AN ESTIMATE OF BREEDING FEMALES

AND ANALYSES OF DEMOGRAPHICS

FOR THE BLUENOSE-EAST HERD OF BARREN-GROUND CARIBOU:

2015 CALVING GROUND PHOTOGRAPHIC SURVEY

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Abstract

This report details the calving ground photo survey of the Bluenose-East caribou herd conducted during June of 2015 in Nunavut (NU), near Kugluktuk, NU. The main objective was to obtain an estimate of breeding females that could be compared to estimates from previous calving ground surveys in 2010 and 2013. Consistent with previous calving ground photographic surveys, data from collared caribou and systematic reconnaissance survey flight lines flown at 10 kilometer intervals in the calving grounds were used to delineate the core calving area, to assess calving status, to allocate sampling to geographic strata of similar caribou density, and to time the photographic survey plane to coincide with the peak of calving. Based on collar movements and observed proportions of calves, it was determined that the peak of calving would occur soon after June 5th and the photo plane survey was flown on June 5th. Photo plane survey effort (transect spacing) was allocated into a single high density block (stratum) where the majority of breeding females resided. Three other strata which had lower densities of breeding caribou were also surveyed visually on June 5th. A double observer method was used to estimate and correct for sightability of caribou from visual surveys. Survey conditions were favorable on June 5th with high ceilings and low snow cover. The estimate of 1+ year old caribou on the core calving ground was 38,041 (95% Confidence Interval (CI) =33,569-42,513) caribou. Using the results of the ground composition survey to adjust this number for breeding females, the estimate of breeding females was 17,396 (CI=15,088-19,704). The estimate of breeding females was very precise with a coefficient of variation of 6.3%. The pregnancy rate of females, as indexed by the proportion of adult females classified as breeding was lower in 2015 than the previous survey in 2013. For this reason, an alternative estimator that used an estimate of total adult females (breeders and non-breeders; 27,246 (CI=24,172-30,320) divided by the proportion females in the herd (from fall composition surveys) was used to estimate herd size. The resulting estimate of herd size was 38,592 (CI=33,859-43,325). Comparison of 2013 and 2015 adult female numbers indicate an annual rate of decline of 20% (CI=7-32%). Assessment of survey issues suggested that this difference could not be attributed to differences in surveys or bias. Assessment of movement of collared females between the Bluenose-East and surrounding herds from 2010-2015 documented minimal movement of collared cows to neighboring herds. Demographic modelling that used composition, collared caribou, and survey data estimated that cow survival rate was low (0.71, CI=0.69-0.72) and calf recruitment has declined. These factors along with harvest pressure have led to the ongoing decline of the herd. We suggest that continued monitoring and proactive management of harvest with a shift from mostly cows to mostly bulls is recommended. In addition, continued monitoring of calving ground distribution and spring productivity should be conducted to allow ongoing monitoring of herd status.

Contents

List of Figures

List of Tables

Introduction

This report describes results of a calving ground photo-survey of the Bluenose-East caribou herd conducted during June of 2015. This herd's calving grounds have 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, where it may overlap with the Bathurst herd (Figure 1).

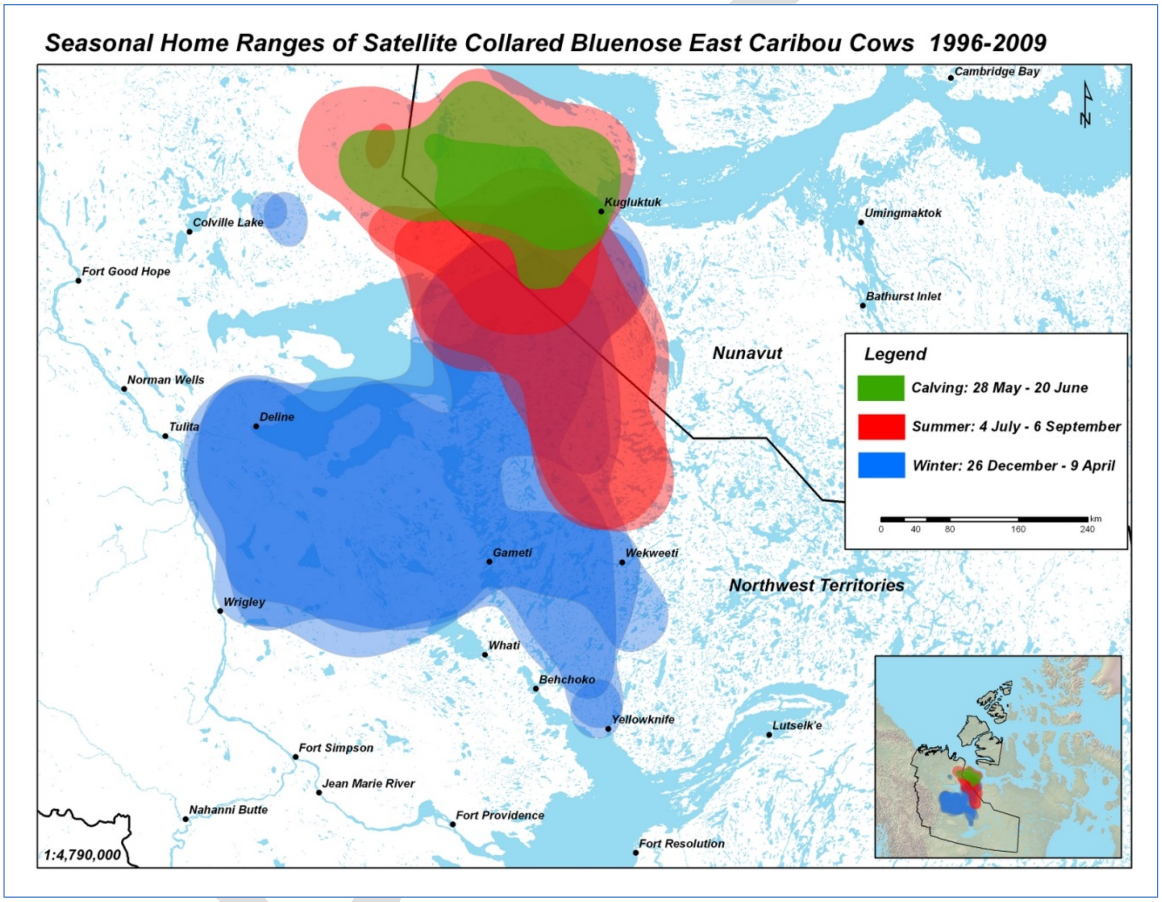

Figure 1: Calving, summer, and winter ranges of the Bluenose, 1996-2009, based on accumulated radio collar locations of cows. Ranges were delineated using Kernel home range (Worton 1989) smoothing of seasonal radio collared cow locations (Nagy et al. 2011). The location of the Bluenose-East range relative to the Northwest Territories is shown as an inset with Nunavut being to the north of the Northwest Territories.

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

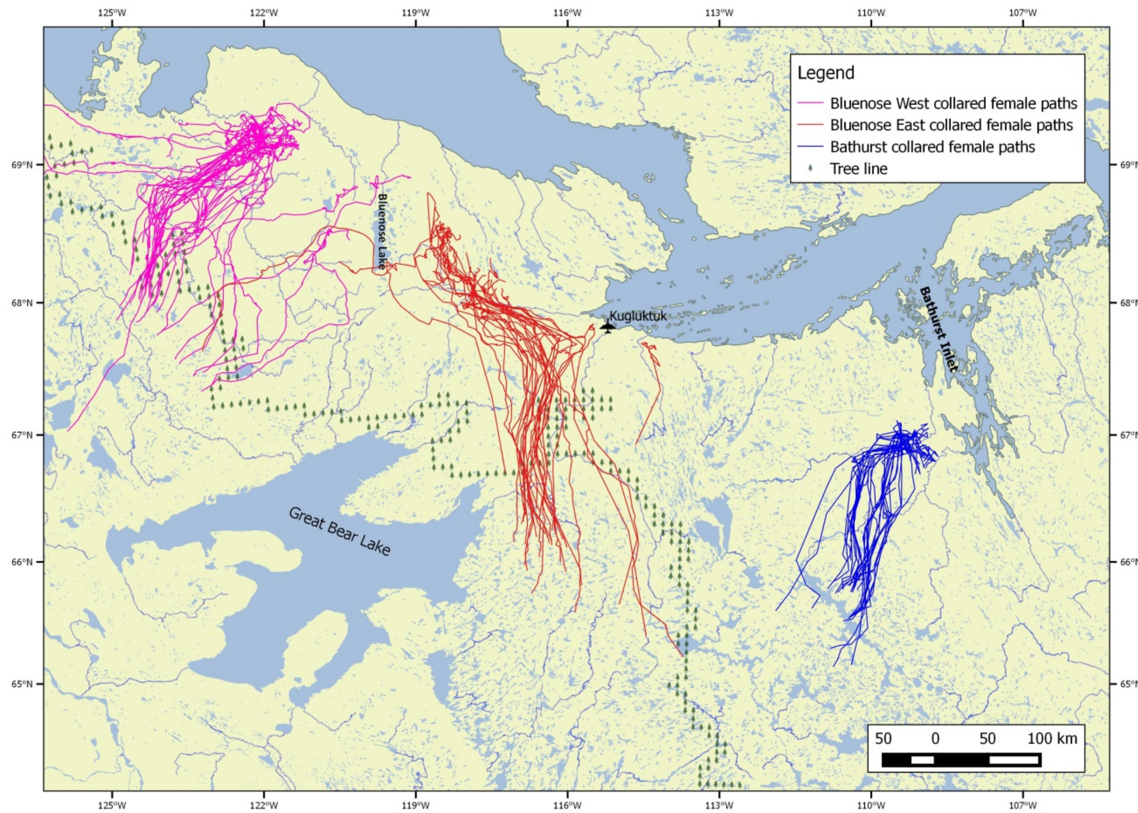

Figure 2: Spring migration paths of the Bluenose West, Bluenose-East and Bathurst herds from May 15 to June 15 2015. Calving grounds surveys for the Bathurst and Bluenose-East herds were conducted in 2015 with a base out of Kugluktuk, Nunavut.

The Bluenose-East herd was previously surveyed on the calving ground in June 2013 (Boulanger et al. 2014b) and in 2010 using a calving ground photo-survey and using post-calving methods in July 2010 (Adamczewski et al. 2014). In earlier years, post-calving surveys were used for this herd (Patterson et al. 2004, Adamczewski et al. 2009) Both the July 2010 post-calving survey and the June 2010 calving ground survey indicated that the herd was over 100,000 adult caribou. However, the 2013 survey estimated the herd at 68,295 (CI=50,255-86,336) adult (1.5+ year old) caribou. A subsequent reconnaissance-level survey in 2014 (Boulanger et al. 2014c) indicated a continued decline in abundance (Figure 3). For this reason, the 2015 Bluenose survey was conducted a year earlier than the usual 3 year survey interval to further estimate herd size and investigate causes for the decline of the Bluenose-East herd.

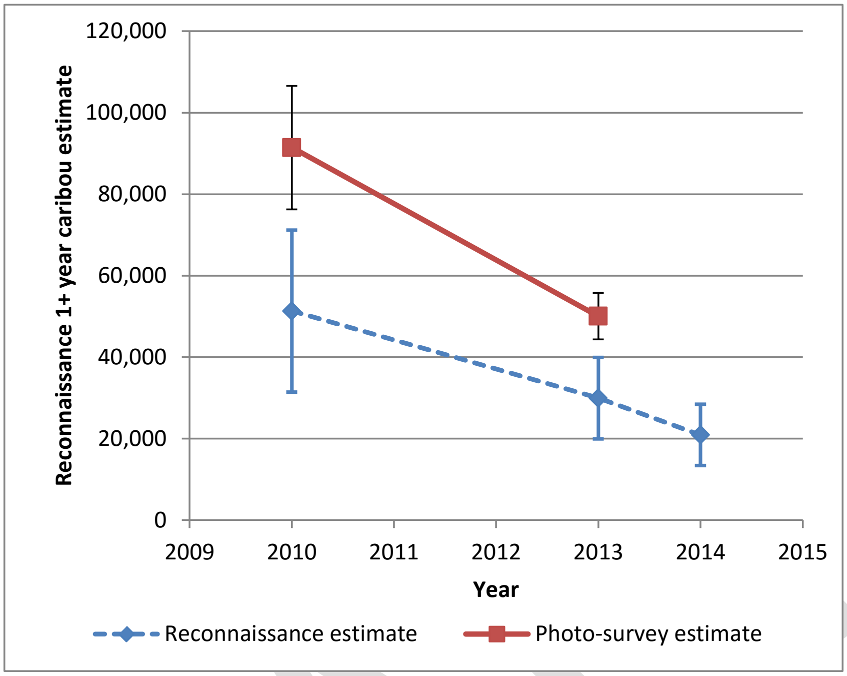

Figure 3: Comparison of estimates of caribou in the core calving area for the Bluenose-East herd from 2010 to 2014. Estimates of caribou in the core area (not herd size) from the photo plane from surveys in 2010 and 2013 are shown for comparison (red squares). Figure taken from (Boulanger et al. 2014c).

Methods

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

1. Locations from collared caribou, historic records of calving ground use, and systematic aerial reconnaissance surveys of the Bluenose-East calving area were used to identify core calving areas between Kugluktuk and Bluenose Lake in Nunavut.
2. A systematic reconnaissance survey was conducted where transects at 10 kilometer intervals were flown to determine areas where breeding females were concentrated, as well as locations of bulls, yearlings, and non-breeding cows near the calving ground. Timing of calving was assessed by evaluating the proportion of cows with newborn calves and from reduced movement rates of collared cows at calving.
3. Using data from the reconnaissance survey, geographic areas called strata (or blocks) were delineated for sampling, either by the photo plane or visually, with the most sampling effort dedicated to areas with the highest densities of breeding female caribou.

4. The higher-density block was flown primarily by the photo-plane and lower-density blocks were flown visually.
5. While the aerial survey was conducted with the photo-plane and by visual survey, a composition survey was conducted using a helicopter using motion-stabilized binoculars. Each stratum was surveyed to determine the proportion of breeding caribou, as well as bulls, yearlings, calves and non-breeding cows.
6. The estimate of breeding females was derived using the estimates of total 1-year old or older caribou within each stratum, and the proportion of breeding females within that stratum.
7. The breeding female estimate was then used to extrapolate the total size of the herd by accounting for non-pregnant cows using an estimate of pregnancy rate in breeding-age females and for males using an estimate of the male-female ratio from a fall composition survey. Trends in numbers of breeding females (Heard 1985, Heard and Williams 1990, Gunn and Russell 2008) were assessed further.

Analysis of collared caribou data

Data from 30 collared female caribou were monitored during the survey to assess relative location of breeding females on the calving grounds. Locations of 24 collared Bluenose-East bulls were also monitored during the survey period but most were not on the calving grounds. In addition, changes in movement rates of collared cows were assessed to determine the timing of calving. In general, movement rates of parturient female caribou are reduced to less than 5 kilometers per day during the peak of calving and for an interval 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

Visual transects were surveyed with 10 kilometer spacing between lines in areas determined to be the main calving area, as well as surrounding areas, particularly where collared caribou were found. This resulted in survey ground coverage of 8% for the reconnaissance survey. Kugluktuk was used as a base of operations (Figure 1). Two Cessna Caravan and a Pilatus Porter aircraft were used for the systematic reconnaissance surveys. During visual surveys, caribou were counted within a 400 meter strip on each side of the survey plane (800 m total, Gunn and Russell 2008). Strip width was defined by the wheel of the airplane on the inside, and wooden doweling attached to the wing strut. Planes were flown at an average survey speed of 160 kilometers per hour at an average altitude of 120 meters above the ground to ensure that the strip width of the plane remained relatively constant.

Two observers were used on both sides of the airplane to minimize the chance of missing caribou. Previous research (Boulanger et al. 2010) demonstrated that this approach increases sightability compared to single observers. During the survey the two observers on each side communicated to ensure that groups of caribou were not double counted.

Caribou groups were classified by whether or not they contained breeding caribou. Breeding caribou were defined by female caribou with hard antlers or presence of calves. A female with hard antlers potentially indicated that the caribou had yet to give birth, as cows usually shed their antlers a few days after birth. Non-breeding caribou were also classified as yearlings (as indicated by a short face and small body), bulls (as indicated by thick, bulbous antlers and large body), and non-antlered or short soft antlered females. In most cases, each group was recorded individually, but in some cases groups were combined given that each plane only had a single data recorder. Data were recorded on Trimble YUMA 2 tablet computers by two data recorders in the plane (Figure 4). As each data point was entered, a real-time GPS waypoint was generated, allowing geo-referencing of the survey data.

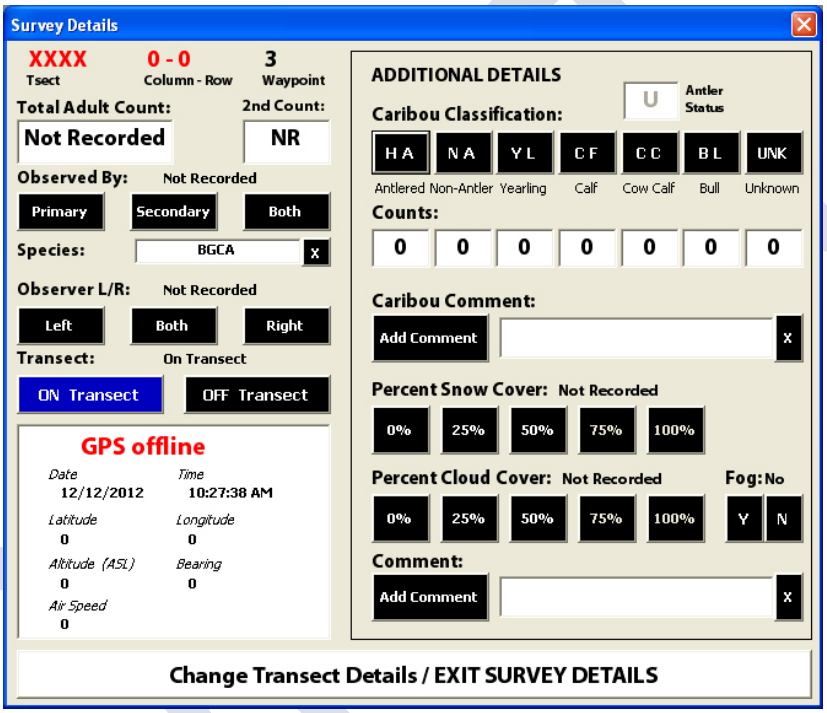

Figure 4: The tablet data entry screen used during reconnaissance surveys. A GPS waypoint was obtained for each observation, allowing efficient entry and management of survey data. In addition, the unique segment unit number was also assigned by the software for each observation to summarize caribou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

Transects were divided into 10 kilometer north-south segments to summarize the 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 caribou was detected. Segments were then displayed spatially and used to delineate core calving ground strata based on the composition and density of the segments. During the survey daily weather briefings were provided by Dr. Max Dupilka of TrueNorth Weather Consulting to assess current and future survey conditions.

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 following the results of the systematic reconnaissance survey, a procedure in which neighboring segments with similar density were grouped into contiguous areas so that each stratum enveloped distributions of similar caribou densities. In addition, stratification was used to determine if a stratum required the use of a photo survey plane, or if visual estimates could be used. In this survey, a single higher-density stratum was identified; this stratum was planned for survey by the photo-plane. Other strata that had lower densities of caribou were planned for visual survey. Given that the objective of the survey was to estimate breeding females, only areas that contained breeding females were surveyed during counts.

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

Two potential strategies for allocation were considered for the aerial survey. First, optimal allocation of survey effort was considered based on sampling theory (Heard 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.

If strata were reasonably small, then optimal allocation was further adjusted to ensure an adequate number of transect lines. In particular, previous surveys suggested that there should be a minimum of 10 transects per stratum with closer to 20 transects being optimal for high density areas. In general, coverage should be at least 15% with higher levels of coverage for high density strata. In the context of sampling, increasing the number of lines in a stratum is "insurance" in that it minimizes the influence of any one line on estimate precision. As populations become more clustered, a higher number of transect lines is required to achieve adequate precision (Thompson 1992, Krebs 1998).

Estimation of caribou on the calving ground

Photo surveys

Photo-surveys were planned for the higher-density stratum to ensure accurate counting of larger groups of caribou on the photo stratum. GeodesyGroup Inc. aerial survey company (Calgary, Alberta) was contracted for photo surveys. They used a Piper PA46-310P Jetprop DLX aircraft with a digital camera mounted on 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. Caribou detected on photos were counted by a team of photo interpreters and supervised by Derek Fisher, president of Green Link Forestry Inc., (Edmonton, Alberta) using specialized software that allowed three dimensional viewing of photographic images. The number of caribou counted was tallied by stratum and transect. The exact survey strip width of photos was also determined using the geo-referenced digital photos by Green Link Forestry.

Visual surveys

Visual surveys were conducted in low and moderate density strata. For visual surveys, the Caravan and Pilatus Porter aircraft was used with 2 observers on each side of the aircraft and a data recorder on each side. The number of caribou sighted by observers were then entered into the Trimble 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 adhered to five basic steps; 1 - The primary observer called out all groups of caribou (number of caribou and location) he/she saw within the 400 meter wide strip transect before they passed halfway between the primary and secondary observer (approximately at the wing strut). This included caribou groups that were between approximately 12 and 3 o’clock for right side observers and 9 and 12 o’clock for left side observers. 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 are 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 only”, “secondary only”, and “both”, entered as separate records; 5 - The observers switched places approximately half way through each survey day (i.e. at lunch) to monitor observer ability. The recorder noted the names of the primary and secondary observer (Boulanger et al. 2010, Buckland et al. 2010, Boulanger et al. 2014a).

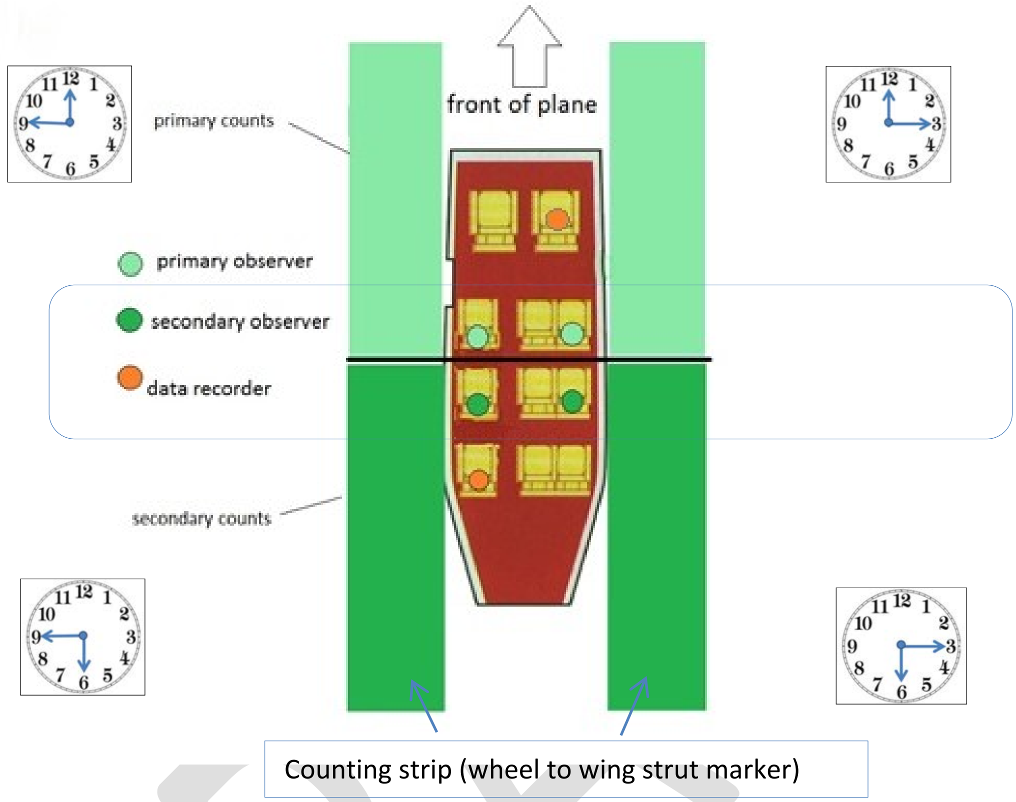

Figure 5: Observer position for double observer methods. The secondary observer calls caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can be used to reference relative locations of caribou groups (i.e. "caribou group at 1 o'clock").

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 2 sample mark-recapture trial in which some caribou are seen ("marked") by the ("session 1") primary observer of which some 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 resighted 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. Therefore, observers were switched midway in each survey day, 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 observed had 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 in which only the beta parameters whose confidence limits did not overlap 0 were retained.

Data from both the Bluenose-East and Bathurst herd calving grounds surveys was used in the double observer analysis given that most planes flew the visual surveys for both calving grounds. It was possible that the different terrain and weather patterns in each calving ground may 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.

Table 1: Covariates used to model variation in sightability for double observer analysis.

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

The fit of models was evaluated using the Akaike Information Criterion (AIC) index of model fit. The model with the lowest AICc score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). The difference in AICc values between the most supported model and other models (ΔAICc) 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 less than 2 was worthy of consideration.

Estimation of caribou in stratum with varying strip widths

During post-processing of the data it was discovered that the Pilatus porter aircraft was flying below the standard survey altitude which resulted in a smaller strip width. This plane surveyed a portion of the East and Central strata. If uncorrected, this could potentially bias estimates since caribou the areas that this plane surveyed would have a lower chance of being sampled given the smaller strip widths. To mitigate this issue, a method was used that estimated population size by equally weighting densities of caribou on each transects line regardless of strip width. More precisely, population size 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 ($\widehat{D}_i = caribou_i/area_i$) were $caribou_i$ 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 therefore ensuring that each transect line contributed to the estimate in proportion to its length. Population size is then estimated using the standard formula ($\widehat{N} = \overline{D}A$). This procedure was used in unison with the double observer method to estimate population size. Double observer estimation methods are provided in Appendix 1. Bootstrap methods were used to estimate standard errors of estimates.

Composition of breeding and non-breeding caribou on the calving ground

The composition sampling was undertaken in the survey strata concurrently with the commencement of the photo and visual surveys. Caribou were classified in strata that contained significant numbers of breeding females to estimate proportions of breeding females and other sex and age classes. For this, a helicopter (ASTAR 350B2) from Great Slave Lake Helicopters was used to systematically survey groups of caribou, allowing more in-depth classification of caribou than was possible from fixed-wing aircraft. Caribou groups were classified primarily classified from the air using motion-stabilized binoculars. Caribou were classified following the methods of Gunn et al. (2005) where antler status, presence/absence of an udder, and presence of 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 antler growth were considered non-breeders.

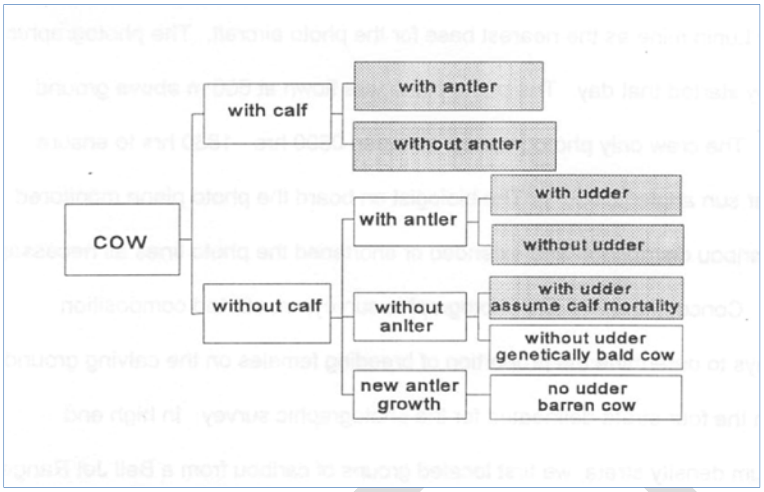

Figure 6: Classification of breeding females used in composition surveys. Shaded boxes were classified as breeding females (diagram from (Gunn et al. 2005)).

The number of each group was totaled as well as the number of bulls and yearlings (calves of the previous year) to estimate the proportion of breeding caribou on the calving ground. Bootstrap resampling methods (Manly 1997) were used to estimate standard errors and percentile-based confidence limits for the proportion of breeding caribou.

Estimation of breeding females 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 in each stratum from composition surveys. This step basically eliminated the yearlings, and bulls from the estimate of total caribou on the calving ground.

Each of the field measurements has 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 total herd size

Total herd size was estimated using two approaches. The first approach, which has been used in historic 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 the assumed pregnancy rate of 0.72 (Dauphin'e 1976, Heard and Williams 1991). The estimate of total females was then divided by the estimated proportion of females in the herd based on bull:cow ratios from fall composition surveys conducted in October of 2015 to provide an estimate of total adult caribou in the herd (methods described in Heard and Williams 1991). Note that this estimate corresponds to adult caribou at least 2 years old and will not include yearlings. 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 2014-5.

Estimate of herd size based upon estimates of adult females

An alternative extrapolated herd size estimate was developed as a means to explore the effect of variable pregnancy rates as part of the 2014 Qamanirjuaq caribou herd survey (Campbell et al. 2016). This estimator first uses data from the composition surveys to estimate total proportion of adult females, and adult females in each of the survey stratum. The estimate of total adult females is then divided by the proportion adult females (cows) in the herd from fall composition surveys. Using this approach, the fixed pregnancy rate is eliminated from the estimate procedure. This estimate assumes that all adult females (breeding and non-breeding) were within the survey strata during the calving ground survey. However, it makes no assumption about the pregnancy rate of the females.

Trends in breeding and adult females.

As an initial step the significance of estimates from the 2013 and 2015 surveys were tested using t-tests (Heard and Williams 1990) with gross and annual rates of changes estimated from the ratio of estimates.

Longer term trends from 2010-5 were estimated using weighted regression analysis (Brown and Rothery 1993). Each estimate of breeding females was weighted by the inverse of its variance to account for unequal variances of surveys, and to give more weight to the more precise surveys. Analyses were conducted with PROC GENMOD and PROC REG within SAS statistical package (SAS Institute 2000).

The population size was log transformed to partially account for the exponential nature of population change (Thompson 1998). The rate of change could then be estimated as the exponent of the slope term in the regression model. 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 λ=1 then a population is stable; values greater or less than 1 indicate increasing and declining populations. The rate of decline was also estimated as 1- λ.

Demographic analyses

Survival rate analyses

Collar data for female caribou for the past three years were compiled for the Bluenose-East caribou herd by GNWT Environment and Natural Resources (ENR, unpublished data., pers. comm.). 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 year" that began during calving of each year (June) and ended during the spring migration (May). Program MARK known fate models (White and Burnham 1999) were used to estimate caribou-year estimates of survival rate from 2010-5. These data were then used as an input into the demographic model described next.

Demographic model analyses

One of the most important questions for the Bluenose-East herd was whether the breeding female segment of the population was declining, increasing or stable. If the number of breeding cows is stable or increasing, then the herd has the potential to increase. 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 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 the ordinary least squares (OLS) model (White and Lubow 2002) developed for the Bathurst herd (Boulanger et al. 2011) to further explore demographic trends in the Bluenose-East data. We used the 2010, 2013 and 2015 breeding female estimates as well as calf-cow ratios, bull-cow ratios (Cluff et al. 2015), 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. The OLS model is a stage based model that divides caribou into 3 age-classes with survival rates determining the proportion of each age class that makes it into the next age class (Figure 7).

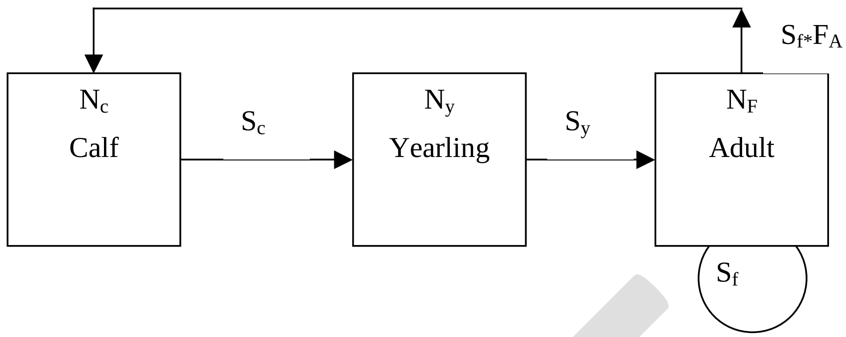

Figure 7: Underlying stage matrix life history diagram for the caribou demographic model. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates of calves (S_c), yearlings (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 2015 which covered the time period in which calving ground surveys had been conducted on the Bluenose-East herd. In addition, this interval basically covered potential recruitment into the breeding female class since any female calf born from 2008-2010 had the potential to become a breeding female in 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 2008 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. It was considered a non-breeder until 2011. Calves born in 2011 and 2012 had the most direct bearing on the number of new breeding females on the 2015 calving ground that were not accounted for in the 2013 breeding female estimate.

Table 2: A schematic of the assumed timeline in the OLS analysis in which calves born are recruited into the breeding female segment (green boxes) of the population. Calves born prior to 2010 were counted as breeding females in the 2010 and 2013 surveys. Calves born in 2011 and 2012 recruited to become breeding females in the 2015 survey.

Calf	Survey years							
Born	2008	2009	2010	2011	2012	2013	2014	2015
2007	yearling	non-breeder	breeder	breeder	breeder	breeder	breeder	breeder
2008	calf	yearling	non-breeder	breeder	breeder	breeder	breeder	breeder
2009		calf	yearling	non-breeder	breeder	breeder	breeder	breeder
2010			calf	yearling	non-breeder	breeder	breeder	breeder
2011				calf	yearling	non-breeder	breeder	breeder
2012					calf	yearling	non-breeder	breeder
2013						calf	yearling	non-breeder

We used a sequential model building process where we first built a model that considered the dominant trends in productivity (calf survival) as indicated by calf-cow ratios. We then tested for trends in adult female survival. Models were evaluated using the sample-size-corrected Akaike Information Criterion (AIC_c) index of model fit (Burnham and Anderson 1998). The model with the lowest AIC_c score was considered the most parsimonious, thus optimizing the tradeoff between bias and precision (Burnham and Anderson 1998). The difference between any given model and the most supported (ΔAIC_c) was used to evaluate the relative fit of models when their AIC_c scores were close. In general, any model with an ΔAIC_c score of ≤ 2 was supported by the data.

Estimates of survival from the OLS model included harvest mortality as well as natural mortality from predation and other causes. Ideally, the total harvest would be tracked reliably and mortality rates due to harvest and natural causes would be tracked independently via adequate numbers of collared cows. Due to the uncertainty as to the true harvest and the limited sample size for estimating survival from collared caribou, we used the model to explore combinations of natural and harvest-based mortality rates that could account for the observed demographic patterns, and particularly the decline in numbers of breeding females. For this exercise harvest was included in the OLS model by subtracting harvest numbers of cows and bulls from the population each year. We then re-estimated survival rates that would produce the observed estimates.

The base OLS model calculations were conducted in an Excel spreadsheet as detailed in Boulanger et al (2011). A bootstrap method (Manly 1997) was used to estimate confidence limits on model prediction using the poptools Excel plug-in (Hood 2009) with additional coding in visual basic programming language (Microsoft Corporation, Redmond, Washington, USA). For this procedure, the base field data set was randomly resampled 1000 times and run through the OLS model to obtain percentile based confidence limits (Manly 1997) on model parameters and estimates of standard error. In some cases, combinations of randomly sampled field values created outlier estimates as indicated by high overall penalty values for overall model fit. To confront this, estimates from model runs with outlier penalty values (as indicated by the top 1 percentile of penalties) were censored from confidence interval calculations.

Results

Survey conditions

Weather conditions were favourable for the majority of the survey with mixed cloud cover during reconnaissance surveys and minimal cloud cover during visual surveys. Snow cover was less than 15%, and in many years below 5% by the time of the visual and photo survey on June 5^{th} (Figure 8). Snow and cloud cover were summarized extensively using data from Trimble YUMA 2 tablet computers for the double observer analysis used in the visual survey conducted on June 5^{th}. A weather system came into the survey area on June 6^{th} with fog and low ceiling grounding aircraft from June 7^{nth} to 9^{nth}.

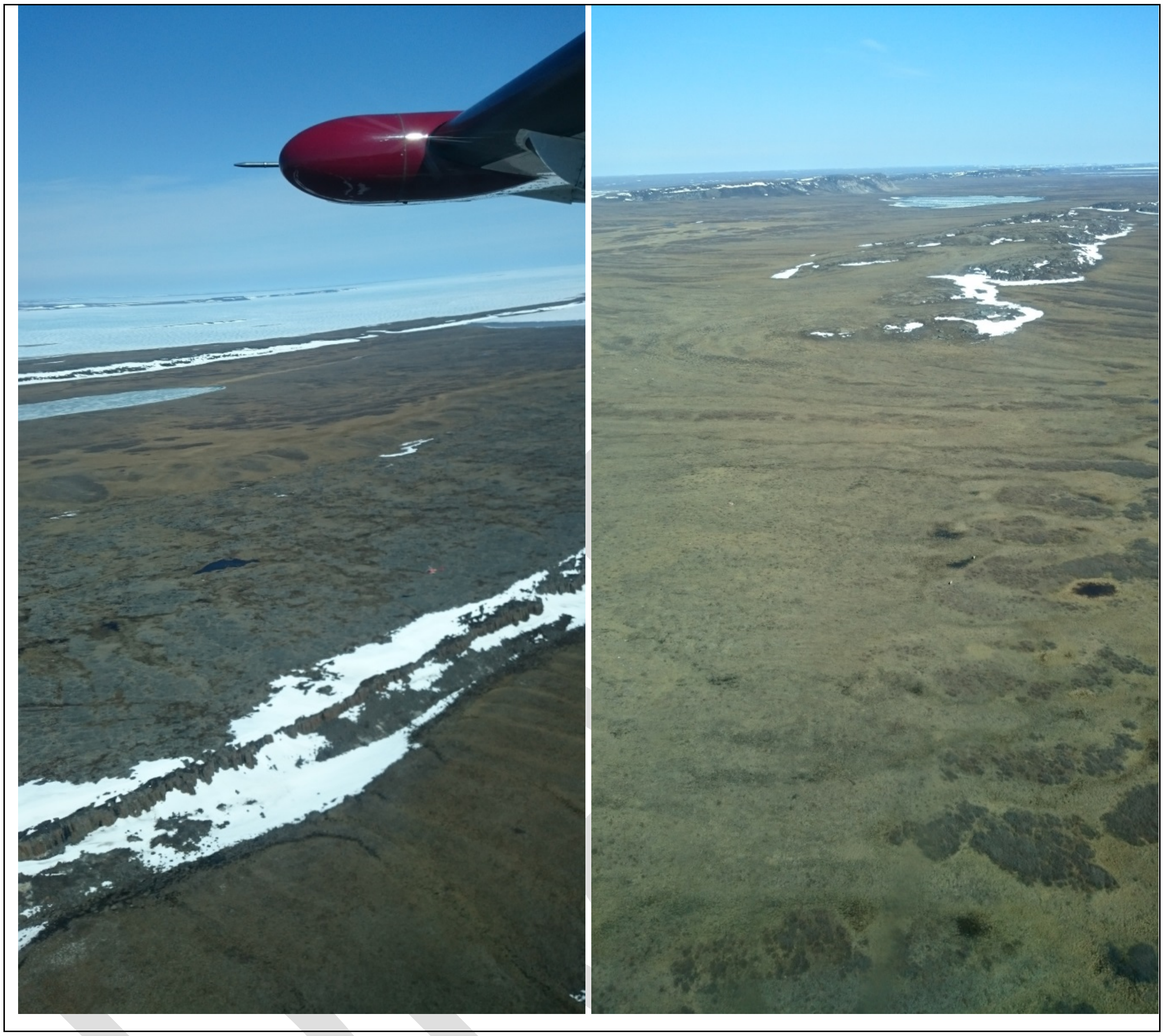

Figure 8: Pictures of survey conditions on June 5th when the visual and photo surveys were conducted (Photos by David Lee, Nunavut Tungavik Inc).

Movement rates of collared caribou

The movements of thirty adult female caribou were monitored during the reconnaissance survey to assess movement rates. The peak of calving is considered close when the majority of collared female caribou exhibit movement rates of less than 5 kilometers per day (Gunn and Russell 2008). Using this rule, we surmised that peak of calving was becoming evident on June 5th and 6th when mean movement rates were 5 kilometers or less for the radio collared caribou (Figure 9). The peak of calving was further verified by reconnaissance survey observations on June 4th and composition surveys conducted on June 5th.

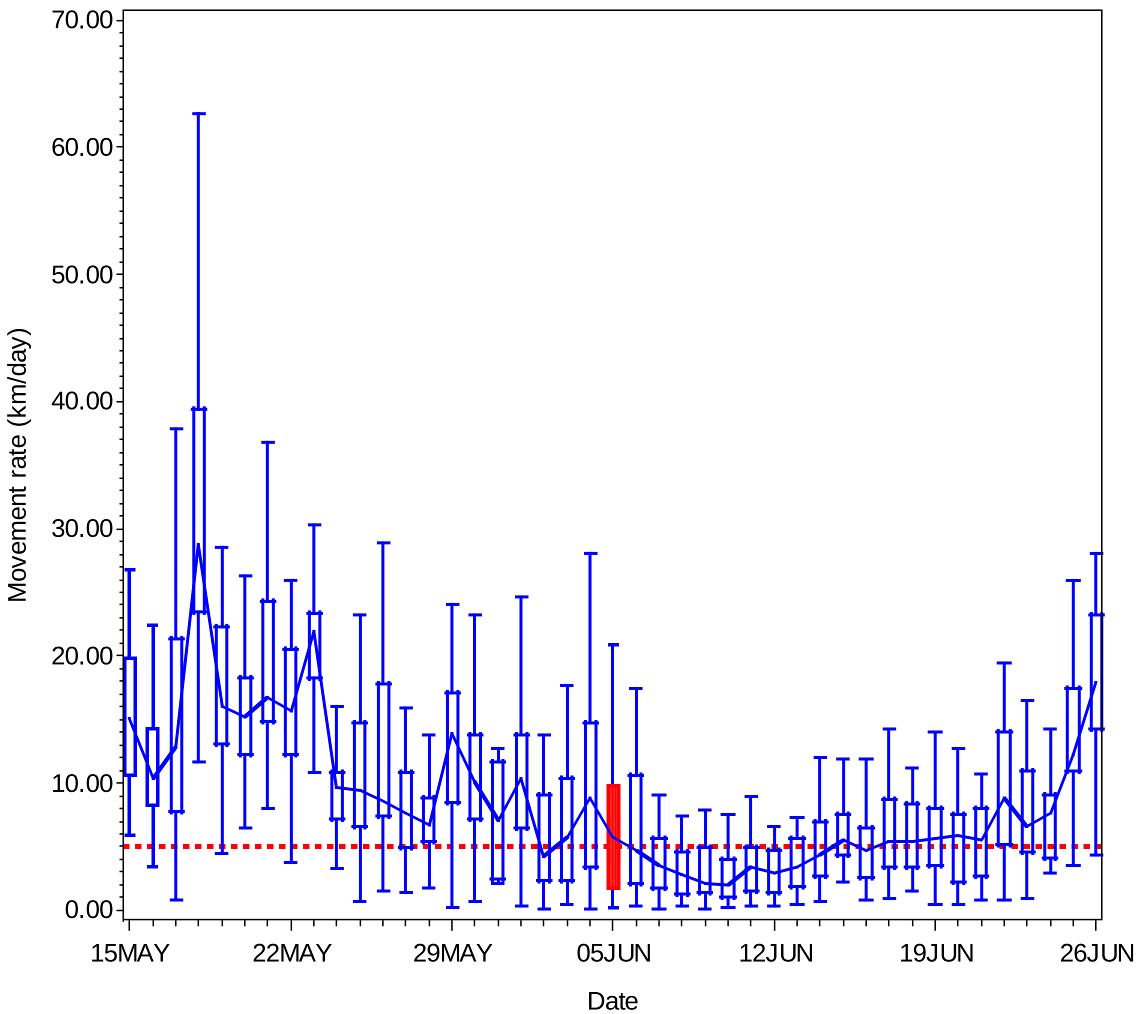

Figure 9: Movements of female collared caribou to the calving ground in 2015. The date (June 5th) the visual and photo survey was conducted in highlighted in red.

Reconnaissance surveys to delineate strata

An initial survey was conducted on June 2nd to assess the breeding status of caribou. This survey focused on collared caribou and determined that calving was in early stages (very few cows with calves). The core area survey was therefore postponed until June 4th and peripheral areas were flown on June 3rd. On June 4th a systematic reconnaissance surveys were flown by three aircraft (Table 3).

The prime objective of reconnaissance surveys was determination of the number of breeding females in the Bluenose-East herd. As with the previous survey in 2013, 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.

Table 3: Summary of reconnaissance and visual survey flying during the 2015 calving ground survey

Date	Caravan 1	Caravan 2	Pilatus Porter
June 2	Initial recon of core BE area	Arrival from YK--survey of area to East of Coppermine	Arrival from Inuvik
June 3	Recon areas E of Coppermine	Bathurst survey	Recon areas south of core area
June 4	Recon of core (high density) area	Bathurst survey	Recon core from Kugluktuk to the west
June 5	Visual S and SW of photo strata	Visual Northern and Eastern stratum	Visual Kugluktuk areas East
June 6	Recon areas N of Visual strata	Recon areas SW of core strata	Recon areas N and South of core strata

On June 4th the core area of calving was re-flown to assess calving status. Of 44 groups that contained breeding caribou, 35% contained calves which indicated that the herd was close to the peak of calving. Newborn calves that are bedded or behind their mothers are easily missed at this time of year. More detailed compositions surveys conducted on June 5th and 6th documented high proportions of cows with calves (>50%) in the core area further demonstrating that the peak of calving was beginning on June 5th as detailed later in Table 9. This was also indicated by reduced movements of collared caribou (Figure 9). The coverage of reconnaissance surveys is illustrated in Figure 10 with density and composition classes denoted.

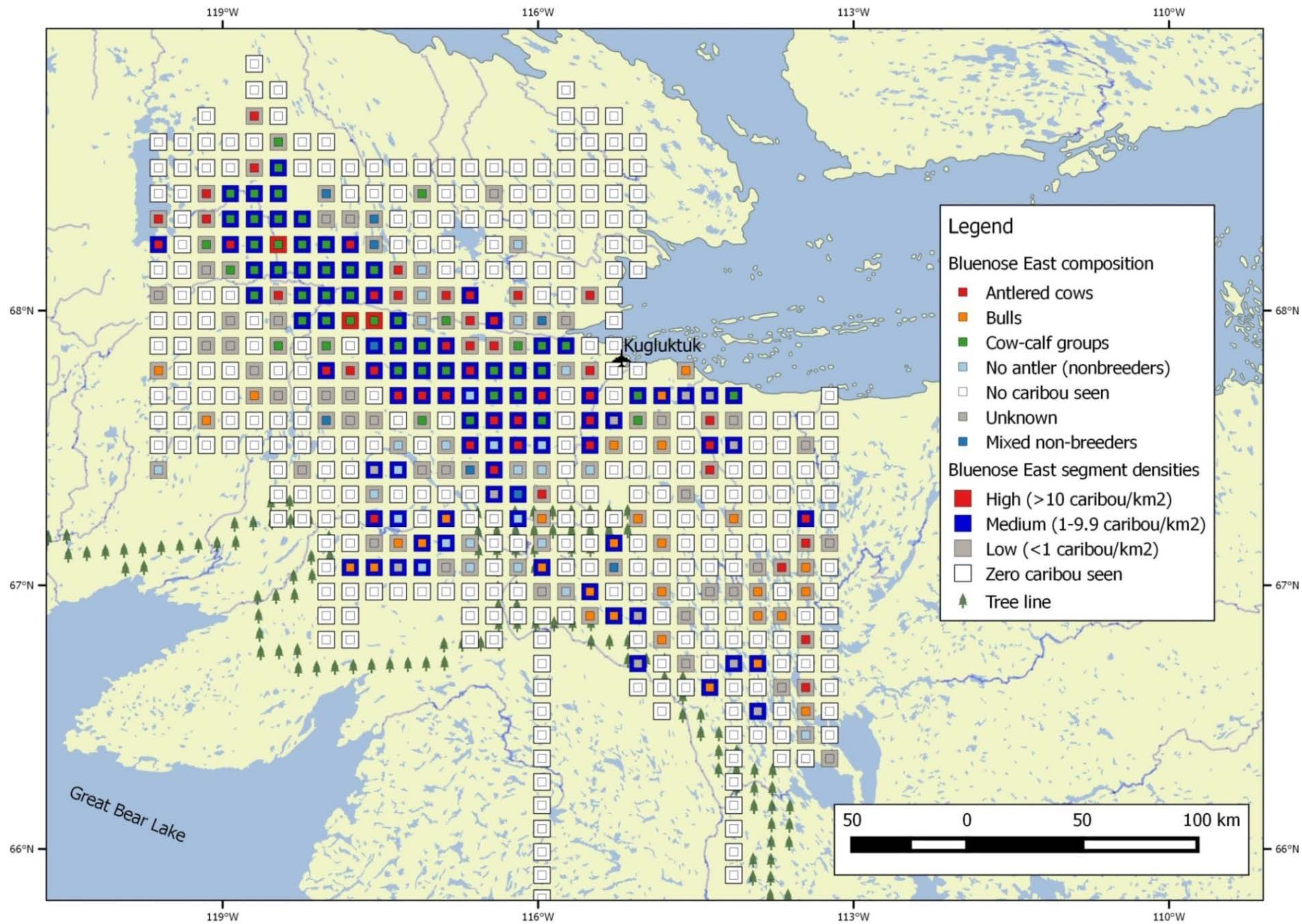

Figure 10: Reconnaissance survey coverage for Bluenose-East calving ground June 2-4 and June 6, 2015

Stratification and allocation of survey effort

The results of the reconnaissance survey revealed that higher densities of breeding caribou were found along the Rae River starting midway between Kugluktuk and Bluenose Lake and extending northwest to 30 km east of Bluenose Lake (Figure 11). Medium and lower density areas were round in the proximity of Kugluktuk which contained mixed breeding and non-breeding caribou. Based on these observations, strata were defined based on the overall distribution of caribou which extended northwest from Kugluktuk to Bluenose Lake.

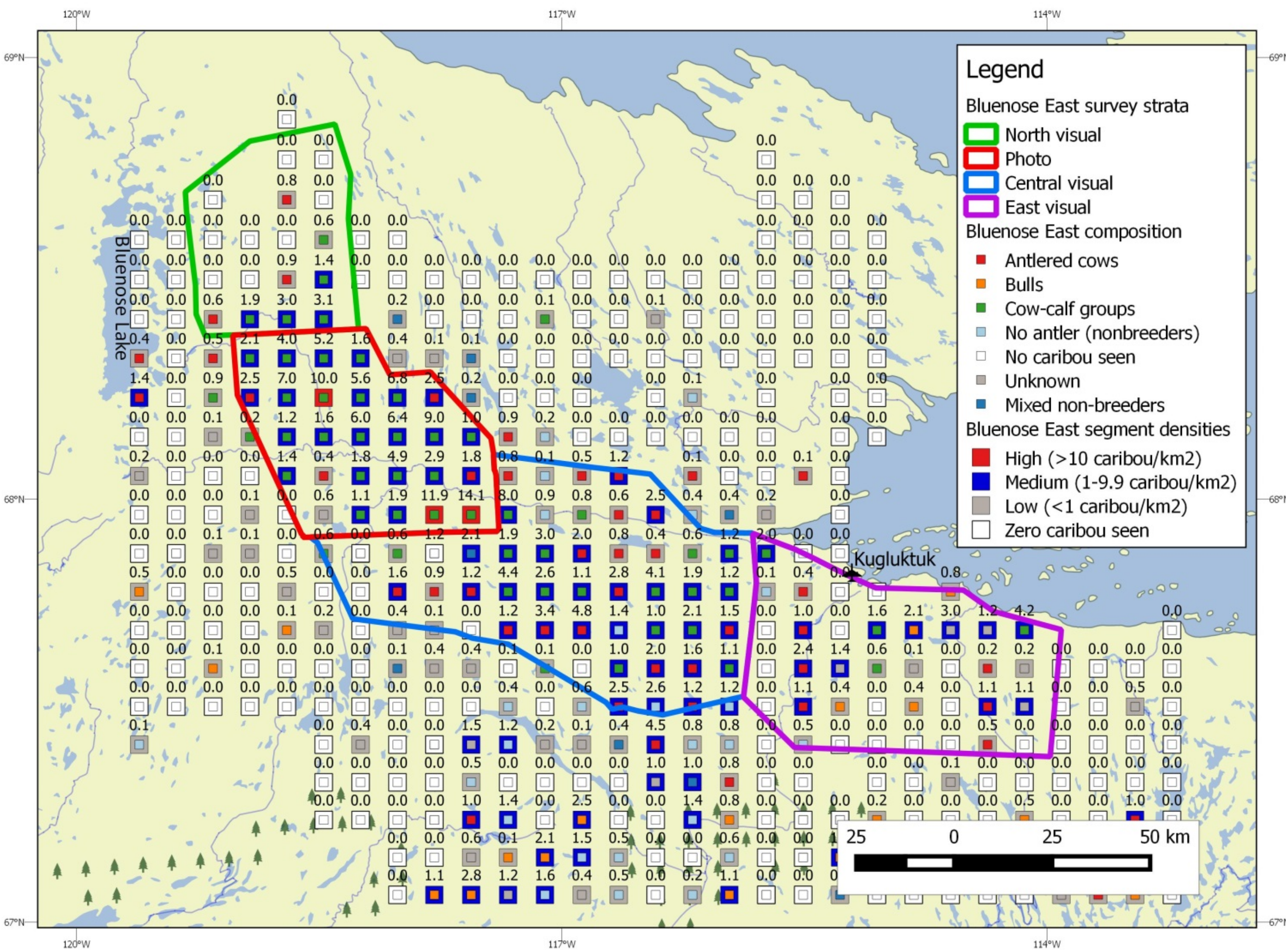

Figure 11: Summary of reconnaissance segment densities listed above segments (caribou per km^2) and composition with strata defined.

A photo stratum was defined based upon higher densities of breeding caribou observed southeast of Bluenose Lake. Visual strata were defined to the north and southwest of the photo strata which contained medium to lower densities of mixed breeders and non-breeders. A third visual stratum was defined south of Kugluktuk to sample mixed distributions of breeders and non-breeders in the vicinity of the Coppermine River. Areas to the south of the strata contained mainly bulls and non-breeding caribou at lower densities and were therefore not surveyed further (Figure 12). The distribution of collared caribou aligned well with reconnaissance observations with the main clusters of collared females occurring in the higher density photo strata (along the Rae River up to Bluenose Lake) with intermittent collared bulls and cows to the southeast.

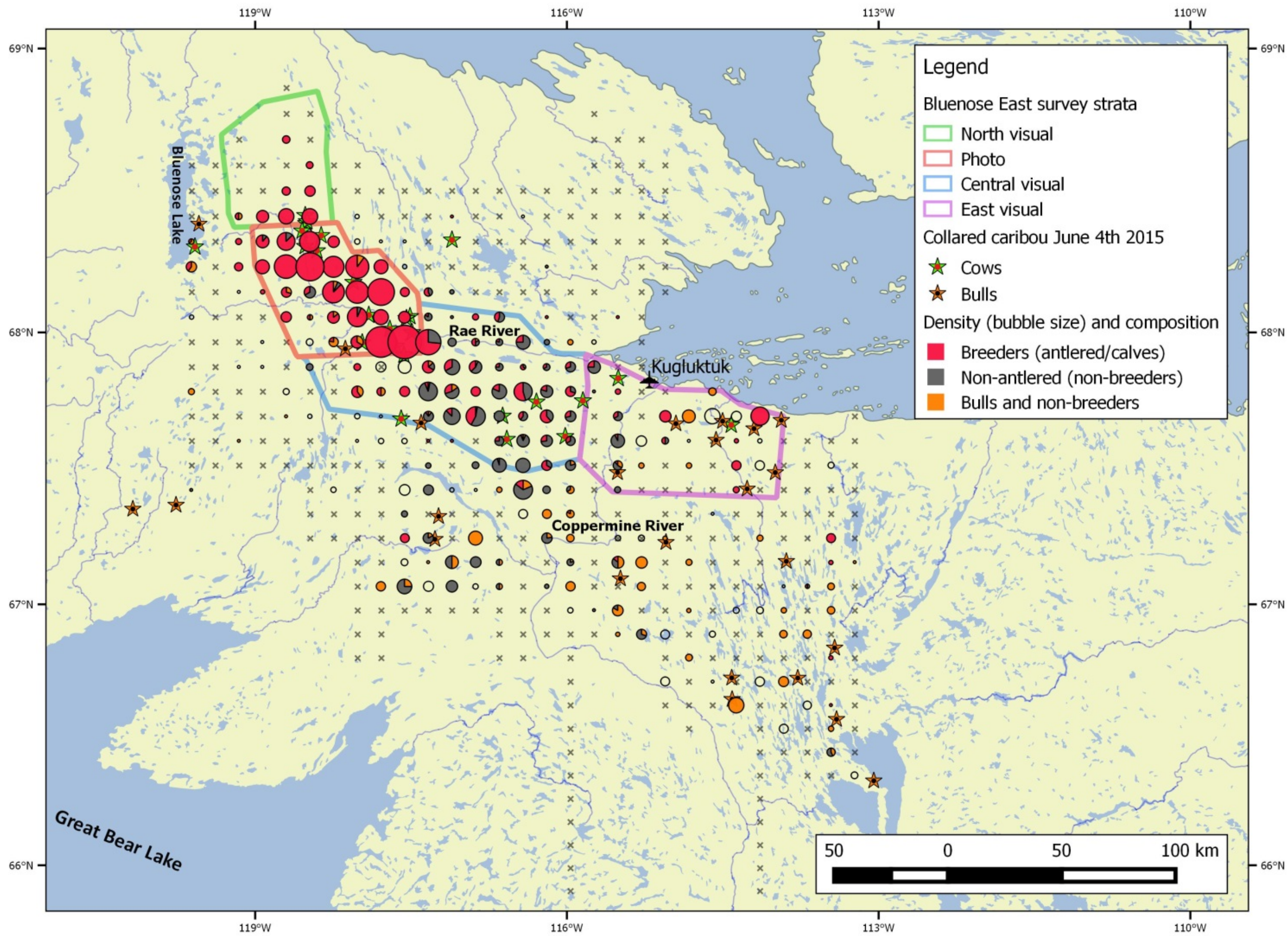

Figure 12: Final strata layout with bubbles representing the relative density of caribou in each segment along with the proportion of breeders classified in the segment. Segments that did not have breeders and non-breeders classified are given as an empty circle (proportional to density) with no color. Segments with no caribou are shown as an "x".

The actual size of the strata were formulated to capture main clusters of similar density within the calving ground and to ensure that the flying could be completed within a single survey day. The size of the photo survey strata was also based upon the likely range of coverage that would be achieved given different survey altitudes (based on forecasted could ceilings for June 5th). Preliminary estimates of caribou in each stratum were run to further verify differences in density in strata and allocate survey effort for visual strata (Table 4).

Table 4: Estimates of relative population size from the reconnaissance survey

Stratum	Area (km^2)	$\widehat{N}$	SE($\widehat{N}$)	Density	CV
Photo	2682.1	11,448	1100.95	4.27	0.10
Central	4587	7,573	976.31	1.65	0.13
North	1889	1,218	471.53	0.64	0.39
East	3431	2,538	419.97	0.74	0.17

Coverage for the photo strata was based upon the maximum number of photographs that could be taken by the photo plane and potential survey altitudes based on forecasted cloud ceilings. The tradeoff in this context was that a higher survey altitude allowed more coverage per photo and line kilometer flown. However, it was possible that lower ceilings may reduce altitude therefore requiring more photos and less overall coverage of the stratum. Previous non-digital photo planes flew at 2000 m. survey altitude so this altitude was used as the starting point and conservative estimate of likely altitude. We used approximately 30% as the lowest coverage for the photo strata. To achieve this coverage, 25 survey lines were required if the plane was flying at 2187 m AGL. Forecasted ceilings were higher than the 2187 AGL level and therefore GSD levels up to 9 (the lowest resolution needed to count caribou on photos) were also considered (Table 5).

Table 5: Range of sample coverages based on photo plane altitude and photo resolution (GSD) considered for the high density photo stratum.

Altitude (AGL)	Photo Resolution GSD	Number of transects	Average transect length	Photo Strip width (approximate)[A]	Estimated Area surveyed	Estimated coverage	Number of photos required
2187	4	25	51.7	692	894.5	33.4%	7142
2734	5	25	51.7	866	1119.5	41.7%	5720
3281	6	25	51.7	1039	1343.1	50.1%	4770
3828	7	25	51.7	1212	1566.7	58.4%	4078
4374	8	25	51.7	1385	1790.4	66.8%	3571
4921	9	25	51.7	1558	2014.0	75.1%	3176

[A]The actual strip width is determined when photos are post processed and will partially depend on local topography and actual survey altitude (as recorded on photos).

Visual strata coverage was allocated based upon the maximum amount of flying time for 3 survey planes within a single survey day when also considering ferry times to each of the stratum. Given weather conditions and the concurrent Bathurst survey it was decided to survey the visual stratum within a single survey day. For this, the maximum kilometers to be flown on transect (excluding ferry kilometers) was set at 2500 km. Allocation was based on number of caribou estimated in each stratum, and the standard error of estimates (from Table 4). The number of actual lines to be surveyed was then adjusted to be at least 10 lines to keep variances low. Allocation results suggested putting the most survey effort in the Central stratum given that it had the highest densities of caribou compared to other stratum. The allocation for the Central was lowered to bring the number of transects to the North stratum to 10. The East stratum was kept at the allocated number of transects (14). The total number of kilometers flown on transect was kept close to the 2500 km limit with adjustments included (Table 6).

Table 6: Allocation of effort for visual lines using population size estimate (Using N) or standard error of estimates (Using SE) and adjustment of lines to meet survey criteria.

Stratum	Optimal No. of transects		Coverage		Percentage effort		Adjusted lines		Km on transect
	Using N	Using SE	Using N	Using SE	Using N	Using SE	transects	coverage	
North	8.0	8.4	13.3	13.8	12.7%	13.2%	10	20.0%	472.0
Central	38.7	38.0	27.0	26.5	62.9%	61.6%	33	24.3%	1394.4
East	14.0	14.4	14.2	14.6	24.4%	25.1%	14	14.2%	609.8
									2476.2

Survey ceilings were high enough on June 5th to allow the photo plane to fly at 3828 meters which resulted in coverage of 55.4% (using corrected coverage from ortho-photo analysis of photos). Visual surveys were mainly flown with a strip width of 800 meters. During post-processing of the data it was discovered that the Pilatus porter flew at lower survey altitudes which reduced the strip width for lines that this aircraft flew (eastern 11 lines of central visual stratum and 4 western lines of the East stratum). This reduced coverage for these strata from planned levels (Table 7). The formula used for estimates were also modified to mitigate any bias caused by differences in strip width as discussed in the methods section.

Table 7: Final dimensions of strata surveyed for the 2015 Bluenose-East caribou survey.

Stratum	Total transects possible	Sampled Transects	Area of stratum (km^2)	Strip width (km)	Transect area (km^2)	Coverage
Photo	50	25	2682.1	1.15	1486.6	55.4%
North	49	10	1889.2	0.8	377.6	20.0%
Central	136	33	4586.8	0.65-0.8[A]	902.98	19.7%
East	102	14	3430.9	0.65-0.8	401.13	11.7%

[A]Mean strip width for stratum reduced due to one aircraft flying at lower altitude.

Survey results

Photo plane survey

The photo plane surveyed the high density photo stratum on June 5th from 330pm to 1130 pm. Survey conditions were excellent with high cloud ceilings (Figure 8) therefore allowing a higher survey altitude and subsequent higher coverage of the stratum. Movement of collared caribou between the reconnaissance and visual survey was minimal with a tendency of north-ward movement for most collared caribou (Figure 13). Three of 30 collared caribou were not in the survey stratum. One was at the south end of Bluenose Lake and was associated with a very low density cluster, and one was to the east of the high density stratum. In both cases these caribou were associated with very low density clusters of caribou (Figure 12). One caribou was in the high density stratum on June 4th but then moved just outside the stratum on June 5th.

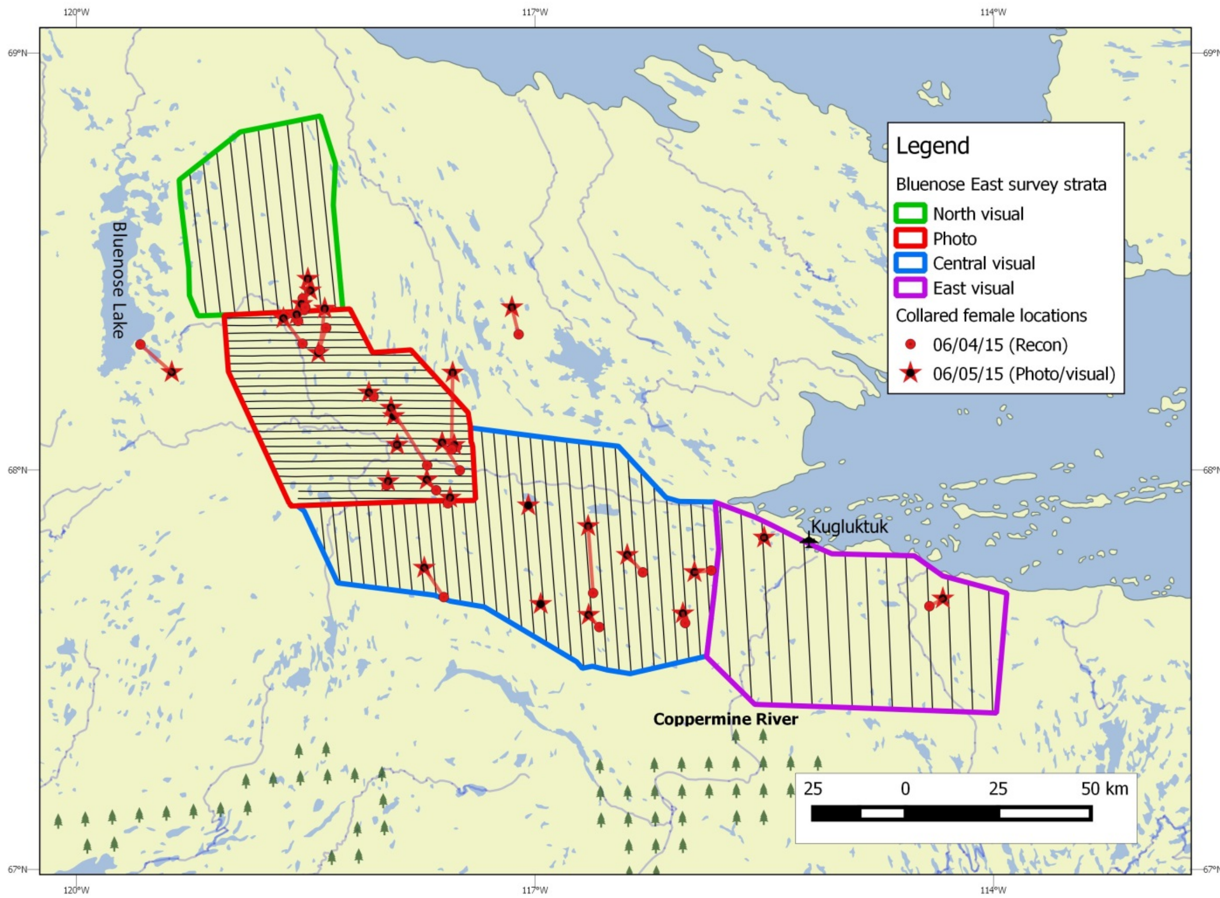

Figure 13: Transect layout of the photo and visual strata. Also shown are the locations of collared females during the primary reconnaissance survey (June 4th) and photo/visual survey (June 5th). Red lines connect the locations for June 4th and 5th for individual caribou.

Visual surveys: Double observer visual analysis

The double observer analysis was conducted with data from both the Bluenose-East and Bathurst calving ground surveys. As a prerequisite for the double observer analysis, data were summarized in terms of group sizes and whether caribou were seen by both or only one observer (Figure 14). Overall, most groups of caribou counted were composed of 20 or less caribou. Some caribou were missed by the primary and secondary observers, but most cases of only one observer counting a caribou group occurred for group sizes of 4 or less. Larger groups were consistently observed by both observers.

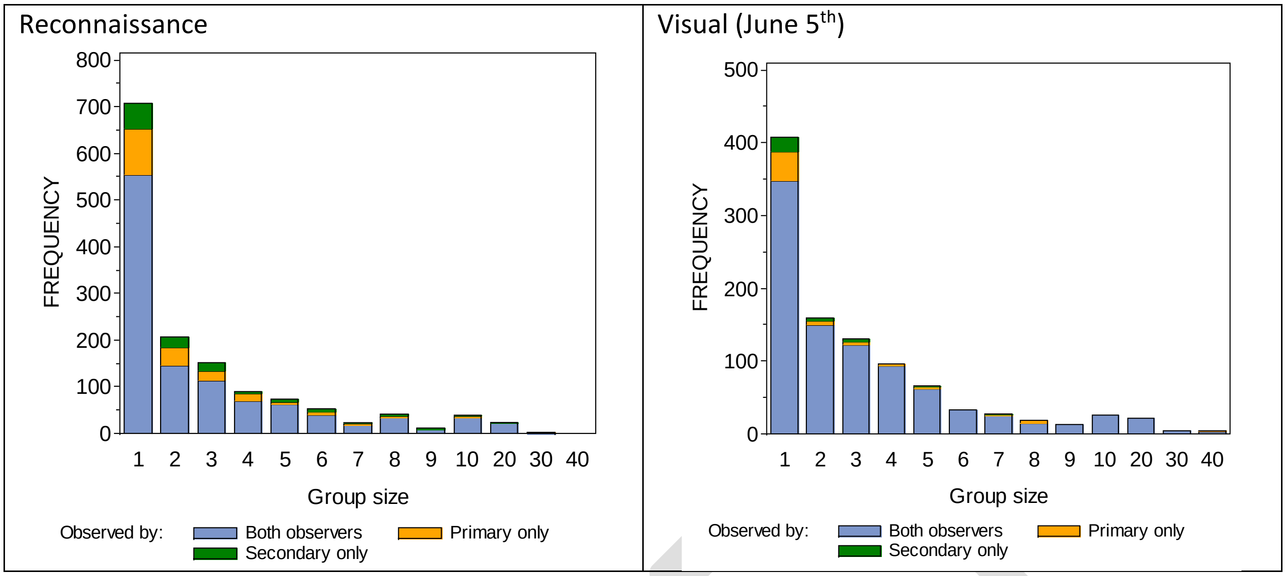

Figure 14: Summary of group sizes, cloud cover, and snow cover observed for the double observer visual plane.

The degree of cloud cover and snow cover decreased between the reconnaissance and visual surveys. Conditions were mixed with higher cloud cover and moderate snow cover in some areas during reconnaissance surveys. Conditions improved for visual surveys with generally clear sky and reduced snow cover which increased sightability (Figure 15).

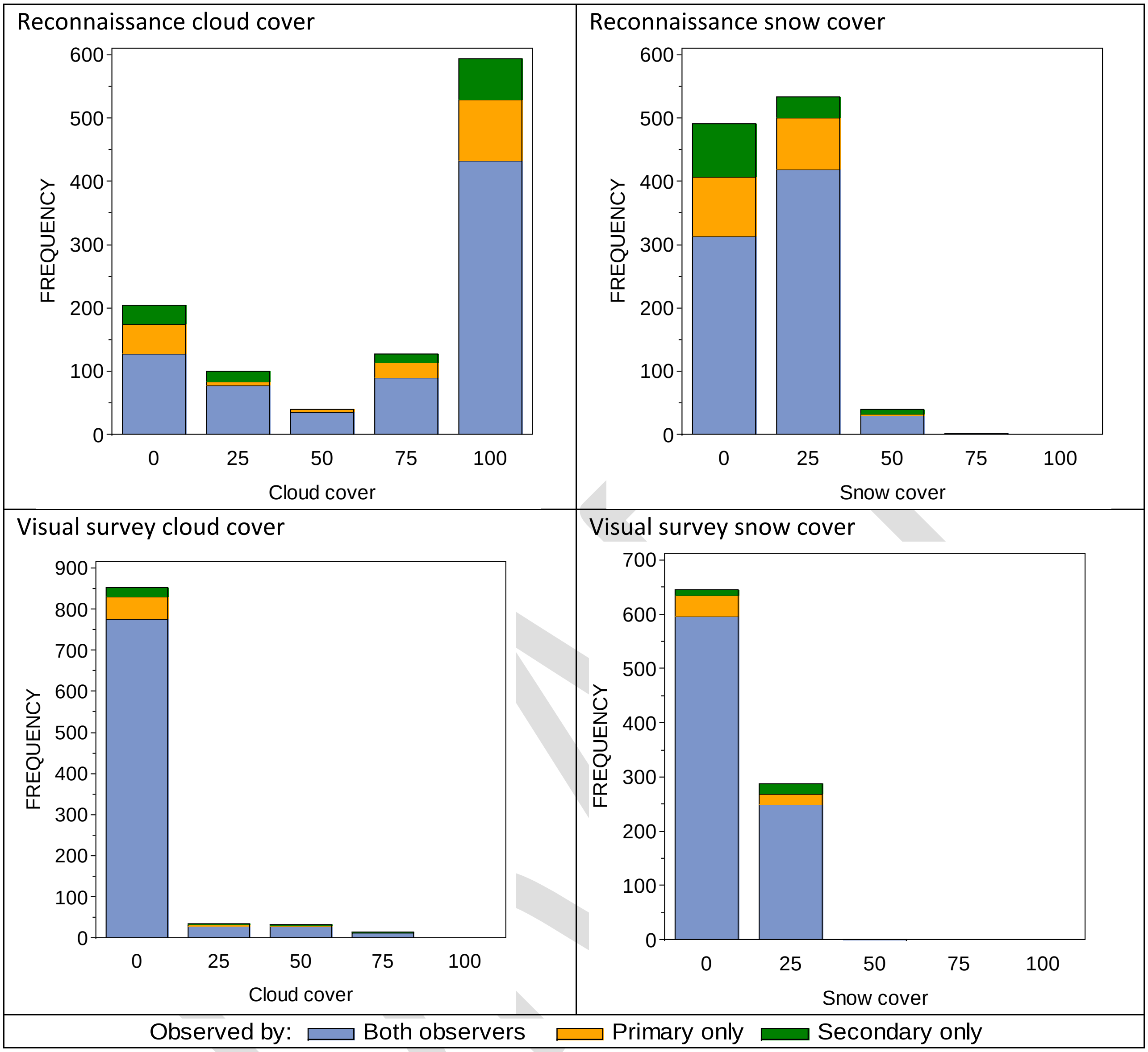

Figure 15: Cloud and snow cover for visual and reconnaissance surveys. The proportion of observation seen by single and both observers is also summarized.

The double observer data were analyzed using the Huggins closed model in program MARK. Model selection focused on building a parsimonious model to describe variation in sightability caused by calving ground/herd (symbolized by *h*) ,group size, snow cover, cloud cover, phase of survey (reconnaissance or visual) and observer variability. An initial model with the log of group size (Table 8, Model 17) was substantially more supported than an intercept model (model 19). A model with all the observer pairs (Model 15) was also substantially more supported than models without observer pairs. A model that considered the order of observer pairs that had applicable sample sizes of observations (Model 14) was also more supported. The next set of models considered phase of survey, snow cover, and cloud cover. Survey conditions were appreciably different on the Bluenose and Bathurst calving grounds. Cloud and snow cover was higher in reconnaissance but not visual surveys for the Bluenose-East (Figure 15). In contrast, cloud and snow cover were more pronounced during both the reconnaissance and visual surveys of the Bathurst herd. This issue and differences in topography made it possible that mean levels of sightability and relationships between sightability and cloud/snow cover could be different for the 2 calving grounds. A model that assumed similar relationships between sightability and snow/cloud cover between the 2 calving grounds (Model 11) was contrasted with models that considered herd-specific relationships (Models 1-8). Of the models considered, a model with herd/calving ground specific relationships between cloud and snow cover was more supported than models that considered similar relationships for each calving ground.

Table 8: Double observer closed Huggins model selection results. Main model terms are listed as columns with covariate names as defined in Table 1. An "x" refers to a linear covariate whereas x^2 refers to the quadratic form of a covariate, an "h" refers to herd-specific estimates for the x term, and log refers to a natural log transformed covariate. Resighting probabilities (c) were modeled as a function of group size for all models. Sample size adjusted Akaike Information Criterion (AICc), the difference in AICc between the most supported model for each model (ΔAICc), AICc weight (w_i), number of model parameters (K) and deviance is given.

No.	Group size	observers	Obs. order	Phase (recon)	Herd (h)	cloud	snow	cloud*snow	plane	AIC_c	ΔAIC_c	w_i	K	Deviance
1	log(x)	all	red	x		$x+hx+hx^2$	$x+x^2+hx$	x		2842.7	0.00	0.36	26	2790.4
2	log(x)	all	red	x		$hx+hx^2$	hx	x		2843.1	0.39	0.30	24	2794.8
3	log(x)	all	red	x		$x+hx+hx^2$	x+hx	x		2844.8	2.07	0.13	26	2792.5
4	log(x)	all	red	x	x	$hx+hx^2$	hx	x		2844.9	2.18	0.12	25	2794.6
5	log(x)	all	red	x	x	$x+hx+hx^2$	$x+x^2+hx^2$	x		2846.6	3.92	0.05	27	2792.3
6	log(x)	all	red	x	x	$hx+x^2$	$hx+x^2$	x		2848.8	6.11	0.02	25	2798.5
7	log(x)	all	red	x	x	hx	hx	x		2849.4	6.64	0.01	23	2803.1
8	log(x)	all	red	x	x	$hx+x^2$	$hx+x^2$	x	x	2850.8	8.13	0.01	26	2798.5
9	log(x)	all	red	x	x	x	x	x		2852.8	10.07	0.00	23	2806.5
10	log(x)	all	red	x		$x+x^2$	$x+x^2$	x		2866.3	23.62	0.00	24	2818.1
11	log(x)	all	red	x	x	$x+x^2$	$x+x^2$	x		2868.3	25.61	0.00	25	2818.1
12	log(x)	all	red	x	x		x	x		2869.4	26.71	0.00	22	2825.2
13	log(x)	all	red	x	x					2871.5	28.79	0.00	20	2831.3
14	log(x)	all	red							2876.6	33.89	0.00	18	2840.5
15	log(x)	all								2922.6	79.92	0.00	14	2894.5
16	log(x)			x	x	x	x	x		2953.8	111.06	0.00	9	2935.7
17	log(x)									3041.4	198.69	0.00	4	3033.4
18	x									3069.8	227.08	0.00	4	3061.8
19										3129.8	287.09	0.00	2	3125.8

Sightability curves for single and double observers were derived from Model 1 to illustrate the effect of group size on sightability (Figure 16). These curves demonstrated that using 2 observers increased sighting probabilities compared to a single observer. Single observer probabilities correspond to that of a single observer on the side of the plane. Double observer sighting probability is the combined sightability for 2 observers working together and is most applicable to the actual survey estimates. For the majority of observers, sightability was close to 1 for both observers combined once group size was greater than 5.

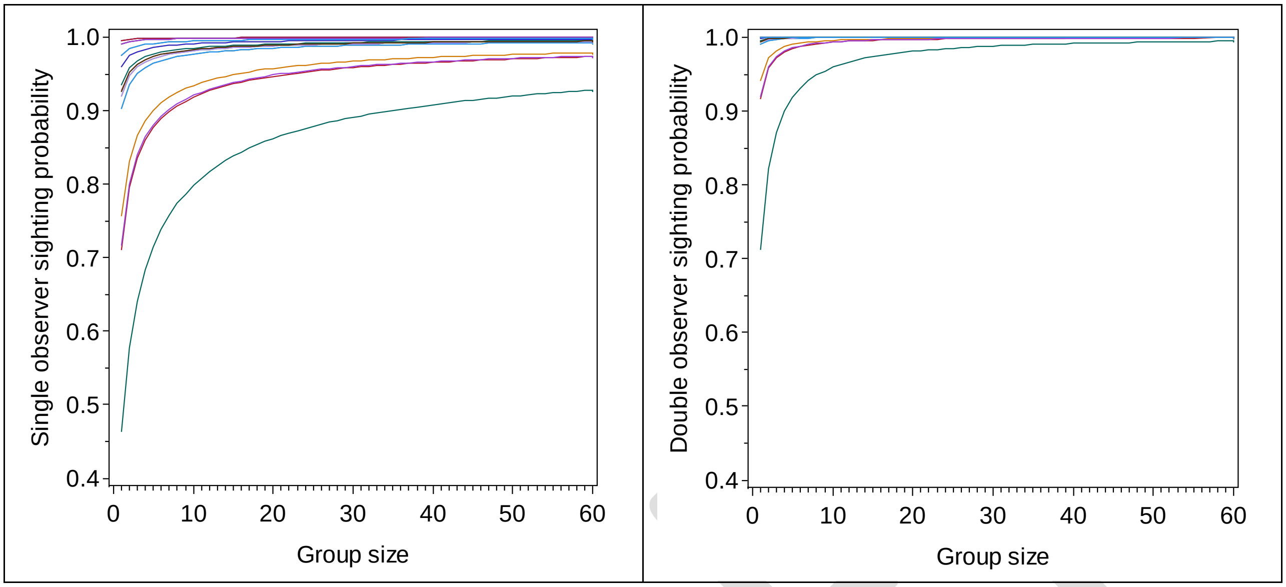

Figure 16 :Predicted single and combined (double) observer sighting probabilities for the visual phase of the survey with other covariates set at mean levels.

The double observer sightability was high (>0.95) for snow cover conditions of less than 50% irrespective of cloud cover for the Bluenose-East calving ground (Figure 17). The distribution of cloud cover was less than 50% (Figure 15) for the visual survey (in contrast to the reconnaissance phase) which led to an overall high mean level of double observer sightability for the Bluenose-East of 0.99 (single observer=0.94) suggesting the majority of caribou were observed during the visual survey. Mean sighting probabilities were lower for the reconnaissance phase (single observer=0.84, double observer=0.94) due to higher levels of snow and cloud cover.

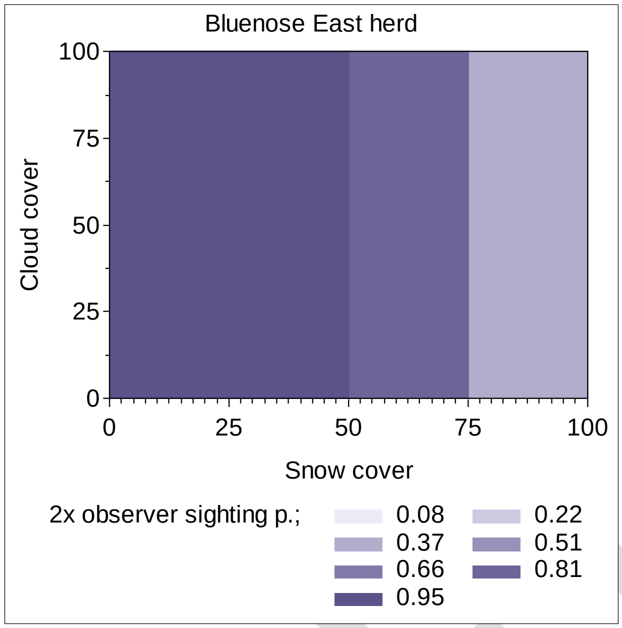

Figure 17: Double observer sighting probabilities as a function of cloud and snow cover for the Bluenose-East survey.

Observed distribution and densities of caribou on calving ground

The distribution of caribou counted on strata (photo and visual) were summarized by estimating the density of caribou on 1 kilometer segments of transects on the each of the strata (Figure 18). The highest densities of caribou counted were observed in the high density stratum with the majority of high density groups counted in central regions. Sporadic medium to lower density groups of caribou were observed in the other stratum.

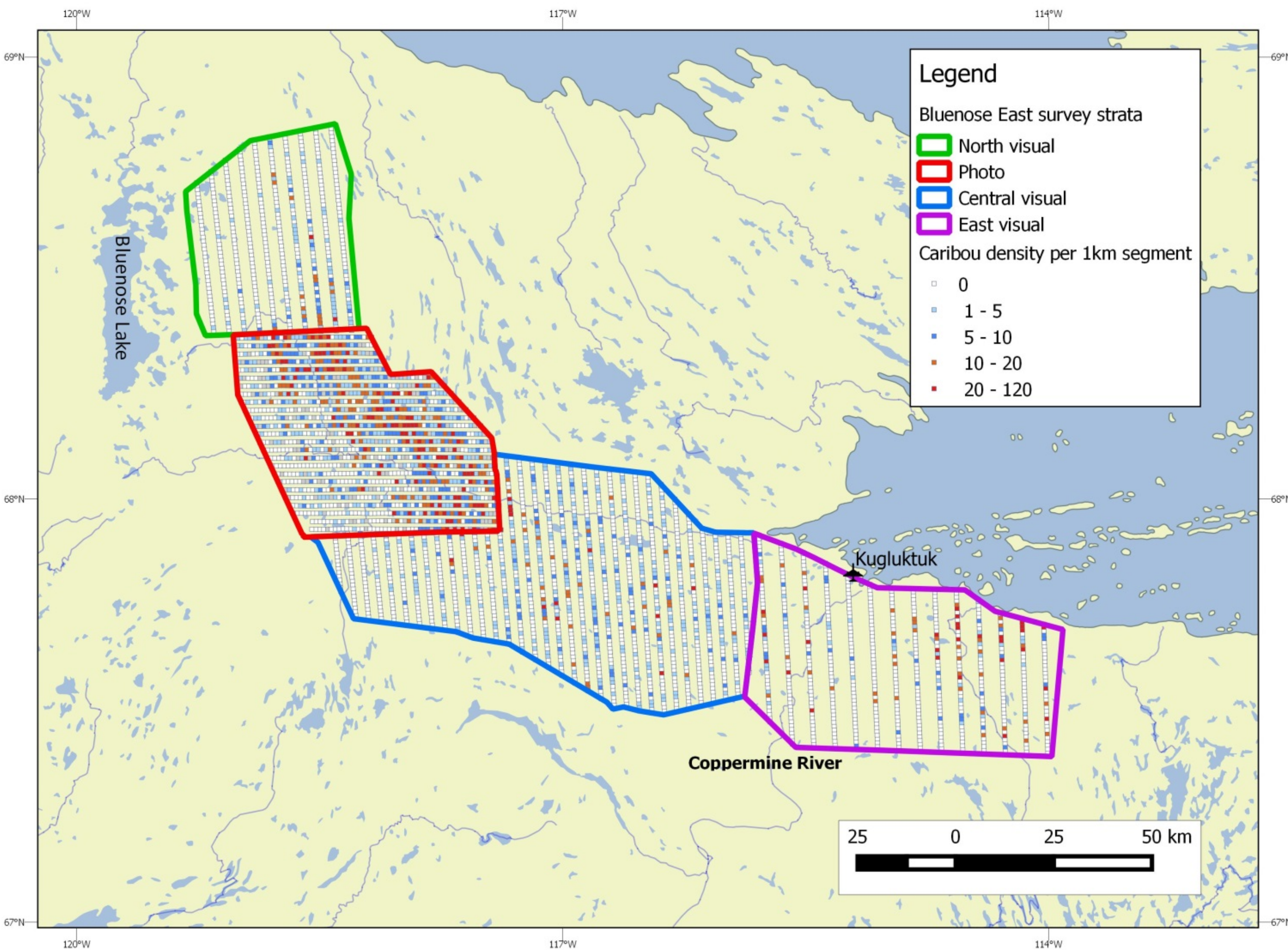

Figure 18: Caribou densities estimated for 1 kilometer transect segments on visual and photo transect lines.

Estimation of caribou on the calving ground.

Caribou on each stratum were estimated from photo and double observer visual estimates on the high density stratum and from double observer estimates on the other strata. The majority of caribou were estimated in the photo stratum (18,165 caribou) and the central visual stratum (11,099) which had relatively precise estimates as indicated by the coefficients of variation of 4.5% and 11.8% (Table 9). As a result the total estimate was relatively precise. The total estimate of caribou at least one year old on the calving ground was 38,041 (CI=33,569-42,513).

Table 9: Estimates of caribou at least one year old on the calving ground based upon raw counts, double observer estimates, and caribou counted on the photos (in the photo stratum).

Strata attributes					Estimates			
Stratum	transects	Transect area	Coverage	Caribou counted or estimated	Density	$\widehat{N}$	SE($\widehat{N}$)	CV
Photo	25	1486.6	55.4%	10,068	6.8	18,164.9	817.8	4.5%
North	10	377.6	20.0%	496.0	1.3	2,481.9	710.9	28.6%
Central	33	903.0	19.7%	2174.9	2.4	11,098.6	1305.5	11.8%
East	14	401.1	11.7%	732.3	1.8	6,295.4	1285.4	20.4%
						38,040.8	2128.6	5.6%

The increase in the overall estimate from the double observer methods was minimal due to favorable conditions during the visual survey (Figures 8 and 15). For example, the estimate of total caribou on the calving ground without double observer sightability correction was 37,958 (SE=1053.2, CV=2.7%), a difference of 83 caribou (<1% difference). Precision of double observer estimates was slightly lower than non-corrected estimates.

Composition on calving ground

Composition surveys were conducted on each of the survey strata on June 5th and 6th. On June 5th the northern part of the Central Visual, Photo, and North stratum were surveyed. Congregations of mixed breeders and non-breeders were found in the Central Visual stratum whereas mainly breeding caribou were found in the Photo and Northern strata. On June 6th the Central Visual and Eastern stratum were surveyed. In the Central Visual stratum, congregations of non-breeding adult females (small antler with no udder/calf) were found intermixed with yearlings and bulls. The Eastern stratum was mainly composed of yearlings and bulls (Figure 19).

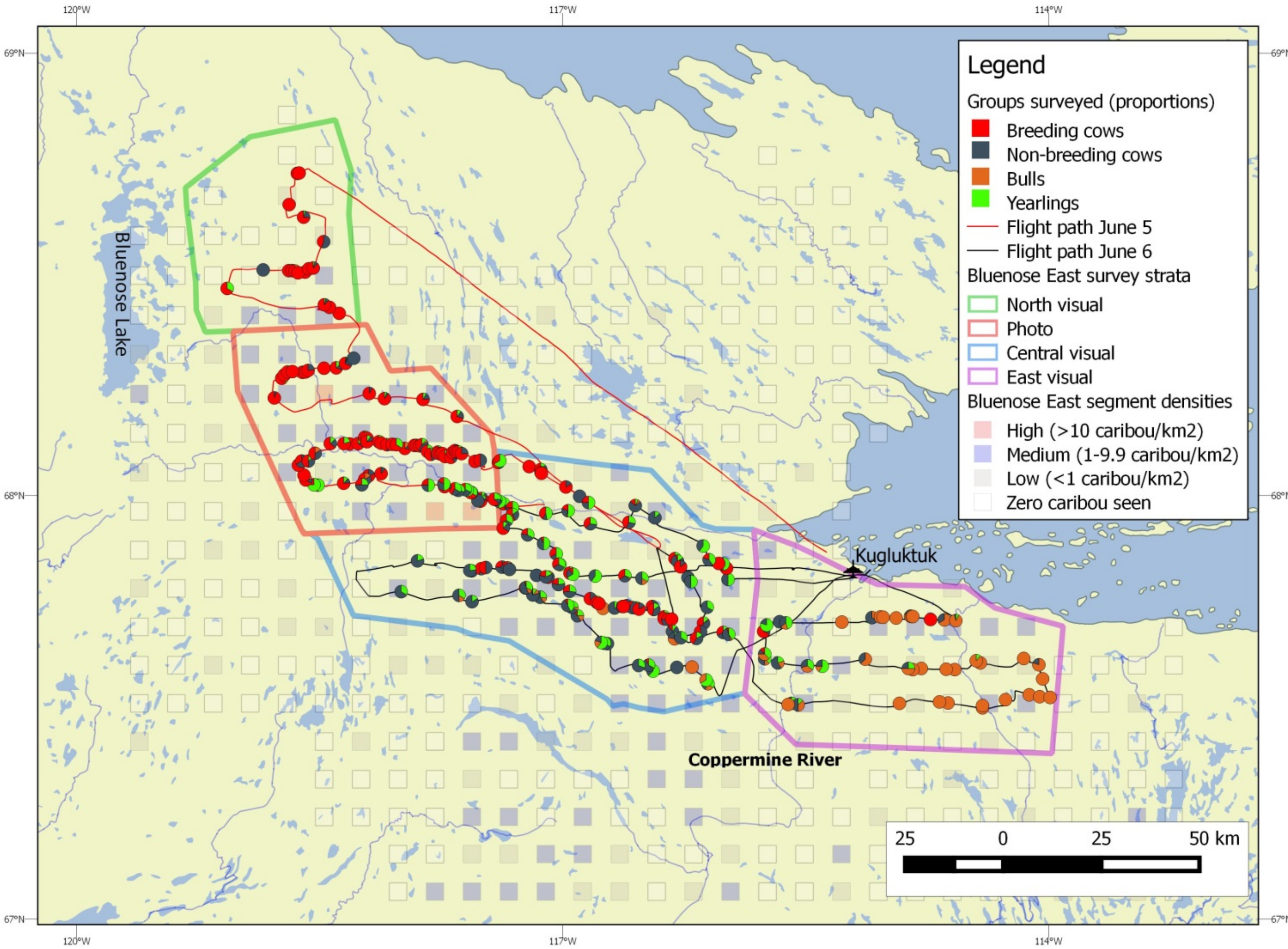

Figure 19: Sampling of composition on the Bluenose-East calving ground from June 5 and 6th. Individual sample points are given as pie charts that reflect proportions of the main composition classes in each group sampled. Reconnaissance based segment densities are given for reference.

The number of caribou classified for each stratum varied with caribou density and size of the survey stratum (Table 10).

Table 10: Summary of composition samples in each of the survey strata.

Category		Sum of counts			
		Photo	North	Central	East
Groups sampled		75	17	101	43
Breeding females	Antler & udder	363	40	119	3
	No antler & udder	61	8	80	3
	Antler & no udder	424	92	117	10
Non-breeding	No Antler/udder	269	21	498	47
	Yearlings	186	6	274	48
	Bulls	10	1	45	167
Calves		478	59	187	9
All 1+ yr caribou		1290	168	1156	278

The proportion of breeding females was estimated by the ratio of the sum of the breeding females divided by the number of one-year-plus caribou observed (Table 11). Proportion adult females were estimated as the number of breeding and non-breeding females observed divided by the number of one-year plus old caribou. Bootstrap resampling was used to estimate percentile based confidence limits and estimates of standard error.

Table 11: Estimates of proportion breeding females, standard error (SE), 95% confidence intervals (CI), and coefficient of variation (CV) in the Low and High strata.

Strata	Proportion breeding females				Proportion females (breeding and non-breeding)			
	Estimate	SE	Confidence Limit		Estimate	SE	Confidence limit	
Photo	0.657	0.027	0.602	0.71	0.848	0.018	0.81	0.879
North	0.833	0.039	0.741	0.894	0.958	0.012	0.93	0.978
Central	0.273	0.026	0.223	0.323	0.724	0.021	0.682	0.765
East	0.058	0.045	0	0.161	0.227	0.05	0.135	0.335

Estimation of breeding females

Breeding females were estimated by multiplying the estimate of 1+ year old caribou for each stratum (Table 8) by the proportion of breeding female estimated in each stratum (Table 11) during composition surveys (Table 12). Decimal places were kept on the stratum-specific caribou estimates to minimize rounding error. The majority of caribou were in the high density stratum and the proportion of breeding females was 0.657 leading to an estimate of 11,934 breeding females. The north stratum had a higher proportion of breeding females; however, the actual estimate of 1+ year old caribou in this stratum was only 4,482. The central stratum had a higher abundance of caribou than the north stratum; however it contained a lower proportion of breeding females. The resulting estimate of breeding females (17,396, CI= 15,088-19,704) was precise mainly due to the high precision of the photo stratum estimate (Table 12).

Table 12: Estimates of breeding females based upon estimates of caribou in each stratum and composition surveys.

Strata	Caribou	Total caribou on calving ground				Proportion Breeding Females			Breeding Females		
	Counted	Density	N	SE(N)	CV	Proportion	SE	CV	N	SE(N)	CV
Photo	10,068	6.77	18,164.9	817.8	4.5%	0.657	0.027	4.1%	11,934	727.5	6.1%
North	496	1.31	2,481.9	710.9	28.6%	0.833	0.039	4.7%	2,067	599.9	29.0%
Central	2,120	2.42	11,098.6	1305.5	11.8%	0.273	0.026	9.5%	3,030	458.6	15.1%
East	699	1.83	6,295.4	1285.4	20.4%	0.058	0.045	77.6%	365	292.8	80.2%
Total			38,040.8	2128.6	5.6%				17,396	1088.6	6.3%

Estimation of adult females

Adult females were estimated as the product of the total number of caribou (Table 8) and the proportion of adult females in each stratum. Proportions of adult females were relatively high in the Photo, North, and Central stratum. The resulting estimate of 27,246 adult females (CI= 24,172-30,320) was` precise with a CV of 5.4% (Table 13).

Table 13: Estimates of adult females based upon estimates of caribou in each stratum and composition surveys.

Strata	Caribou	Total caribou on calving ground				Proportion Adult Females			Adult Females		
	Counted	Density	N	SE(N)	CV	Proportion	SE	CV	N	SE(N)	CV
Photo	10,068	6.77	18,164.9	817.8	4.5%	0.848	0.018	4.2%	15,403.8	766.7	5.0%
North	496	1.31	2,481.9	710.9	28.6%	0.958	0.012	4.6%	2,377.7	681.7	28.7%
Central	2,120	2.42	11,098.6	1305.5	11.8%	0.724	0.021	9.9%	8,035.4	973.5	12.1%
East	699	1.83	6,295.4	1285.4	20.4%	0.227	0.05	76.7%	1,429.1	429.2	30.0%
Total			38,040.8	2128.6	5.6%				27,246	1478.0	5.4%

Fall composition surveys to estimate adult sex ratio

Surveys were conducted from October 28 to 30, 2015 to estimate the adult sex ratio for the Bluenose-East herd (Figure 20). A helicopter was used to sample caribou in the vicinity of collared Bluenose-East females and males.

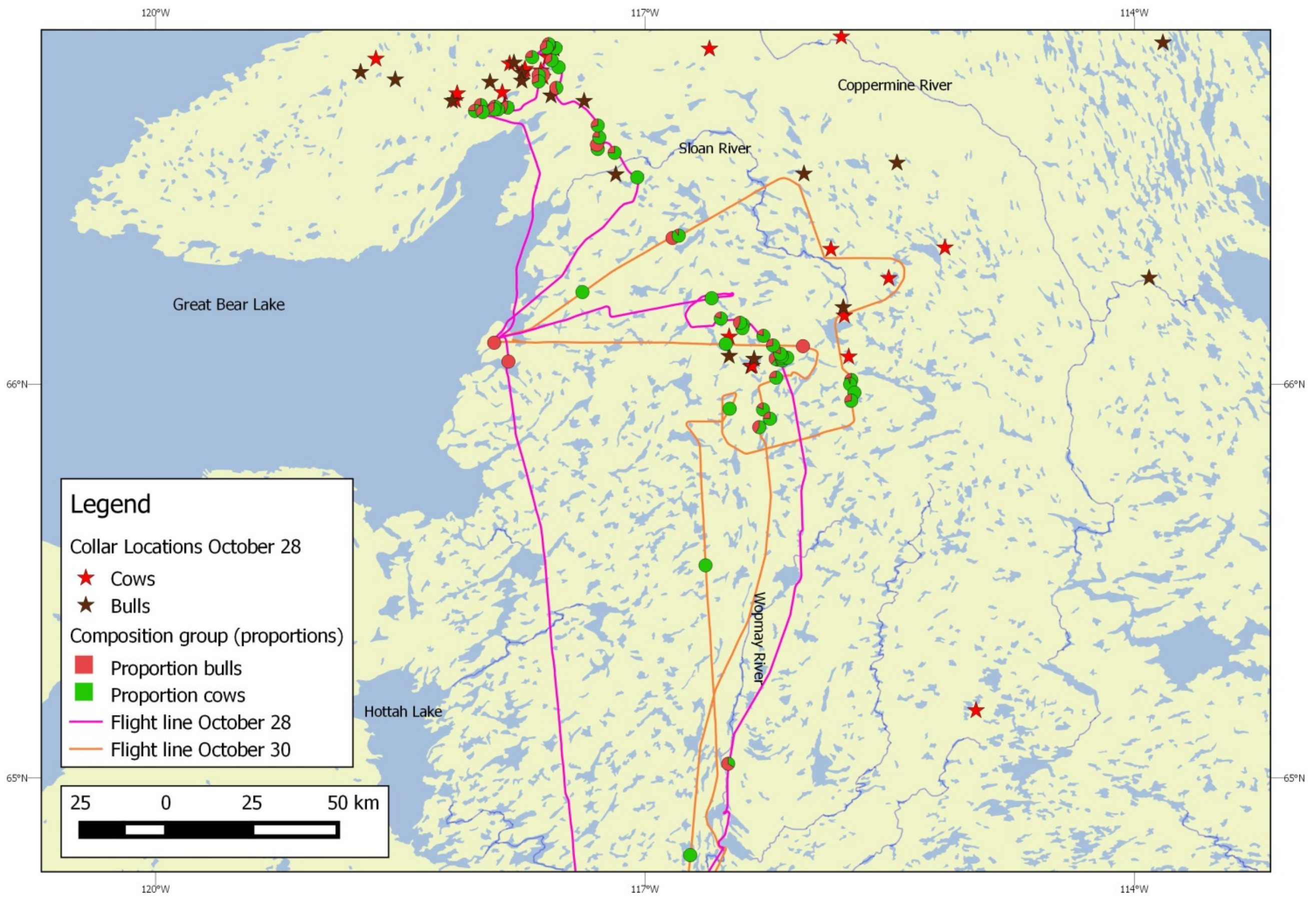

Figure 20: Flight path and groups sampled for fall 2015 composition survey conducted from October 28-30 2015. Pie charts are given as data points to show proportion cows and bulls observed.

During this time, 58 groups composed of 4199 individuals were classified with a mean group size of 58.2 individuals (Table 14).

Table 14: Summary statistics for fall composition surveys conducted in 2009, 2013, and 2015.

Statistic	Year		
	2009	2013	2015
Number of groups	79	117	58
Mean group size	43.38	36.73	58.2
Total caribou	4531	5381	4199
Total adults (1.5+ year old)	3427	4297	3373
Total cows	2399	3004	2381
Total bulls	1028	1281	992
Total yearlings	0	12	0
Total calves	1104	1084	826

The estimated proportion of cows and the bull-cow ratios were similar in 2009, 2013, and 2015 (Table 15).

Table 15: Proportion of cows and bull-cow ratios from the 2009 and 2013 composition surveys. The proportion is based upon the total adults counted (excluding calves of the year) as listed in Table 11. Percentile-based confidence limits are shown (CI).

Year	Proportion of Cows	SE	Confidence Limit		Bull:Cow Ratio	SE	Confidence Limit	
2009	0.700	0.008	0.684	0.716	0.429	0.017	0.396	0.463
2013	0.701	0.009	0.685	0.720	0.426	0.019	0.389	0.461
2015	0.706	0.014	0.678	0.734	0.417	0.029	0.367	0.479

Extrapolated estimate of total herd size

Using assumed pregnancy rates

An estimate of herd size was derived by dividing the estimate of breeding females (Table 12; 17,396) by a fixed pregnancy rate (0.72, CV=10%) to obtain an estimate total adult females in the herd of 24,161 (±6,042). This estimate is then divided by the proportion females in the herd (0.706 from Table 15) to estimate total herd size. Using this method, the overall herd size estimate is 34,223 1.5+ year old caribou (SE=4095.4, CV=12.0%, CI=25,541-42,904). This estimate is lower than the number of caribou estimated on the core calving ground (Table 16).

Table 16: Extrapolated estimate of total herd size for 2015 using breeding female estimates (Table 12), assumed proportion of females pregnant, and estimates of proportion of adult females in the entire herd from 2015 fall composition surveys (Table 15).

Survey data	Estimate	SE	CV	Confidence limit	
Number of caribou on the breeding ground	38,041	2128.6	5.6%	33528	42553
Number of breeding females	17,396.0	1088.6	6.3%	19704	19704
Proportion 1.5$^+$ year females pregnant	0.720		10.0%		
Proportion adult females in the entire herd	0.706	0.0142	2.0%		
Total herd estimate (1.5+ year old caribou)	34,223	4095.4	12.0%	25541	42904

Using estimates of adult females

For the Bluenose-East herd in 2015, the estimate of total adult females in the core calving area was 27,246 (Table 13). Note that this estimate is higher than that derived using a fixed pregnancy rate (24,161) suggesting that pregnancy rates were lower than the assumed 0.72 level in 2014-5. The resulting estimate of herd size (27,246 divided by 0.706 from Table 3) is 38,592 (SE=2232.8, CV=5.8%, CI=33,859-43,325) 1.5+ year old caribou (Table 17).

Table 17: Extrapolated estimate of total herd size for 2015 using adult female estimates (Table 13) and estimates of proportion of adult females in the entire herd from 2015 fall composition surveys (Table 15) without the use of an assumed pregnancy rate.

Survey data	Estimate	SE	CV	Confidence limit	
Number of caribou on the breeding ground	38,041	2128.6	5.6%	33,528	42,553
Number of adult females	27,246	1478.0	5.4%	24,113	30,379
Proportion adult females in the entire herd	0.706	0.014	2.0%		
Total herd estimate (1.5+ year old caribou)	38,592	2232.8	5.8%	33,859	43,325

Given the variation in pregnancy rates, as indexed by proportion of females that were breeding, we suggest that the adult female based extrapolated estimate is the best estimate of herd size for the 2015 survey. In the next section we compare estimates from previous years.

Comparison of herd size estimates

A comparison of estimates using the pregnancy-based and adult female-based methods reveals relative similarity between the two methods (Figure 21) for the 2010, 2013, and 2015 surveys. In 2010 and 2015 the female-based methods was higher than the pregnancy-based methods whereas in 2013 it was lower.

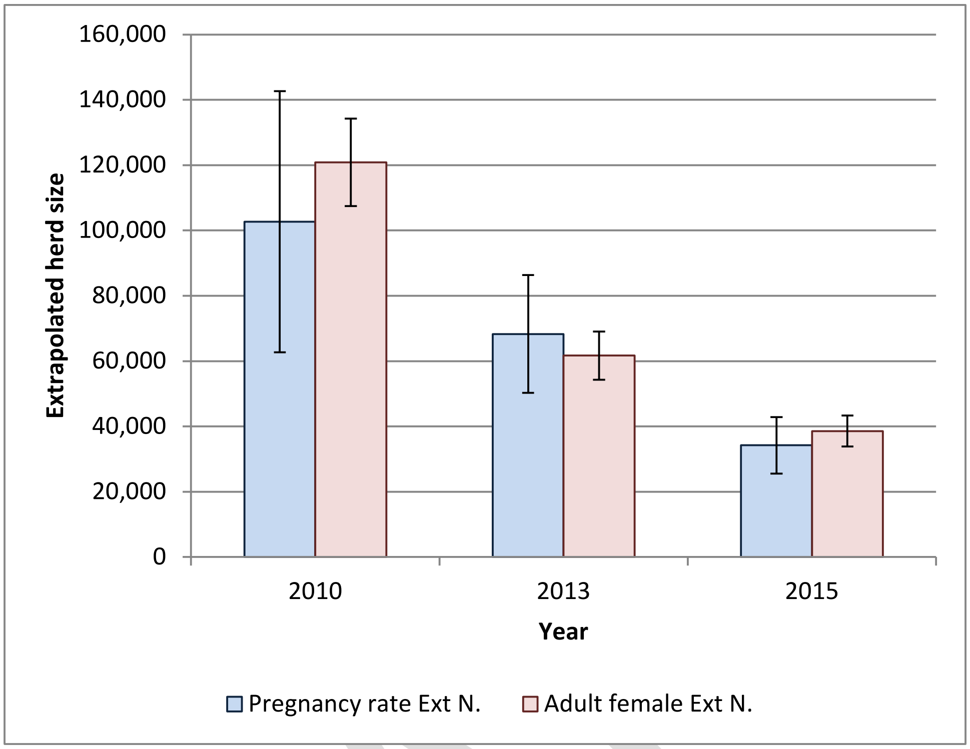

Figure 21: Estimates of extrapolated herd size for 2010, 2013, and 2015 calving ground surveys using pregnancy-based and adult female-based methods.

One potential reason for variation in estimates for the pregnancy-based method was different pregnancy rates in each survey year compared to the assumed rate of 0.72. In 2010 and 2015 there was a higher proportion of non-breeding females on the calving ground (Figure 23) which may have indicated a lower pregnancy rate than the assumed mean level of 0.72 which resulted in the pregnancy-based estimate being lower. In contrast, the proportion of non-breeders was lower in 2013 which potentially indicated a pregnancy rate that was closer or higher than the mean level.

One of the main assumptions of the adult female-based extrapolated estimate is that the majority of adult females are within the survey strata. The proportion of collared adult females within the survey strata was 0.92 (33 of 36 collars), 0.87 (27 of 31 collars), and 0.90 (27 of 30 collars) for 2010, 2013 and 2015 respectively. This indicates that a high proportion of adult females were within the survey stratum each year. Regardless, confidence limits from the 2 methods overlap in all years and therefore differences in estimates could also be due to statistical uncertainty. Most importantly, estimates from both methods indicate substantial declines in herd size.

Trends in breeding and adult females between 2010, 2013, and 2015

Comparison of 2013 and 2015 estimates

The estimate of breeding females for 2010 (51,757 (CI=40,665-62,849) and 2013 (34,472, CI= 30,109-38,836) was compared to the estimate from 2015 (Figure 22) which suggested a large decline in overall abundance. Estimates of breeding females were significantly different between 2013 and 2015 (t=-8.7, df=73.2, p<0.0001) with an overall change in estimates of 50% which amounts to an annual rate of change of 0.71 (CI=0.6-0.82). This translates to an annual rate of decline of 29% (CI=18-40%).

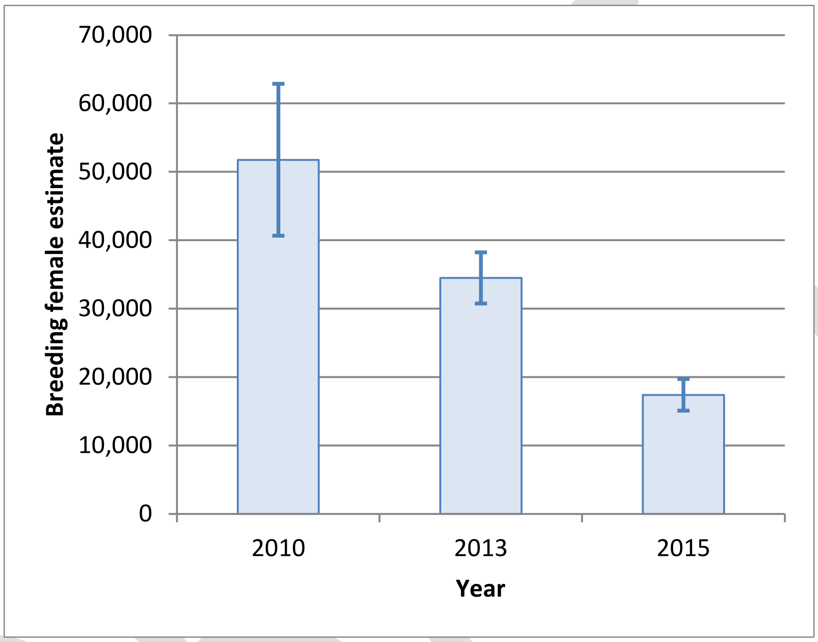

Figure 22: The 2010 and 2013 breeding female estimates with confidence limits.

One additional factor that influenced trends in breeding females was lower pregnancy rates in 2010 and 2015 which influenced the proportion of adult females that were breeding (Figure 23). It could be argued that this is a better estimate of overall trend in females given that the breeding female estimate was influenced by variable proportions of adult females breeding. In this case, the estimates from 2013 and 2015 were significantly different (t=5.9, df=81.0, p<0.0001) with an overall change in estimates of 63% which results in an annual change of 0.79 (CI=0.68-81). This translates to an annual rate of decline of 20.6% (CI=9.0-32.3%). The change in adult female estimates from 2010 and 2013 was 20.0% (CI=6.5-33.6%) suggesting a similar rate of decline in adult females the intervals between the 2010, 2013, and 2015 surveys.

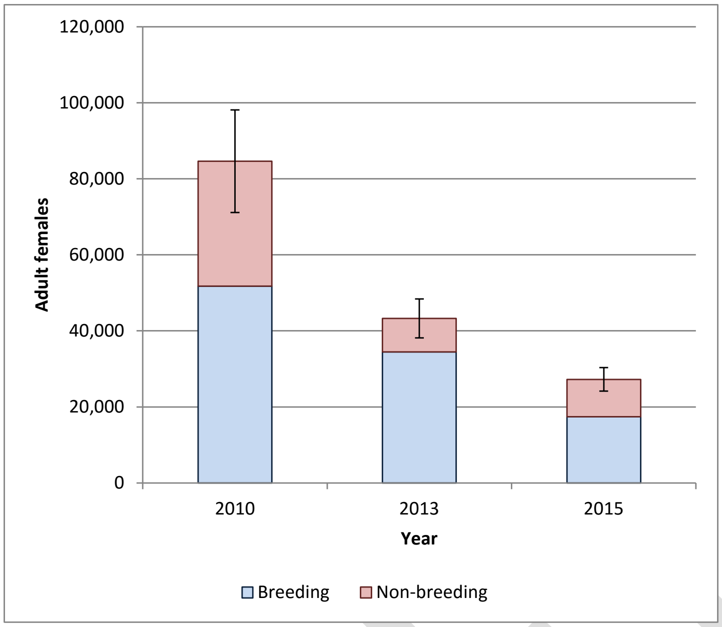

Figure 23: Comparison of 2015 estimate of adult females with estimates from the 2013 and 2010 calving ground surveys.

Overall trends from 2010-2015

Weighted regression analyses of the breeding female abundance estimates a significant annual decline rate (lambda) of 0.80 (CI=0.68-0.93). This translated to an annual rate of decline of 20% (CI=7-32%). In simple terms, breeding females are being reduced by 20% each year (Table 18).

Table 18: Weighted regression analysis estimates of mean rate of change in breeding females for the Bluenose-East caribou herd

Parameter	DF	Estimate	SE	Confidence limits		χ^2	$P(\chi^2)$
Intercept	1	11.255	0.349	10.572	11.939	1041.750	<.0001
year	1	-0.229	0.078	-0.382	-0.077	8.710	0.003
lambda		0.80	1.08	0.68	0.93		

A plot of predictions demonstrates the overall declining trend but also the potential influence of change in proportion females breeding. Namely, higher proportions of females breeding in 2013 increased breeding female estimates. An additional proportion breeding females terms was significant in the regression model (χ^2, df=1, p=0.005), however, the overall effect of this term on estimates of lambda was negligible with an overall estimate of 0.80, as was an estimate of trend that used adult females (Figure 24). The principal reason for the negligible impact of differences in proportion females on trend estimates was that pregnancy rates were similar for 2010 and 2015 which therefore minimized the impact of the 2013 survey estimate (where pregnancy rates were higher). Small sample sizes of annual estimates (and subsequent model degrees of freedom) precluded further analysis. The relationship between pregnancy rate and overall demography is considered further in the context of the OLS model in the next section of this report.

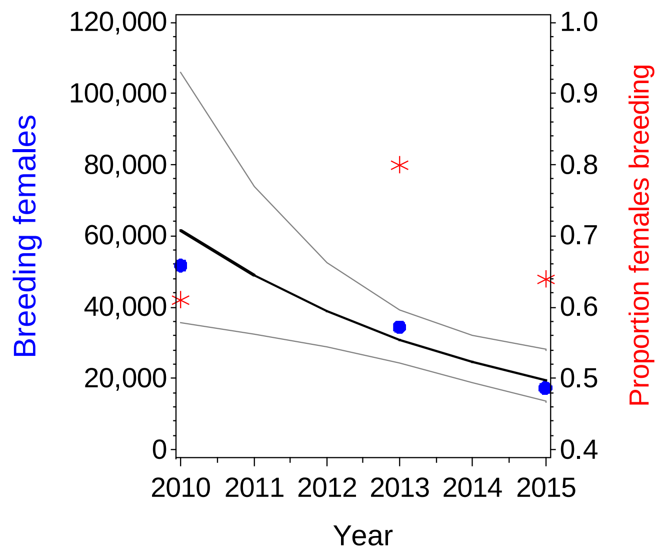

Figure 24: Weighted regression estimates of trends in breeding females. Estimates of proportion females breeding is given for comparison on the right axis in red. Confidence limits on regression model prediction are given as grey lines.

Comparison of trend with reconnaissance survey estimates

Estimates of trend were compared with reconnaissance survey estimates conducted prior to calving ground surveys each year (Figure 25). These estimates will correspond to all caribou found in the core calving area with no differentiation of breeding females or other cohorts. A similar decline was observed with estimates of annual change of 0.83 (CI=0.79-0.88, χ^2=1929.5, df=1 p<0.0001) from weighted regression of the 3 estimates. This estimate of trend is similar to that of breeding females or adult females (0.80). Of the estimates, the breeding female or adult female estimate will be more indicative of herd trend given higher precision of photo survey estimates.

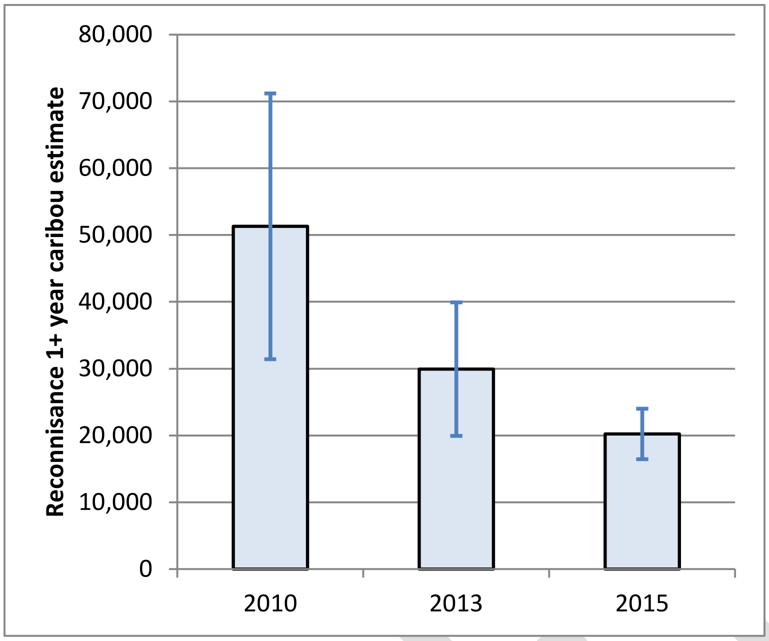

Figure 25: Reconnaissance estimates of caribou on the core calving area.

Exploration of potential reasons for decline in herd size

The apparent large decline in breeding females on the Bluenose-East calving ground could have resulted from movement of caribou to adjacent calving grounds, changes in productivity (pregnancy), reduced calf survival, or reduced survival of adult caribou. We considered the likelihood of each factor contributing significantly to the estimated reduction in abundance.

Movement to adjacent calving grounds

We assessed movements of collared cows between the Bluenose-East, Bluenose West, and Bathurst caribou calving grounds from 2010 to 2015 determine if a significant number of female caribou switched calving grounds between years. The sample size of caribou for this analysis was the number of caribou monitored for 2 or more consecutive years so that fidelity to calving grounds could be assessed (Table 19). Note that this sample size will be lower than the actual number of collars employed each year on a calving ground.

Table 19: Sample sizes of caribou collared for 2 or more consecutive years, by year, for the Bathurst, Bluenose-East, and Bluenose West caribou herds.

Year	Bathurst	Bluenose-East	Bluenose West
2010	8	19	14
2011	10	22	13
2012	15	30	33
2013	10	26	31
2014	14	24	18
2015	13	19	12

Frequencies of movement events were assessed for caribou monitored for consecutive years and tabulated (Figure 26). For example, caribou those were on the Bluenose-East calving ground returned to the Bluenose-East calving ground 85 times. Two caribou that were on the Bluenose West calving ground switched to the Bluenose-East calving ground and 2 caribou on the Bathurst calving ground switched to the Bluenose-East calving ground. One caribou that was on the Bluenose-East calving ground switched to the Bluenose West calving ground. Results of this summary suggest that there was negligible switching of caribou between the Bluenose-East and other calving grounds. This factor was not likely responsible for the decline in Bluenose-East breeding females. The low rate of switching of collared cows is consistent with previous estimates of about 97% fidelity in the Bathurst herd (Adamczewski et al. 2009) and similar fidelity in the Cape Bathurst, Bluenose-West and Bluenose-East herds (Davison et al. 2014).

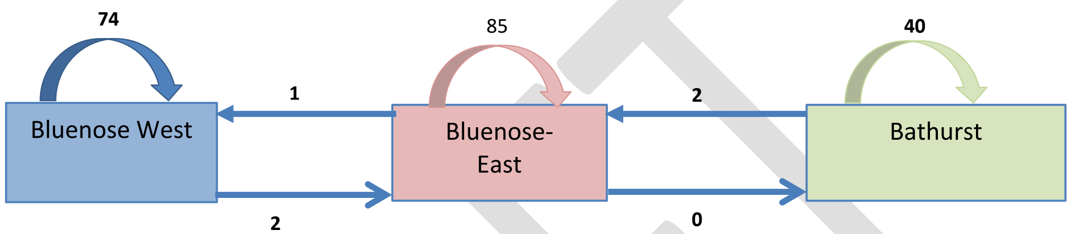

Figure 26: Frequencies of caribou movement events from 2010 to 2015 based on locations on calving grounds. The arrows above the boxes indicated the number of times a caribou returned to each calving ground for successive years. The arrows indicate movement of caribou to other calving grounds.

Demographic analysis using multiple data sources

The main objective of the OLS demographic model exercise was to determine the most likely cow survival levels given the difference in breeding female estimates in 2010 and 2015 when levels of productivity as estimated by calf-cow ratios and proportion females breeding are considered. Initial survival rate was estimated from seventy five female collared caribou that were monitored from June 2010 to May 2015. The mean number of collared caribou monitored each month varied from 44 during 2012 to 5 collars during the fall/rut of 2011. The mean number of mortalities each month by season varied from 0 to 8 mortalities during May 2012. Yearly survival rates were estimated as input data for the OLS model.

The first step of the modeling exercise was to formulate a parsimonious model that explained dominant demographic trends with the least number of parameters. Models that varied calf survival, adult female survival, and fecundity were considered. The most supported model had cubic variation in calf survival, quadratic variation in fecundity with constant adult female survival, yearling survival and bull survival levels (Table 20, Model 1). This model was more supported than a model with trends in cow survival (Model 2), variation in bull survival (Model 3), or yearly variation in calf survival (Model 4). All models with trends in parameters were more supported than a model that assumed constant values for all parameters (Model 11).

Table 20: AICc model selection for demographic analysis of Bluenose-East herd data 2008-13 Akaike Information Criteria (AIC_c), the difference in AIC_c values between the *i*th and most supported model 1 (ΔAIC_c), Akaike weights (w_i), and number of parameters (K), and sum of penalties are presented. Trend models were indicated by a T (T-log-linear, T^2=quadratic, T^3=cubic), year-specific trends were indicated by a subscript under the T symbol. Yearly models allowed unique values for each year in the analysis. Yearling survival was held constant for all models. Twenty three field observations were used in model fitting and AIC_c calculations.

No	Calf survival (S_c)	Fecundity (F_a)	Cow survival (S_f)	Bull survival (S_m)	AIC_c	ΔAIC_c	w_i	K	∑Penalties
1	$T+T^2+T^3$	$T+T^2$	Constant	Constant	110.5	0.00	0.99	11	64.47
2	$T+T^2+T^3$	$T+T^2$	T	Constant	119.6	9.15	0.01	12	64.42
3	$T+T^2+T^3$	T+T2	Constant	T	121.1	10.59	0.00	12	65.87
4	Year	$T+T^2$	Constant	Constant	123.2	12.72	0.00	14	42.69
5	$T+T^2+T^3$	Constant	Constant	Constant	124.1	13.62	0.00	9	92.25
6	$T+T^2$	T	Constant	Constant	130.0	19.49	0.00	10	91.63
7	$T+T^2+T^3$	$T+T^2$	$T+T^2$	Constant	130.9	20.39	0.00	13	64.42
8	$T+T^2+T^3$	$T+T^2$	T	T	131.3	20.81	0.00	13	64.83
9	$T+T^2$	Constant	Constant	Constant	151.9	41.44	0.00	8	125.62
10	$T+T^2+T^3$	$T+T^2$	Year	Constant	257.0	146.48	0.00	18	49.95
11	Constant	Constant	Constant	Constant	324.7	214.24	0.00	6	307.47

Comparison of model predictions and field estimates suggested reasonable fit for adult female survival, calf survival, breeding cow estimates, and fecundity levels (Figure 27). An increase then decrease followed by lower constant calf cow ratios was suggested as modeled by the cubic calf survival terms in Model 1. An increase then decrease in fecundity as indicated by proportion of females breeding on the calving ground was indicated by the quadratic term in the OLS model. Constant adult female survival rates were within the confidence limits of collar based estimates for 4 out of 5 years. The collar-based survival rate estimates were imprecise which most likely contributed to yearly variation in estimates as also indicated by no support for an OLS model where cow survival was allowed to vary yearly (Table 20, Model 10). Model predictions were very close to point estimates of breeding female abundance.

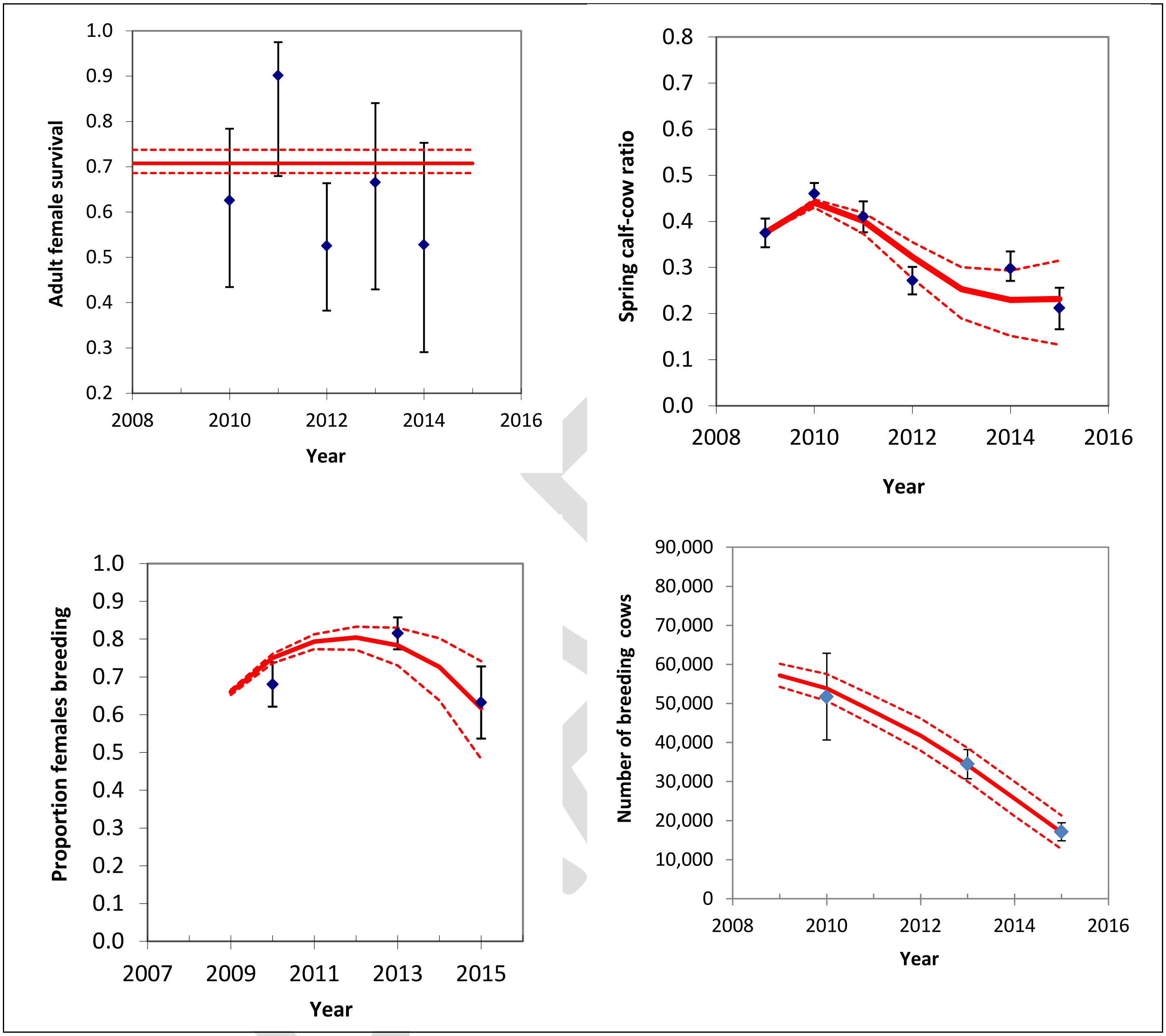

Figure 27: Estimates of adult female survival (from collared caribou), spring calf-cow ratios (from March composition surveys), proportion females breeding and breeding cow (female) population size estimates (from calving ground surveys). Confidence limits are shown on field estimates. OLS model predictions are given as red lines (from Model 1, Table 20) with 95% confidence limits on OLS predictions given as dashed red lines.

Model estimates for fall composition data also suggested reasonable fit to bull-cow ratios and fall calf-cow ratios (Figure 28). The OLS model suggests a declining trend in bull-cow ratio which is presumably due to the effects of lowered productivity and reduced recruitment of caribou to the adult age class. In simpler terms, when productivity and recruitment is low, bulls decline at a faster rate than cows due to their higher mortality rates causing a reduced bull-cow ratio.

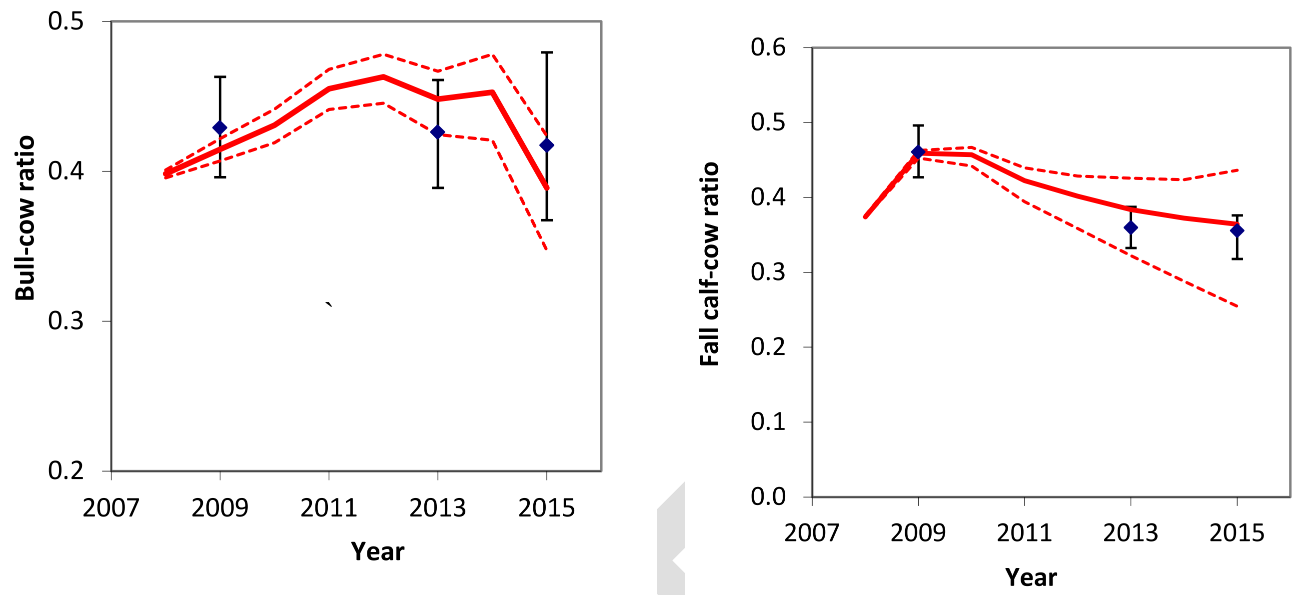

Figure 28: Estimates of bull cow ratios and fall calf-cow ratios from fall composition surveys. Confidence limits are shown on field estimates. OLS model predictions are given as red lines (from Model 1, Table 20)

Confidence limits on OLS model predictions varied for field comparisons with the exception of adult female survival where confidence limits were relatively narrow. This may seem counter-intuitive give the imprecision of the collar-based survival rate estimates. The principal reason for tight confidence limits lies on the high degree of sensitivity of the OLS model to adult female survival rates. The bootstrap method used to obtain confidence limits basically estimated the range of potential values of adult survival that would result in the observed values in the data set (within the constraints of OLS model). Given high sensitivity to cow survival, only a narrow range of survival rates were estimated by the OLS model from the data set even when the data set was randomly resampled many times. One way to interpret this is that the observed trend in herd size and other factors could only result from a relatively narrow range of cow survival values. The other factor that influenced the width of confidence limits was the number of field data points that were used in model formulation. Wider confidence limits resulted in cases where there were few (i.e. 3) observed field data points.

Demographic parameter estimates from the OLS model illustrated variation in calf survival and constant values for other parameters (Figure 29). Adult female and yearling survival was estimated at 0.71 (SE=0.01, CI=0.69-0.72), bull survival at 0.57 (SE=0.01, CI=0.55-0.60). Overall productivity, which is the product of fecundity and calf survival, declined to lower levels in 2014 up to the 2015 calving ground survey.

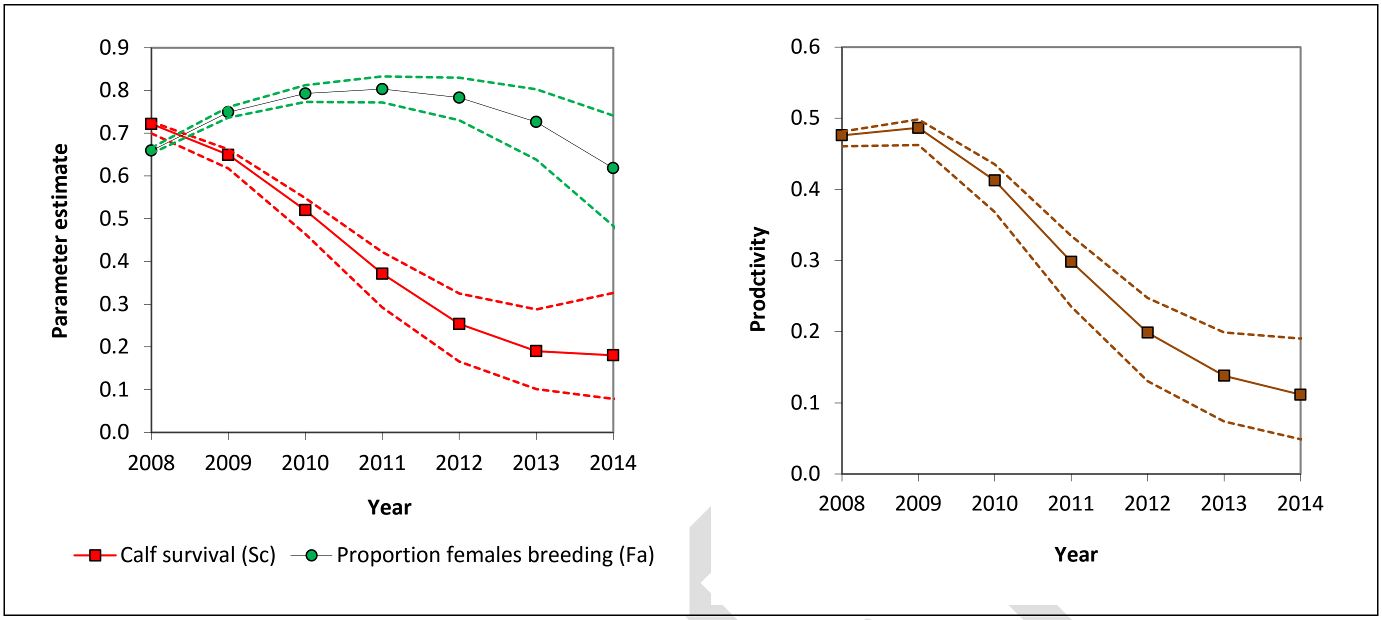

Figure 29: Estimates of calf survival and proportion females breeding from the most supported OLS model (Model 1, Table 20). In addition productivity, which is the product of calf survival and proportion females breeding, is displayed.

Population size estimates for each cohort demonstrated that all cohorts declined from 2008 to 2015 (Figure 30).

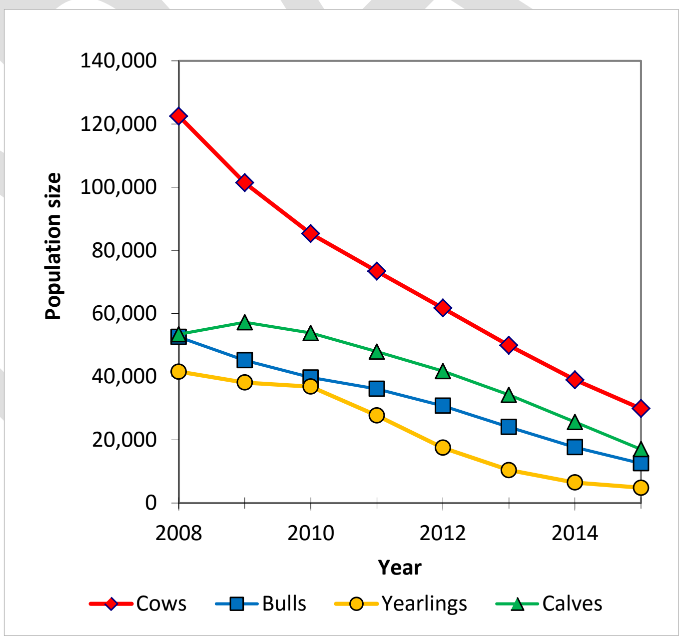

Figure 30: Estimates of population size for each age-sex class from the most supported OLS model (Table 20)

Estimates of adult female survival from the OLS model include harvest mortality as well as natural mortality (e.g. wolf and grizzly bear predation). Reported harvest for years 2009-2010, 2010-2011, 2011-2012, and 2012-2013 averaged about 2700 caribou, with the sex ratio likely 65% or more females (Table 21). Harvest information for winter 2014-2015 was incomplete; harvest was likely substantially reduced from previous winters as the herd was generally remote through the winter. For 2014-5, harvest was likely below the 1800 limit recommended for the herd in NWT. Observations from harvest monitors and wildlife staff suggest that these figures are conservative and under-estimate the true harvest. Factors that most likely influence under-reporting of harvest are; hunters not stopping at reporting stations, under-reporting of harvest, wounding loss, and under reporting to community monitors.

Table 21: Estimated caribou harvest for the Bluenose caribou herd from 2009-14

Winter Season	Estimated Caribou Harvest	% Cows in Harvest
2009-2010	3,466	≥ 65%
2010-2011	2,918	≥ 65%
2011-2012	1,766	≥ 65%
2012-2013	2,562	≥ 65%
2013-2014	3,016	≥ 65%

Due to the uncertainty as to the true harvest and the limited sample size for estimating survival from collared caribou, we used the model to explore combinations of natural and harvest-based mortality rates that could account for the observed demographic patterns, and particularly the decline in numbers of breeding females. For this exercise harvest was included in the OLS model by subtracting harvest numbers of cows and bulls from the population each year. We then re-estimated survival rates that would produce the observed estimates. As with other OLS runs, bootstrap resampling was used to obtain confidence limits on survival rates (Figure 31).

Estimates of natural survival rate for caribou ranged from 0.71 with no harvest up to 0.77 with a harvest of 8000 caribou (5200 cows, 2800 bulls). Assuming a median annual harvest of 4000 (2600 cows, 1400 bulls) the resulting cow survival rate estimate is 0.74 (CI=0.72-0.75). Regardless, the level of adult natural survival is lower than levels needed to allow population stability. Or in other words, the reduction of adult survival by an assumed range of harvest levels cannot fully explain the recent rapid decline of the Bluenose-East herd, although this level of harvest certainly contributed substantially to that decline. Our analyses suggest that a low natural adult survival in cows and bulls also contributed substantially to the decline.

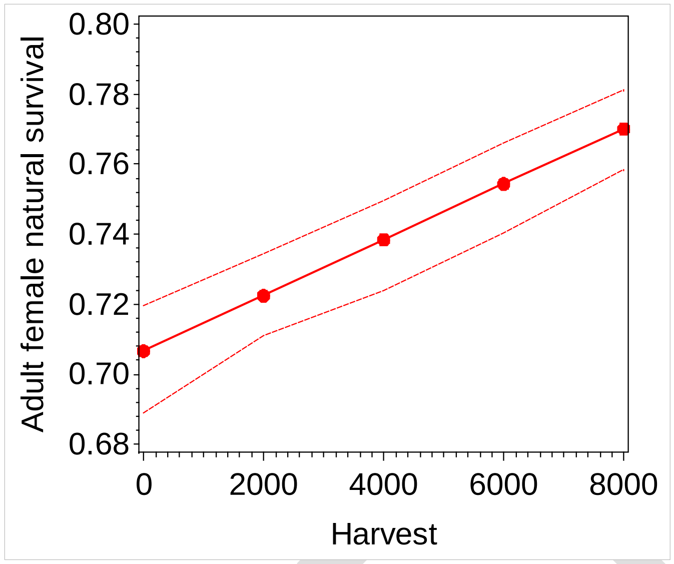

Figure 31: Estimated natural survival for adult females under a range of harvest levels. Harvest levels assume 65% cow / 35% bull ratio of harvested caribou with demographic parameters from the OLS model. 95% confidence limits on survival estimates are given as dashed lines.

Discussion

General comments

Results from the Bluenose-East 2015 survey documented a significant decline in breeding females and an overall decline in the herd since the 2010 calving ground survey. This decline cannot be attributed to sampling variation given the overall efficiency of the 2015 calving ground survey. An analysis of the demography using multiple data sources suggests that low productivity (Figure 29) as indicated by declining calf survival rates and pregnancy rates combined with lower adult female survival rates both contributed to the continuing decline of the Bluenose-East herd. Adult female survival rates ranged from 0.71 (CI=0.69-0.72) to 0.74 (CI=0.72-0.75) with an assumed annual harvest of 4000 caribou (2600 cows/1400 bulls). Most likely this low overall cow survival rate reflects both a substantial cow harvest from a declining herd, similar to the Bathurst herd 2006-2009 (Boulanger et al. 2011), and a low natural survival rate. In any case, the estimated levels of survival as well as productivity are indicative of a declining population. The switching of collared caribou between neighbouring calving grounds was very low and therefore changes in abundance cannot be attributed to movement to other calving grounds.

Extrapolated herd size

We adopted a new method to estimate extrapolated herd size based on adult females rather than using an assumed pregnancy rate. The reason for development of this estimator was increased variation in pregnancy rate making it unlikely that estimates with an assumed constant pregnancy rate were unbiased. This estimator assumes that all adult female caribou (breeders and non-breeders) as classified in composition surveys occurred within the core calving area as delineated by the survey strata (Figures 11 and 12). It does not make any assumptions about the distributions of yearling or bull caribou. The distribution of female collared caribou observed in 2015 suggests that this assumption was reasonable given that all 27 of 30 collared females were contained within the survey strata (Figure 13). The herd size estimate of 38,592 (Table 17) was similar to the estimate of total caribou on the calving ground (38,041). Note that the extrapolated estimate will not contain yearlings (calves of 2014) whereas the estimate of total caribou on the calving ground will contain yearlings. Therefore, extrapolated estimates and estimates of total caribou on the calving ground are not directly comparable.

We do not suggest the adult female based method of extrapolation is applicable to all calving ground surveys. For example, the degree of aggregation of the herd, the extent of the survey area relative to herd distribution, and other factors may affect the proportion of adult females that will be in the survey area in any given year. The main criteria for determining the applicability of this method can be evaluated using the following criteria.

1. Comparison of direct estimates of adult females to those derived by breeding females/0.72 (0.72 being the assumed pregnancy rate). If the direct adult female estimate is higher than this would suggest a lower pregnancy rate (and the appropriate use of the direct adult female estimator).
2. Evaluation of the proportion of collared females in the core surveyed/stratified area. If the proportion is high then it would suggest the survey has sampled the majority of adult females. The surveyed area is defined as the area that was sampled using aerial transect and composition surveys (to estimate adult females). A model-based framework is being developed to provide a statistical test of this assumption.
3. Comparison of estimates of proportion breeding (from composition surveys on the calving ground). This comparison is integrated currently into the OLS model demographic analysis. In addition, use of faecal pellets collected on spring composition surveys has potential to index or estimate pregnancy rates.

We note that the overall declining trend in herd size is apparent using the adult-female based extrapolation method as well as the past pregnancy-based method of herd estimation (Figure 21). In addition, the tracking of trends of breeding females is potentially the best method to assess herd status given that the relative number of breeding females will indicate the relative productivity of the herd for the survey year.

The effect of constant harvest levels on a declining herd

The estimated yearly rate of decline of breeding females in the Bluenose-East caribou herd from 2010 to 2015 was -20% (CI=7-32%) (Figure 24). This rate of decline falls in between the rates of decline for the Bathurst from 2003-2006 of -12% (CI=-29-6%) and 2006-2009 of -32% (CI=-40 - -26%) (Adamczewski et al 2009). In the case of the Bathurst herd, the accelerated decline from 2006-9 was caused by low productivity prior to 2006, a low cow survival rate, and constant higher numbers of caribou harvested between 2006 and 2009 (Figure 32). Assuming an annual harvest of 6000 cows prior to 2009, the proportion of the population harvested increased from 5% in 2006 to 18% in 2009 which resulted in a lower adult female survival rate of 0.67 and subsequent acceleration in the rate of decline (Adamczewski et al. 2009, Boulanger et al. 2011). The reduction of harvest levels after 2009 decreased the rate of decline of the Bathurst herd as indicated in the 2012 survey (Boulanger et al 2014d).

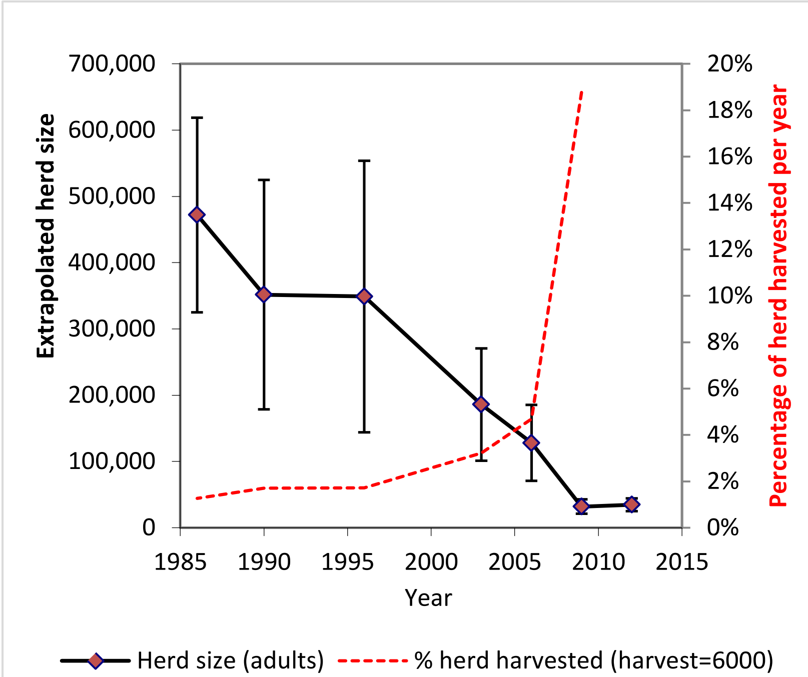

Figure 32: Extrapolated herd size of the Bathurst caribou (left axis) and estimated proportion of the population harvested (right axis) assuming an annual harvest of 6000 caribou.

The current status of the Bluenose East herd is similar to the Bathurst herd before 2006 in that the population is declining due to low adult cow survival with lower productivity during the past three years (Figure 29). If the continued annual decline rate of 20% continues into the future then the proportion of the herd harvested would increase from 5 % in 2015 to 10% in 2018 assuming annual harvest rates of 2600 (Figure 33). If an annual harvest of 4000 is assumed, than the proportion harvested could increase to 20% in 2018. It is likely that higher levels of harvest combined with recent lower productivity could accelerate the decline of the Bluenose East to greater than 20% in the future in a similar way as the Bathurst herd between 2006 and 2009 if harvest is not reduced from historic levels.

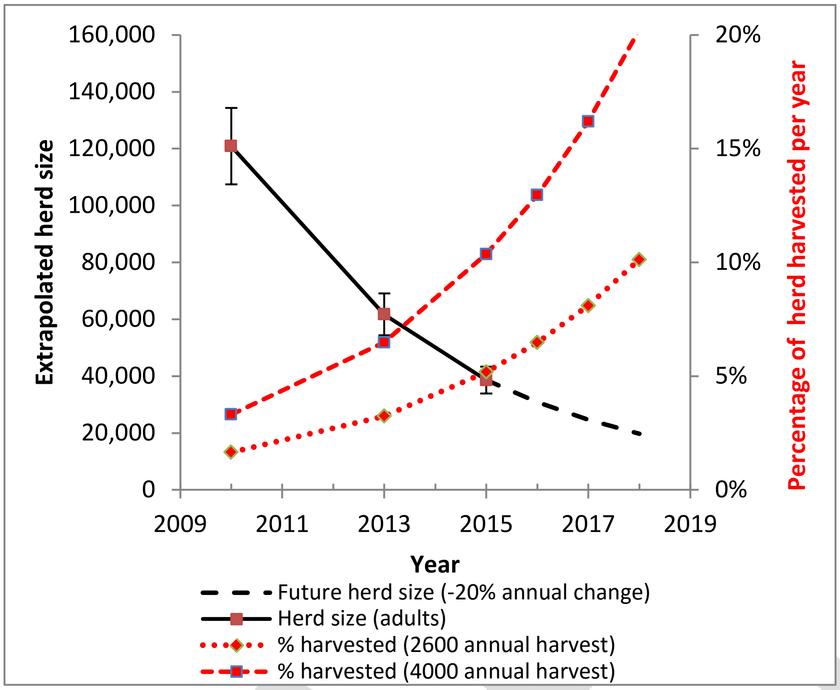

Figure 33: Herd estimates for the Bluenose East herd and projected herd size assuming the 20% annual decline continues to occur. On the right axis is the proportion of the herd harvested each year under assumed yearly historic harvest levels of 2600 and 4000.

General conclusions

The decline in breeding females, coupled with the low estimated survival rates, a low recent calf: cow ratio, and substantial harvest rates, is cause for serious concern. In general, barren-ground caribou herds have a high probability of declining, regardless of harvest, if cow survival rates are below 80-85% (Crete et al. 1996, Boulanger et al. 2011). 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 2000 to 2006-2008 in part reflected late calving and sustained low calf recruitment (Adamczewski et al. 2009, Adamczewski et al. 2015).

Management Implications and Recommendations

We suggest the following monitoring and management measures should be considered for the Bluenose-East herd.

1. Continuation of reconnaissance surveys on the calving ground on a yearly basis to track relative trend of the herd before the next calving ground survey in 3 years, along with annual monitoring of calf recruitment. This will allow determination of whether the negative trend is still occurring. Another calving ground survey in 2 or 3 years should be conducted to re-assess herd status.
2. Annual monitoring of spring calf:cow ratios to monitor recruitment and more frequent assessments of pregnancy rate to better assess the role of low calf productivity and low calf survival in the declining trend.
3. Proactive management of harvest levels with a shift from mostly cows to mostly bulls, and reliable reporting of harvest levels, as called for by the ACCWM (2014) management plan for the Cape Bathurst, Bluenose-West and Bluenose-East caribou herds. It is difficult to assess the relative impact of harvest at this time given that the levels are likely under-reported. A reduction of harvest of the Bluenose-West herd in 2006-2007 to a maximum of 4% harvest and 80% bulls was effective in halting that herd's rapid decline 2000-2006 (Adamczewski et al. 2009); similarly, closure of the Cape Bathurst harvest helped stabilize that herd 2006-2009 (Adamczewski et al. 2009) and major reduction in the Bathurst harvest in 2010 helped stabilize that herd over the 2009-2012 period (Boulanger et al. 2014).
4. Continuation of collar-based survival estimation and monitoring of mortality. Lighter collars that have longer battery life spans (less frequent locations) are more useful for demographic monitoring. Assessment of collar fate is essential to obtain unbiased survival estimates.
5. Further assessment of likely causes for lower survival levels such as better estimates of predation rates and factors affecting range condition and caribou productivity is warranted.
6. Regular monitoring of the bull:cow ratio in the event of a bull-focused harvest to ensure that ratios remain within acceptable limits.

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Appendices

Appendix 1: Double observer estimation methods

MARK produced estimates of sighting probability (*p*) and when possible resighting probability (*c*) for the secondary observer. The combined probability that a group of caribou was seen by at least one of the observers (p^*) therefore *1-(1-p)(1-p).* Corrected counts for each group encountered were then estimated as group size divided by p^* for each group. The total corrected count for a series of observations could then be estimated as:

$$\hat{Y} = \sum_{i=1}^{j} \frac{y_i}{p_i^*}$$

where there were j groups encountered and y_i is the count or average count (if 2 observers both counted the caribou) and p^*_i was the sighting probability (from both observers that was potentially influenced by the size of the group) of the ith group. Therefore, for each stratum it was possible to add up all the corrected counts to obtain a corrected count of caribou observed on transect for the given stratum. Using the ratio of transect area sampled (a) to total stratum area (A) it was then possible to obtain an estimate of total population size for the stratum (Buckland et al. 2010).

$$\hat{N} = \frac{A}{a} \sum_{i=1}^{j} \frac{y_i}{p_i^*}$$

Note that this formula is equivalent to the estimator of (Jolly 1969) used for uncorrected visual estimates (used in previous calving ground surveys) if p* is assumed to 1 (sightability is 1).

$$\hat{N} = \frac{A}{a} \sum_{i=1}^{j} \frac{y_i}{1}$$

A bootstrap method was used to obtain variance estimates for stratum population estimates. For this procedure, strata were randomly resampled using transect as the sampling unit (i.e. data from each transect was considered a group rather than individual observations) (Buckland et al. 1993, Manly 1997). One thousand resamplings conducted and the standard deviation of the bootstrap resamples was used to estimate standard error of the strata population estimates. This procedure was conducted for the uncorrected estimates and the standard error estimates were compared to the estimates using the Jolly (1969) formula.

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