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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

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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).

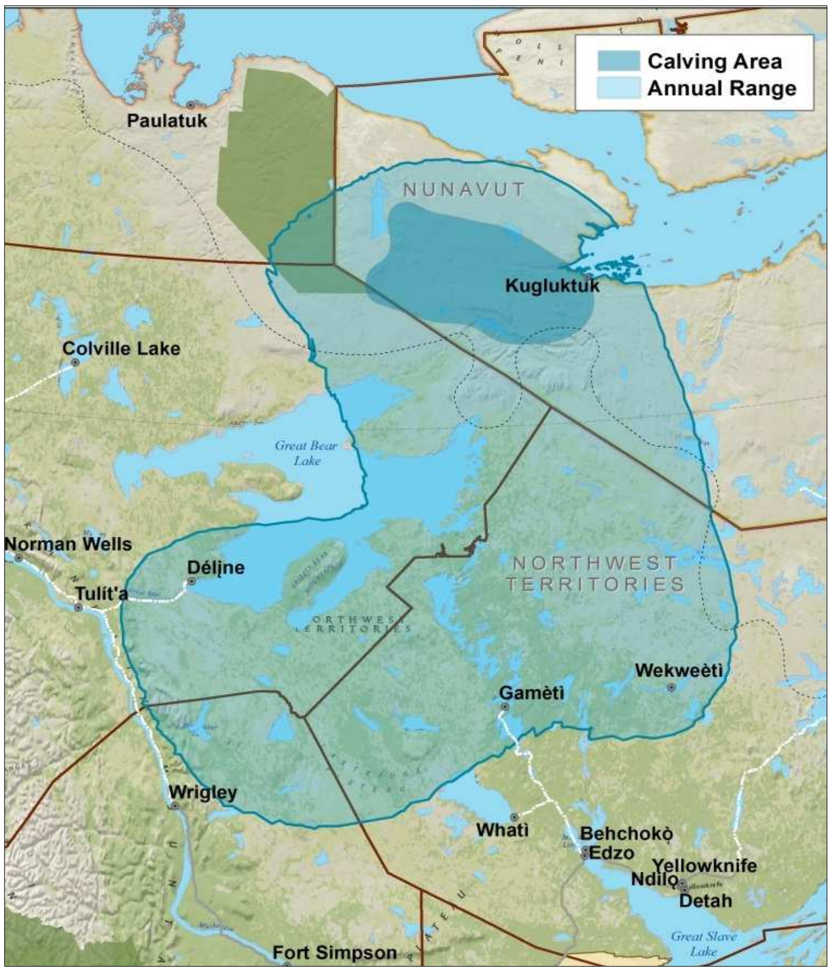

Figure 1: Annual range and extent of calving for the Bluenose-East herd, 1996-2009, based on accumulated radio collar locations of cows (Nagy et al. 2011). The calving area and a portion of the summer range are in Nunavut (NU) and the rest of the range is in the Northwest Territories (NWT).

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.

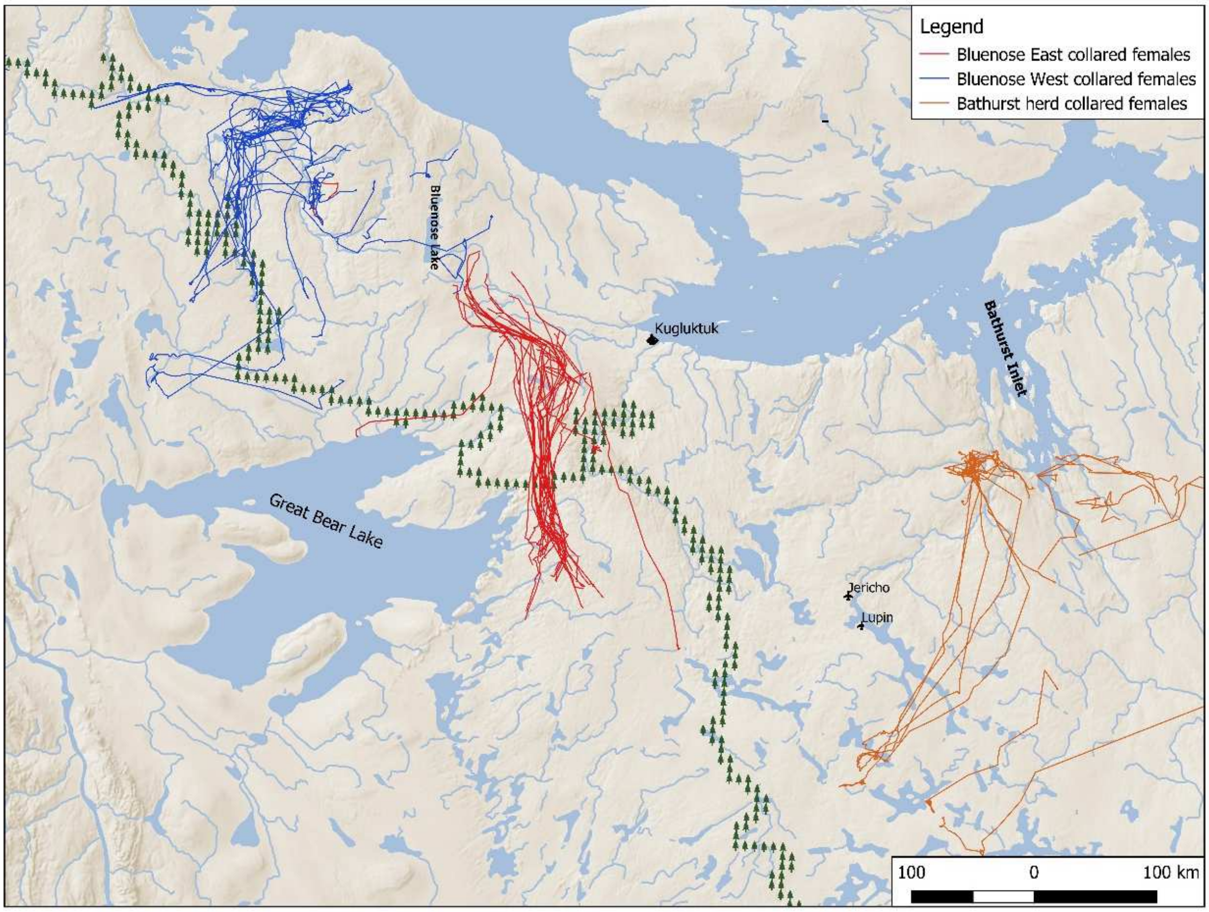

Figure 2: Spring migration paths of satellite collared Bluenose-West (blue), Bluenose-East (red) and Bathurst (orange) cows from May 15 - June 8, 2018.

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).

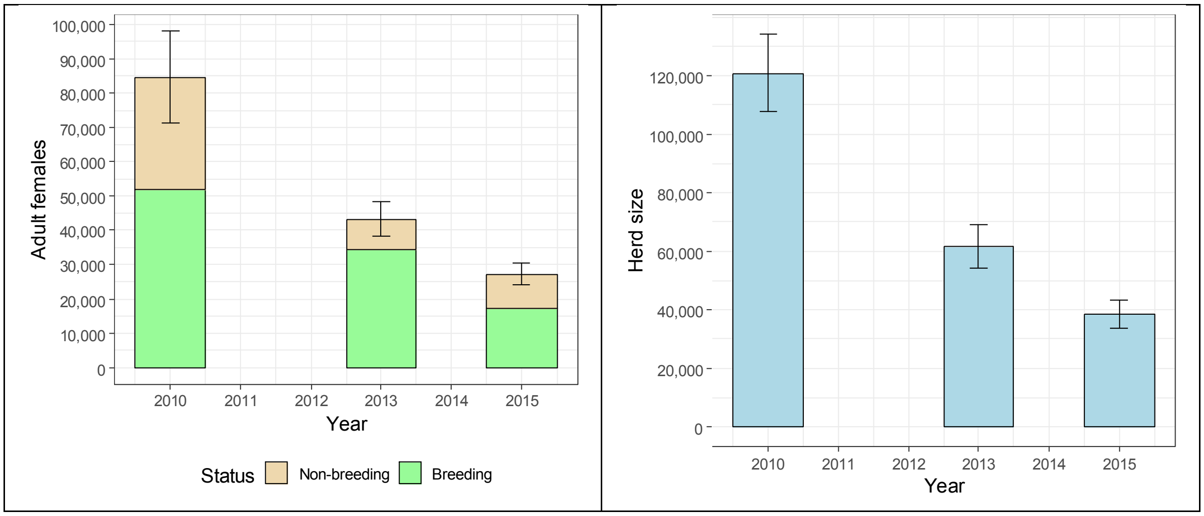

Figure 3: Estimates of adult females (subdivided by breeding status) on the left and extrapolated herd size on the right, from 2010, 2013, and 2015 calving ground surveys of the Bluenose-East caribou herd.

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. >~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 km strip width x 10 km = 8 km^2). The segment was classified as a “breeder” segment if at least one breeding female caribou (or newborn calf) was identified. Segments were then displayed spatially and used to delineate strata within the annual concentrated calving area based on the composition and density of the segments. During the survey, daily weather briefings were provided by Dr. Max Dupilka (Beaumont, AB) to assess current and future survey conditions.

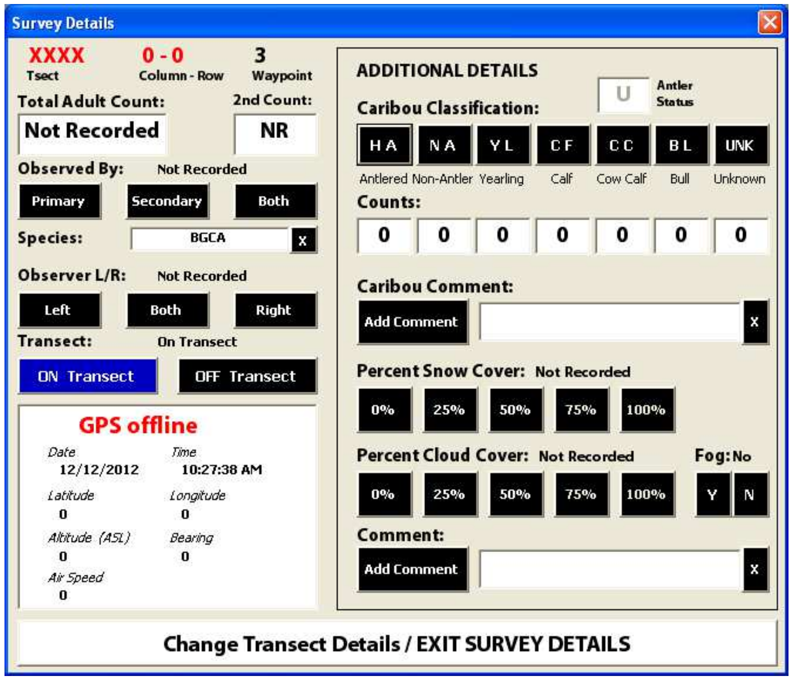

Figure 4: The tablet data entry screen used during reconnaissance and visual survey flying on Bathurst and Bluenose-East June surveys in 2018. A GPS waypoint was obtained for each observation, allowing efficient entry and management of survey data. In addition, the unique segment unit number was also 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 ($\widehat{N}$: 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 ($\overline{D}$) of caribou observed within the strata ($\widehat{N} = \overline{D}A$) where density is estimated as the sum of all caribou counted on transect divided by the total area of transect sampling ($\overline{D}$=caribou counted/total transect area). An equivalent estimate of mean density can be derived by first estimating transect-specific densities of caribou ($\widehat{D}_i = caribou_i/area_i$) where $caribou_i$ is the number of caribou counted in each transect and $area_i$ is the transect area (as estimated by transect length X strip width). Each transect density is then weighted by the relative length of each transect line (w_i) to estimate mean density ($\overline{D}$) for the stratum. More exactly, $\overline{D} = \sum_i^n \widehat{D}_i w_i / \sum_i^n w_i$ where the weight (w_i) is the ratio of the length of each transect line (l_i) i to the mean length of all transect lines($w_i = l_i/\overline{l_i}$.) and n is the total number of transects sampled. Using this weighting term accommodates for different lengths of transect lines within the stratum, ensuring that each transect line contributed to the estimate in proportion to its length. Population size is then estimated using the standard formula ($\widehat{N} = \overline{D}A$) (Norton-Griffiths 1978).

When survey aircraft first flew north to Kugluktuk on June 1, snow cover on the survey area was 90 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 (c-hat) was estimated as the ratio of the bootstrapped (photo-based) and simple binomial variance. Sightability-corrected estimates of caribou were then generated as the original estimate of caribou on each stratum divided by the photo sightability estimate for the stratum. The delta method (Buckland et al. 1993) was used to estimate variance for the final estimate, thus accounting for variance in the original stratum estimate and in the sightability estimate.

Visual Surveys 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.

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

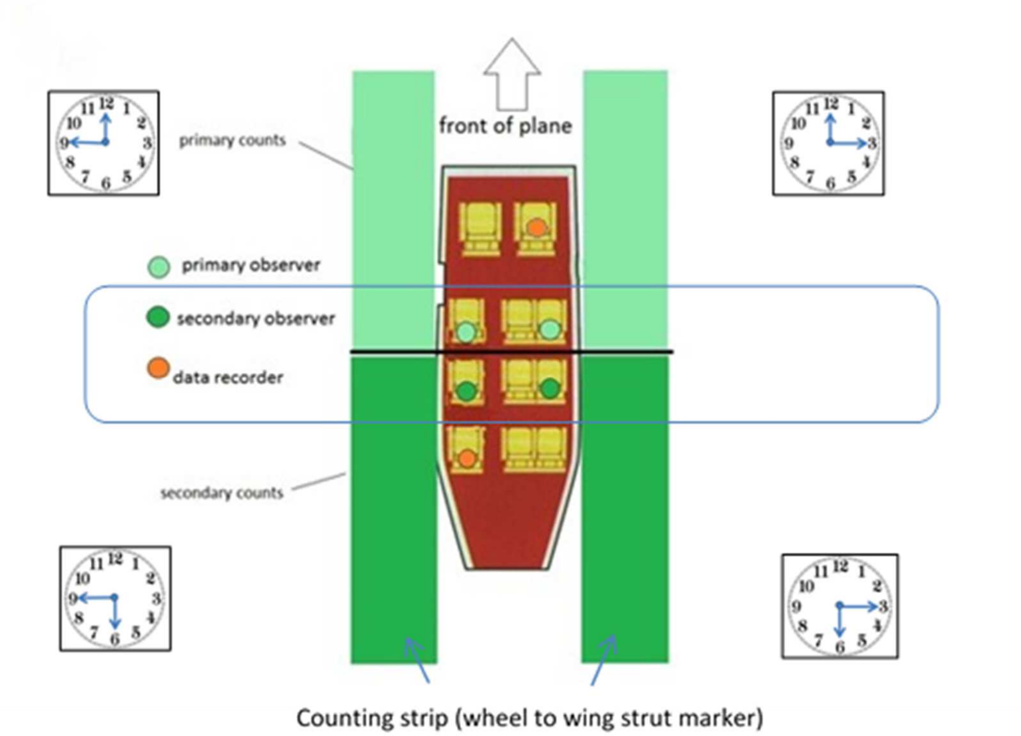

Figure 5: Observer and recorder positions for double observer methods on June 2018 caribou survey of Bluenose-East caribou. The secondary observer confirmed or called caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock 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 ~<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.

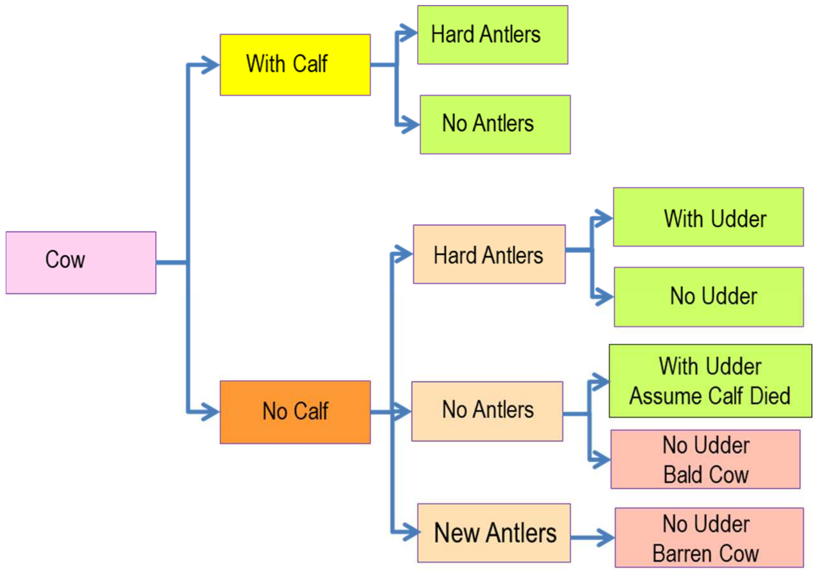

Figure 6: Classification of breeding females used in composition survey of Bluenose-East caribou in June 2018. Shaded boxes were classified as breeding females (diagram adapted from Gunn et al. (2005b)). Udder observation refers to a distended udder in a cow that has given birth, and antler observation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

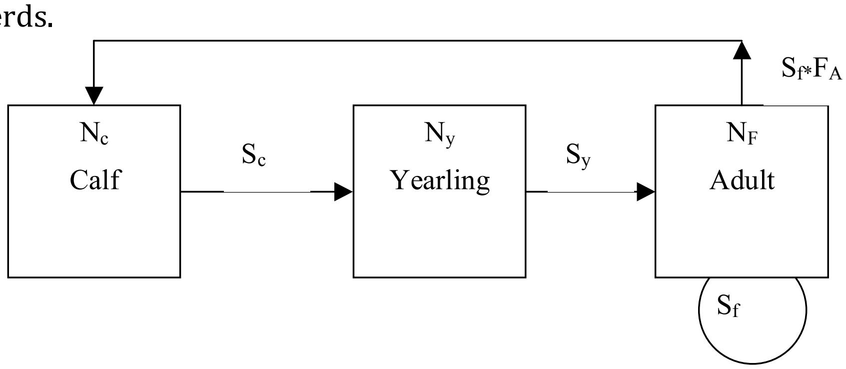

Figure 7: Underlying stage matrix life history diagram for the caribou demographic model used for Bluenose-East and Bathurst caribou. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected 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	**Survey Years**							
Born	**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.

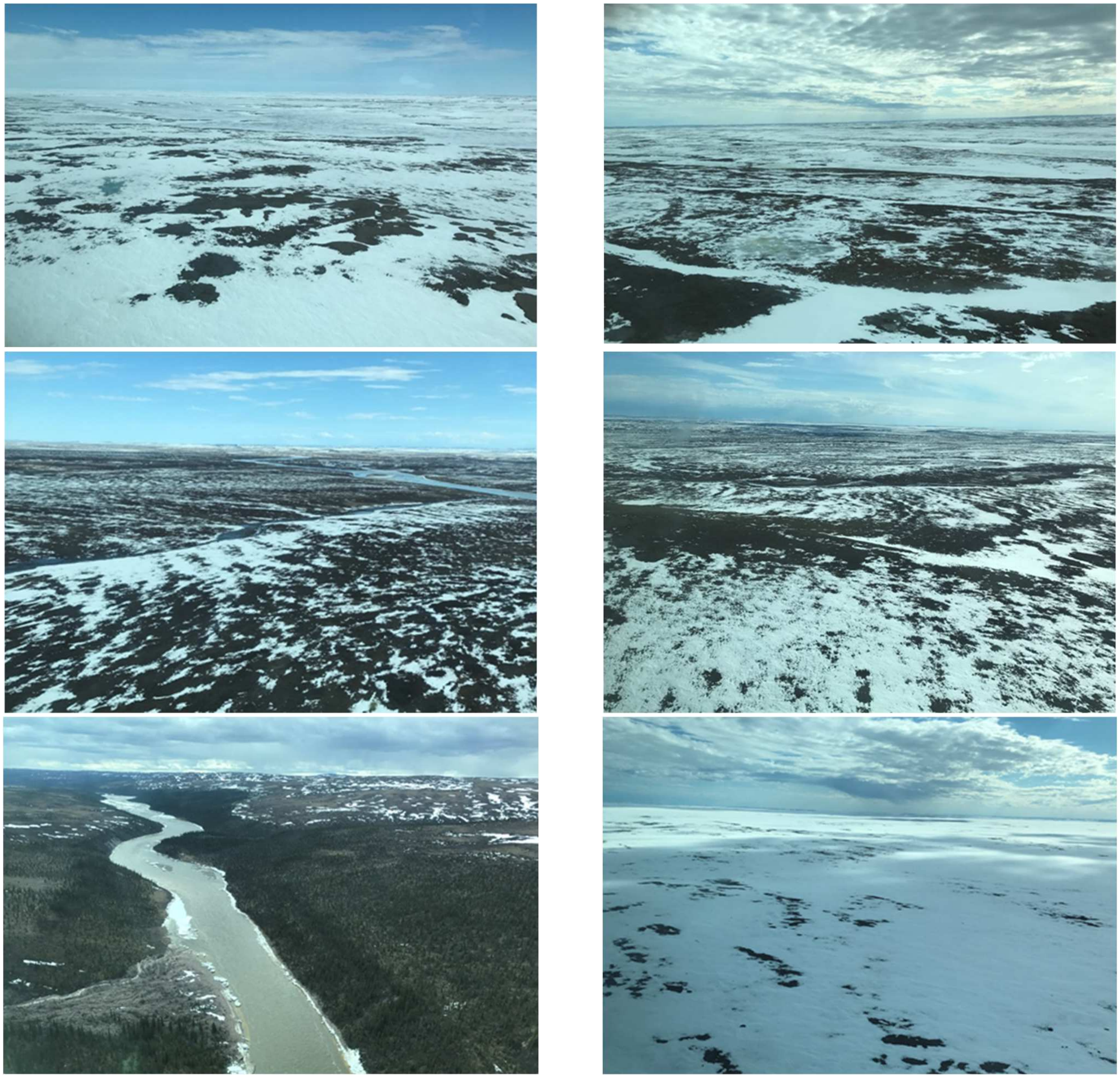

Figure 8: Photos of variable Bluenose-East survey conditions on June 8, 2018 when the visual and photo surveys were conducted (photos J. Adamczewski). Snow cover ranged from 95 percent or more at the north end near Bluenose Lake (bottom right) to nearly bare ground near the Coppermine River (bottom left).

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.

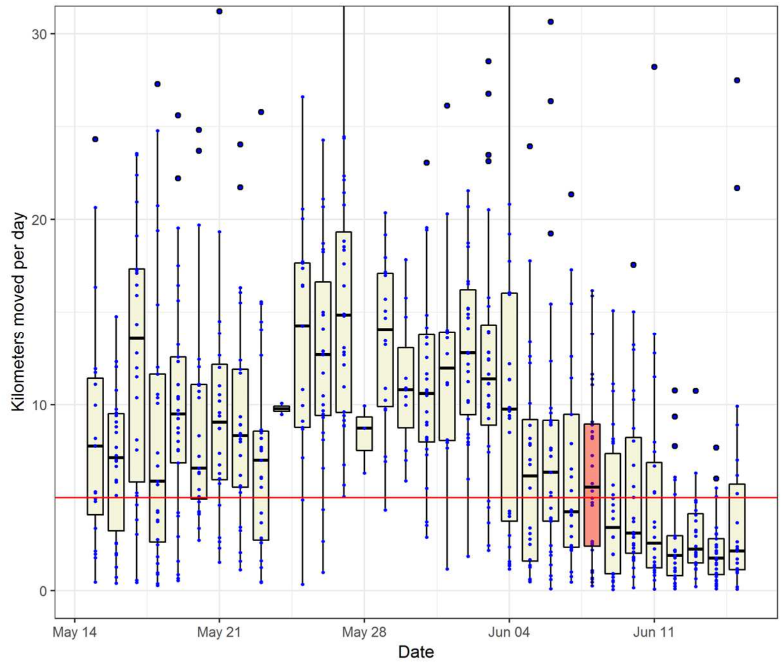

Figure 9: Movement rates of female collared caribou on or around the Bluenose-East calving ground before and during calving in 2018. The boxplots contain the 25th and 75th percentile of the data with the median shown by the central bar in each plot. The ranges up to the 95th percentile are depicted by 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).

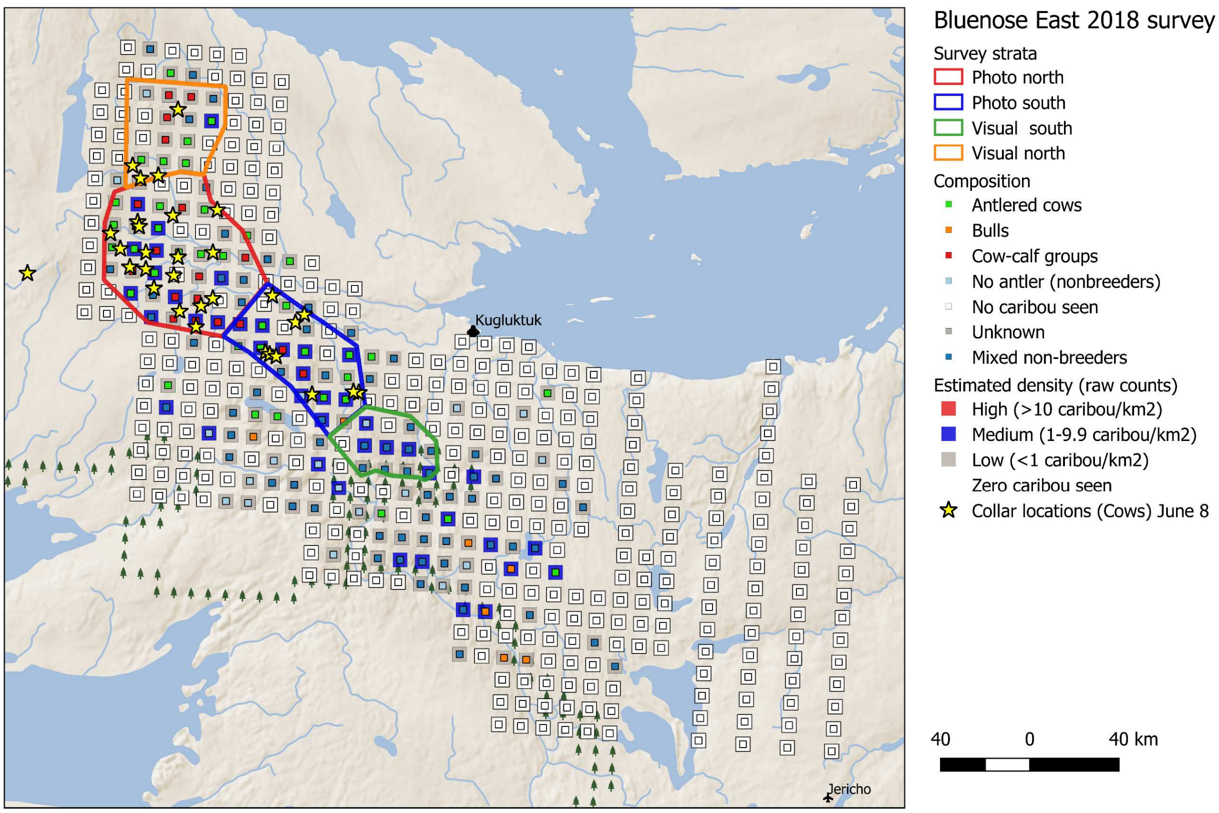

Figure 10: Reconnaissance survey coverage for the June 2018 Bluenose-East calving ground survey. The two photo blocks are shown in red and blue outlines and the two visual blocks are shown to the north and south in orange and green. Outer squares show density of the caribou found (high, medium and low), 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.

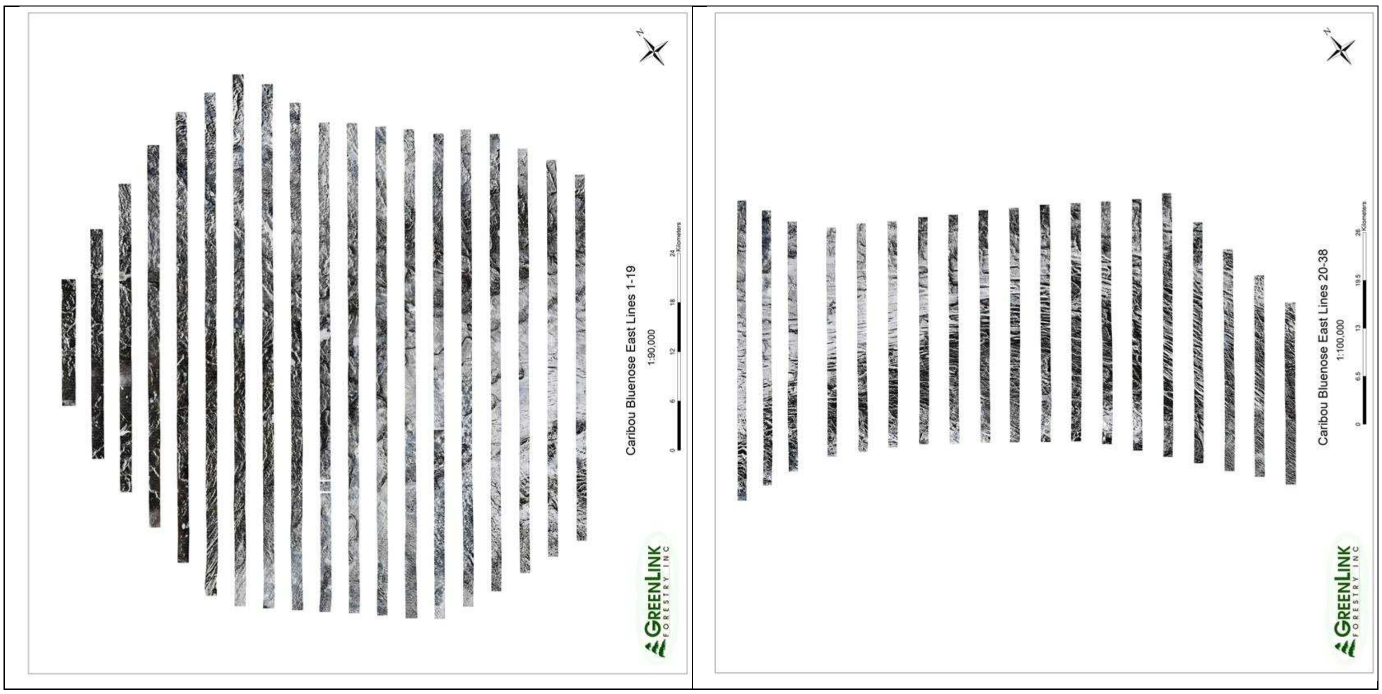

Figure 11: Composite photos of the Bluenose-East North and South photo strata.

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.

	Stratum Dimensions				Approximate No. of Photos at GSD				Estimated % Coverage at GSD			
Strata	Stratum Area (km^2)	Average Transect Length (km)	No. Transects	Total Transect Length (km)	5	6	7	8	5	6	7	8
Bathurst	1,159	35.0	15	525	2,389	2,003	**<u>1,715</u>**	1,458	40%	48%	**<u>56%</u>**	74%
Bluenose-East												
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).

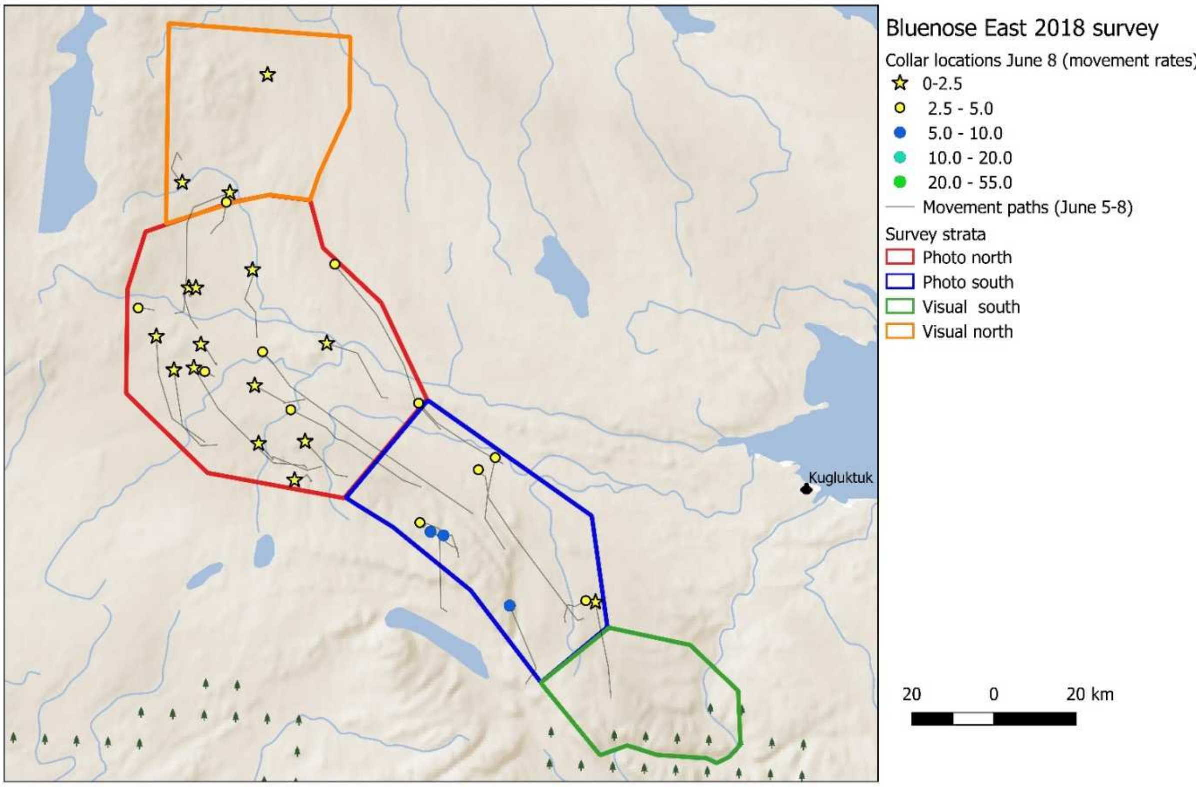

Figure 12: Locations of collared Bluenose-East female caribou and movements up to and during June 8, 2018 when the photo and visual surveys occurred.

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.

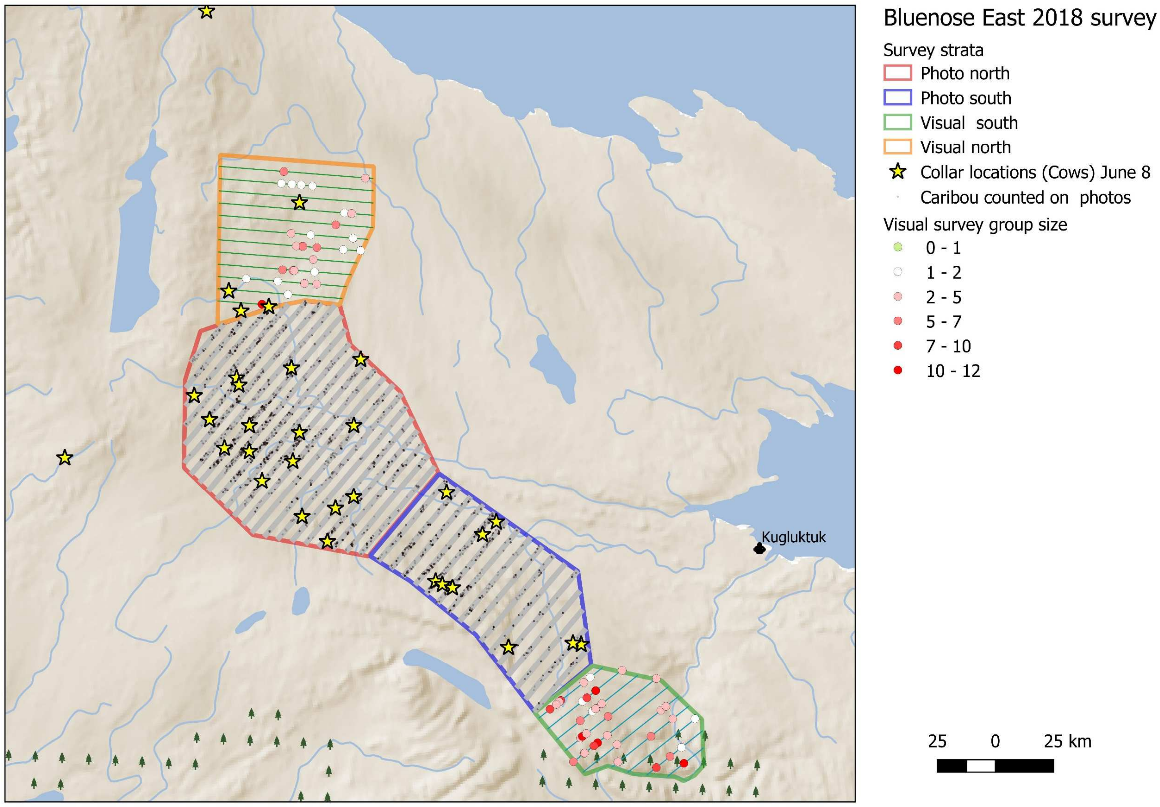

Figure 13: A plot of the Bluenose-East photo data counts and visual survey results with collar locations on June 8, 2018 when surveys occurred. Collared caribou south and north of Bluenose Lake were Bluenose-West females.

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).

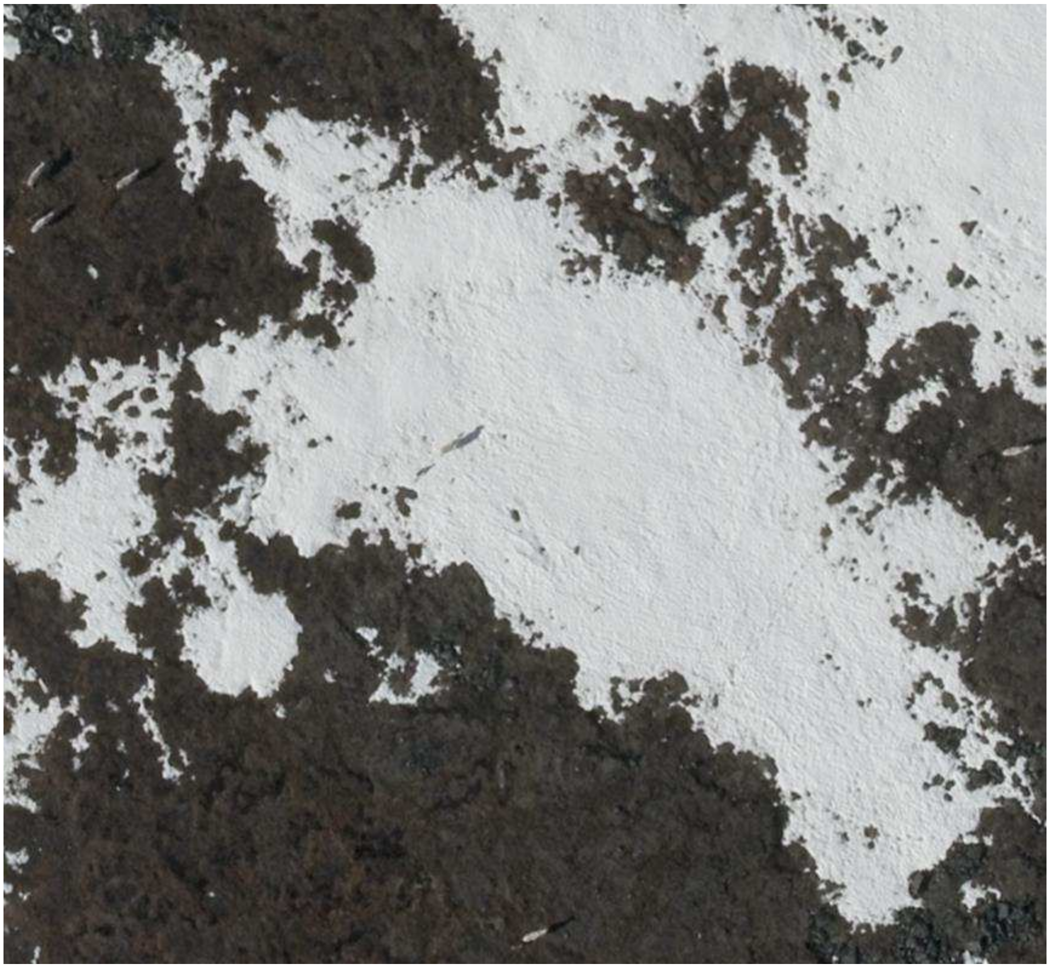

Figure 14: Close-up view of one zoomed-in portion of an aerial photo on Bluenose-East survey on June 8, 2018. Among others, three caribou are visible in the upper left corner, and a cow and calf can be seen walking (along with their shadows) across the snow-patch in the middle of the photo. Caribou in 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).

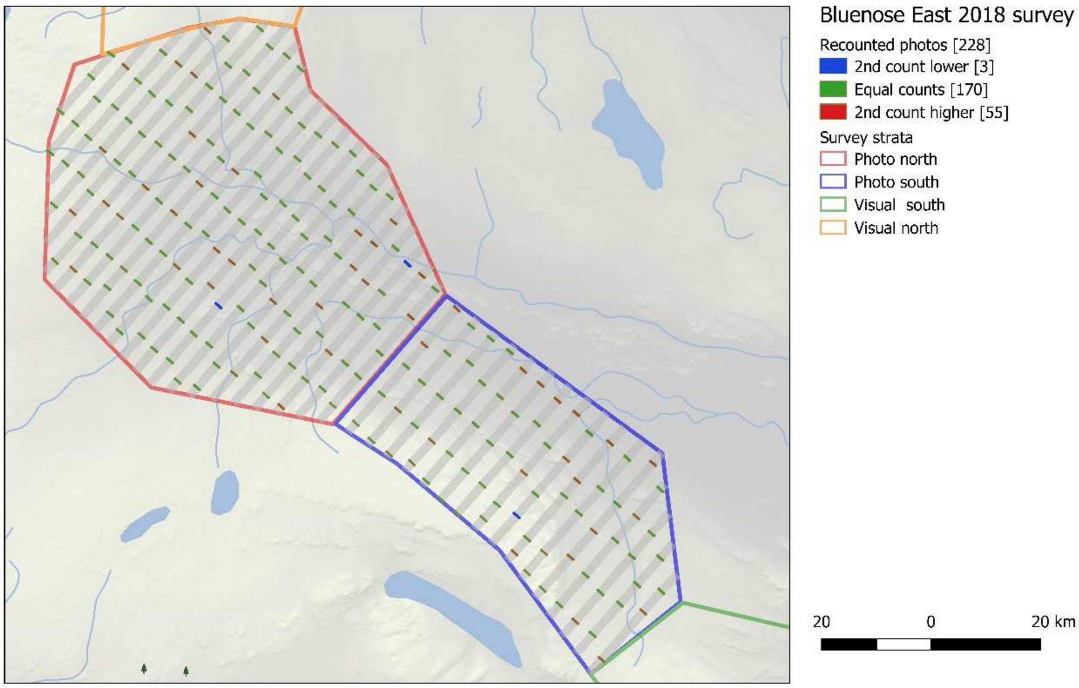

Figure 15: Systematic sampling design for cross validation of photos for the Bluenose-East June 2018 calving ground survey.

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 $\Delta QAIC_c$, the model weight (w_i), number of parameters (K) and quasi-Deviance (QDeviance) is given.

Model		**Model Selection**				
First Count	**Second Count**	**$QAIC_c$**	**$\Delta QAIC_c$**	**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)**	
1st count-North stratum	0.912	0.013	0.014	0.015	0.016	0.884	0.941
1st count -South stratum	0.853	0.020	0.024	0.035	0.040	0.782	0.919
2nd 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).

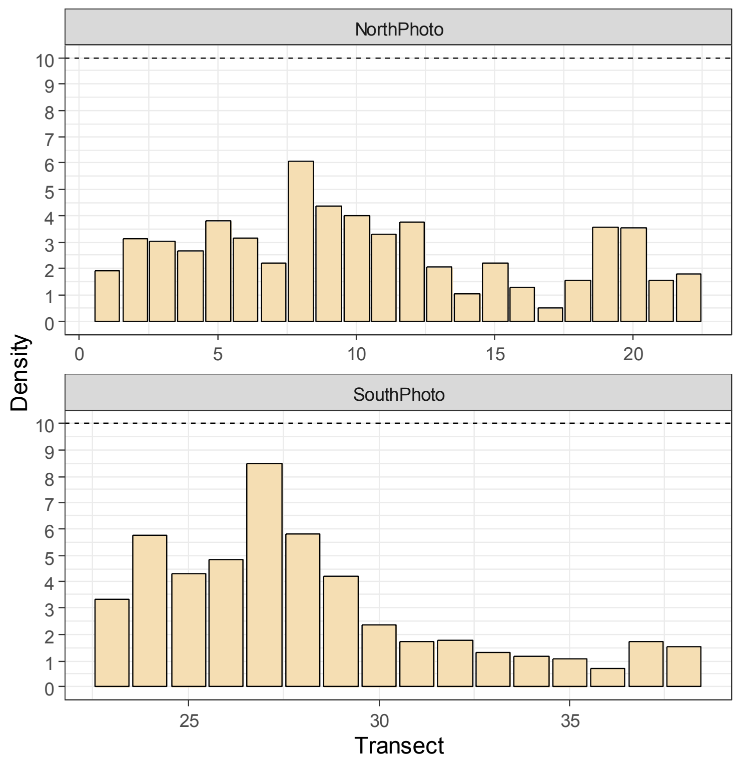

Figure 16: Transect-specific densities for the Bluenose-East photo blocks in June 2018. Transects go from west to east. Sightability was accounted for in density estimates.

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.

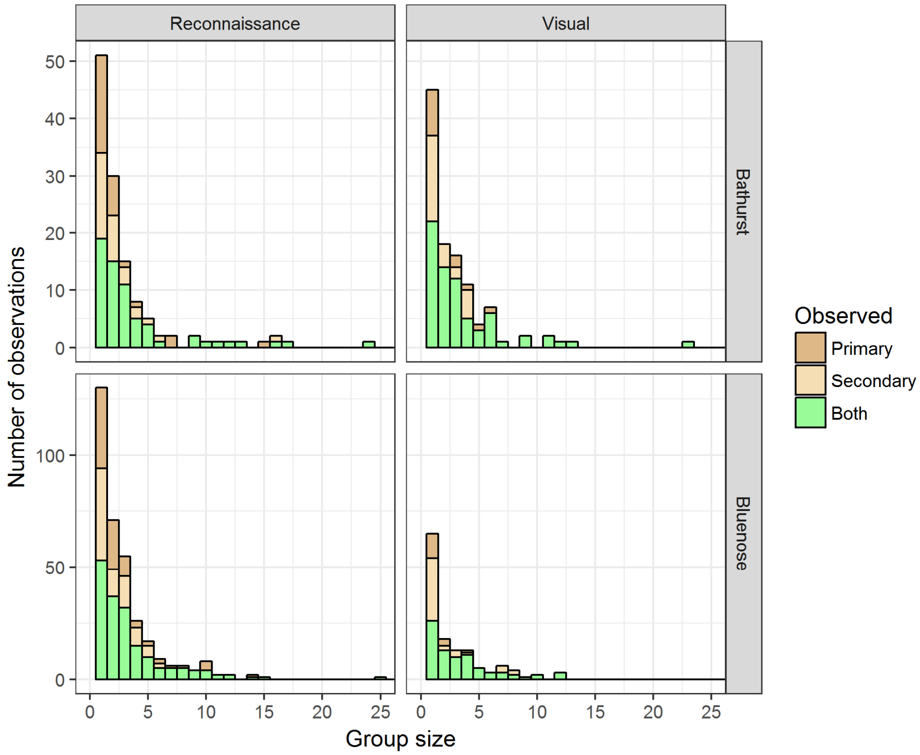

Figure 17: Frequencies of double observer observations by group size, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary (brown), secondary (beige), or both (green) observers.

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.

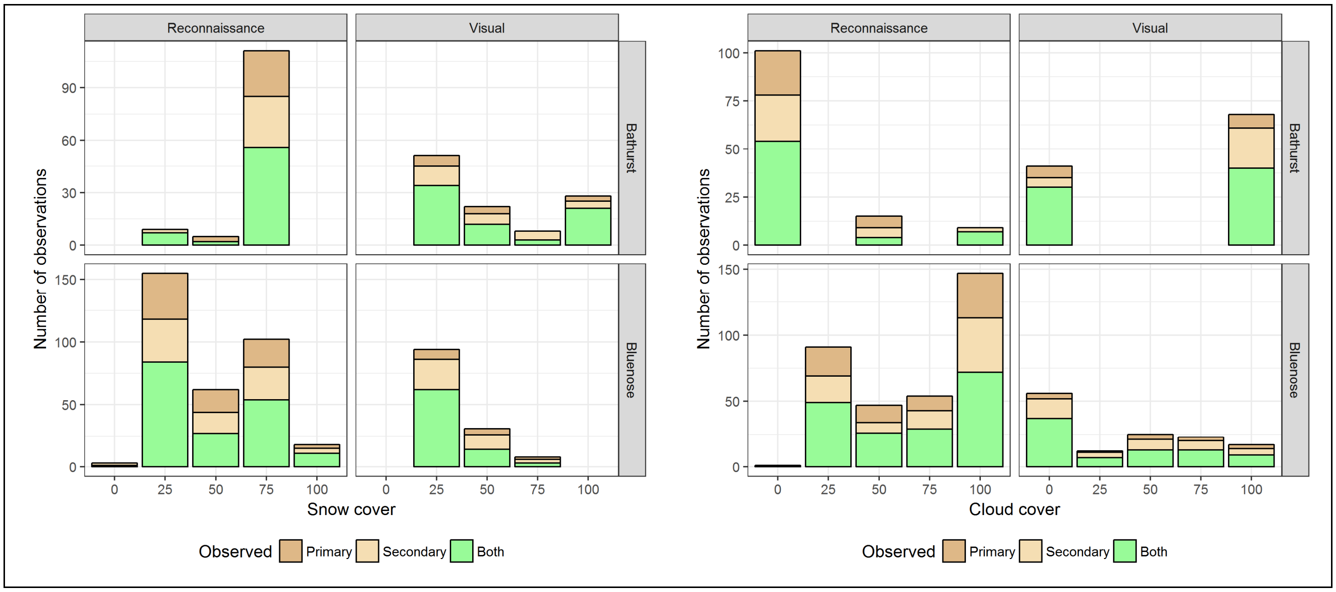

Figure 18: Frequencies of double observer observations by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation was categorized by whether it was observed by the primary, secondary, or both observers.

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.

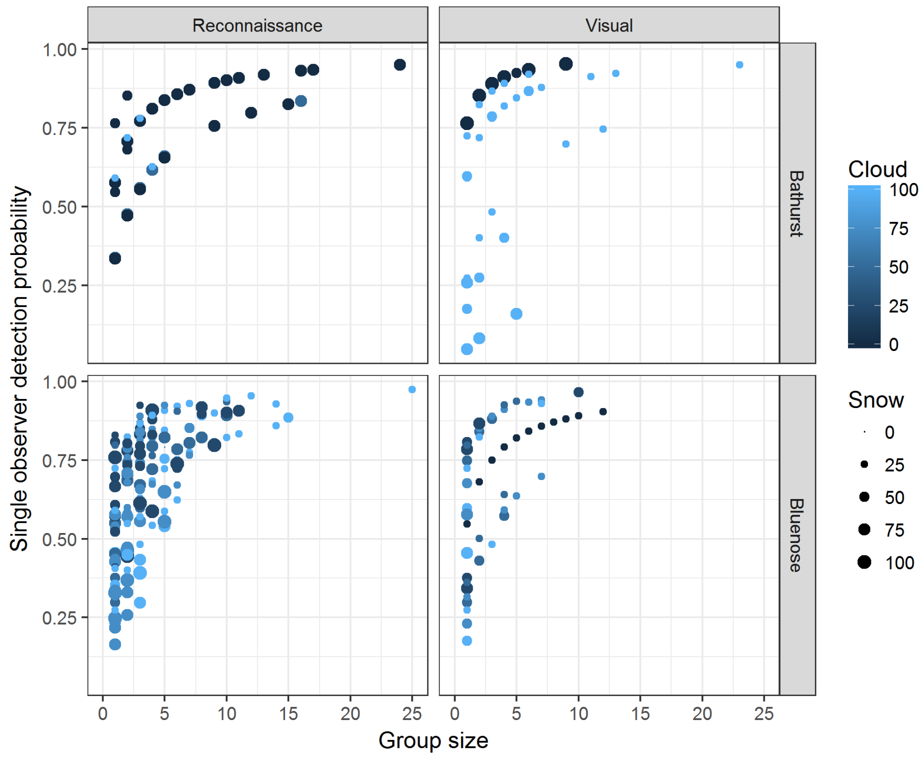

Figure 19: Estimated single observer probabilities from model 1 (Table 12) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

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).

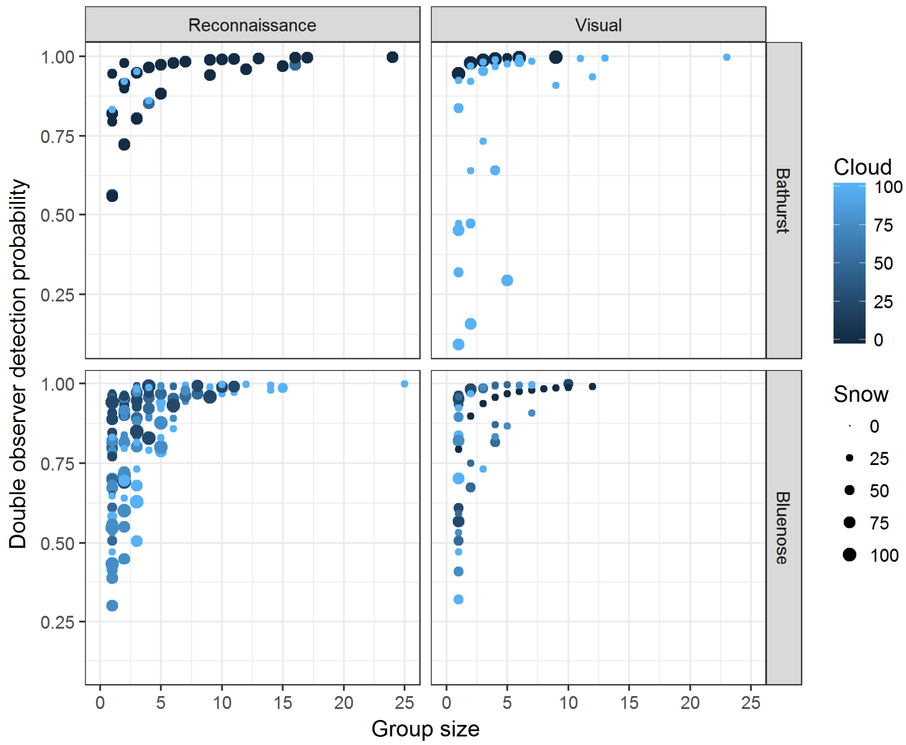

Figure 20: Estimated double observer probabilities from model 1 (Table 12) by snow cover, cloud cover, survey phase and survey for Bluenose-East and Bathurst June 2018 caribou surveys. Each observation is categorized by whether it was observed by the primary, secondary, or both observers.

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.

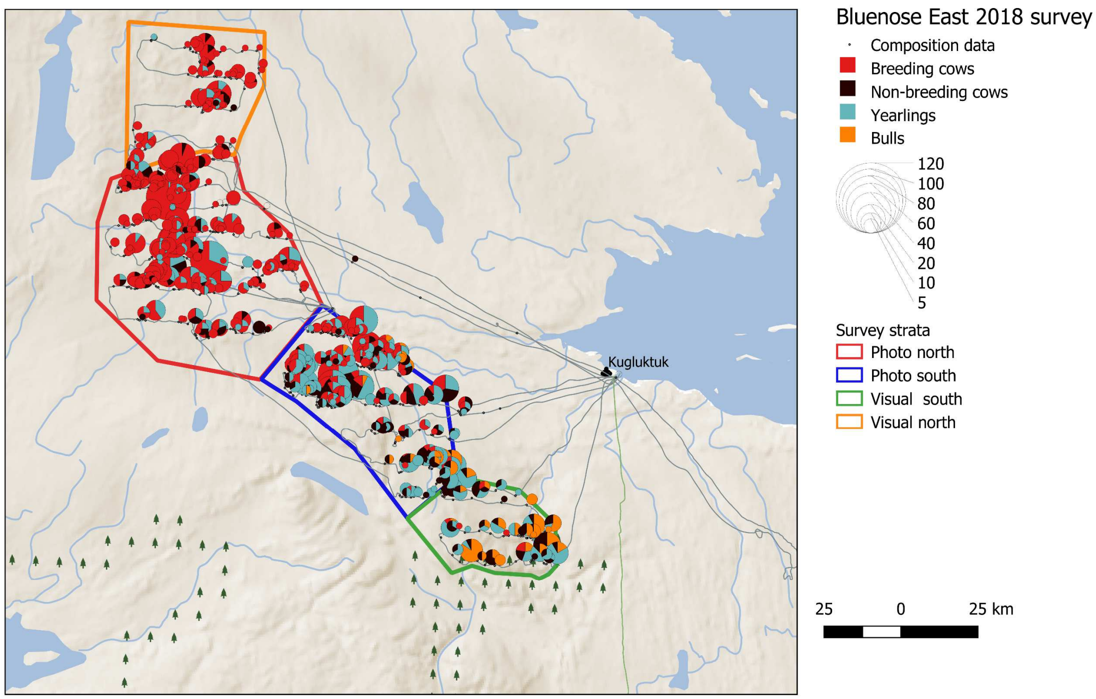

Figure 21: Helicopter flight paths and pie charts of groups classified during calving ground composition survey of Bluenose-East caribou in 2018. The size of pie charts is proportional to the number of caribou in each classification group as indicated by the scale diagram. Proportions of age-sex classes 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	Adult Females			Yearlings	Bulls	Total Caribou (1 yr+)
		Total	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	
Breeding females=breeding females/caribou 1 yr+				
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
Adult females=Adult females/caribou 1 yr+				
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.

	Proportion Cows					Bull-cow Ratio			
Year	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 ± 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 ($t=-3.9$, $df=47$, $p=0.002$).

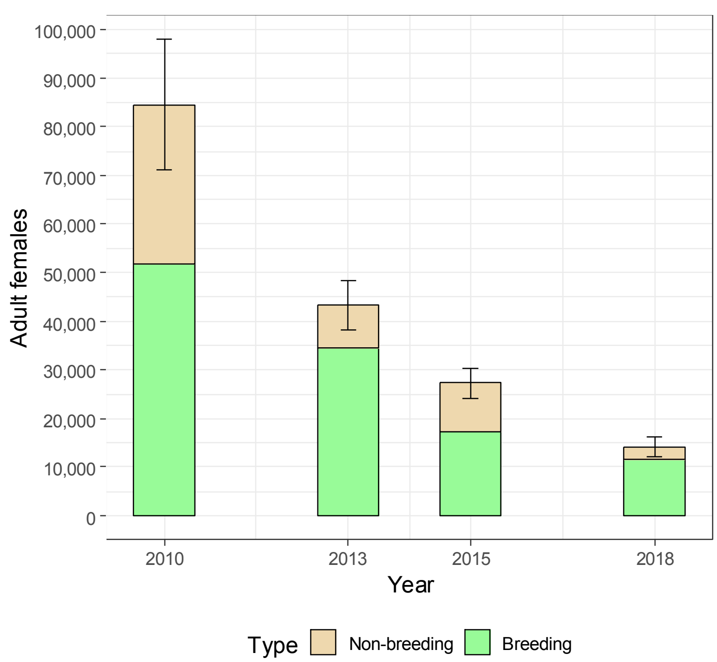

Figure 22: Estimates of total adult females in the Bluenose-East herd from 2010-2018 dichotomized shown by breeding and non-breeding females status from 2010-2018.

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 λ) 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).

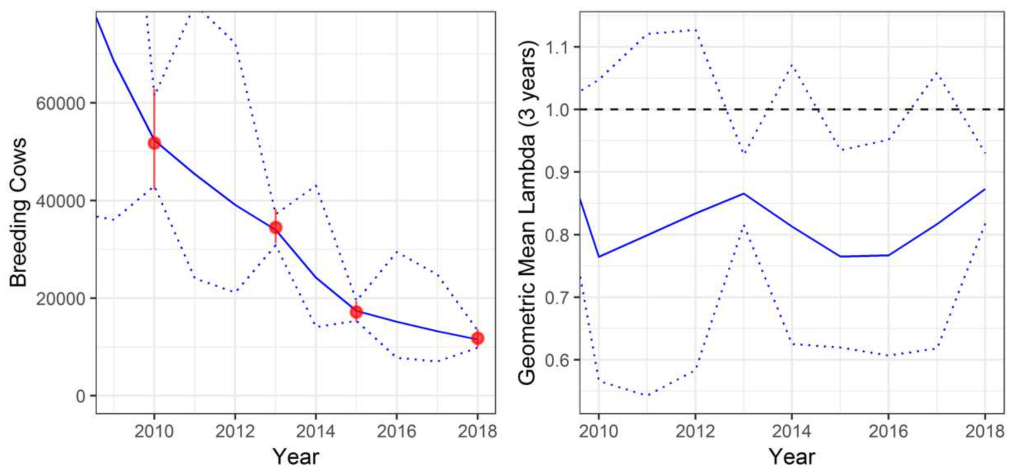

Figure 23: Estimates of breeding cows and λ (geometric mean of three previous years) in the Bluenose-East herd 2010-2018 from Bayesian state space model analysis.

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).

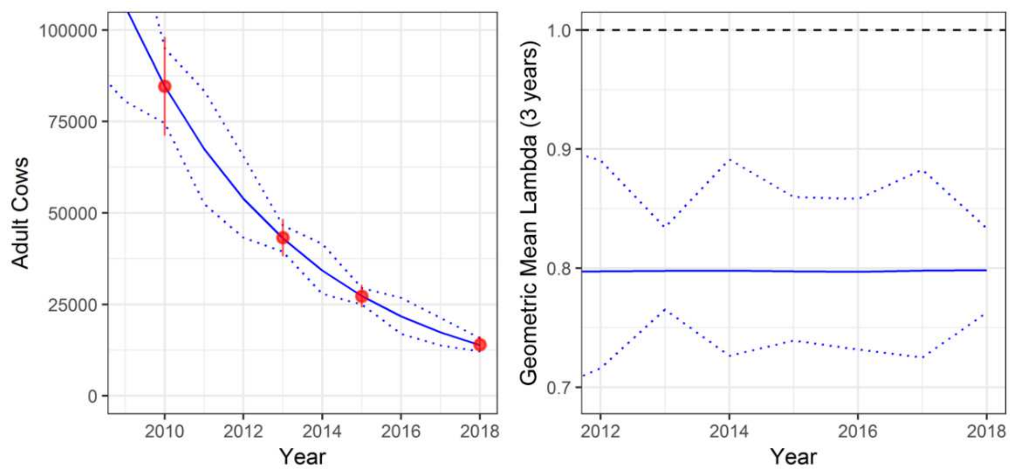

Figure 24: Estimates of adult cows and λ (geometric mean of three previous years) in the Bluenose-East herd 2010-2018 from state space model analysis.

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

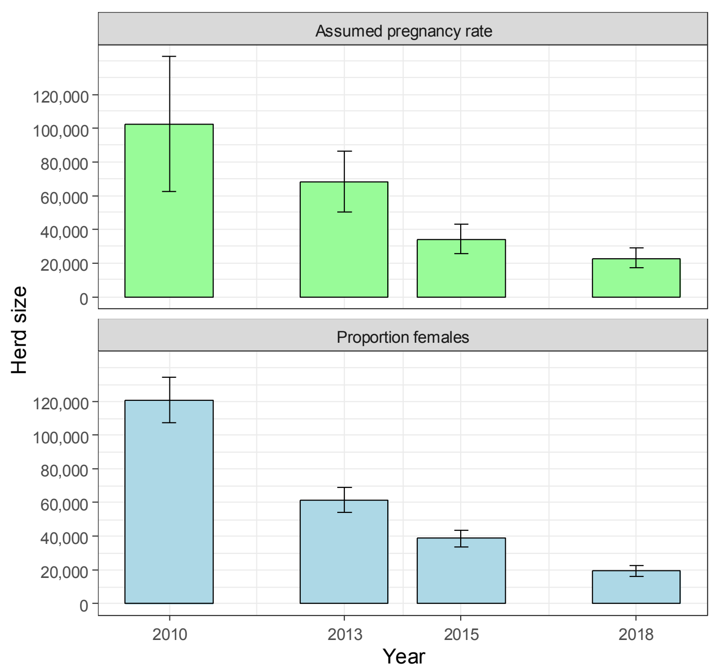

Figure 25: Estimates of Bluenose-East herd size (adults at least two years old) using the constant pregnancy rate of 0.72 and proportion of females method from 2010-2018. We suggest the estimates based on proportion of females (bottom) are more reliable.

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.

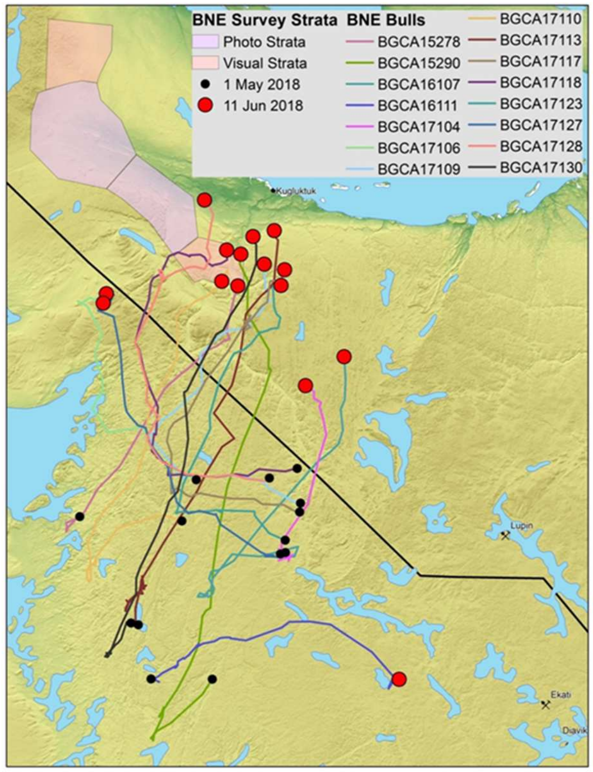

Figure 26: Spring movements (May 1 - June 11) of 15 Bluenose-East collared bulls in 2018 in relation to the survey area. Most bulls were concentrated at the south end of the survey area and some were scattered far to the south.

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.

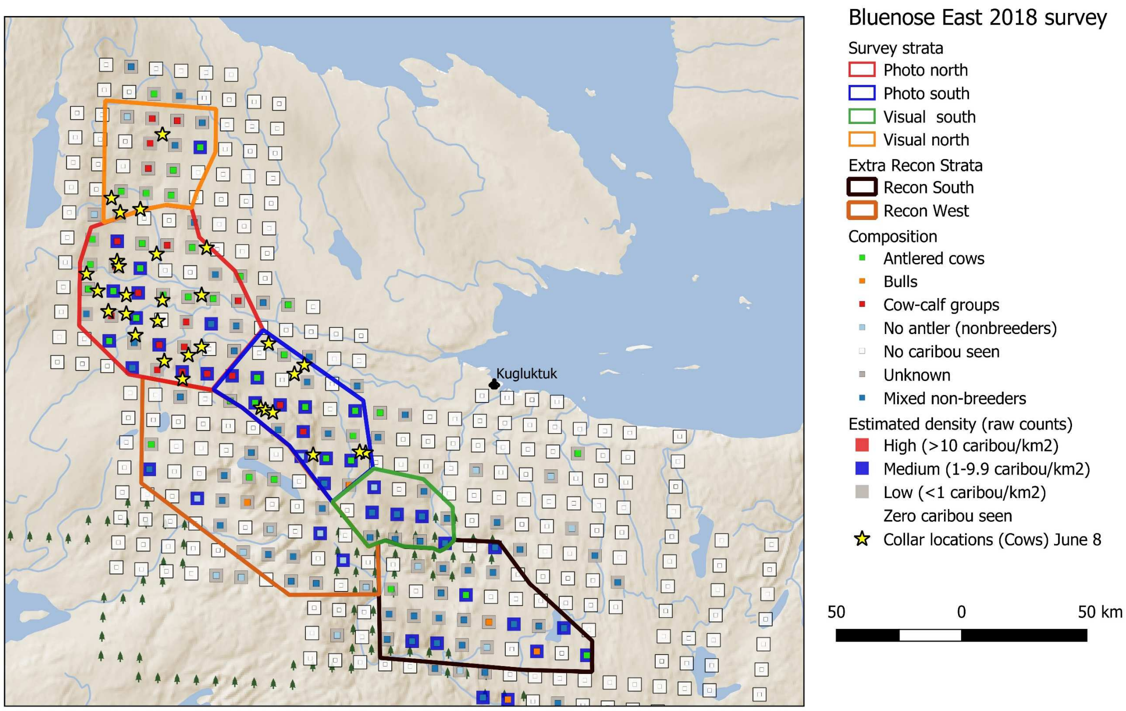

Figure 27: Bluenose-East June 2018 survey area with extra (post-hoc) reconnaissance-based strata at bottom in black and brown outlines.

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.

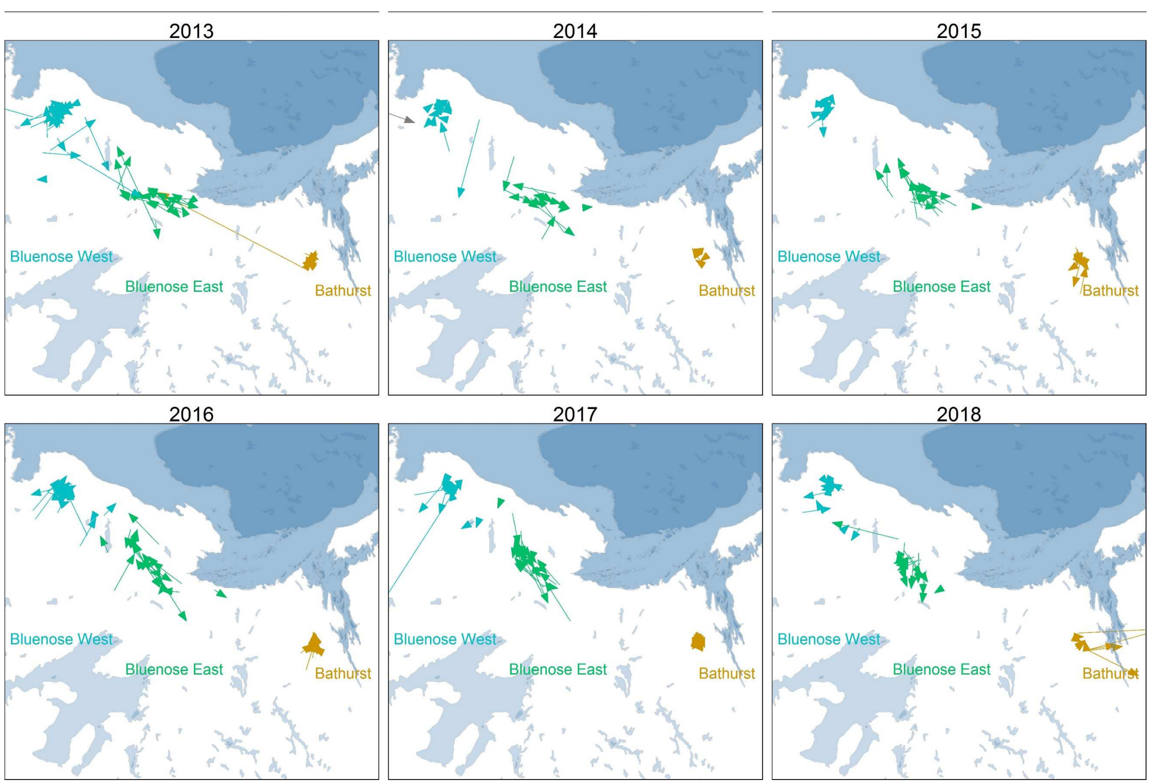

Figure 28: Yearly fidelity and movements to calving grounds in the Bluenose-West, Bluenose-East and Bathurst herds 2013-2018. The head of the arrow indicates the current calving ground in the given year and the tail indicates the mean location from the previous year calving ground.

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 2015-2018. 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.

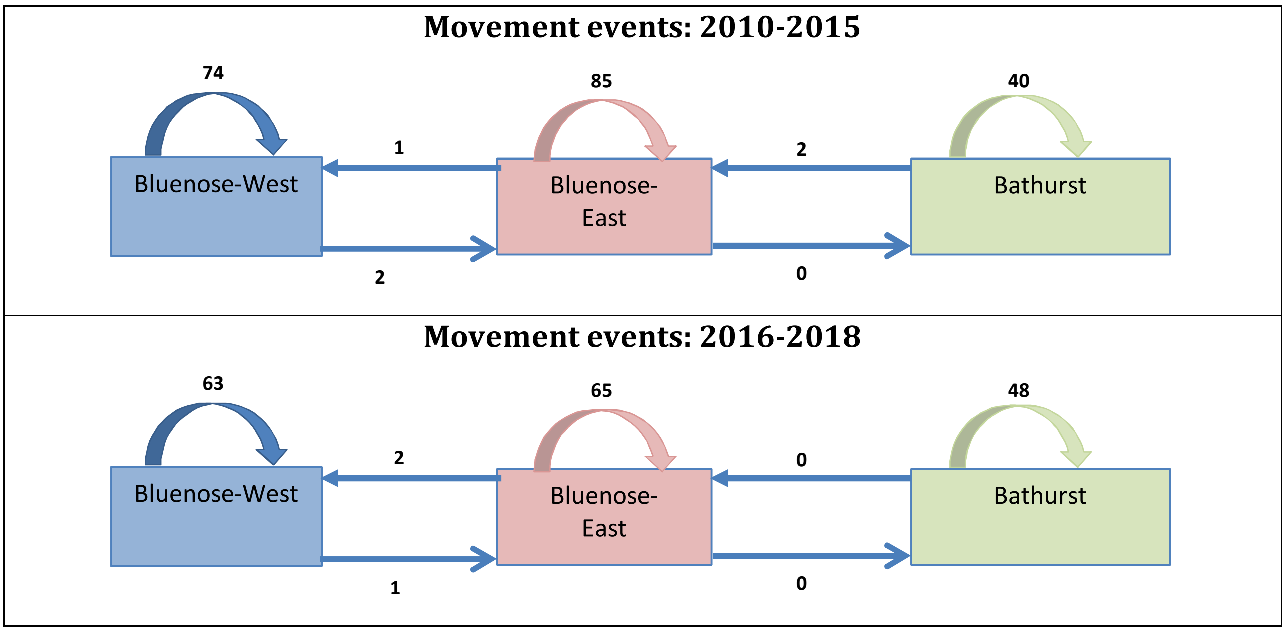

Figure 29: Frequencies of caribou movement events for the Bluenose-East and neighbouring Bluenose-West and Bathurst herds from 2010-2015 and 2016-2018 based on consecutive June locations of collared females on calving grounds. The curved arrows above the boxes indicated the number of times a caribou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

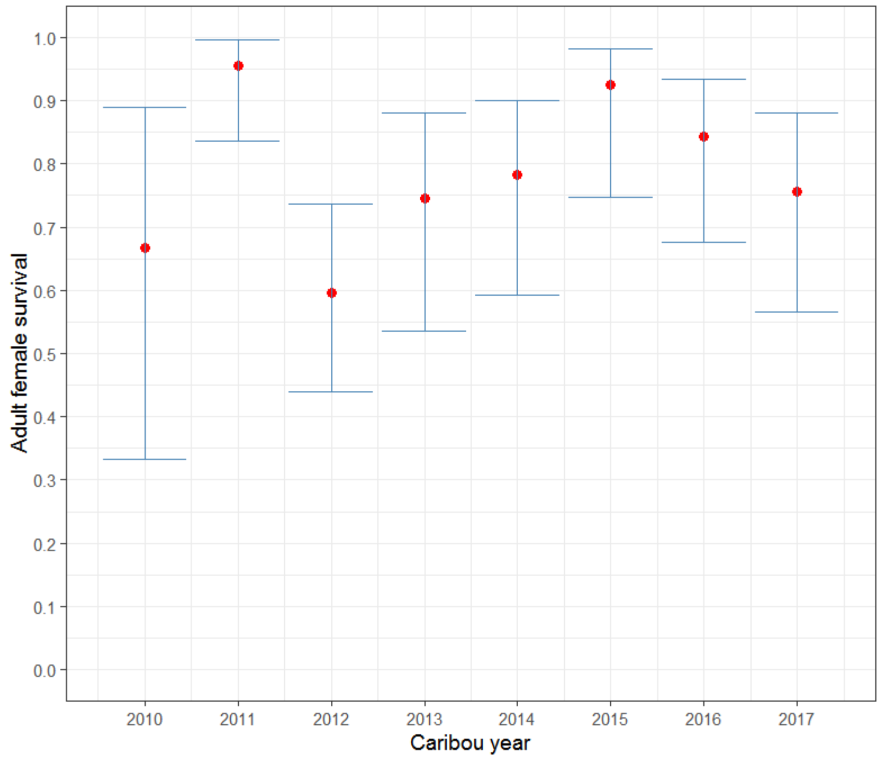

Figure 31: Annual Kaplan-Meier estimates of survival from collared Bluenose-East female caribou for caribou years 2010-2017, based on collar data in Table 24.

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.

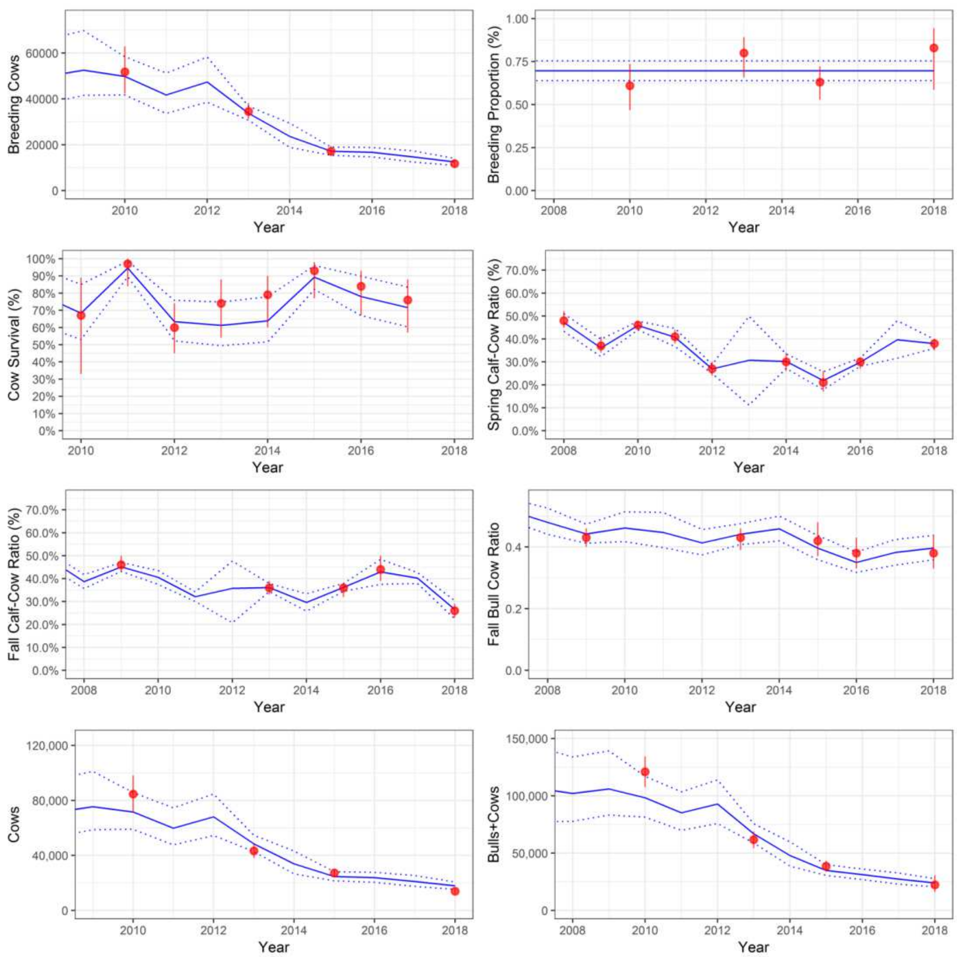

Figure 32: Predictions of demographic indicators from Bayesian IPM analysis compared to observed values, for Bluenose-East herd 2010-2018. The solid blue lines represent model predictions and confidence limits are shown as hashed blue lines. The red points are field estimates with associated confidence 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.

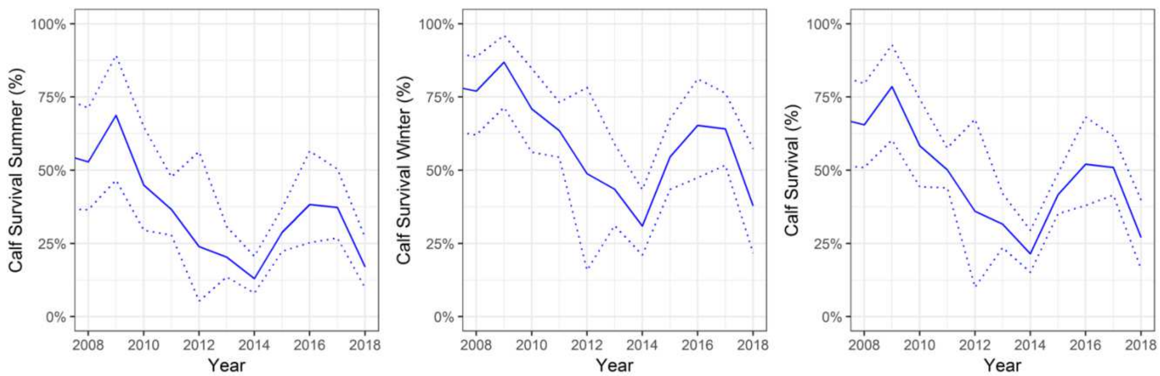

Figure 33: Trends in summer and winter and overall calf survival for the Bluenose-East herd 2010-2018 from the IPM analysis.

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.

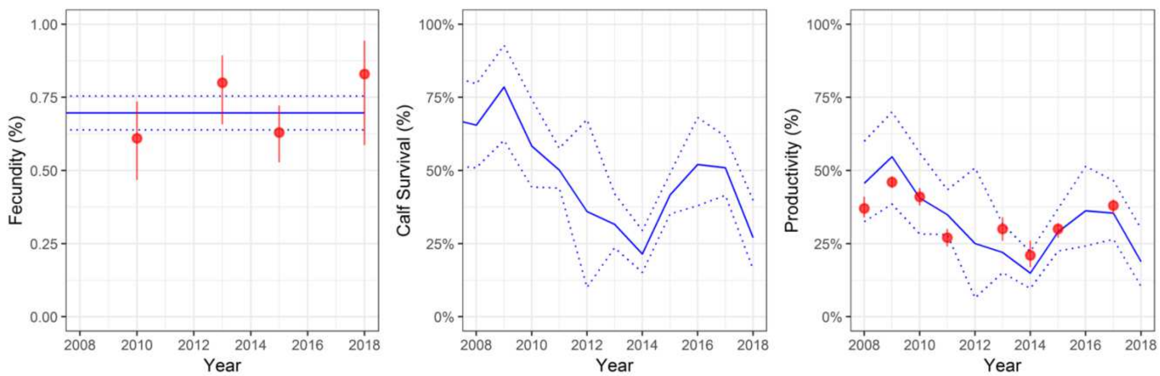

Figure 34: Trends in fecundity, calf survival and productivity (which is the product of the previous year's fecundity times the current year calf survival) for Bluenose-East herd 2010-2018. Spring calf cow ratios, which are lagged by one year (so that they correspond to the productivity/caribou year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

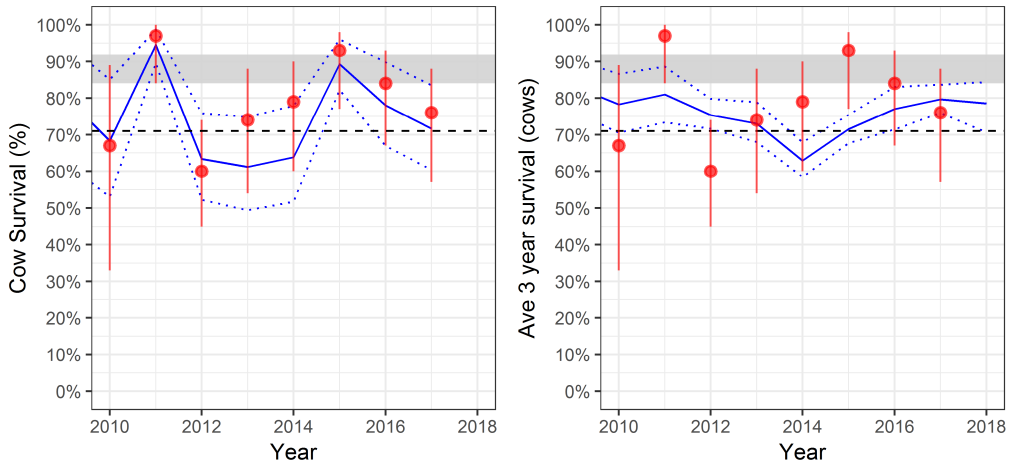

Figure 35: Trends in Bluenose-East cow survival 2010-2018 from IPM analysis. The solid blue lines represent model predictions and confidence limits are the hashed blue lines. The right graph represents a three-year moving average. The red points are field estimates from collars with associated Confidence 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.

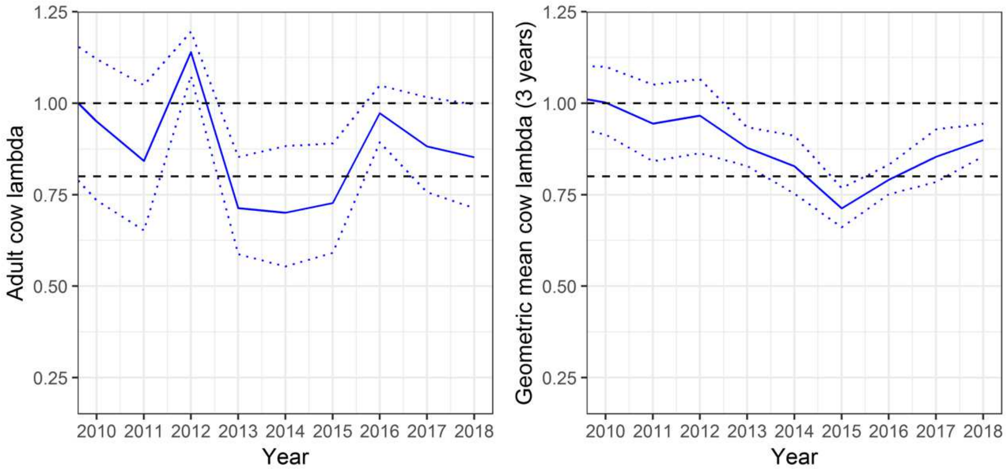

Figure 36: Overall trends in Bluenose-East adult female trend (λ) 2010-2018 from the IPM analysis. A value of 1.0 indicates stability.

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 Délı̨nę (*Belare Wíle Gots'ç Æekwç* , the Délı̨nę 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)	Délı̨nę, 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	Délı̨nę RRC	GN wildlife staff		
2017-2018	142 bulls	7 caribou	174 caribou	323caribou	Most N. Slave hunters harvested Beverly caribou in east; Délı̨nę harvest possibly boreal caribou
Source	Tłı̨chǫ Government	Délı̨nę 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, ≈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). 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 (Cows Only)	Stable Age Distribution Proportions at 2018		
	F_a*S_c	Cow (S_f)	Calf (S_c)	Bull (S_m)	Yearling (S_y)	F_a		Calves	Yearlings	Cows
High productivity (95th 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 λ=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 (λ=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.

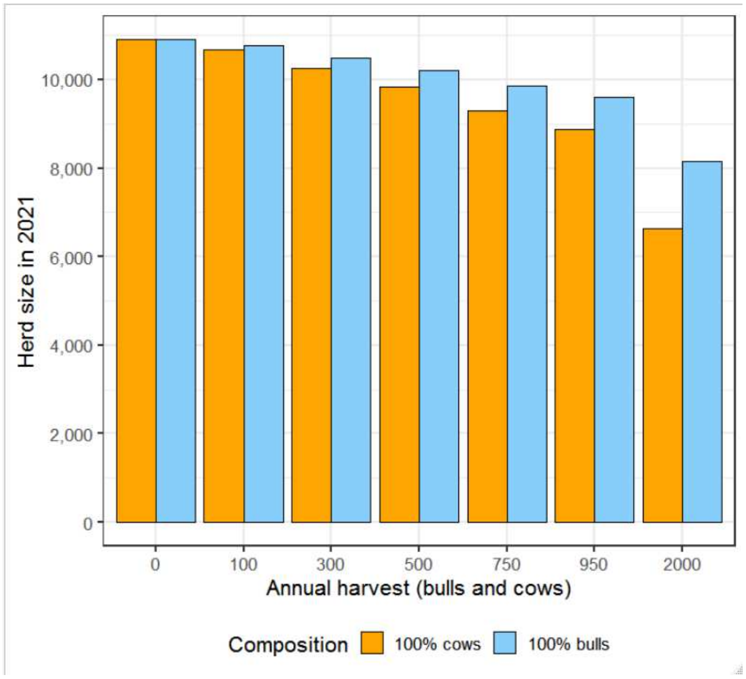

Figure 37: Projected herd size of the Bluenose-East herd in 2021 with various levels of harvest and harvest sex ratio of 100 percent bulls and 100 percent cows. Key assumptions: cow survival rate of 0.716 and average calf productivity of 0.301 (Table 27). Further simulations conducted across the range 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 6,000-8000 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 Tłı̨chǫ Boots-on-the-Ground program (Tłıçhǫ 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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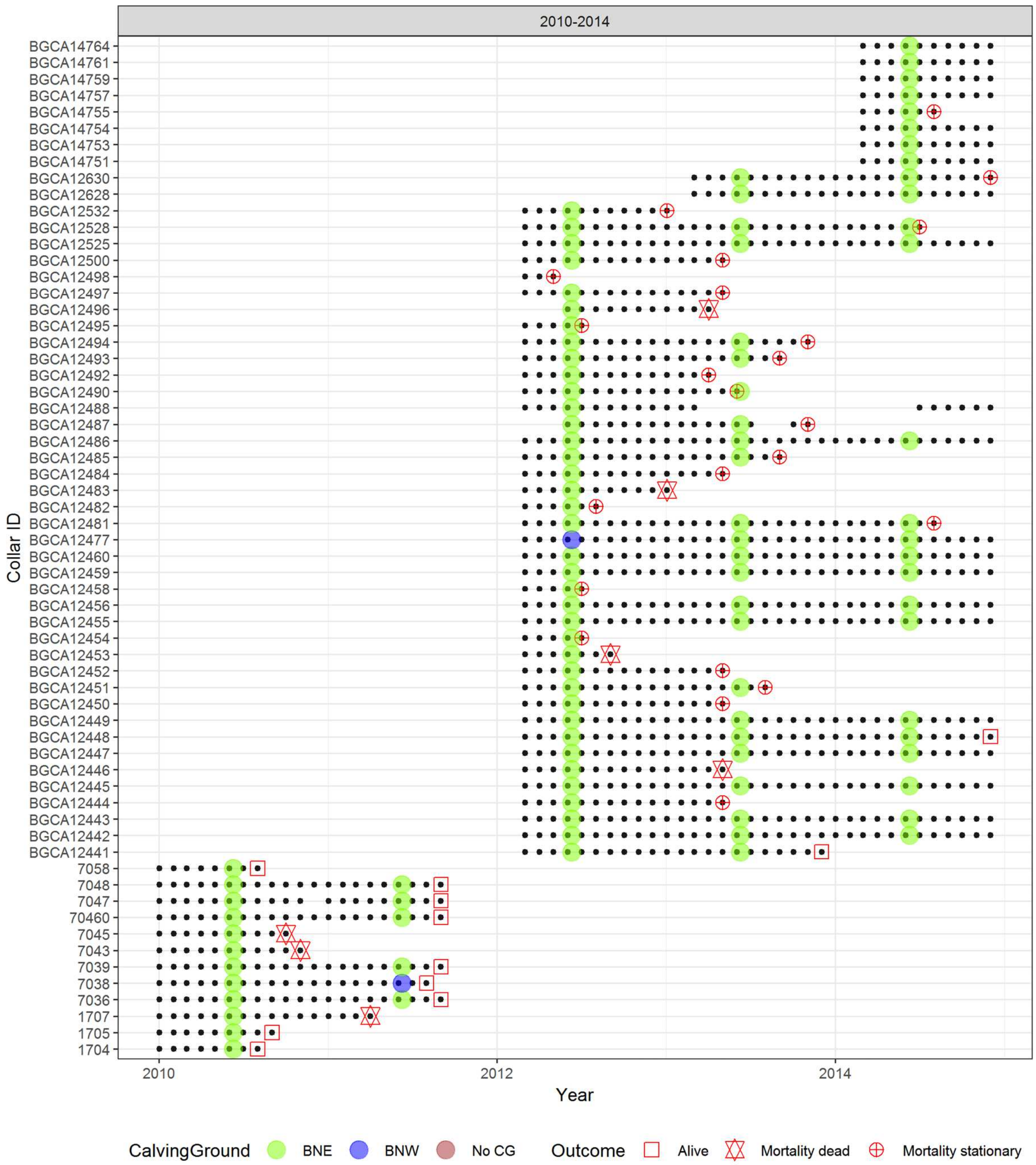
Appendix 1: Double observer visual model observer pairings

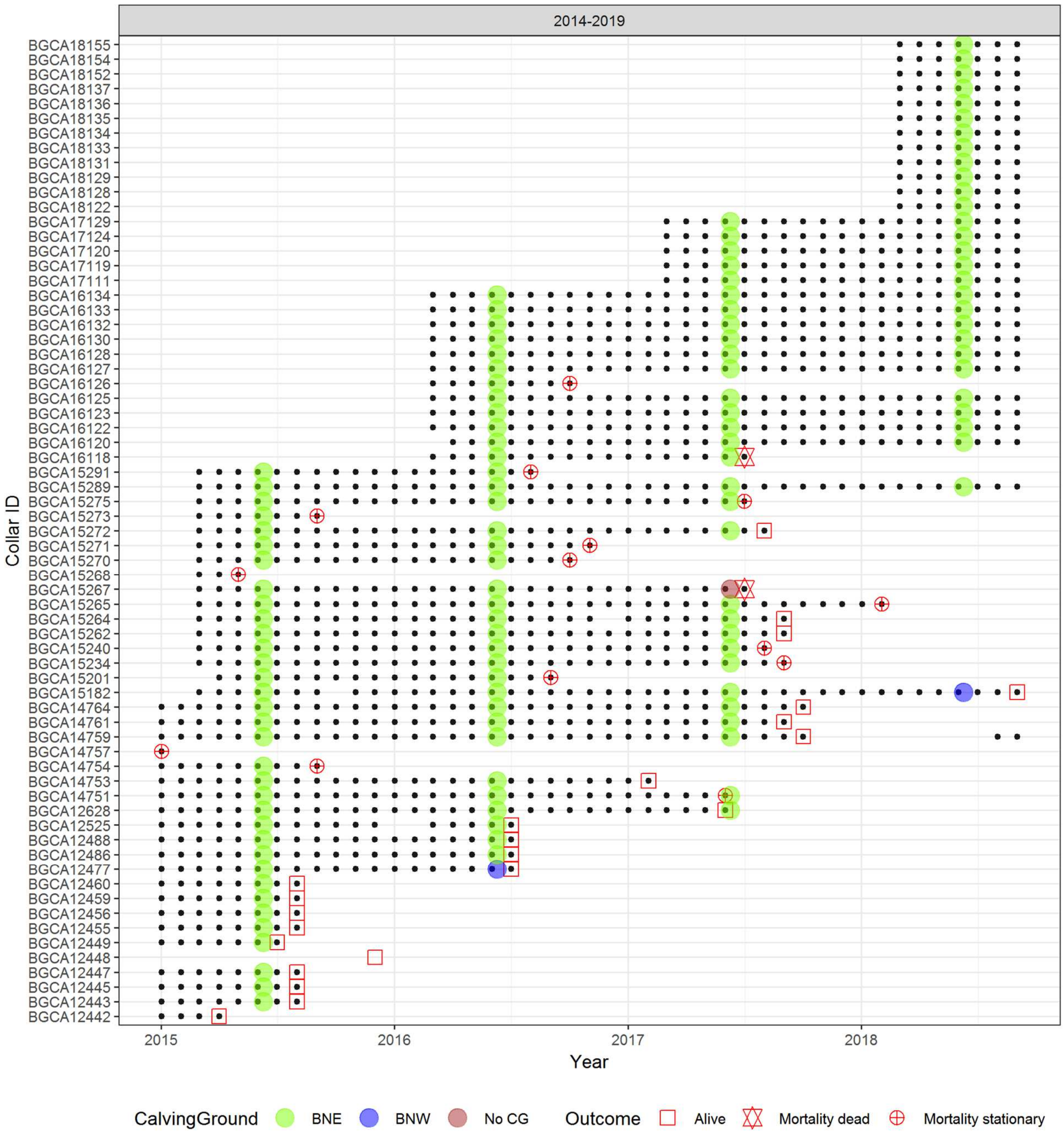
Double observer pairings with associated summary statistics.

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).





2014-2019
BGCA18155
BGCA18154
BGCA18152
BGCA18137
BGCA18136
BGCA18135
BGCA18134
BGCA18133
BGCA18131
BGCA18129
BGCA18128
BGCA18122
BGCA17129
BGCA17124
BGCA17120
BGCA17119
BGCA17111
BGCA16134
BGCA16133
BGCA16132
BGCA16130
BGCA16128
BGCA16127
BGCA16126
BGCA16125
BGCA16123
BGCA16122
BGCA16120
BGCA16118
BGCA15291
BGCA15289
BGCA15275
BGCA15273
BGCA15272
BGCA15271
BGCA15270
BGCA15268
BGCA15267
BGCA15265
BGCA15264
BGCA15262
BGCA15240
BGCA15234
BGCA15201
BGCA15182
BGCA14764
BGCA14761
BGCA14759
BGCA14757
BGCA14754
BGCA14753
BGCA14751
BGCA12628
BGCA12525
BGCA12488
BGCA12486
BGCA12477
BGCA12460
BGCA12459
BGCA12456
BGCA12455
BGCA12449
BGCA12448
BGCA12447
BGCA12445
BGCA12443
BGCA12442
Collar ID
2015
2016
2017
2018
Year
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 ≥ 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 (50^{th} percentile) of the MCMC samples, the z-score is mean/sd and the 95 percent CLs are the 2.5^{th} and 97.5^{th} 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
Main effects						
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
Random effects						
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 $i\text{-}1^{th}$ year to the i^{th} year
CowSurvivalSE[i]	The SE for CowSurvivalSE[i]
FallBullCow[i]	The data point for the bull cow ratio in the fall of the i^{th} year
FallBullCowSE[i]	The SE for FallBullCow[i]
FallCalfCow[i]	The data point for the calf cow ratio in the fall of the i^{th} year
FallCalfCowSE[i]	The SE for FallCalfCow[i]
SpringCalfCow[i]	The data point for the calf cow ratio in the spring of the i^{th} year
SpringCalfCowSE[i]	The SE for SpringCalfCow[i]
sSurvivalCalfAnnual	The SD of bSurvivalCalfAnnual
sSurvivalCowAnnual	The SD of bSurvivalCowAnnual

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).

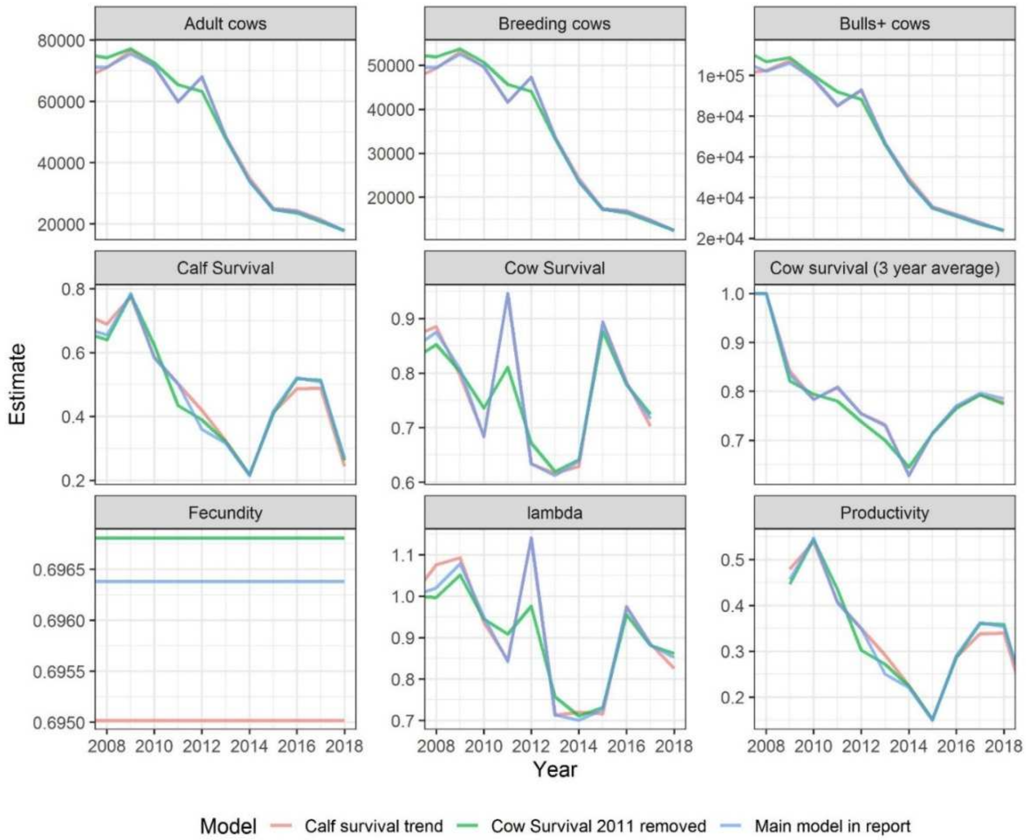


Figure 1: Comparison of model predictions of the main model used in report to a model with calf survival trends and the main model run without the 2011 collared cow survival data point.

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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 (Sf=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	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)	F_a		Calves	Yearlings	Cows
High productivity (95th 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 λ=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 (λ=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.

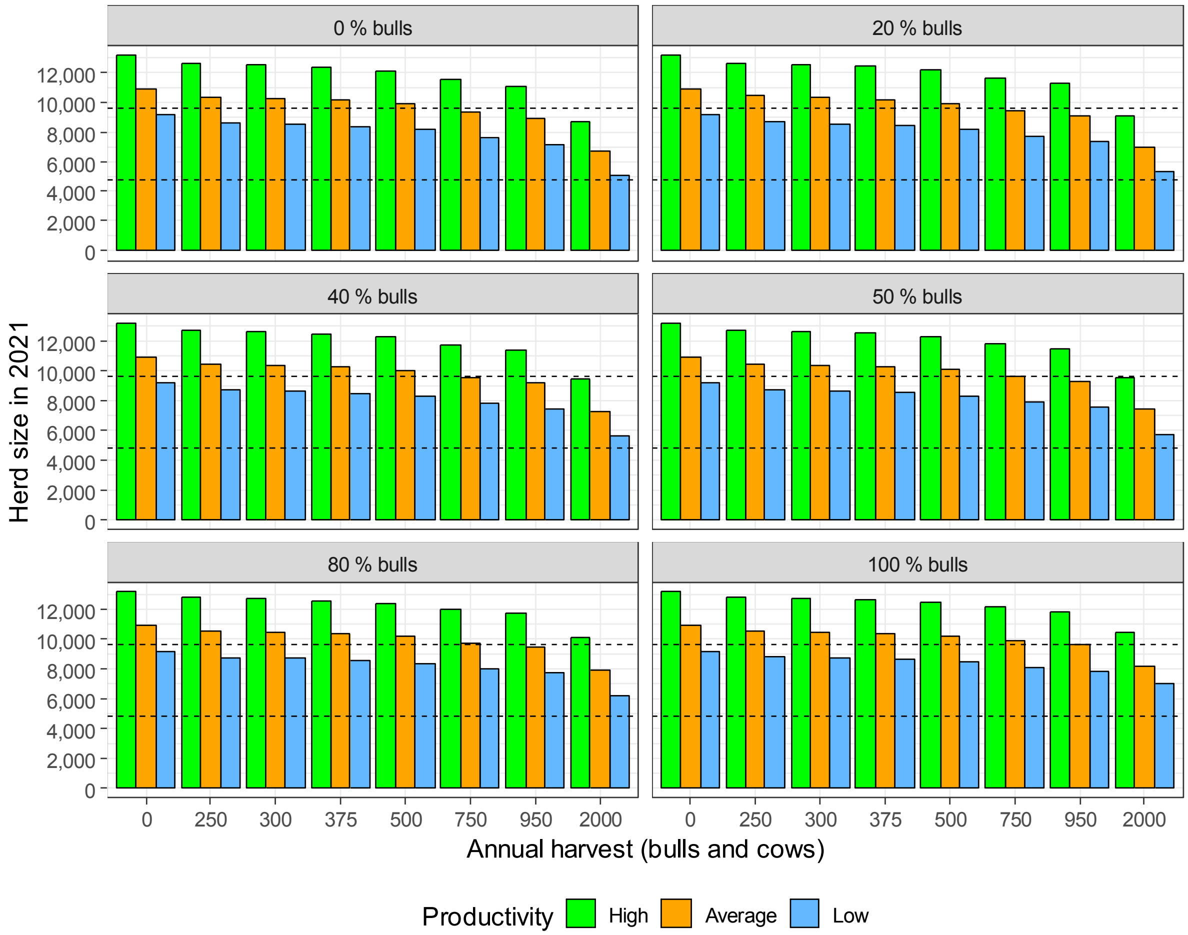

Figure 1: Projected Bluenose-East herd size in 2021, assuming a cow survival of 0.716 and three levels of calf productivity, across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

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

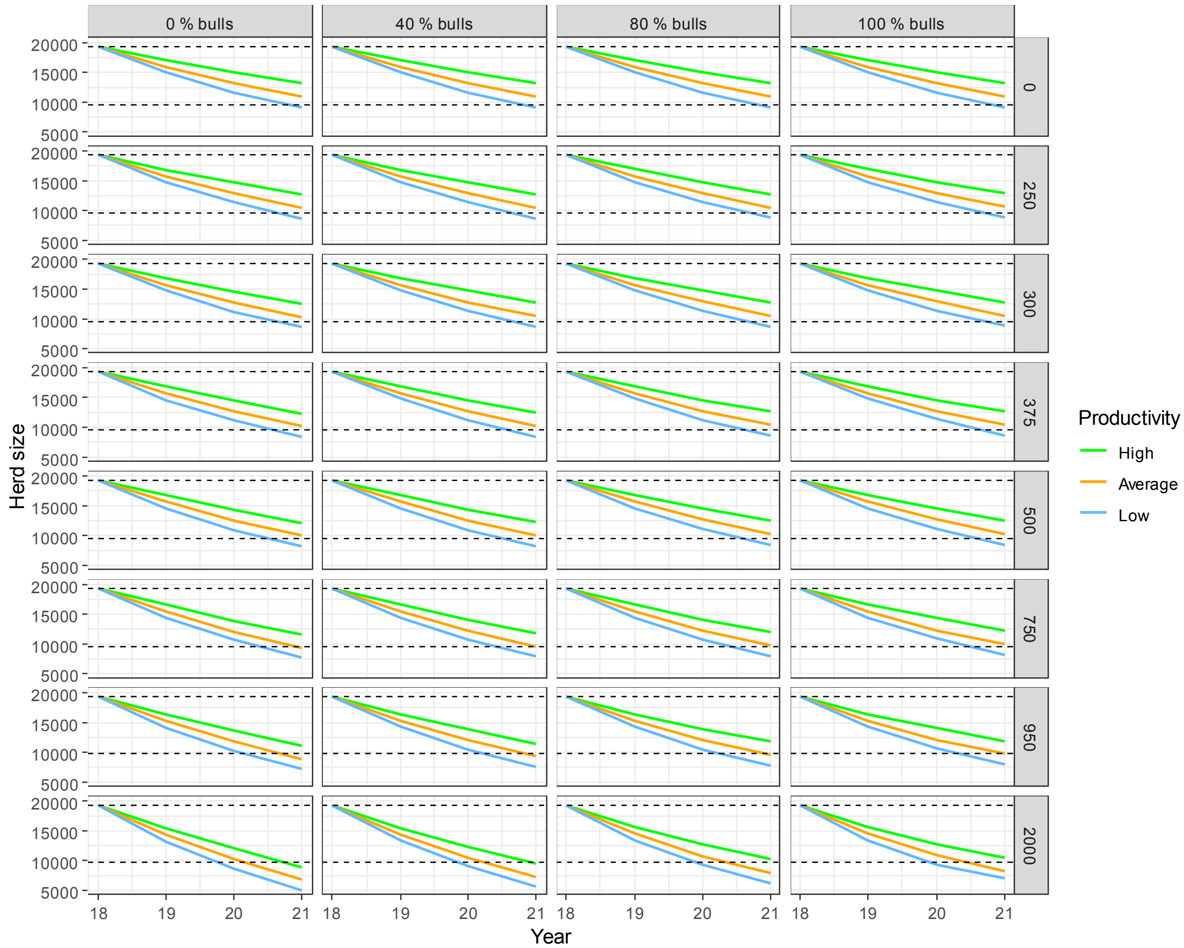

Figure 2: Projected herd trajectories for the Bluenose-East herd 2018-2021 assuming cow survival of 0.716 and three levels of calf productivity across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

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.

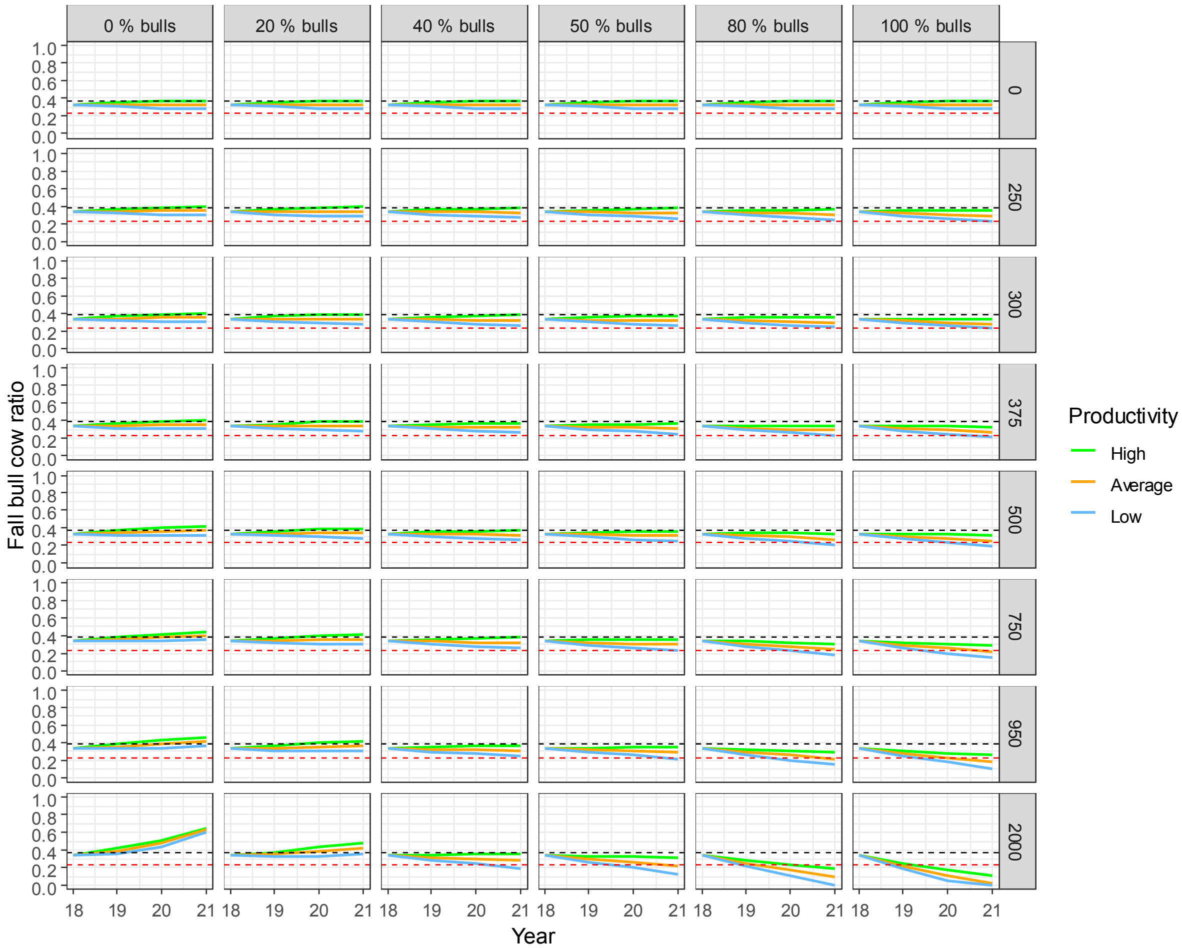

Figure 3: Projected bull-cow ratios in the Bluenose-East herd 2018-2021 assuming cow survival of 0.716 and bull survival of 0.523 and three levels of calf productivity, across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

Figure 4 shows predicted bull cow ratios in 2021 for the BNE herd; these are essentially the end-points 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).

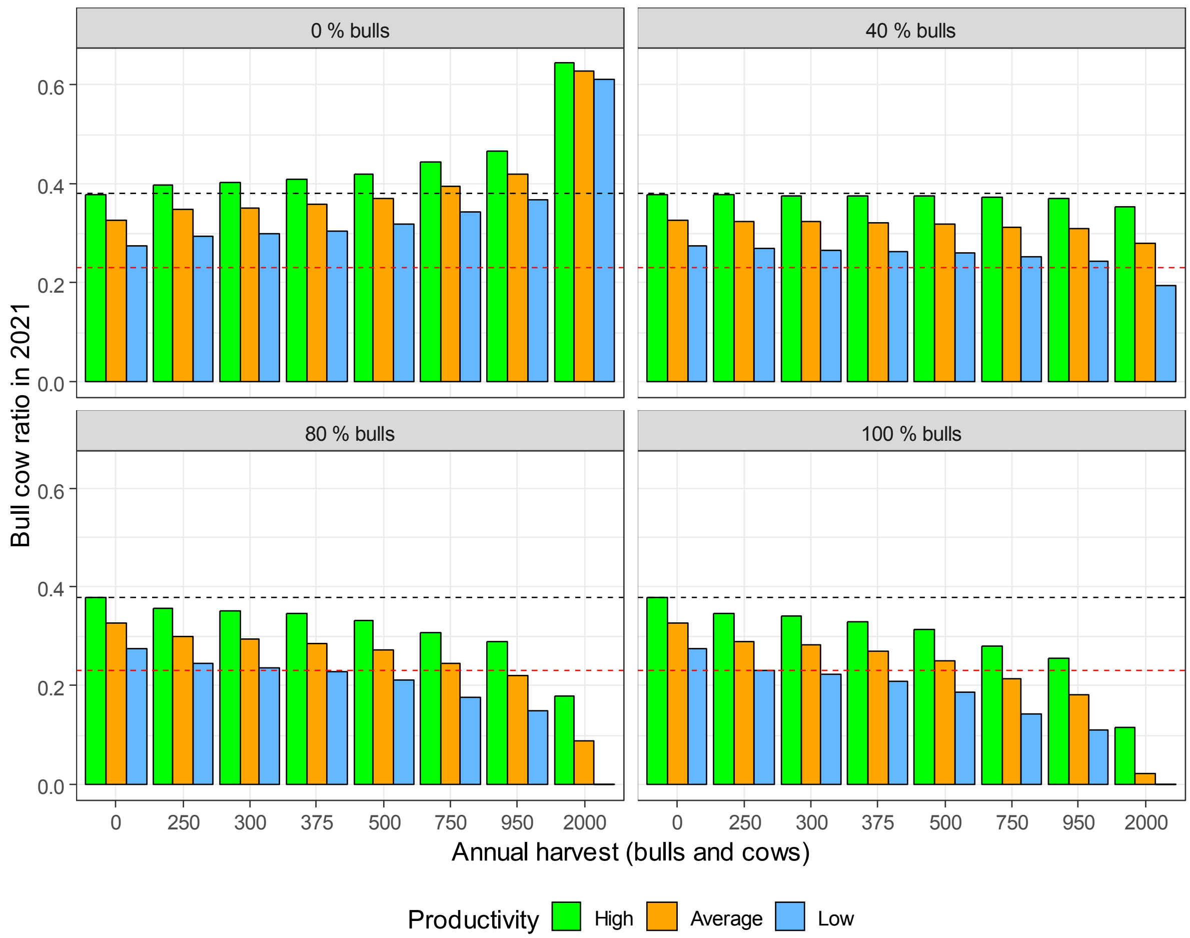

Figure 4: Projected bull-cow ratios in the Bluenose-East herd in 2021 assuming cow survival of 0.716 and bull survival of 0.523 and three levels of calf productivity, across a range of harvest levels and percent bulls in the harvest. See Table 1 for the parameterization of each productivity level.

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.

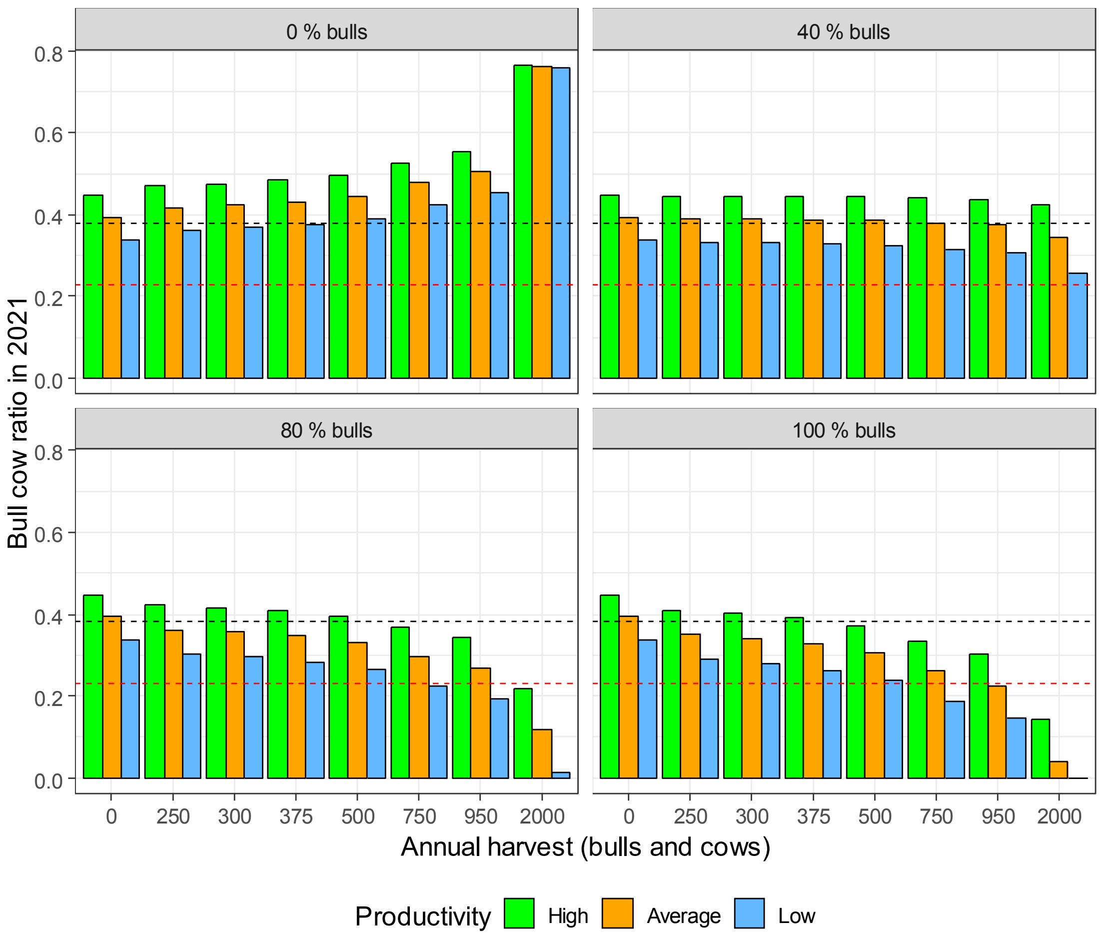

Figure 5: Projected bull cow ratios in the Bluenose-East herd in 2021, assuming cow survival of 0.716 and three levels of calf productivity and a bull survival of 0.58 (value from 2015 demographic model analysis). See Table 1 for the parameterization of each productivity level.

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.

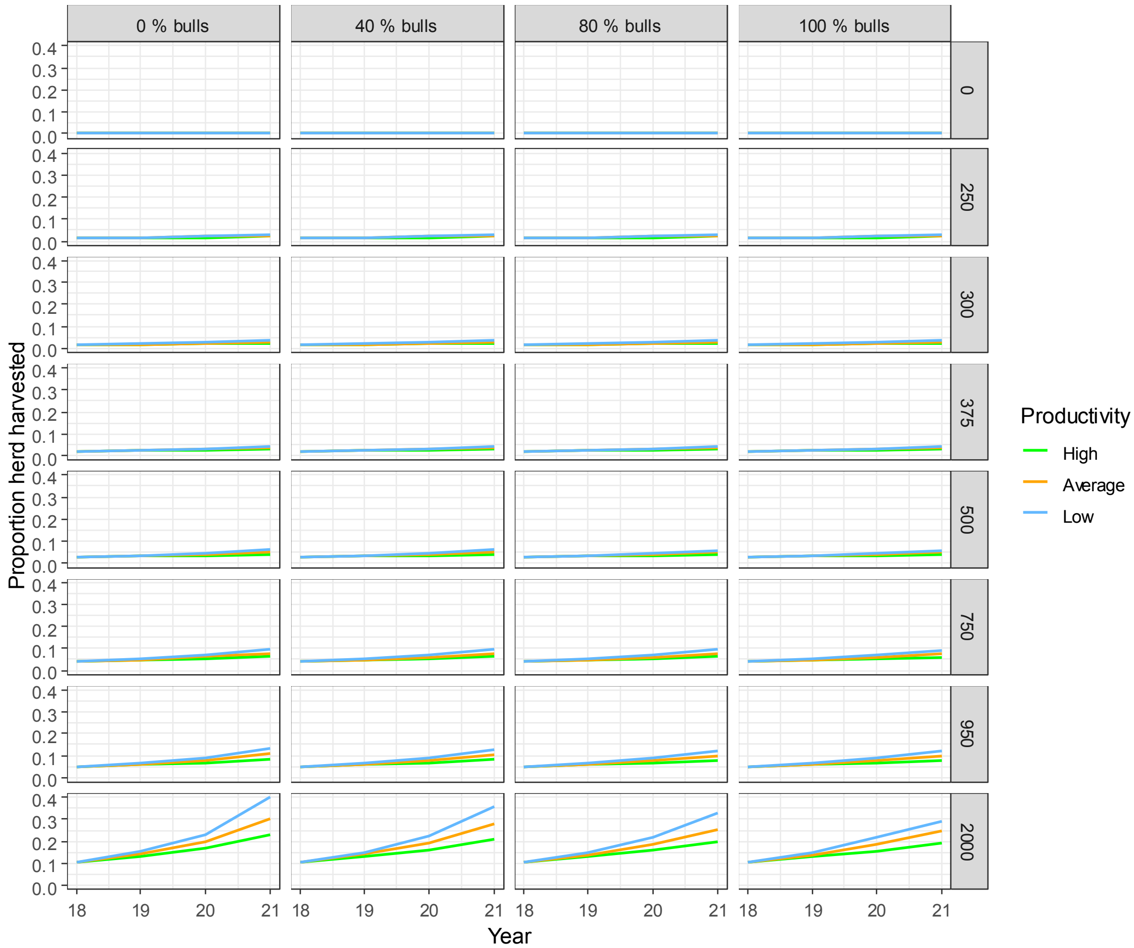

Figure 6: Proportion of the Bluenose-East herd harvested through 2021 across a range of harvest levels and proportion of the bulls in the harvest. See Table 1 for the parameterization of each productivity level.

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.

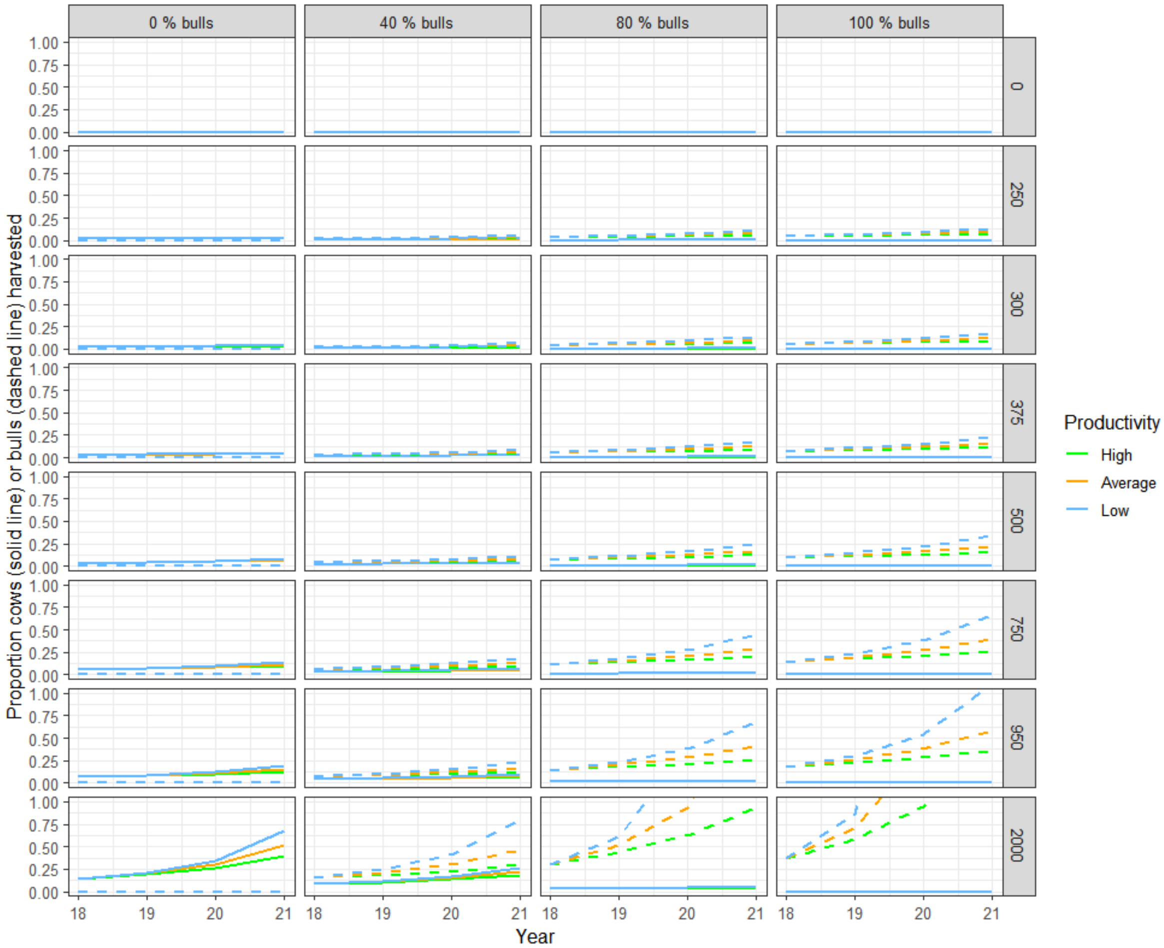

Figure 7: Proportion of bulls and cows harvested for each harvest and productivity scenario. This figure basically summarizes proportion harvested in Figure 6 by bulls and cows. See Table 1 for the parameterization of each productivity level.

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 km^2 stratum had 20 percent breeding females, then its core area was estimated as 20 km^2. 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/km^2) 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.

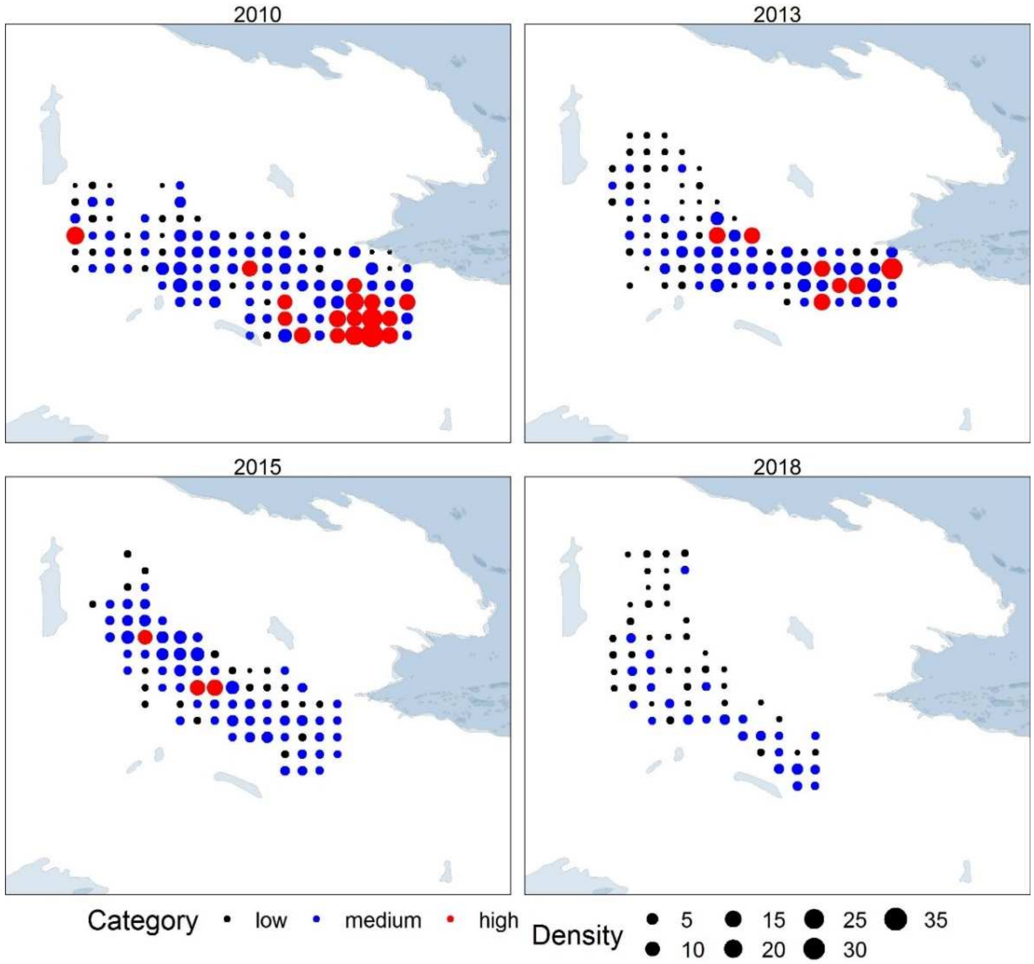

Figure 1: Segment densities in core calving areas for the Bluenose-East caribou herd 2010-2018 from calving photo surveys. Low density = <1 caribou/km^2, medium density = 1-9.9 caribou/km^2, and high density = at least 10 caribou/km^2.

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

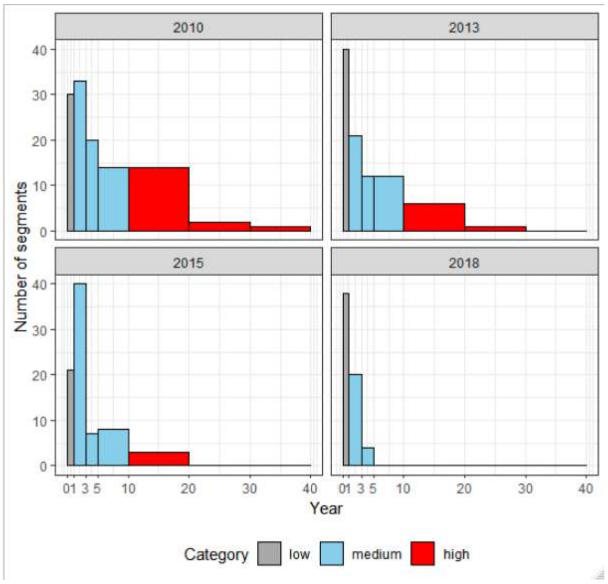

Figure 2: Segment densities in core calving areas for the Bluenose-East caribou herd 2010-2018. Low density = <1caribou/km^2, medium density = 1-9.9 caribou/km^2, and high density = at least 10 caribou/km^2.

A boxplot of the Bluenose-East segment data set shows that the median segment densities were generally <5 caribou per km^2 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/km^2.

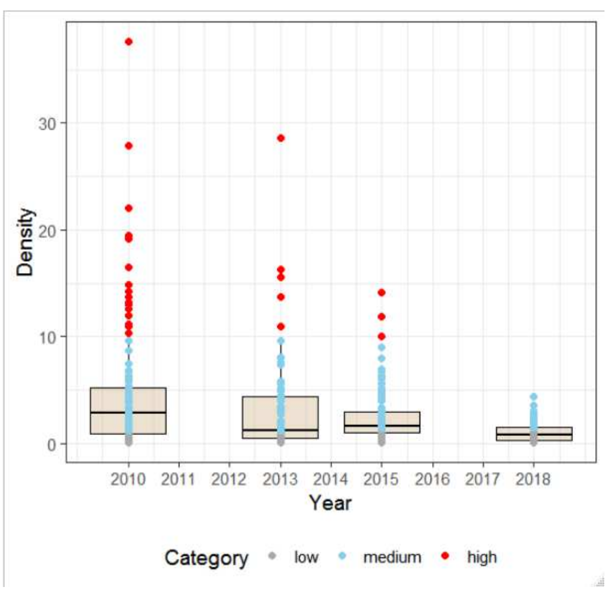

Figure 3: Boxplot of segment densities for the Bluenose-East herd 2010-2018.

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 n 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.

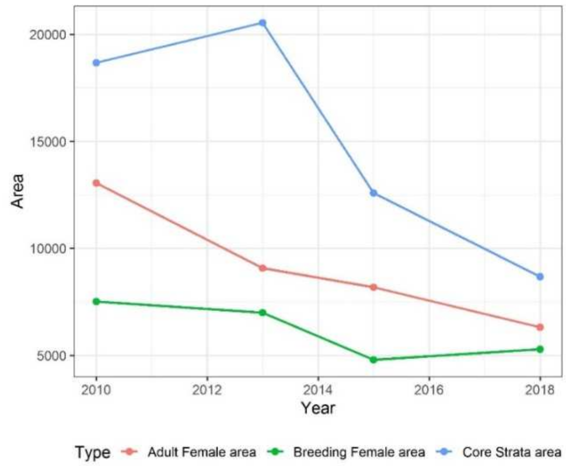

Figure 4: Estimated area of core survey strata, area weighted by proportion of breeding females, and proportion adult females in survey strata for the Bluenose-East caribou herd 2010-2018.

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.

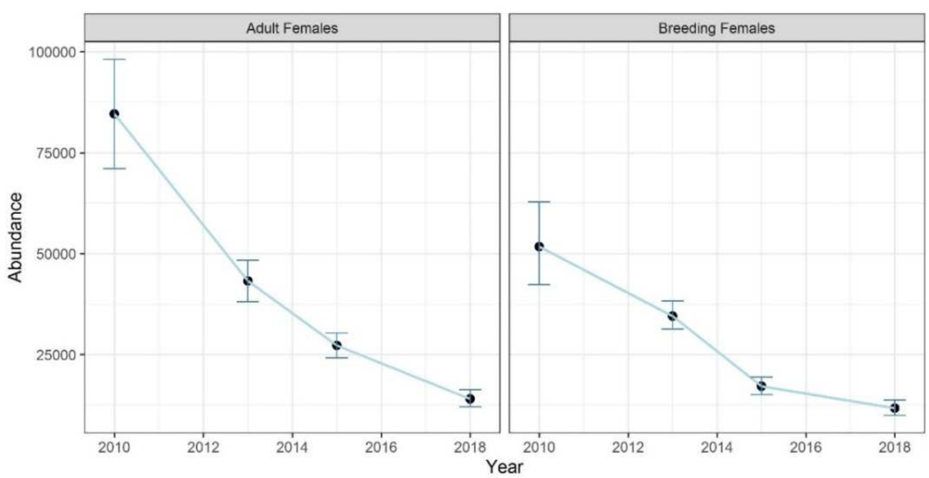

Figure 5: Estimate of abundance of adult and breeding females on core calving areas from 2010-2018 for the Bluenose East herd.

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).

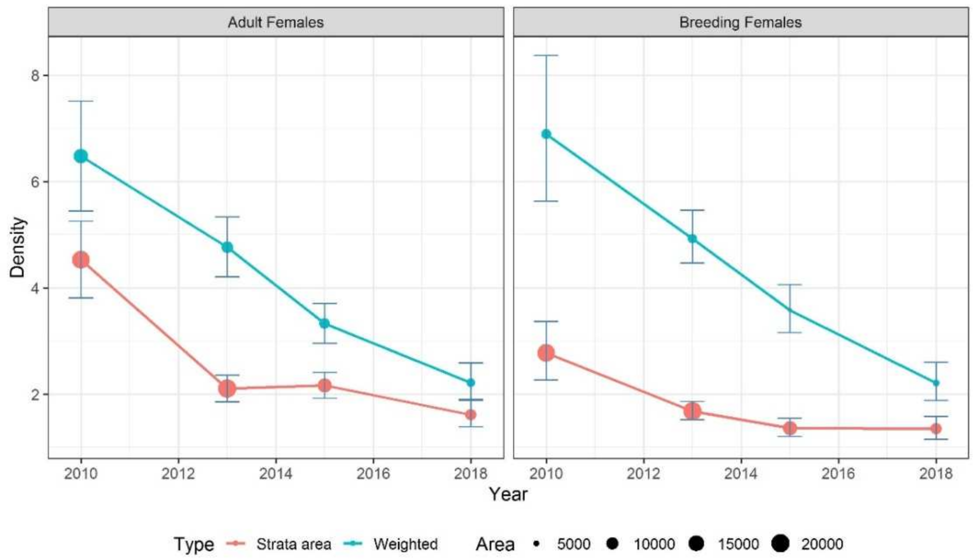

Figure 6: Density (number/km^2) of adult females and breeding females in survey strata using total area (Strata area) and corresponding breeding female or adult female areas, for the Bluenose-East caribou calving grounds 2010-2018. The symbol size is proportional to the calving ground area used to estimate 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).