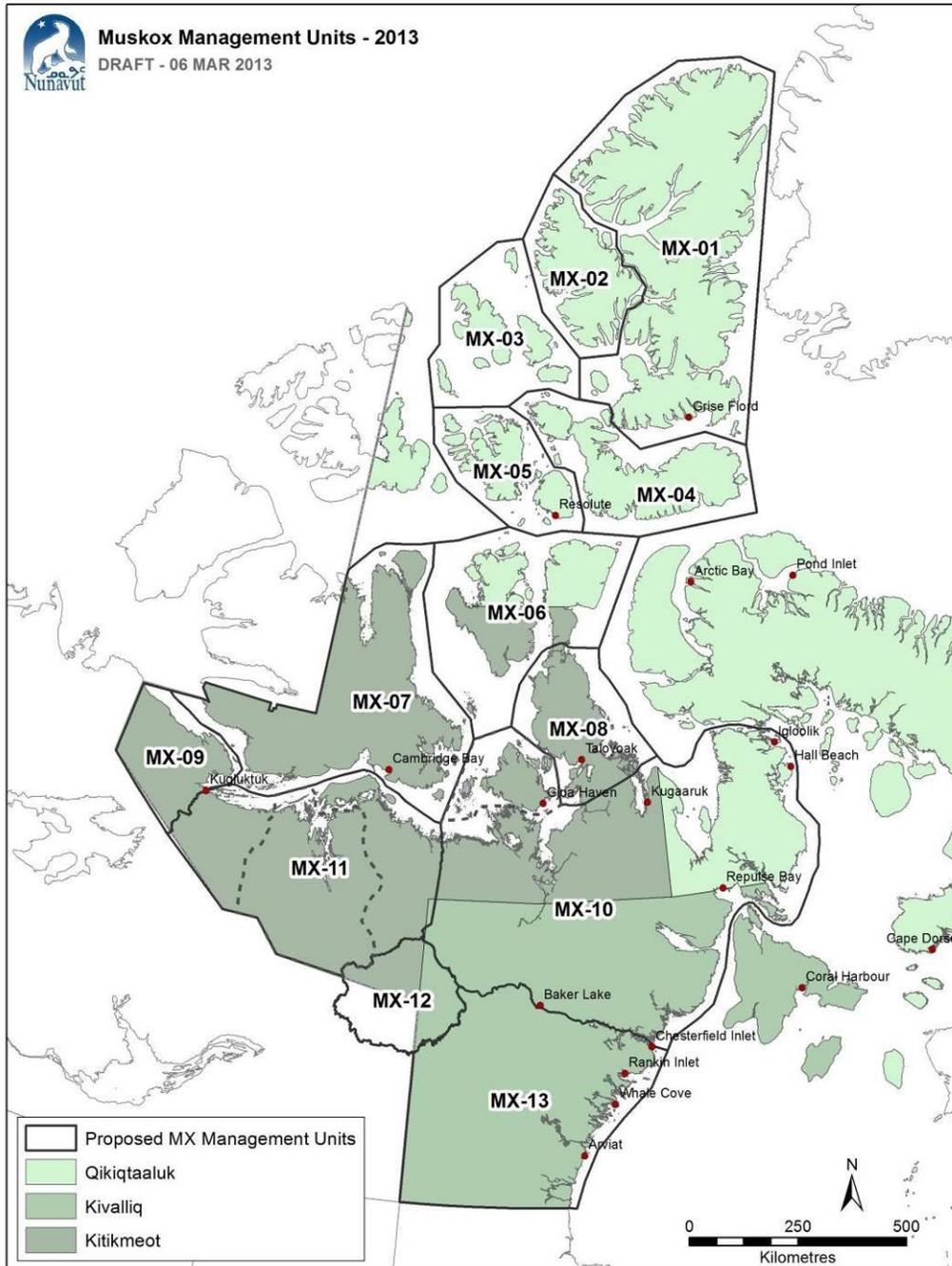


Figure 1. Nunavut's muskox management zones. The northern Kivalliq muskox subpopulation (NKMx) extents are represented by the southern extents of the northeastern mainland group (MX-10).

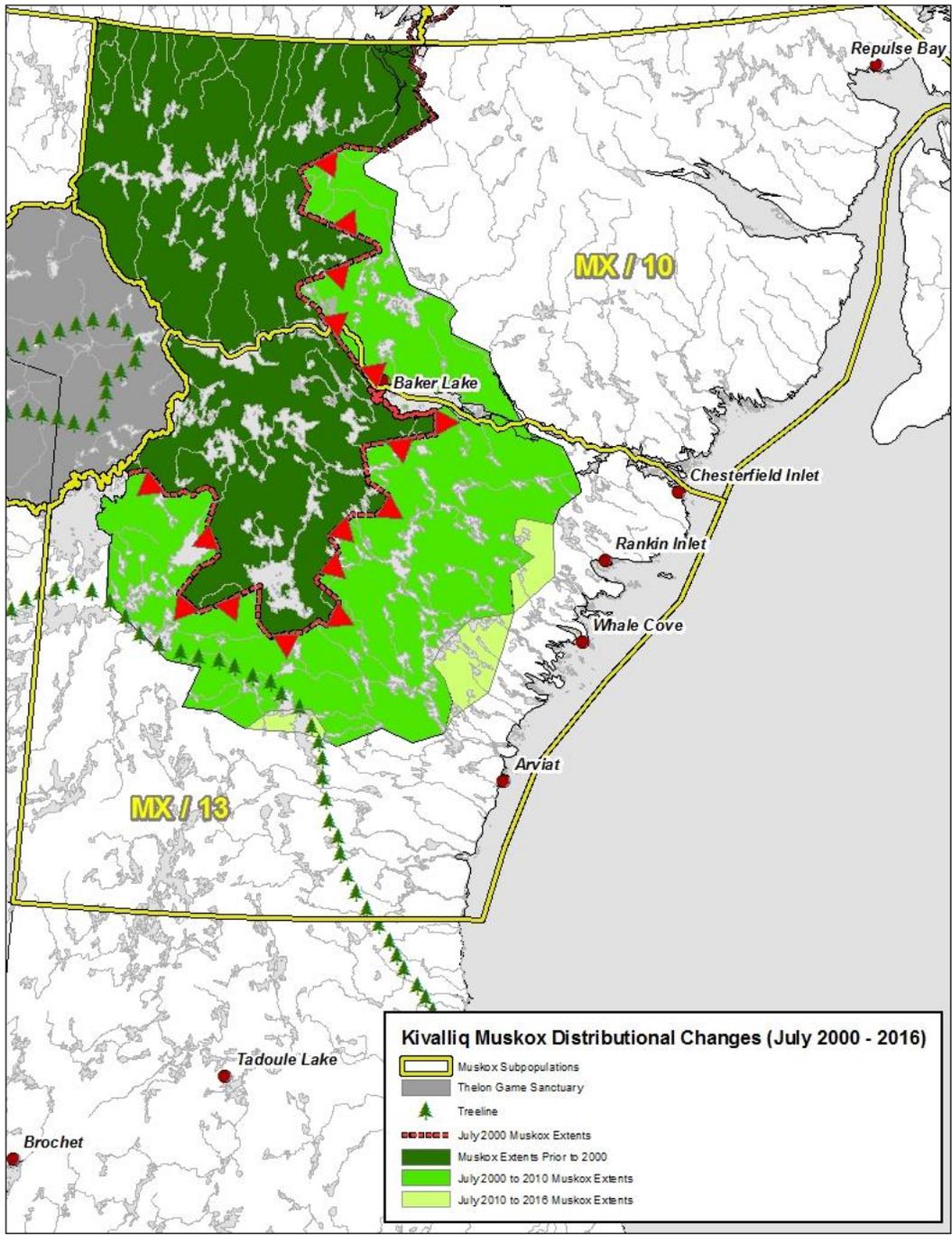


Figure 2. Indicated central and northern Kivalliq muskox range expansion from pre-2000 extents, to July 2010, and to July 2016 extents (Campbell, 2017).

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Study Area:

The NKMX survey study area was based on the July 1999 and 2012 survey observations and extents, as well as observations from local hunters and other reported sightings, collected during consultations with local HTOs. Local HTO representatives taking part in the survey also indicated areas where muskox range expansion had likely occurred in recent years. Efforts were also made to survey outside of known distributions to ensure questions regarding range expansion were addressed, and to ensure overlap between survey years was achieved, for distributional and density-related comparisons. The July 2017 NKMX survey area is an estimated 60,576 km² and encompassed the lower half of the MX/10 muskox management zone (**Figure 3**). The NKMX study area included portions of the Back River Plain, the Garry Lake Lowland ecoregions of the Southern Arctic ecozone, and the Wager Bay Plateau ecoregion of the Northern Arctic ecozone (Wiken, 1986; Ecological Stratification Working Group, 1996) (Error! Reference source not found., **Figure 3**).

Table 1. Ecoregions of the northern Kivalliq muskox survey study areas in the Kivalliq region of Nunavut.

Study Area	Ecozone	Ecoregion
NKMX	Southern Arctic	Back River Plain
		Garry Lake Lowland
	Northern Arctic	Wager Bay Plateau

Northern Arctic Ecozone:

The Northern Arctic Ecozone covers an estimated 1.5 million square kilometres, or about one seventh of Canada, and extends over most of the non-mountainous areas of the Arctic islands and parts of northeastern Kivalliq, western Baffin Island, and northern Quebec. This ecozone covers the eastern half of the NKMX survey area and is one of the largest arctic ecosystems in the world (**Figure 3**). Winters in this ecozone pass in near darkness. Snow may fall any month of the year and usually remains on the ground from September to June. Extremely low temperatures and an average precipitation of about 200 mm per year characterize the climate. When not covered in snow, much of the landscape is typified by barren plains covered in frost-patterned soils and the occasional rock outcrop (Wiken, 1986; Ecological Stratification Working Group, 1996).

The Wager Bay Plateau ecoregion, a part of the Northern Arctic Ecozone, covers the eastern half of the survey area (**Figure 4**). This ecoregion is classified as having a low arctic ecoclimate with a mean annual temperature of approximately -11°C. Seasonal mean temperatures are 4.5°C in summer and -26.5°C in winter. The mean annual precipitation ranges between 200 and 300 mm. Vegetation of the ecoregion includes a discontinuous cover of tundra plant communities dominated by dwarf birch (*Betula glandulosa*), willow (*Salix spp.*), northern Labrador tea (*Ledum decumbens*), Mountain Avens (*Dryas integrifolia*), and *Vaccinium spp.* Taller dwarf birch, willow, and alder (*Alnus spp.*) occur on warm sites while wet sites are dominated by willow and sedge (*Carex spp.*). Lichen-covered rock outcroppings are prominent throughout the ecoregion. Massive Archean rocks of the Canadian Shield form broad, sloping uplands, plains, and valleys within this ecoregion, rising gradually westward from Chesterfield Inlet to 600 m asl elevation, where it is deeply dissected. Turbic and Static Cryosols developed on discontinuous, thin, sandy moraine and alluvial deposits are the dominant soils in the ecoregion, while large areas of Regosolic Static Cryosols are associated with marine deposits along the coast. Permafrost is continuous with low ice content (Wiken, 1986; Ecological Stratification Working Group, 1996).

Southern Arctic Ecozone:

The Southern Arctic Ecozone forms an extensive ecosystem covering close to a million square kilometres of sprawling shrub lands, wet sedge meadows, and cold, clear lakes. This ecozone covers the western half of the NKMX survey area (**Figure 3**). Habitats within this ecozone are characterized by intense frost action and the resultant formation of frost-patterned soils. The two ecoregions covering the western half of the NKMX survey area and include the Garry Lake Lowland, covering the central quarter of the survey area, and the Back River plain, covering the western quarter (**Figure 4**).

The Garry Lake Lowland extends across a vast area of massive granitic Archean rocks, forming a broad, level to gently sloping plain that reaches about 300 m asl in elevation. This ecoregion is classified as having a low arctic ecoclimate with a mean annual temperature of -10.5°C. Summer and winter mean temperatures are 5.5°C and -26.5°C, respectively. The mean annual precipitation ranges from 200 to 275 mm. Dominant plant communities include shrub tundra composed predominantly of dwarf birch, willow, and alder on warm, dry sites. Poorly drained sites are dominated by willow, sedge, and moss. Soils within this ecoregion are composed of Turbic and Static Cryosols developed on discontinuous, thin, sandy moraine with Organic Cryosolic soils on level high-centre peat polygons. Permafrost is continuous with low ice content throughout the ecoregion (Wiken, 1986; Ecological Stratification Working Group, 1996).

The Back River Plain ecoregion occurs in the central Kivalliq from the Back River south to Aberdeen Lake. The ecoregion is characterized by relatively level terrain, differing from adjacent ecoregions which tend to have greater relief. The Back River Plain has a low arctic ecoclimate and an estimated mean annual temperature of -10.5°C with a summer mean of 5.5°C and a winter mean of -26.5°C. Mean annual precipitation ranges from 200 to 300 mm. Plant communities within the ecoregion are characterized by shrub tundra consisting of dwarf birch, willow, Labrador tea, Mountain avens, and the genus *Vaccinium*. Tall dwarf birch, willow, and alder occur on warm sites with well-drained upper slopes tending to have a discontinuous vegetative cover. Wet sites are dominated by willow, moss, and sedge hummocks and tussocks. The ecoregion includes areas of nearly flat-lying sandstones and volcanic rocks that are commonly expressed on the surface by sandy flats covered with sparse vegetation. Soils of the ecoregion are typified by Turbic Cryosols developed on level to undulating, discontinuous veneers of sandy morainal and fluvioglacial material. Within wetlands, Organic Cryosols with associated frost-formed patterned ground are typical. Permafrost is continuous with low ice content throughout the ecoregion (Wiken, 1986; Ecological Stratification Working Group, 1996).

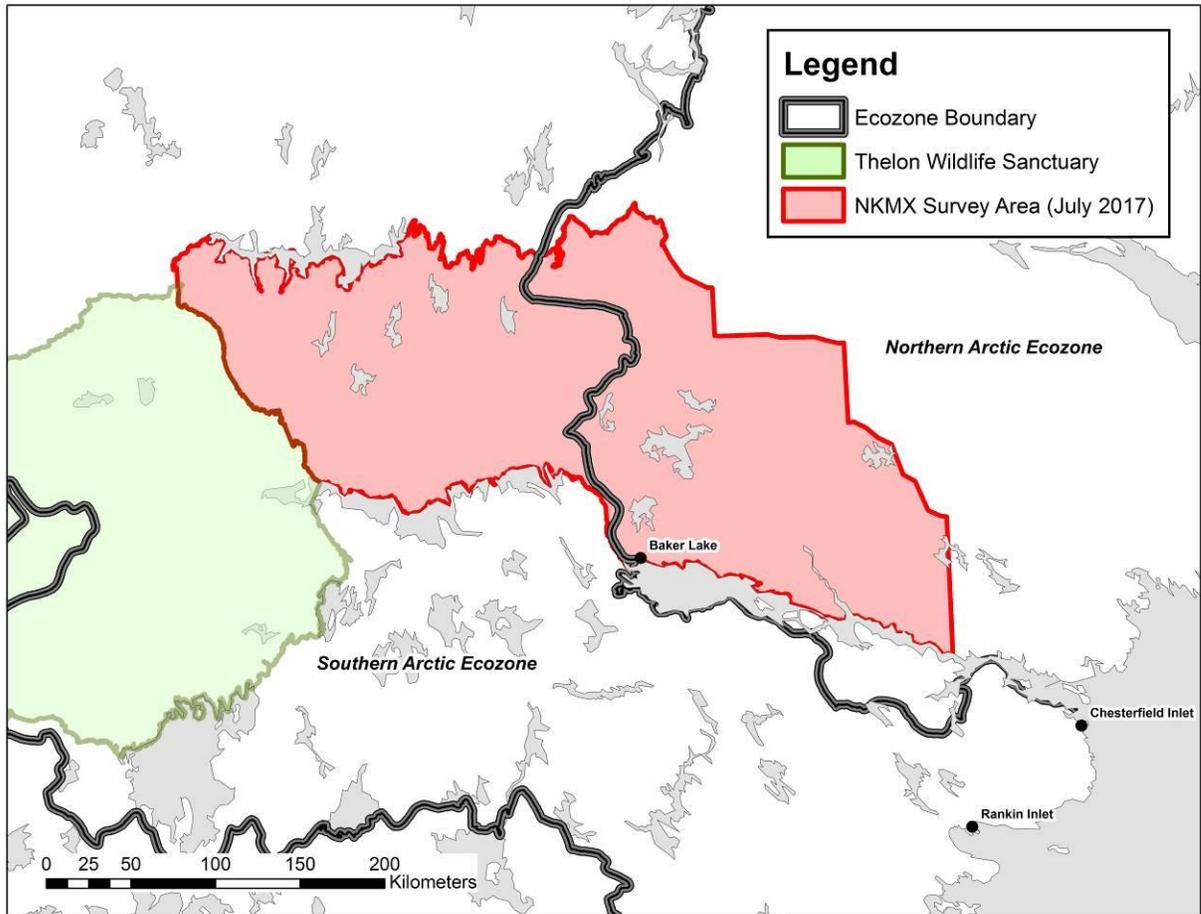


Figure 3. Ecozones of the northern Kivalliq muskox subpopulation (After Wiken, 1986; Ecological Stratification Working Group, 1996).

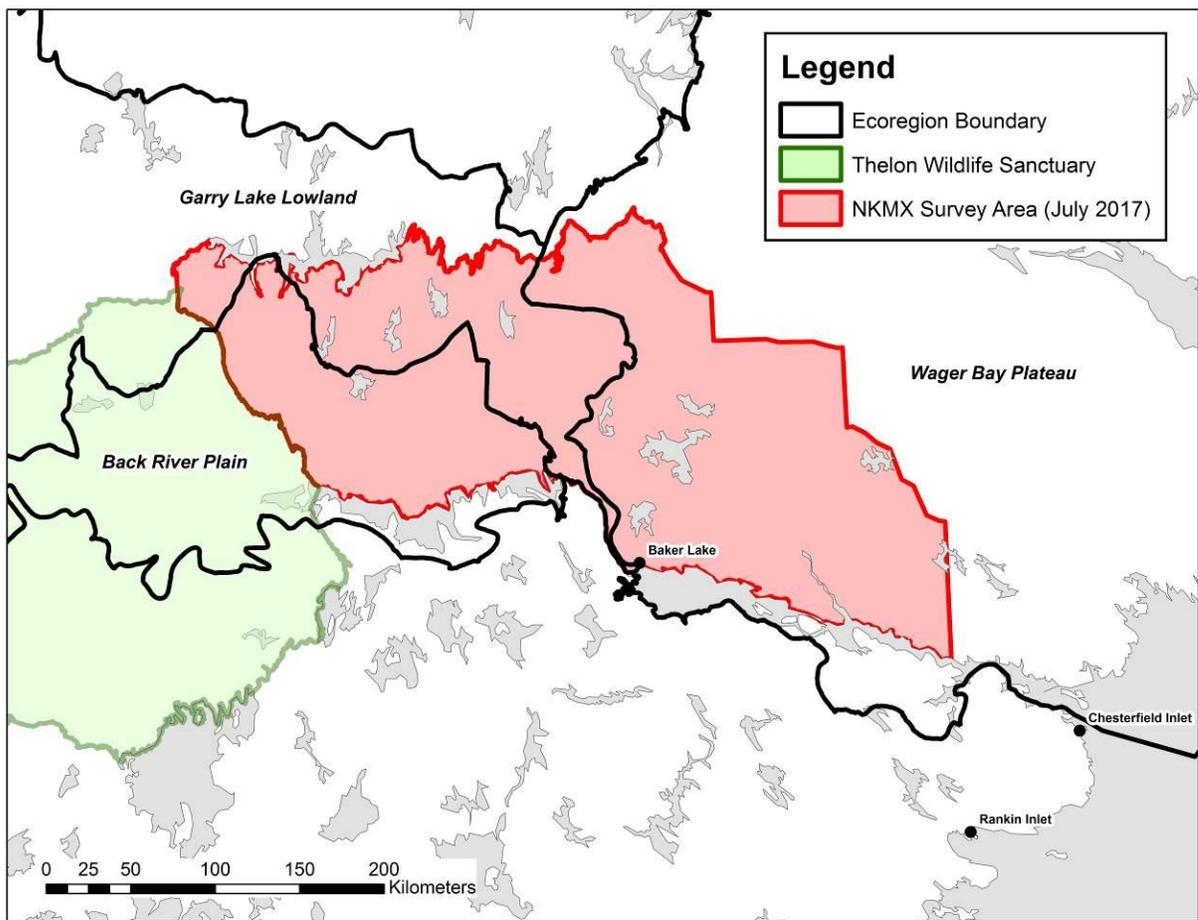


Figure 4. Ecoregions of the northern Kivalliq muskox subpopulation and survey area (After Wiken, 1986; Ecological Stratification Working Group, 1996).

Methods:

Two methods were used to determine the geographical extent of the July 2017 NKMX abundance survey: the first being the collection of *Inuit Qaujimagatuqangit* (IQ) and local knowledge to determine contemporary distributions of the NKMX subpopulation, and the second: an examination of past survey extents and estimates based on muskox observation data. IQ and local knowledge was collected and compiled during annual consultation visits with the communities of Rankin Inlet, Baker Lake, Chesterfield Inlet and Naujaat. The whole of the information collected was then used to help determine subpopulation boundaries and survey study area extents. Once the survey study area was designated, systematic transects were drawn every 7.0 kilometers, with a random starting point. Survey transect placement was the same as that used in July 2012, with some necessary additions and/or extensions to accommodate hypothesized range expansion (Campbell and Lee, 2013). All transects were placed perpendicular to the longitudinal axis of the survey area (Campbell and Lee, 2013). Transects were numbered west to east and oriented north-south across major riparian habitat as in previous Kivalliq based muskox surveys (Fournier and Gunn, 1998; Campbell, 2017; Campbell and Settingington, 2006; Case and Graf 1986; Graff et al. 1989; Mulders and Bradley 1991). Transects were flown at an altitude of 152 meters (500 ft.) above ground level (agl) which, when configured on the survey planes wing struts, provided a cumulative left side and right side observer strip width of 2,000 meters (1,000 meters per side). The 2,000 meter strip width yielded 29.2% coverage of the entire survey area (**Figure 5**). Due to the size of the study area, the relatively limited data on muskox densities within much of the study area, and time and other logistic limitations, we decided to allocate all of the survey effort into one systematic random transect survey. We also used this same allocation of effort during the previous July 2012 survey of the NKMX population.

Due largely to the exceptional sightability of muskox in July, visual transect survey methods are widely accepted as being the most cost-effective means of estimating muskox populations, while also still providing an acceptable level of precision (Case and Graf, 1986; Graf and Case, 1989; Graf *et al.*, 1989; Gunn, 1995; Mulders and Bradley, 1991). The July 2017 visual survey was flown using a Cessna 206 Grand Caravan high wing single engine turbine aircraft, based out of Rankin Inlet and Baker Lake. To facilitate distance sampling techniques, strip widths of 0 to 250 meters, 250 to 500 meters, 500 to 750 meters and 750 to 1,000 meters were established on the wing struts on both sides of the aircraft using streamers to mark off the 0 meter, 500 meter and 1,000 meter markers and tape to delineate the remaining 250 and 750 meter segments (Buckland et al., 1996; Buckland et al., 2004; Buckland et al., 2010). Strip width (w) was calculated using the formula of Norton-Griffiths (1978, **Figure 6**). The strip width area for density calculations was 1,000 meters out each side of the aircraft, for a total of 2,000 m strip width along each transect. To investigate the accuracy of distance bins, each observed group of muskox was overflown at survey altitude

and a waypoint of the exact location of the group recorded. Following any deviations from the transect to mark the position of groups, the aircraft would backtrack, parallel to the transect, and then rejoin the transect 1 to 2 kilometers behind the point of departure thus ensuring continuous observations along each transect. Survey altitude was maintained as close as possible to 152 m above ground level (agl.) using a radar altimeter. Ground speed was maintained between 175 and 195 kilometers per hour. The July 2017 NKMX abundance survey was initiated on July 21st, and completed July 29th, 2017.

The July 2017 NKMX survey was flown using an independent double observer pair, sight-re-sight method (Borchers et al., 1998; Buckland et al. 2010; Laake, et al., 2008). To configure the double observer pair and distance sampling methods, we employed a survey crew of 7; two (2) data recorders/navigationers (one in the front right seat and the second in the rear left seat), two left side observers, two right side observers and the pilot in the front left seat (**Figure 7**). We installed visual barriers between each of the left and right side front (primary) and rear (secondary) observers to ensure no visual cues to muskox presence could be passed between same side observers. Additionally, we isolated all intercom systems between the front observers, data recorder and pilot, and the rear observers and data recorder. We also installed a quick intercom link between the front and rear in case of emergency. As part of the double observer pair sampling method, front and rear observers on both the left and right side switched between the front and rear positions half way through the day though remained on their designated sides. This switching between front and rear positions was important to determine potential sightability, issues either with aircraft related limitations to viewing, and/or differences between observer ability.

Observations from all survey crew members were recorded along with the observer's role and position. Where a dedicated observer was indisposed, the data recorder would move to the appropriate side to temporarily cover that position. In the case, this was to happen to the front left observer, and then the pilot, when feasible, would temporarily cover that side. For survey estimates, only observations from the four dedicated observers were used. Two of the selected observers, one for each side of the aircraft, had experience surveying wildlife visually from aircraft while the two remaining observers were selected by the local HTO/HTOs and were both Nunavut Inuit who had hunting grounds located within the survey area (Rankin Inlet, Baker Lake, Chesterfield Inlet, and Naujaat). The observers were further divided into front and rear teams, each isolated from the other using visual barriers between the seats as well as isolated through the use of two independent, intercom systems monitored by each of a front data recorder/navigationer and a rear data recorder/navigationer. The pilot's responsibilities were to monitor air speed and altitude while following transects pre-programmed on a Garmin Montana 650 T geographic positioning system device (GPS). The data recorder/navigationers were responsible for monitoring a second and third identically programmed GPS unit for the purposes of double-checking the position, as well as to record the waypoints and numbers of observed muskox groups, composed of adults and calves, on data sheets. The

responsibilities of the observers were to constantly and thoroughly search their 1,000 meter strips and call out numbers of muskox within each of the delineated bins marked out on the wing struts. All observations were separated into adults and calves within each designated 250 meter wide sub-strip. In addition to binning observations, actual group locations were also recorded by flying off transect to each observation to record position. The rear right and front left observers, the pilot and the two data collector/navigators remained consistent throughout the 2017 survey. Though calves were recorded, only counts of adults and yearlings were used in the final population estimate.

Statistical Analyses:

Survey data collected within the NKMX strata were analyzed using the Jolly method (1969). This method has been used effectively for several decades to estimate the abundance of numerous wildlife populations including muskox (Campbell and Settington, 2006; Jolly, 1969; Mulders and Bradley, 1991). Only counts of adults and yearlings (> 1 year old) were used for the final population estimates and lake areas were not subtracted from the total area calculations used in density calculations. To further assure reliability in the setting of any TAH using the current analysis, this report will base any harvesting recommendations on the lower 95% Confidence Interval of the population mean estimate.

As of writing this report, we are continuing analysis of the survey data using sight re-sight and distance sampling methods, which will appear in the final GN DOE file report. The double observer pair sight-re-sight and distance sampling analysis might provide a more precise estimate of muskox abundance within the NKMX survey area. As a result, the final estimates presented in this report could change, though we are confident that any changes in estimated abundance will likely fall within the current 95% confidence limits given here using the Jolly method. The completion of the full file report is expected in the fall of 2019 and will replace any and all previous reports produced for co-managers including the present work. As other analyses are ongoing, the authors of this report and the GN DOE would like to ensure the reader understands that the results presented herein may change following more comprehensive analyses and may update the results presented in this report within the final GN DOE File Report. Any and all GN DOE research projects are required to produce a comprehensive thoroughly peer reviewed File Report following the completion of the research program. The GN File Reports represent the most comprehensive and complete reporting format and as a result will be the main documents used to make management recommendations.

Trend Analyses:

For the purposes of determining the significance of any change detected, we first conducted a z-test to compare the most recent population estimate (2017) and the previous population estimate (2012) to assess any significant difference in the population estimates. Specifically, we compared the 2017 population estimate to the 2012 population estimate using equation 5.3 of Thompson *et al.* (1998):

$$z = \frac{Y_{2017} - Y_{2012}}{\sqrt{\text{Var}(Y_{2017}) + \text{Var}(Y_{2012})}}$$

Where:

Y = Muskox Population Estimate

z = z Statistic;

Yx = Population Estimate for Year

$\text{Var}(Yx)$ = Variance of the Population Estimate

We then compared the 2017 population estimate to the 1999 population estimate. We used the two-tailed probability of the z statistic because there was no *a priori* prediction about whether there would be an increase or decrease in the population size. Hence the research hypothesis stipulated that there is a significant difference between 2012 and 2017, and the null hypothesis stated that there is no significant difference. To further explore potential differences between the 2017 and 2012 population estimates, we used Monte Carlo computer simulation methods. We assumed a log-normal distribution and built a probability distribution for each survey through random draws ($n = 1,000,000$) that were based upon the population estimate and standard error of each aerial survey. Several levels of difference between the two surveys were then assessed. We plotted the three survey estimates and applied a simple linear model, Poisson (log) model, and binomial (logit) model to further assess the observed changes in abundance.

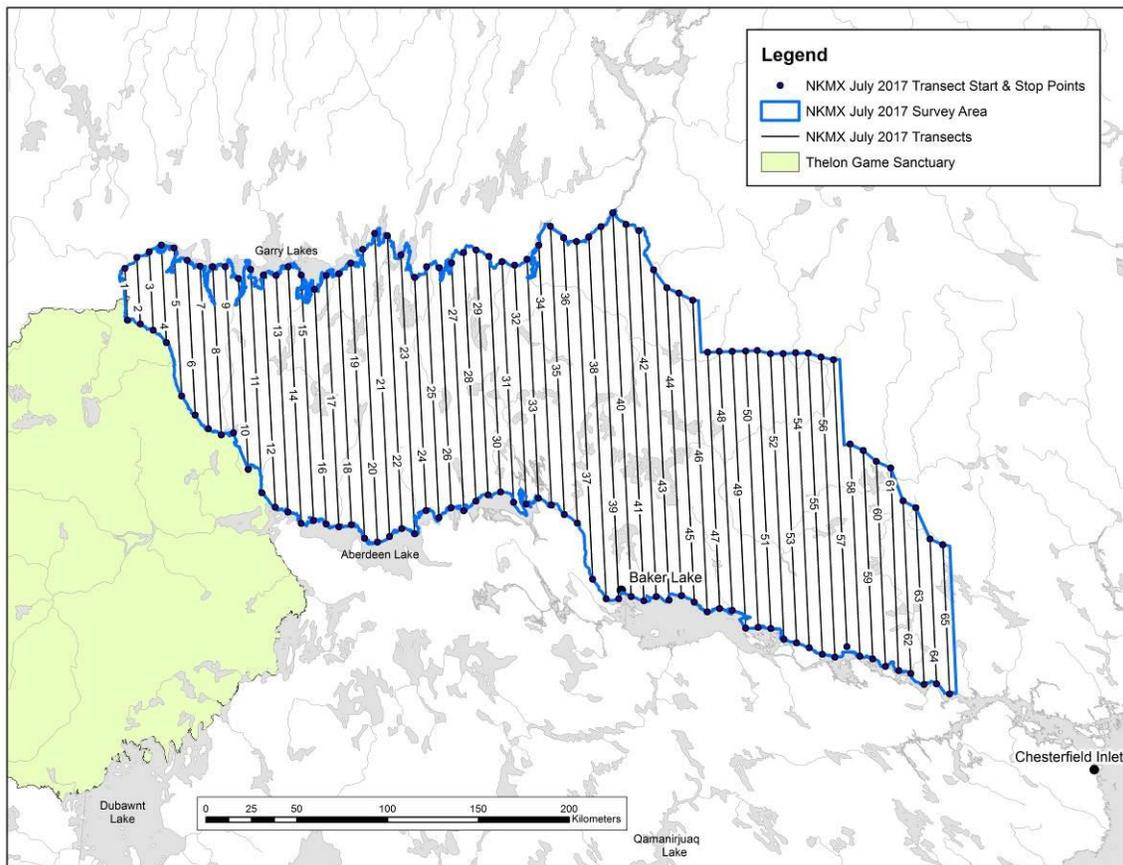


Figure 5. Study area and transects of the July 2017 northern Kivalliq muskox survey. The study area delineated based on estimated densities from IQ studies and past survey results.

$$w = W * h/H$$

where:

W = the required strip width;

h = the height of the observer's eye from the tarmac; and

H = the required flying height

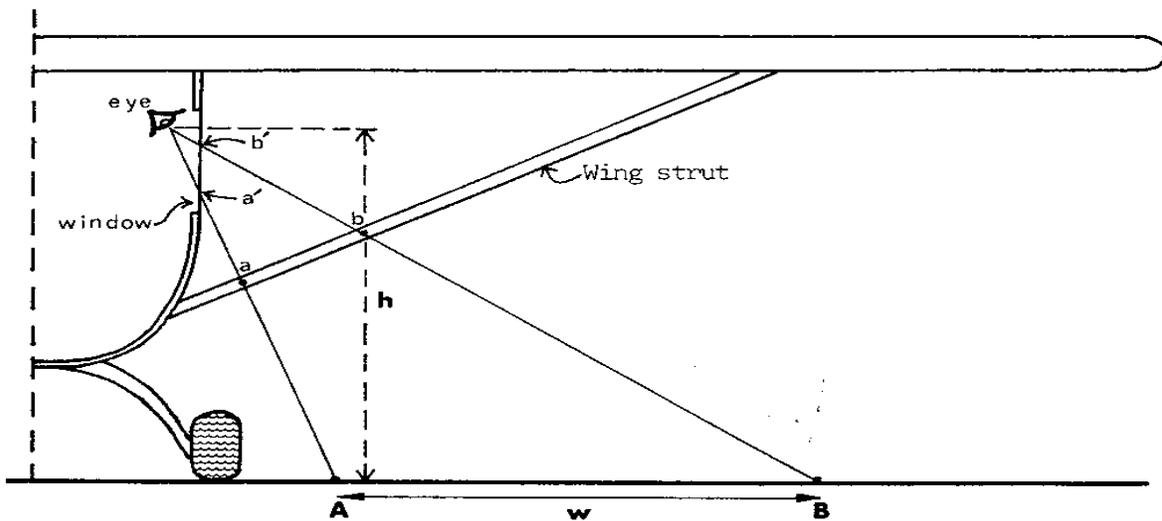


Figure 6. Schematic diagram of aircraft configuration for strip width sampling (Norton-Griffiths, 1978). W is marked out on the tarmac, and the two lines of sight $a' - a - A$ and $b' - b - B$ established. The streamers are attached to the struts at a and b . a' and b' are the window marks.

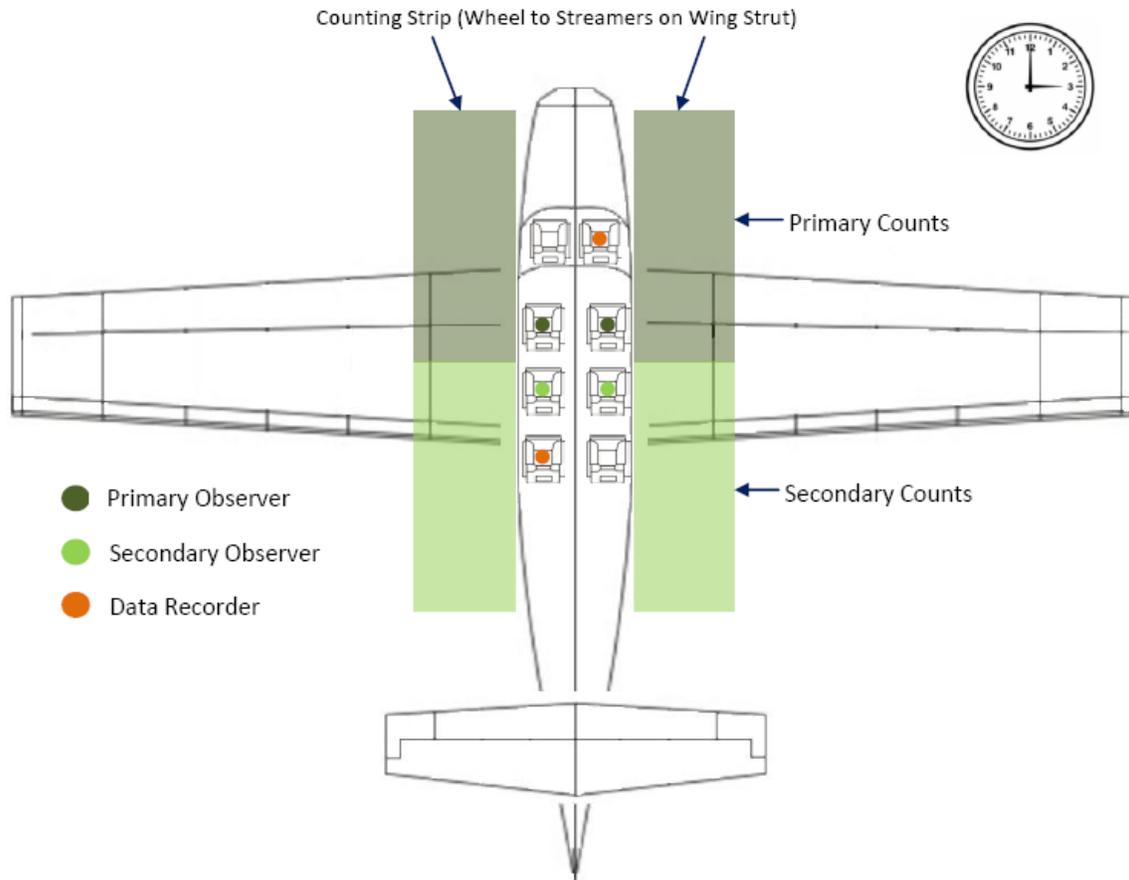


Figure 7. Observer position for the double observer sight-re-sight and distance sampling methods deployed on this survey. The secondary (rear) observer calls out muskox not seen by the primary (front) observer after the muskox have passed the main field of vision of the primary observer to their 9 (left side) or 3 (right side) o'clock. The small hand on a clock is used to reference relative locations of muskox groups (e.g. "muskox group at 3 o'clock" would suggest a muskox group 90° to the right of the aircraft's longitudinal axis.).

Results and Discussion:

Initial results of the July 2017 NKMx muskox survey using Jolly (1969) indicate a continued increase in abundance from July 1999 through July 2017 (**Figure 8**). Current estimates show the northern Kivalliq muskox subpopulation to have increased from an estimated 1,522 (95% CI = 396; CV = 0.09) adult and yearling muskox in July 1999 to 2,341 (95% CI = 545; CV = 0.12) in July 2012, and 3,239 (95% CI = 1,050; CV = 0.16) by July 2017 (Campbell and Settingington, 2006; Campbell and Lee, 2013).

There was not a significant statistical difference between the 2012 and 2017 population estimates ($z = 1.55$, $p = 0.12$) using the z-test. However, there was a significant statistical difference ($z = 2.83$, $p = 0.0047$) between the 1999 mean estimate of 1,522 (CI = 843—2201, CV=0.22) and the 2017 mean estimate of 3,239 (CI = 2221—4257, CV=0.16) using the z-test, which is consistent with information gathered through local hunters that the numbers of muskox observed in the area have increased over the past two decades. In the Monto Carlo simulations, 92.4% of the runs demonstrated an increase of 100 animals from 2012 to 2017 (**Figure 8**). See **Table 2** for levels of increase ranging from 100 to 500.

Table 2 – Percentage of Runs that resulted in an increase, for each level of difference value explored.

Level of Difference between 2012 and 2017 (absolute numbers)	Percentage of Runs demonstrating an increase by the Value indicated
+100	92.4%
+200	89.2%
+300	85.3%
+400	80.5%
+500	74.9%

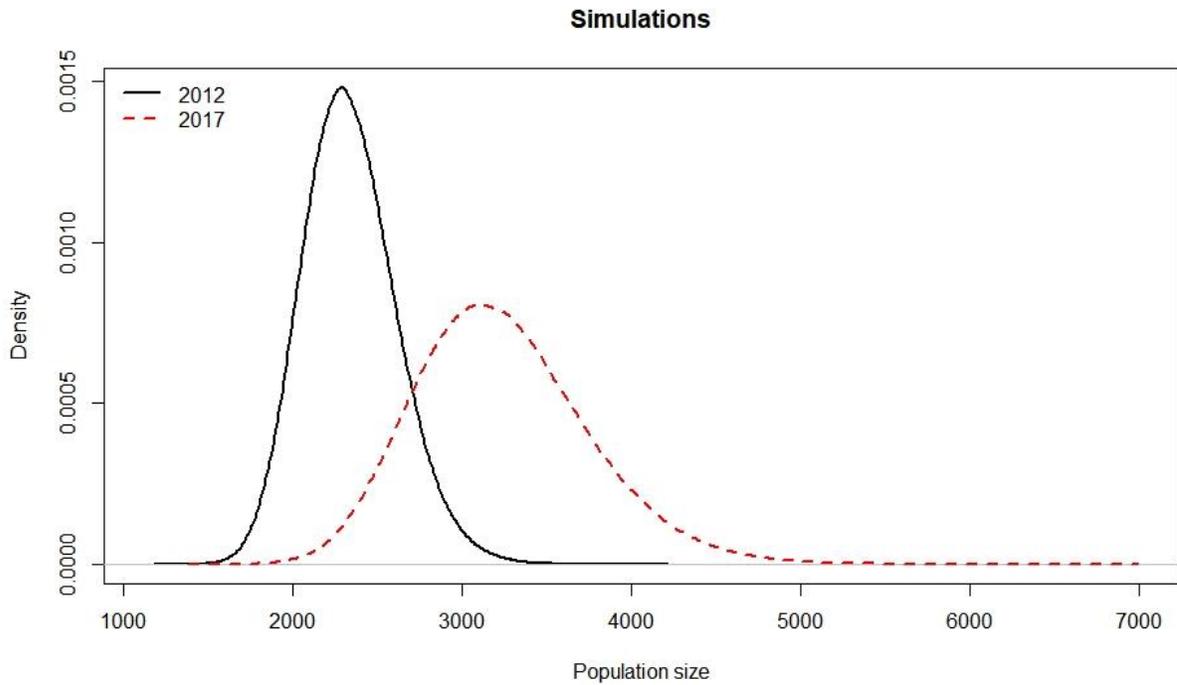


Figure 8. Distributions that were generated and used in the Monte Carlo simulation exercise to explore differences between the northern Kivalliq muskox 2012 and 2017 aerial surveys.

Generalized Linear Models:

We also fit a simple linear model, Poisson (log) model, and binomial (logit) model to the three years of survey data. The observations and models suggest population growth occurred between 1999 and 2017 in NKMX. Based on the simple linear regression model ($R^2 = 0.92$, $p = 0.18$), the population was increasing at an average rate of 4.3% per year from 1999 to 2012 and 6.5% from 2012 to 2017 (**Figure 9**). Carrying capacity for the population is unknown.

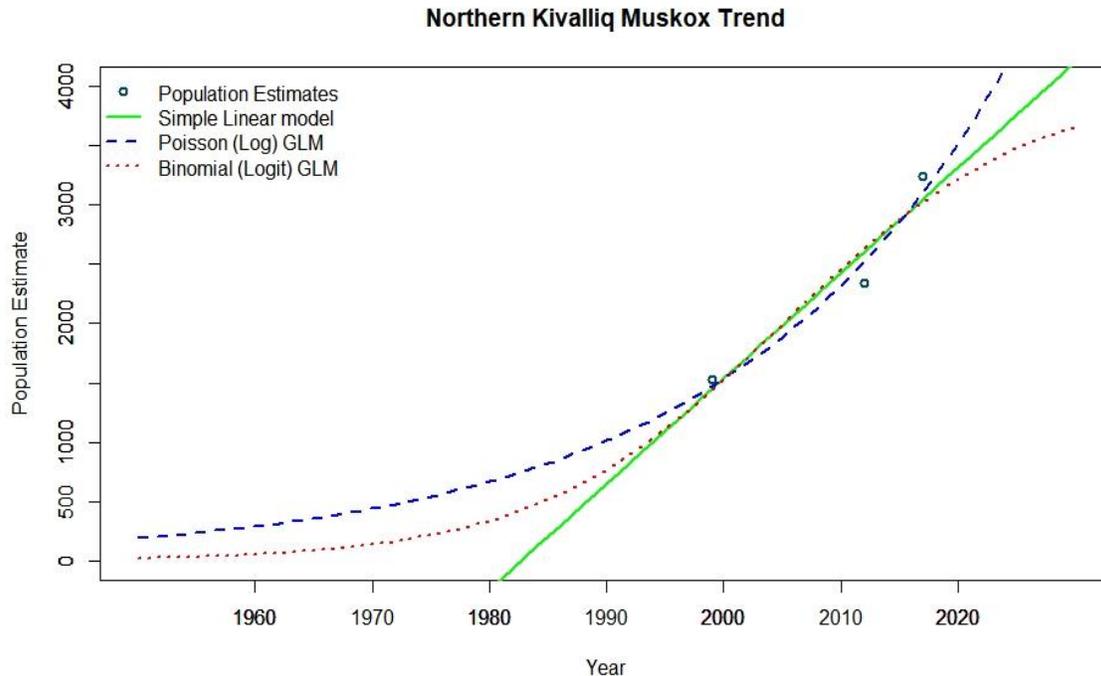


Figure 9. Plots of northern Kivalliq muskox population estimates with generalized Linear Models.

As with the CKMX subpopulation (MX/13), survey observations also suggest an expansion of the NKMX subpopulation's geographic distribution, eastwards (**Figure 10**). Survey areas, based on the extents of previous survey observations and IQ, have increased from 35,378 Km² in July 1999 to 49,302 Km² in July 2012 and to 60,576 Km² by July 2017, yielding an estimated increase in NKMX range area, between 1999 and 2017, of 41% (**Table 3**). A comparison using survey observations of muskox to construct a minimum convex polygon show continued expansion of the NKMX primarily to the east and southeast between July 1999 and July 2017 (Campbell et al. 2012) (**Figure 11**). Although our survey was not designed to estimate predator densities, in total we observed five wolves and no grizzly bears in July 2017. This provides no indication of quantitative changes in

predator numbers from July 2012, when we observed 8 wolves and single grizzly bear (**Figure 12**).

Table 3. A summary of northern Kivalliq muskox survey results north of Chesterfield Inlet/Thelon River and west to the NWT/Thelon Game Sanctuary boundaries (1999–2017).

Year	Total stratum area (km²)	Population estimate	Standard error	CV	Lower 95% CI	Upper 95% CI	% calves	Authors
1999 (July)	35,378	1,522	331	0.22	843	2,365	12.5	Campbell & Setterington, 2006
2012 (July)	49,302	2,341	275	0.12	1,796	2,886	13.2	Campbell & Lee, 2013.
2017 (July)	60,576	3,239	510	0.16	2,228	4,249	17.0	This Study

In addition to range expansion, the relative densities of the NKMX subpopulation have also increased when compared to the July 1999 abundance survey (**Table 4**). Relative densities of adult muskox within survey areas has increased from 0.043 muskox/km² in July 1999, to 0.048 muskox/km² in July 2012, and most recently, to 0.054 muskox/km², in July 2017. Relative densities within the 2017 survey extents are consistent with muskox densities of adjacent subpopulations, outside the survey area, and suggest that population stability and/or growth had occurred, compared with earlier findings of density in NKMX. A survey flown in July 1998 in the vicinity of the Thelon Game Sanctuary found between 0.021 and 0.063 adult muskox/km² (Bradley et al., 2001). Surveys flown to the north of the NKMK survey area in the vicinity of the Queen Maud Gulf (1996) found between 0.030 and 0.090 adult muskox/km², while a survey flown over the Adelaide Peninsula in June 1992 recorded 0.78 adult muskox/km² (Gunn et al., 1996; Nishi, 2001). Further north on the Boothia Peninsula, a survey flown in late July-early August recorded 0.030 adult muskox/km² (Gunn and Dragon, 1998). The most recent assessment of abundance and relative densities north of the survey area was reported following the July 2000 Northeast Kitikmeot muskox survey

(Figure 13). This July 2000 survey led to estimates which suggested stability in muskox abundance in Northeast Kitikmeot since the late 1990s, with reported relative densities within the southern extents of the survey area extending to the north shores of Garry Lakes of 0.056 adult muskox/km². Northern extents of the 2000 survey, extending to the northern shores of Adelaide Peninsula, reported adult muskox densities of 0.030/km², which was well below the June 1992 findings of 0.78/km² (Campbell and Settingington, 2006; Gunn et al., 1996).

Calf proportions within the NKMX subpopulation have increased between survey years: from 12.5% in July 1999, to 13.2% in July 2012 and to 17.0% in July 2017. The 2017 calf proportions are consistent with the estimated productivity that would be related with a stable to increasing abundance. An examination of muskox abundance on the Adelaide Peninsula across three abundance survey years including July 1986, June 1992, and July 2000, suggested a period of strong growth between July 1986 and June 1992, which was reflected in an estimated increase in abundance from 213 (Coefficient of Variation, CV = 0.59) in July 1986 to 1,165 (CV = 0.33) adult muskox in July 1992. However, the high CVs for both surveys make it difficult to determine the confidence of this increase, although actual observations support the likelihood of an increase.

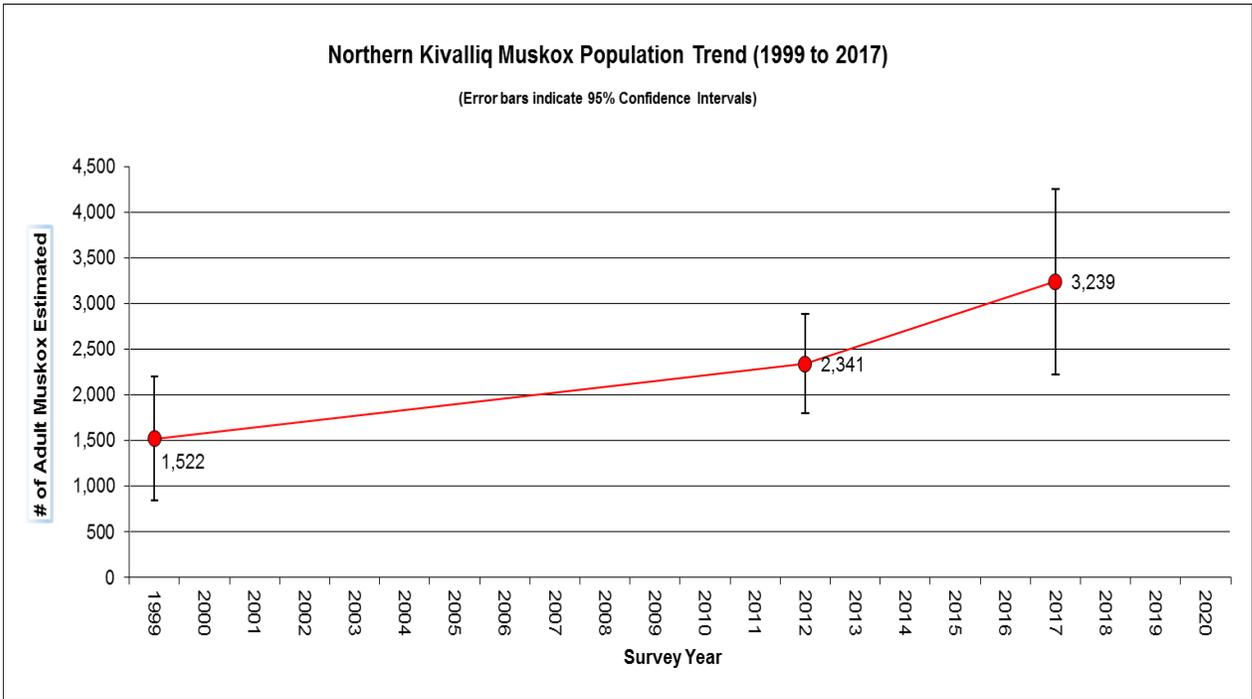
On-transect observations of animals increased from 44 adult muskox in 1986 to 233 adult muskox in 1992. Over the same survey periods calf proportions were reported as 17.1% in 1986 and 6.6% in 1992 (Gunn et al., 1996). While a survey flown in July 2000 over the Adelaide Peninsula did not subsample nor estimate the population of the Adelaide Peninsula due to low abundance, an examination of the July 2000 observations over the same survey area covered by Gunn et al. (1996) revealed a total count of 142 adult muskoxen and calf proportions of 14.8%. Examining these past trends suggest that caution must be exercised when extrapolating calf proportions as an indication of longer term trends. Additionally, calf proportions can vary widely from year to year. With this caution in mind, a comparison between calf proportions recorded in 1986, just prior to a reported increase in muskox relative densities within an area close to the July 2017 survey area, though qualitative, does corroborate the likelihood of the observed calf proportions in July 2017 as being consistent with increasing muskox abundance between July 2012 and 2017, when compared to a similar muskox subpopulation with a similar relative distribution and shared Ecozone.

Overall, the July 2017 NKMX surveys CV exceeded ten percent of the mean estimate, suggesting the need for stratification into two to three strata in future. The more clumped distributions of muskox encountered in 2017 were the main cause of the increased CVs. Because of the relatively high variance within the current analysis, these results should be used with caution. In an attempt to reduce overall survey variance, more statistical analysis of the July 2017 results are ongoing for the entire Kivalliq Muskox survey program. The complete reassessment of the July 1999, 2010, and 2016 central Kivalliq muskox surveys and the July 1999, 2000, 2012 and 2017 northern Kivalliq muskox surveys utilizing the double observer pair sight-re-sight and distance sampling analysis

procedure is nearing completion and will be provided to all co-management partners in the form of a GN File Report fall 2019.

Table 4. Data summary for the July 1999 northern Kivalliq muskox abundance survey, Nunavut.

Statistic		July 1999	July 2012	July 2017
Maximum number of transects	N	136	205	227
Number of transects surveyed	n	28	60	65
Total stratum area (km ²)	Z	35,378	49,302	60,576
Transect area (km ²)	z	7,276	14,405	17,600
Number of adult muskox counted	y	313	684	941
Number of Calves Counted		39	90	160
Muskox density (muskox/km ²)	R	0.043	0.048	0.054
Proportion Calves Observed		12.5 %	13.2 %	17.0 %
Population estimate (Adult Muskox)	Y	1,522	2,341	3,239
Population variance	Var (Y)	109569	75543	259659
Standard error	SE (Y)	331	275	510
95% confidence limits	(±)	679	566	1,050
Coefficient of variation	CV	0.22	0.12	0.16



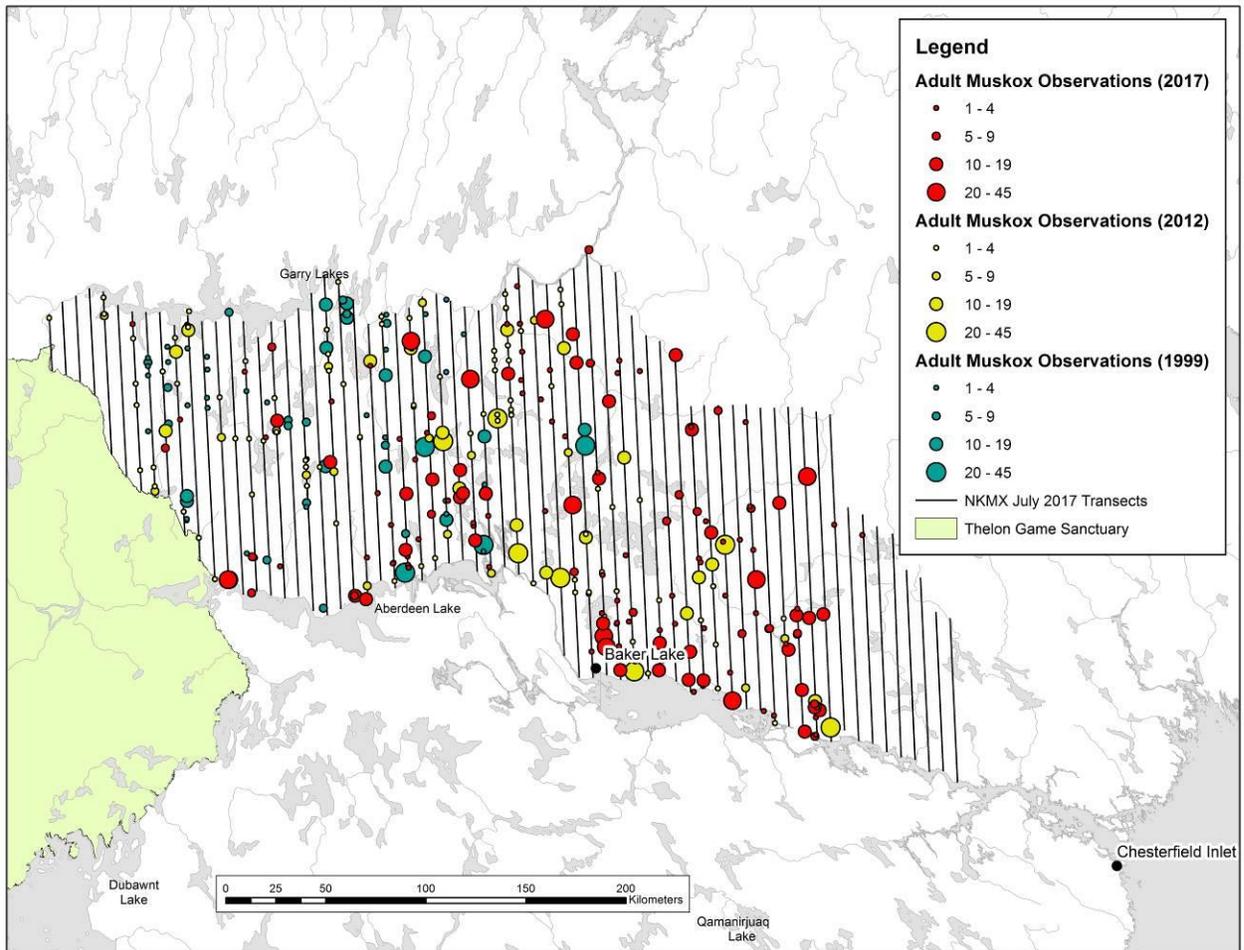


Figure 10. Northern Kivalliq muskox aerial survey observations of muskox from July 1999 (blue), to July 2012 (yellow), and July 2017 (red).

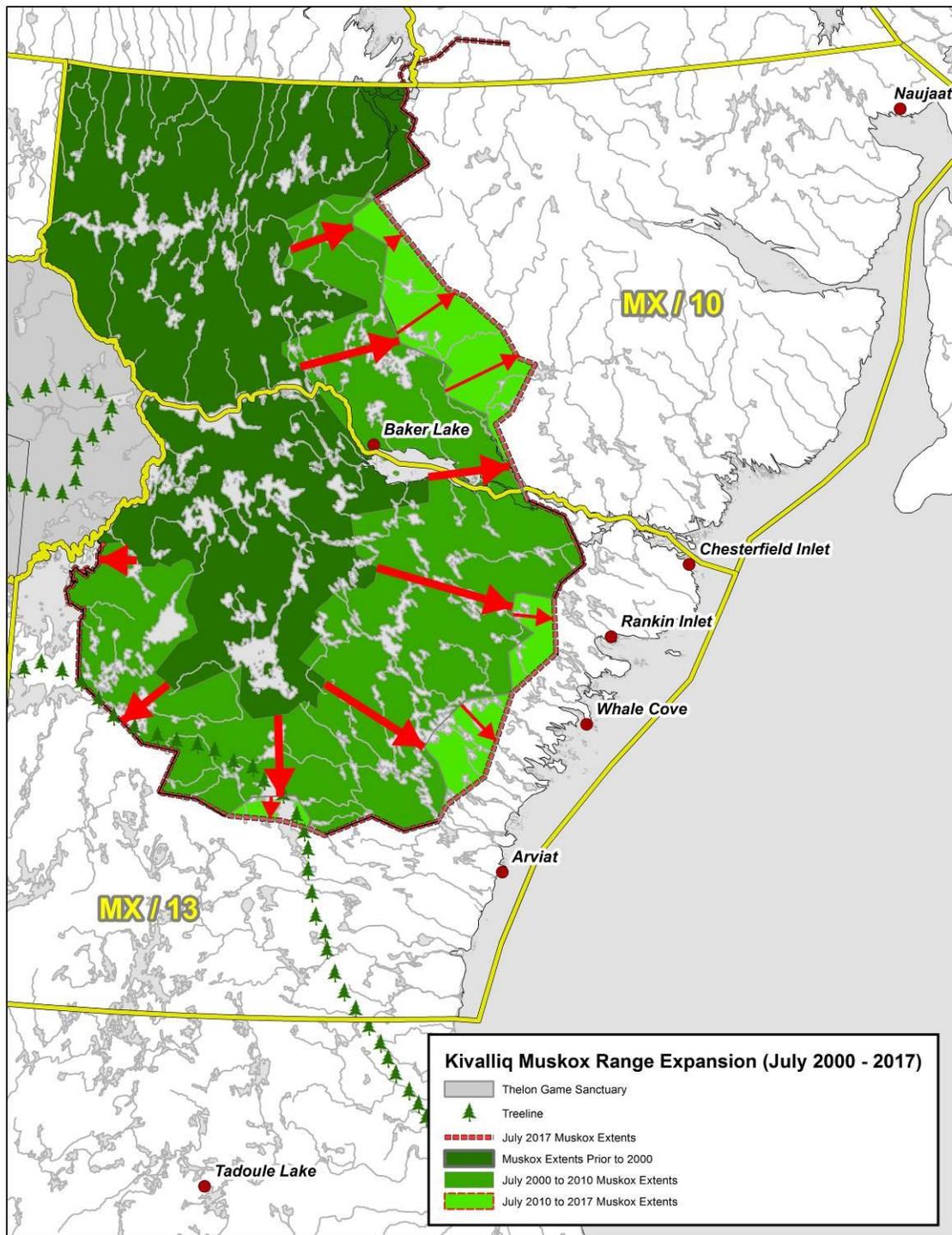


Figure 11. Indicated central and northern Kivalliq muskox range expansion between July 1999 and July 2016 (Central Kivalliq) and July 2017 (Northern Kivalliq).

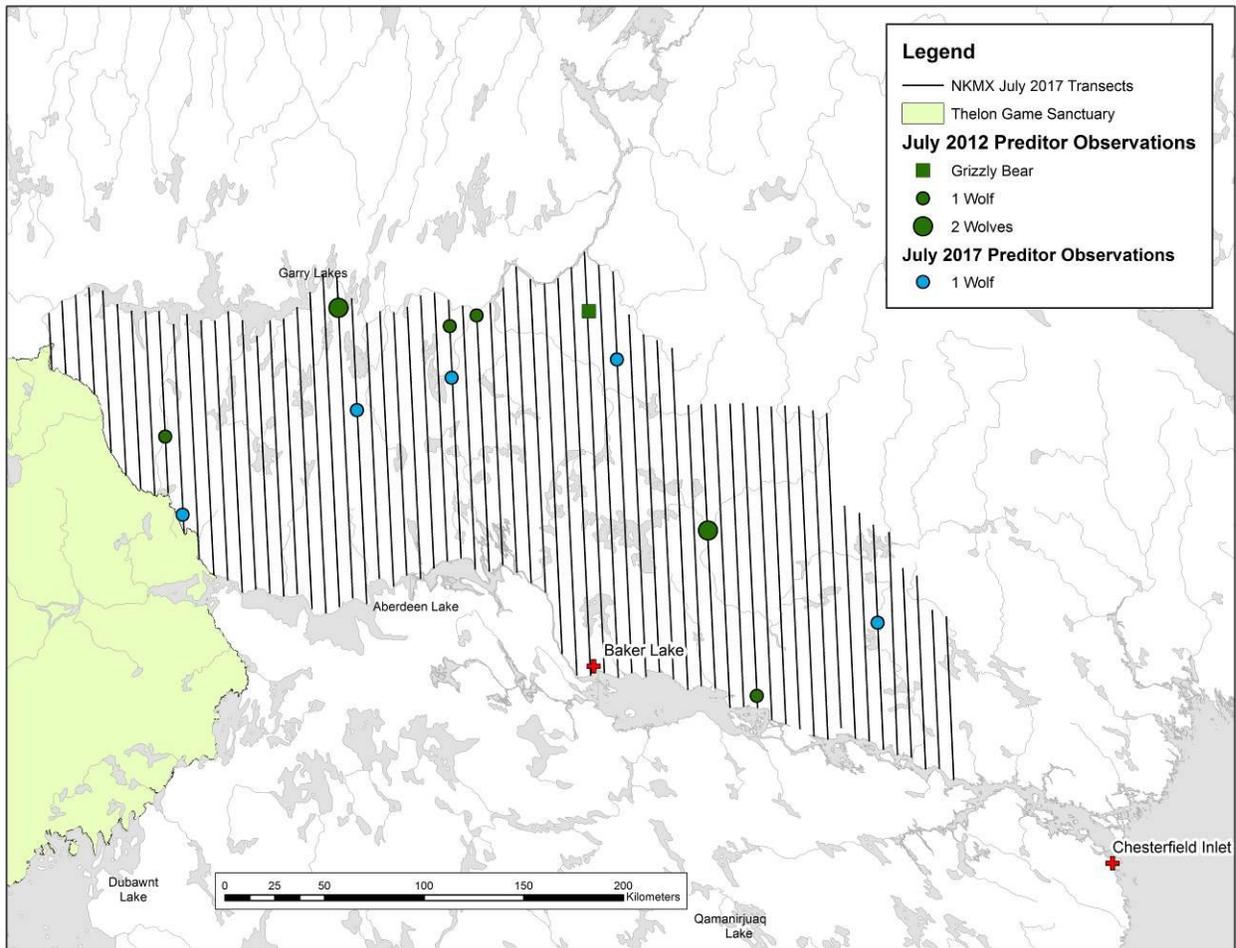


Figure 12. Predator observations during the July 2012 and 2017 northern Kivalliq muskox aerial surveys.

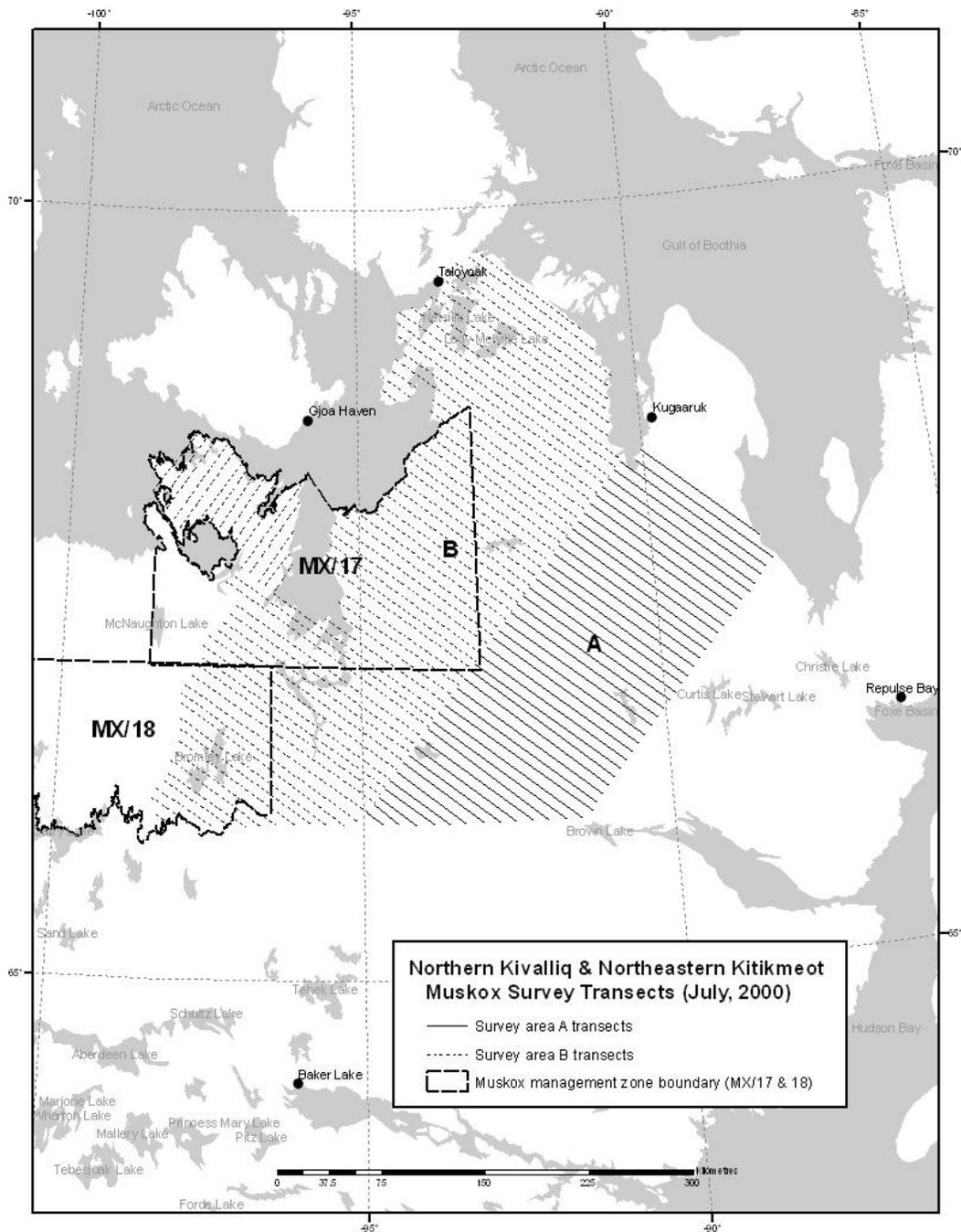


Figure 13. Survey areas and the transects flown over the northeastern Kitikmeot survey area in July 2000 (Campbell and Settrington, 2006).

Community consultation:

In October 2018, the GN DOE met with the Kivalliq Wildlife Board (KWB) and its representatives from the communities of Arviat, Whale Cove, Rankin Inlet, Baker Lake, Chesterfield Inlet, Repulse Bay, and Coral Harbour, to discuss all preliminary results and draft population estimates for NKMX. During this meeting, it was agreed that until the northern Kivalliq muskox survey results were ready, no decision would be made concerning the adjustment of either the subpopulations TAH and/or NQL. Following the completion of this report, all Kivalliq HTOs and the KWB will be provided with a copy for discussion. Letters indicating agreement with initial survey findings and support of GN management recommendations have been requested from all HTOs and the KWB. Presently, HTO members, local Conservation officers and local hunters are taking part in the continued collection of local knowledge concerning the location of muskox groups across the central and northern Kivalliq, and incorporating IQ and local knowledge in the possible mechanisms surrounding their continued range expansion into new habitats.

Management Findings/Actions/Recommendations:

Central Kivalliq Muskox Subpopulation (MX-13):

1. By July 2010, the central Kivalliq muskox subpopulation (MX-13) had expanded outside of its previously documented distribution, particularly to the south (towards the Manitoba Border) and eastward (to the coast of the Hudson Bay). The July 2016 survey observations provided evidence of a slowing of this expansion, though small areas along the eastern and southern extents indicated some continued expansion of their contemporary range extents;
2. A management plan was developed in 2010 by the Kivalliq Wildlife Board, GN DOE, and NTI Wildlife and Environment. The July 2016 initial survey results have been released (Campbell, 2017).
3. Additional monitoring of muskox must include the ongoing collection of IQ as well as periodic population assessments as deemed necessary by local communities, HTOs, and IQ.
4. To improve TAH recommendations and overall management, additional muskox research should focus on determining demographic parameters such as sex and age characteristics and levels of natural mortality within the population;
5. To improve TAH recommendations and overall management, additional muskox research should also focus on barren-ground grizzly bear abundance, distribution, and feeding behavior and their effects on muskox behavior, distribution, and general ecology;
6. The central Kivalliq muskox subpopulation (MX-13) boundaries should remain as indicated (**Figure 13**);
7. Due to the lack of a statistically significant change in abundance of the central Kivalliq muskox subpopulation, and in the absence of more recent abundance information, the DOE give a preliminary recommendation of no change in TAH, which is currently set at 182 muskox and calculated using 5% of the July 2016 estimates lower 95% Confidence Interval) (**Figure 13**). Following the complete reassessment using double observer pair sight re-sight and distance sampling analytical methods, the GN DOE recommends conducting consultations on these recommendations with all co-management partners to generate management recommendations for CKMX;
8. We continue to recommend no non-quota limitations of seasons and sex selectivity for subsistence muskox harvesting based on the most recent abundance estimate.

Northern Kivalliq Muskox Subpopulation (MX-10):

The DOE is planning to speak with the KWB (by teleconference) to discuss survey results in spring 2019. During this meeting, a new TAH will be discussed and recommendations to the GN DOE and NWMB made;

1. The northern Kivalliq muskox subpopulation (Southern extents of MX-10) has continued to expand outside of previously documented distribution, particularly eastward along the north shore of Chesterfield Inlet (**Figure 11**);
2. A management plan was developed in 2010 by the Kivalliq Wildlife Board, NTI and GN DOE. The management plan utilizes the results of abundance surveys to help guide management actions and recommendations for Kivalliq muskox populations;
3. The northern Kivalliq Muskox subpopulation appears to have increased from 2,341 +/- 545 (95% CI) in July 2012 to 3,239 +/- 1,050 (95% CI) adult muskox in July 2017, although the change was not statistically significant (**Figure 9**);
4. Utilizing a harvest ratio of 5% of the July 2017 adult estimate (lower 95% confidence interval) is not directly applicable in the current situation due to the lack of statistical significance detected between the 2012 and 2017 surveys. For Monte Carlo simulations, 92.4% of the runs demonstrated an increase of only 100 animals from 2012 to 2017 and for this reason, we would recommend a more cautious approach (Table 2). Pending consultation with co-management partners, we would recommend the northern Kivalliq muskox subpopulation TAH be increased from 90 to 95 muskox to maintain the stability of the population. This recommendation is based on the increase in abundance indicated between survey years and the upward trend detected in the trend analysis. (**Figure 14**);
5. Pending consultation with co-management partners, we would also recommend no NQLs (Non Quota Limitations) for the northern Kivalliq subpopulation be maintained until such time as observed changes in muskox abundance and distribution suggests a re-consideration of these restrictions, following full consultation with all co-management partners;
6. To improve TAH recommendations and overall management, additional muskox research should also focus on barren-ground grizzly bear abundance, distribution and feeding behavior;
7. The boundaries of the northern Kivalliq muskox subpopulation (within MX-10) should be re-examined to assess the relevance of expanding northern and eastern extents (**Figure 11, Figure 14**).

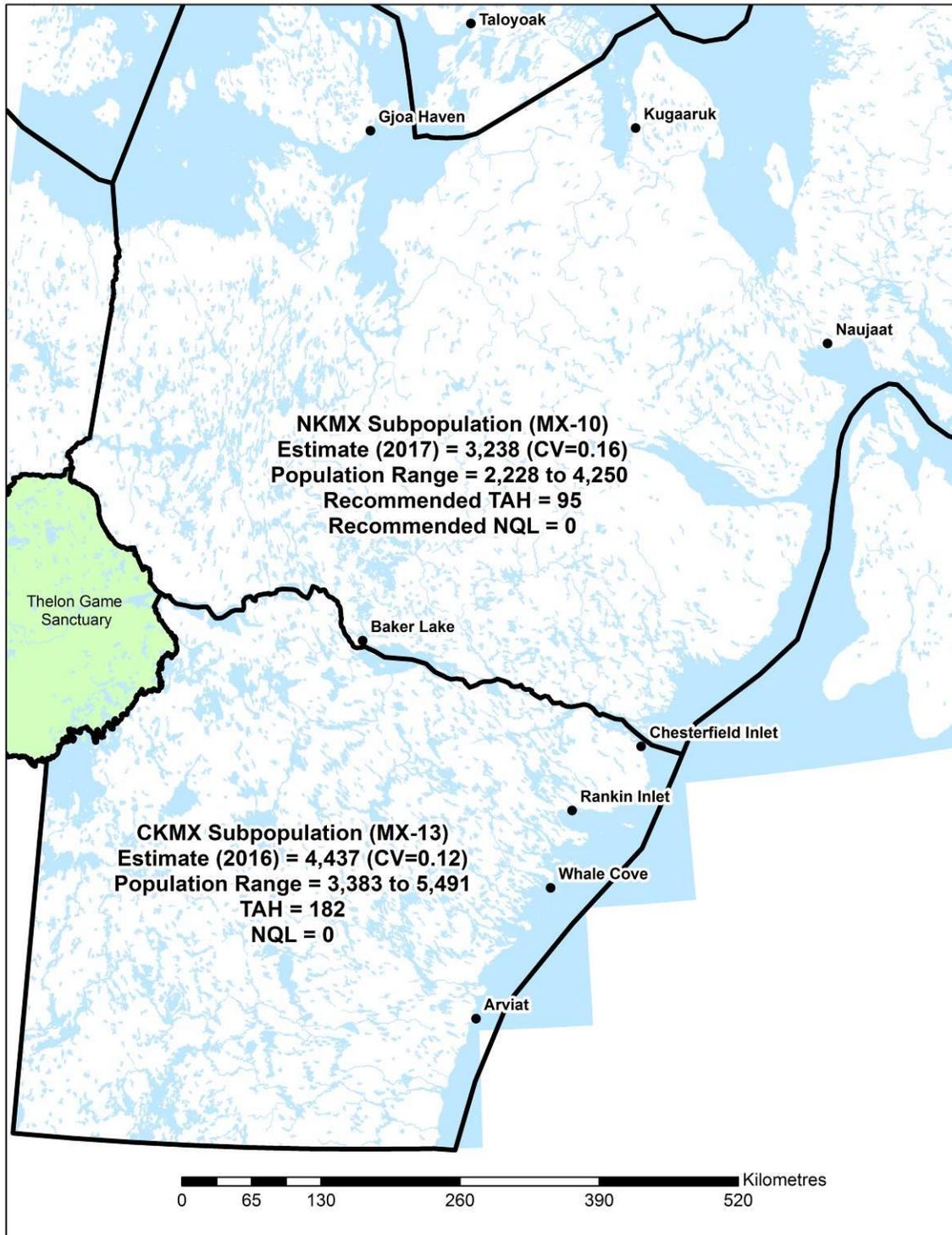


Figure 14. Recommended population boundaries and TAH for the Central Kivalliq Muskox (MX-13) and Northern Kivalliq muskox (MX/10) subpopulations. TAH based on July 2016 and July 2017 preliminary survey estimates respectively.

Acknowledgments:

We would like to thank the Kivalliq Wildlife Board, and the Baker Lake, Rankin Inlet, Chesterfield Inlet, and Naujaat HTOs for their ongoing support of muskox research programs within the northern Kivalliq. I would like to extend a special thanks to our community based observers Quentin Quinangnaq, Timothy Eviuk, and Leo Ikakhik for their professionalism and keen observation skills. Keenan Lindell, Kivalliq Regional Wildlife Technician, commendably handled travel, lodgings, and worked with the HTOs to select and manage observers on top of his many other survey-related tasks including his participation as an observer. We would also like to thank our Pilot Paige Moritz for her skillful handling of our survey aircraft, bringing us to a safe and successful conclusion to the 2017 muskox survey program. We would also like to thank Lynda Orman, the former Manager of Wildlife Research, for her support of the Kivalliq Ungulate Monitoring Program. We are also grateful to the Nunavut Wildlife Management Board for their continued financial support of the Kivalliq ungulate monitoring program.

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September 27, 2019

Mitch Campbell
Department of Environment
P.O. Box 120
Arviat, Nunavut
X0C 0E0

Dear: Mr. Campbell,

Increasement of Musk Ox Tags; MX-13

The Arviat Hunters and Trappers Organization held their regular meeting on Tuesday, September 24, 2019 and the board of directors would like to inform you that you have been approved for the letter of support.

This letter is written to state that we, the Arviat Hunters and Trappers Organization Board of Directors have discussed and are in support of increasing Status Quo MX-13; Musk Ox Tags by 5 from 90 to 95 and keep the other management the same from all other wildlife; (MX-10)

If you have any questions, comments or concerns, please contact the Arviat HTO. Thank you.

Sincerely,

Thomas Alikaswa
Arviat HTO Chairperson

Re-evaluation of The Central Kivalliq Muskoxen (Ovibos moschatus) Distribution, Abundance and Quotas in muskox management unit MX-13

Final Technical Report

Government of Nunavut, Department of Environment

Arviat, Nunavut, Canada.

For submission to the Nunavut Wildlife Management Board
2019

Prepared by:

Mitch W Campbell¹

¹ Nunavut Department of Environment, Arviat, Nunavut.



Introduction / Summary:

Prior to the enactment of protection in 1917 (Burch, 1977), muskox populations throughout the central arctic were hunted to near extirpation. Muskox populations throughout Nunavut are currently re-colonizing much of their historical range, but there remain gaps in information on the status of muskox populations in much of the eastern Mainland (Fournier and Gunn, 1998). At its greatest extent the distribution and abundance of muskox in the Kivalliq region of Nunavut has occurred within an area extending south of Latitude 66° north, west to the NWT/Thelon Game Sanctuary boundaries, east to the Hudson Bay coast line and south to the Manitoba border. Distribution and abundance of muskox within the Kivalliq reliably occurs within a slightly smaller geographic area that has been expanding for over 50 years (Figure 1). Kivalliq muskox subpopulations have been estimated using fixed-width line transect surveys in July of 1985, July 1986, July 1991, and July 1999. By 2010 concern was raised over the ten year lapse of information coupled with hunter's observations of muskox closer to communities. A re-evaluation of the central Kivalliq muskox status was conducted in July 2010, and July/August 2016, while a re-assessment of the Northern Kivalliq Muskox subpopulation was undertaken in July 2012 and most recently in July/August 2017. Based on these most recent survey results, central Kivalliq muskox numbers steadily increased up to July 2010, and then appeared to have stabilized between 2010 and 2016. The most recent survey of the northern Kivalliq subpopulation is still in the analysis stage, however, an increasing trend was documented between July 2000 and 2012.

To date there are no indications of health problems within the herd. A research program examining the distribution of the lungworm (*Omingmakstrongylus pallikuukensis*) amongst mainland muskox has been initiated in MX-10 but all tests have shown no indication of presence in the Kivalliq subpopulations. Future research should continue to examine the extent to which muskox have occupied range outside presently defined management areas.

Recently, hunters have been reporting increased observations of muskox closer to their communities both south and east of previously known distributions (Mulders and Bradley, 1991; Rankin Inlet HTO pers. comm.; Baker Lake HTO pers. comm.; Arviat HTO pers. comm.; Chesterfield Inlet HTO pers. comm.; Repulse Bay HTO pers. comm.; Coral Harbour HTO, pers. comm.; Whale Cove HTO, pers. comm. 2008). Ideally communities in the Kivalliq region would like to have easier access to healthy muskox populations. Both population estimates and distribution observations discussed herein will provide information that will enable regional wildlife organizations, local HTOs and biologists to determine the potential long-term effects of current harvest regimes on muskox populations in the Kivalliq while providing information on the continued expansion of muskox into their historical range.

Based on the results derived from strip transect quantitative methods, total allowable harvests for the 2 populations of muskox within the Kivalliq region (one north of the Thelon/Chesterfield Inlet waterways (Northern Kivalliq – MX-10) and the second south

(Central Kivalliq – MX-13) are currently based on 5% of the estimated adult muskox population (lower 95% confidence limit). At present within the Nunavut Wildlife Act and Regulations, a total allowable harvest (TAH) of 182 muskox is recommended for the central Kivalliq muskox population (MX-13) (Figure 2).

At this time, and based on the 2016 population re-assessment of muskox in the central Kivalliq region, there is no new recommended change to the TAH of 182 and no new recommendations to the Nunavut Wildlife Management Board (NWMB).

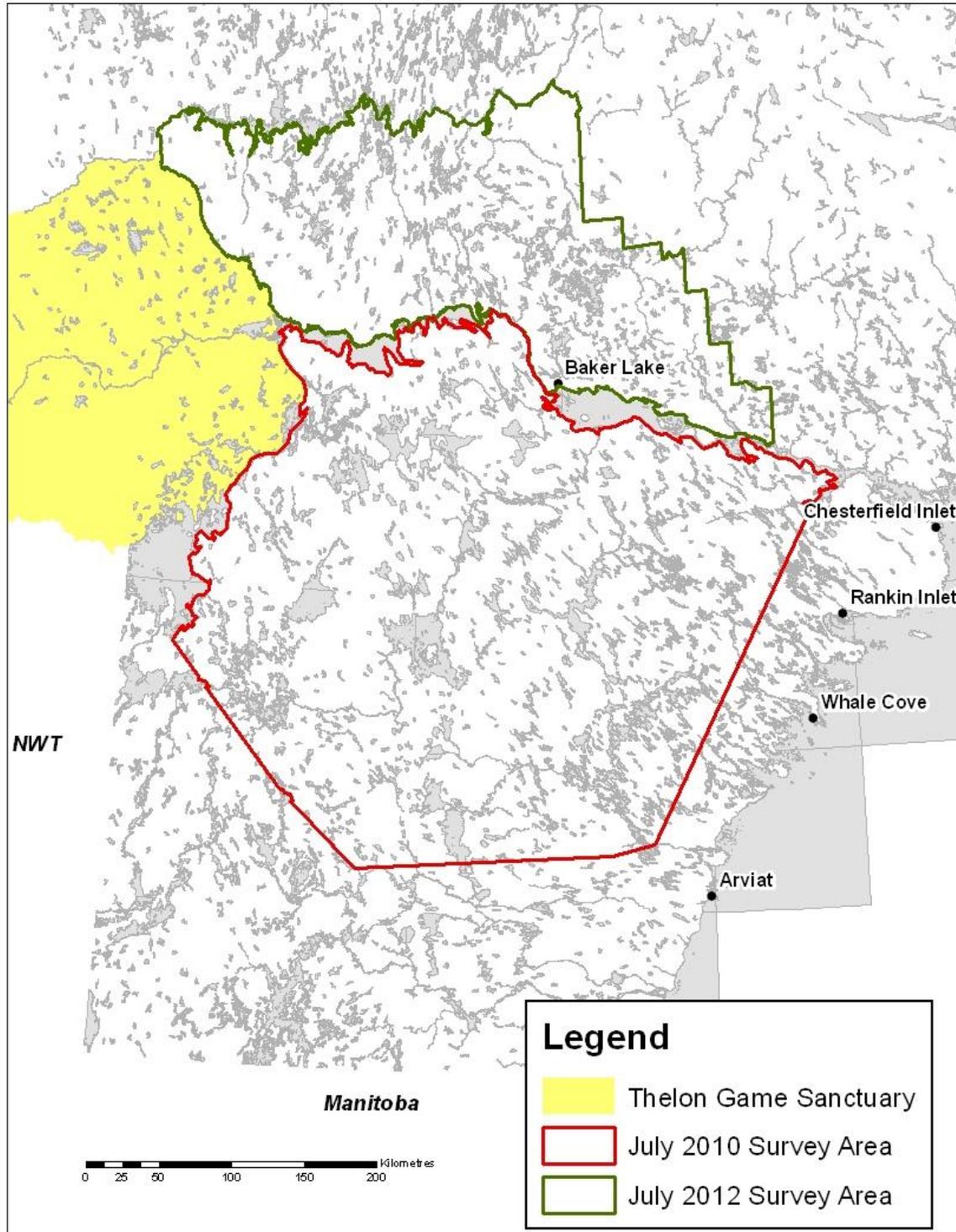


Figure 1. Survey study areas for the central (July 2010 &16) and northern (July 2012) Kivalliq muskox subpopulations (MX-13 & MX-10).

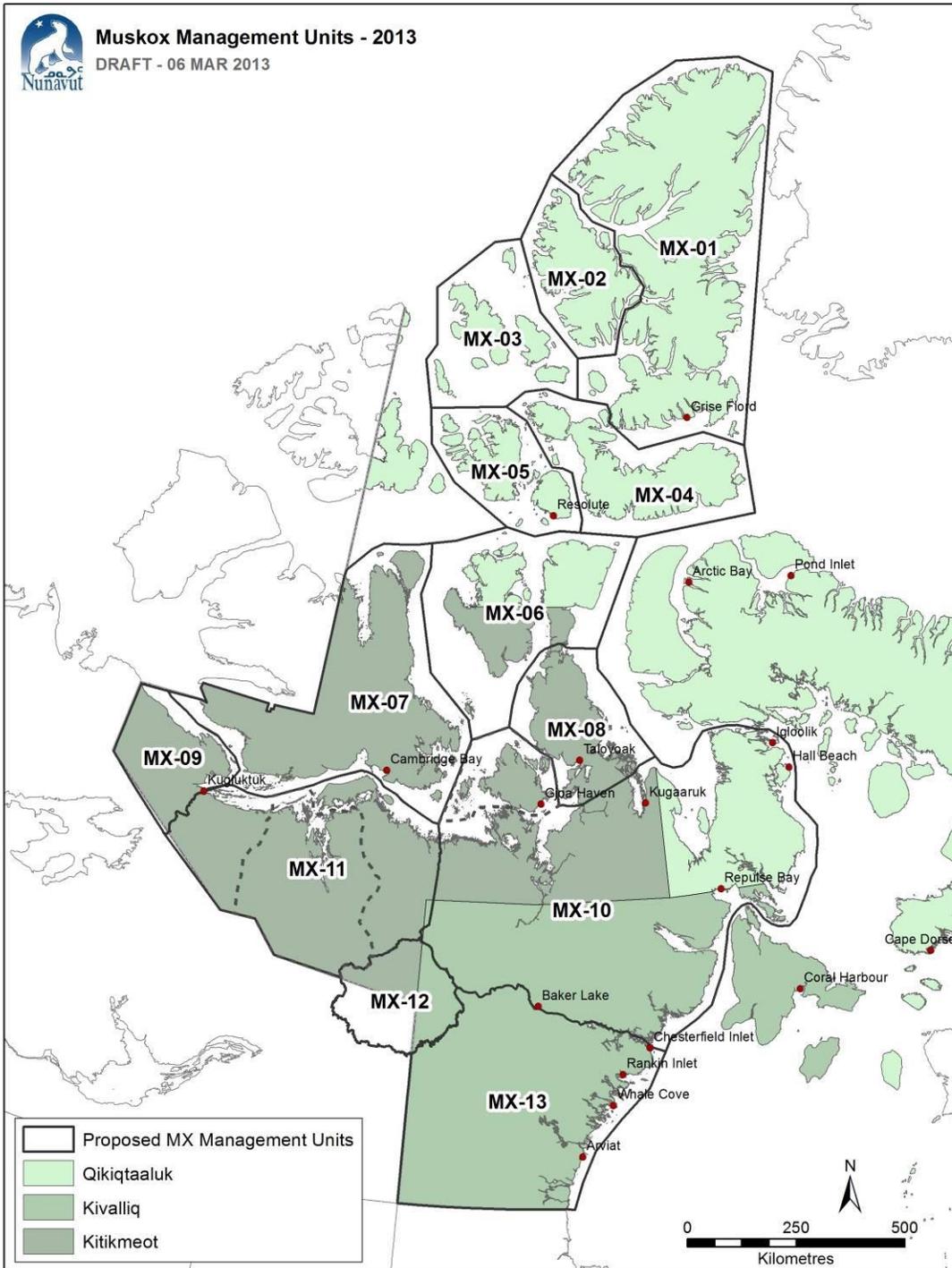


Figure 2. Nunavut’s muskox management zones. The Northern Kivalliq muskox subpopulation extents are represented by MX-10, and the central Kivalliq muskox subpopulation extents are represented by MX-13.

Objectives:

The objectives of the project were to utilize *Inuit Qaujimagatuqangit* and aerial survey methods to determine the subpopulation status of muskox in the Central (MX-13) and Northern (MX-10) Kivalliq Region of Nunavut. The results are currently being used to address requests by Kivalliq HTOs to sustainably harvest more muskox closer to their communities. The results of the surveys have provided recommendations for harvest levels (TAH) and population boundaries as well as the adjustment to non quota limitations (NQL). The information from these surveys has been used to determine the numbers of muskoxen within MX-10 and MX-13 as part of the requirement outlined in the Central Kivalliq Muskox Management plan developed by the Kivalliq Regional Wildlife Board in partnership with the Department of Environment, Government of Nunavut, and Nunavut Tunngavik Inc.. Muskox populations in the Kivalliq must be estimated regularly in order to provide recommendations on sustainable harvest.

Another objective of this research program was to determine the number of muskoxen on the periphery of previously delineated distributions. A comprehensive estimation of the muskoxen population outside known and historic distributions needs to be updated. Observations made by hunters suggest that there has been an increase in the number of muskox and that muskox have occupied a much larger range than reported in July 1999 and 2010. The expansion of muskox beyond previously delineated boundaries is confirmed in this report. The shorter growing season and thicker snow cover reported for the eastern arctic could make muskox expansion into historic range more sensitive to harvesting (Gunn, 1983; Forchammer and Boertmann, 1993). In order to develop harvest management recommendations, effort was put into determining the present status of the periphery of muskox populations relative to previous management zones.

Study Area:

The July 2010 and 2016, and 2012 and 2017 central and northern Kivalliq Muskox surveys incorporated an area stretching from the Hudson Bay coast to the Kivalliq Regional Boundary in the West, and North from the Manitoba Boundary to latitude 66^o north. The study area exists primarily within tundra habitats characterized by continuous permafrost, while a smaller portion extends along the fringe of the forest ecotone (Taiga) (Figure 1).

The central and northern study areas included portions of the Maguse River Upland, Dubawnt Lake Plain/Upland, Back River Plain, and the Garry Lake Lowland ecoregions of the Southern Arctic ecozone, and the Wager Bay Plateau ecoregion of the Northern Arctic ecozone (Environment Canada 2001; Table 1). These ecoregions are characterized by a cover of shrub vegetation consisting of dwarf birch (*Betula glandulosa*), willow (*Salix* spp.), and alder on warm, dry sites.

Poorly drained sites are dominated by willow, sphagnum moss, and sedge. The region is associated with areas of continuous permafrost and Turbic Cryosolic soils, but unfrozen organic (Mesisol and Regosolic) soils also occur. Bedrock forms broad, sloping uplands and lowlands. Hummocky bedrock outcrops covered with till are dominant, and prominent esker ridges occur in some parts of the area. Twenty-five to 50% of the Maguse River Upland ecoregion is wetlands that are characteristically lowland low- and high-centered polygon fens (Environment Canada 2001). Sandy flats sparsely covered with vegetation characterize the Dubawnt Lake Plain/Upland ecoregion, and the southwestern portion is characterized by rolling terrain forming broad sloping uplands and lowlands where small and medium sized lakes are common. Soils in most of the southern study area are Turbic and Static Cryosols on level to undulating discontinuous veneers of sandy morainal and fluvio-glacial deposits. The small portion of the central study area that falls within the northern Arctic ecozone is characterized by discontinuous cover of tundra vegetation including dwarf birch, willow, Labrador tea, *Dryas* spp., and *Vaccinium* spp. Lichen-covered rock outcroppings are common (Environment Canada 2001).

Table 1. Ecoregions of the central (MX-13) and northern (MX-10) muskox survey study areas in the Kivalliq and northeast Kitikmeot region of Nunavut.

Study Area	Ecozone	Ecoregion
Central (MX-13)	Southern Arctic	Maguse River Upland
		Dubawnt Lake Plain/Upland
		Back River Plain
		Garry Lake Lowland
	Northern Arctic	Wager Bay Plateau
Northern (MX-10)	Southern Arctic	Chantrey Inlet Lowland
		Queen Maud Gulf Lowland
	Northern Arctic	Wager Bay Plateau
		Victoria Island Lowlands
		Boothia Peninsula Plateau

Methods:

Survey Area

Two methods were used to meet the stated objectives. The first was a collection of *Inuit Qaujimagatuqangit* and local knowledge to determine currently known distributions of muskox. Information was collected and compiled during consultation visits with the communities of Rankin Inlet, Baker Lake, Whale Cove, Chesterfield Inlet and Arviat. The information collected was then used to help determine the survey study area extents. Once the survey study area was designated, systematic transects, drawn with a random starting point, were placed throughout the survey study area at a spacing of 7.0 km which when flown at an altitude of 152 meters (500 ft.) provided a maximum strip width of 2000 meters. All surveys were flown using an independent double observer pair (sight-resight) distance sampling method. The 2000 meter strip width provided 29.2 percent coverage of the entire survey area (Figure 3). Due largely to the exceptional sightability of muskox in July, visual transect survey methods are widely accepted as being the most cost effective means of estimating muskox populations while still providing an acceptable level of precision (Case and Graf, 1986; Graf and Case, 1989; Graf *et al*, 1989; Gunn, 1995; Mulders and Bradley, 1991).

Aircraft Configuration

All surveys were flown using a Cessna 206 Grand Caravan high wing single engine turbine aircraft based out of Rankin Inlet and Baker Lake. Strip widths of 0 to 250 meters, 250 to 500 meters, 500 to 750 meters and 750 to 1000 meters were established on the wing struts on both sides of the aircraft using streamers to mark off the 0 meter, 500 meter and 1000 meter markers and tape to delineate the remaining 250 and 750 meter segments (Figure 4). Strip width (w) was calculated using the formula of Norton-Griffiths (1978):

$$w = W * h/H$$

where:

W = the required strip width;

h = the height of the observer's eye from the tarmac; and

H = the required flying height

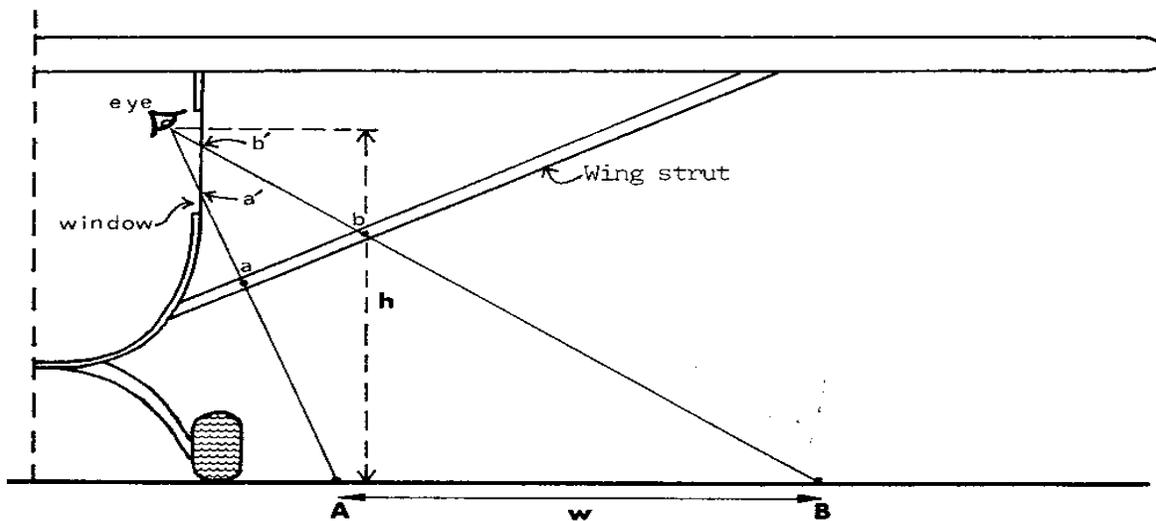


Figure 4. Schematic diagram of aircraft configuration for strip width sampling (Norton-Griffiths, 1978). W is marked out on the tarmac, and the two lines of sight $a' - a - A$ and $b' - b - B$ established. The streamers are attached to the struts at a and b . a' and b' are the window marks.

The strip width area for density calculations was 1000 meters out each side of the aircraft, for a total of 2000 m along each transect. The further division of the 1000 meter markers into 250 meter segments was to facilitate estimates using distance sampling techniques. Due to the size of the study area, the relatively limited data on muskox densities within much of the study area, and time and other logistic limitations, it was decided to allocate all of the survey effort into one systematic random transect survey over both survey years. Survey altitude was maintained as close as possible to 185 m above ground level (agl) using a radar altimeter. Ground speed was maintained between 175 and 195 kilometers per hour. The 2010 central Kivalliq muskox survey was initiated July 10, and completed July 22, 2010, while the 2016 central Kivalliq muskox survey was initiated July 24, and completed August 24. The 2012 northern Kivalliq muskox survey was initiated July 6th, and completed July 11th, while the 2017 northern Kivalliq muskox survey was initiated July 21 and completed July 29.

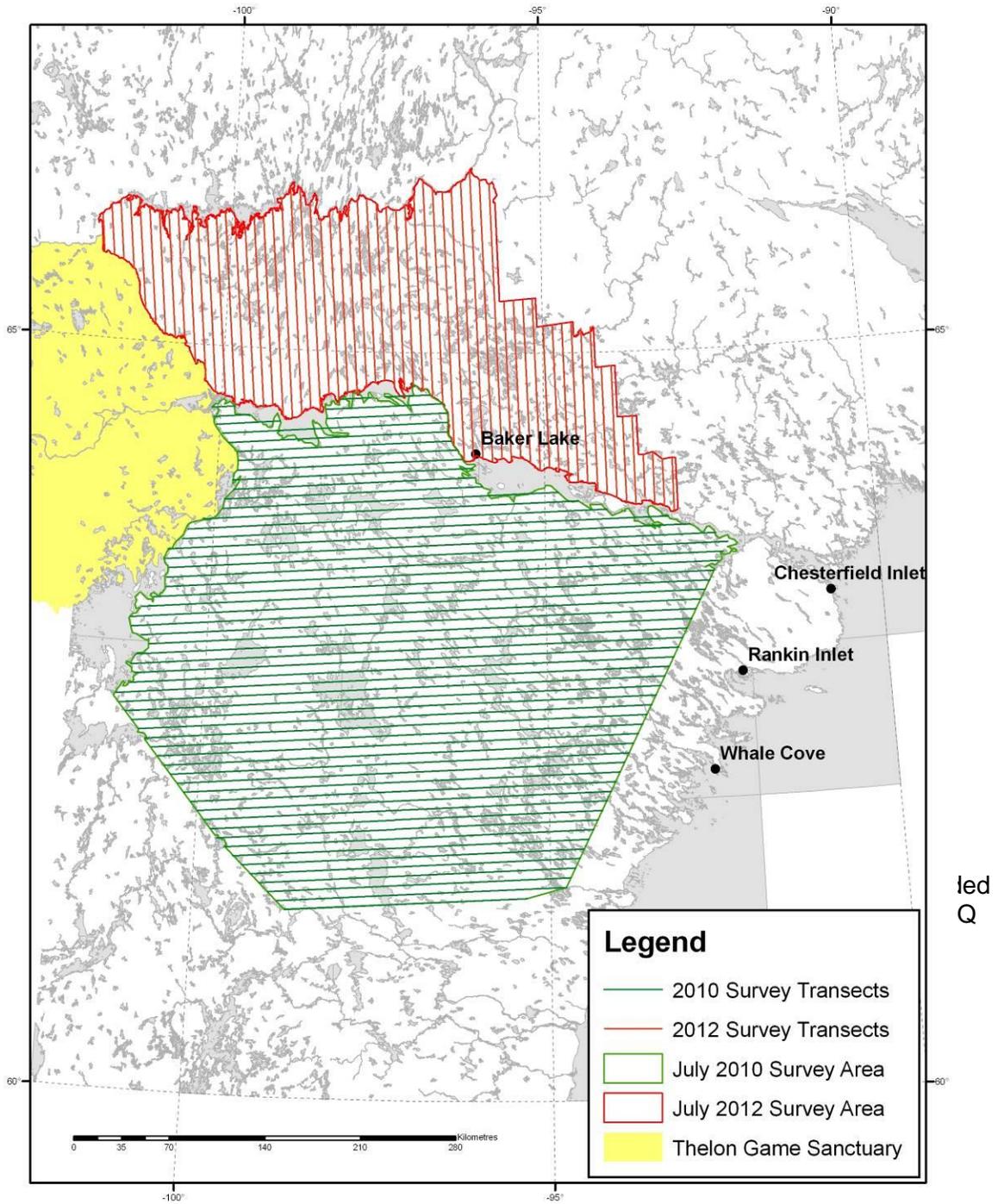
The entire survey was set up as an independent double observer sight-resight (capture/mark-recapture) distance sampling platform utilizing a survey crew of 7; two data recorders/navigators, two left side observers, two right side observers and the pilot (Figure 5). Two of the selected observers, one for each side of the aircraft, had experience surveying wildlife visually from aircraft. The two remaining observers were selected by the local HTO pertinent to each of the survey areas (Rankin Inlet, Baker Lake, and Arviat). The observers were further divided into front and rear teams, each isolated from the other using visual barriers between the seats as well as isolated through the use of two independent intercom systems monitored by each of a front data

recorder/navigator and a rear data recorder/navigator. The pilot's responsibilities were to monitor air speed and altitude while following transects pre-programmed on a Garmin GPS 176 and 650t geographic positioning system devices (GPS). The data recorder/navigators were responsible for monitoring a second and third identically programmed GPS unit for the purposes of double-checking the position as well as to record the waypoints and numbers of observed muskox groups composed of adults and calves on data sheets. The responsibilities of the observers were to monitor their 1,000 meter segmented strips and call out numbers of muskox, separated by adults and calves observed within each designated 250 meter wide sub-strip (distance sampling). The rear right and front left observers, the pilot and the two data collector/navigators remained consistent throughout the 2010, 2012, 2016 and 2017 surveys while the observers varied depending on survey. All experienced observers remained consistent across each individual survey period. The 2012, 2016 and 2017 survey observers switched positions half way through the day (front to rear and rear to front) to provide data with which to assess changes in sightability between the front and rear positions. Only counts of adults and yearlings were used in the population estimate.

Statistical Analyses

Survey data collected within each of two pre-stratified strata were analyzed using Jolly's Method 2 for unequal sample sizes (Jolly 1969 *in* Norton-Griffiths 1978). Only counts of adults were used for the final population estimates. Lake areas were not subtracted from the total area calculations used in density calculations.

Sight-resight and Distance sampling analysis are ongoing and will appear in their entirety following the completion of a fully reviewed GN DOE file report. The completion of the file report is expected in the fall of 2018 and will replace any and all previous reports produced for co-managers including the present work. As other analyses are ongoing, the authors of this report and the GN DoE would like to ensure the reader understands that the results presented herein may change following further more comprehensive analysis and to this end reserve the right to update the results presented in this report within the final GN DOE File Report. Any and all GN DOE research projects are required to produce a comprehensive thoroughly peer reviewed File Report following the completion of the research program. The GN File Reports represent the most comprehensive and complete reporting format and as a result will be the main documents used to make management recommendations.



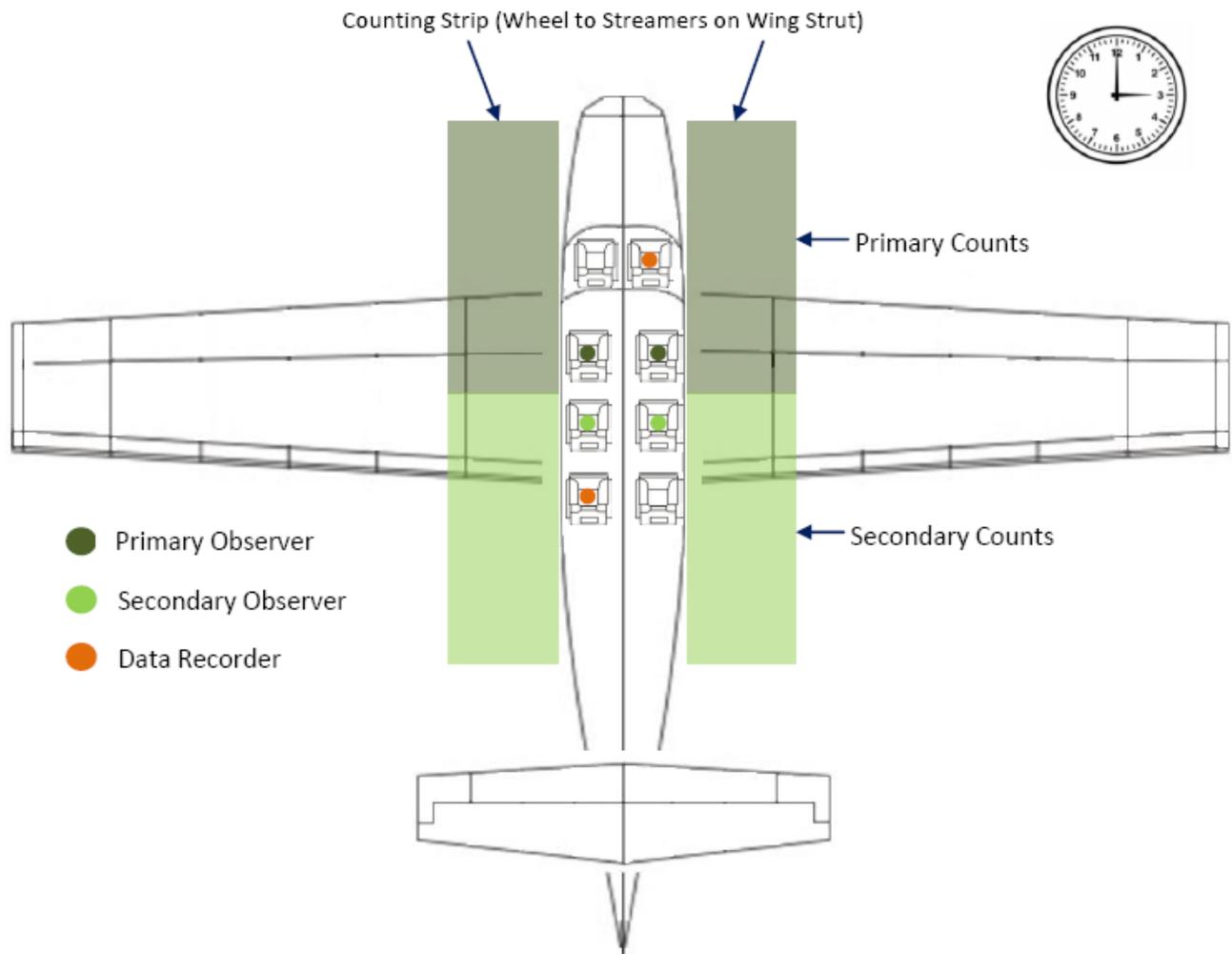


Figure 5. Observer position for the double observer method employed on this survey. The secondary observer calls muskox not seen by the primary observer after the muskox have passed the main field of vision of the primary observer. The small hand on a clock is used to reference relative locations of muskox groups (e.g. “muskox group at 3 o’clock” would suggest a muskox group 90° to the right of the aircrafts longitudinal axis.).

Results and Discussion:

Central Kivalliq Muskox Survey

The Central Kivalliq muskox subpopulation had been steadily increasing between July 1986 and July 2010 (Figure 6). The most recent July 2016 estimate, however, suggests a stabilization in abundance across the central Kivalliq. Central Kivalliq muskox abundance estimates of 838 (+/- 362, 95% CI) in July 1986 steadily increased to 1,203 (+/-284, 95% CI) in July 1991, 2,143 (+/- 396, 95% CI) in July 1999, and finally 4,506 (+/- 948, 95% CI) by July 2010. An estimate of 4,437 muskox (+/- 1,054, 95% CI) in July 2016 indicates a stabilization in growth with no statistically validated change detected (Figure 6, Table 2). Of note was the survey flown in July 1991 which found muskox in a much smaller area than the July 1999 survey over the same general survey extents. Despite this discrepancy in area occupancy, similar relative densities were recorded. The 2010 survey results did indicate an increase in abundance but for the first time since 1985 showed a dramatic decline in muskox density within the survey area. This same general trend in relative density continued into 2016. This could be an artifact of the much larger survey area or it could suggest a punctuated/accelerated range expansion since the July 1999 survey. Further research and analysis is necessary before making any conclusions as to the mechanisms behind these changes in relative density.

Limitations to comparisons made with pre-1999 muskox surveys in the central Kivalliq were noted above. The primary limitation relates to variations in survey study areas, where the 1999, 2010 and 2016 central Kivalliq survey extents included a broader area designed to encompass all muskox within the central Kivalliq region and as a result were overlapping. Overall, central Kivalliq muskox were found over a much broader area in both 2010 and 2016 than previously recorded, suggesting not only an increase in abundance but an expansion of their range as well (Figure 7, Figure 8). During the July 1999 survey, muskox were more concentrated within smaller geographic areas than observed in July 2010 and 2016. One of the most surprising observations was the presence of numerous carnivores, and most specifically grizzly bears. A total of 21 grizzly bears (of all ages and sexes) were observed within both the July 2010 and July 2016 survey areas. All were observed in very good to exceptional body condition (Figure 9). This represents a considerably higher number than the 6 observed during the July 1999 survey though the survey area in July 1999 was considerably smaller. Additionally, wolf relative densities appeared to be higher in more recent years. In July 1999, 16 wolves were observed on transect while in July 2010, 39 wolves were observed. In July 2016, 30 wolves of all ages and sexes were observed on transect.

Observations of muskox in what was previously considered marginal habitat raised several questions, while at the same time densities in what was previously

considered better quality habitat dropped substantially. All these observations raise questions as to whether muskox populations are poised to increase further or are reacting to change in environmental conditions, predator-prey dynamics, or anthropogenic changes within the environment. Further analysis is ongoing in attempts to explain the changes observed in both July 2010 and 2016.

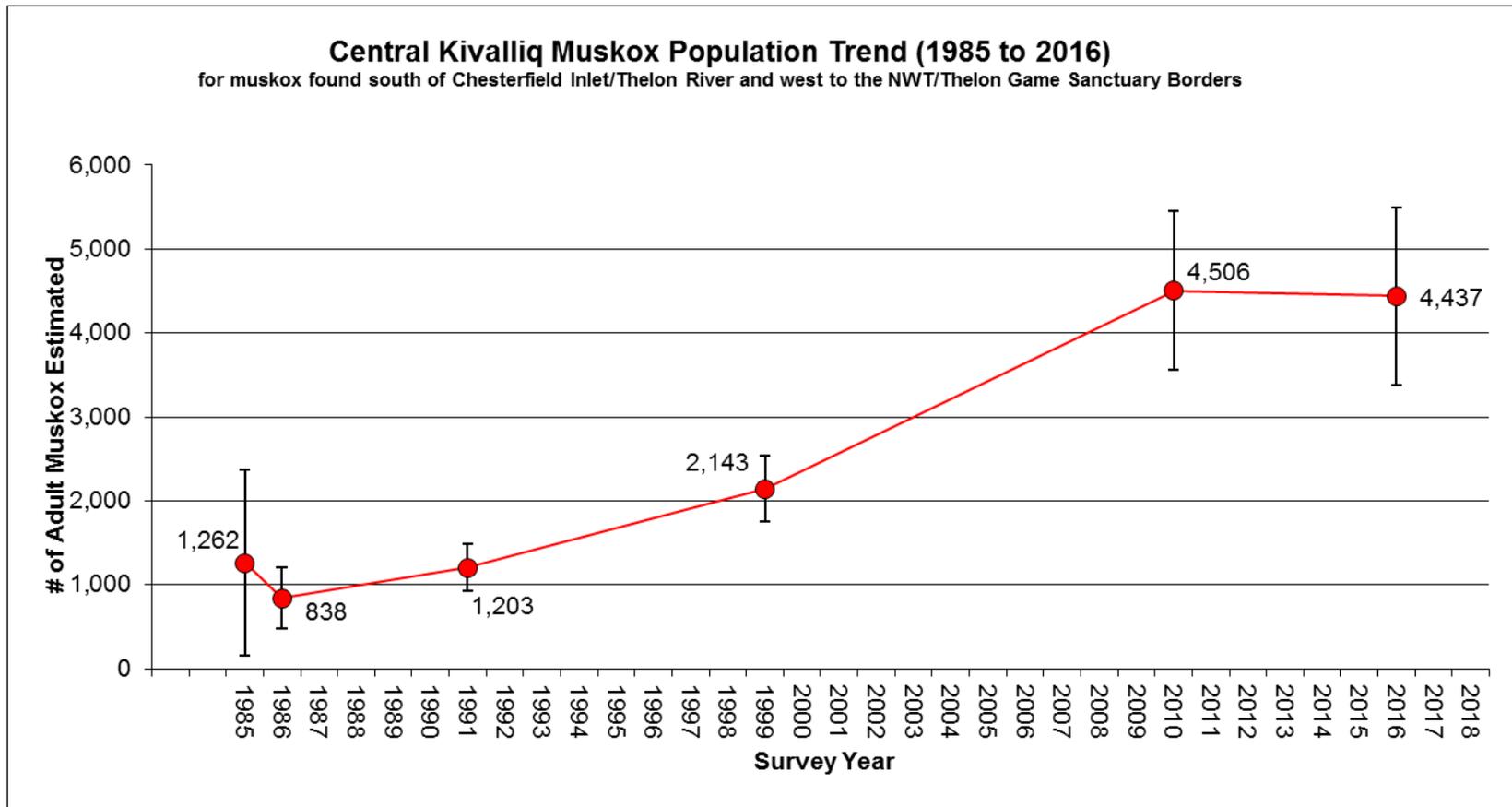


Figure 6. The trend of the central Kivalliq Muskox Population from 1985 through July 2016.

Table 2. A summary Central Kivalliq muskox survey results south of Chesterfield Inlet/Thelon River and west to the NWT/Thelon Game Sanctuary boundaries (1985–2010).

Year	Total stratum area (km²)	Population estimate	Standard error	CV	Lower 95% CI	Upper 95% CI	% calves	Authors
1985 (Nov)	19,706	1,262	563	0.45	159	2,365	17.9	Case & Graf 1986
1986 (July)	8,261	838	176	0.21	476	1,200	11.5	Case et al. 1986
1991 (July)	12,555	1,203¹	145	0.13	919	1,487	15.9	Mulders & Bradley 1991
1999 (July)	19,475	2,143	199	0.09	1,747	2,539	18.4	Campbell & Settingington, 2001
2010 (July)	114,618	4,506	478	0.11	3,558	5,455	15.4	Campbell & Lee, 2015.
2016 (July)	129,074	4,437	531	0.12	3,383	5,491	22.6	This Study

¹ The calculation of lake areas were subtracted from the Mulders and Bradley (1991) estimate.

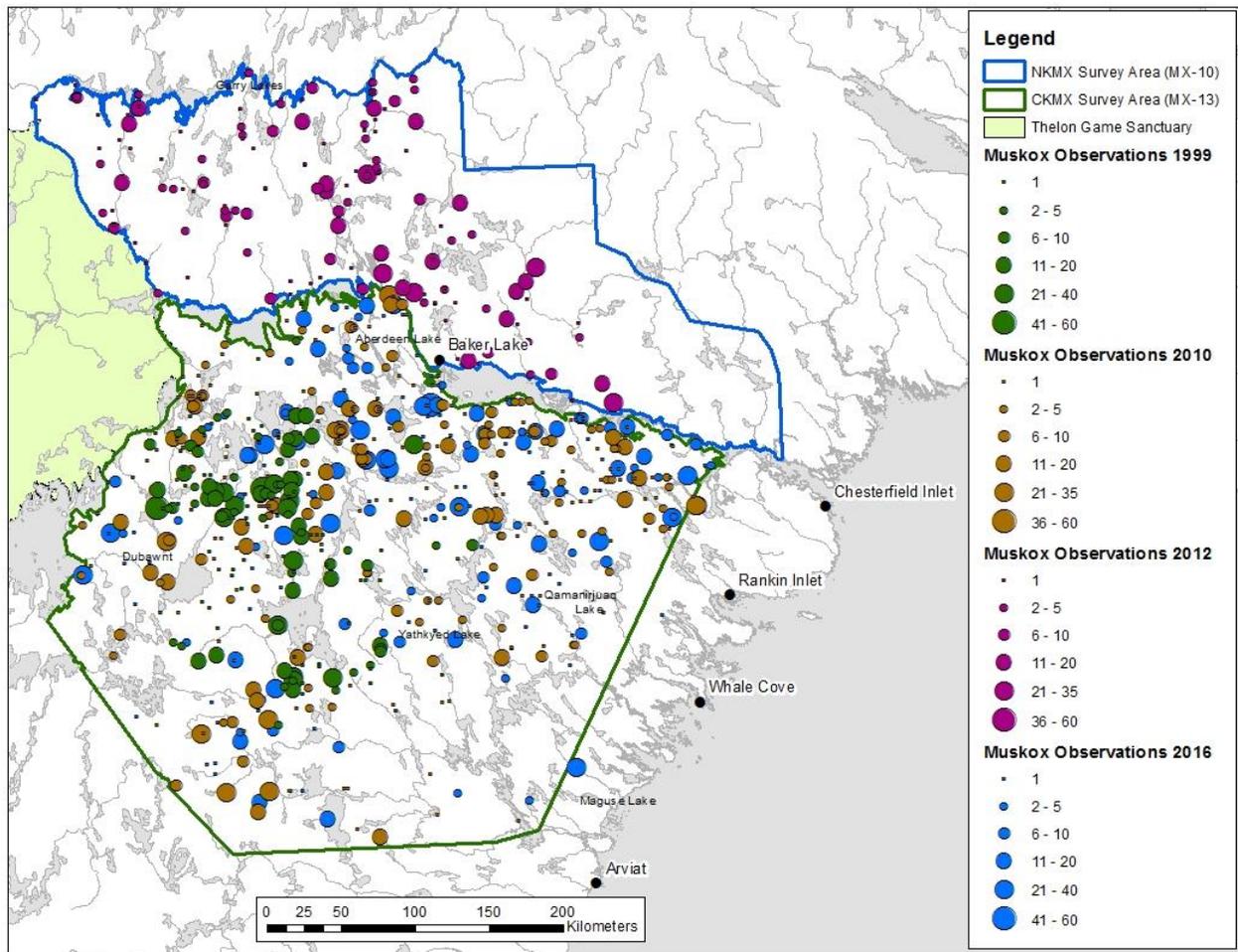


Figure 7. Central Kivalliq muskox survey observations of muskox from July 1999 through July 2016.

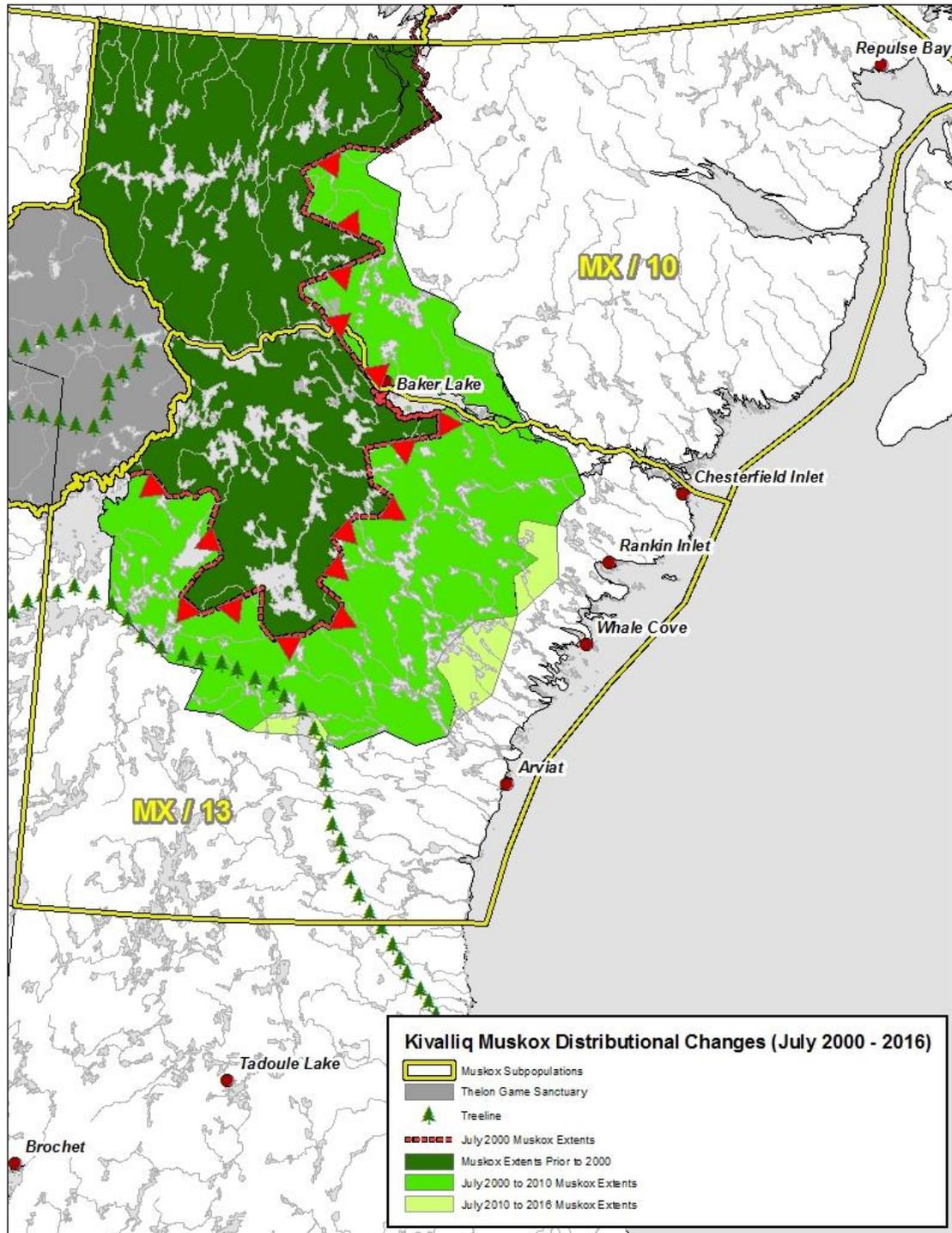


Figure 8. Indicated central and northern Kivalliq range expansion between July 1999 and July 2016 (Central Kivalliq) and July 2012 (Northern Kivalliq).

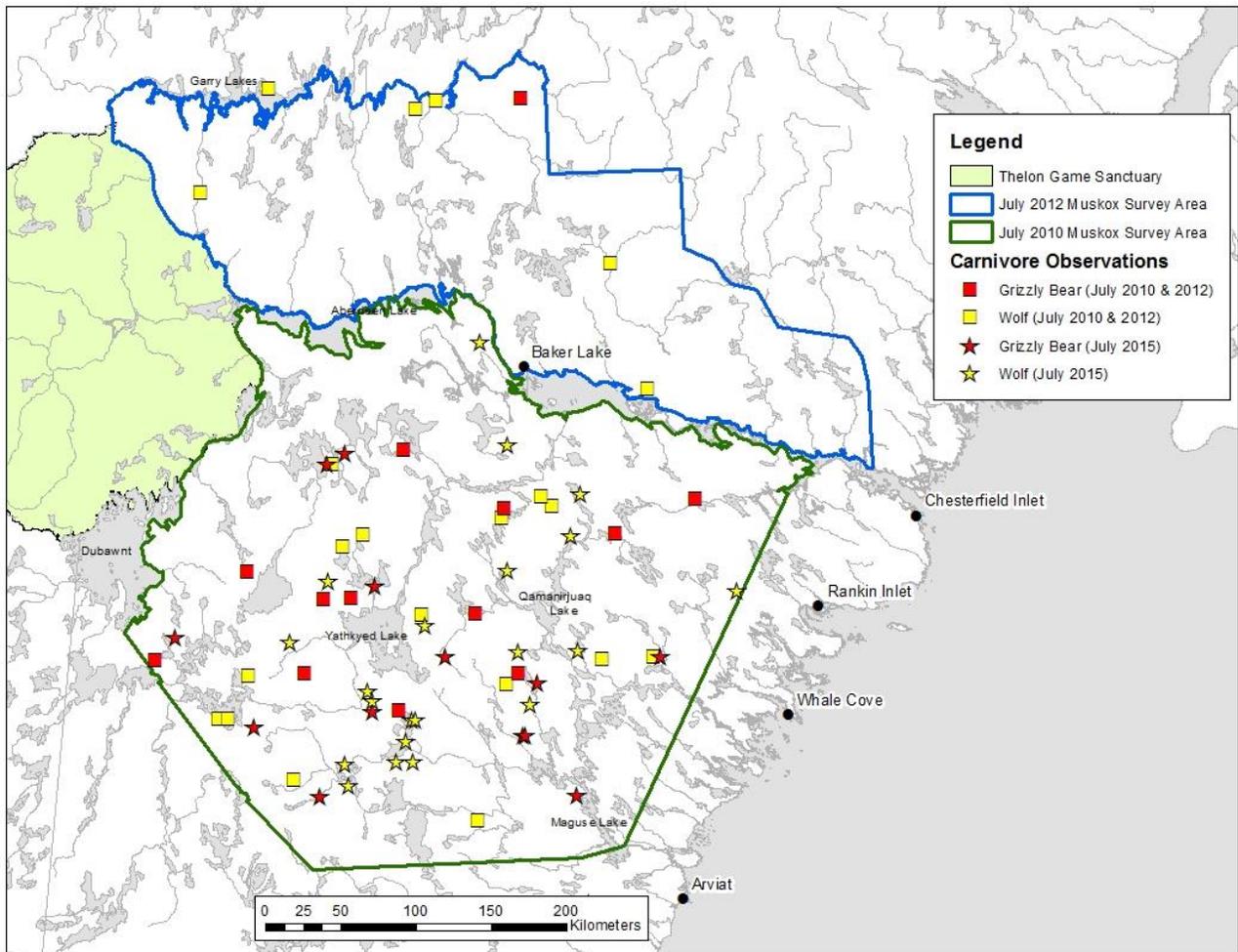


Figure 9. Carnivore observations during the July 2010 (Central Kivalliq), 2012 (Northern Kivalliq), and 2016 (Central Kivalliq) aerial surveys.

Northern Kivalliq Muskox Survey

Results of the 2012 northern Kivalliq muskox survey are still in the analysis stage but clearly indicate an increase from the July 1999 abundance estimates (Figure 10). Initial estimates show the northern Kivalliq muskox population to have increased from an estimated 1,522 (SE = 331; CV = 0.22) in July 1999 to 2,341 (SE = 275; CV = 0.12) in July 2012. As with the central Kivalliq population, survey observations (Figure 7) also suggest an expansion in the subpopulations geographic distribution eastward (Figure 8). Once again, these results should be used with caution as more extensive statistical analysis of the July 2012 results are ongoing as a completion to the July 2017 northern Kivalliq Muskox survey program. The complete reassessment of the July 1999, 2010, and 2016 central Kivalliq muskox surveys and the July 1999, 2000, 2012 and 2017 northern Kivalliq muskox surveys utilizing the double observer pair sight-resight and distance sampling analysis procedure is nearing completion and will be provided to all stake holders in the form of a GN File Report on or about April 2018.

The GN DOE has met as recently as October 2017 to discuss all preliminary results and draft estimates with the Kivalliq Wildlife Board and its representatives from the communities of Arviat, Whale Cove, Rankin Inlet, Baker Lake, Chesterfield Inlet, Repulse Bay, and Coral Harbour. During this meeting it was agreed that until the northern Kivalliq muskox survey results are ready, no decision will be made concerning the adjustment of either the subpopulations TAH and/or NQL.

Community consultation:

All seven Kivalliq communities (Arviat, Whale Cove, Rankin Inlet, Chesterfield Inlet, Baker Lake, Repulse Bay and Coral Harbour) and the Kivalliq Wildlife Board (KWB) have been informed of the projects preliminary results and are in agreement with the management recommendations presented in this report. All Kivalliq community HTOs agreed that the preliminary results are consistent with local IQ. All parties agree that the TAH should be re-assessed following the production of the Departmental File Report. To this end, validated results from the 2010 and 2012 surveys were used to apply an exemption permit for the 2012/2013 harvesting season. Northern Kivalliq muskox survey results are still in the analysis stage and will be discussed further at the next KWB meeting expected in late January or early February, 2018. Presently, HTO members, local Conservation officers and local hunters are taking part in the continued collection of local knowledge concerning the location of muskox groups across the central and northern Kivalliq, and incorporating IQ in the possible mechanisms surrounding their continued range expansion into marginal habitats and observed lower relative densities.

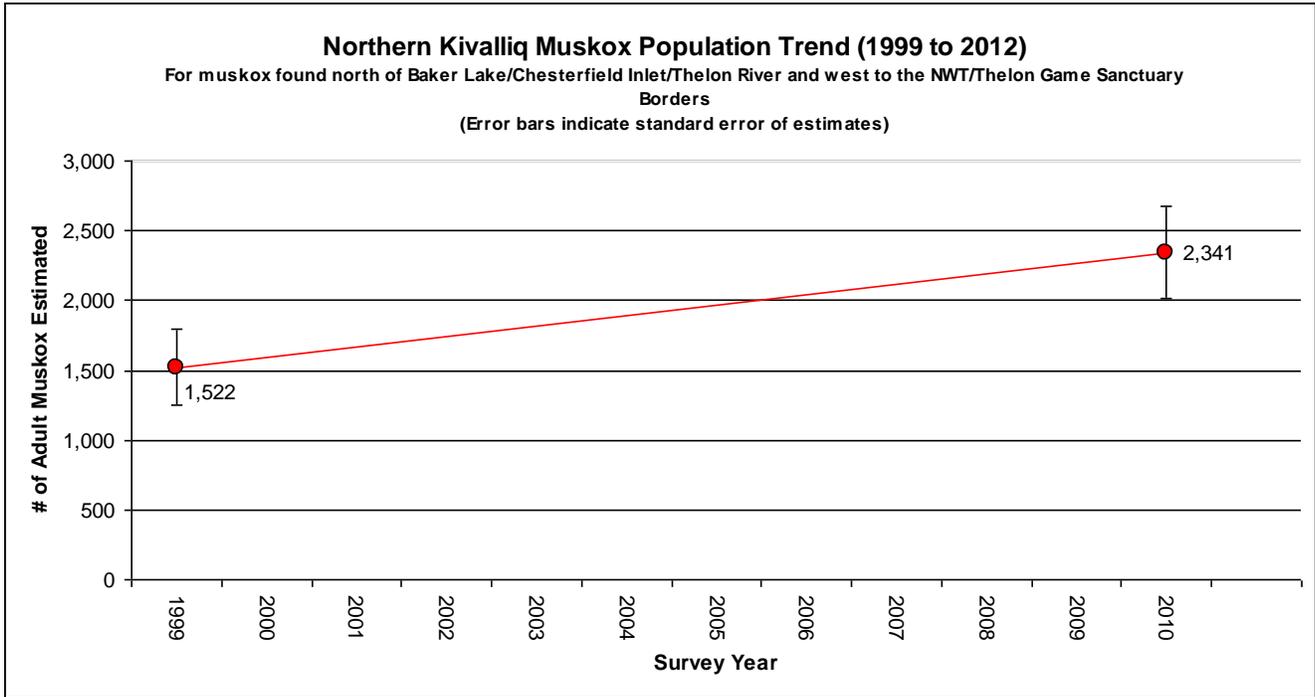


Figure 10. Trends of muskox abundance within the northern kivalliq subpopulation, July 2012.

Management Findings/Actions/Recommendations:

Central Kivalliq Muskox Subpopulation (MX-13)

1. By July 2010, the central Kivalliq muskox subpopulation (MX-13) had expanded outside of previously documented distribution, particularly to the south (towards the Manitoba Border) and eastward (to the coast of the Hudson Bay). The July 2016 survey observations provided evidence of a slowing of this expansion, though small areas along the eastern and southern extents indicated some continued expansion of their contemporary range extents;
2. A management plan was developed in 2010 by the Kivalliq Wildlife Board, GN DOE, and NTI Wildlife. The July 2016 initial survey results presented herein, are meant to provide an update with which to assess the validity of current management actions as laid out within the 2010 Management Plan. These results are not meant to supersede the results provided in a reviewed GN DOE File Report expected in March 2018;
3. Additional monitoring of muskox must include the ongoing collection of IQ as well as periodic population assessments as deemed necessary through collected IQ. We suggest that the aerial survey flown in July 2016 be repeated in future survey years and expanded as necessary;
4. To improve TAH recommendations and overall management, additional muskox research should focus on determining demographic parameters such as sex and age characteristics and levels of natural mortality within the population;
5. To improve TAH recommendations and overall management, additional muskox research should also focus on barren-ground grizzly bear abundance, distribution, and feeding behavior and their effects on muskox behavior, distribution, and general ecology;
6. The central Kivalliq muskox subpopulation (MX-13) boundaries should remain as indicated (Figure 8);
7. Due to the lack of a statistically significant change in abundance of the central Kivalliq muskox subpopulation, we recommend status quo (TAH set at 5% of the July 2010 estimates lower 95% Confidence Interval) and that no changes be made to the current management recommendations including any and all recommendations concerning NQLs (Figure 11). Following the complete reassessment using double observer pair sight re-sight and distance sampling analytical methods, the GN DOE recommends re-visiting and re-assessing these recommendations with all stake holders;

8. We continue to recommend that the non-quota limitations of seasons and sex selectivity be dropped for subsistence muskox harvesting based on the most recent abundance estimate.

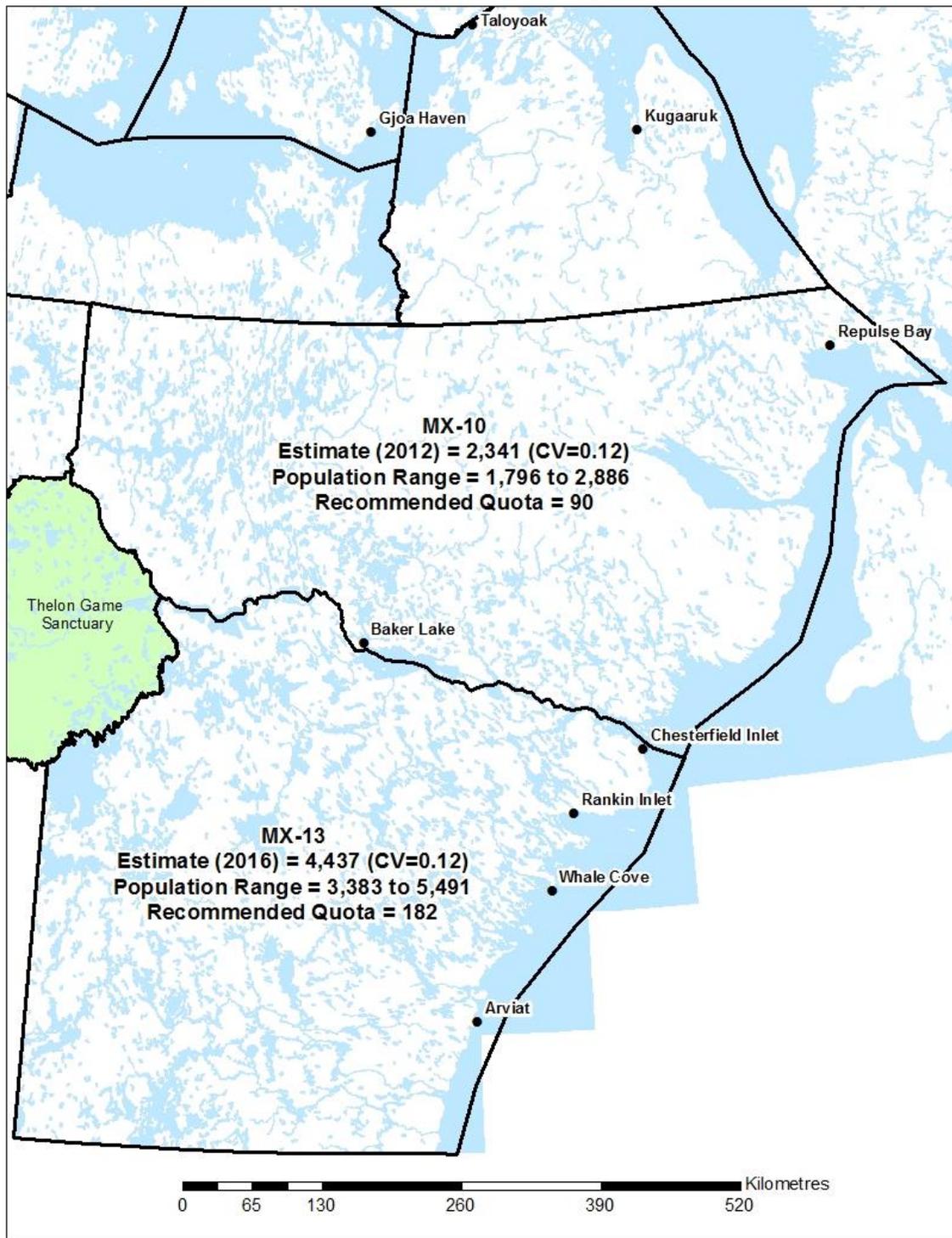


Figure 11. Recommended population boundaries and TAH for the Central Kivalliq Muskox (MX-13) and the Northern Kivalliq muskox population (MX-10). TAH based on July 2016 and July 2012 preliminary survey estimates respectively.

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Baffin Island Caribou Spring Composition Survey Report 2019

John Ringrose¹

¹ Regional Wildlife Biologist, Department of Environment, Government of Nunavut,

P.O. Box 400, Pond Inlet, NU X0A 0S0

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Executive Summary

Barren-ground caribou (*Rangifer tarandus groenlandicus*) occur across Baffin Island and are distributed roughly into north, south and central groupings across Baffin, and ancillary Islands. Local hunters, trappers, and community members began to suspect a decline in the Baffin Island caribou population in the mid to late 1990s. In February and March of 2014 the Government of Nunavut, Department of Environment (DOE), conducted aerial surveys on Baffin Island, Melville Peninsula and surrounding islands, to estimate the number of caribou on Baffin Island. The 2014 survey effort estimated 4,652 (95%CI=3,462-6,250; SE=702.79; CV=0.15) adult and yearling caribou across Baffin Island and ancillary islands. This finding confirmed a major decline of caribou on Baffin Island from the estimates of caribou in the 1990s based on Inuit Qaujimagatuqangit.

The 2014 survey results and community-based observations lead to the establishment of an eight-month moratorium beginning on January 1, 2015. Following a round of intensive consultations with all Baffin Island communities, and a letter submitted for decision to the NWMB recommending the establishment of a TAH of caribou be established on Baffin Island, a decision was reached to establish a Total Allowable Harvest (TAH) of 250 male caribou.

Since the 2014 survey, the DOE has conducted fall and/or spring aerial composition surveys from 2015 to 2019 as a means to monitor productivity and relative densities of caribou across Baffin Island. The objectives of these monitoring indices were to:

- 1) Estimate the overall composition of the subpopulations including the north Baffin grouping, south Baffin grouping, and central Baffin grouping (Figure 1); i.e. what proportion of the population are young bulls, old bulls, cows, yearlings, and calves.
- 2) Estimate the trajectory of abundance of the three main groupings of the Baffin Island caribou population based on demographic composition. Using spring composition results, determine through a comparison between fall composition results, and where possible, similar tundra-wintering barren-ground subpopulations, if an index of calf productivity (measured as calves per 100 cows) suggests an increasing or decreasing population trend.
- 3) Monitor the proportion of bulls in the population to ensure that the bull only harvest is not reducing bulls to a proportion that could interfere with breeding (rutting) success.
- 4) Build a database with which to estimate the current population trend through demographic modeling, utilizing all demographic composition data to project a trend from the 2014 population estimate.
- 5) Provide information for discussions regarding management actions (including TAH) and monitoring plans and intensity.

In the spring of 2019, we classified 1,584 caribou (bulls, cows, yearlings, and calves) on southern Baffin Island. Calf:cow ratios for South Baffin were varied from the lowest ratio of 42 calves:100 cows on Hall Peninsula to the highest ratio of 69 calves:100 cows on Loks Land, suggesting good productivity in the

spring of 2019. All regions combined or otherwise, produced ratios within or above the suggested 30 calves per 100 cow baseline for taiga-wintering populations. However, there is risk associated with using baseline values from taiga-wintering populations to identify population trend in tundra-wintering caribou. The regional variation in calf:cow ratios between relatively close areas highlights the importance of surveying multiple regions to determine trends in productivity.

To effectively monitor and manage the successful recovery of caribou on Baffin Island, there are many additional pieces of information required. These include: 1) The total harvest between the 2014 population estimate and the 2019 spring composition survey (legal and illegal), 2) Multiple year estimates of recruitment (over winter calf survival), 3) Productivity and sex ratio trends for the different sampling areas, and 4) Overall health of caribou within the different survey regions.

Delineation of caribou groups on Baffin Island would allow management and monitoring to occur at smaller scales, specific to group/subpopulations. A Global Positioning System (GPS) telemetry program would greatly increase the effectiveness of composition surveys and could provide the information required to delineate subpopulations/groupings of caribou on Baffin.

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Introduction

Caribou on Baffin Island are of the barren-ground subspecies, *Rangifer tarandus groenlandicus*. This subspecies can be further divided into two separate ecotypes: taiga wintering and tundra wintering. Baffin Island caribou remain on Baffin Island and ancillary Islands year round and are therefore of the tundra wintering ecotype. Tundra wintering caribou generally occur in small groups and vary widely in their migratory behaviour. This can make surveying more difficult as the animals tend to be distributed unevenly across the landscape, and in smaller groups than the taiga wintering ecotypes, particularly when their numbers are low.

There has been limited scientific research conducted on Baffin Island caribou, however, there is a wealth of Inuit Qaujimagatuqangit (IQ) that depicts the long-term population and distributional trends for the region. Due to the lack of quantitative data available, historical population estimates of caribou on the island are largely speculative. Telemetry studies (2008-2011) in North Baffin along with past survey findings, IQ studies (Ferguson, 1993; Ferguson and Gauthier, 1992; Ferguson and Messier, 1997; Ferguson et al 1998), and an island-wide collaring program from the late 80s to early 90s, point to the existence of potential sub-populations on the island (Figure 1). However, further research is required to delineate specific groupings and/or subpopulations across Baffin Island.

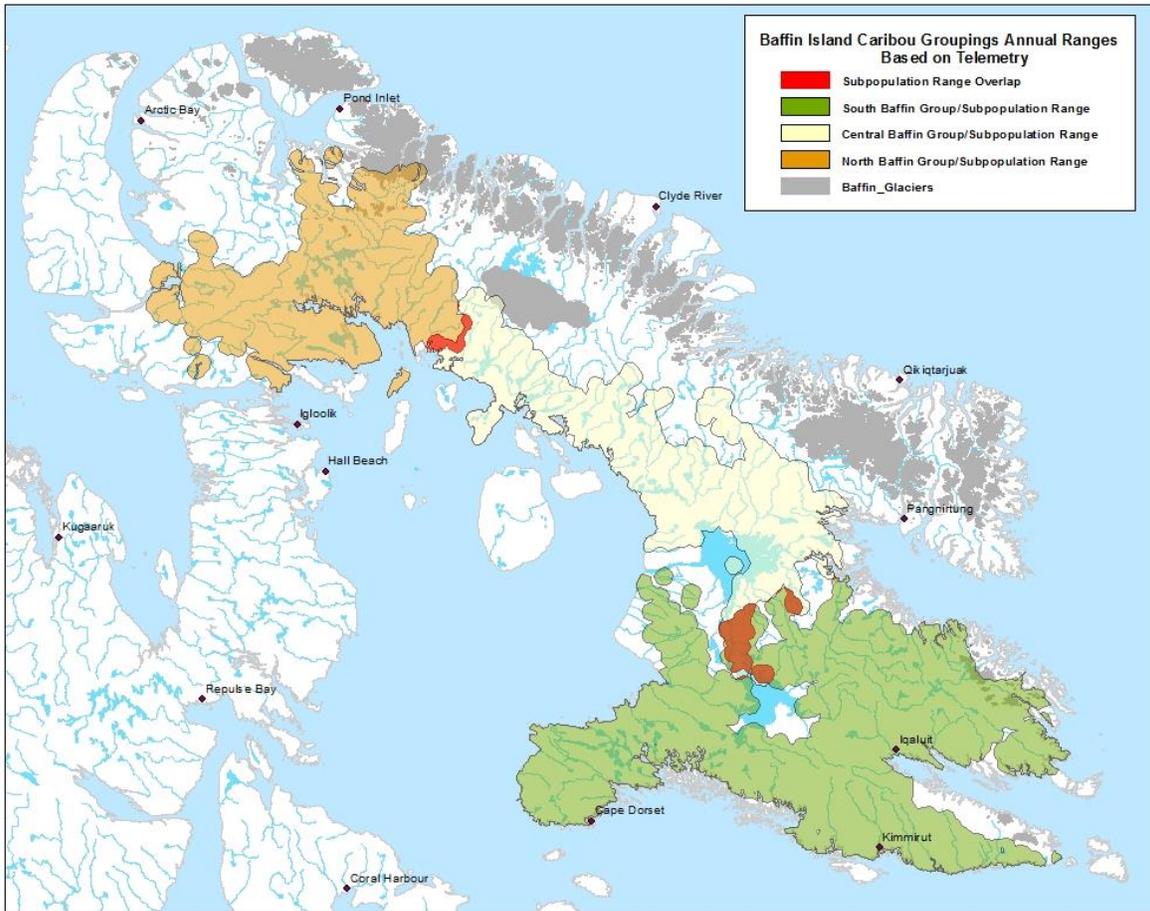


Figure 1. Caribou grouping annual range delineation based on telemetry studies from 1987 to 1994 (primarily South Baffin), and 2008 to 2011 (North Baffin). Polygons created utilizing a kernel analysis (See methods) of telemetry point data collected for 107 collars (North=35; Central = 17; South = 55). Excerpt from Campbell et al. 2015. Used to identify survey area during 2015-2019 composition studies.

Local hunters, trappers, and community members began to detect declines in the caribou population on the island in the mid to late 1990s (Jenkins et al 2012; Ferguson, 1993; Ferguson and Gauthier, 1992; Ferguson et al. 1998). In February/March 2014 the Government of Nunavut, Department of Environment (DOE) conducted aerial surveys across Baffin Island, Melville Peninsula and surrounding islands to estimate the abundance and general distribution of caribou. Aerial surveys were conducted in February and March of 2014 using a combined double observer pair and distance sampling method (Campbell et al, 2015). The survey identified the estimated number of caribou within different geographic locations, including North and South Baffin Island, Baffin Island as a whole, Baffin Island and its ancillary islands, and Baffin Island and northern Melville Peninsula. A total of 1,157 Caribou were observed during the survey, 50 caribou in 8 groups in North Baffin, 347 in 104 groups in South Baffin, 557 caribou in 164 groups on Prince Charles Island, and 31 caribou in 7 groups on Melville Peninsula (Campbell et al. 2015). From these results, it was estimated that 315 (95% CI=159-622; SE=109; CV=0.35) caribou were in North Baffin, 2,734 (95% CI=1,777-4,207; SE=607; CV=0.22) caribou in South Baffin (including Foxe Peninsula and Central

Baffin), 1,603 (95% CI=1,158-2,220; SE=250; CV=0.16) caribou on Prince Charles Island, and 220 (95% CI=88-551; SE=101; CV=0.46) caribou within northern Melville Peninsula, yielding a Baffin wide estimate of 4,872 (95% CI=3,462-6,484; SE=712.23; CV=0.15) caribou. Campbell et al. (2015) also re-analyzed results from surveys flown in North Baffin in April 2009, and South Baffin in 2012, and found no statistically significant change in abundance between these and the 2014 surveys.

As a result of the low abundance of caribou on Baffin Island estimated in 2014, an eight-month moratorium was put in place on January 1, 2015. Following this moratorium, a Total Allowable Harvest (TAH) and a non-quota limitation (NQL) of a male-only harvest was implemented by the Nunavut Wildlife Management Board (NWMB) in 2015. The total number of male-only tags allocated to the communities of Baffin Island were 170 in 2015/2016 and 250 in 2016 to present. Allocations of the 250 tags to Baffin communities are controlled by the Qikiqtaaluk Wildlife Board (QWB) and can vary.

Since the 2014 survey the DOE has conducted fall and/or spring aerial composition surveys from 2015-2019 as a means to monitor productivity and relative densities of caribou across Baffin Island. The objectives of these monitoring indices were to:

- 1) Estimate the overall composition of the subpopulations including the north Baffin grouping, south Baffin grouping, and central Baffin grouping (Figure 1); i.e. what proportion of the population are young bulls, old bulls, cows, yearlings, and calves.
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- 4) Build a database with which to estimate the current population trend through demographic modeling, utilizing all demographic composition data to project a trend from the 2014 population estimate.
- 5) Provide information for discussions regarding management actions (including TAH) and monitoring plans and intensity.

Methods

Surveys were conducted in the spring of 2019 (March 27-April 15) on Baffin Island, Nunavut. Weather and logistical constraints limited the extent of surveying to key areas where a greater chance of caribou encounters were suspected based on past telemetry studies, surveys, and IQ in South Baffin for the spring season (Figure 2). Surveys were conducted using a Eurocopter AS350 B2 rotary wing aircraft, and a survey crew consisting of a biologist, two HTO (Hunters and Trappers Organization) appointed observers and a pilot. Study areas were selected based on previous aerial surveys and telemetry programs, and

information gathered from hunters from each of the 12 Baffin communities during consultations conducted in 2012, 2013, 2014, and 2015 (DOE 2013, 2014, 2015a, 2015b; Jenkins and Goorts 2013). Refinement of survey locations was completed based on advice from the HTO observers prior to and during the survey flights. Refined survey study areas were flown through using two to three transects evenly spaced, bisecting riparian habitat, or until a track was sighted. The method mainly relied on tracking groups and/or individual caribou until they were sighted; however, visual sighting methods were used when tracking was either difficult or not possible. Once tracks were sighted, they would be followed until the group was sighted. Once a group was sighted, transects through the study area would be tightened up to 1 to 2 km apart to take advantage of clustering behaviour observed during previous survey and tracking studies where many caribou groups were observed in small geographic clusters during late winter and spring. Once sighted, caribou would be classified into 5 categories; 1) Cow, 2) Calf, 3) Yearling, 4) Mature Bull and 5) Young Bull. We used image stabilizing 14X binoculars to reduce approach distances as much as possible to limit disturbance to animals, however, in the spring of 2019 the binoculars were damaged early in the survey so identifications required closer approach distances to obtain accurate composition data. In cases where groups could not be located due to fuel and/or weather related issues, and where time allowed, tracking was resumed the following day or after refuelling.

Results

We flew a total of 61 hours in South Baffin from 27 March-15 April 2019. Flights were focused in similar locations to previous spring and fall surveys (Figure 2). We observed a total of 1,584 caribou (bulls, cows, yearlings and calves) (Table 1).

Considering the high number of caribou observed within the south Baffin grouping, we suggest the number of caribou observed is sufficient to address our main objectives. With increased sample effort and spatial coverage, more individuals would have been observed, however the current method of high-grading/target areas with high encounter rate probability has been effective and efficient and we suggest continued use of this method.

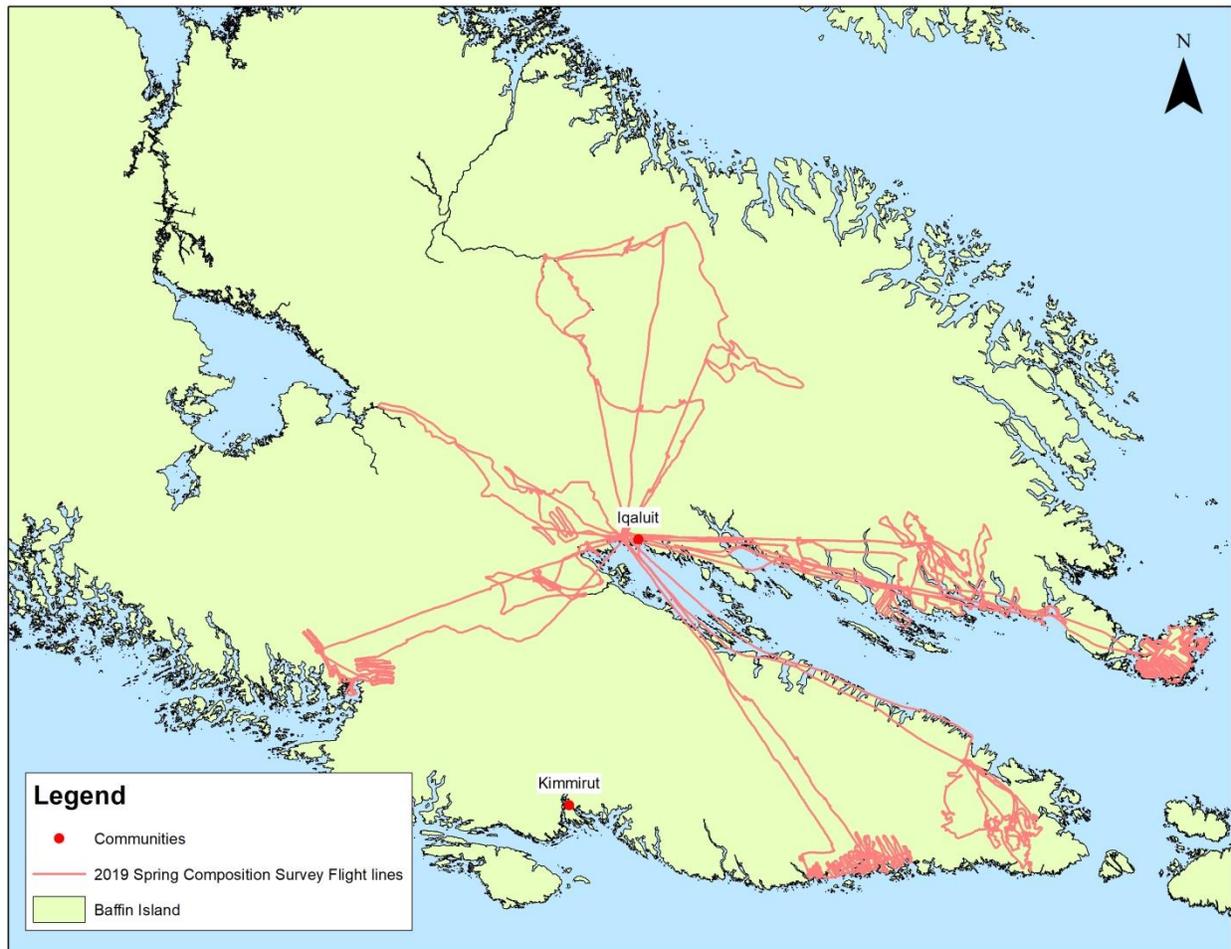


Figure 2. Baffin Island Composition Survey flight lines 2019 in the South Baffin survey area. Search areas based on “high grading” historically and recently known areas with seasonally high to moderate densities of caribou. South Baffin survey area is based on Campbell et al. 2015 (Figure 1).

Table 1 Number of observed caribou by sex/age group during Baffin Island composition surveys in South Baffin 2019.

Year	2019								
Season	Spring								
Location	North	Central	Prince Charles Island	Central Baffin + Prince Charles Island	South (Meta + Hall +Loks Land)	Meta Incognita Peninsula	Hall Peninsula	Loks Land	Hall + Loks Land
<i>Calves Observed</i>	not completed	not completed	not completed	not completed	347	203	71	73	144
<i>Cows Observed</i>					664	388	170	106	276
<i>Calves/100 Cows</i>					52	52	42	69	52
<i>Average Group Calves/100Cows</i>					62	63	42	88	61
<i>Yearlings Observed</i>					108	69	22	17	39
<i>Bulls Observed</i>					465	317	116	32	148
<i>Bulls/100 Cows</i>					N/A	N/A	N/A	N/A	N/A
<i>Bull + Cows</i>					1129	705	286	138	424
<i>Adults + Yearlings Observed</i>					1237	774	308	155	463
<i>Total Observed (Calves, Yearlings and Adults)</i>					1584	977	379	228	607

Discussion

Calf recruitment is an important factor in the assessment of population growth for caribou (Boulanger and Adamczewski 2015). Calf:cow ratios can indicate general trends in abundance population trends which in turn provides important information for effective population monitoring and management. It is important to compare the observed calf:cow ratios to baseline values of similar barren-ground caribou populations to determine the population trajectory. There has been little research conducted on tundra-wintering caribou and as a result there is no directly comparable baseline value that exists for either calf:cow ratio or bull:cow ratio for this ecotype. However, we believe until such a baseline is developed for Baffin Island caribou, it is reasonable to use the baselines for taiga wintering barren-ground caribou as a guide. Previous studies suggest that calf:cow ratios in barren-ground caribou can be as high 70-90 calves:100 cows at calving, 50-70 calves:100 cows in the fall and 30-50 calves:100 cows following winter (Adamczewski et al. 2009; Tobey 2001; Gunn et al 2005). These same studies further suggest that spring calf/cow ratios in excess of 30 calves per 100 cows represents an increasing population, and anything under that ratio, a decreasing population. There is an inherent amount of risk associated with using baseline values from a different population and therefore these composition baselines, when used with Baffin Island caribou, should be treated with caution.

Surveys were not completed in South Baffin in the fall of 2018 and therefore estimating the overwinter survival compared to fall ratios is not possible. Due to weather and logistical constraints, some areas had less than desired coverage. As a result, the identification of regional variation in calf:cow ratios in the south Baffin survey area is reported as calf:cow ratios for each of Hall Peninsula, Loks Land and ancillary islands, and Meta Incognita Peninsula (Table 1). Ratios are reported in two different ways; 1) as an average calf:cow ratio for all calves and cows in a particular region; 2) an average calf: cow ratio for observed groups.

Spring calf:cow ratios were 52 calves per 100 cows, 42 calves per 100 cows, and 69 calves per 100 cows on Meta Incognita Peninsula, Hall Peninsula, and Loks Land, respectively. Similarly, average group calf:cow ratios were 63 calves per 100 cows, 42 calves per 100 cows, and 88 calves per 100 cows on Meta Incognita Peninsula, Hall Peninsula and Loks Land. Combining Hall Peninsula and Loks Land resulted in a ratio of 52 calves per 100 cows. Combining all results from spring 2019 resulted in a calf:cow ratio of 52 calves per 100 cows. All regions combined or otherwise, produced ratios within or above the suggested 30 calves per 100 cow baseline, which suggests an increasing population in South Baffin. However, there is risk associated with using baseline values from taiga-wintering populations to identify population trend in tundra-wintering populations.

During spring composition surveys in 2018, the calf:cow ratio for South Baffin was 39 calves per 100 cows, which when compared to spring 2019 results, suggests improved calf survival in 2019. In fact, the spring of 2019 had the highest calf:cow ratio in southern Baffin in the past 4 years.

Of particular interest are regional variations in calf:cow ratio on Hall Peninsula. Although being in relatively close proximity (approximately 100 km apart), calf:cow ratios on Hall Peninsula were 42 calves per 100 cows, whereas the ratio was 68 calves per 100 cows on Loks Land. The regional variation becomes more

evident when comparing the average group calf: cow ratio; 42 calves per 100 cows and 88 calves per 100 cows on Loks Land, and Hall Peninsula, respectively. This difference in calf:cow ratios between relatively close areas highlights the importance of surveying multiple regions to determine an overall trend in productivity.

Limitations of the data

The calf:cow ratios we report from this study should not be taken out of context and applied to the population across Baffin Island in its entirety. A second abundance survey is needed to verify observed trends and the applicability of the taiga wintering caribou baseline values. To limit seasonal and sampling variability, trend indices require long term data sets and therefore caution should be taken until more years of data have been collected.

Since survey areas are being high graded to locations where the highest concentration of caribou are expected, it is possible that seasonal variation in productivity may be influenced by survey timing and location. Therefore, the total number of caribou observed in 2019 could be skewed by large aggregations of caribou that were missed the previous year. Our ability to determine the best areas to conduct these composition surveys would be greatly improved with information collected using a Global Positioning System (GPS) telemetry program.

Because composition surveys mainly provide demographic proportions and indices of productivity, they are limited in their ability to predict short-term trends, particularly when there are external factors, such as disease or overharvest, which influence mortality of age classes other than calves. Over the longer-term, these surveys can provide a useful index of population trend, offering a tool with which to determine the most effective timing of the more costly abundance estimates.

Given that regional variations in calf:cow ratios were observed over relatively short distances (less than 100 kms), and that some evidence supports different groupings or subpopulations across the island, it would be unwise to manage island-wide populations on trends observed at this scale. Trends observed in South Baffin are likely not reflective of trends in North Baffin (1000 kilometres away). Instead, long-term trends should be used as an index to inform on the necessity of abundance surveys, and influence their frequency and timing. Trend assumptions must be taken with caution as sampling is completed within few, relatively small geographic areas. There are also many other factors, in addition to productivity (calf:cow ratios), that contribute to population growth and decline. In order to accurately predict population growth or decline, it is important to use results from these surveys in conjunction with other data driven indices, such as local knowledge, IQ, and semi-regular reconnaissance and abundance surveys.

Consultation progress

HTO consultations are being planned for the fall of 2019 to inform HTOs of the results from the 2019 spring composition surveys on Baffin Island. The intent of these discussions is to inform HTOs of yearly variation in calf:cow ratios as an index for calf survival and associated trends.

Management implications and next steps

There has been relatively limited research on Baffin Island caribou so there are many areas where additional information could be collected through IQ and scientific studies. One limitation to effective caribou management on Baffin Island is the large spatial extent, greater than 500,000 km², of the island. There has been some indication based on IQ, and supported by early telemetry surveys, that Baffin Island caribou form distinct herds or subpopulations, but this delineation has not been verified. If in fact there are distinct caribou herds on Baffin, survey efforts could more efficiently focus their limited resources and timing windows on smaller spatial and temporal scales, ultimately increasing survey effectiveness and decreasing costs associated with monitoring. Successful delineation of caribou groups on Baffin Island would also allow the use of different management techniques and recommended actions, specific to the group/subpopulation being identified. If the suggested delineations are confirmed, harvesting pressure could be allocated proportionally with higher allocations to populations with greater abundance, providing groups with lower populations some relief from excessive harvesting pressure. Shifting harvest pressure will allow faster recovery of groups with low abundance. The most effective method to delineate subpopulations/groupings on Baffin Island would be to utilize GPS tracking collars. Additionally, GPS tracking of caribou would provide valuable information on seasonal movement patterns and key habitats for behaviours such as calving, to help all stake holders have critical information for land use planning, environmental assessment, and wildlife management processes.

Calf productivity, recruitment (over-winter survival), and adult sex ratios can vary by season, and sampling region. Continued island-wide sampling is essential to determine long-term trends and population trajectory. In the absence of a multi-year satellite collaring program or second abundance estimate, additional composition surveys should be completed to determine the long term trend of Baffin Island caribou. Regular aerial reconnaissance surveys should also be considered as a best practice; however, in the absence of a collaring program these surveys could be excessively expensive, and possibly ineffective.

Barren-ground caribou on Baffin Island have experienced a cyclical pattern of abundance lasting 60-80 years from highs through to the current low. Presently, the population is believed to be at the low cycle with recovery expected to take approximately 30-50 years (Ferguson et al. 1998). Caribou on Baffin Island will likely face different factors during recovery that have not been faced previously, including; climate change, increased industrial development, increased harvest pressure and success due to advances in snowmobile technology and navigation, and the establishment of additional road corridors (Campbell et al 2015). In order to effectively monitor and manage the successful recovery of caribou on Baffin Island, there are many key pieces of information required. These include: 1) The total harvest between the 2014 population estimate and the 2019 spring composition survey (legal and illegal), 2) Multiple year estimates of recruitment (over winter calf survival), 3) Productivity and sex ratio trends for the different sampling areas, and 4) Overall health of caribou within the different survey regions. The results of the past 4 years of composition surveys have been extremely helpful in allowing us to begin to understand the basic population dynamics of the Baffin Island caribou groups, however, much more needs to be done if we are to effectively steer harvest management into recovery.

Support provided

Hunters and Trappers Organizations (HTOs) provided valuable local knowledge and locational information that contributed to the success of this survey. A special thanks to volunteer observers Moses Kilabuck, Davidee Qaumariaq, Levi Qaumariaq, Drikus Gissing, and our pilot Daniel Belanger. Amaruq HTO was particularly helpful this year and without their support, we would not have had such high quality HTO observers.

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**Abundance Trends of the Beverly Mainland Migratory
Subpopulation of Barren-Ground Caribou (*Rangifer
tarandus groenlandicus*): June 2011 – June 2018**

FILE REPORT

Government of Nunavut
Department of Environment
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Mitch Campbell

Department of Environment, Arviat, NU

David S. Lee

Nunavut Tunngavik Inc., Ottawa, ON

&

John Boulanger

Integrated Ecological Research, Nelson, BC

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EXECUTIVE SUMMARY

The Beverly barren-ground caribou (*Rangifer tarandus groenlandicus*) herd migrates annually into Nunavut from winter ranges in northern Saskatchewan and the southeastern Northwest Territories. Abundance estimates suggest that the herd has declined from an estimated 276 000 individuals in 1994 to approximately 136,608 animals in 2011. Since 2011, reconnaissance surveys conducted in 2013 and 2016 indicated further declines in relative densities of Beverly caribou. The results of these monitoring efforts provided impetus for an updated estimate of the Beverly subpopulation abundance in 2018. A general eastward shift in the Beverly herd's calving distribution towards the Adelaide Peninsula was also detected. While the Adelaide Peninsula is also used by the Ahiak subpopulation, analysis of historical collar data demonstrated that the Beverly herd showed a greater affinity for the area than the Ahiak or other NEM herds (Wager Bay and Lorillard).

In June 2018, we estimated the abundance of the Beverly barren-ground caribou herd based on the estimated numbers of breeding and non-breeding female barren-ground caribou within the herd's annual concentrated calving area (ACCA). The Beverly ACCA extends from the Queen Maud Gulf coastline to the eastern shores of Chantrey Inlet. We further re-assessed our 2011 abundance estimate to include the Adelaide Peninsula based on updated information gathered from collared Beverly caribou movements between 2011 and 2018.

We conducted the June 2011 and 2018 abundance surveys in five main stages, including a collar reconnaissance, Reconnaissance survey, abundance survey, calving ground composition survey, and fall composition survey. We used a systematic aerial transect visual survey technique for reconnaissance surveys to stratify the survey area by caribou density. Following reconnaissance, we flew a stratified systematic aerial transect visual survey to estimate the number of adult and yearling female and breeding female caribou within the Beverly ACCA. Our survey protocol employed a dependant

double observer pair method, developed during the 2011 abundance survey, and survey effort focused on estimating the number of adult and yearling caribou during peak calving. Additionally, we conducted composition surveys within all abundance survey strata to estimate the proportion of breeding and non-breeding females in each stratum. To obtain estimates of females, breeding females, males, and overall adult and yearling caribou within the the survey area, the estimated number of adult caribou (≥ 1 year-old) for each survey stratum were multiplied by the sex and age class proportions of that stratum as estimated during composition surveys. Finally, whole herd estimates were extrapolated using sex ratios, quantified during fall composition studies.

The June 2018 abundance survey, including the Adelaide Peninsula, yielded a breeding female estimate of 48,977 (SE = 2600.9; CV = 0.053) and a total female estimate of 61,070 (SE = 2887.8; CV = 0.047). The extrapolated June 2018 whole herd estimate, based on the proportion of females within the herd, was 103,372 (SE = 5109.3; CV = 0.049).

Following an in-depth analysis of collar movement data, we reanalyzed June 2011 results to include the Adelaide Peninsula as an abundance stratum based on new findings suggesting the Beverly subpopulation from 2011 through 2018, showed a greater affiliation to the Adelaide Peninsula than the NEM caribou subpopulations. The reanalysis of the June 2011 results showed a change in the breeding female estimated abundance from 52,834 (SE = 2638.0; CV = 0.05) not including the Adelaide Peninsula, to 67,414 (SE = 3250.5; CV = 0.048) when the Adelaide Peninsula was included. Similarly, the estimate of adult females changed from 62,620 (SE = 2936.3; CV = 0.047) to 80,705 (SE = 3724.3; CV = 0.046). The extrapolated herd size using the proportion of females quantified using fall composition studies, changed from 105,995 (SE = 5199.0; CV = 0.049) to 136,608 (SE = 6603.3; CV = 0.048) with the inclusion of the Adelaide Peninsula. Our June 2018 estimate and revised 2011 estimate suggest an annual rate of decline from June 2011 to June 2018 of between 4 and 5%. We

performed t-tests for the significance of the observed decline. The decline in females, the most precise metric of change from our survey method, proved statistically significant, confirming a continued decline in the Beverly subpopulation.

ABSTRACT.

The Beverly barren-ground caribou herd migrates annually from winter ranges in northern Saskatchewan and the southeastern Northwest Territories. Abundance estimates suggest that the herd has declined from an estimated 276 000 individuals in 1994 to approximately 124 000 animals in 2011 (but note that we have provided a re-analysis of the survey and revised estimate herein). Since 2011, reconnaissance surveys conducted in 2013 and 2016 indicated further declines in relative densities, and a general shift in the calving distribution east toward the Adelaide Peninsula. These monitoring efforts provided impetus for an updated estimate of the Beverly subpopulations abundance. In June 2018, we estimated the abundance of the Beverly barren-ground caribou herd based on the estimated numbers of breeding and non-breeding female barren-ground caribou within the herd's annual concentrated calving area (ACCA). The Beverly ACCA extends from the Queen Maud Gulf coastline to the eastern shores of Chantrey Inlet. We further re-assessed our 2011 abundance estimate to include the Adelaide Peninsula based on updated information gathered from collared Beverly caribou movements between 2011 and 2018.

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and yearling caribou within the the survey area, the estimated number of adult caribou (1+ year old) for each survey stratum was multiplied by the sex and age class proportions of that stratum that were estimated with the composition surveys. Finally, whole herd estimates were extrapolated using sex ratios quantified during fall composition studies.

The June 2018 abundance survey, including the Adelaide Peninsula, yielded a breeding female estimate of 48,977 (SE = 2600.9; CV = 0.053) and a total female estimate of 61,070 (SE = 2887.8; CV = 0.047). The extrapolated June 2018 whole herd estimate based on the proportion of females within the herd was 103,372 (SE = 5109.3; CV = 0.049).

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Key words: Calving ground visual survey, Caribou calving ground, Kitikmeot region, Double observer pair method, Barren-ground caribou, Beverly Subpopulation, Ahiak subpopulation, Northeast Mainland, Queen Maud Gulf, Adelaide Peninsula, Nunavut, *Rangifer tarandus groenlandicus*, abundance, population survey, decline.

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1.0 INTRODUCTION

Following the last glacial period, caribou (*Rangifer tarandus*) in North America recolonized their range from several refugia, resulting in the emergence of multiple ecotypes (Yannic et al., 2014). Although Inuit have relied on several caribou subpopulations and ecotypes for survival over centuries, the first written reference to barren-ground caribou was likely that of Martin Frobisher in 1576 (Banfield, 1951). Hearne recorded the earliest detailed account of migratory behavior, distribution and movements, and the use of caribou by subsistence harvesters, in 1795 (Banfield, 1951). Early reports and interviews with residents, however, yielded little insight into the dynamic nature and distributions of barren-ground caribou (*Rangifer tarandus groenlandicus*) subpopulations west of Hudson Bay (**Figure 1**).

The mid 1900s through to the late 1980s saw an increase in demographic studies of barren-ground caribou herds (Calef, 1979). Eight major barren-ground caribou herds were identified within the then Northwest Territories (NWT), now the NWT and Nunavut (NU), during this period. Together these herds likely exceeded 600,000 caribou (Calef, 1979). Work during this period identified subpopulations including the Melville Peninsula, Wager Bay, and Bluenose herds (then thought to be increasing). Also included were the Bathurst, Beverly and Porcupine herds (then thought to be stable), and the Qamanirjuaq and Baffin Island herds (then thought to be declining) (Calef, 1979; Heard and Jackson, 1990; Thomas, 1969; Rippin, 1971; Moshenko, 1974; Gunn and Decker, 1982; Stephenson et al., 1984; Gunn, 1984; Heard, 1982; Gunn and Sutherland, 1997; Williams and Heard, 1990; Williams et al., 1989; Thomas and Kiliaan, 1985; Thomas and Barry, 1990).

Our study focuses on one of these subpopulations, the Beverly, which migrates annually into Nunavut from winter ranges in northern Saskatchewan and the southeastern Northwest Territories. Abundance estimates suggest that the herd

has declined from an estimated 276 000 individuals in 1994 to approximately 136,608 animals in 2011 (estimate revised in this report from Campbell et al. 2012). Since 2011, reconnaissance surveys conducted in 2013 and 2016 indicated further declines in relative densities, and a general shift in the calving distribution east toward the Adelaide Peninsula.

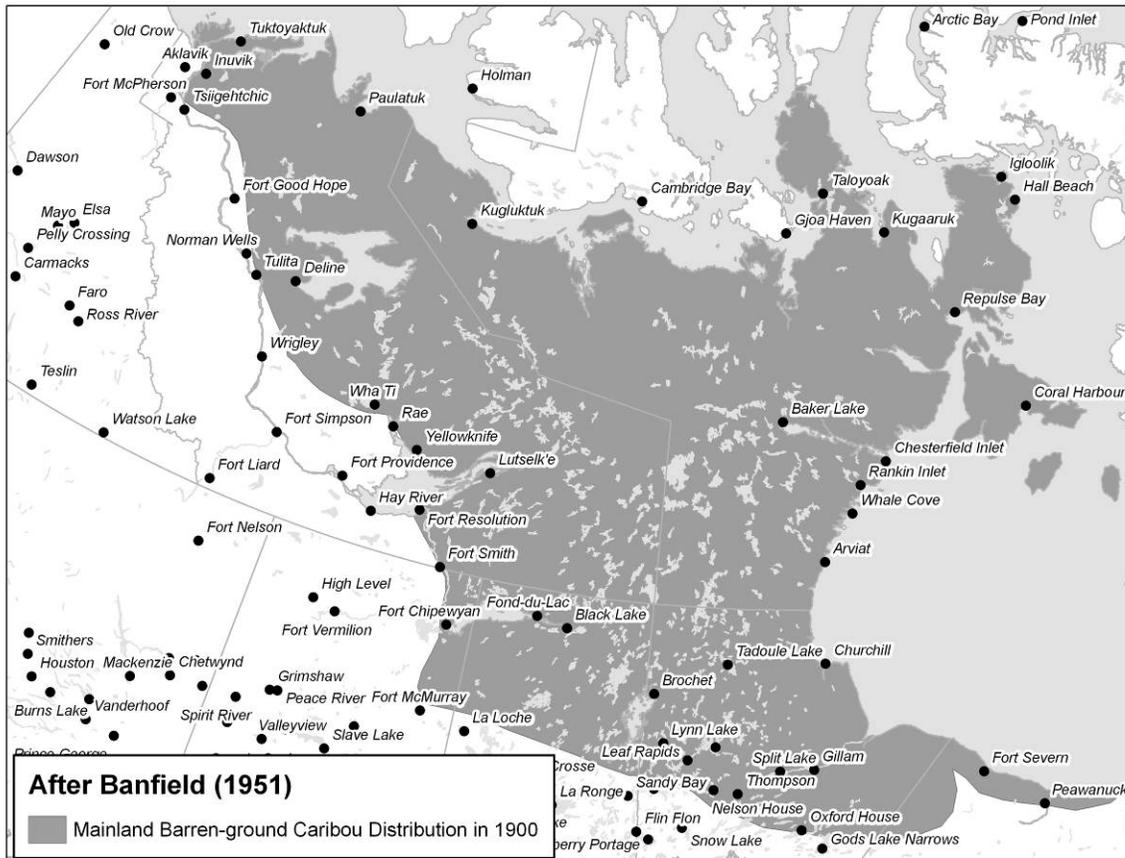


Figure 1. Mainland barren-ground caribou distribution based on local observations and studies from the early 1900s (after Banfield, 1951).

The survey history of the Beverly herd has been irregular, and complicated in some ways by apparent distributional shifts of the herd. For example, a June 2007 calving ground survey found too few breeding females on the “traditional” Beverly calving area near Beverly and Garry lakes (175 observed on transect; relative density of 0.40 caribou/km²) to conduct a photo-survey (Johnson et al., 2008). In the following years, the GNWT continued to observe lower densities of caribou during reconnaissance surveys flown over the same area in June 2008, 2009 and 2010 (90 - 100 caribou observed on transect in June 2010; relative density of 0.20 caribou/km², unpublished GNWT data). At the time, these results suggested a severe decline in the Beverly subpopulation. However, despite all indications from reconnaissance surveys up to June 2010 suggesting a population crash with the threat of extirpation, local knowledge and an assessment of collar movements over the same period suggested another possible reason for the decline. Collar relocations suggested a shift in concentrated calving of the Beverly herd some 200 to 250 km north of their previous “traditional” annual concentrated calving area (ACCA) to the western Queen Maud Gulf Lowlands (QMGL) (Nagy et al. 2011). The knowledge of local hunters (Baker Lake, Gjoa Haven, and Kugaaruk Hunters and Trappers Organisation [HTO] meetings and pers. comm.) agreed that the Beverly herd had been calving further north in recent years. Still, competing views suggested that the primary mechanism was a major decline coupled with a distributional shift, ending with a switching to the QMGL calving area to maintain the advantages of gregarious calving (Gunn et al, 2010; Gunn et al. 2012, Adamczewski et al. 2015). Small sample sizes of collars deployed prior to 2002, and the lack of reproductive assessments associated with these initial captures, render a quantitative assessment of this period unreliable, and it is difficult to conclude which mechanisms were responsible for the numbers observed on the traditional calving area prior to 2007. However, quantitative evidence from more recent telemetry, combined with local knowledge, strongly support the theory of a distributional shift in calving area having occurred, and provide explanation for the observed increases in abundance in the QMGL during calving. Though

inconclusive, we believe that the movement northward from the southern calving area began much earlier than 2005. Reconnaissance data from June 2016 showed no re-establishment of calving within the traditional calving area near Beverly and Garry lakes.

In addition to monitoring movements of individuals from the surveyed herd, it is also important to consider the potential for movements of animals from other herds into the study area during a survey. This is particularly true for surveys in the QMGL area, where historically other caribou subpopulations have also calved. The Bathurst herd has previously calved annually within the western extents of the current Beverly QMG ACCA. Prior to the shift of their calving area to the west of Bathurst Inlet (Williams and Heard, 1990; Sutherland and Gunn, 1996; Gunn et al, 2000), the Bathurst herd calved across an area west of the Perry River extending to the eastern shore of Bathurst Inlet (Gunn, 1996; Heard et al., 1986; Sutherland and Gunn, 1996). Furthermore, a small number of caribou from the Ahiak subpopulation (a tundra wintering caribou ecotype previously known as the Baker Lake herd) also calve in close proximity to the Beverly ACCA along its eastern extents. Overall, however, analyses of collar movements suggest that the majority of the Ahiak subpopulation tend to calve further to the east of Adelaide Peninsula (Sutherland and Gunn, 1996; Gunn et al., 2000; Gunn, 1996; Gunn et al, 2008; Campbell et al in prep). Nagy et al. (2011) and Nagy and Campbell (2012) delineated caribou subpopulations calving east of the Beverly subpopulation and within the eastern part of the QMGL. The Ahiak subpopulation's main calving areas extend from the Adelaide Peninsula to the west coast of Simpson Peninsula with the majority of calving occurring east of Chantrey Inlet. Since 2011, the GNWT has expanded its satellite telemetry monitoring efforts on Beverly caribou yielding a more detailed monitoring of Beverly caribou cow and bull seasonal range use and movements. Though variable from year to year, there is some spatial overlap between the adjacent Beverly and Ahiak subpopulations as well as between the Beverly and Bathurst subpopulations during the calving season (since

2017). However, analysis of telemetry data shows that in recent years this overlap has been minor (Campbell et al. 2014).

Calving ground aerial survey methods have been improving since the first barren-ground caribou surveys were flown in the mid to late 1960s. Early estimates often varied in reliability, making comparisons through time challenging. Photographic methods were first deployed for Beverly calving-ground abundance surveys in 1982, and were then used consistently thereafter (June 1984, 1988, 1993, and 1994 with the exception of June 1987). Photographic methods improved count accuracy and abundance estimate precision where high animal densities made accurate counts by observers difficult or unmanageable. We first deployed the dependent double-observer pair method for caribou in June 2011 to estimate the abundance of the Beverly herd (Campbell et al. 2012). Where densities permit, this method improves precision by correcting visual counts for sightability biases thereby allowing efficient, unbiased estimates without the use of the photo plane. This visual method can effectively be used when densities of less than 15 caribou/km² were encountered (Cook and Jacobsen, 1979; Buckland et al., 2010). When caribou densities are not too high, the dependent double-observer pair visual method has proven to be more cost effective than traditional photographic methods, without compromising accuracy or precision. Though survey methods will continue to improve, other factors, such as the late arrival of breeding females onto the calving grounds in some survey years (for example 1993), can make generating abundance estimates and determining trends problematic. For these reasons, monitoring caribou movements and movement rates in spring and during the calving season, in order to identify peak calving and female arrivals and departure times (to and from calving areas), is a critical component of the design of contemporary calving ground abundance surveys.

Our main objective for the June 2018 survey was to obtain an estimate of caribou (the Beverly herd specifically) within the QMGL from the eastern shore of Kent Peninsula to the western shore of Chantrey Inlet and the Back River, including

Adelaide Peninsula. We used retrospective analysis and published studies both prior to, and following the survey for the purposes of delineating subpopulations from the survey strata. The main contents of this report are the survey results. We emphasize that the main objective of this study is to provide an abundance estimate for the Beverly herd to address the status of caribou subpopulations in the region to inform co-management. The large geographic scale of the observed spatial shifts described above, the lack of information of population trend prior to 2005, combined with the socioeconomic importance of this herd, made this work a priority for the jurisdictions of Saskatchewan, Northwest Territories and Nunavut.

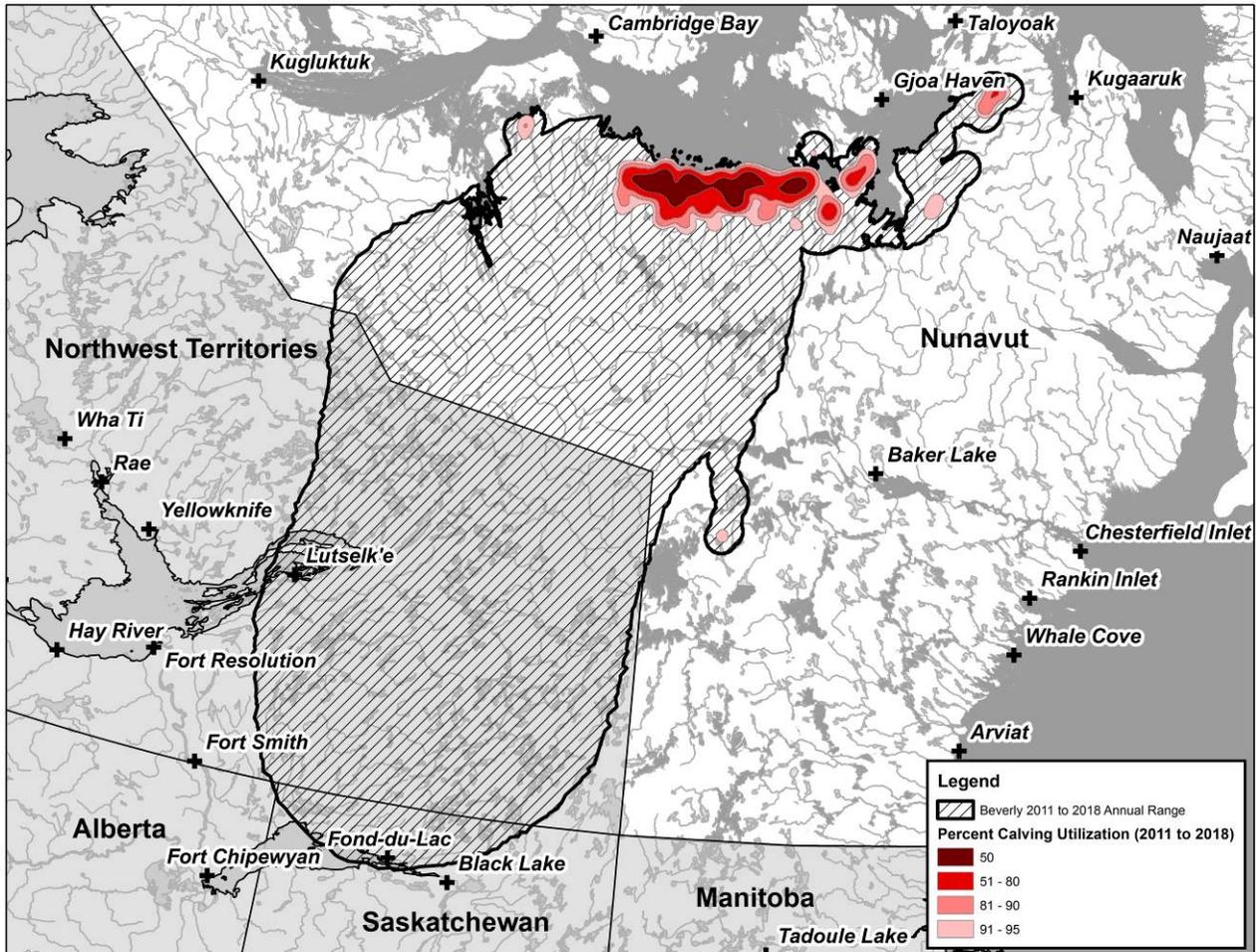


Figure 2. The annual range and concentrated calving area of the Beverly barren-ground caribou subpopulation based on kernel analysis analysis of telemetry data between 2011 and 2018 (Modified from Nagy and Campbell, 2012).

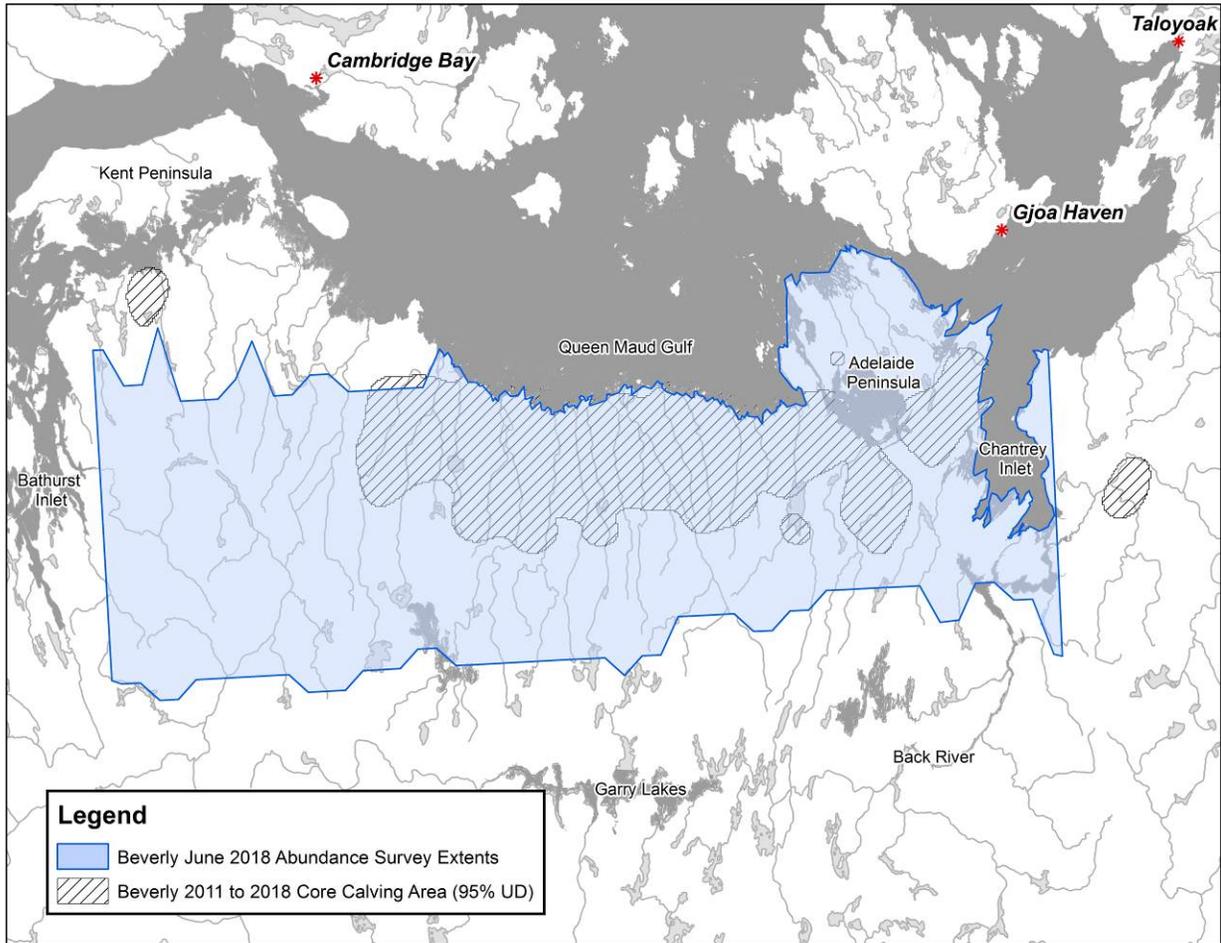


Figure 3. The June 2018 Beverly calving ground survey extents and annual core calving area. Core calving area based on a kernel analysis of telemetry data between 2011 and 2018. Calving extents based on the 95% utilization distribution.

2.0 STUDY AREA

The estimated annual range of the Beverly herd, based on satellite-collar location data collected between 2000 and 2011, is approximately 426,160 km² (Nagy et al. 2011, Nagy 2011, Nagy and Campbell 2012, Campbell et al. 2014). The Beverly 2011 to 2018 annual concentrated calving area (ACCA), including both the Garry Lakes and Queen Maud Gulf calving extents, was estimated using kernel analysis, and found to be 38,491 km², of which the 2011 Beverly Lakes calving proportion represented an estimated 16,131 km² (Nagy et al. 2011, Nagy and Campbell 2012, Campbell et al. 2014). The majority of the calving extent, fall and spring range, including the spring and fall migratory corridors, and the majority of the post-calving habitat, lie within Nunavut (**Table 1**). The annual range of the Beverly subpopulation spans areas across Nunavut, Saskatchewan, and the NWT. The communities of Black Lake and Fond-du-Lac in Saskatchewan, Lutselk'e in the Northwest Territories, and Baker Lake, and Gjoa Haven, in Nunavut, are all within the Beverly subpopulation's annual range.

The June 2018 Beverly calving ground survey area covered an estimated 73,184 km². It extended south from the shores of the Queen Maud Gulf and northern shores of Adelaide Peninsula to a latitude of approximately 66.5°N, and east from the eastern shores of Bathurst Inlet, to the western shores of Chantrey Inlet and the Back River (Wiken, 1986).

The Beverly subpopulation's annual range extends from the Southern Arctic Ecozone south through the Taiga Shield Ecozone (Wiken, 1986) crossing a total of nine Ecoregions including the Queen Maud Gulf Lowland, the Takijua Lake Upland, the Garry Lake Lowland, the Back River Plain, the Coppermine River Upland, the Dubawnt Lake Plain/Upland, the Kazan River Upland, the Tazin Lake Upland and the Selwyn Lake Upland (Wiken, 1986; Ecological Stratification Working Group, 1996) (**Figure 4**).

The Beverly subpopulation's late-winter range lies predominantly within the Tazin Lake Upland and Selwyn Lake Upland Ecoregions; spring and fall migration corridors lie wholly or partially within the Kazan River Upland, the Dubawnt Lake Plain/upland, the Takijua Lake Upland (western extents) and the Garry Lake lowland (Campbell et al. 2012, Campbell et al. 2014). Post-calving range varies but lies predominantly within the Garry Lake Lowland, the Back River Plain, and the Takijua Lake Upland to the west.

2.1 QUEEN MAUD GULF LOWLAND ECOREGION.

The majority of the survey area covering the Beverly ACCA, lies within the Queen Maud Gulf Lowland Ecoregion with its eastern boundary extending into the Chantrey Inlet lowland in recent years (**Figure 5**). The Queen Maud Gulf Lowland extends eastward along the Arctic slope, from Bathurst Inlet to near Chantrey Inlet with association to the lowlands south of Queen Maud Gulf. The mean annual temperature of this ecoregion is approximately -11°C with a summer mean of 5.5°C and a winter mean of -27°C. The mean annual precipitation of this ecoregion varies according to latitude, ranging from 125 mm within its northern extents, to 200 mm within its southern extents.

The Queen Maud Gulf Lowland Ecoregion is classified as having a low Arctic ecoclimate and is characterized by a cover of shrub tundra vegetation, consisting of dwarf birch (*Betula glandulosa*), willow (*Salix spp.*), northern Labrador tea (*Ledum decumbens*), mountain avens (*Dryas spp.*), and Ericaceous shrubs (*Vaccinium spp.*). Tall dwarf birch, willow, and alder (*Alnus crispa*) occur on warm sites; wet sites are dominated by sphagnum moss (*Sphagnum spp.*) and sedge (*Carex spp.*) tussocks. Geologically the region is composed of massive Archean rocks that form broad, sloping uplands that reach about 300-m above sea level (ASL) in the south, and subdued undulating plains near the coast. The coastal areas are mantled by silts and clay of postglacial marine overlap. Bare bedrock is

common, and turbic and static cryosols, developed on discontinuous, thin, sandy moraine, level alluvial and marine deposits, are the dominant soils. Permafrost is continuous and deep with low ice content. The Queen Maud Gulf Lowlands are an important habitat for waterfowl and shorebirds, and the Queen Maud Gulf Bird Sanctuary covers most of the ecoregion (Wiken, 1986; Ecological Stratification Working Group, 1996).

2.2 CHANTREY INLET LOWLAND ECOREGION.

The eastern extents of the Beverly ACCA lie within the Chantrey Inlet Lowland Ecoregion (**Figure 5**). The Chantrey Inlet lowland is associated with lowlands surrounding Chantrey Inlet and Adelaide Peninsula. The mean annual temperature of this ecoregion is -12°C, with a summer mean of 4.5°C and a mean winter low of -28°C. The mean annual precipitation is similar to the western extents of the Beverly ACCA, and ranges from 125 mm to 200 mm. The Chantrey Inlet Lowland Ecoregion is classified as having a low Arctic ecoclimate characterized by large areas of exposed, sparsely vegetated bedrock, in association with shrub tundra vegetation, consisting of dwarf birch, willow, northern Labrador tea, *Dryas spp.*, and *Vaccinium spp.* Tall dwarf birch, willow, and alder occur on warm sites while wet sites are dominated by sphagnum moss and sedge tussocks.

Near the coast, the surface is mantled by silts and clay of postglacial marine overlap, and is underlain by massive Archean rocks that form a level to undulating plain that reaches about 300-m ASL within its southern extents. Turbic and static cryosols developed on discontinuous, thin, sandy moraine, and level alluvial and marine deposits, are the dominant soils in the ecoregion. The east and west sides of Chantrey Inlet are underlain by continuous permafrost with low ice content. The northern half of the Adelaide Peninsula is characterized by continuous permafrost

with medium to high ice content in the form of ice wedges and massive ice bodies (Wiken, 1986; Ecological Stratification Working Group, 1996).

Table 1. Beverly mainland migratory barren-ground caribou seasonal range areas within the Northwest Territories and Nunavut based on telemetry data, current to 2012 (Campbell et al. 2014). Note that though the annual range of the Beverly subpopulation crosses into Saskatchewan, the 95% utilization distribution of all Beverly seasonal ranges do not.

Season	Total Area (km²)	NU Area (km²)	NWT Area (km²)	NU %	NWT %
Spring	53,287	36,858	16,428	69%	31%
Calving	16,131	15,951	179	99%	1%
Post-calving	35,119	34,808	311	99%	1%
Summer	176,940	151,380	25,560	81%	19%
Fall Migration	27,781	8,344	19,437	32%	68%
Rut	96,953	24,581	72,372	25%	75%
Winter	91,459	19,024	72,436	21%	79%

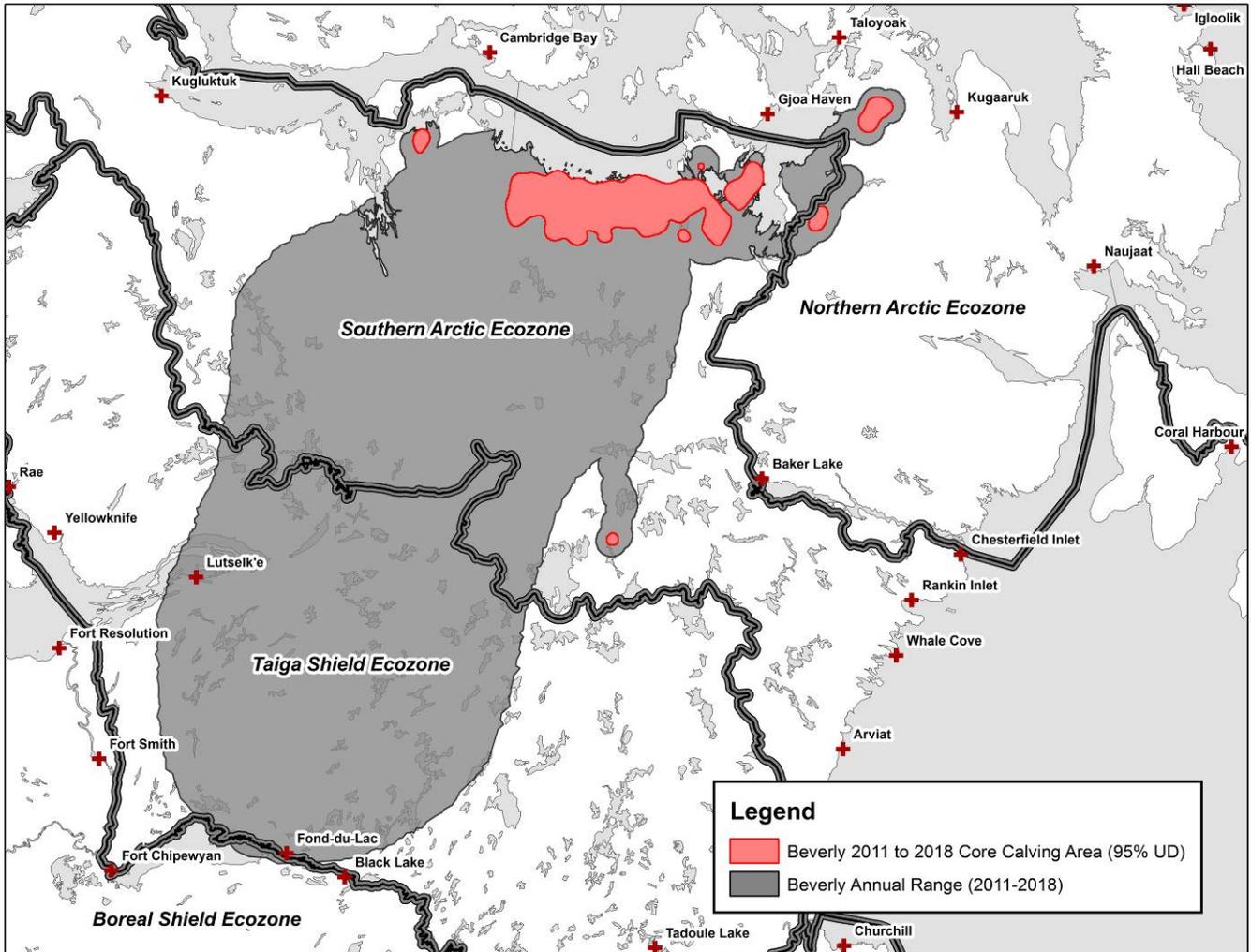


Figure 4. Ecozones of the Beverly barren-ground caribou subpopulations annual range extents and annual concentrated calving areas (ACCA) (Wiken, 1986, Ecological Stratification Working Group 1996, Campbell et al. 2014).

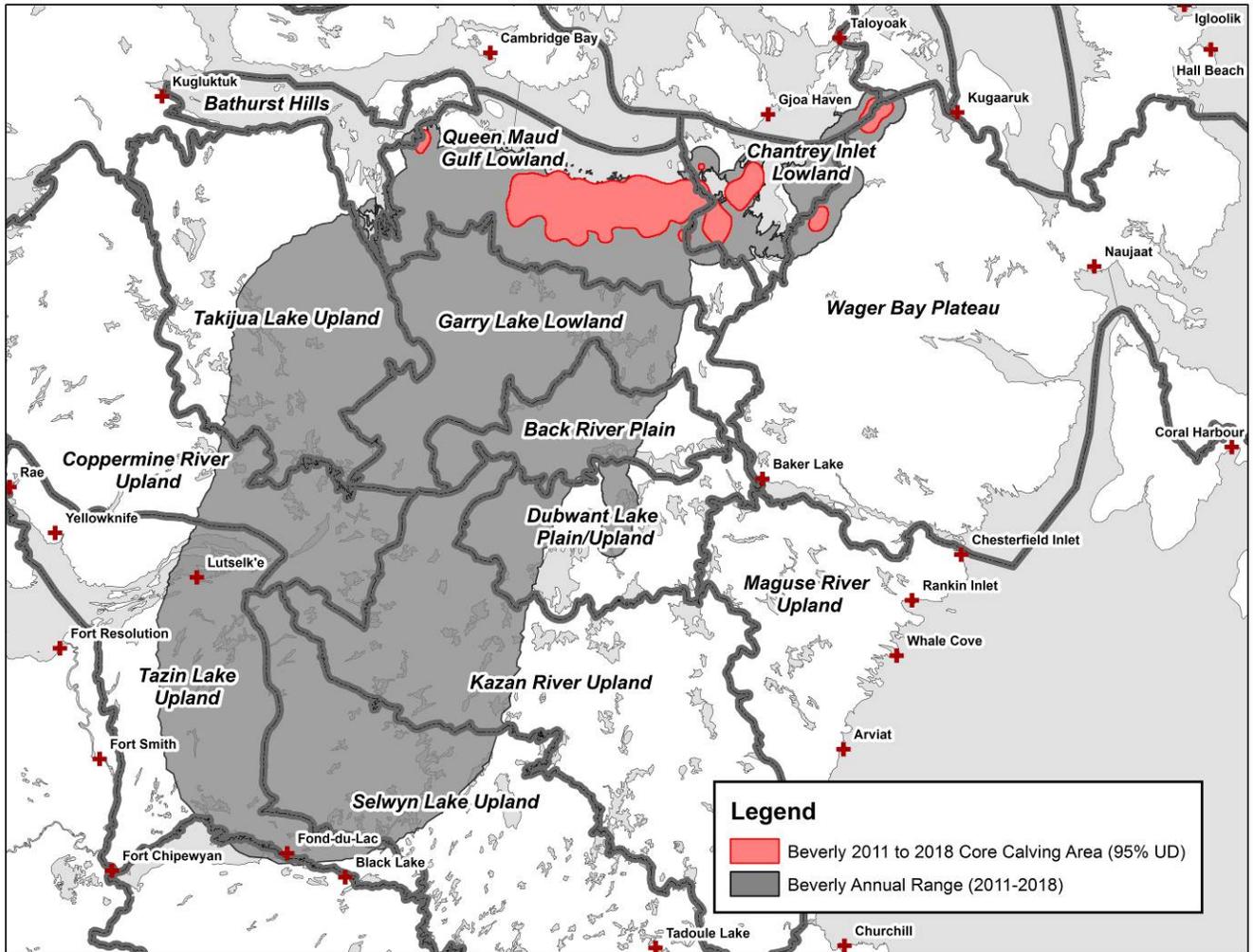


Figure 5. Ecoregions of the Beverly barren-ground caribou subpopulations annual range extents and annual concentrated calving areas (ACCA) (Wiken, 1986, Ecological Stratification Working Group 1996, Campbell et al. 2014).

3.0 METHODS.

3.1 RECONNAISSANCE AND ABUNDANCE SURVEYS.

The 2018 Beverly barren-ground caribou dependent double-observer visual survey was based out of the communities of Cambridge Bay, Kugaaruk, and Gjoa Haven. Our survey aircraft were two Cessna Grand Caravans, both equipped with radar altimeters to ensure that an altitude of 121.92 m (400 feet) above ground level (AGL) was maintained. The strip width on each side of the aircraft was 400 meters, for a total transect width of 800 m. Survey strips widths were marked by streamers attached to the wing struts (**Figure 6**) and were calculated using the formula of Norton-Griffiths (1978):

$$w = W * h/H$$

Where W is the required strip width (400 m), h is the height of the observer's eye from the tarmac and H is the expected flying altitude (400 ft)

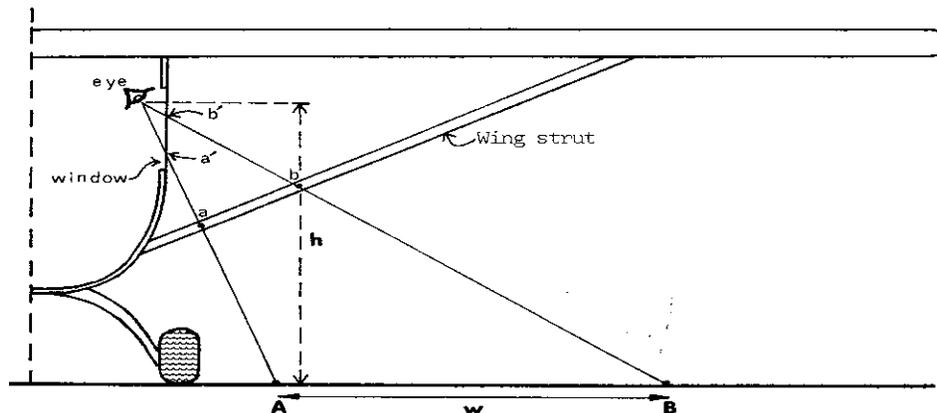


Figure 6. Schematic diagram of aircraft configuration for strip width sampling (Norton-Griffiths, 1978). W is marked out on the tarmac, and the lines of sight $a' - a - A$ and $b' - b - B$ established. The streamers are attached to the struts at a and b , and a' and b' are the window marks.

The survey utilized a dependent double-observer pair method. The typical configuration was comprised of the pilot, two data recorders (rear left and front right) and four observers (two on the left side of the aircraft and two on the right side) (**Figure 7**). Only caribou observed within the strip, as defined by the inner and outer streamers attached to the left and right struts, were recorded.

The survey comprised five main components:

- 1) Collar reconnaissance, used in combination with telemetry based daily movement rates, to determine the timing and extent of calving;
- 2) Dependent double-observer reconnaissance surveys to assess relative density and aggregations of female caribou;
- 3) Dependent double-observer stratified abundance survey to estimate caribou abundance;
- 4) Calving-ground composition surveys to estimate female and breeding female abundance within the survey area, and;
- 5) Fall composition surveys to estimate the proportion of females within the subpopulation.

3.1.1 Collar Reconnaissance.

We used collar reconnaissance surveys and daily movement rates of collared Beverly caribou to identify the dates of peak calving. From collars, we estimated peak calving as the dates where female daily movement rates were lowest. The calculation of daily movement rates of collared Beverly females, has been shown to indicate the beginning of peak calving when movement rates drop below 5 km per day (Campbell et al. 2012; Boulanger et al. 2018), and an example of this is provided in **Figure 8** (for the Qaminarjuaq caribou herd). Collar reconnaissance flights provided an index of the proportion of calves per 100 females observed across the extents of the Beverly ACCA. Generally, proportions of 15% or higher indicate the beginning of peak calving (Campbell et. al. 2012, Boulanger et. al. 2018).

3.1.2 Reconnaissance Survey.

We initiated the reconnaissance survey when the collar survey indicated 15% or more newborn calves, and daily movement rates dropped below 5 km per day. The reconnaissance survey is a low coverage survey (9%) and its purpose is to survey beyond known calving extents to ensure all possible aggregations of females are located and included in the abundance survey to follow. This phase of the study collects data to generate relative densities of caribou and their general composition (such as breeding and non-breeding females). We can use the results of the reconnaissance survey to calculate and to plot relative densities of females for the purposes of stratification, with areas of similar density grouped together into strata for the visual abundance phase of the survey. Defining strata in this way increases precision of the population estimate (i.e., reduces the coefficient of variation or CV). Following the development of strata into polygons of similar densities of caribou, survey effort (determined by the percent coverage of transects per strata) was allocated with the greatest survey effort apportioned to strata with the highest relative densities. We aligned transects perpendicular to the longitudinal axis of each stratum.

In total, fifty-one north-south oriented reconnaissance survey transects ranging from 50 to 180 km long were distributed systematically at 10-km spacing across the northern mainland from Bathurst Inlet to Committee Bay (**Figure 9**) using UTM coordinates and the WGS 84 datum. In total, the reconnaissance transects covered 7,570 linear kilometers. Each transect had associated transect station points that were located at 10-kilometer intervals along it (**Figure 9**). Each station had an alphanumeric identifier (e.g. Bv83) allowing it to be easily referenced. Each 10-kilometer transect segment was named after its northern station. Transects were created using Environmental Systems Research Institute (ESRI) ArcMap Geographic Information System (GIS) software and were based on the UTM zone 15 World Geographic System and the (WGS) 1984 coordinate system.

Following the systematic reconnaissance but prior to the initiation of the visual abundance survey, we entered all observations into ESRI ArcMap GIS software to calculate relative densities of breeding females using a tool utility. The tools allowed us to calculate the relative density of observed caribou locations along the sample transects and display these results on a map. We used vector-based analysis methods based on the following steps:

1. The survey transect segments were buffered by a user-specified width (1,000m in this survey; i.e., 800m strip width and 200m blind spot under the aircraft) yielding polygons that were 10 km² (i.e., 1.0 km wide x 10 km long).
2. The survey observation points were intersected with the derived buffer polygons.
3. The density was calculated for each polygon by dividing the number of 1+ year-old caribou by the area of the buffer polygon (# of 1+ year old caribou/km²).
4. The relative density (#obs/km²) was thematically displayed on a map based on pre-defined classes or bins.

We then used the resulting graphics to stratify the breeding female distribution into high, medium and medium/low-density strata.

Survey resources were partitioned based on relative densities whereby the highest densities detected during the reconnaissance stage received the highest allocation of survey time during the abundance stage. We based the allocation of effort on the following formula (Heard, 1987), although other considerations played a role (see below):

$$N_i = \frac{M Y_i}{TL_i \sqrt{TL_i} \sum \left(\frac{Y_i}{\sqrt{TL_i}} \right)}$$

Where:

N_i = number of transects in stratum i

Y_i = Population estimate in stratum i .

M = Total fixed wing flying distance available for abundance transects.

TL_i = Mean length of transect in stratum i .

Transects within each stratum were aligned at right angles to the long axis of the stratum to maximize the total number of transects (N). For each stratum, an initial transect was randomly placed perpendicular to the longest stratum boundary and the remaining transects systematically placed at regular intervals according to the allocation of survey effort. During the allocation of effort process, we also had to consider available resources in the final determination of strata total coverage (Heard 1987, Campbell et al. 2012).

3.1.3 Abundance Survey.

The abundance and composition surveys immediately followed the reconnaissance survey in order to minimize changes in caribou densities observed during the reconnaissance phase of the survey. The abundance survey began June 13th, and were completed June 16th, following the completion of the reconnaissance survey on June 12th (**Table 2**). The abundance survey used the same survey methods deployed during the reconnaissance survey, with the exception that we did not collect composition data. Both the abundance and composition surveys were completed as quickly as possible, and were highly dependent on weather. The study area within which all survey phases were flown, covered 288,312 km² and encompassed the known extent of caribou calving in the area of the Queen Maud Gulf and Adelaide Peninsula ACCA (Johnson and Mulders 2002; Johnson et al. 2008; Johnson and Williams 2008; Kelly in prep. 2010; Nagy et al. 2011, Campbell et al. 2012) (**Figure 9**).

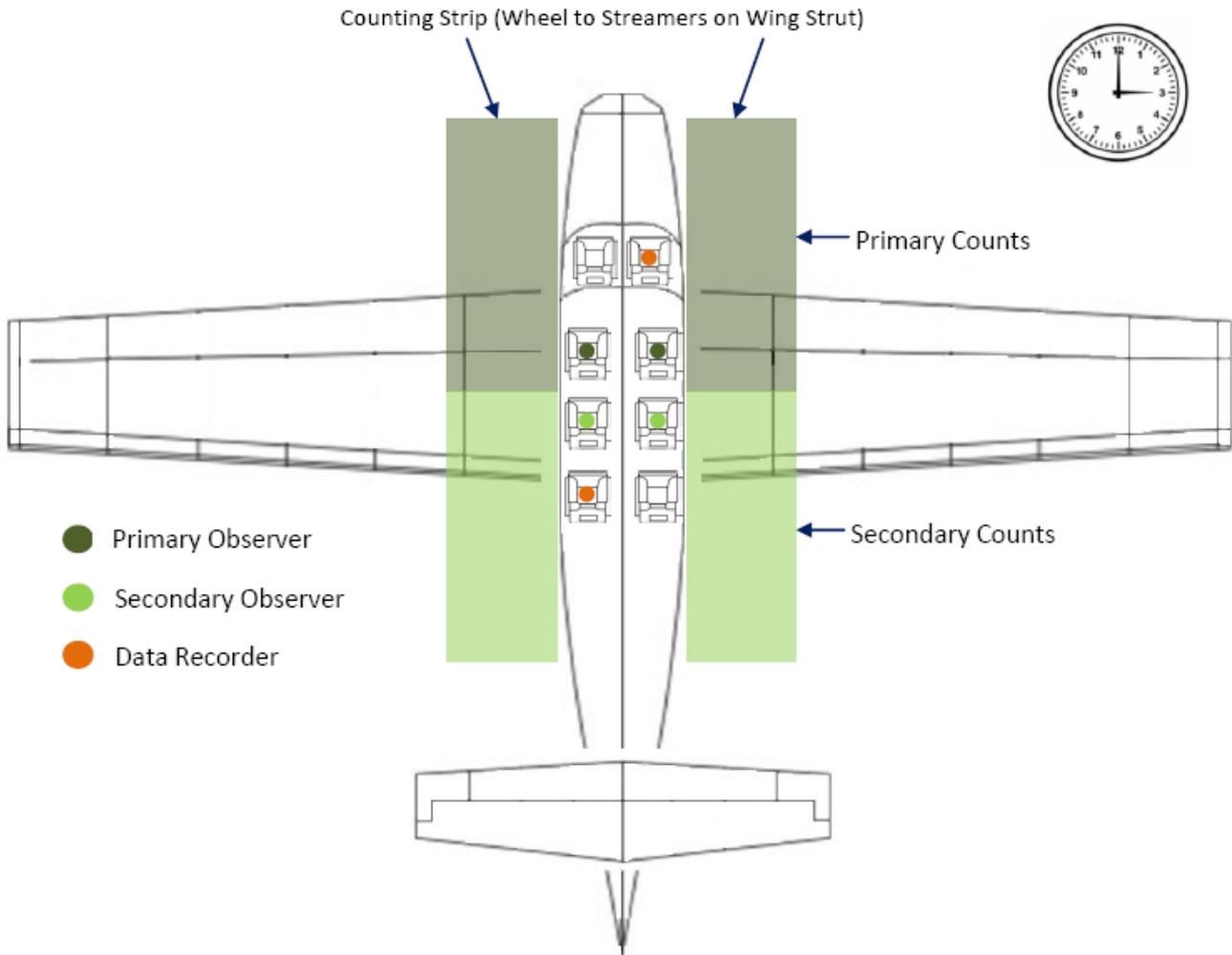


Figure 7. Observer position for the double observer method employed on this survey. The secondary observer calls caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. The small hand on a clock is used to reference relative locations of caribou groups (e.g. “Caribou group at 3 o’clock” would suggest a caribou group 90° to the right of the aircrafts longitudinal axis.).

Table 2. A comparison between the June 2011 and 2018 Beverly Mainland migratory caribou subpopulation abundance survey timing. Note the earlier start to the 2018 survey but similar abundance and composition survey dates suggesting similar dates for peak calving.

Survey Activity	Date (2011)																
	Jun-04	Jun-05	Jun-06	Jun-07	Jun-08	Jun-09	Jun-10	Jun-11	Jun-12	Jun-13	Jun-14	Jun-15	Jun-16	Jun-17	Jun-18	Jun-19	
Collar Reconnaissance					X						Ice Fog & Freezing Rain						
Systematic Reconnaissance						X	X	X	X								
Abundance										X			X	X	X		
Composition													X	X	X	X	
NEM Reconnaissance																	X
Survey Activity	Date (2018)																
	Jun-04	Jun-05	Jun-06	Jun-07	Jun-08	Jun-09	Jun-10	Jun-11	Jun-12	Jun-13	Jun-14	Jun-15	Jun-16	Jun-17	Jun-18	Jun-19	
Collar Reconnaissance	X	Ice Fog & Freezing Rain	X	X													
Systematic Reconnaissance					X	X	X	X	X								
Abundance										X	X	X	X				
Composition											X	X	X	X	X		
NEM Reconnaissance																X	X

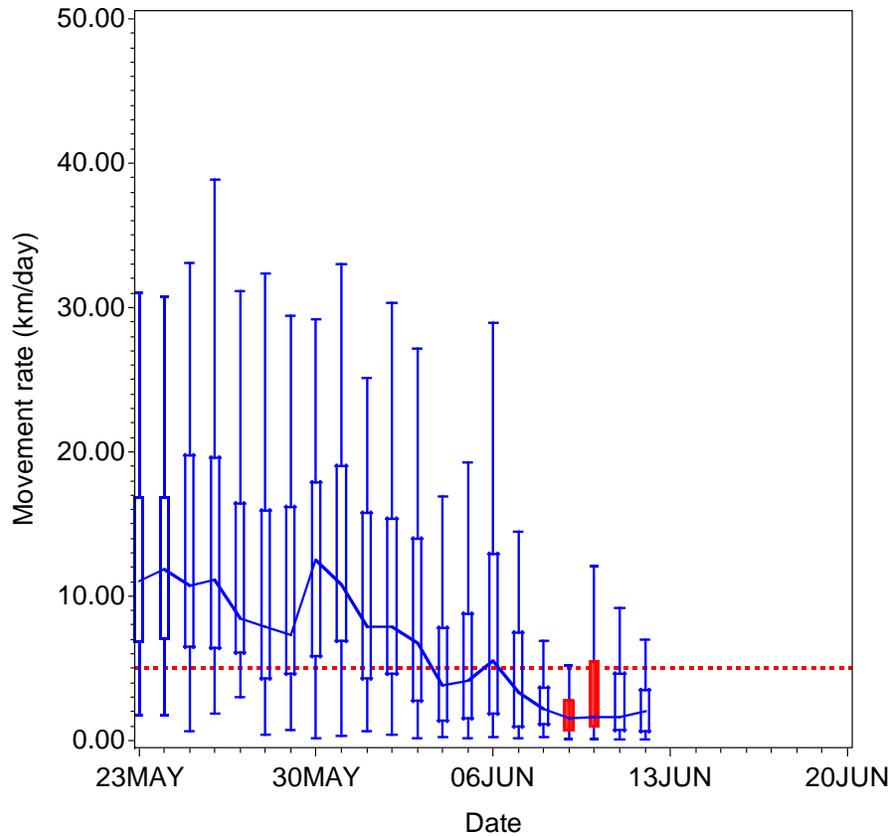


Figure 8. Movement rates of Qamanirjuaq caribou during the June 2017 calving ground survey, shown by way of example to illustrate the identification of peak calving periods based on movement rates. The red line (cow movement rate of 5 km/day) indicates movement rates consistent with the beginning of peak calving (bright red bars, Boulanger et al. 2018).

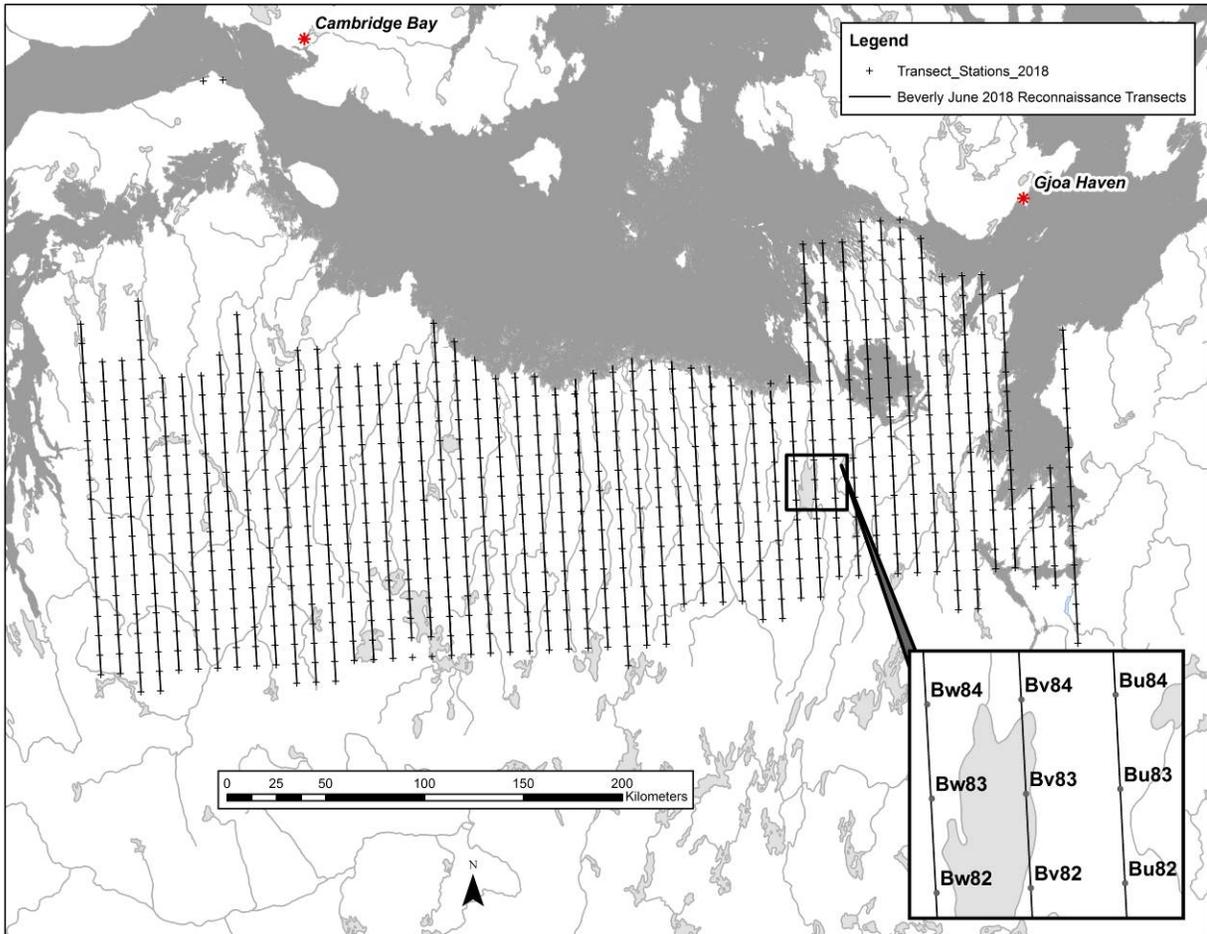


Figure 9. Reconnaissance transects and transect stations of the Beverly 2018 calving ground abundance survey. Transects placed to cover the known extents of female caribou based on real-time observations of the Beverly subpopulation of barren ground caribou.

3.2 DEPENDENT DOUBLE OBSERVER PAIR VISUAL METHOD.

The dependent double-observer pair method used in the Beverly 2018 calving ground survey was designed to replace the need for a photo plane for surveys encountering densities of ≤ 15 caribou per square kilometer (Campbell et al. 2012). The method requires two observers on each of the left- and right-hand sides of the aircraft: A front or “primary” observer who sits in the front seat of the plane and a rear or “secondary” observer who occupies the seat behind the front observer (**Figure 7**).

The dependent double observer pair method adhered to 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 halfway between the primary and secondary observer (approximately at the wing strut). 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 (**Figure 7**). The main requirement was that the primary observer should have enough time to call out all caribou seen before the secondary did;
- 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 had passed half- way between the observers;
- 3- The observers discussed any differences in group counts (Hence the term “dependent” double observer pair) to clarify whether they had called out the same groups or different groups, and to ensure accurate counts of larger groups;
- 4- The data recorders, one in the right-hand seat beside the pilot, and the other in the rearmost seat on the left side of the aircraft, categorized and recorded counts of each caribou group into “primary only”, “secondary only”, and “both”;

- 5- The primary observer on each side switched places with the secondary observer approximately half way through each survey day (i.e. at lunch or during refueling) to address observer fatigue and to monitor observer ability based on their position within the aircraft. The recorders noted the names of the primary and secondary observer for all observations.

The 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. We considered individual caribou within an estimated 100 meters of one another as a group.

3.2.1 Analysis methods.

Estimates of herd size and associated variance were developed using the mark-recapture distance sampling (MRDS) package (Laake et al. 2012) in the statistical program R (Cran-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, therefore making 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).

3.2.2 Modelling of sighting probability variation.

One assumption of the dependent double observer pair method is that each caribou group observed had an equal probability of being sighted (**Figure 10**). To account for differences in sightability we also considered the following sightability covariates in the MRDS analysis (**Table 3**). Each observer pair was assigned a

binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. Previous analyses (Campbell et al. 2012, Boulanger et al. 2014) suggested that the size of the group of caribou had strong influence on sighting probabilities and therefore we considered linear and log-linear relationships between group size and sightability (**Table 3**). Data recorders documented cloud and snow cover as ordinal rankings as they changed along transects. We suspected that sightability was most likely lowest in mixed snow cover conditions and therefore we considered both categorical and linear models to describe variation in sightability caused by snow cover. Cloud cover could also influence sightability by causing glare, flat light, or variable lighting. We used the same basic strategy to model cloud cover variation as we did for snow cover variation.

We evaluated model fit using the Akaike Information Criterion corrected for small sample size (AIC_c) 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 models with a ΔAIC_c score of less than two were considered for further investigation along with the most supported model.

Table 3. Covariates used to model variation in sightability for double observer analysis.

covariate	acronym	description
observer pair	observers	each unique observer pair
group size	size	size of caribou group observed
	Log(size)	Natural log of group size
snow cover	snowcat	snow cover (0,25,75,100)
	snow	continuous
cloud cover	cloudcat	cloud cover (0,10,25,75,100)
	cloud	continuous

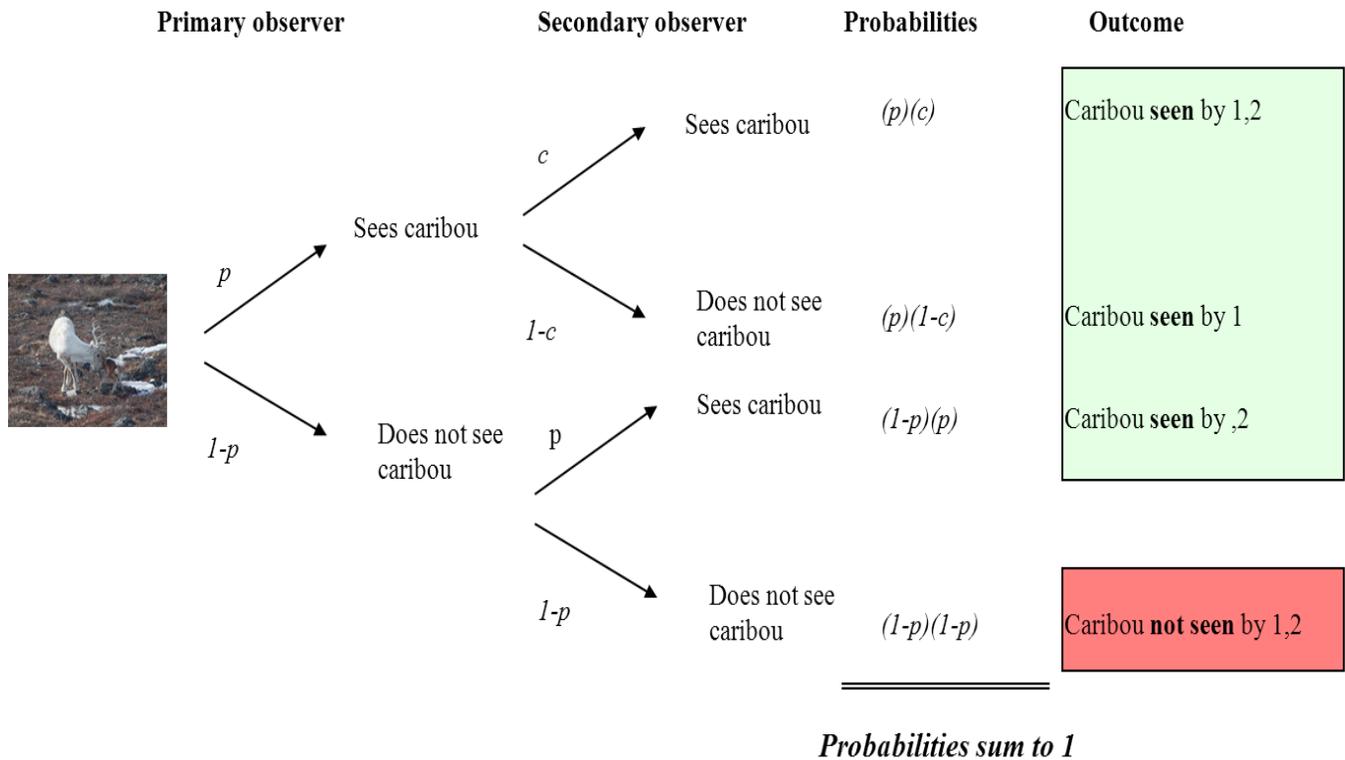


Figure 10. Conceptual diagram of how the probability of both observers not sighting a caribou group is estimated, and how the probability that at least one of the observers sees the caribou group (p^*) is estimated. The green boxes correspond to outcomes where caribou are seen and the red box corresponds to both observers missing a caribou group.

3.3 COMPOSITION SURVEYS – CALVING.

June composition surveys were timed to begin concurrently with visual abundance, from 13 – 16 June, 2018, and 13 – 17 June, 2011 respectively, surveys to ensure minimal movement of animals occurred between strata. Sampling was structured to begin at a fuel cache and then proceed to a predetermined transect station within a maximum of two (2) kilometers of the strata corner/boundary. From this station the aircraft would proceed to the next nearest transect station to the north and/or south priority sampling the next nearest caribou group (including individuals) encountered in a zigzag pattern using the proximity of transect stations to equally distribute composition effort (**Figure 11**). At times, observed groups of caribou “pulled” the aircrew from the pre-planned flight path. When sampling caused deviation from the preplanned flight path, the aircrew would stop sampling caribou groups that were seen greater than 5 kilometers perpendicular to the original flight path. From this point, only caribou groups observed within this five-kilometer buffer would be sampled and an attempt to rejoin the original flight path made. During re-positioning flights from the stratum to the fuel caches, caribou encountered within a maximum of 2 km inside of target stratum boundaries were classified opportunistically and variation of flight paths was held to within 2 km to reduce deviation from the planned flight paths and fuel caches.

During surveys, caribou were classified as yearlings (≥ 1.0 years and < 2 years of age), bulls, cows with calves (calves $<$ one month old), cows with udders, udderless cows with antlers, and udderless cows without antlers. Breeding cows were tallied as cows with calves, cows with udders, and udderless cows with antlers. Non-breeders were tallied as udderless cows with no antlers, yearlings and bulls. Using this information, we estimated the proportions of breeding females, adult females and adults for each stratum surveyed on the calving ground.

3.4 ESTIMATES OF BREEDING FEMALES, ADULT FEMALES, AND ADULTS.

We used bootstrap methods to obtain variance estimates of composition proportions for all abundance strata. Additionally, we used the bootstrapped mean and standard deviation as point estimates, and associated standard error of the proportion of breeders and females (Manly 1997).

Variances for composition survey's and abundance estimates for each strata were obtained for the combined estimates using the delta method (Seber 1982, Williams et al. 2002) assuming no correlation between the two estimates. Degrees of freedom for combined estimates were estimated using the formulas of Buckland et al. (1993). Estimates of the proportion of breeding females were then multiplied by the double-observer estimate of all adult caribou and yearlings for each stratum to obtain an estimate of the number of breeding females. Variances were obtained for the combined estimate using the delta method (Seber 1982; Williams et al. 2002), again, assuming that there is no correlation between the two estimates.

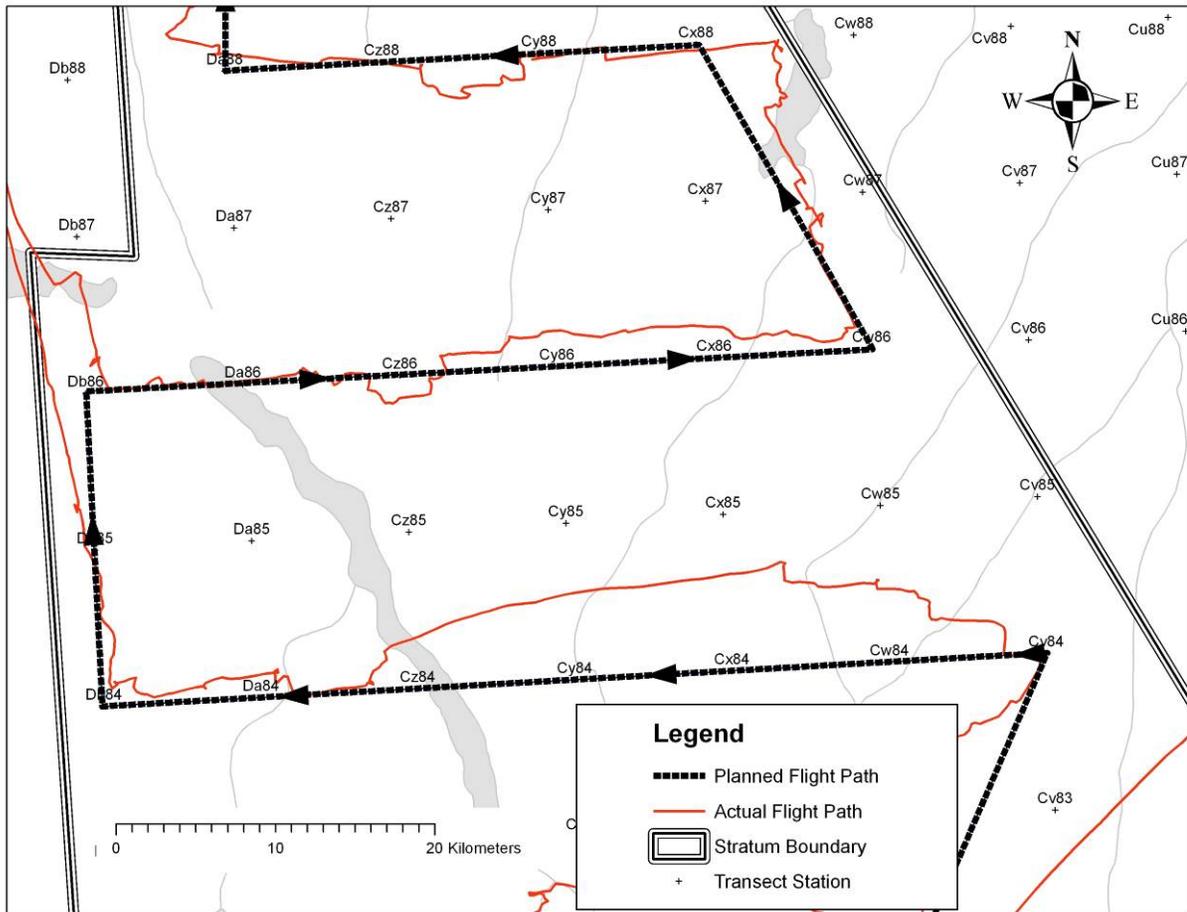


Figure 11. Stratum composition flight lines for the 2018 Beverly calving ground survey vs. planned routes. Deviations (red line) away from planned routes (black lines) were required to classify all observed caribou groups. The next nearest group would be classified up to a maximum of 5 km perpendicular to the planned route (half way between transect stations).

3.5 FALL COMPOSITION SURVEY – WHOLE HERD ESTIMATE.

The GNWT conducted a composition (sex ratio) survey in the fall of 2011. Due to funding constraints, a fall composition survey following the June 2018 survey was not possible. Therefore, we are using the 2011 fall composition results, as the best available scientific information, to develop the whole herd estimate derived in this report. The objective of the 2011 fall composition survey was to determine bull-cow ratios on the Beverly subpopulation fall rut seasonal range (**Figure 12**). The survey was conducted during the rut when all caribou ages and sexes are gathered together in mixed sex and aged groups. The bull-cow ratio is needed to extrapolate subpopulation estimates from the calving ground survey by dividing the estimate of the number of breeding females on the calving ground by the sex ratio of the subpopulation. Our use of composition data from 2011 could bias our results, because over time and across different population cycles, adult sex ratios can and likely do change.

A three-person crew conducted the fall composition surveys: front seat observer, rear seat data recorder, and pilot. Caribou were classified from the helicopter as cows, prime bulls, young bulls or calves (less than 1 year-old) and yearlings (greater than 1 but less than 2 years old). Females were classified based on the presence of a dark vulva patch, and calves were identified based on their small body size and rounded skull profile. Bulls were classified as either prime bull or young bulls based on body size and height of antlers. Classifications were recorded with tally counters and recorded into a notebook as an observation point. Each observation point was accompanied by a GPS waypoint. Cochran's (1977) jackknife technique was used in the field to calculate associated variances in age and sex ratios to determine optimum sample size. Bootstrap methods (Manly 1997) were used to estimate variances in age and sex ratios for final whole herd calculations.

Before the 2011 fall composition survey, a fixed-wing reconnaissance survey was conducted to determine the distribution of caribou in the study area. The sampling area was determined using the location of collared cows during the survey, as well as the geographic areas used by collared Beverly cows during the rut season, since 2006 (Nagy et al., 2011). Collars were radio-tracked to determine the relative numbers of caribou associated with each collar. This information was used to finalize the sampling design so that information from a representative portion of the subpopulation could be obtained during the composition survey.

The bull-cow ratio is reported as the count of bulls divided by the count of cows, whereas the proportion of adult cows is the number of cows divided by the number of adult cows and adult bulls. As with the calving ground composition survey data, a bootstrap procedure was used with the raw composition data for point estimates, standard error, and percentile-based confidence limits. One thousand resamples were conducted with the original data set (Manly, 1997).

We used an extrapolation method to estimate total subpopulation size, whereby the estimate of breeding females is divided by the proportion of adult females pregnant which is then divided by the proportion of adult cows in the population (collected in the fall composition survey) to estimate total subpopulation size (of caribou that are 1+ years old) (Heard, 1985). Estimates of adult females alone are solely based on the proportion of females derived from fall composition results (Campbell et al., 2012). Variances for photo and visual strata, or composition survey and strata estimates, were obtained for the combined estimates using the delta method assuming no correlation between the two estimates (Seber 1982, Williams et al. 2002). Degrees of freedom for combined estimates were estimated using the formulas of Buckland et al. (1993). Log-normal confidence limits were used for both the dependent double observer pair visual estimates and extrapolated estimates, as log-normal estimates provide better coverage than standard parametric intervals (Buckland et al. 1993).

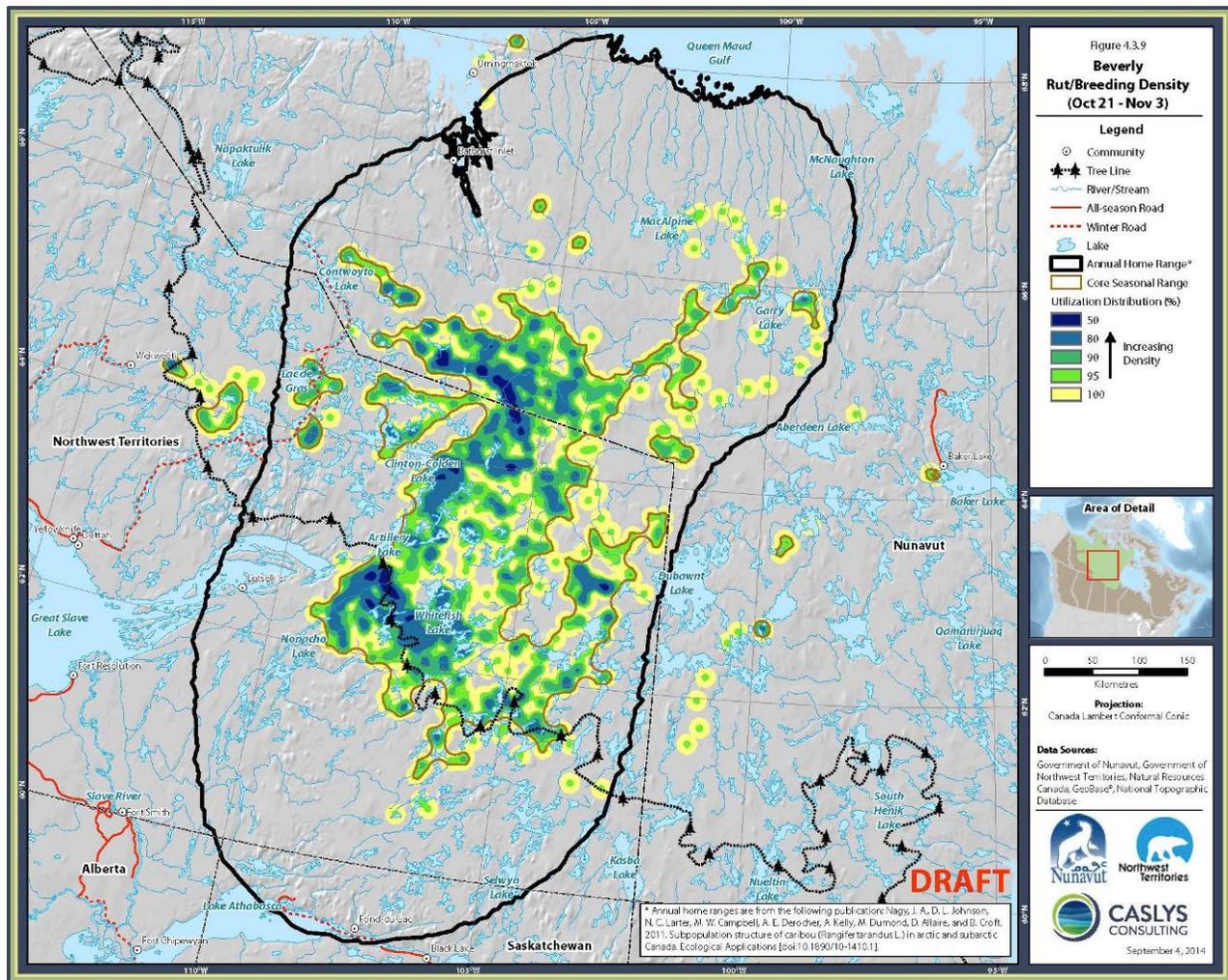


Figure 12. The Beverly mainland migratory barren-ground caribou rutting seasonal range. Kernel analysis based on telemetry data, current to 2012 (Campbell et al. 2014, Nagy et al. 2011).

3.6 AERIAL WILDLIFE SURVEY – OBSERVATION COLLECTOR.

To increase data entry speed without reducing accuracy, and to reduce the time required to perform preliminary analysis of reconnaissance data for abundance stratification, a digital data entry system, termed the “Aerial Wildlife Survey – Observation Collector” (AWS-OC), was developed and utilized for this survey. The software was originally developed by the Government of Nunavut, Wildlife Research Division, in collaboration with Integrated Ecological Research, Caslys Consulting Ltd, and Nunavut Tunngavik Inc (NTI), in 2011, and originally deployed on the June 2011 Beverly mainland migratory barren-ground caribou calving ground abundance survey (Campbell et al. 2012). Since its original launch, improved hardware, and some enhancements to the AWS-OC software had been undertaken prior to its deployment in June 2018 (Boulanger et al. 2018).

The AWS-OC software operates with Windows editions 7 through 10 and was developed specifically for use in both independent and dependent double-observer pair aerial caribou surveys, including distance-sampling applications, to facilitate the collection of field data, and the subsequent management of the resultant observation dataset. This tablet-based system allows for the instantaneous entering of caribou group waypoints (observations) directly into a digital database. Data entry time was cut by approximately 50% over standard hand written datasheets, with the added benefits of continuous back up onto a USB drive into a digital database with no additional data entry required. The application includes two modules:

1- The **AWS-OC Field Collection Module** is designed for collecting observation data while airborne. The application is spatially enabled to connect with a Global Positioning System (GPS), and displays the current location on maps that are compatible with ESRI’s ArcGIS software. Minimal training is required to operate the system;

2- The **AWS-OC Data Manager Module** is designed for use on the ground or

in the office for data management and field planning tasks. Advanced user functionality is focused on tabular data accessible with MS Access database software and integration with ESRI ArcGIS.

The AWS-OC is designed for use on windows touch screen tablets and has been designed and tested to integrate with the internal (integrated) GPS signal of the Xplore (Motion) R12 touch screen tablet. Configuration still allows for external GPS connections if required. For added durability and stability in severe turbulence, the tablets have been equipped with solid-state hard drives. The tablets also included swappable batteries that allow for uninterrupted operation during a flight, and USB ports to allow for data transfer following field collection. Additional equipment and tools that complete the AWS-OC field kit include a spare battery to provide added insurance for power supply for a full day of fieldwork, USB flash memory stick, and two software utility applications to merge text files and merge shapefiles to assist with data management tasks.

The data entry page of the *Survey Session Details* form (**Figure 13**) allows the entry of common details (i.e., unique aircraft ID, crew assignments, and appropriate transect file, which enables the auto-completion of transect details based on the GPS signal). Additionally, the software automatically records altitude, ground speed. Input fields for the entry of co-variate data such as cloud cover, snow cover, alternate species, and habitat type are also provided.

Figure 13. The data entry screens of the AWS-OC tablet interface used during the June 2018 Beverly mainland migratory barren-ground caribou abundance survey. Screen shots include the Survey Session Details (Top), and Primary Data Collection display (Bottom).

3.7 TELEMETRY SPATIAL ANALYSIS (2011 TO 2018)

We analysed the core calving range for the Beverly barren-ground caribou subpopulation using telemetry data between survey periods (2011 and 2018). In addition, we reviewed telemetry data for the Bathurst and Northeast Mainland subpopulations (including the Ahiak, Wager Bay, and Lorillard subpopulations) to identify the extent of overlap between the subpopulations during the calving season. GPS telemetry data are collected for the barren-ground caribou subpopulations in Nunavut and NWT (GNWT Environment and Natural Resources, 2018) as part of long-term population monitoring programs within both jurisdictions. These data are used in spatial analyses to gain an understanding of the movement patterns and area affiliations of caribou on the landscape. These movement patterns are of specific importance when assessing abundance survey results where potential for subpopulation overlap exists.

For this analysis, GPS telemetry data were restricted to locations for collars belonging to the Bathurst, Beverly and NEM (Ahiak, Lorillard, and Wager Bay) subpopulations collected between June 1st and June 20th for 2008 to 2018. As data collection frequencies varied between collars, all data were re-sampled to daily fixes (i.e., 24 hours) to ensure a standardized measure for daily displacement. Additionally, locations that were either pre-deployment or post-mortality (e.g., locations that ended up in communities) were removed from the analysis.

We also examined the data to verify that the herd designation was appropriate for the analysis. In Nunavut, the collars are assigned to a herd based on the deployment location and the spatial analysis of the data. The majority of the NEM collars were deployed to the northwest and northeast of Baker Lake, well within Ahiak and Lorillard subpopulations spring seasonal range (Campbell et al. 2014). There are a few instances where collared NEM caribou cows switched calving ground affiliations between years. These observations occurred mainly between

the Beverly subpopulations ACCA and the Ahiak subpopulations ACCA east of Adelaide Peninsula and Chantrey Inlet.

In the NWT, collared caribou are categorized into different herds based on their calving ground affiliation and not the subspecies specific late winter/early spring seasonal range on which they were captured. Three affiliations were noted within GNWT telemetry data and included Beverly, Ahiak, and Beverly/Ahiak designations. In some cases, GNWT designated subpopulation affiliations changed for the same animal within its collared life (length of time the animal wore the collar) based on where the collared animal calved. This was not the case for the few Bathurst collared caribou that we observed to calve within the Beverly ACCA in 2018. In these cases, the Bathurst designation did not change based on their calving location. All GN collared caribou cows were assigned herd affiliations based on the known subpopulation seasonal range on which they were collared. These designations remained the same throughout the collared life of the specific caribou.

To accommodate these different approaches, we used only animal ID numbers specific to one animal, and removed any reference to herd designation. We assessed each collar and its deployment location individually (**Figure 14**). We identified subpopulation affiliations based on both the subpopulation specific seasonal range on which they were captured, and the subpopulation specific range within which they calved throughout the life of the collared caribou cow.

To generate the full calving extent and core calving areas, kernel density layers were generated for each of the subpopulations using the Spatial Analyst extension in ArcGIS software. To determine the appropriate search radius (i.e., bandwidth) the telemetry locations were imported into R and used the *adehabitat* LT (Calenge 2006) package to calculate the appropriate bandwidth (Worton, B. 1989). The derivative kernel densities were then reclassified into the utilization distribution (UD) ranges (100%, 95%, 90%, 80% and 50%) and converted to polygons. The

full calving extent is represented by the 100% UD boundary and the core calving area is the 95% boundary.

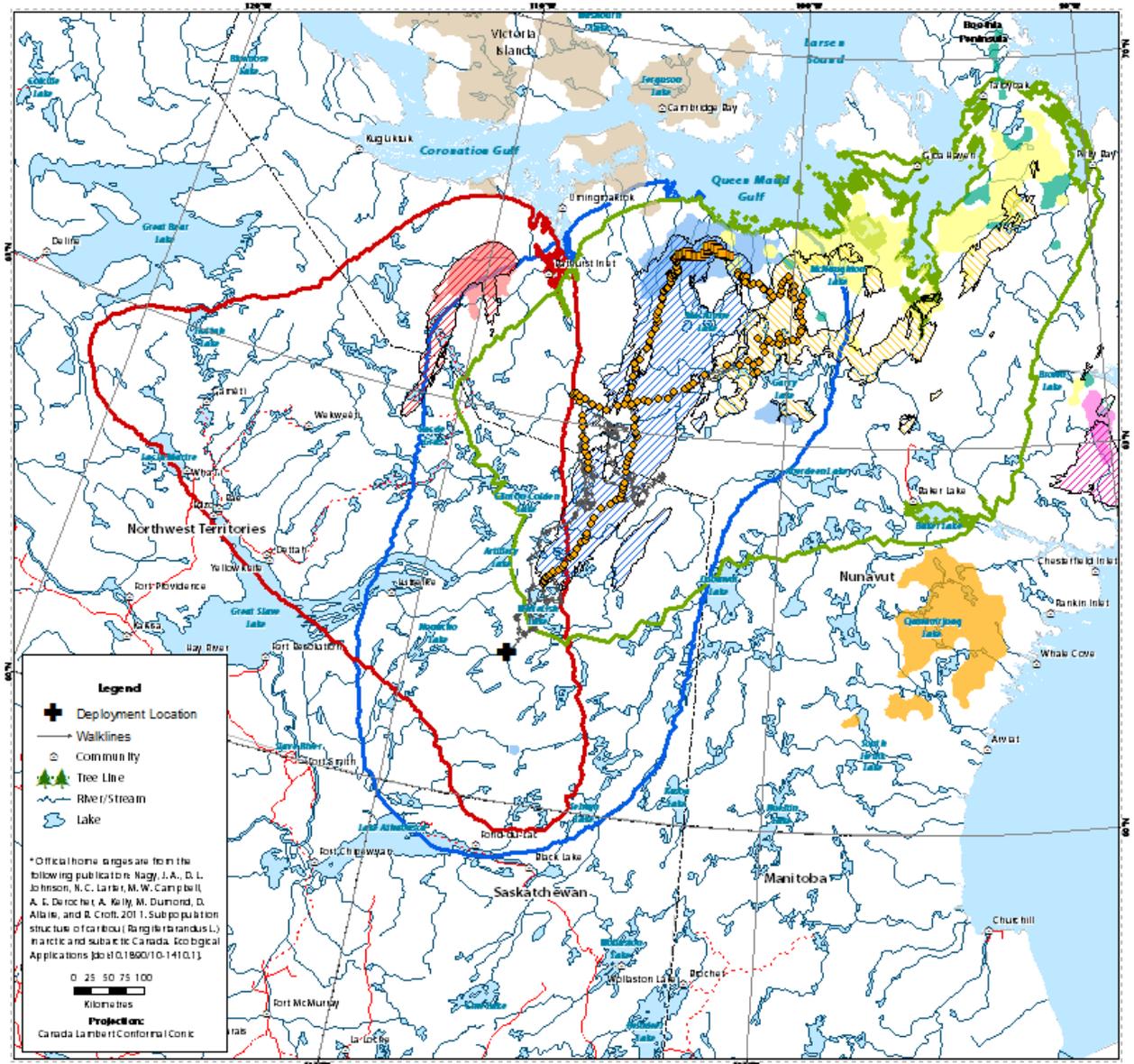


Figure 14. An example of the spatial review of collars. The black cross indicates the capture location, and the brown squares the track of a single collared caribou. Note the light red polygon indicates the Bathurst spring range, the light blue polygon indicating the Beverly spring range, and the light green polygon indicating Ahiak spring range (Campbell et al. 2014). This caribou was captured in the Beverly spring range, and calved in the Beverly calving ACCA, so was included in this analysis as a Beverly caribou.

3.8 MOVEMENT ANALYSIS.

An important question in interpretation of trend estimates from caribou calving within the Queen Maud Gulf (Beverly), the Adelaide Peninsula (Beverly and Northeast Mainland (NEM)), and areas east of the Adelaide Peninsula (NEM) is if directional movement of caribou occurs from east to west across Chantrey Inlet. This is important to assess given that the Ahiak subpopulation of the NEM has only been surveyed once, in 2011. An additional question is which of the caribou calving in the QMG or with the Northeast Mainland/Ahiak subpopulations are more affiliated with the Adelaide Peninsula.

Collared caribou data were analyzed to assess movement rates between the Bathurst calving ground (in the immediate vicinity or to the west of Bathurst Inlet), the Queen Maud Gulf/Beverly calving ground (from the Bathurst border to Chantrey Inlet), and the NEM calving grounds (as represented by the Ahiak and Lorillard subpopulations) east of the Back River and the eastern shore of Chantrey Inlet. To do this, the mean locations of collared cows were classified into calving strata based on geographic/calving ground location (**Figure 19**). For caribou that were monitored for more than one year, a calving ground history was created which allowed assessment of relative fidelity as well as movements of cows between calving ground/geographic areas in successive years.

One challenge with the analysis of calving ground fidelity is related to effort. Some subpopulations (and caribou of different calving grounds) have seen higher levels of collaring effort than others. Given this differential effort, multi-strata models (Hestbeck et al. 1991, Brownie et al. 1993) in the program MARK were used to estimate rates of movement (termed 'transition probabilities') between calving grounds, yearly survival, and recapture rates using yearly records of calving ground location for individual collared cow caribou (White and Burnham, 1999, White et al. 2006). Our use of a multi-state model considers the calving ground history, to estimate fidelity of a caribou to a given calving ground, as well as

movement to other calving grounds. Year-specific estimates of movements were challenging due to low sample sizes so we mainly focused on analyzing overall trends for the 2011-2018 period. Survival and detection probabilities were considered constant across all groups for this analysis. Multinomial logit-link terms were used to force the sum of movement transition probabilities to sum to 1 within stratum. Simulated annealing (the generation of a novel potential solution to the specified problem), and Markov Chain Monte Carlo (MCMC) methods were also used to test estimates for convergence. As with the dependent double observer pair methods, AICc methods of model selection were used to determine the simplest (most parsimonious) models that described fidelity and movement between calving ground areas.

3.9 ANALYSIS OF TREND FROM RECONNAISSANCE SURVEY DATA.

The reconnaissance survey data from 2011, 2013, 2016, and 2018, were analyzed to determine relative trends in numbers of caribou utilizing the Queen Maud Gulf and Adelaide Peninsula calving extents. We delineated survey areas based on the extent of flying, in the area, each year. Identical methods were used to summarize and analyse the four reconnaissance survey data sets. Estimates of abundance using the standard Jolly 2 strip transect estimator were generated for each year within survey extents determined by the presence of females and breeding females (Jolly, 1969). A single stratum, spanning the entire known Beverly subpopulation's calving extents, was used for each year. Log-linear models were used to analyze trends from the reconnaissance abundance estimates for the increase and decrease phase of the data set (McCullough and Nelder 1989, Thompson et al. 1998, Williams et al. 2002). We weighted survey estimates by the inverse of their variance, therefore giving more weight to the more precise estimates. The slope term of the regression is the per-capita rate of change (r) which translates to the population rate of change ($\lambda=e^r$). Interestingly, rates of change were similar, regardless of survey area considered, or method used for analysis.

4.0 RESULTS & DISCUSSION.

4.1 SPATIAL ANALYSIS OF COLLAR DATA.

Based on an analysis of collar affiliations related to late winter and spring 95% utilization distributions (current to 2012), we found that 153 collars were deployed between 2011 and 2018 on female Beverly caribou (**Table 4**). We mapped the travel routes of all Beverly designated collars for both the 2017 and 2018 calving seasons (June 1st to 20th, both years) in **Figure 15**. Using kernel analysis, we mapped the 95% utilization distributions of Beverly affiliated collars to delineate an annual core calving area (ACCA) for the Beverly subpopulation from 2011 to 2018 (**Figure 16**). Based on Campbell et al. (2014), the core calving range lies within the indicated 95% utilization distribution. Over the same period, there were 159 and 118 active collars on Bathurst and NEM-affiliated caribou cows, respectively. As described in the methods section of this report, out of all the collars used in this analysis, only three of the NWT Bathurst collars were reassigned to a different herd. Additionally, three cows that had been collared on the Bathurst late winter/early spring range and calved their first year within the known Bathurst ACCA, calved within the known Beverly ACCA east of Bathurst Inlet in June 2018. This suggests some level of mixing between the Bathurst and Beverly subpopulations within the western extents of the Beverly ACCA (**Figure 17**).

Bandwidth values for the kernel analysis (appropriate search radius for each subpopulation) were calculated for all three subpopulations and resulted in a wide range of values. The NEM group consists of three different subpopulations (Ahiak, Lorillard and Wager Bay), which are spread over a large spatial extent. This resulted in a large bandwidth value which can have the net effect of overestimating the calving area. Bandwidths ranged from 10.6 km for the Bathurst subpopulation, to 20.5 km for the Beverly subpopulation and 49.0 km for the NEM subpopulations. Due to the wide range of bandwidth values, and for comparative purposes, the

result for Beverly (20.5 km) was used in a kernel analysis for all three subpopulations. The utilization of this smaller bandwidth could underestimate calving extents, so caution in the interpretation of the NEM calving extents should be used. Overall Beverly collared caribou cows showed good affiliation to the known Beverly calving extents including the Adelaide Peninsula (ADP), from 2011 through 2018. NEM affiliated collars however, displayed extensive overlap over most of the known Beverly subpopulations ACCA, when the 100% utilization distribution is used (**Figure 18**). Caution should however be exercised in the interpretation of the implication of this overlap due to:

- 1- The much reduced bandwidth used and,
- 2- The NEM affiliated collared caribou cows displayed a much higher frequency of switching between known calving ACCAs of the Beverly subpopulation than either the Beverly or Bathurst subpopulations, for which the switching of calving ground affiliations was far less frequent.

An examination of collar movement and calving ground affiliations through time is detailed in the following sections of this report.

Table 4. Collars deployed on adult female barren-ground caribou of the Beverly, Bathurst, and Northeast Mainland (Ahiak, Lorillard, and Wgger Bay) subpopulations, between 2011 and 2018.

Year	Number of Collars		
	Beverly	Bathurst	Northeast Mainland
2011	13	18	24
2012	21	21	19
2013	11	13	12
2014	29	18	8
2015	13	31	12
2016	13	27	26
2017	24	31	17
2018	29	22	38
Totals	153	181	156

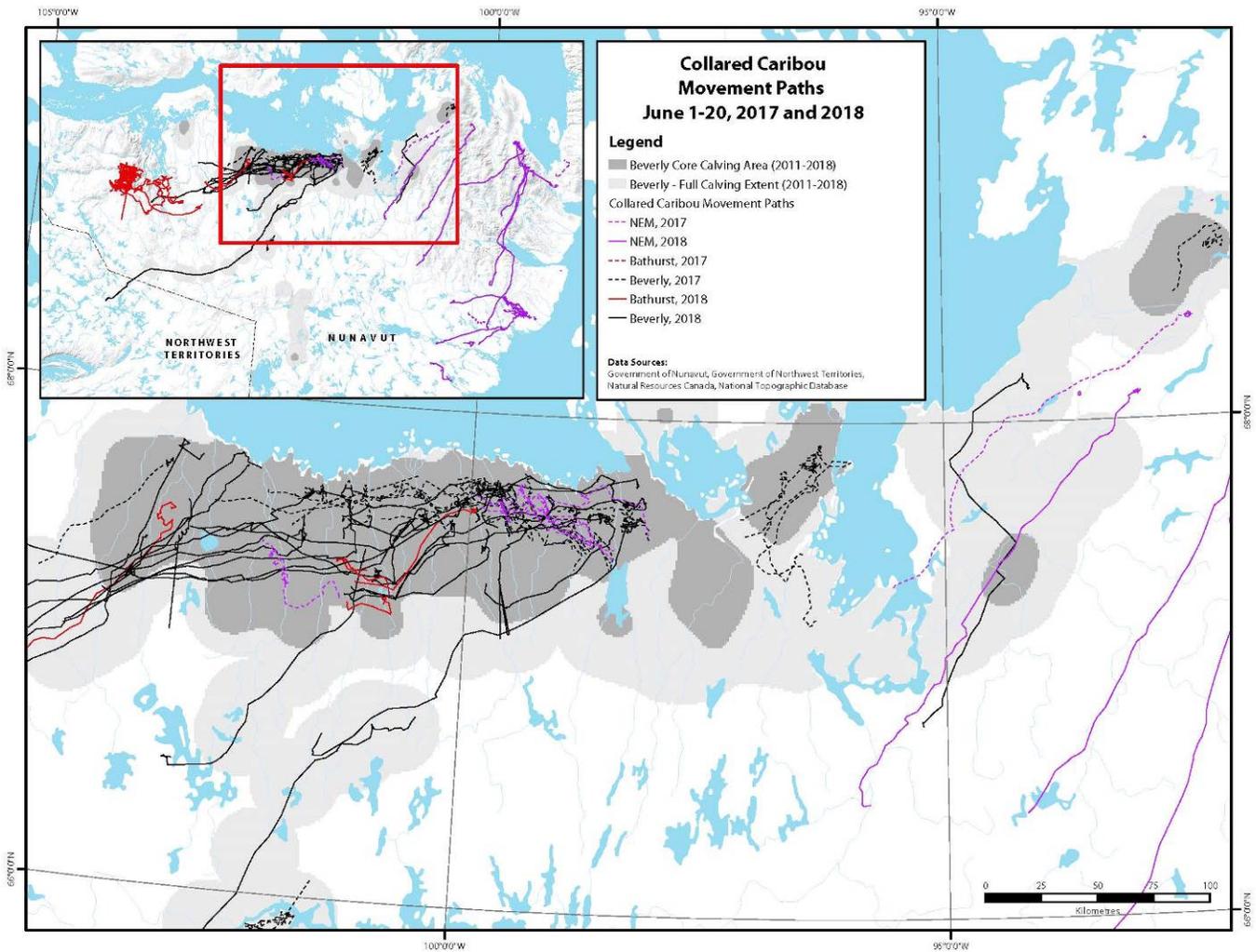


Figure 15. Telemetry walk lines for the Beverly, Bathurst, and NEM subpopulations for the 2017 and 2018 calving periods. Note: Black lines represent Beverly collared caribou cows, Purple lines the NEM, and red lines the Bathurst subpopulation. Dotted lines indicate 2017 movements, and solid lines, 2018. Note that though there is mixing, the Beverly collars dominate the Beverly ACCA.

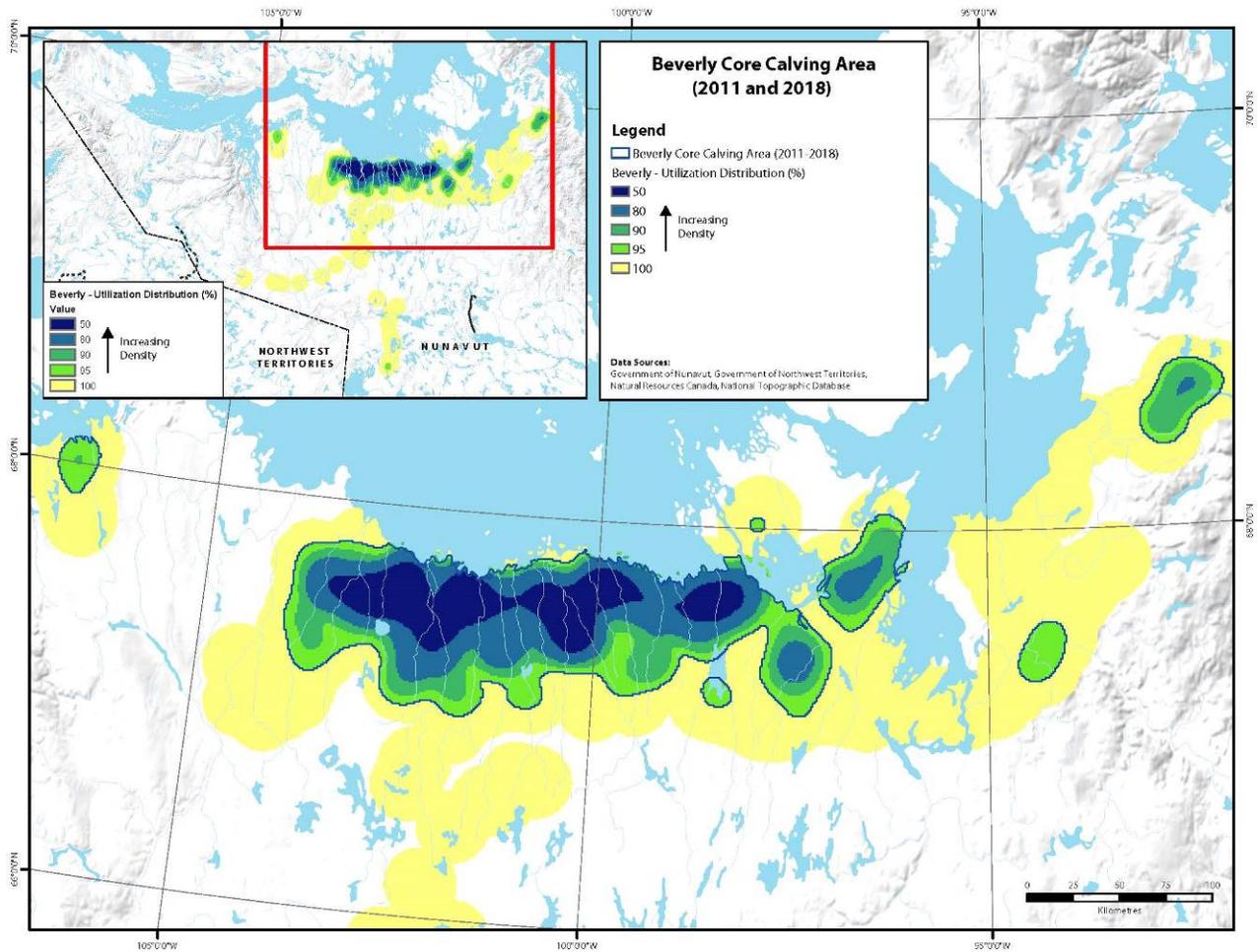


Figure 16. The Beverly mainland migratory barren-ground caribou subpopulations 2011 to 2018 calving extents, based on subpopulation affiliations related to both calving ground use and capture location.

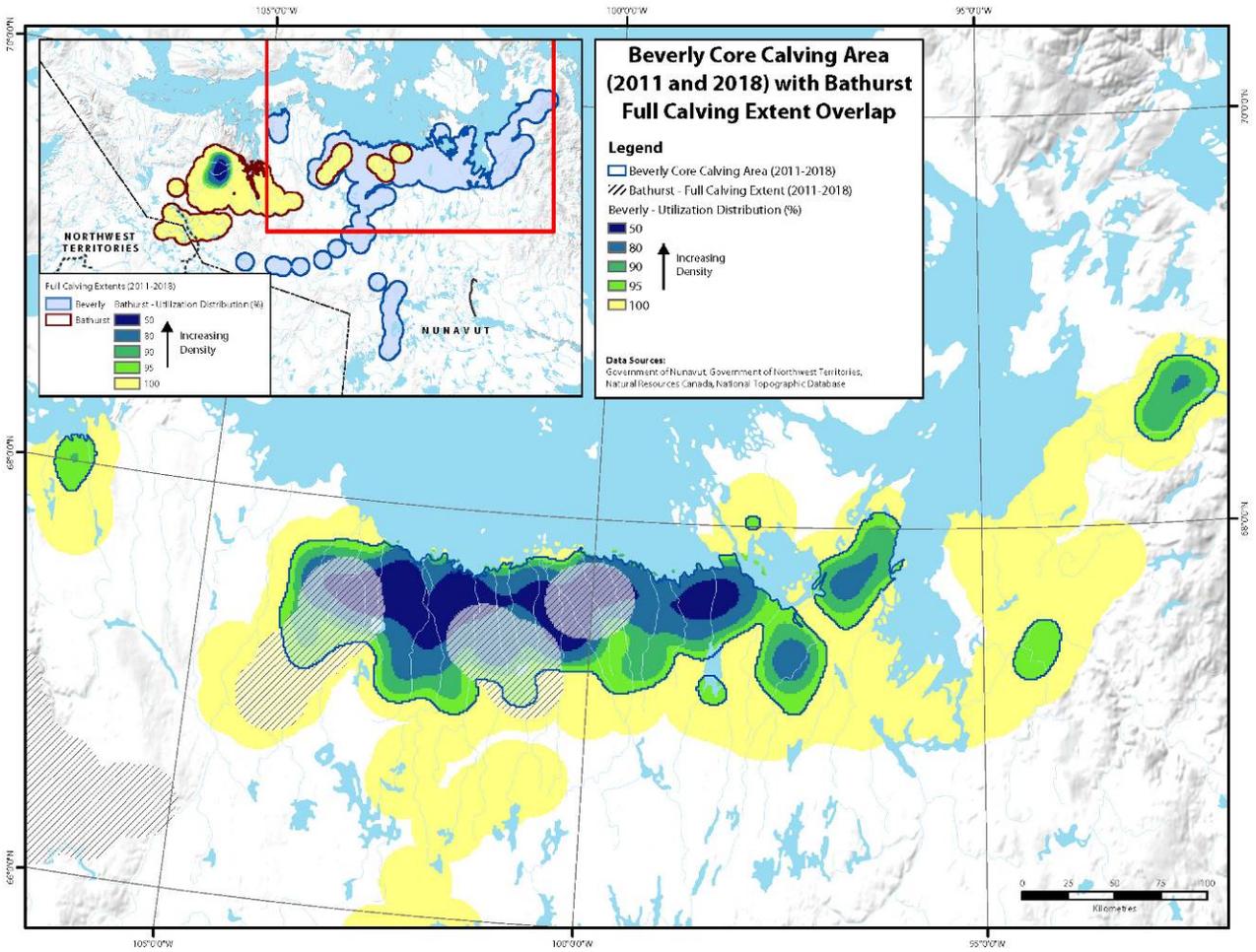


Figure 17. Overlap between the Beverly ACCA (2011 to 2018) and the 2018 Bathurst subpopulation calving extents.

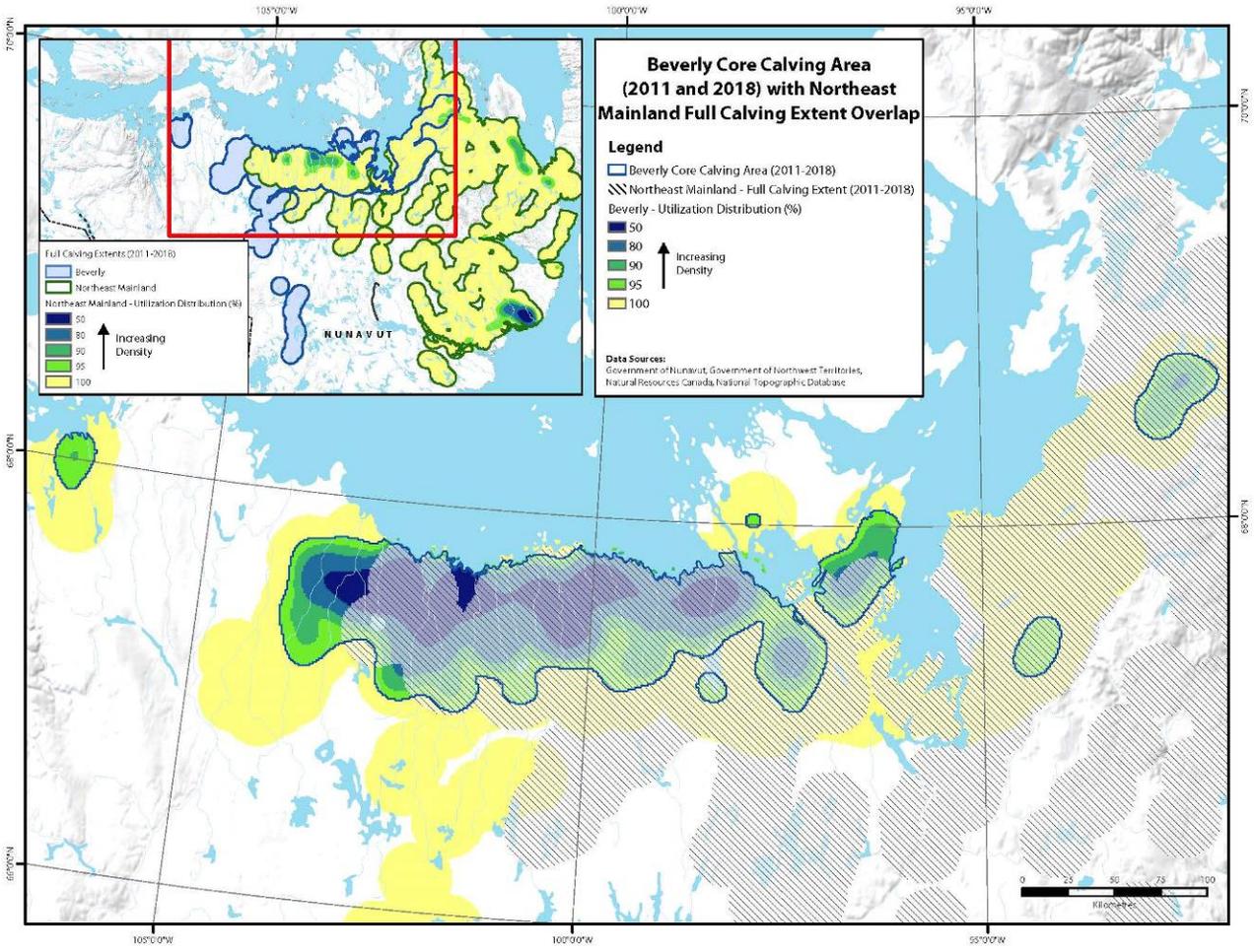


Figure 18. Overlap between the Beverly ACCA (2011 to 2018) and the Northeast Mainland subpopulations calving extents (2011 to 2018).

4.2 ANALYSIS OF FIDELITY OF CARIBOU TO CALVING AREAS USING COLLAR DATA.

We classified and summarized the locations of collared females monitored for more than one year yielding a much smaller sample size than total collared cows. We further confined collar selection based on Bathurst, Beverly, and NEM calving ground strata (**Table 5**). Of note, is the large difference in sample sizes between the Bathurst, Beverly, and Northeast Mainland (Ahiak and Lorillard) collared cows. Namely, there were only 36 collared caribou locations between 2010 and 2018 occurring in the Northeast Mainland subpopulations, when compared to 116 Beverly (Queen Maud Gulf and Adelaide Peninsula), and 101 Bathurst collar locations. For this reason, interpretation of frequencies of movement alone, between the Northeast Mainland affiliated collars and the Bathurst and Beverly collar affiliations, should be treated cautiously because lower sample sizes utilizing delineated calving strata would likely lead to fewer NEM movement events to and from known calving strata. For additional clarification, the movement events in **Table 5** are shown spatially in **Figure 20**, which illustrates the differences in collar sample sizes between the calving areas as well as yearly variation in relative location of cows on the calving strata.

4.2.1 Beverly, Bathurst, and Northeast Mainland Calving Affiliations.

This first analysis investigated whether there were directional movements of caribou from the NEM to the Beverly (BEV) and Adelaide Peninsula strata (ADP). For this analysis we pooled the Queen Maud Gulf and Adelaide Peninsula strata, to emulate reconnaissance surveys conducted between 2011 and 2018. One challenge with this analysis is that the majority of collars are Beverly, where collar deployment was centered on the Beverly seasonal range (**Table 6**). In contrast, the Northeast Mainland (Ahiak and Lorillard) collared caribou program, focused collar deployment on the Northeast Mainland (Ahiak and Lorillard) subpopulations seasonal range. A potential bias might exist if the majority of collared caribou cows

were originally collared on the Beverly early spring range, and therefore, are more likely to return to the BEV and ADP calving strata regardless of their occasional use of the NEM calving strata. To address this issue, Northeast Mainland and Beverly subpopulation affiliated collars were entered as groups in the analysis, which allowed testing of whether there were differences in fidelity and movement based on initial collaring location. Herd affiliations were based on calving location, rutting location, and seasonal collar affiliations based on Nagy et al., (2011) and Nagy and Campbell, (2012). Models that assumed equal movements for collars of different origin, were then contrasted with models that assumed unique movement for the two-collar subpopulation affiliations. The model that assumed equal fidelity for the Beverly and Adelaide Peninsula calving strata, but collar group-specific rates of movement to the NEM calving strata, was most supported (**Table 7**: Model 1). However, a model that had unique fidelity for collars was also equally supported (Model 2). This result indicates that there was support for collar-group influencing movement rates; however, the strongest effect was evident for the NEM collar group.

Estimates from Model 2 for the NEM (Ahiak and Lorillard) collared caribou cows, suggest equal probabilities of movement between the Beverly and Adelaide Peninsula strata, and NEM (0.13) calving strata, with higher fidelity to the NEM calving strata (0.87) (**Table 8**). In contrast, the GNWT deployed Beverly collars deployed by the GNWT displayed high fidelity to the Beverly and Adelaide Peninsula pooled calving strata (0.924), but zero fidelity to the NEM calving strata. This was also indicated by no instances where a collared Beverly cow calved on the NEM calving strata for more than 1 year out of its collar life. The general conclusion from this analysis is that fidelity is relatively high for the Beverly calving ground (Beverly and Adelaide Peninsula pooled data) regardless of collar group. An estimate of fidelity from Model 1, for the Beverly subpopulation, and averaged across all collars for the Beverly and Adelaide Peninsula pooled calving strata, is 0.913 (SE=0.02, CI=0.5-0.95). However, estimated fidelity for the NEM depends on collar group. The most representative sample in this case would be from the

NEM collar group, with an estimated fidelity to the NEM calving strata of 0.92 CI=0.85-0.96).

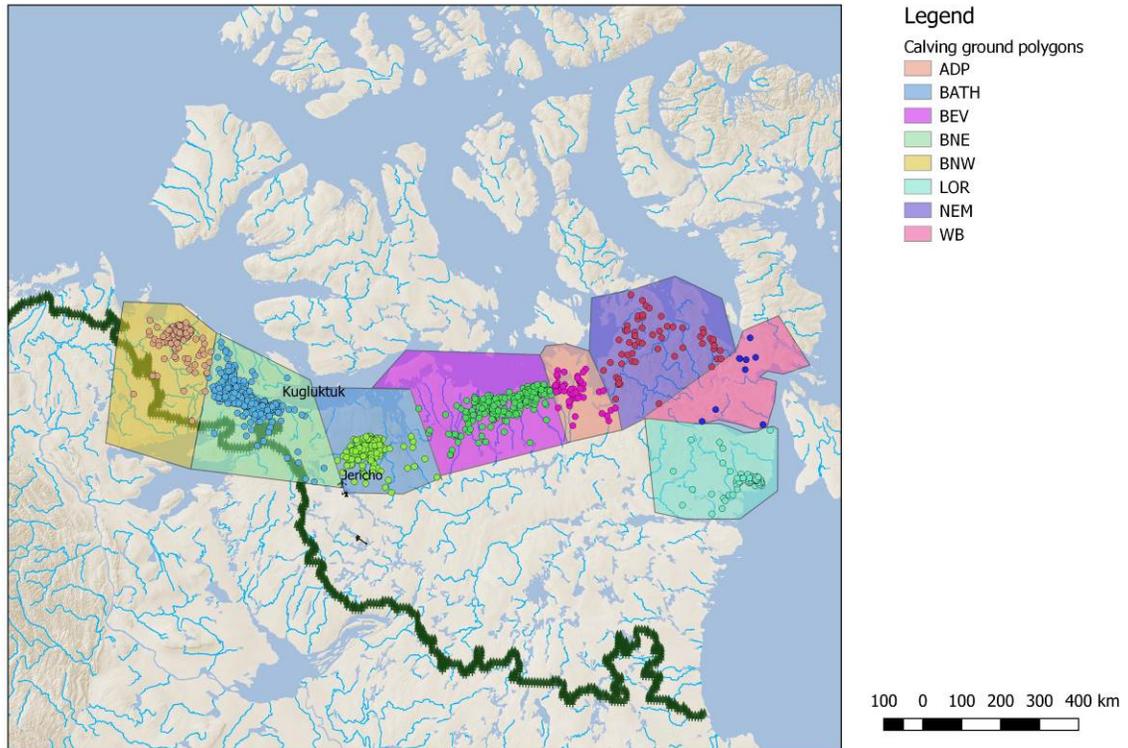


Figure 19. Polygons defining calving ground areas for collar analysis (ADP = Adelaide Peninsula, BATH = Bathurst, BEV = Beverly, BNE = Bluenose East, BNW = Bluenose West, LOR = Lorillard, NEM = Ahiaik and mixed, WB = Wager Bay).

Table 5. Collar movement events in the Bathurst, Beverly (Queen Maud Gulf (QMG) & Adelaide Peninsula (ADP)), and Ahiak (NEM & ADP) calving grounds (CG). Only collars that were monitored two or more years are listed in this table. See **Table 9** for a summary that separates QMG and ADP collars.

Movement event		Year									
Previous CG	Current CG	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Bathurst	Bathurst	6	5	7	10	4	13	20	20	8	93
Bathurst	Beverly	0	0	0	0	0	0	0	0	3	3
Beverly	Beverly	2	3	6	7	8	24	23	16	17	106
Beverly	NEM/Ahiak	0	1	1	3	0	1	2	1	1	10
NEM/Ahiak	NEM/Ahiak	0	5	4	1	1	0	2	3	3	19
NEM/Ahiak	Beverly	0	1	1	0	2	0	1	1	1	7
Totals		8	15	19	21	15	38	48	41	33	238

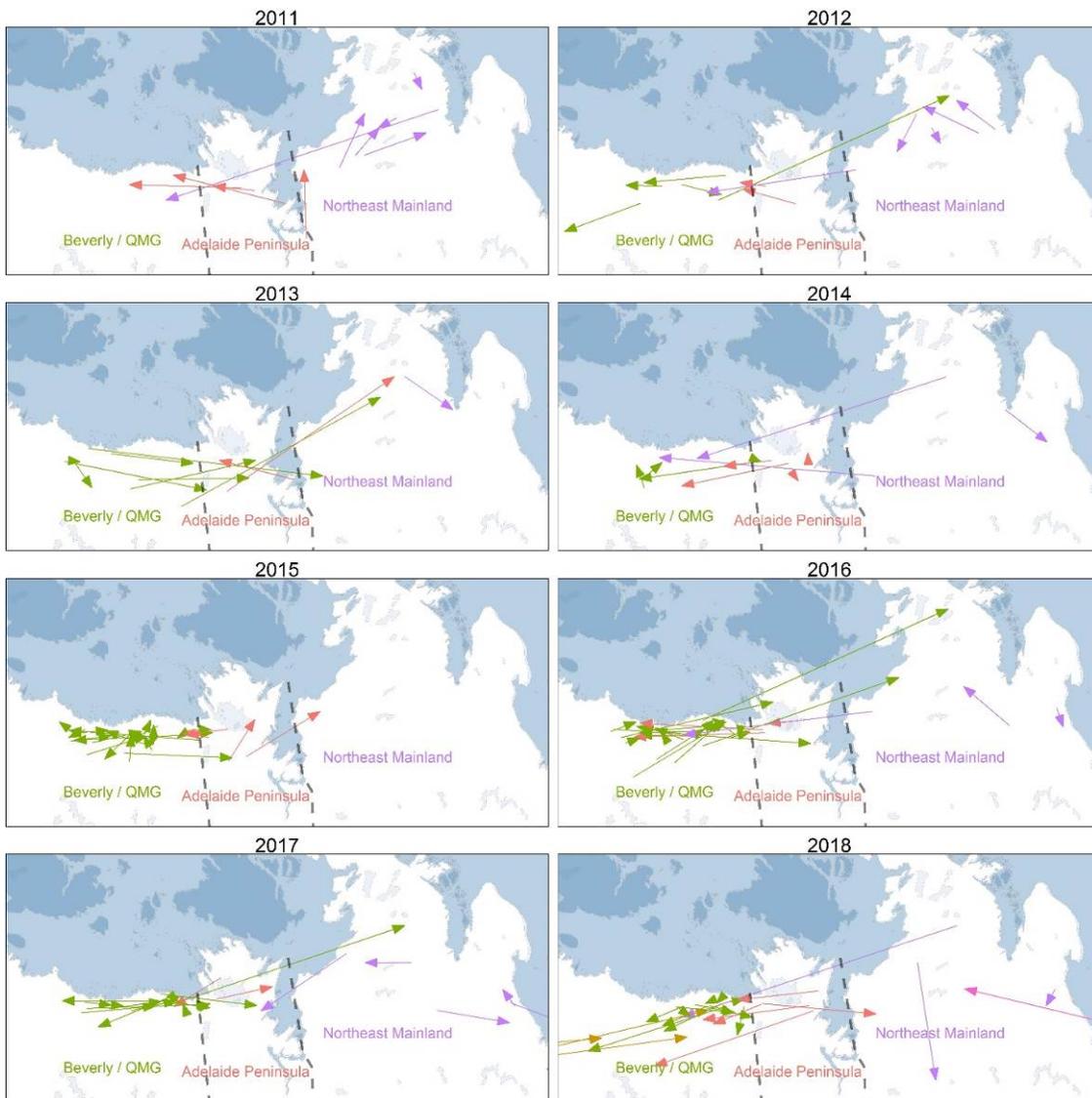


Figure 20. Movement of caribou between yearly calving grounds. The direction and colour of the arrow in each figure corresponds to the movement of a caribou from the previous year's calving ground. The head of the arrow is the mean location of the caribou on the present year calving ground and the tail of the arrow is the mean locations in the previous year. Calving grounds are labelled and delineated by color. The boundary of the three principal calving grounds are delineated by hatched lines.

Table 6. Sample sizes of collared caribou by original collar location and yearly calving grounds

Original collar location	BATH	BEV	ADP	NEM	Total
Beverly (ENR)	204	156	24	7	401
NEM (GN)	0	21	19	52	92
Total	204	177	43	59	483

Table 7. Multi-state model selection results for pooled BEV & ADP, and NEM multi-strata model, with collar origin as a group. Sample size adjusted for Akaike Information Criterion (AICc). The difference in AICc between the most supported model and the subsequent model (e.g. Model 2 AICc – Model 1 AICc = $\Delta AICc$), for number of model parameters (K), and associated deviance is summarized. A (.) notation under “Model Number & Description” indicates the parameter was constant, whereas (collars) indicates collar-group specific estimates.

Model Number & Description	AICc	$\Delta AICc$	wi	K	Deviance
<u>1</u> - BEV/ADP(.), NEM(collars)	325.56	0.00	0.69	5	183.1
<u>2</u> - BEV/ADP (collars), NEM(collars)	327.15	1.59	0.31	6	182.5
<u>3</u> - BEV/ADP(.), NEM(.)	336.63	11.07	0.00	4	196.3
<u>4</u> - All =	339.94	14.38	0.00	3	201.7

Table 8. Multi-strata estimates with the Northeast Mainland (NEM) (GN/Baker Lake collared caribou), and Beverly (BEV & ADP) (GNWT/Beverly collared caribou), as groups. Events are equal to the number of occurrences within a given set of previous and current use of designated calving grounds from 2011 to 2018 (CS = Calving strata, **Figure 19**). Data highlighted in red explained in 4.2.3 of this report.

Previous CS	Current CS	events	Estimate	Confidence interval	
<u>NEM collar group</u>					
BEV & ADP	BEV & ADP	21	0.874	0.675	0.959
BEV & ADP	NEM	3	0.126	0.041	0.325
NEM	NEM	19	0.869	0.662	0.957
NEM	BEV & ADP	3	0.131	0.043	0.338
<u>Beverly collar group</u>					
BEV & ADP	BEV & ADP	85	0.924	0.849	0.963
BEV & ADP	NEM	7	0.076	0.037	0.151
NEM	NEM	0	0.000	0.000	0.000
NEM	BEV & ADP	4	1.000	1.000	1.000

4.2.2 Bathurst caribou movements and fidelity.

Of additional interest was the movement probability of Bathurst caribou to the Beverly calving strata in 2017 and 2018. We initially ran a model to estimate mean fidelity of Bathurst caribou to the Bathurst calving ground/strata and probability of movement to the Beverly calving strata between June 2011 and 2018. The estimate of mean fidelity of Bathurst caribou to the Bathurst calving strata was 0.969 (CI=0.91-0.99) with estimates of movement to the BEV calving strata of 0.03 (CI=0.01-0.09). Only three (3) occurrences of Bathurst collared cows moving from the Bathurst to the Beverly calving strata occurred from 2011 to 2018, compared to 93 occurrences of cows returning to the Bathurst in successive years (Table 5) which explains the higher estimate of fidelity. To obtain an estimate of movement probability of Bathurst collared cows to the Beverly calving strata in 2018, we fixed Bathurst calving strata fidelity at one (1) from 2011-2017 (to aid in model convergence, given that no movement events from the Bathurst occurred except for in 2017-18). We estimated a specific movement probability to the Beverly calving strata from 2017-18 of 0.275 (MCMC confidence limits = 0.09-0.54). Our estimate is based only on 13 known Bathurst collared cows (of which 3 moved to the Beverly) and therefore should be interpreted cautiously.

4.2.3 Adelaide Peninsula Affiliations.

An objective of the collar affiliation analysis was to assess if affiliated with the Adelaide Peninsula calving strata had higher association with either the NEM or Beverly (Queen Maude Gulf) calving strata, based on directional movements of collared caribou cows from the Bathurst, Beverly, and NEM (Ahiak and Lorillard) subpopulations. **Table 9** summarizes movement events as well as the limited sample sizes of collared animals in the Adelaide Peninsula calving strata. As with previous analyses, we analyzed the data from NEM collared cows and the Beverly collared cows as groups. The abridged multi-state (MS) model was run to estimate movement rates between the Beverly, Adelaide Peninsula, and NEM, calving strata (**Figures 19 and 20**), as well as collar-specific estimates within each stratum. In general, estimates of movement were similar for most strata except for the NEM

estimates, which are highlighted in red in **Table 8**. In this case, the NEM collared cows showed low movement probabilities (high fidelity) to the NEM calving strata and higher movement probabilities (lower fidelity) to the BEV calving strata (**Table 10**). In contrast, the Beverly collared cows, showed no fidelity to the NEM calving strata and a high degree of fidelity to the Beverly and Adelaide Peninsula pooled calving strata. Overall, model selection suggested that fidelity to the BEV calving strata was similar for Northeast Mainland, and Beverly collared cows.

4.3 SUMMARY OF TELEMETRY ANALYSES.

In conclusion, even when collared cows are grouped by origin of collaring, fidelity to a calving strata/stratum for the Beverly subpopulation increases from 78% to 91% when the Adelaide Peninsula calving strata is included, suggesting that the Beverly calving area between 2011 and 2018 included both the Queen Maud Gulf and Adelaide Peninsula. We also found that movement from the combined Beverly and Adelaide Peninsula calving strata was influenced by collar origin, with the Beverly collared cows showing low fidelity to the NEM calving strata located east of Adelaide Peninsula. Those few Beverly collars that did calve in the NEM calving stratum east of Adelaide Peninsula did so for only a single year and then returned to the Beverly calving strata the following year. In contrast, the NEM (Ahiak and Lorillard) collared cows, showed a higher level of fidelity to the NEM calving strata, with equal rates of movement to and from the combined Beverly and Adelaide Peninsula calving strata. Both NEM and Beverly collared cows displayed similar fidelity to the combined Beverly and Adelaide Peninsula calving strata. When collar origin is considered, results suggest that the Bathurst, NEM (Ahiak and Lorillard), and Beverly collared cows had relatively distinct calving ground units for the 2011 to 2018 interval, with minimal directional movement between calving ground areas (**Figure 21**). For clarity, a simplified version is presented, showing only the NEM deployed collars (**Figure 22**). We note that all GN collars were

deployed on the NEM (Ahiak and Lorillard) spring range, an estimated 250 to 300 km east-northeast of known Beverly spring range.

The main implications of these findings are that the Beverly and Adelaide Peninsula calving strata can be considered a subgrouping/calving ground, given the relative fidelity of Beverly collared caribou cows to this area. The NEM collared caribou cows, however, exhibited lower rates of movement to and from the Beverly calving strata. In contrast, Bathurst collared caribou cows, have shown high fidelity to the Bathurst calving strata, with minimal movement to the Beverly calving strata until the 2017 and 2018 calving seasons, when the probability of movement was moderate (0.275).

Table 9. Collar movement events in the BATH (Bathurst), BEV (Beverly), ADP (Adelaide Peninsula), and NEM (Ahiak and Lorillard) calving grounds (CG) (**Figure 19**). Only collars that were monitored 2 or more years are listed in this table.

Previous CG	Current CG	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
BATH	BATH	6	5	7	10	4	13	20	20	8	93
BATH	BEV	0	0	0	0	0	0	0	0	3	3
BEV	BEV	0	0	4	3	3	18	18	10	13	69
BEV	NEM	0	0	1	2	0	0	2	1	0	6
BEV	ADP	1	0	0	3	1	3	2	4	0	14
ADP	BEV	0	2	2	0	2	2	2	1	4	15
ADP	NEM	0	1	0	1	0	1	0	0	1	4
ADP	ADP	1	1	0	1	2	1	1	1	0	8
NEM	BEV	0	1	1	0	2	0	1	0	1	6
NEM	NEM	0	5	4	1	1	0	2	3	3	19
NEM	ADP	0	0	0	0	0	0	0	1	0	1
Totals		8	15	19	21	15	38	48	41	33	238

Table 10. Multi-state model estimates for a constant parameter (non-time varying) formulation for NEM (Ahiak and Lorillard) collars, and BEV (Beverly) collars. Estimates that differ significantly between collar type are in red. Calving ground designations are based on **Figure 19**.

Previous CG	Current CG	Estimate	SE	Conf. Interval	
<u>Ahiak and Lorillard collars</u>					
BEV	BEV	0.75	0.13	0.45	0.92
BEV	ADP	0.17	0.11	0.04	0.48
BEV	NEM	0.08	0.08	0.01	0.42
ADP	BEV	0.50	0.14	0.24	0.76
ADP	ADP	0.33	0.14	0.13	0.62
ADP	NEM	0.17	0.11	0.04	0.48
NEM	ADP	0.00	0.00	0.00	0.00
NEM	NEM	0.87	0.07	0.66	0.96
NEM	BEV	0.13	0.07	0.04	0.34
<u>Beverly collars</u>					
BEV	BEV	0.78	0.05	0.67	0.86
BEV	ADP	0.16	0.04	0.09	0.25
BEV	NEM	0.07	0.03	0.03	0.15
ADP	BEV	0.60	0.13	0.35	0.81
ADP	ADP	0.26	0.11	0.10	0.53
ADP	NEM	0.13	0.09	0.03	0.40
NEM	ADP	0.25	0.21	0.03	0.76
NEM	NEM	0.00	0.00	0.00	0.00
NEM	BEV	0.75	0.21	0.24	0.97

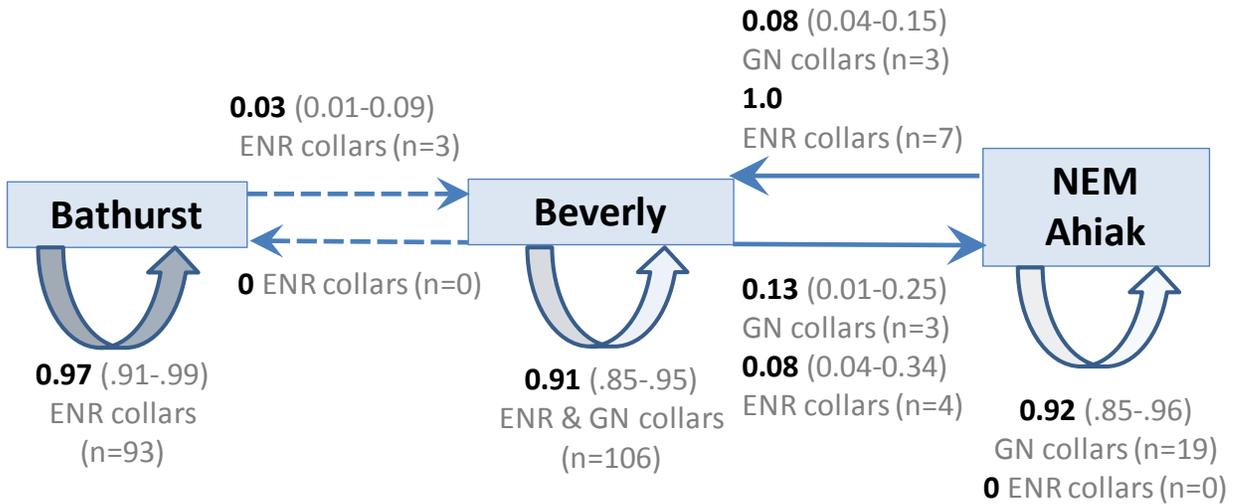


Figure 21. A graphical representation of multi-state model results. Movement probabilities are shown between the three main areas along with sample sizes of movement events and confidence limits on predictions. Estimates for the NEM are shown for Baker Lake/GN collars and Beverly/GNWT collars. The Beverly strata includes the Queen Maud Gulf and Adelaide Peninsula, combined.

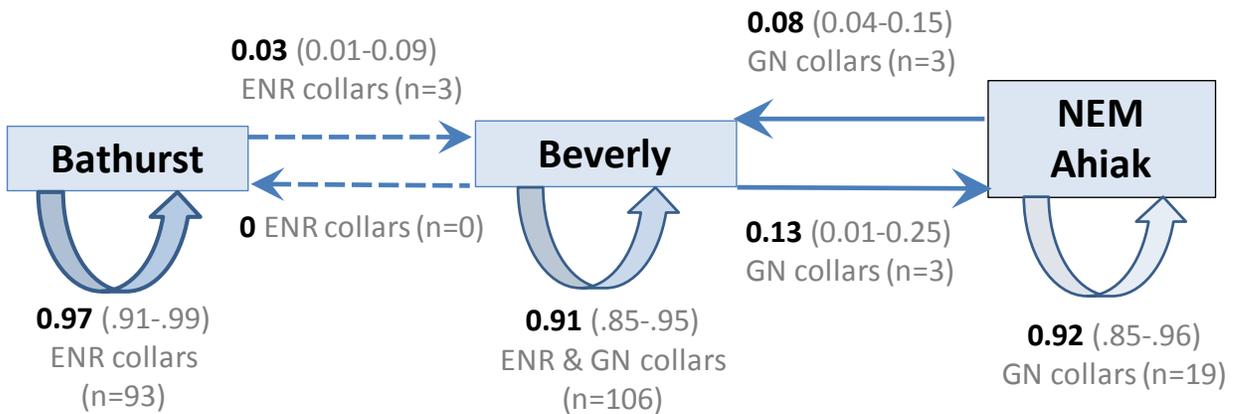


Figure 22. A simplified version of Figure 22 that shows only the GN collar results for the NEM. The Beverly strata includes the Queen Maud Gulf and Adelaide Peninsula combined.

4.4 ABUNDANCE ESTIMATES.

Based on a spatial analysis indicating overlap between the Bathurst subpopulation to the west and the NEM (Ahiak and Lorillard) subpopulations to the east of the Beverly ACCA, reconnaissance survey extents also overlapped with the Bathurst calving extents in the west and NEM (Ahiak and Lorillard) calving extents to the east (**Figures 17 and 18**). We only surveyed the Bathurst subpopulation and NEM subpopulation into their eastern and western extents respectively, in order to clarify the scale of any possible mixing between these subpopulations and the Beverly subpopulation. In general, densities were low within the eastern extents, and very low within the western extents of the Beverly reconnaissance survey area. Further, along the western extents of the Beverly reconnaissance survey area, a drop to very low densities just to the east of Bathurst Inlet, suggested the extent of mixing between the Beverly and Bathurst subpopulations was likely very low, where in all but two (2) segments, density was less than 10 caribou per km² (**Figure 23**).

During all phases of the survey, we observed the highest densities of females to the southwest of the Adelaide Peninsula (**Figure 24**). Additionally, there was a pronounced east to west movement in caribou up to approximately June 11 when median movement rates of collared caribou fell below 5 km per day, suggesting the peak of calving had occurred (**Figure 25**).

Reconnaissance observations recorded the presence of female caribou and caribou relative density, and these observations were used to assign strata for the abundance phase of the survey (**Table 11**). In total, two (2) high density strata, two (2) medium density strata, one (1) low density strata, and four (4) very low-density strata were delineated across the Beverly 2018 ACCA (**Table 12, Figure 26**). The visual surveys started on June 12 with the V_low strata occurring earlier during the reconnaissance survey. All abundance phase visual strata were surveyed between June 12 and June 16, 2018, with the exception of the V_Low

strata and Low_A stratum for which data collected during the reconnaissance survey were used (**Figure 24**).

In total, we observed 16,136 adult and yearling caribou within all strata during the Beverly 2018 abundance survey. The standard Jolly strip transect estimator was used to produce preliminary estimates of abundance resulting in an overall estimate of 89,025 caribou within the entire Beverly survey area with an overall coefficient of variation (CV) of 3.7%, suggesting very high precision (**Table 12**). The double observer estimate which accounts for sightability, discussed in the following section, should be considered as the more robust estimate.

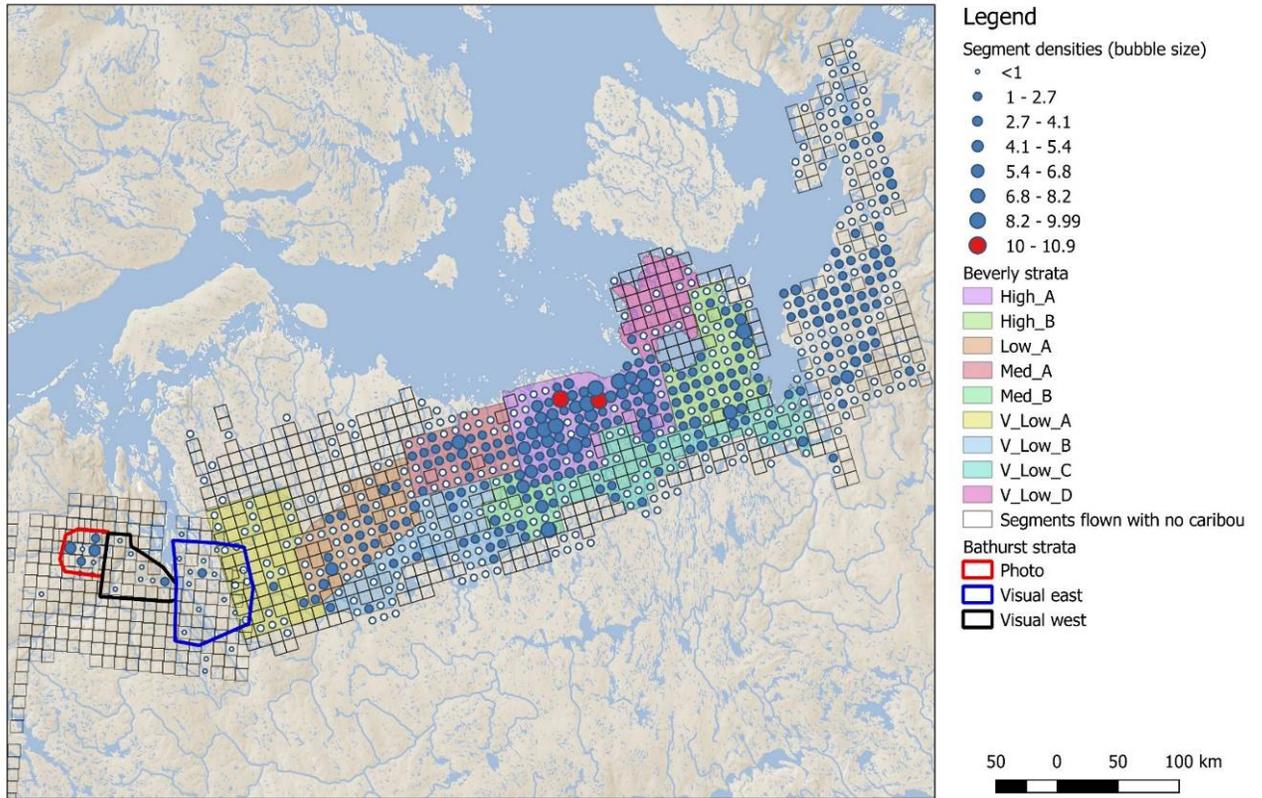


Figure 23. Summary of reconnaissance observations of relative densities of caribou during the Beverly 2018 survey. Observations along reconnaissance transects summed for every 10 km segment for greater visual clarity. Bathurst survey observations are included (Adamczewski et al. 2019).

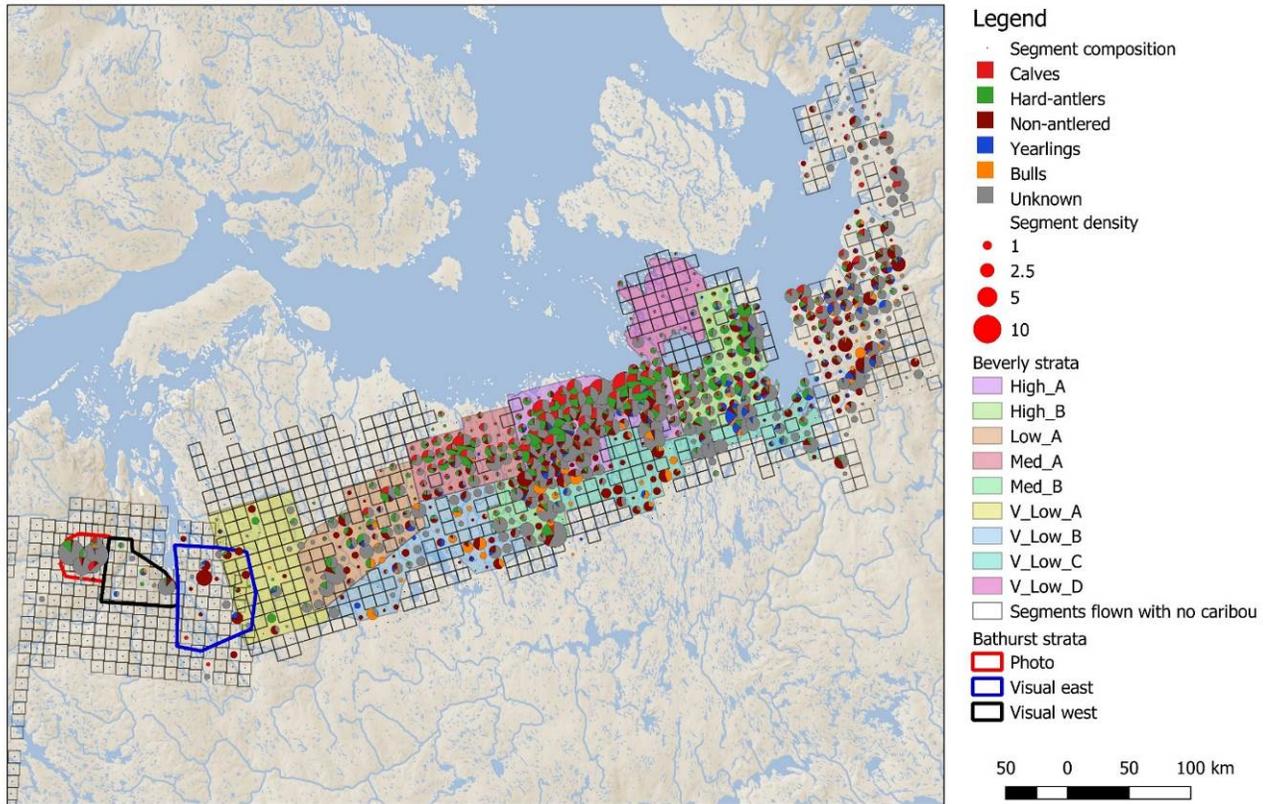


Figure 24. Summary of reconnaissance caribou composition observations of during the Beverly 2018 survey. Observations along reconnaissance transects summed for every 10 km segment for greater visual clarity. Bathurst survey observations are included (Adamczewski et al. 2019).

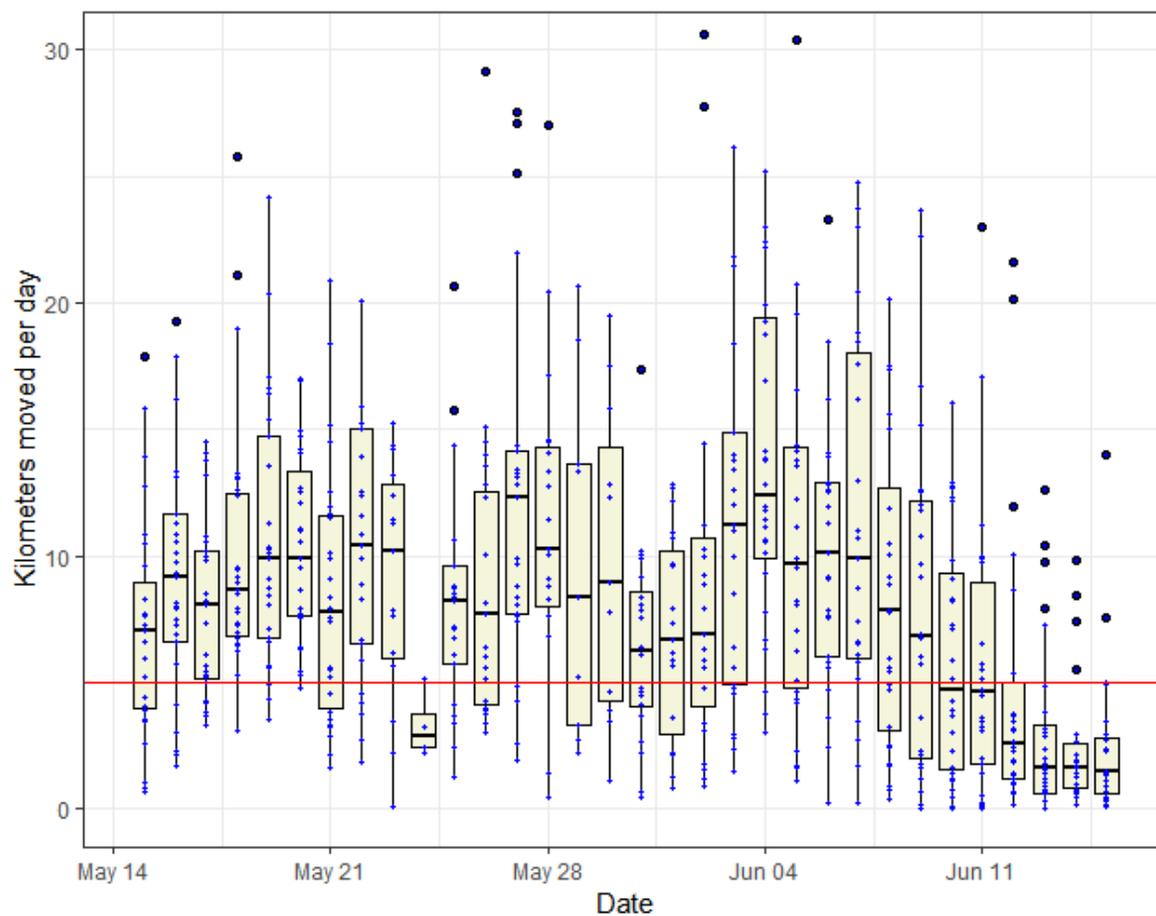


Figure 25. Movement rates of Beverly caribou prior to and during the 2018 survey. Red line represents a movement rate of 5km per day, used as a benchmark for the calving period.

Table 11. Strata identification and dimensions for 2018 Beverly survey. Strata effort for the abundance phase was defined based on the allocation of remaining survey resources, survey logistics, and relative densities of caribou in the strata (**Table 2**).

Strata	Area (km ²)	transects	Average transect length (km)	Baseline length	Total transect (km)	Total area surveyed (km ²)	Coverage
High_A	8867.2	38	67.4	131.5	2562.3	2049.8	23.1%
High_B	5909.9	21	53.5	110.4	1123.8	899.0	15.2%
Med_A	4634.3	20	51.8	89.5	1035.2	828.2	17.9%
Med_B	2439.7	12	39.2	62.3	469.9	375.9	15.4%
Low_A	6442.6	11	59.4	108.5	653.5	522.8	8.1%
V_Low_A	7309.1	8	89.9	81.3	718.9	575.2	7.9%
V_Low_B	6501.3	19	34.6	187.8	657.8	526.2	8.1%
V_Low_C	6771.1	22	30.7	220.4	675.8	540.6	8.0%
V_Low_D	3680.9	7	55.8	66.0	390.5	312.4	8.5%

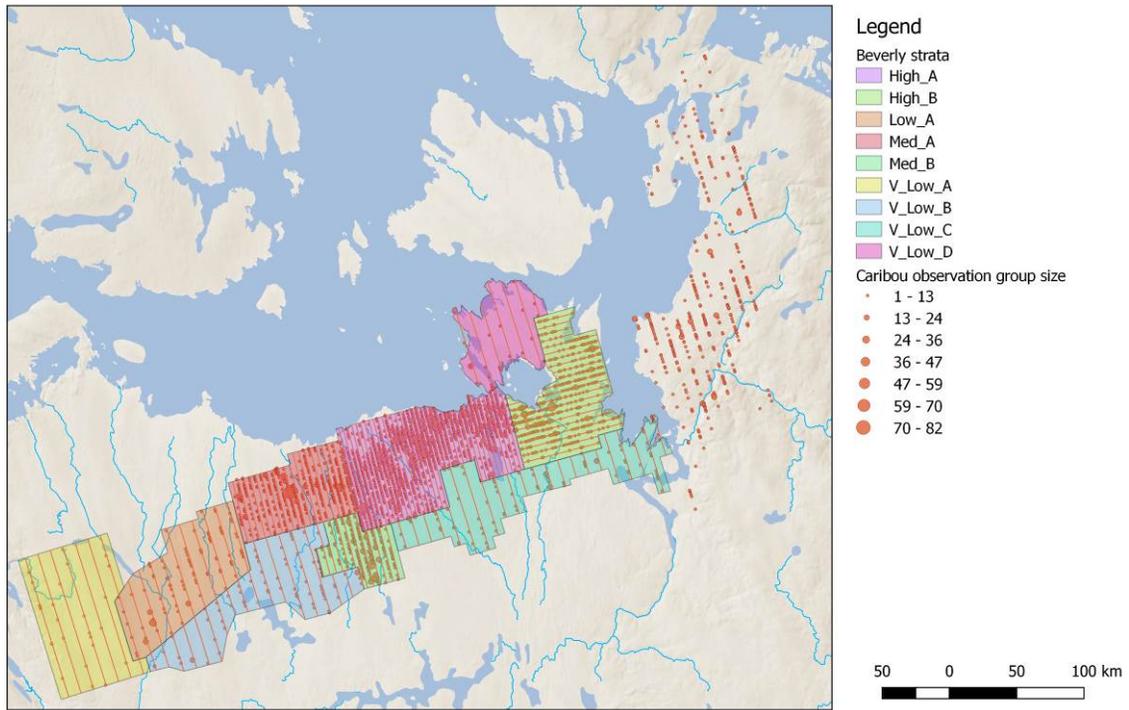


Figure 26. The June 2018 Beverly mainland migratory barren-ground caribou abundance survey strata, transects, and observed group sizes. Eastern most observations represent the bordering Ahiak subpopulation.

Table 12. Beverly June 2018 caribou abundance survey estimates of density, and abundance using the standard Jolly 2 strip transect estimator.

Strata	Caribou counted	Density	N	SE (N)	CV
High_A	10,193	4.9727	44094	2109.9	4.8%
High_B	1,948	2.1668	12806	1391.2	10.9%
Med_A	1,696	2.0479	9490.6	1207.3	9.9%
Med_B	995	2.6468	6457.4	1331.1	12.7%
Low_A	435	0.8321	5360.9	528.35	20.6%
V_Low_A	104	0.1808	1321.6	254.19	19.2%
V_Low_B	302	0.5739	3731.1	485.78	13.0%
V_Low_C	417	0.7713	5222.5	821.22	15.7%
V_Low_D	46	0.1472	542	187.56	34.6%
Totals	16,136		89,025	3302.4	3.7%

4.4.1 Dependent Double Observer Pair.

Overall there were 18 combinations of observers in the front and rear positions of the aircraft during the June 2018 Beverly abundance survey. Some observer pairs had low sample sizes or did not switch and therefore, were pooled, which resulted in 10 observer pairings. Summary statistics for primary observer pooling suggest reasonable sample sizes for all 10 pairs (**Table 13**). Naive sighting probabilities (1-Rear/Total) suggest some difference in sightability between pairs; however, in most cases, sighting probabilities were high. Frequencies of observations missed by a single observer within either a left or right observer pair, increased when caribou group sizes were lower, which is consistent with previous studies and suggests that sightability is directly correlated with caribou group size (**Figure 27**).

Variables potentially affecting sightability were recorded with caribou observation data. For model selection, cloud and snow cover were considered as categorical (in this case based on percent cloud cover to the nearest 5%), and continuous (assumes a linear relationship between cloud or snow cover and sighting probabilities) (**Figure 28**). In general, the categorical forms of snow and cloud cover were more supported. In addition, the the most supported model included the effect of observers and group size on sighting probabilities (Model 1, **Table 14**). Plots of predictions from Model 1 show the effect of group size with the scatter of points being influenced by observer pair, snow, and cloud cover (**Figure 29**). The lowest probabilities occurred for higher snow cover. Another way to view predicted sighting probabilities is through an examination of observer pair vs group size. Our analysis demonstrates that some observer pairs had higher sighting probabilities than others when group size was lower, however, in most cases, sighting probabilities were close to 1 (equal) when groups sizes were larger (**Figure 30**).

The estimate of total caribou on the calving ground from the most supported double observer model was 89,362 (**Table 15**). The estimate from the most supported model (89,362) was only 337 caribou larger (<1%) than the standard strip transect estimate using Jolly. The reason for this was that the dependent

double observer pair sighting probabilities were reasonably high, especially at larger group sizes, which make up the majority of caribou included in estimates (**Figure 27, 28, 29, and 30**). For example, a lower sighting probability of a single caribou contributes little to the overall estimate, so the overall effect of lower probabilities of smaller group sizes does not influence overall estimates substantially.

Table 13. Summary for pooled pairs. Naive single sighting probabilities ($p1x=1-\text{rear frequency} / \text{total observations}$) and double observer ($p2x=1-(1-p1x)^2$) probabilities are given.

Pool pair no	Observation frequencies				Sighting probabilities	
	Front	Rear	Both	total	single	double
1	161	15	196	372	0.96	1.00
2	40	66	716	106	0.38	0.61
3	25	18	152	43	0.58	0.82
4	54	75	950	129	0.42	0.66
5	14	2	180	16	0.88	0.98
6	5	15	614	20	0.25	0.44
7	49	28	450	77	0.64	0.87
8	11	7	281	18	0.61	0.85
9	21	11	422	32	0.66	0.88
10	36	30	145	66	0.55	0.79

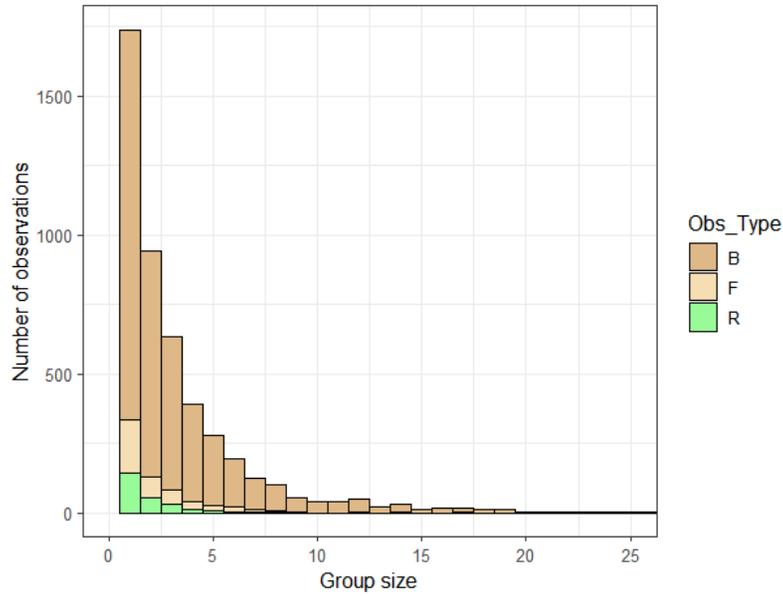


Figure 27. Frequencies of observation by group size as a function of observation type (B=Both, F=Front, R=Rear).

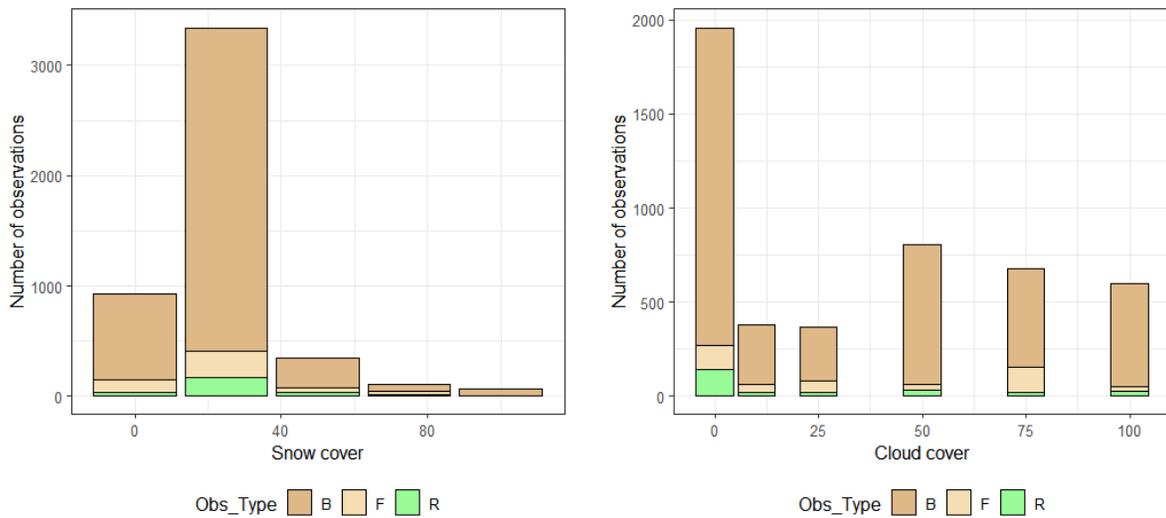


Figure 28. Observation frequencies by snow and cloud cover as a function of observation type (B=Both, F=Front, R=Rear).

Table 14. Dependent double observer pair model selection results. Sample size adjusted Akaike Information Criterion (AIC_c), the difference in AIC_c between the most supported model for each model (Δ AIC_c), AIC_c weight (w_i), number of model parameters (K) and deviance is given. Results suggest that group size, observer pairs, cloud, and snow cover affected sightability the most.

No	Model	AIC _c	Δ AIC _c	w_i	K	LL
1	size+observers+cloudcat+snowcat	1884.6	0.00	0.37	20	-922.2
2	size+observers+cloud+snow+snow*cloud	1884.7	0.07	0.35	14	-928.3
3	size+observers+cloud+snow	1885.5	0.89	0.24	13	-929.7
4	log(size)+observers+cloud+snow+snow*cloud	1889.0	4.34	0.04	14	-930.4
5	size+observers	1925.9	41.29	0.00	11	-951.9
6	log(size)+observers	1929.5	44.90	0.00	11	-953.7
7	size+snow+cloud+snow*cloud	1940.6	55.93	0.00	5	-965.3
8	log(size)+snow+cloud	1945.1	60.49	0.00	4	-968.6
9	size+cloudcat+snowcat	1945.5	60.90	0.00	11	-961.7
10	size+snowcat	1949.5	64.84	0.00	6	-968.7
11	size+snow	1954.5	69.87	0.00	3	-974.3
12	log(size)+snow	1958.5	73.86	0.00	3	-976.2
13	size+cloud	1976.1	91.47	0.00	3	-985.1
14	size+cloudcat	1977.1	92.46	0.00	7	-981.5
15	size	1993.7	109.08	0.00	2	-994.9
16	log(size)	1997.5	112.88	0.00	2	-996.8
17	constant	2063.2	178.57	0.00	1	-1030.6

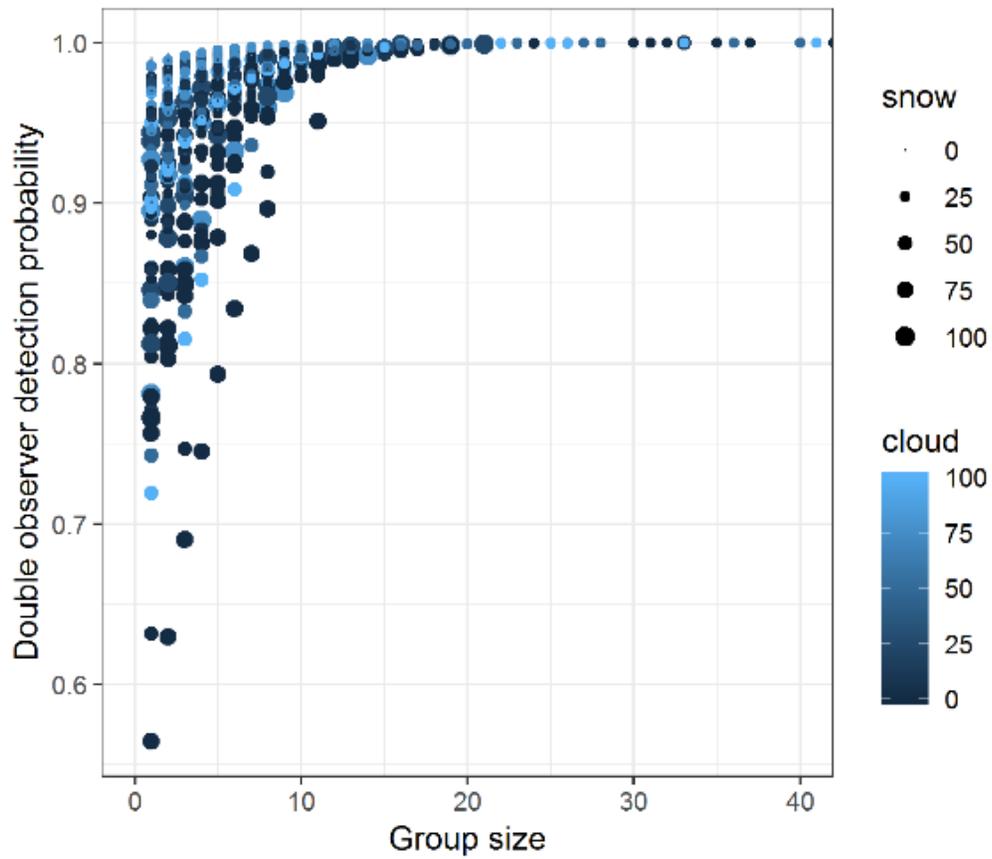


Figure 29. Predicted dependent double observer pair sighting probability as a function of group size, snow cover, and cloud cover from Model 1, **Table 14**. Each point represents an observation and its associated double observer probability.

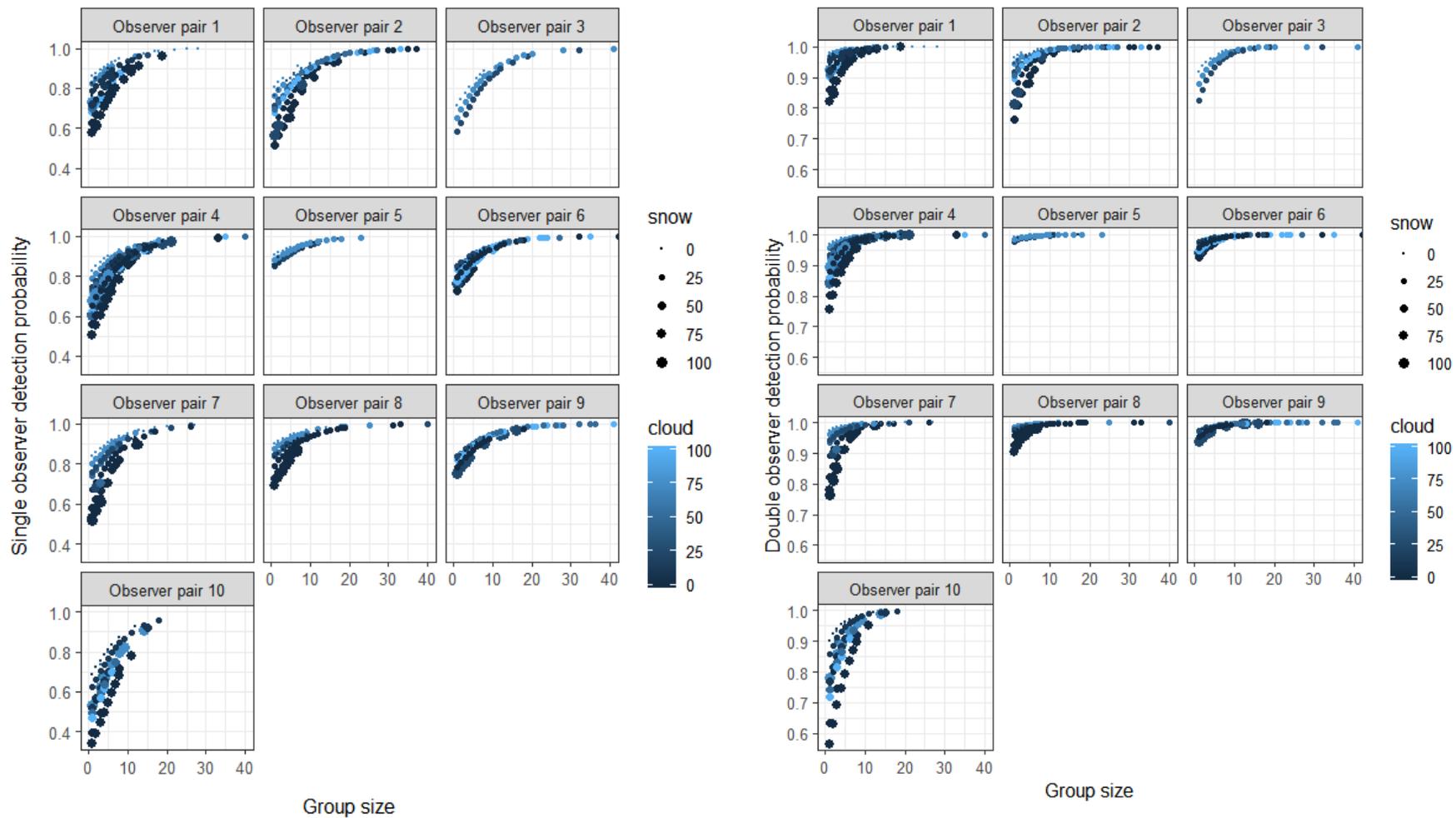


Figure 30. Predicted single and dependent double observer pair sighting probability as a function of group size, observer pair, cloud cover, and snow cover.

Table 15. Double observer abundance estimates from Model 1 (**Table 14**) for each strata showing the number of caribou sighted (Counted) and the abundance estimate derived for each strata (N), with the Standard Error (SE), Confidence Intervals (CI), and Coefficient of Variation (CV).

Strata	Counted	N	SE	CI low	CI high	CV
High_A	10193	44,169	2406.9	39,555	49,321	5.4%
High_B	1948	12,875	1510.2	10,090	16,431	11.7%
Low	435	5,380	551.6	4,284	6,756	10.3%
Med_A	1696	9,499	1332.4	7,093	12,723	14.0%
Med_B	995	6,458	1447.4	3,968	10,513	22.4%
V_Low_A	104	1,363	279.1	845	2,196	20.5%
V_Low_B	302	3,758	511.0	2,828	4,994	13.6%
V_Low_C	417	5,308	873.8	3,779	7,457	16.5%
V_Low_D	46	552	198.3	235	1,294	36.0%
Total	16,136	89,362	3660.1	82,392	96,923	4.1%

4.4.2 June Composition survey.

Composition surveys were conducted concurrently with visual surveys (**Figure 31**). Coverage was good in all the main strata and 7,872 caribou were classified across all abundance strata (**Table 16**). Overall, sample sizes of groups were reasonably high in the main strata sampled. Breeding and non-breeding cows were primarily found in the High A, High B, Medium A and Medium B strata with other strata being composed primarily of yearlings and bulls. Estimates of proportions of breeding females and proportions adult females, suggested that the highest proportions were in the two high strata and the Medium A stratum (**Table 17**). Estimates of breeding females were derived by multiplying the overall estimates for the calving ground by the proportion of breeders in each stratum (**Table 18**). Estimates of adult females were derived by multiplying total caribou within each stratum by their respective proportions of adult females (**Table 19**). An index of pregnancy rate can be derived by calculating the ratio of breeding to adult females. For the June 2018 Beverly survey, we estimated an overall pregnancy rate of 80%, which is reasonably high when compared to similar assessments from neighboring herds (Boulanger et al. 2011, Campbell et al. 2012). Interestingly, surveys on the Bathurst and Bluenose-East herd in June 2018, estimated higher pregnancy rates (Bathurst: 70.4% in 2018 compared to 60.9% in 2015. Bluenose East: 83% in 2018 compared to 63% in 2015) than other survey years (Boulanger et al. 2019, et al. 2019, Adamczewski et al. 2019).

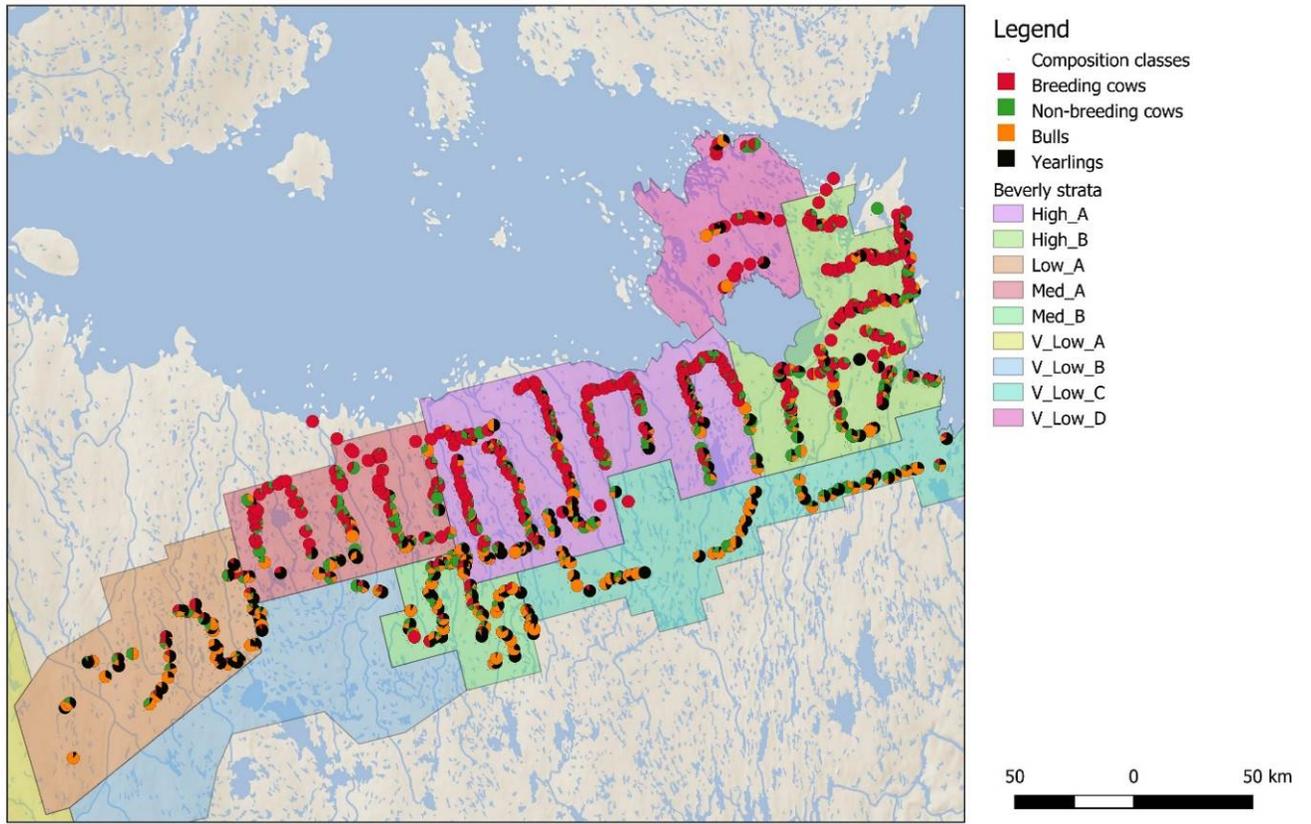


Figure 31. The Beverly June 2018 Composition survey flight paths with pie charts depicting composition classes from each group sampled.

Table 16. Summary of observations made during the Beverly June 2018 caribou composition survey. Values indicate total number of caribou classified within each breeding and age/sex category. Yearlings represent calves from the 2017 calving season.

Strata	Breeding cows	Non-breeding cows	bulls	yearlings	total	N (groups)
High_A	2256	440	197	202	3095	208
High_B	1022	272	154	152	1600	147
Low_A	60	78	239	263	640	50
Med_A	750	159	55	48	1012	96
Med_B	80	113	418	411	1022	68
V_Low_C	6	54	167	161	388	49
V_Low_D	88	5	10	12	115	26

Table 17. Estimated proportion of breeding females (breeding females/total caribou classified), and adult females (breeding+non-breeding females/total caribou classified). Standard errors (SE) and confidence intervals (CI) were based on bootstrap resampling.

Strata	Proportion breeding females				Proportion adult females			
	estimate	SE	CI low	CI high	estimate	SE	CI low	CI high
High_A	0.729	0.027	0.669	0.776	0.871	0.018	0.832	0.903
High_B	0.639	0.033	0.564	0.696	0.809	0.024	0.757	0.850
Low_A	0.094	0.023	0.055	0.142	0.216	0.039	0.145	0.292
Med_A	0.741	0.034	0.668	0.796	0.898	0.023	0.843	0.937
Med_B	0.078	0.019	0.044	0.118	0.189	0.033	0.135	0.260
V_Low_C	0.015	0.008	0.003	0.033	0.155	0.027	0.105	0.214
V_Low_D	0.765	0.080	0.577	0.889	0.809	0.070	0.649	0.918

Table 18. Final estimates of breeding females in each abundance stratum from the 2018 population survey of the Beverly subpopulation of barren-ground caribou showing abundance estimates (N), Coefficients of Variation (CV), Standard Error (SE), and Confidence Interval (CI).

Strata	N total caribou	CV	Prop. breeders	CV	N breeding females	SE	CI low	CI high	CV
High_A	44,169	5.4%	0.729	3.7%	32,199	2121.6	28,179	36,792	6.6%
High_B	12,875	11.7%	0.639	5.2%	8,227	1054.4	6,304	10,737	12.8%
Low_A	5,380	10.3%	0.094	24.5%	506	134.16	283	904	26.5%
Med_A	9,499	14.0%	0.741	4.6%	7,039	1038.8	5,177	9,571	14.8%
Med_B	6,458	22.4%	0.078	24.4%	504	166.74	248	1,024	33.1%
V_Low_C	5,308	16.5%	0.015	53.3%	80	44.442	27	235	55.6%
V_Low_D	552	36.0%	0.765	10.5%	422	157.97	174	1,023	37.4%
Total	84,241	4.3%			48,977	2600.9	44,056	54,448	5.3%

Table 19. Final estimates of adult females in each abundance stratum from the 2018 population survey of the Beverly subpopulation of barren-ground caribou showing abundance estimates (N), Coefficients of Variation (CV), Standard Error (SE), and Confidence Interval (CI).

Strata	N total caribou	CV	Prop. Adult Females	CV	N Adult Females	SE	CI low	CI high	CV
High_A	44,169	5.4%	0.871	2.1%	38,471	2242.1	34,189	43,289	5.8%
High_B	12,875	11.7%	0.809	5.2%	10,416	1260.2	8,100	13,394	12.1%
Low_A	5,380	10.3%	0.216	24.4%	1,162	241.3	735	1,837	20.8%
Med_A	9,499	14.0%	0.898	4.6%	8,530	1216.3	6,339	11,479	14.3%
Med_B	6,458	22.4%	0.189	24.6%	1,221	346.8	661	2,254	28.4%
V_Low_C	5,308	16.5%	0.155	51.6%	823	197.2	504	1,345	24.0%
V_Low_D	552	36.0%	0.809	10.5%	447	165.0	187	1,071	36.9%
Total	84,241	4.3%			61,070	2887.8	55,583	67,099	4.7%

4.4.3 Fall Composition Survey.

We utilized fall composition results from the June 2011 Beverly mainland migratory barren-ground caribou abundance estimate (Campbell et al. 2012). In October 2011, 8 Beverly collars managed by the GNWT were active. Using fixed wing aircraft followed by rotary wing aircraft, GNWT crews assessed the composition of caribou in association with near real time collar location data. A fixed wing reconnaissance survey was flown from 22 to 28 October, 2011, during which 3 collars were successfully radio-tracked. No caribou were observed in the northern portion of the reconnaissance study area. Caribou were concentrated between Mary Frances Lake and the Thelon River, and in the area around Whitefish and Lynx Lakes (**Figure 32**).

The fall composition survey was flown from the 25 to 29 of October, 2011. In total 12,421 caribou were classified in 252 groups within the southern part of the reconnaissance area (**Table 20, Figure 33**). The overall bull: cow ratio was 69 bulls to 100 cows, with group composition varying across the study area from a high of 99:100 in the area around Zucker/Whitefish/Lynx Lakes, to a low of 40:100 east of Thelon River.

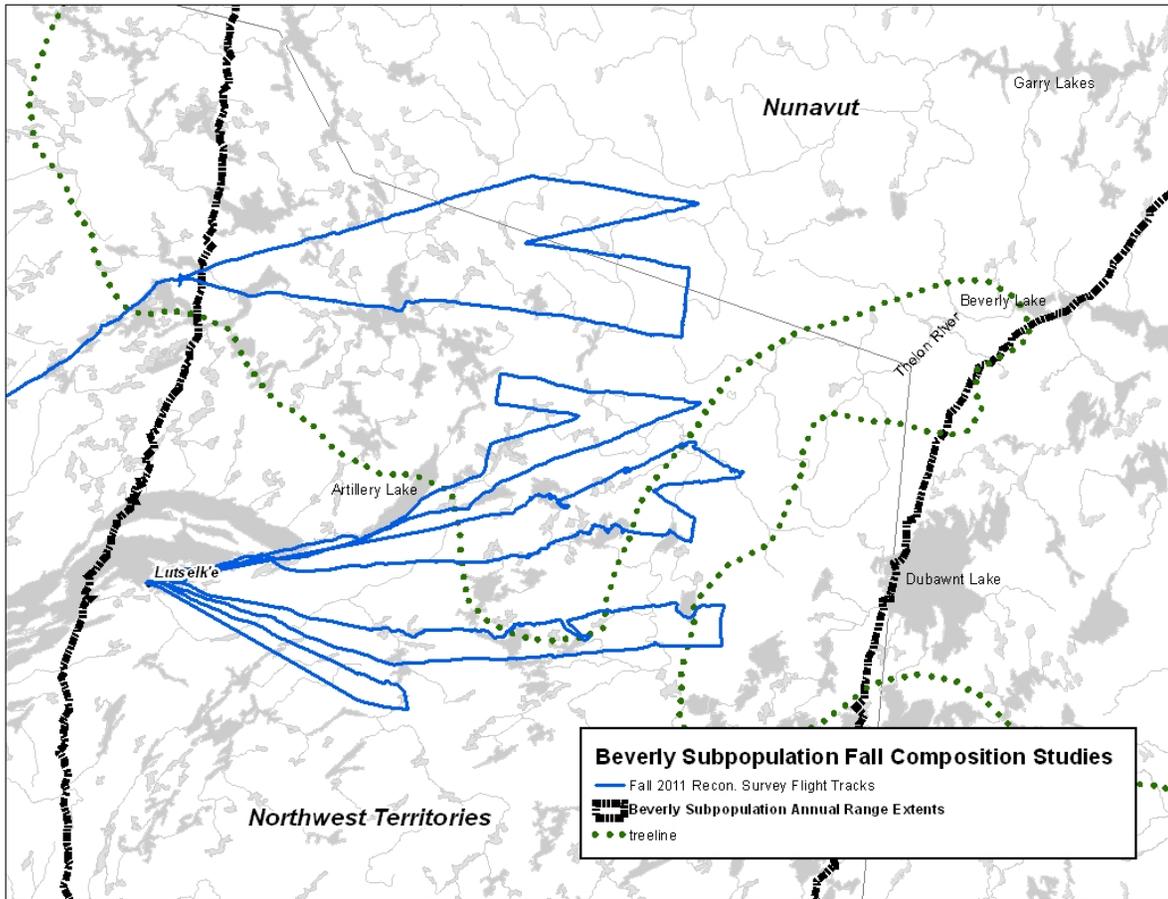


Figure 32. Fall composition flight tracks flown between the 22 and 28 of October, 2011 for the Beverly subpopulation fall composition survey.

Table 20. Beverly 2011 fall composition survey sampling effort and summary statistics.

Sampling Details	Summary Statistics
Mean Group Size	49
Median Group Size	29
Total Number of Groups Classified	252
Total Number of Cows Classified	5,570
Total Number of Calves Classified	3,004
Total Number of Bulls Classified	3,847
Total Number of Yearlings Classified	0
Total Number of Caribou Classified	12,421
Bull: Cow Ratio	69.0 bulls:100 cows (SE 3.6)

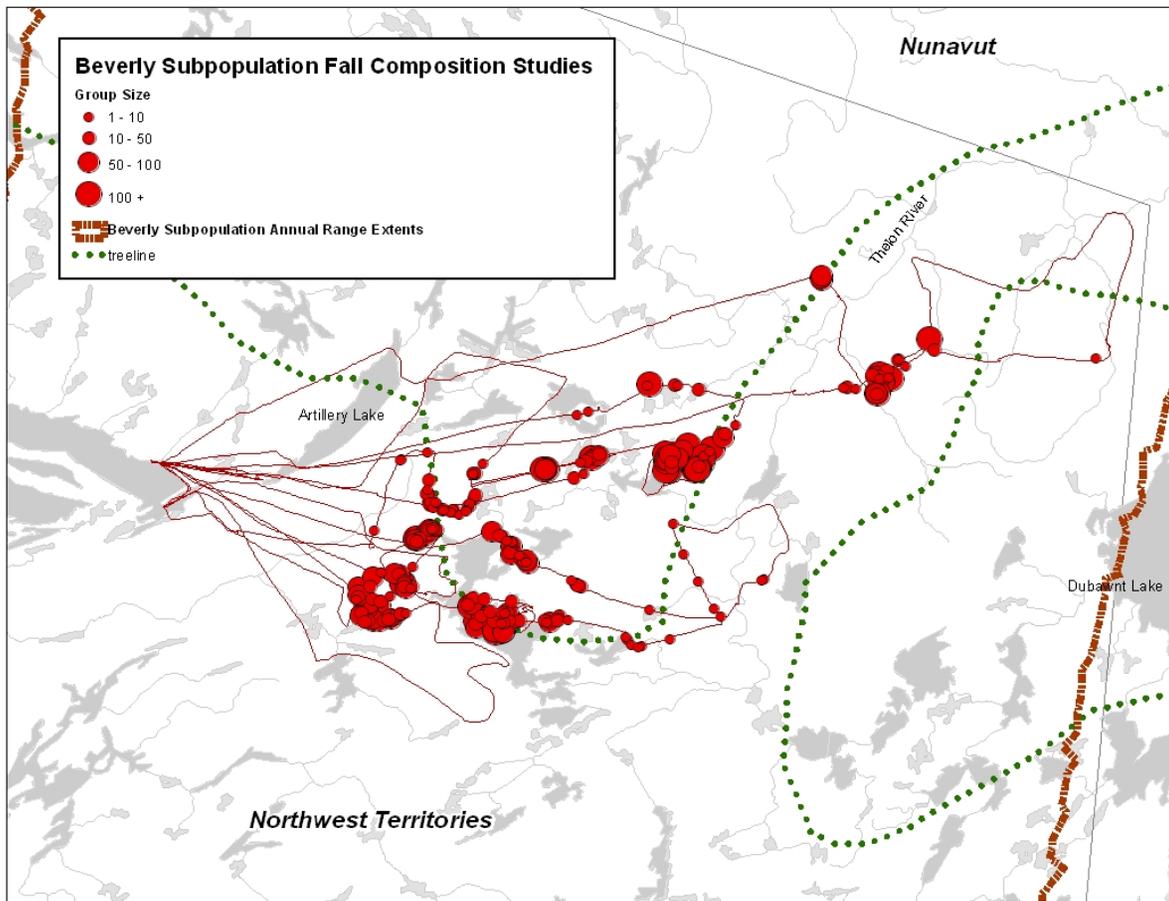


Figure 33. Composition flight tracks and observations of barren-ground caribou during the Beverly fall composition survey conducted from 25 to 29 October, 2011.

4.4.4 Extrapolated herd estimates.

We used the 2011 sex ratio data to obtain an estimate of overall herd size using the proportion of females method, which is currently being utilized to assess all Nunavut-based mainland migratory barren-ground caribou whole herd estimates (herd size = $N_{\text{adult females}}/\text{proportion females in herd (fall)}$). For comparability with historic whole herd estimates we also developed the assumed pregnancy rate method which specifically derives the herd estimate from only the number of breeding females (herd size = $N_{\text{breeding females}}/(\text{proportion females in herd} \times \text{assumed pregnancy rate (0.72)})$). Estimates using assumed pregnancy rate (breeding females) were higher, potentially due to a higher observed pregnancy rate (80%) than the assumed pregnancy rate (72%) (**Table 21**). Estimates utilizing adult females as the primary estimator have been considered more reliable (Campbell et al. 2012, Boulanger et al. 2018). We use the whole herd estimate of adult females to generate final estimates in this report.

Table 21. Estimates of extrapolated herd size from the 2018 survey, using both adult female and breeding female estimators. In this study, we relied upon adult female estimates as they have proven to be more the most reliable than estimates derived using the number of breeding females.

Method	N	SE	CI low	CI high	CV
Proportion females	103,372	5109.3	93,684	114,061	4.9%
Breeding females	115,142	13141.9	91,759	144,484	11.4%

4.4.5 Comparison between survey years (2011 & 2018).

The distribution of caribou during the 2011 and 2018 surveys differed spatially. Generally, the 2011 Beverly calving distribution was concentrated within the central Queen Maud Gulf (QMG) area. In 2018, the herd displayed more of an obvious eastern distributional extension onto the Adelaide Peninsula to the western shores of the Back River and Chantrey Inlet (**Figure 34**). The most obvious change in June 2018 was an eastern shift in Beverly core calving that is reflected in the differences in high-density abundance strata delineated for the two surveys (**Figure 35**).

We reanalyzed the June 2011 Beverly survey with and without the Adelaide Peninsula area added to the QMG area (**Figure 35**). The reanalysis included an expanded eastern stratum (Adelaide Peninsula) to sample the same area stratified in 2018 and based on an updated spatial analysis of collar telemetry (this report) between June 2011 and 2018, which suggested a strong affiliation between the Beverly subpopulation and the QMG/Adelaide Peninsula calving areas. In general, core strata used also had some degree of composition data associated with them which allowed for estimates of breeding and adult females. However, composition surveys were not conducted on the northern Adelaide Peninsula in 2011. To obtain estimates of breeding and adult females it was assumed that composition was similar to the southern Adelaide Peninsula (**Table 22**). One issue with this the re-analysis is that the associated expansion of the 2011 abundance survey area extends the area to strata with differential survey coverage. For this reason, a method that weighted transects by coverage was used to estimate abundance (N), which enabled us to account for potential biases due to unequal coverage.

The full dependent double observer pair analysis conducted in 2011 was repeated with bootstrap methods used to estimate standard errors. This approach was similar to that used to account for unequal strip widths in previous surveys (Campbell et al. 2012, Boulanger et al. 2016). Dependent double observer pair estimates, analysed using the MRDS package (used for the 2018 data set), were

not possible given that MRDS could not account for the weighted transect estimator, however, the bootstrap approach was theoretically equivalent to MRDS and therefore provided comparable estimates. Estimates were also obtained for just the QMG area for the 2011 survey during the re-analysis (**Tables 22 and 23**). Estimates derived from the 2011 re-analysis are summarized along with estimates derived from the 2018 survey (**Table 24**).

Extrapolated herd estimates were then obtained for both the proportion of adult females (our preferred estimator), and proportion of breeding females using an assumed pregnancy rate (as described in previous sections for the 2018 survey) (**Table 25**). The same sex ratio data used for extrapolated estimates for the Beverly 2011 survey was used for the 2018 abundance assessment. The assumed breeding female-based estimators (assumed pregnancy rates) of whole herd trend between the June 2011 and June 2018 Beverly abundance surveys was directly proportional to trends in the number of breeding females estimated within the calving extents. The trends in whole herd estimators between June 2011 and June 2018 based on adult females, were based on the fall composition derived sex ratio between adult males and females.

We used t-tests to compare the significance between derived whole herd estimates for each of the Beverly June 2011 and 2018 abundance surveys (**Table 26**). Herd estimates based on the proportion of adult females (our more accurate estimator) confirmed a significant decline ($\alpha=0.1$) in Beverly subpopulation abundance between the June 2011 and the June 2018 survey estimates (**Figure 36**).

Of greater interest than the difference between abundance estimates, is the actual yearly rate of change in herd size. As expected, rates of change were similar between adult female estimates, and whole herd estimates, providing additional confidence in our assessment of the observed decline in abundance from June 2011 to June 2018. All estimates of yearly rate of change suggested an annual rate of decline between the June 2011 and 2018 abundance estimates of 4 to 5%

(Tables 26 and 27). This result suggests that the estimated trend in the Beverly herd has been minimally affected by the inclusion or exclusion of the Adelaide Peninsula. With an apparent shift in calving extents to the east between 2011 and 2018, this effect could change in the future making the inclusion of Adelaide Peninsula essential when estimating Beverly abundance and trend.

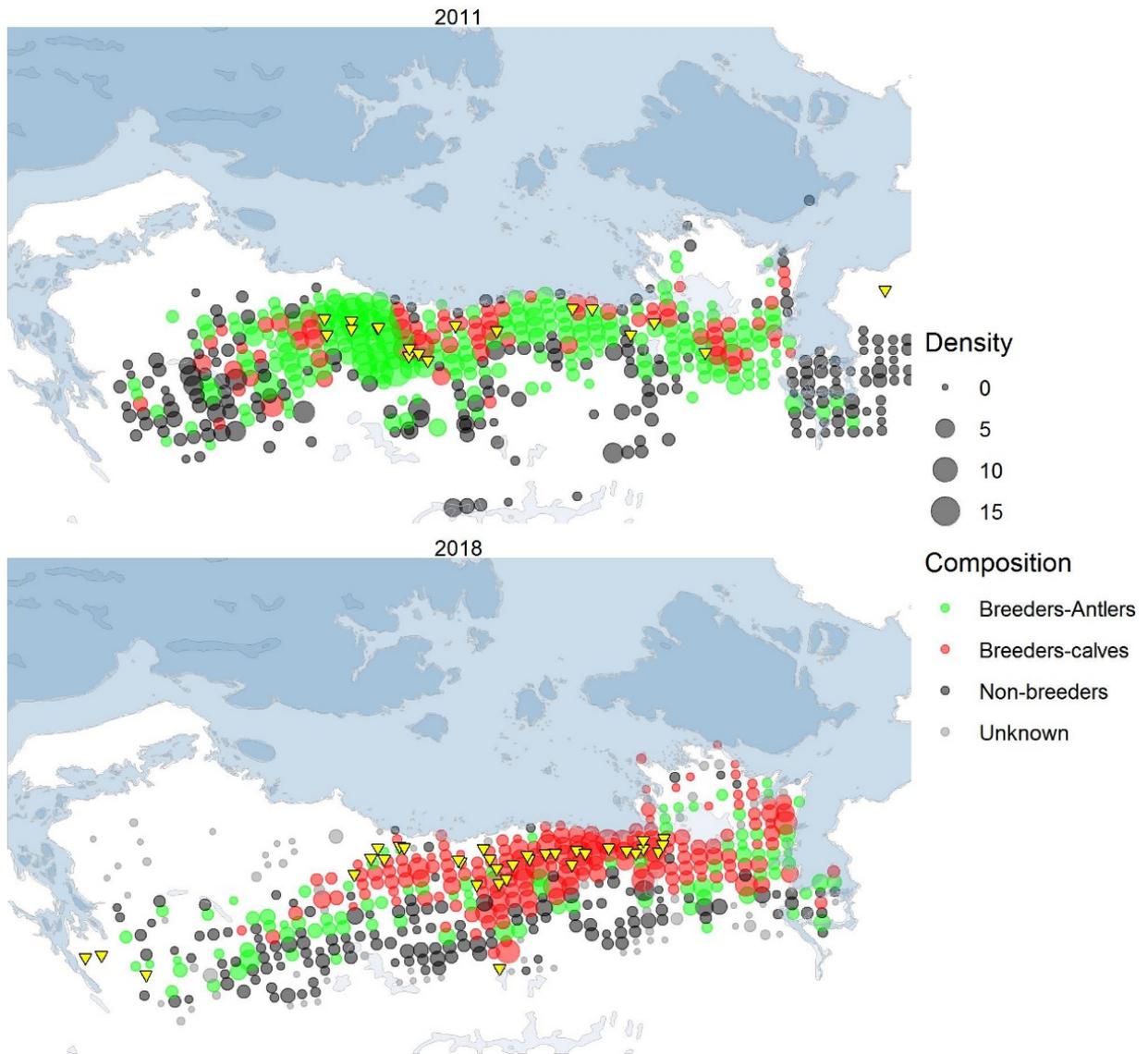


Figure 34. Distribution of caribou in the Queen Maud Gulf and Adelaide Peninsula during the 2011 and 2018 June abundance estimate surveys for the Beverly caribou subpopulation, as indicated by collared caribou (yellow triangles) and reconnaissance surveys.

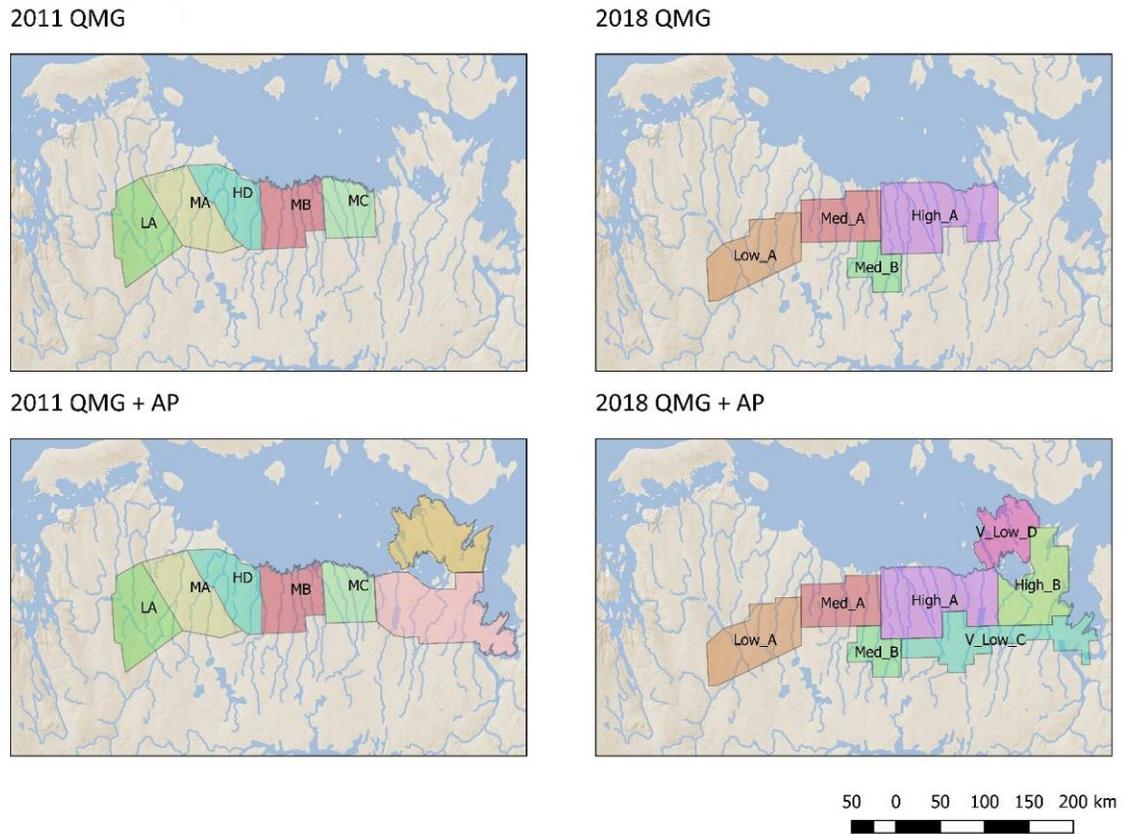


Figure 35. Survey strata for the 2011 and 2018 June abundance surveys for the Beverly caribou subpopulation for the Queen Maud Gulf (QMG) and Adelaide Peninsula (AP). Survey strata labels are given for each year, with the exception of the two revised 2011 strata covering the Adelaide Peninsula for the 2011 survey.

Table 22. Estimates of ***breeding females*** for the June 2011 Beverly caribou subpopulation abundance survey when the Adelaide Peninsula (ADP) strata (ADP-N (north) and ADP-S (south)) are included with the Queen Maud Gulf (QMG) strata in the final estimate. (HD = high density, LA = low density A, MA = medium density A, MB = medium density B, MC = medium density C).

Strata	N total caribou	CV	Proportion. Breeding females	CV	N Breeding females	SE	Conf. Limit		CV (%)
QMG_HD	27,296	0.080	0.878	0.015	23,977	1950.2	20,326	28,284	8.1%
QMG_LA	14,429	0.174	0.048	0.236	694	203.3	366	1,315	29.3%
QMG_MA	11,645	0.087	0.681	0.038	7,932	752.8	6,518	9,653	9.5%
QMG_MB	18,843	0.087	0.710	0.042	13,380	1290.9	10,849	16,502	9.6%
QMG_MC	11,160	0.127	0.614	0.053	6,851	938.8	5,074	9,250	13.7%
ADP-N	3,495	0.379	0.640	0.041	2,236	853.2	971	5,148	38.2%
ADP-S	19,297	0.131	0.640	0.041	12,344	1696.6	9,261	16,454	13.7%
Total	106,165				67,414	3250.5	61,257	74,190	4.8%

Table 23. Estimates of **adult females** for the June 2011 Beverly caribou subpopulation abundance survey when the Adelaide Peninsula (ADP) strata (ADP-N (north) and ADP-S (south)) are included with the Queen Maud Gulf (QMG) strata in the final estimate. (HD = high density, LA = low density A, MA = medium density A, MB = medium density B, MC = medium density C).

Strata	N total caribou	CV	Proportion. Adult females	CV	N Adult females	SE	Conf. Limit		CV
QMG_HD	27,296	0.080	0.959	0.006	26,179	2097.0	22,248	30,805	8.0%
QMG_LA	14,429	0.174	0.119	0.136	1,717	378.3	1,057	2,789	22.0%
QMG_MA	11,645	0.087	0.887	0.014	10,324	910.5	8,601	12,392	8.8%
QMG_MB	18,843	0.087	0.853	0.022	16,065	1436.0	13,227	19,512	8.9%
QMG_MC	11,160	0.127	0.747	0.034	8,335	1091.1	6,256	11,105	13.1%
ADP-N	3,495	0.379	0.793	0.020	2,773	1053.8	1,208	6,365	38.0%
ADP-S	19,297	0.131	0.793	0.020	15,312	2034.2	11,597	20,217	13.3%
Total	106,165				80,705	3724.3	73,636	88,452	4.6%

Table 24. Summary of the estimates of adult and breeding females in 2011 and 2018 Queen Maud Gulf (QMG) and Adelaide Peninsula (ADP) stratum. T-statistics were used to test the difference between the 2018 and accompanying 2011 estimates and in both cases the difference is significant ($p < 0.001$).

Year	Area	Estimate	SE	Conf. Limit		CV	df	t-statistic	df	p
Breeding females										
2011	QMG+ADP	67,414	3250.5	61,257	74,190	4.8%	88			
2011	QMG	52,834	2638.0	47,821	58,372	5.0%	64			
2018	QMG+ADP	48,977	2600.9	44,056	54,448	5.3%	68	-4.43	155	0.000
2018	QMG	40,248	2371.9	35,763	45,296	5.9%	52	-3.55	116	0.001
Adult females										
2011	QMG+ADP	80,705	3724.3	73,636	88,452	4.6%	88			
2011	QMG	62,620	2936.3	57,029	68,760	4.7%	67			
2018	QMG+ADP	61,070	2887.8	55,583	67,099	4.7%	75	-4.17	158	0.000
2018	QMG	49,384	2585.5	44,470	54,841	5.2%	56	-3.38	123	0.001

Table 25. Summary of estimates of extrapolated herd size for the June 2011 and 2018 surveys for Queen Maud Gulf (QMG) only and Queen Maud Gulf and the Adelaide Peninsula together (QMG+ADP) survey areas. The assumed pregnancy rate is based upon breeding females, whereas the proportion of females uses the actual estimated number of adult females on the calving ground as an estimate of total adult females in the herd.

Year	Method	N	SE	Conf. Limit		CV
<u>QMG only</u>						
2011	Breeding females	124,210	13997.7	99,241	155,459	11.3%
2018	Breeding females	94,621	11067.0	74,886	119,556	11.7%
2011	Proportion females	105,995	5199.0	96,117	116,889	4.9%
2018	Proportion females	83,591	4538.7	74,982	93,189	5.4%
<u>QMG+ADP</u>						
2011	Breeding females	158,486	17741.9	126,961	197,840	11.2%
2018	Breeding females	115,142	13141.9	91,759	144,484	11.4%
2011	Proportion females	136,608	6603.3	124,102	150,373	4.8%
2018	Proportion females	103,372	5109.3	93,684	114,061	4.9%

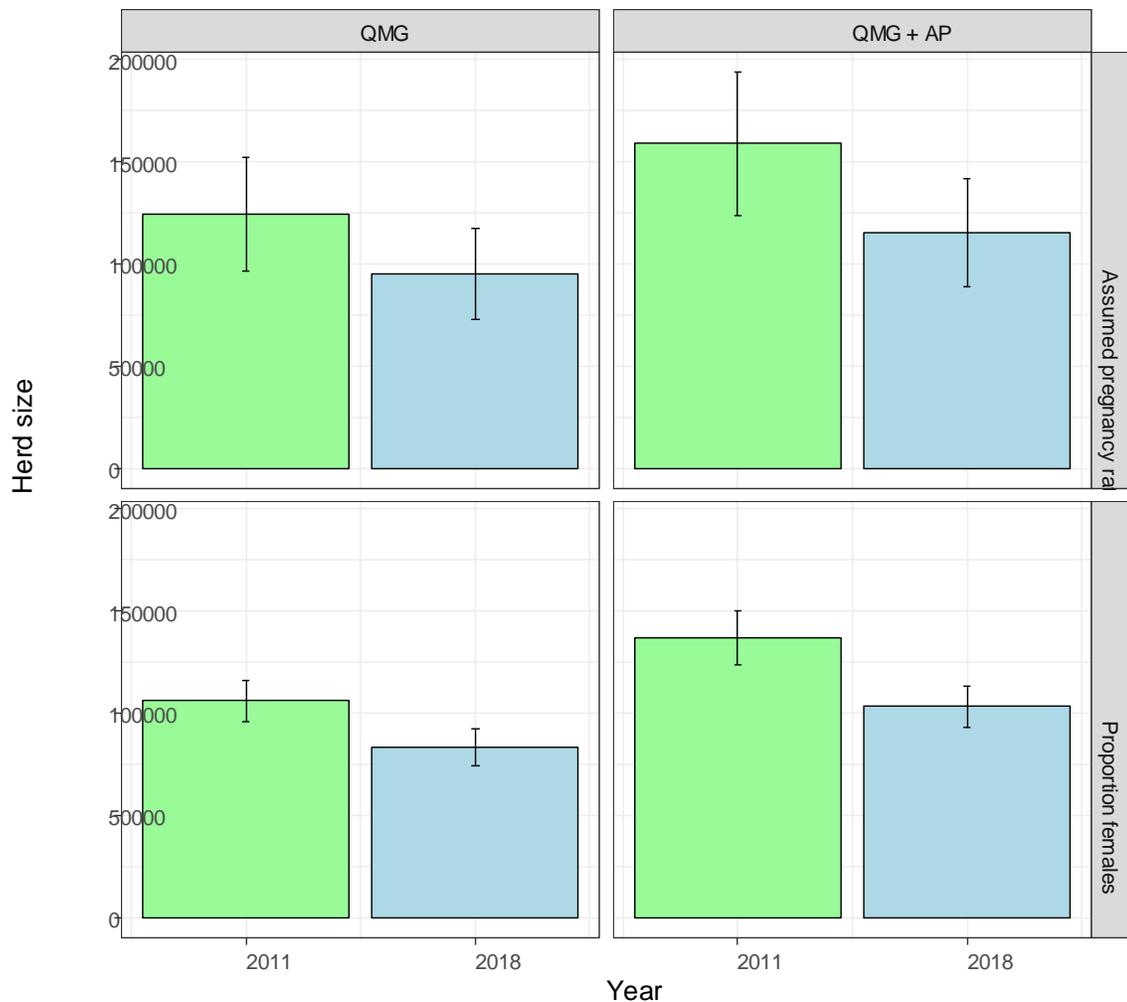


Figure 36. Comparison of extrapolated herd size estimates from June 2011 and 2018 surveys of the Beverly mainland migratory barren-ground caribou subpopulation, for estimates derived from the Queen Maud Gulf (QMG, left) and Queen Maud Gulf and Adelaide Peninsula together (QMG + AP, right) and extrapolated based on the number of breeding females calculated from an assumed pregnancy rate (top) and based on the total number of breeding females (bottom).

Table 26. Estimates of gross rate of change and t-tests for differences of abundance estimates for Beverly caribou in the Queen Maud Gulf (QMG) and Queen Maud Gulf and Adelaide Peninsula together (QMG+ADP) between 2011 and 2018, based on abundance estimates derived from the proportion of breeding females and proportion of total adult females, as listed in **Table 25**.

Scenario	Method	Gross change	SE	t	df	p
QMG	Breeding females	0.76	0.15	-1.66	51	0.104
QMG	Proportion females	0.79	0.10	-3.25	52	0.002
QMG + ADP	Breeding females	0.73	0.15	-1.96	43	0.056
QMG + ADP	Proportion females	0.76	0.11	-3.98	42	0.000

Table 27. Estimates of rate of change from 2011 to 2018 for the Queen Maud Gulf only (QMG) and Queen Maud Gulf and Adelaide Peninsula together (QMG + ADP). Note that all treatment types indicate a decline between survey periods.

Area and method	<i>r</i>	SE	Conf. Int		Lambda	Conf. Int	
<u>QMG only</u>							
Adult females	-0.034	0.010	-0.054	-0.014	0.967	0.948	0.986
Breeding females	-0.039	0.023	-0.084	0.007	0.962	0.919	1.007
Proportion females	-0.034	0.011	-0.054	-0.013	0.967	0.947	0.987
<u>QMG+ADP</u>							
Adult females	-0.040	0.009	-0.058	-0.021	0.961	0.943	0.979
Breeding females	-0.046	0.023	-0.090	-0.001	0.955	0.914	0.999
Proportion females	-0.040	0.010	-0.059	-0.021	0.961	0.943	0.980

4.4.5 Reconnaissance survey analysis of caribou utilizing the Queen Maud Gulf and Adelaide Peninsula Calving area.

In support of both the spatial and quantitative analysis of abundance trend developed in this report, we also assessed trends in relative density and calving extents by analyzing aerial reconnaissance survey data collected over the Beverly subpopulation calving period for each of June 2011, 2013, 2016, and 2018 (Nagy et al. 2011, Campbell et al. 2014). Survey study areas remained relatively consistent across all four survey years, with minor changes based on caribou observations along pre-determined reconnaissance transects that remained constant across all surveys (**Figure 37**). All survey study area outlines were based on the extent of flying in the calving area each survey year (the dark outlines around each survey area for each survey year). The spatial extents of calving and associated relative densities of caribou clearly show a progressive distributional shift in core calving towards the east of the survey study area from June 2011 through to June 2018.

Additionally, as reconnaissance transects flown for each survey were identical, we were able to track the gradual shift in the Beverly subpopulation's core calving area from the western most reconnaissance transects to the easternmost (**Figure 38**). The plot of transect densities (from west to east) for each year reveals large differences in distributions each year as well as an overall shift to the east, with an associated decline in densities. An analysis of the Beverly caribou subpopulations GPS collar movement data for the same area reveals similar distributions of collars as well as a distinct shift in migration paths over the 2016 and 2017 spring migratory and calving seasons (**Figure 39**). We would also like to note that in all reconnaissance survey years, collar locations at the peak of calving were within reconnaissance survey strata (**Figure 40**).

Estimates for the reconnaissance areas were derived using the standard Jolly formula. Estimates suggest an overall decrease in abundance of Beverly caribou, especially between the June 2011 and 2013, and June 2016 and 2018 survey

periods (**Table 28**). The estimated annual rate of change, using just the 2011 and 2018 reconnaissance data is 0.94 (CI=0.89-0.98). If the full data set is used, we estimate a regression-based λ of 0.91 (CI=0.87-0.94) based on weighted regression (**Table 29**).

A plot of the data demonstrates the decline that occurred from 2011 to 2018 (**Figure 41**). Comparison of reconnaissance estimates of total caribou in June 2011 and June 2018 (**Table 29**), suggests a similar trend (6% decline per year) as that which derived from the full survey estimates from 2011 and 2018 (**Table 27**: 4-5% per year). If all the reconnaissance data are used, the decline is more pronounced at 9% per year. The main reason for this is the higher reconnaissance estimate in 2013, and the lower estimate in 2016 (**Figure 41**).

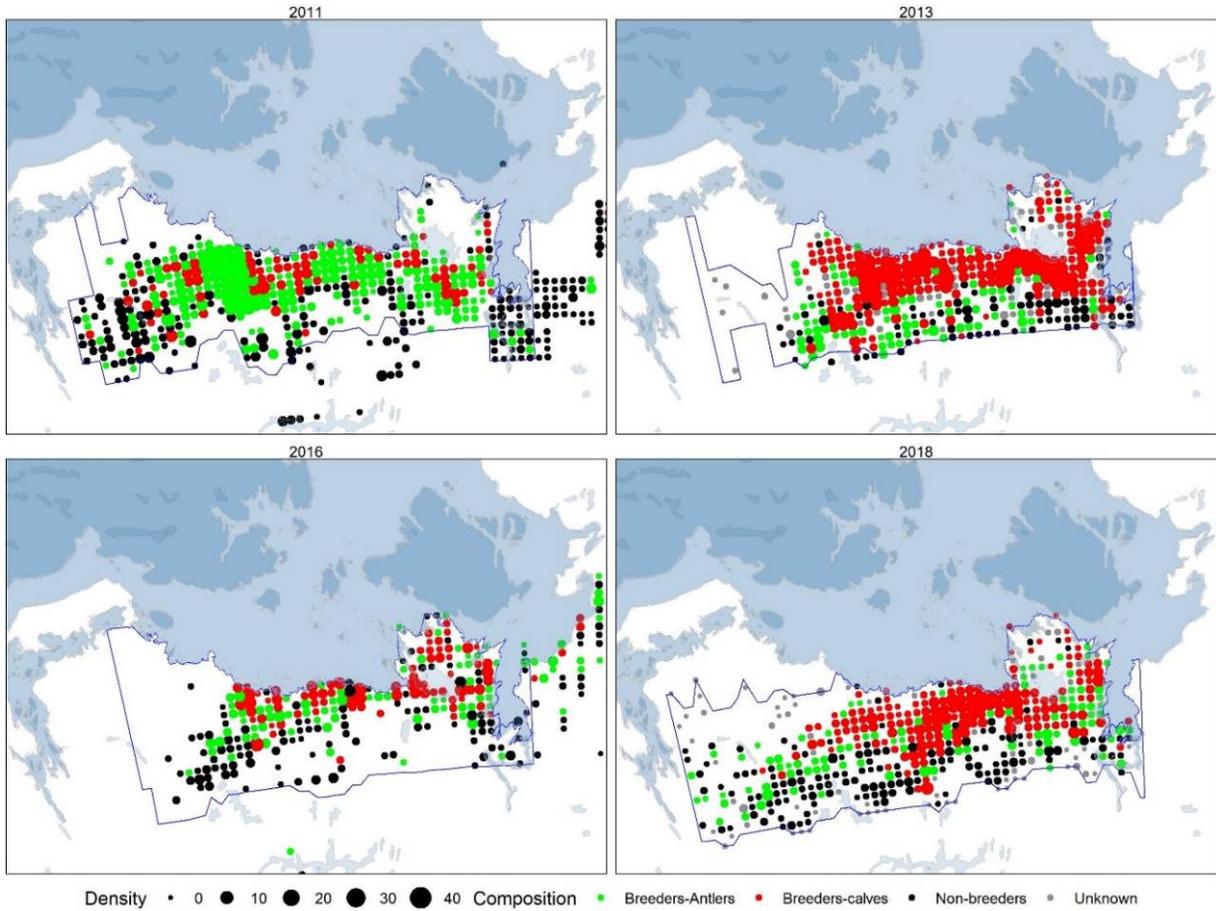


Figure 37. A comparison of relative densities of Beverly caribou on their calving grounds. Extent of transects each year is delineated by a grey border. Data based on observations of caribou made during the 2011, 2013, 2016, and 2018 Beverly caribou June reconnaissance surveys. Note a general shift of breeding females (Red and Green) to the eastern extents of the survey study area.

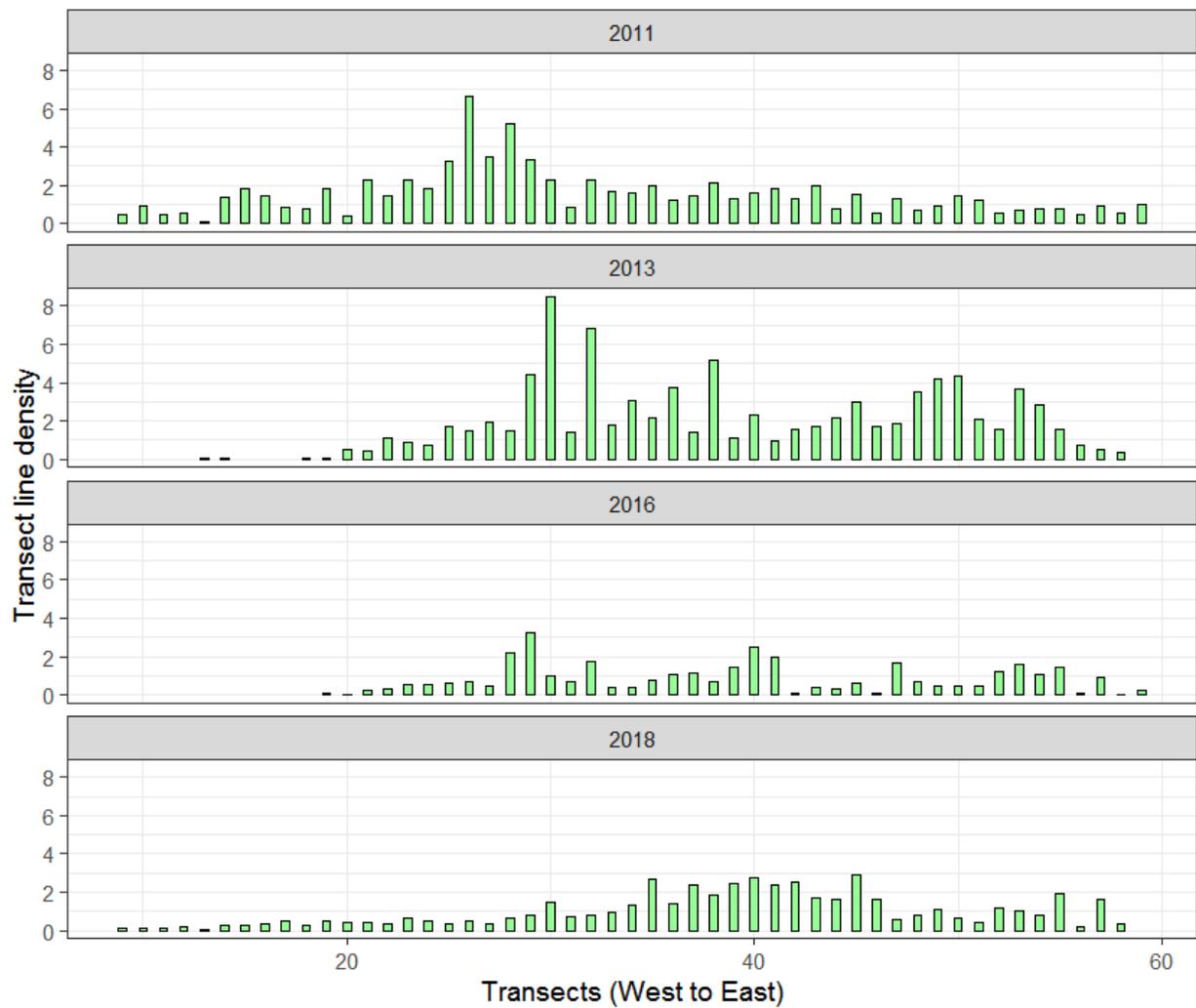


Figure 38. Transect-specific observed densities of caribou (caribou/km²) from four June reconnaissance surveys in four different years of the Beverly barren-ground caribou subpopulation, within their known calving extents.

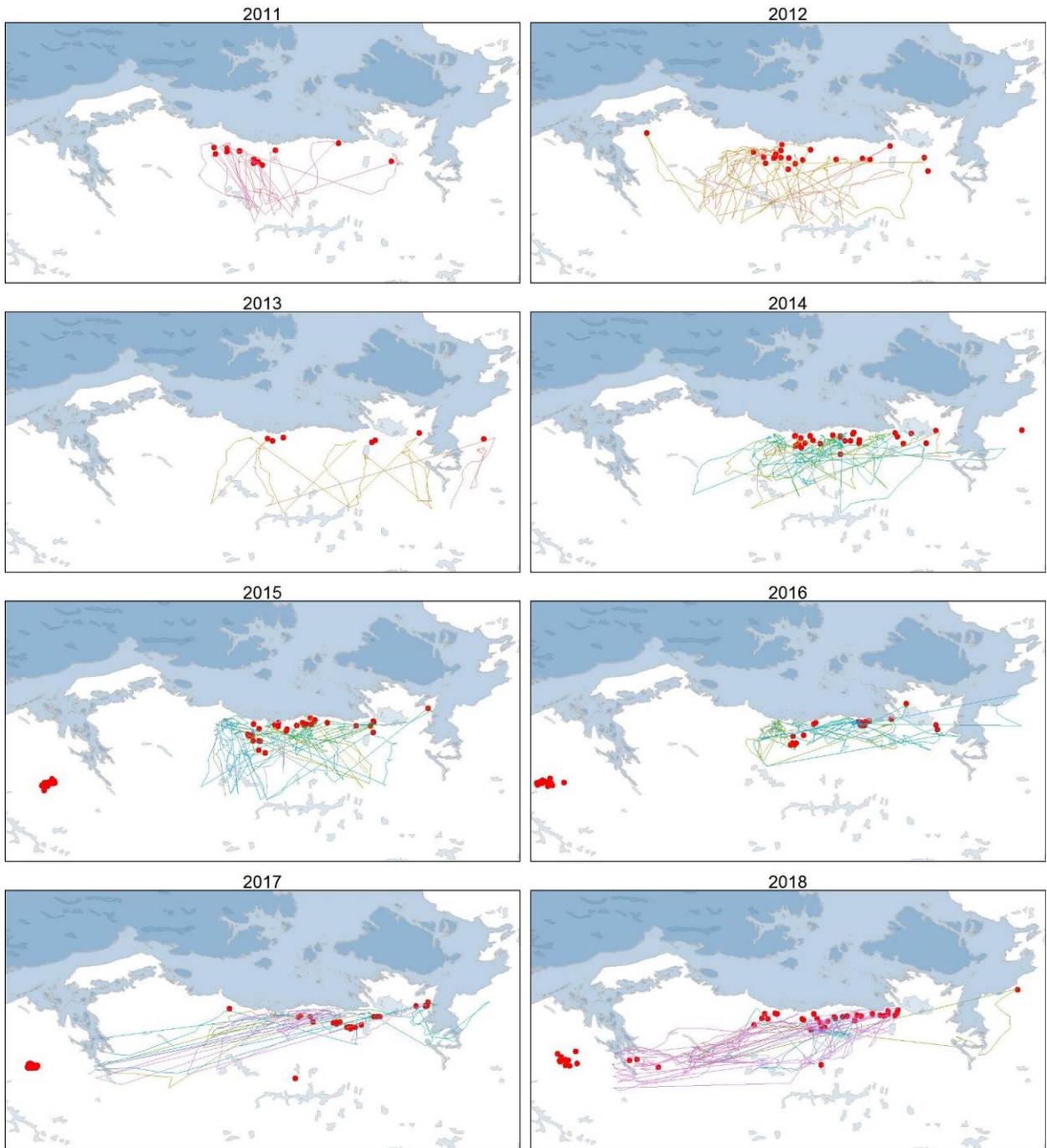


Figure 39. Annual collar locations for mid-June (red dots) and migration paths (pink, green, blue, and yellow lines) for mid-May through mid-June for different years between 2011 and 2018. The Bathurst herd is included from 2015-2018. Note the change in migration routes between some years.

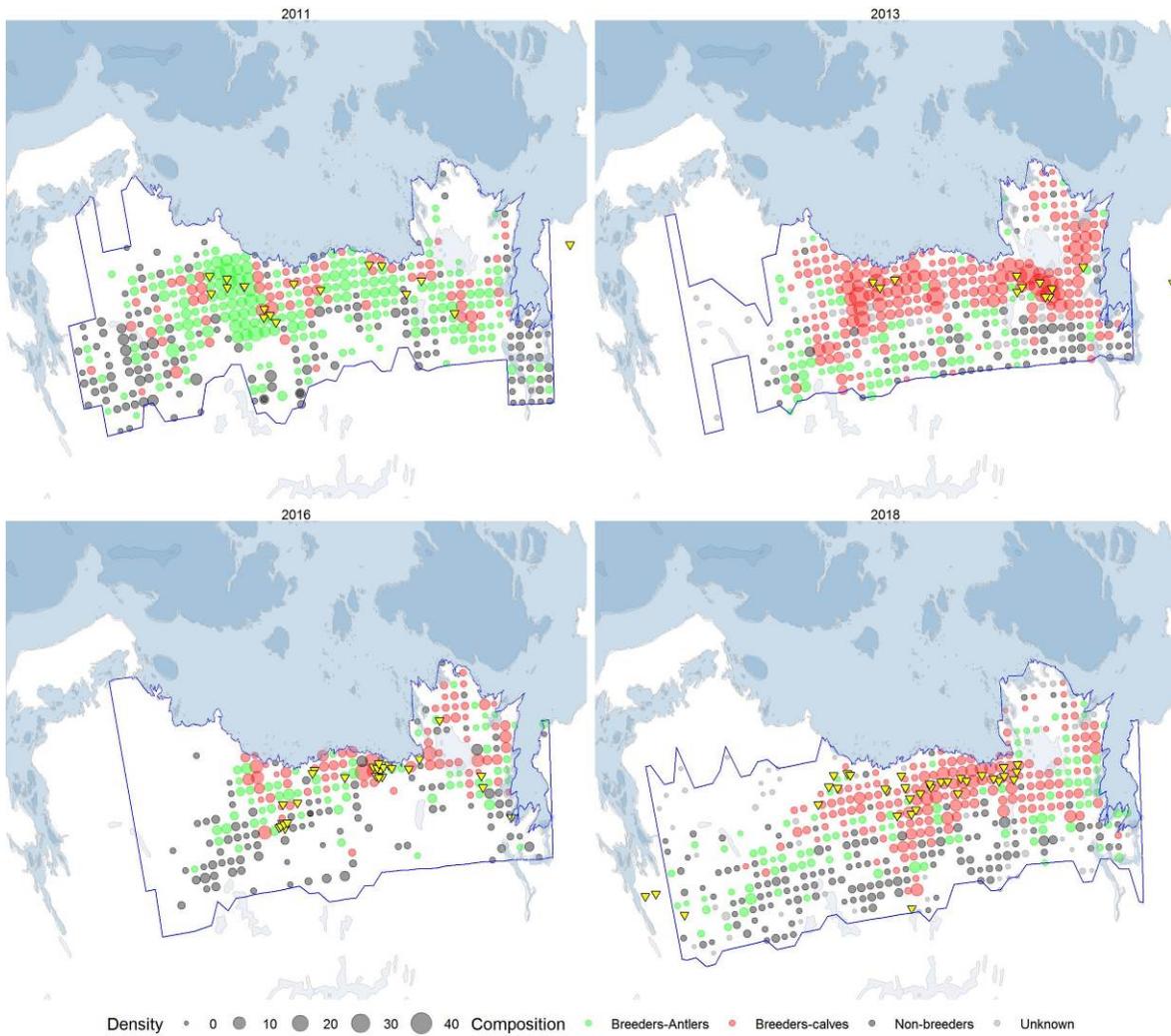


Figure 40. Beverly collared caribou locations relative to reconnaissance survey strata flown between June 2011 and 2018. Note that all Beverly collared caribou remained within the reconnaissance survey extents for all survey periods.

Table 28. Abundance estimates of caribou (N), with standard error (SE), confidence intervals (Conf. Limit), and the coefficient of variation (CV) on the calving ground, based on reconnaissance data (**Figure 37**).

Year	N	SE	Conf. Limit		CV
2011	105,342	11436.22	82,372	128,313	10.9%
2013	118,553	14005.29	90,327	146,778	11.8%
2016	48,086	5803.453	36,382	59,790	12.1%
2018	66,600	7523.741	51,488	81,712	11.3%

Table 29. Weighted regression-based estimates of trend for the reconnaissance observation data set.

Data used	<i>r</i>	SE	Conf. Limit		Lambda	Conf. Limit	
Full data set	-0.098	0.021	-0.139	-0.057	0.907	0.870	0.944
2011 & 2018 only	-0.066	0.022	-0.109	-0.022	0.937	0.896	0.979

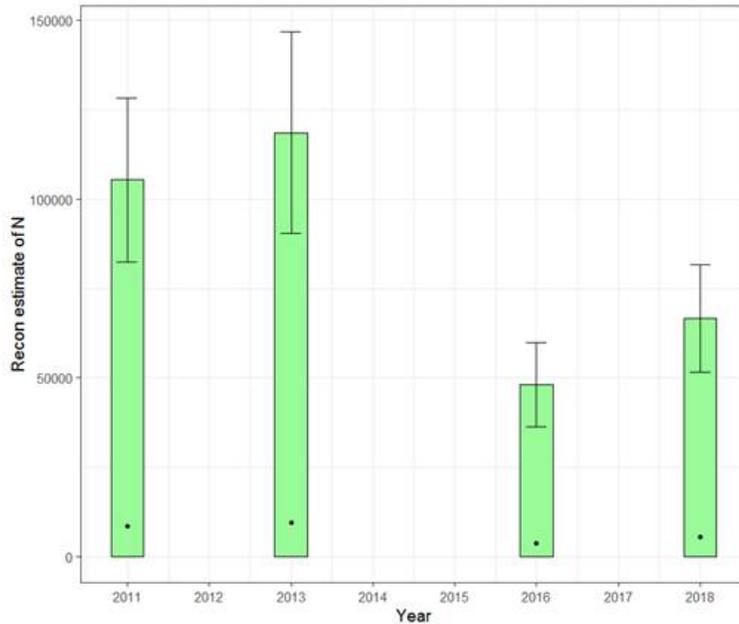


Figure 41. Reconnaissance survey abundance estimates of caribou (N) in the Beverly subpopulation for the Queen Maud Gulf and Adelaide Peninsula calving area. The dots represent the actual counts of caribou from each survey. Because coverage was consistent at 8%, the estimates are proportional to these counts. Note the lack of overlap between the June 2011 and June 2018 reconnaissance survey estimates, indicating a significant decline.

5.0 CONCLUSIONS

5.1 THE BEVERLY CARIBOU JUNE 2018 ABUNDANCE SURVEY.

Overall, the survey was successful with good coverage in both visual and composition surveys. Overall allocation of effort across delineated strata proved effective at generating a precise estimate for both adult female and whole herd estimates.

Though the timing of the visual abundance survey corresponded well to the peak of calving, one initial concern was the early June 4, 2018 start to the reconnaissance survey. The concern was related to the potential movement of caribou between the strata that occurred before June 12th when movement rates decreased. In this case some caribou might have been double counted during the reconnaissance phase, given the directional movement eastward, affecting abundance survey stratification and allocation of effort. However, composition observations suggested little movement during that period, thought in part to be due to the overlap of the western extents of the reconnaissance survey with the earlier calving Bathurst caribou and evidenced by 3 Bathurst collared cows calving within the delineated Beverly subpopulations annual core calving area (ACCA) (Campbell et al. 2014, Nagy et al. 2011). Reports of earlier peak calving by the Government of the Northwest Territories survey crews working in the Bathurst ACCA in June 2018 also support this hypothesis. Regardless, the 'western low' and 'very low' reconnaissance strata delineated in June 2018 on the Beverly ACCA did not contribute substantively to the breeding female, adult female, and final estimates.

5.2 COMPARISON OF 2011 AND 2018 ESTIMATES.

Comparison of the 2011 and 2018 estimates suggests similar trends whether the Adelaide Peninsula is included or excluded (**Table 27 and Figure 36**). The collar analysis also suggests the Adelaide Peninsula is more linked to the Beverly

subpopulation then the Northeast Mainland (Ahiak and Lorillard) subpopulations. T-tests were added to test for significance. The results confirmed a statistically significant decline in the numbers of the Beverly caribou herd between June 2011 and 2018. The t-tests for the adult females displayed a higher level of significance than those for the whole herd estimates, though both confirmed a significant decline. Recent analyses suggest that the assumption of a constant pregnancy rate is problematic and therefore adult female-based herd estimates are likely more robust (Campbell et al. 2012, Boulanger et al. 2018, Adamczewski et al. 2019).

A comparison of June reconnaissance survey estimates of total caribou, flown in 2011 and 2018, suggests a similar trend (6% decline per year), to the visual abundance survey estimates of June 2011 and 2018 (4-5% per year). If we compare the June 2011, 2013, 2016, and 2018 reconnaissance survey estimates, then the decline is more pronounced at 9% per year, largely due to the higher reconnaissance estimate in 2013, and the lower estimate in 2016 (**Figure 41**).

5.3 SPATIAL ANALYSIS OF COLLAR AND CALVING AREA AFFILIATIONS.

Results suggest that subpopulation-specific capture location has a substantial effect on the fidelity of the same caribou to specific calving ground strata (**Figure 19**). We concluded that the GN caribou cows collared out of Baker Lake were most likely to be of the NEM (Ahiak and Lorillard) subpopulations, and the GNWT collared Beverly cows, collared on known Beverly late winter/early spring range were most likely to be of the Beverly subpopulation. We found that the NEM collared caribou had higher fidelity to the NEM calving strata than to the the Adelaide and Queen Maud Gulf calving strata most heavily utilized for calving by collared Beverly caribou (**Figure 22**). Based on these findings, we believe that there was minimal directional movement to the Beverly from the NEM calving area. We also conclude that caribou on the Adelaide Peninsula are more affiliated with the Beverly subpopulation than NEM (Ahiak and Lorillard) subpopulations. Further, the QMG and Adelaide Peninsula pooled calving strata, and the NEM calving

strata, based on **Figure 19**, are relatively separate calving areas with few but similar movements between these calving areas from 2011 through 2018. However, collar analysis considers *mean movement* rates as opposed to year-specific rates, so it is still possible that some years did have directional movements.

5.3.1 BATHURST OVERLAP.

The June 2018 abundance estimate of the Beverly subpopulation was potentially influenced by the movement of caribou from the Bathurst herd, as evidenced by 3 Bathurst collared cows calving within the known Beverly subpopulation ACCA. However, the estimate of adult females of the Bathurst herd was 13,265 (CI=8,308–18,222) in 2015 (Boulanger et al 2017), and 5,162 (CI=3,922–6,793) in 2018 (Adamczewski et al 2019), with the overall herd size being 19,769 (CI=12,349–27,189) in 2015 and 8,210 (CI=5,706–11,814) in 2018. Using the ratio of collared caribou that occurred in the Bathurst Inlet calving strata, compared to the Beverly calving strata (8 of 11 known Bathurst cows), an approximate estimate of 1,936 (CI=497–4,595) Bathurst cows occurring in the Beverly calving strata can be derived. This is an approximate estimate given the low sample size of collared cows, and should be treated cautiously. However, the relatively low number of Bathurst cows (1,936) compared to the estimate of adult females in the Beverly calving ground in 2018 (61,070 (CI=55,583–67,099 as listed in **Table 24**), suggests that the movement of Bathurst cows into the Beverly subpopulations June 2018 survey extents would not have substantively affected the estimates of herd abundance or trend.

In summary, the Beverly subpopulation reconnaissance and visual abundance estimates, for all analytical treatments, whether based on survey study areas encompassing the Queen Maud Gulf calving area alone, or in union with the Adelaide Peninsula, all represent a statistically significant decline. An overall decline of 24% is estimated to have occurred between the June 2011 and June 2018.

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K. Mager, M. Musiani, K. L. Parker, K. H. Røed, T. Sipko, S. G. Pórisson, B. V. Weckworth, A. Guisan, L. Bernatchez, and S. D. Côté. 2014. Genetic diversity in caribou linked to past and future climate change. Macmillan Publishers Limited, Nature Climate Change. Vol: 4, Feb. www.nature.com/natureclimatechange 137.



Mon 2019-06-10 1:18 PM

Gissing, Drikus <DGissing@GOV.NU.CA>

RE: FOR REVIEW Proposed Downlisting of three bird species under the Federal Species at Risk Act

To: Tufts, Teresa (EC)

Cc: csmith@gocv.nu.ca

Hi Teresa

The GN support the proposed downlisting of the three bird species identified below.

Regards

Drikus

From: Tufts, Teresa (EC) [<mailto:teresa.tufts@canada.ca>]

Sent: June 10, 2019 9:28 AM

To: Gissing, Drikus

Cc: csmith@gocv.nu.ca

Subject: FOR REVIEW Proposed Downlisting of three bird species under the Federal Species at Risk Act

Hello,

The purpose of this email is to seek your response on whether the GN supports the proposed downlisting of three birds: Peregrine Falcon, Common Nighthawk and Olive-sided Flycatcher under the federal Species at Risk Act (SARA). Peregrine Falcon can be found throughout Nunavut. The known occurrence of Olive-sided flycatcher and Common Nighthawk in Nunavut is limited to the islands in James Bay.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) re-assessed Peregrine Falcon in November 2017 and designated it as Not at Risk. COSEWIC re-assessed Common Nighthawk and Olive-sided Flycatcher in April 2018 and designated them as Special Concern. The assessment reports were released in January 2019.

Attached is a summary of the COSEWIC status reports but the full COSEWIC status reports can be found here:

- https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/srOlive-sidedFlycatcher2018e.pdf
- https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/srCommonNighthawk2018e.pdf
- https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/srPeregrineFalcon2017e.pdf

Your decision will be shared with the NWMB when they are asked to make a decision on the downlisting.

If you have any questions, concerns or additional information that you feel should be considered in the listing decision, please don't hesitate to contact me. If you could provide a response by, at the latest, August 31st, it would be much appreciated.

Best regards,

Teresa Tufts

Species at Risk Biologist
Canadian Wildlife Service
Environment and Climate Change Canada / Government of Canada
Teresa.Tufts@canada.ca / Tel: +1 (867) 979 7058



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Canadian Wildlife Service
Environment and Climate Change Canada / Government of Canada
Teresa.Tufts@canada.ca / Tel: +1 (867) 979 7058

Recommendation Form

The Committee or Board

Name: Arviq Hunters and Trappers Organization **of Community:** REPULSE BAY

SUPPORTS or DOES NOT SUPPORT

the proposed 2018-19 Migratory Game Bird hunting regulation changes

Send your comments back to:

Address:

FAX number:

E-mail:

Eric Reed – Canadian Wildlife Service

5019-52nd St., Box 2310, Yellowknife, NT, X1A 2P7

(867) 873-8185

Eric.Reed@Canada.ca

Signature:

of Chair, President, Committee or Board.

Date: 11/27/17

Louis Augustinger

Reasons for decision:

The board of directors for Arviq H.T.O. supports the proposed 2018-19 Migratory Game bird hunting regulation changes, the migratory birds most times are in large numbers and are still in large numbers.

Also in the future if migratory game bird hunting planning on taking place in and near Naujaat Nunavut the board would like to be informed.

Recommendation Form

The Committee or Board

Name: Ekaluktutiak Hunters and Trappers Association **of Community:** CAMBRIDGE BAY

SUPPORTS or DOES NOT SUPPORT

the proposed 2018-19 Migratory Game Bird hunting regulation changes

Send your comments back to:

Address:

FAX number:

E-mail:

Eric Reed – Canadian Wildlife Service

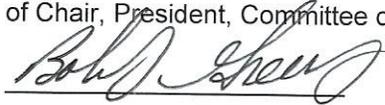
5019-52nd St., Box 2310, Yellowknife, NT, X1A 2P7

(867) 873-8185

Eric.Reed@Canada.ca

Signature:

of Chair, President, Committee or Board.



Date: 12/08/17

Reasons for decision:

Recommendation Form

The Committee or Board

Name: Kugluktuk Hunters and Trappers Association **of Community:** KUGLUKTUK

SUPPORTS or DOES NOT SUPPORT

the proposed 2018-19 Migratory Game Bird hunting regulation changes

Send your comments back to:

Address:

FAX number:

E-mail:

Eric Reed – Canadian Wildlife Service

5019-52nd St., Box 2310, Yellowknife, NT, X1A 2P7

(867) 873-8185

Eric.Reed@Canada.ca

Signature:

of Chair, President, Committee or Board.

Date: Feb 11 2017



CHAIRMAN KUGLUKTUK HUNTERS & TRAPPERS ASSOC.

Reasons for decision:

NUNAVUT MIGRATORY BIRDS HUNTING REGULATIONS
Proposed Changes for the 2018-2019 Season

The Canadian Wildlife Service is proposing several minor changes to the allowable bag and possession limits in Nunavut. They are described in textual form below and highlighted in Table 1.

Increase in possession limits:

The possession limit of ducks for non-residents of Canada was 16 for the 2016-2017 hunting season, for Canada Geese, Cackling Geese, White-fronted Geese and Brant was 10 and for Snipe was 20. These represent twice the daily bag limit. ***It is proposed to increase these possession limits to three times the daily bag limit – 24 ducks, 15 Canada Geese, Cackling Geese, White-fronted Geese and Brant and 30 Snipe*** to increase limit consistency with surrounding Provinces in Canada such as Manitoba, Ontario and Quebec.

The possession limit of White-fronted Geese for non-residents of Canada is currently restricted to four (subscript *f*, Table 1); twice the daily bag limit. ***It is proposed to increase the possession limit of White-fronted Geese to 6 for non-residents.*** In adjacent jurisdictions (Manitoba, Ontario, Quebec), the number of White-fronted Geese allowed in possession is not differentiated from that of other dark geese (i.e. excluding Snow and Ross's geese) for non-residents with the exception of Ontario for which the possession limit is three times the daily bag limit.

There are no anticipated conservation concerns or implications associated with the changes in possession limits for these species.

Barrow's Goldeneye and Blue-winged Teal are currently considered to be species of conservation concern or which could be negatively affected by increased hunting pressure. As such, no changes to possession limits for those species are proposed.

Increase in daily bag limit for overabundant Snow and Ross Geese in James Bay

the daily bag limit of Snow Geese and Ross's Geese in the portion of the islands and waters of James Bay that are south of 55°N latitude is currently restricted to 20 (subscript *g*, Table 1), whereas elsewhere in the Territory and adjoining jurisdictions in Ontario and Manitoba the limit is 50. ***It is proposed to remove this restriction and allow a daily bag limit of 50 Snow and Ross Geese across Nunavut.***

Due to habitat damage resulting from foraging activities, Snow and Ross's geese are considered an overabundant species. Geese using the islands and waters of James Bay are from the midcontinent population of Lesser Snow Geese which has continued to increase despite the implementation of more liberalized bag and possession limits (Figure 1). Therefore, rather than limiting daily harvest in any one portion of the Territory we believe hunting opportunities should be maximized across the Territory. Adjacent jurisdictions (Ontario and Manitoba) have daily bag limits of 50 Snow and Ross' geese. The James Bay area of Quebec has a daily bag limit of 20 Snow Geese but the harvest in that area of Quebec

is mainly composed of Greater Snow Geese, which are closer to population objectives than midcontinent Lesser Snow Geese.

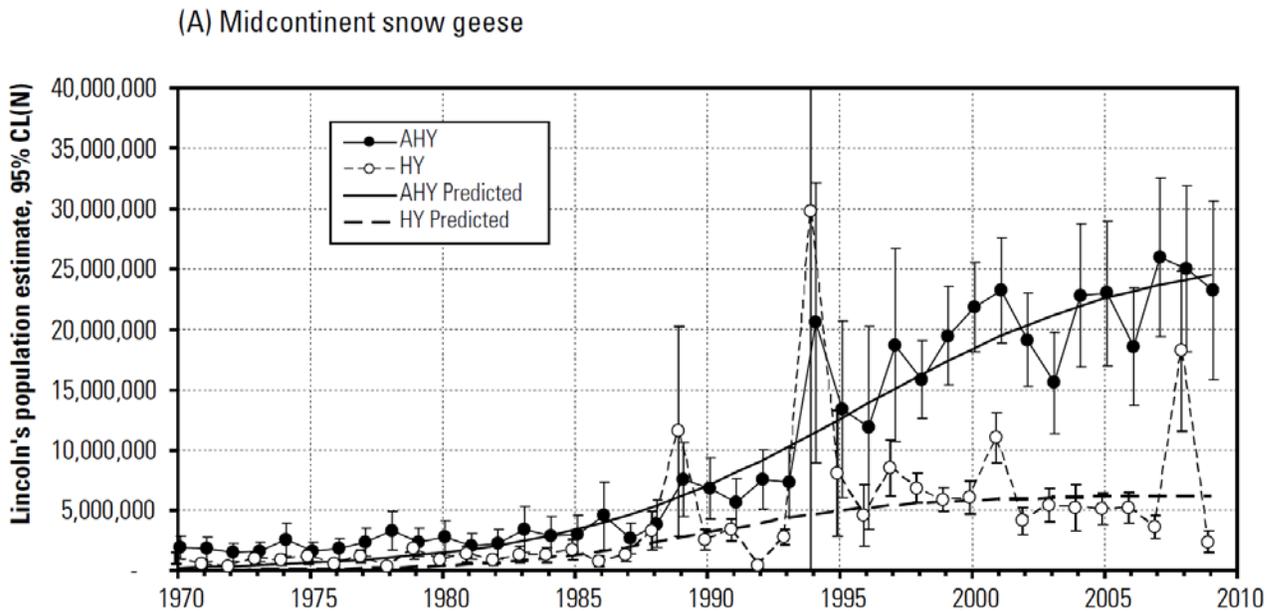
Table 1. Summary of 2016-17 Nunavut hunting regulations (daily bag and possession limits). Proposed changes are highlighted in bold red font.

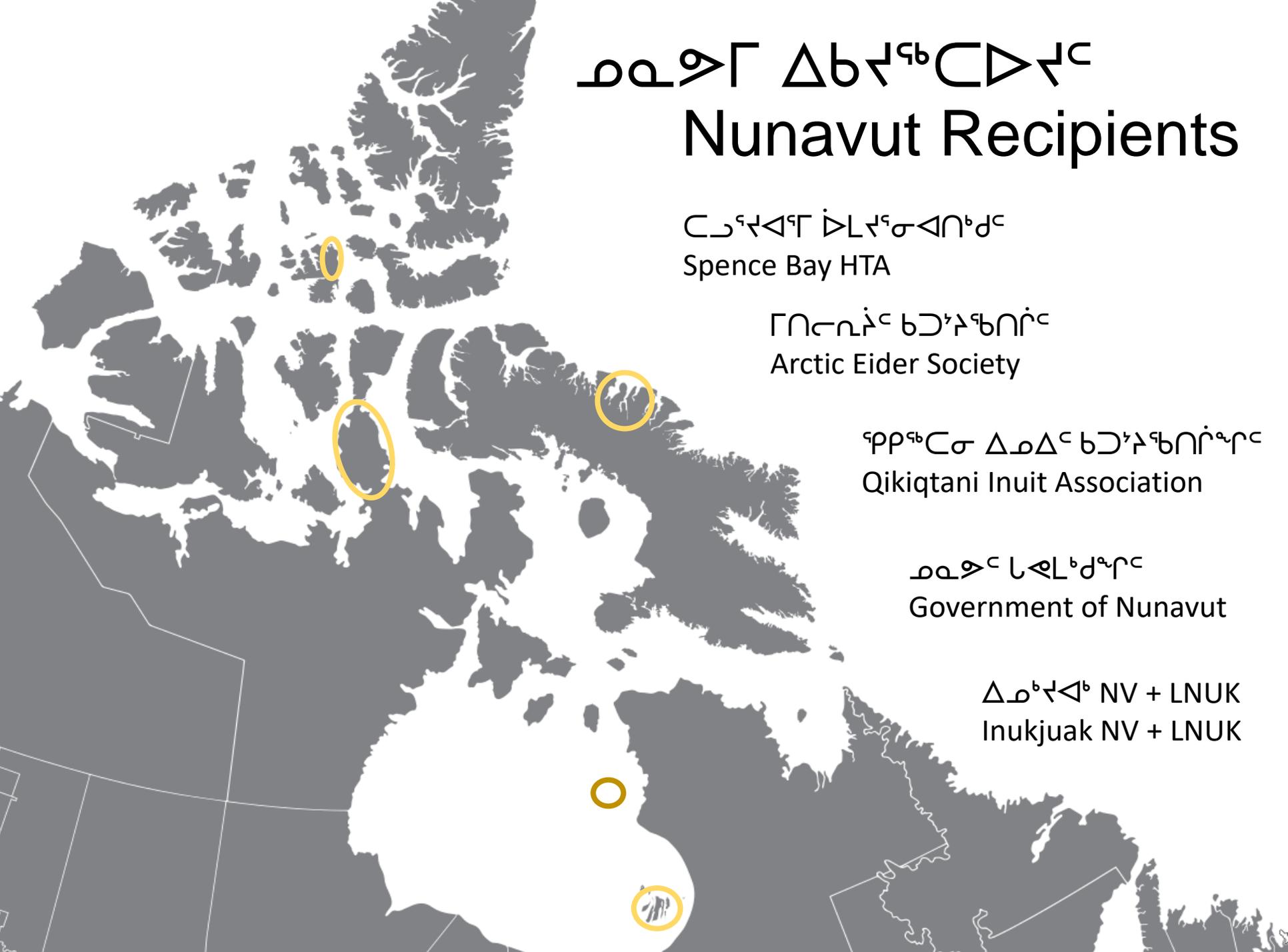
BAG AND POSSESSION LIMITS IN NUNAVUT

Limits	Ducks RESIDENTS OF CANADA	Ducks NON-RESIDENTS OF CANADA	Canada Geese, Cackling Geese, White-fronted Geese and Brant RESIDENTS OF CANADA	Canada Geese, Cackling Geese, White-fronted Geese and Brant NON-RESIDENTS OF CANADA	Snow Geese and Ross's	Coots	Snipe RESIDENT S OF	Snipe NON-RESIDENTS OF CANADA
Daily bag	25(a)	8(a)	15(c)	5(e)	50(g)	25	10	10
Possession	No limit(b)	16(b) Proposed : 24	No limit(d)	10(d)(f) Proposed: 15	No limit	No limit	No limit	20 Proposed : 30

- (a) Except in that portion of the islands and waters of James Bay that are south of 55°N latitude, where the limit is 6, of which (i) not more than 2 may be American Black Ducks and 1 may be Barrow's Goldeneye, in the area west of 80°15' W longitude; and (ii) not more than 4 may be American Black Ducks, 1 may be Barrow's Goldeneye, and 1 may be Blue-winged Teal, in the area east of 80°15' W longitude.
- (b) Except in that portion of the islands and waters of James Bay that are south of 55°N latitude, where the limit is 18, of which (i) not more than 6 may be American Black Ducks and 1 may be Barrow's Goldeneye, in the area west of 80°15' W longitude; and (ii) not more than 1 may be Barrow's Goldeneye and 2 may be Blue-winged Teal, in the area east of 80°15' W longitude.
- (c) In that portion of the islands and waters of James Bay that are west of 80°15' W longitude and south of 55°N latitude, not more than 5 may be Canada Geese or Cackling Geese or any combination of them.
- (d) Except in the portion of the islands and waters of James Bay that are east of 80°15' W longitude and south of 55°N latitude, where the limit is 20.
- (e) Not more than 2 may be White-fronted Geese.
- (f) Not more than 4 **Propose 6** may be White-fronted Geese. In that portion of the islands and waters of James Bay that are west of 80°15' W longitude and south of 55°N latitude, there is no limit on Canada Geese and Cackling Geese.
- (g) Except in that portion of the islands and waters of James Bay that are south of 55°N latitude, where the limit is 20. **Propose to delete this footnote**

Figure 1. Population size and trend of the midcontinent Lesser Snow Goose population. AHY refers to adults while HY refers to juvenile birds. Taken from Leafloor et al. (2012).





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Nunavut Recipients

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Spence Bay HTA

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Arctic Eider Society

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Qikiqtani Inuit Association

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Government of Nunavut

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Inukjuak NV + LNUK

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Received 4 years of funding (2019-2023) to support two projects



ᐅᑦᑭᑦ ᓂᓄᓂᑦᑦᑦᑦ Government of Nunavut



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Funding will be used to support the establishment of the Agguttinni Territorial Park, located north of Clyde River



ᐱᐅᑦᑦᑦᑦ Thank you



Canada's Government invested \$1.3B in Canada's nature, because...



- Nature is vital to Canadian's cultural, social and economic well-being and our national identity

Nature is vital to Canadian's cultural, social and economic well-being and our national identity

- Canada is the custodian of significant share of the world's natural habitat and resources

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- Canada's nature is declining: 520 species at risk, habitats are being reduced

Canada's nature is declining: 520 species at risk, habitats are being reduced

- This collaborative investment is intended to enable change: to protect and conserve Canada's natural legacy for our future generations

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