An Estimate of Breeding Females and Analyses of Demographics for the Bluenose-East Herd of Barren-ground Caribou: 2013 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 2013 in Nunavut (NU), near Kugluktuk, NU. The main objective was to obtain an estimate of breeding females that could be compared to estimates from a previous calving ground survey in 2010. Consistent with previous calving ground photographic surveys, data from collared caribou and systematic reconnaissance survey flight lines at ten km intervals in the calving ground area 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 planned for June 5th. Photo-plane survey effort (transect spacing) was allocated into a single high density block (stratum) where the majority of breeding females resided. Four other strata which had lower densities of breeding caribou were surveyed visually June 5-7. A double observer method was used to estimate and correct for sightability of caribou from visual surveys. Survey conditions were acceptable for June 5th with moderate ceilings and lower snow cover in most areas. Conditions deteriorated later on June 6th with an oncoming storm front. The photo-plane was unable to survey the entire high stratum due to technical issues and as a result part of it was surveyed using visual methods on June 6th. The rest of the survey stratum was surveyed on June 6th and 7th. A portion of the high-density block (nine lines) was flown visually and by photo-plane to verify similarity of counts. The estimate of 1+ year old caribou on the core calving ground was 60,387 (95% CI=54,512-66,262) caribou. Using the results of the ground composition survey to adjust this number for breeding females, the estimate of breeding females was 34,472 (CI=30,109-38,836). The estimate of breeding females was very precise with a coefficient of variation of 5.5%. The extrapolated herd estimate was 68,295 1.5+ year old caribou (CI=50,255-86,336). The estimate of breeding females was 66.6% (CI=52.9-80.3%) lower than the 2010 estimate of 51,757 (CI=40,665-62,849) which amounted to a statistically significant annual rate of decline of 12.6% (CI=7.0-18.9%). Assessment of survey issues suggested that this difference could not be attributed to differences in surveys or estimate bias. Assessment of movement of collared females between the Bluenose-East and surrounding herds 2010-2013 documented no cases of emigration to other herds. Calf recruitment has been generally good for this herd in recent years. Estimation of survival rates and demographic modelling suggest that cow survival rates were low (0.73), which contributed to the decline. This may have been due to a combination of low natural survival and harvest. We suggest that continued monitoring and more complete harvest reporting are essential to better understand this decline. A conservative approach to harvest should be considered in the short-term, along with close monitoring of the herd.

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INTRODUCTION

This report describes results of a calving ground photo-survey of the Bluenose-East caribou herd conducted during June of 2013. 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.

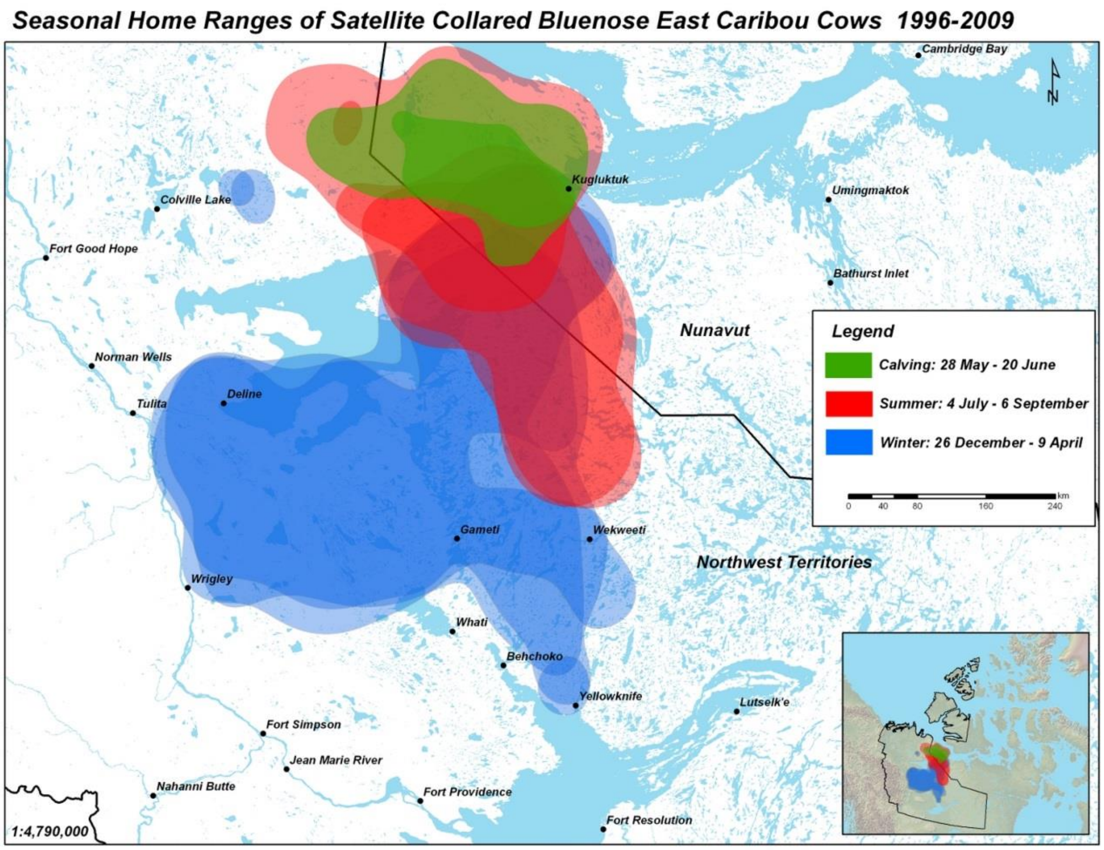

Figure 1: Calving, summer, and winter ranges of the Bluenose-East herd, 1996-2009, based on accumulated radio collar locations of cows. Ranges were delineated using Kernel home range (Worton 1989) smoothing of seasonal radio collared cow locations (Nagy et al. 2011). The location of the Bluenose-East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

Analyses of satellite collared caribou from the Cape Bathurst, Bluenose-West, Bluenose-East and Bathurst herds show that each herd has distinct migration patterns that lead to the spring calving grounds. Figure 2 provides an example of movement and distribution of these four herds.

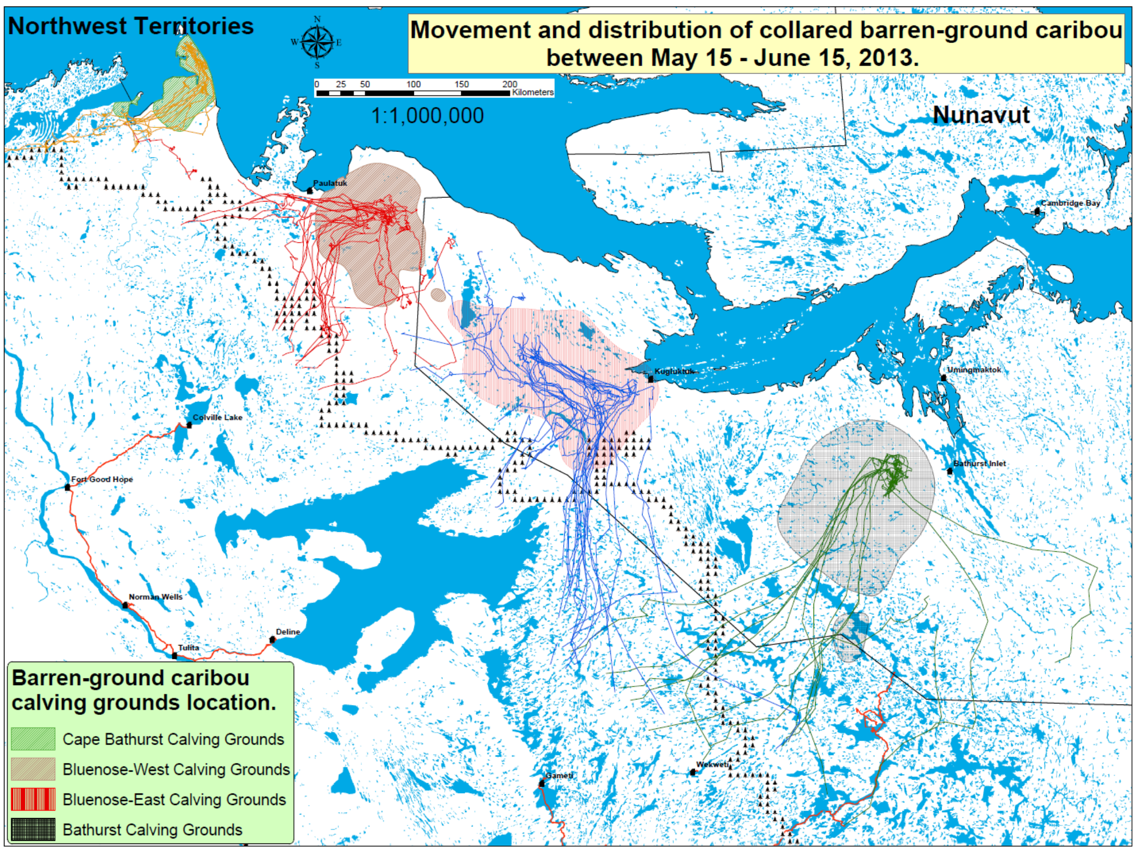

Figure 2: Spring migration paths of the Bluenose-East, Bluenose-West, Bathurst, and Cape Bathurst caribou herds as indicated by paths of radio collared caribou in the spring of 2013. Bluenose Lake lies on the western boundary of the Bluenose-East calving ground.

The Bluenose-East herd was previously surveyed on the calving ground in June 2010 using a calving photo-survey and using post-calving methods in July 2010 (Adamczewski et al. 2012 In Prep.). In earlier years, post-calving surveys were used for this herd (Patterson et al. 2004, Adamczewski et al. 2009 In Prep.). Both the July 2010 post-calving survey and the June 2010 calving survey indicated that the herd was over 100,000 adult caribou. A post-calving survey of this herd was attempted in July 2012 but failed due to insufficient aggregation of caribou. The main objective of the June 2013 survey was to compare estimates of breeding females with breeding female estimates from the June 2010 survey to determine population trend.

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, NU.
2. A systematic reconnaissance survey was conducted where transects at ten km 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 ground-based composition survey was conducted using a helicopter that landed

repeatedly within each stratum to determine the proportion of breeding caribou, as well as bulls, yearlings, calves and non-breeding cows. Some groups of caribou were also classified from the air.

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 31 collared female caribou were monitored during the survey to assess relative location of breeding females on the calving grounds. Locations of nine collared Bluenose-East bulls were also monitored during the survey period but most were not on the calving grounds. In addition, change in movement rates was assessed to determine the timing of calving. In general, movement rates of parturient female caribou are reduced to less than five km per day during the peak of calving and for an interval after calving (Gunn et al. 1997, Nishi et al. 2007, Gunn et al. 2013, Gunn and Russell 2008, Nishi et al. 2014 In Prep.).

Reconnaissance surveys to delineate strata

Visual transects were surveyed with ten km 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 DeHavilland turbo beaver aircraft were used for the systematic reconnaissance surveys, each equipped with a radar altimeter to ensure consistent survey altitude. In visual surveys, caribou were counted within a 400 m 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 km/h at an average altitude of 120 m AGL 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 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 a Trimble YUMA 2 tablet computer by a single data recorder in the plane (Figure 3). As each data point was entered, a real-time GPS waypoint was generated, allowing geo-referencing of the survey data.

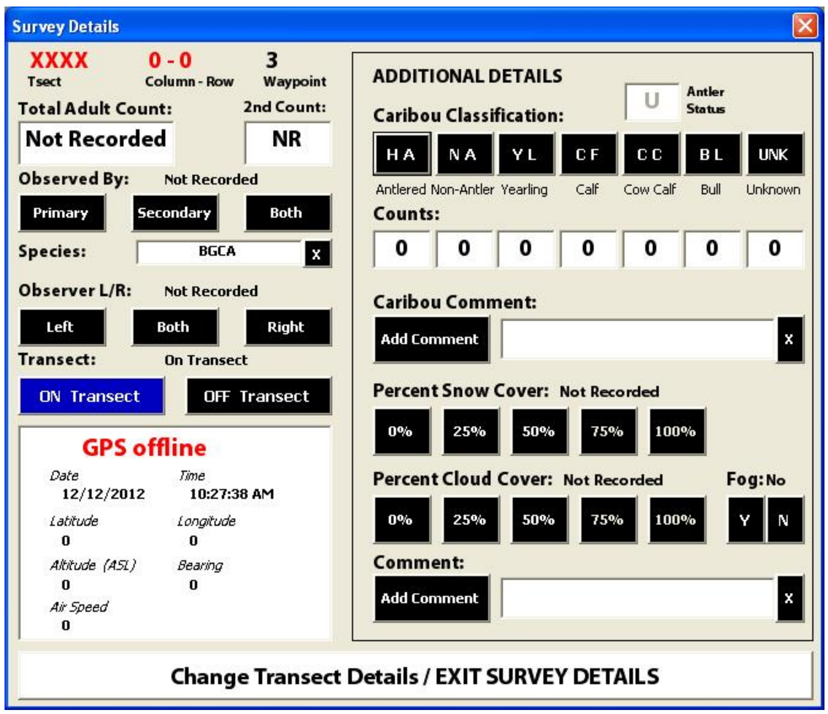

Figure 3: Tablet data entry screen used during reconnaissance surveys. A GPS waypoint was obtained for each observation, allowing efficient entry and management of survey data. In addition, the unique segment unit number was also assigned by the software for each observation to summarize caribou density and composition along the transect lines.

Transects were divided into ten km north-south segments to summarize the distribution of geo-referenced caribou counts (Figures 3, 10). 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. Four 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. In practice, a portion of the high stratum could not be flown by the photo-plane, and was flown visually. Verification of the validity of the visually flown section of the high-density block was determined by visually re-flying another portion of the high-density block that had been flown by the photo-plane, allowing a side-by-side comparison of density estimates.

Once the survey strata were delineated, an estimate of caribou numbers was derived from the reconnaissance data using the formulas of Jolly (1969). The relative population size of each stratum and the degree of variation of each estimate was 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 ten 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. Geographic Air Survey Limited [Edmonton, Alberta (AB)] was contracted to fly aerial transects. They used a twin engine Aero-Commander 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, AB 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. A subset of photos was counted by the Department of Environment and Natural Resources (ENR) staff to cross-validate counts from photos.

Visual surveys

Visual surveys were conducted in low and moderate density strata. For visual surveys, the DeHavilland turbo beaver aircraft was used with two observers on each side of the aircraft and a data recorder on each side. The number of caribou sighted by observers was then entered into the Trimble tablet computers and summarized by transect and stratum.

On one of the survey planes a double observer method was used to estimate the sighting probability of caribou for 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 4). 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 m wide strip transect before they passed halfway between the primary and secondary observer (approximately at the wing strut). This included caribou groups that were between approximately 12 and 3 o’clock for right side observers and 9 and 12 o’clock for left side observers. 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. 2014 In Prep.).

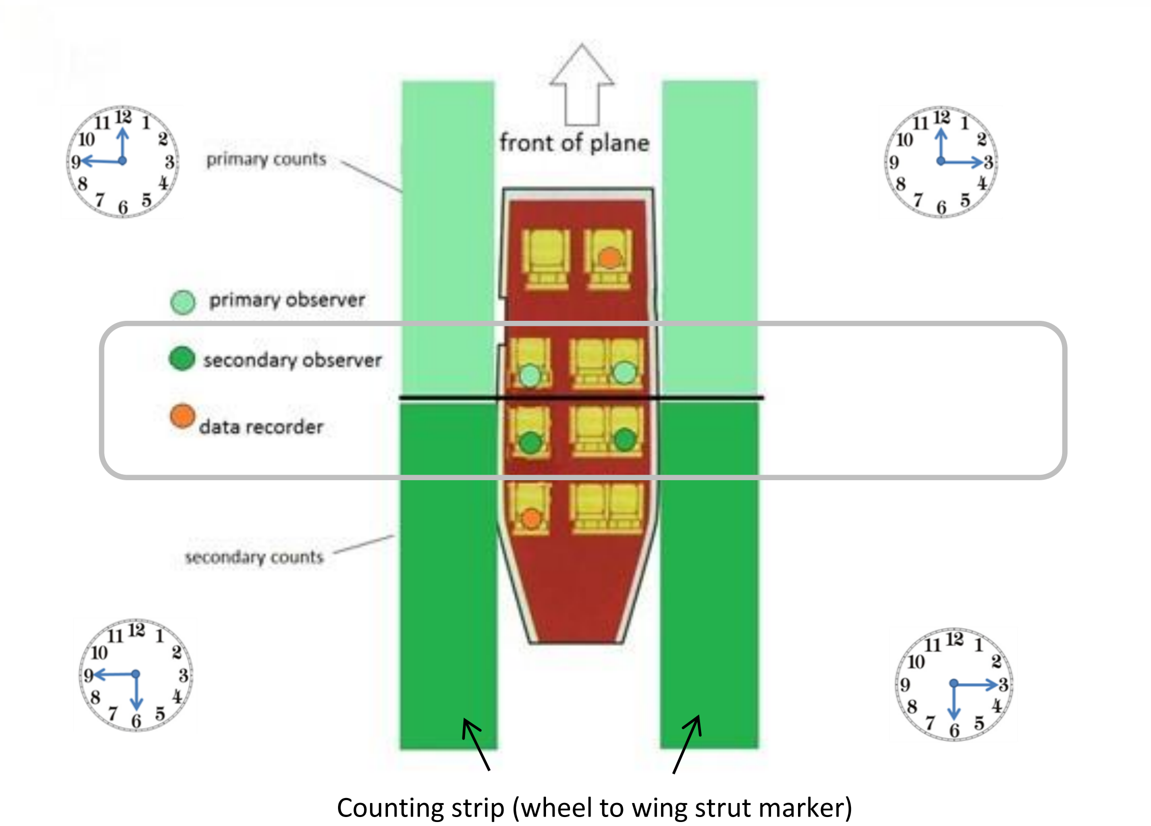

Figure 4: Observer position for double observer methods. The secondary observer calls caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can be used to reference relative locations of caribou groups (i.e. "caribou group 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 two 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 differences between primary and secondary observers. 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. Appendix 2 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
Stratum	Stratum	Stratum area 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 AIC_c score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). The difference in AIC_c values between the most supported model and other models (ΔAIC_c) was also used to evaluate the fit of models when their AIC_c scores were close. In general, any model with a ΔAIC_c score of <2 was worthy of consideration.

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 from the ground, using a telescope. A few small groups were classified from the air. 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 5). 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.

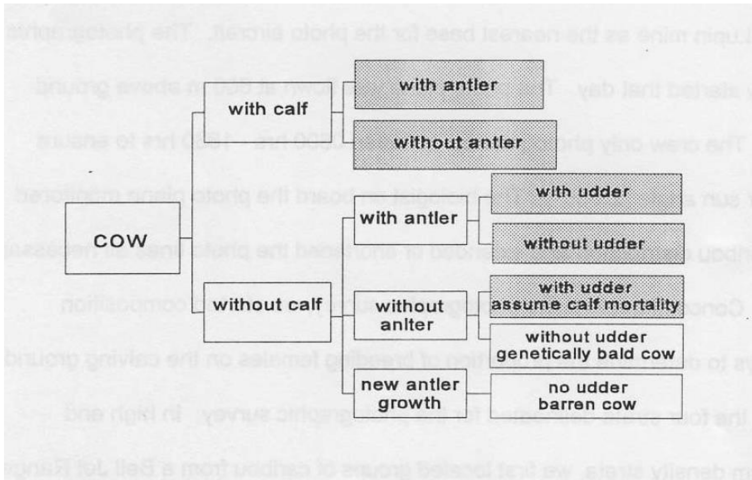

Figure 5: Classification of breeding females used in composition surveys. Shaded boxes were classified as breeding females [diagram from (Gunn et al. 2005)].

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

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. Each of these 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 in a two-step process. First, the total number of adult (1.5+ 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 (Dauphine 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 2013 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 that are >1 year old on the calving ground and will not include yearlings (calves of the previous year). All of the estimates associated with herd size have standard errors and the delta method (Buckland et al. 1993) was used to combine variance for the entire herd estimate.

Demographic analyses

Survival rate analyses

Collar data for female caribou for the past three years were compiled for the Bluenose-East caribou herd by ENR (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). Within each year, months were grouped by seasons (calving/summer: June-August, fall-rut: September-November, winter: December-April, spring migration: May) to assess mortality at different times of the year.

Program MARK known fate models (White and Burnham 1999) were used to model seasonal variation and estimate survival rates for female caribou in the Bluenose-East herd from 2010-2013. 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 trade-off 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.

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 developed for the Bathurst herd (Boulanger et al. 2011) to further explore demographic trends in the Bluenose-East data. We used the 2010 and 2013 breeding female estimates as well as calf-cow ratios, bull-cow ratios, 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 three age-classes with survival rates determining the proportion of each age class that makes it into the next age class (Figure 6). The details of this model are given in (Boulanger et al. 2011).

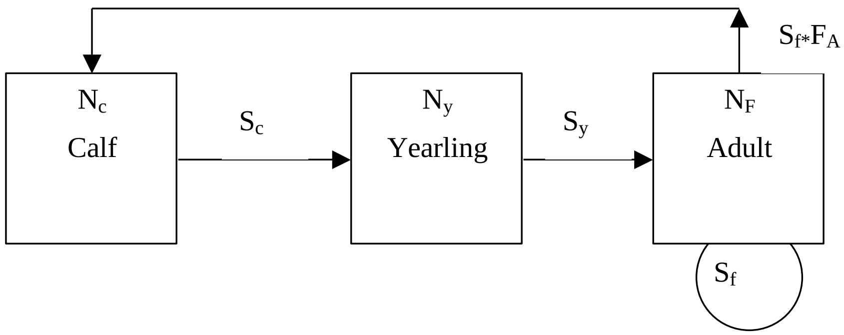

Figure 6: Underlying stage matrix life history diagram for the caribou demographic model. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates of calves (S_c), yearlings (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 survey results between 2008 and 2013. This interval basically covered potential recruitment into the breeding female class since any female calf born 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 2008, 2009, and 2010 had the most direct bearing on the number of new breeding females on the 2013 calving ground that were not accounted for in the 2010 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 (brown boxes) of the population. Calves born prior to 2008 were counted as breeding females in the 2010 survey and calves born after 2010 had not recruited into the breeding female segment and were therefore not counted. Surveys in 2010 and 2013 estimated breeding females.

Status						
Calf born	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
2008	calf	yearling	non-breeder	breeder	breeder	breeder
2009		calf	yearling	non-breeder	breeder	breeder
2010			calf	yearling	non-breeder	breeder
2011				calf	yearling	non-breeder
2012					calf	yearling
2013						calf

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 compared using information theoretic methods as for the female survival analysis.

Estimates of adult female survival were then compared to levels of productivity to assess the demographic mechanisms for change in the relative numbers of breeding females. Various adult female survival values were inputted into the most supported model to determine the relative influence of adult female survival on breeding female trend and on overall herd trend.

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. As there is uncertainty around the true harvest and collar numbers were limited, model simulations were used to assess the likeliest combinations of natural and harvest-related mortality. For these simulations, a range of survival and harvest levels were used with starting breeding cow population sizes based on the 2010 survey. Combinations of harvest and survival that were within the range of the 2013 estimate were then summarized as potential harvest and survival levels.

RESULTS

Survey conditions

Weather and snow cover during the survey were variable. During initial surveys on May 31st, snow cover was substantial. By the time of the visual and photo survey, snow cover was 25% or less in most areas (Figure 7). Weather was variable with mixed cloud cover and high survey ceilings up to the evening of June 6th at which time a storm front from the north created deteriorating conditions. The weather forecast for June 4th, when stratification occurred, is given in Appendix 1. 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 5th and 6th.

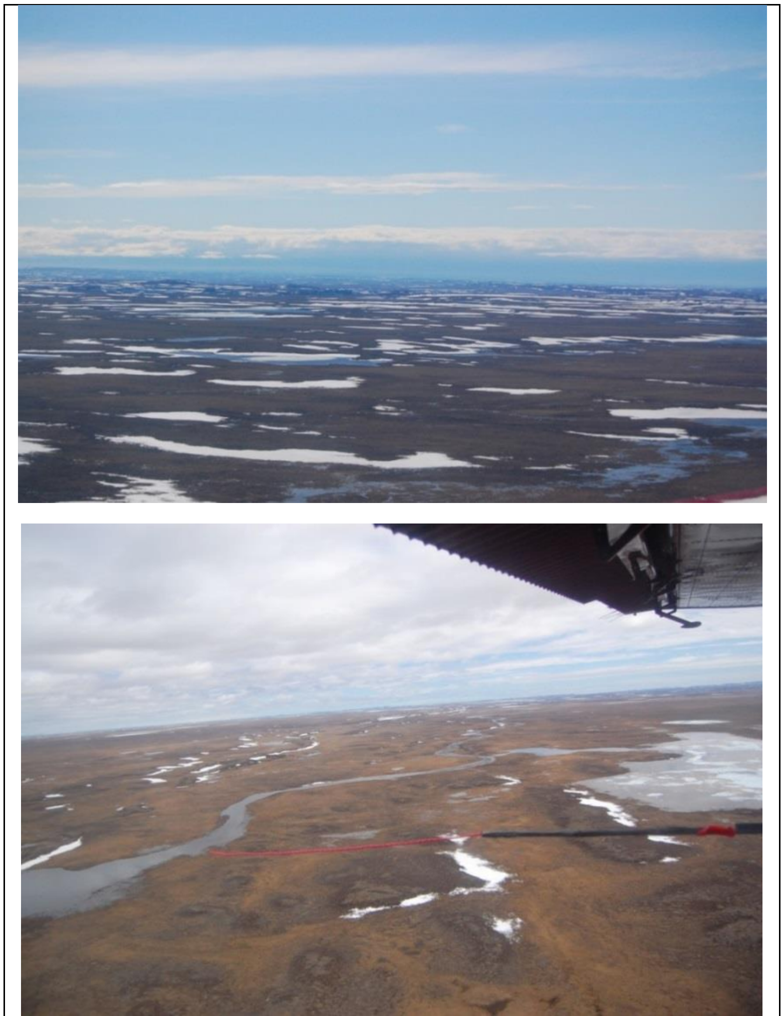

Figure 7: Pictures of survey conditions on June 6th. Cloud cover was mixed and snow cover ranged from 0-50%. An incoming weather system can be seen to the north in the top photo. This system moved into the survey area of June 7th.

Movement rates of collared caribou

The movements of 31 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 <5 km/day (Gunn and Russell 2008). Using this rule, we surmised that peak of calving was becoming evident on June 4th and June 5th when mean movement rates were 5 km or less for the radio collared caribou (Figure 8).

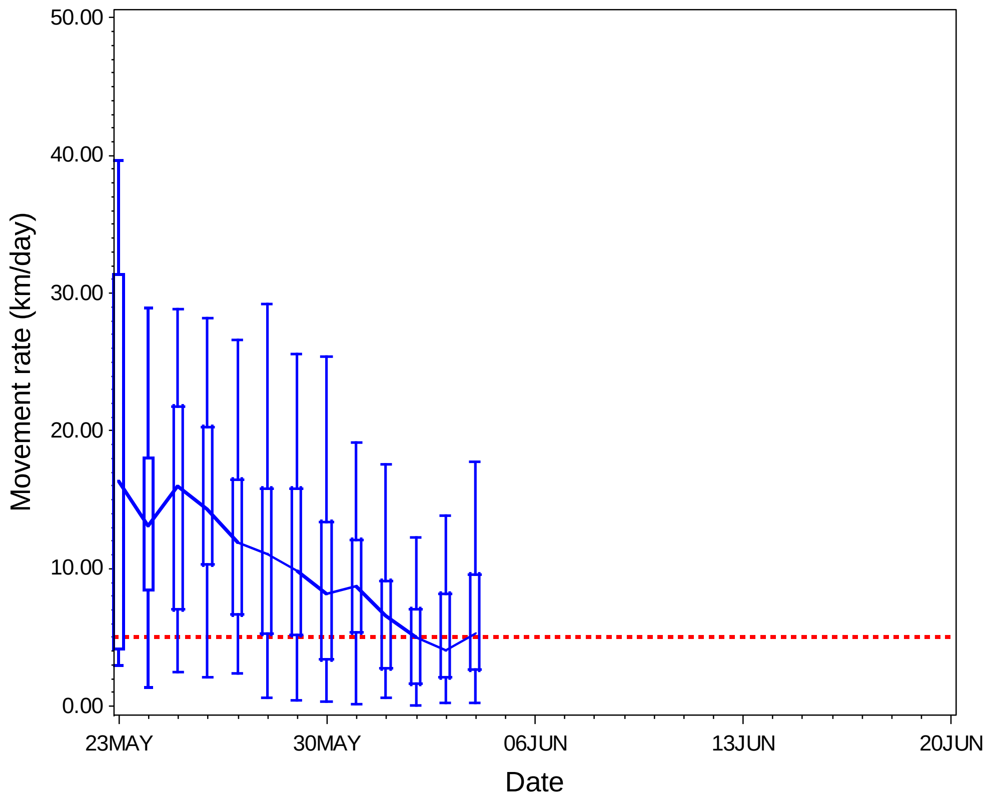

Figure 8: Movements of female collared caribou to the calving ground up to the stratification of sampling on June 4th.

Reconnaissance surveys to delineate strata

An initial survey was conducted on May 31st 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 survey was therefore postponed until June 2nd and 3rd at which time systematic reconnaissance surveys were flown by two 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 2010, 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. This finding, and results from the 2010 survey made it very unlikely that this area would contain substantive number of breeding females and therefore it was not surveyed further.

Table 3: Summary of reconnaissance and visual survey flying of the two turbo beaver aircraft during the 2013 calving ground survey as also summarized in Figure 9.

Date	Turbo Beaver 1 (OPE)	Turbo Beaver 2 (OEV)
May 31st	• Yellowknife to Kugluktuk • Preliminary delineation of core calving area and assessment of breeding status of caribou	• Yellowknife
June 2nd	• Recon of collar locations to assess breeding status	• Yellowknife
June 3th	• Systematic reconnaissance of western areas	• Arrives from Yellowknife
June 4th	• Recon of core calving areas	• Recon of core calving areas and southern areas
June 5th	• Visual survey of SW stratum	• Visual survey of NW stratum
June 6th	• Visual survey of part of high density stratum and SW stratum	• Visual survey of high density stratum and southern strata
June 7^{nth}	• Visual survey of south stratum	

On June 4th the core area of calving was re-flown to assess calving status. Of 43 segments flown, the mean proportion of calves for groups that contained breeders was 22.1% (SE=0.27, min=0, max=1) which indicated that the herd was close to the peak of calving. 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 had occurred by June 5-6 (as detailed later in Table 9). This was also suggested by reduced movements of collared caribou (Figure 8). The coverage of reconnaissance surveys is illustrated in Figure 9 with density and composition classes denoted.

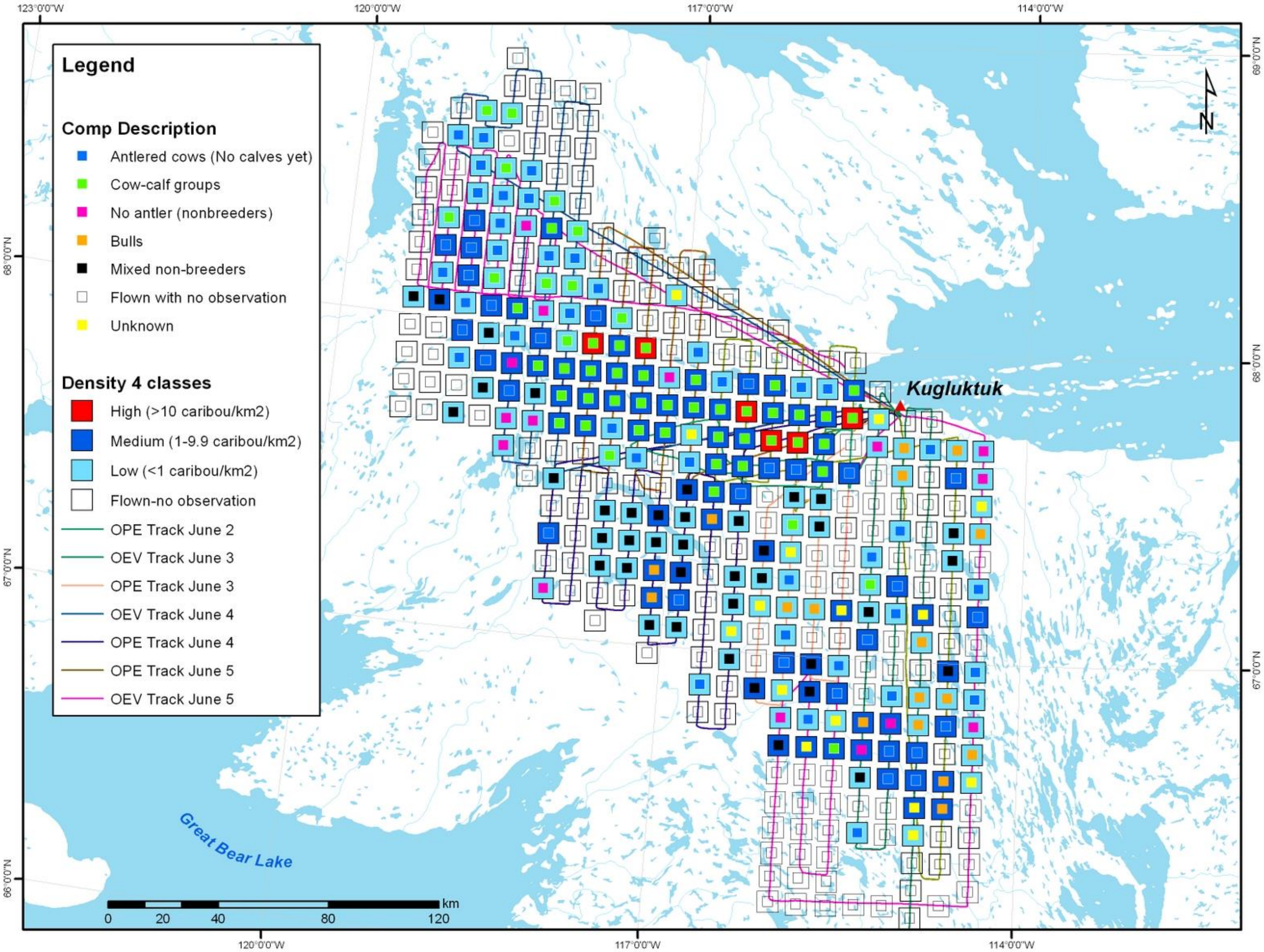

Figure 9: Reconnaissance survey coverage for two turbo beaver aircraft with flight lines by date.

Stratification and allocation of survey effort

The results of the reconnaissance survey revealed that the majority of caribou and all the higher-density areas were located starting just west of Kugluktuk extending 100 km W, with generally smaller numbers of caribou east and south of Kugluktuk (Figure 9, Table 4). No directional gradients in density were evident in the main higher-density area west of Kugluktuk with high density segments located sporadically throughout the area. As a result, we decided to survey this area as a single high-density stratum (Figure 10). The rationale was that stratifying only reduces precision if there are defined geographic differences in density of caribou or logistics prevent flying a stratum within a shorter time period. Dividing this area into smaller strata also risked biases caused by movement of caribou between strata. The main objective for allocation of transects to the high density stratum was allocating enough transects to ensure reasonable coverage, but also ensuring that the photo-plane was able to survey the area within a single survey day, given the possibility of deteriorating weather.

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

Stratum	Area (km^2)	$\widehat{N}$	SE($\widehat{N}$)	Density	CV
High	4,502.39	24,921	3,808.77	5.54	0.15
NW	2,490.72	1,463	211.82	0.59	0.14
SW	2,503.52	3,560	533.84	1.42	0.15
SE	3,717.80	5,835	1,988.75	1.57	0.34
SR	7,364.6	7,178	1,067.48	0.97	0.15

The other four strata were defined based on densities and presence of significant numbers of breeding females. Of the four visual strata, priority for flying was given to the northwest and southwest strata where larger numbers of breeding caribou were seen. In this case, these two strata were allocated flight lines to ensure that they could also be flown with three plane trips while allowing for 280 km of ferrying for each trip. This reduced the total number of survey kilometers for these two strata to 460 km per trip or 1,380 km of survey kilometers. Using this limit, the optimal number of transects for the NW and SW was ten for the NW and 19 for the SW for calculations using the estimate of caribou, and calculations using the SE of the estimate. The resulting coverages were 13.1% and 30% for the NW and SW strata (Table 5). We adjusted the allocation to ensure at least 15% coverage for both strata by adding one line to the NW stratum and reducing one line for the SW stratum. The resulting coverages were 15.2% and 27.3% for the NW and SW strata.

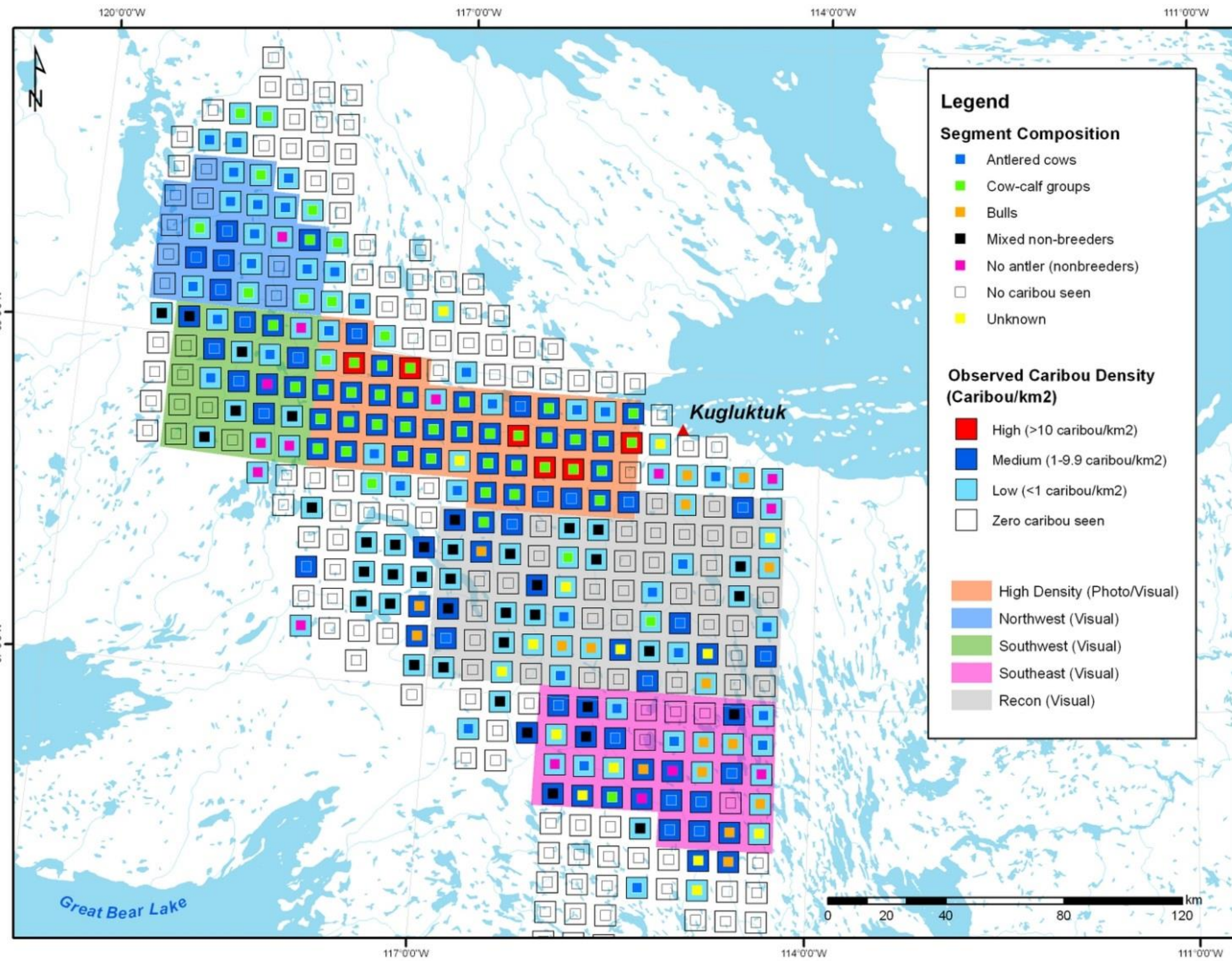

Figure 10: Summary of reconnaissance segment densities and composition with strata defined.

As a second priority the south east stratum, where low densities of breeding caribou had been observed, were allocated survey lines to ensure they could be flown within a second survey day. For these strata we assumed two plane trips with 120 km of ferrying to the further southeast (SE) stratum and 0 km for the closer south reconnaissance (SR) stratum which amounted to 1,360 km of flying. Of the two strata, the SE was of higher priority due to the fact that some breeding caribou were observed in this stratum during the reconnaissance survey. Results from the allocation program suggested 15 lines for the SE and ten lines for the SR strata. We adjusted this allocation up to 12 lines for the SR stratum which was basically reconnaissance coverage with 14.7% coverage for the SE stratum (Table 5). In this context, re-flying the SR stratum allowed a second assessment of the presence of any breeding caribou in this large stratum and an approximate estimate to verify low densities observed during the initial reconnaissance survey.

Table 5: Allocation of effort for visual lines for the Bluenose-East 2013 survey.

Stratum	Optimal No. of transects		Coverage		Percentage effort		Adjusted lines	
	Using N	Using SE	Using N	Using SE	Using N	Using SE	Transects	Coverage
West strata								
NW	10.2	10.0	13.1	12.9%	31.0%	30.4%	11	15.2%
SW	19.1	19.2	30.5	30.7%	69.0%	69.6%	18	27.3%
South strata								
SE	14.9	15.4	14.9	15.4%	49.4%	50.8%	15	14.7%
SR	10.6	10.3	7.1	6.9%	50.6%	49.2%	12	8.0%

The high density (HD) and southwest visual (SW) received the highest coverage of all strata given that these two strata had the highest densities of breeding females (Table 6).

Table 6: Final dimensions of strata for the Bluenose-East 2013 survey. The number of lines total for the HD stratum assumed the photo-plane was flying with a strip width of 1.11 km. Visual transects were flown for the other strata with a strip width of 0.8 km.

Stratum	Total transects possible	Sampled Transects	Area of stratum (km^2)	Transect area (km^2)	Coverage
HD	100	38	4,502.4	1,703.6	37.8%
NW	73	11	2,490.7	378.2	15.2%
SW	63	18	2,503.5	684.1	27.3%
SE	102	15	3,717.8	545.1	14.7%
SR	147	12	7,364.6	554.7	8.0%

A bubble plot with bubbles proportional to the density of caribou in segments further demonstrates that intermittent high densities of caribou occurred in the high density stratum with lower densities in other strata (Figure 11). The higher density groups observed in the SR were non-breeding caribou as shown in Figure 10.

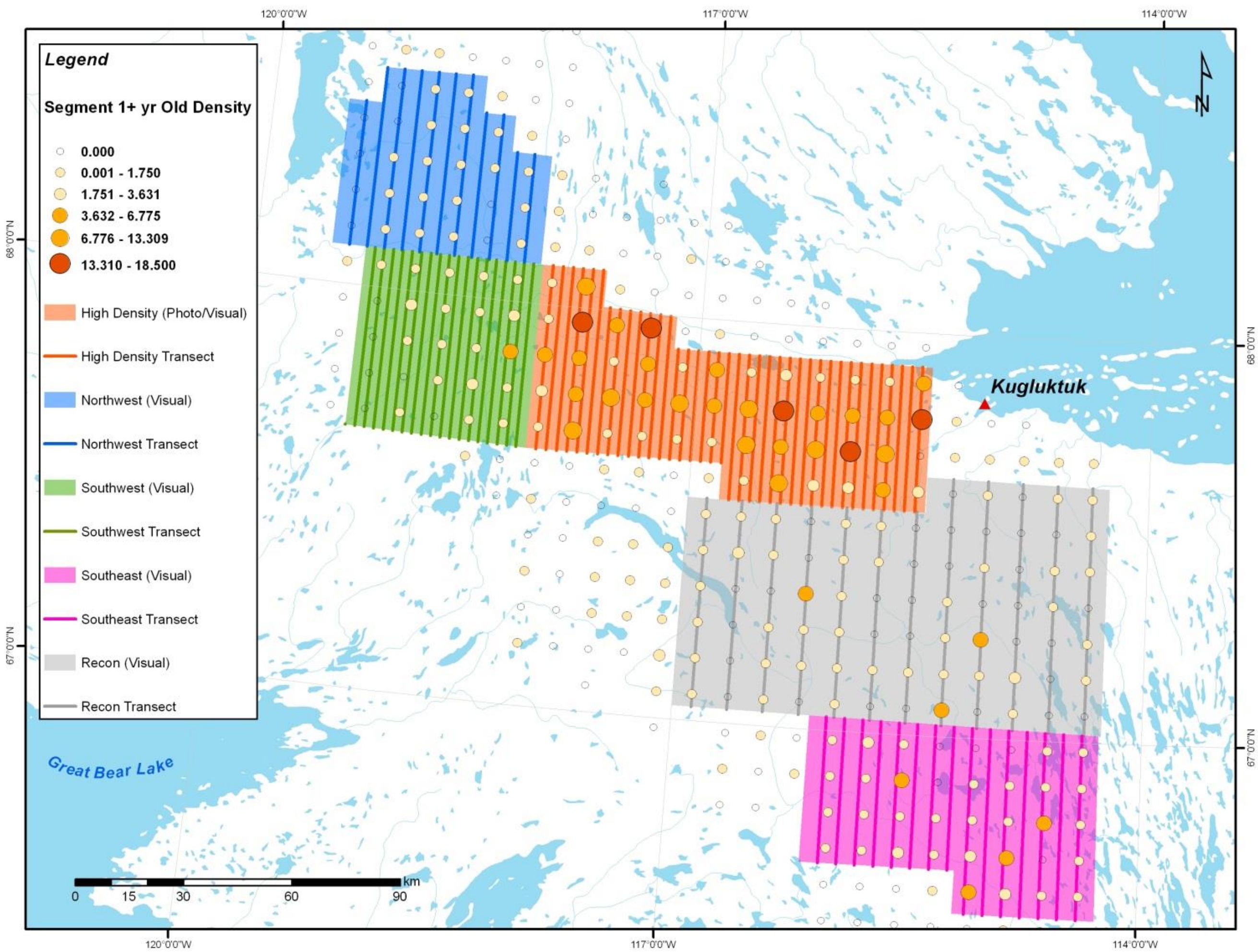

Figure 11: The final transect layouts with segment densities shown as varying sized circles.

Survey results

Photo-plane survey

The challenger photo-plane initially completed 26 of the 38 lines of surveys on June 5th before technical issues with the digital camera forced an overnight delay. Survey conditions were optimal on June 5th with scattered clouds. On June 6th the photo-plane resumed surveys, however, lower cloud ceilings made the flying of only four lines possible (Figure 12). Eight lines initially planned for the photo-plane were instead flown visually on June 6th. In addition, nine lines flown by the photo-plane were also flown visually on June 6th to allow direct comparison of photo and visual counts from the same transects in the high-density stratum.

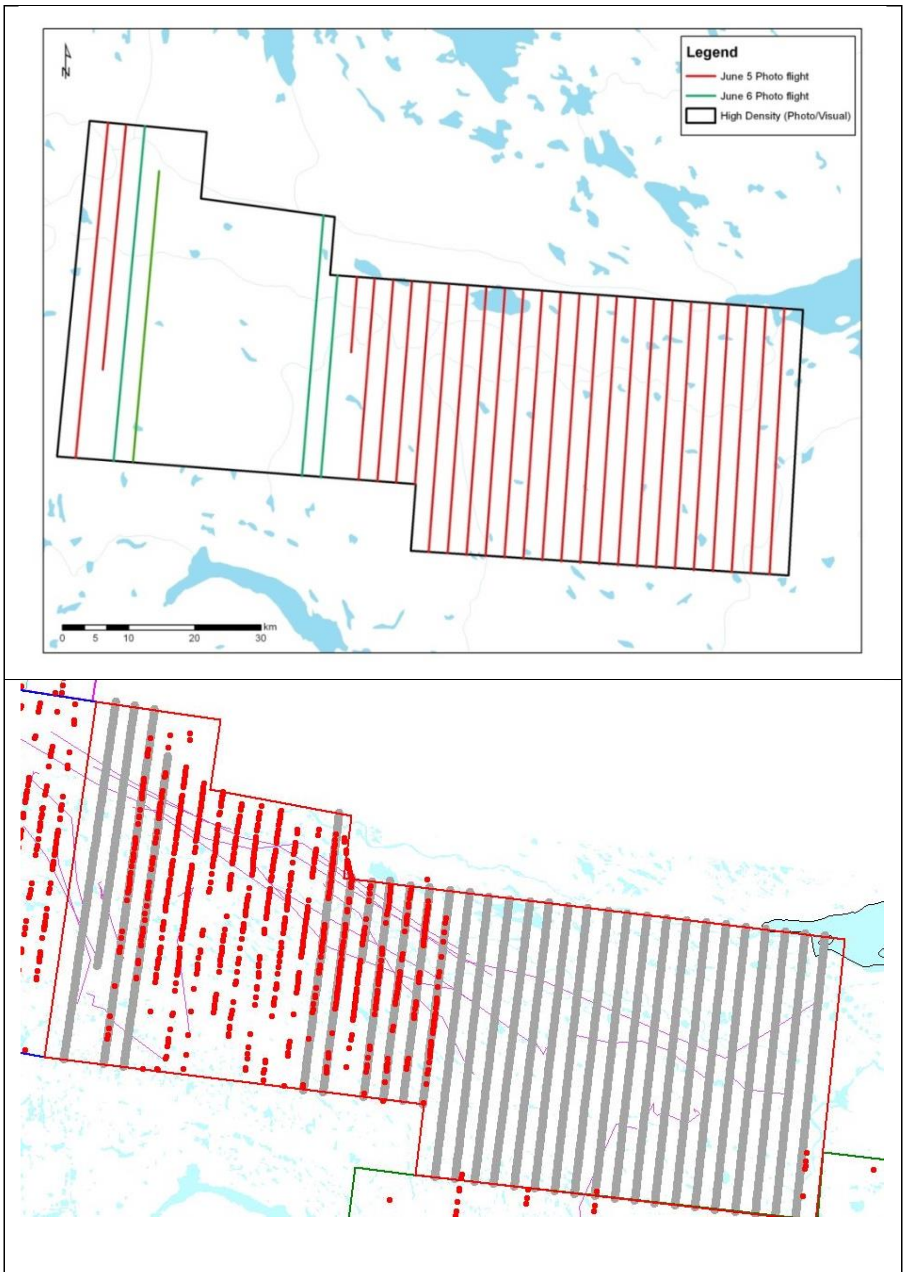

Figure 12: Lines flown by the photo-plane on June 5th and 6th (top) and lines flown by the photo-plane (grey) and visual plane (red dots) on June 6th (bottom) illustrating the overlap of lines flown by both visual and photo-planes.

Visual surveys: Double observer visual analysis

Visual surveys were flown for the NW and the eastern half of the SW stratum on June 5th. As described earlier, 17 lines in the high-density block were flown visually on June 6. In addition, the western portion of the southwest stratum, the SE stratum, and part of the S stratum were flown on June 6. The remainder of the SE stratum and SR stratum were flown on June 7th. Survey conditions were marginal on June 7th and therefore some lines of the SR stratum were only partially flown.

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 13). Overall, most groups of caribou counted were composed of 20 or less caribou (Figure 13, top panel). 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 five or less. Larger groups were consistently found by both observers. Skies were generally clear during the survey (Figure 13, left bottom) and snow cover was limited (Figure 13, right bottom).

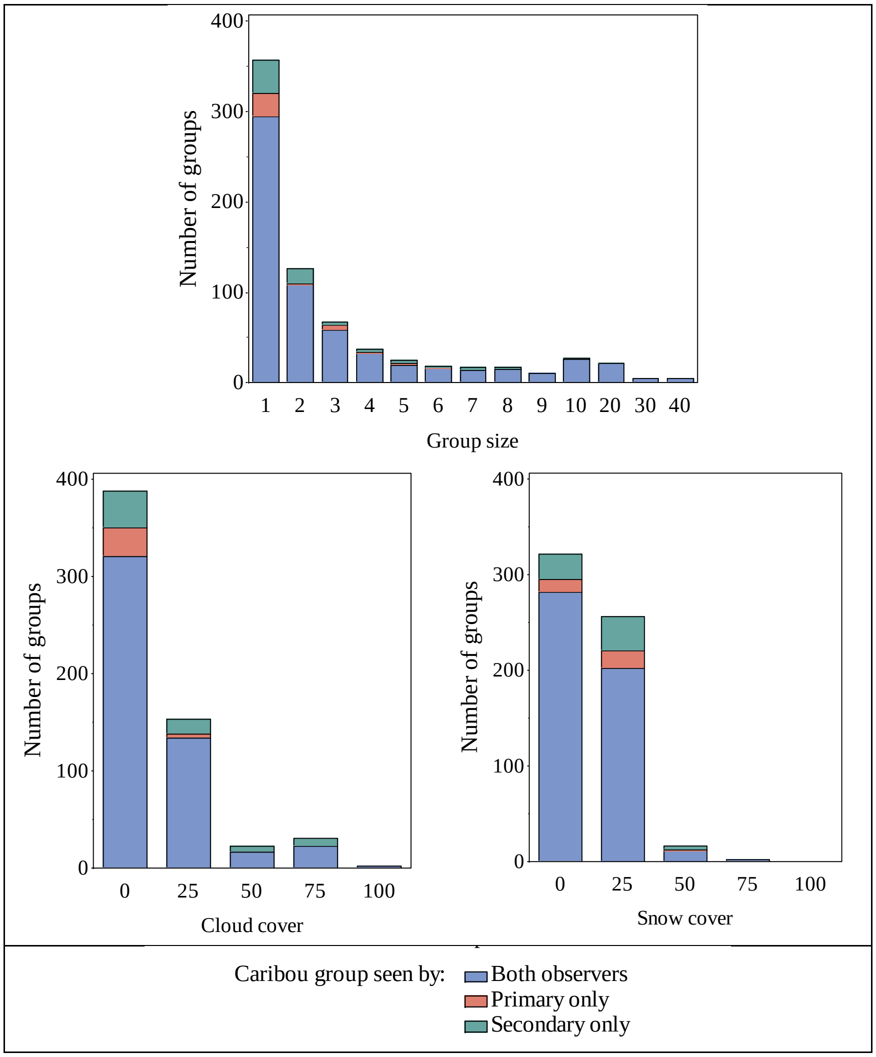

Figure 13: Summary of group sizes, cloud cover, and snow cover observed for the double observer visual plane.

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 group size, snow cover, cloud cover, and observer variability. Initial model selection suggested that the sighting probabilities of observers were equal with less support for a model with pooled observer sighting probabilities (Table 7: Model 16) compared to models with observer pair specific sighting probabilities (Models 17, 18). A model with the log of group size was established as a base model (Model 15). Subsequent model building focused on building a model to describe sightability variation caused by cloud and snow cover. Models with snow and cloud as categorical and continuous covariates were tested. A model (Model 1) with sightability varying as a function of the log of group size, cloud cover (quadratic) and snow cover was most supported.

Table 7: Model selection for double observer analysis of observer sightability. Sample-size adjusted Akaike Information Criteria (AIC_c), difference in AIC_c between most supported and given model (ΔAIC_c), Akaike weight (w_i), the number of parameters (K), and Deviance are shown.

No.	Model	AICc	ΔAIC_c	w_i	K	Deviance
1	log(groupsize)+cloud^2+snow	630.3	0.00	0.35	8	614.2
2	log(groupsize)+cloud+snow	630.4	0.10	0.33	8	614.3
3	log(groupsize)+cloud^2+snow+snow*cloud	631.7	1.44	0.17	9	613.6
4	log(groupsize)+cloud+snow+snow*cloud	632.1	1.83	0.14	10	612.0
5	log(groupsize)+cloud^2	637.8	7.53	0.01	6	625.8
6	log(groupsize)+cloud	638.5	8.17	0.01	6	626.4
7	log(groupsize)+cloud$_{>50}$	640.9	10.63	0.00	5	630.9
8	log(groupsize)+cloud$_{>25}$	643.9	13.54	0.00	6	631.8
9	log(groupsize)+cloud$_0$	643.9	13.54	0.00	6	631.8
10	log(groupsize)+snow$_{>25}$	644.0	13.71	0.00	6	632.0
11	log(groupsize)+snow	645.3	15.03	0.00	6	633.3
12	log(groupsize)+snow +snow^2	647.3	16.95	0.00	8	631.2
13	log(groupsize)+stratum	650.2	19.85	0.00	8	634.1
14	log(groupsize)+snow^2	650.6	20.29	0.00	6	638.5
15	log(groupsize)	653.0	22.70	0.00	4	645.0
16	groupsize	653.3	22.97	0.00	4	645.2
17	groupsize+obspair	657.0	26.74	0.00	6	645.0
18	groupsize+obsair*order	659.1	28.75	0.00	7	645.0
19	stratum	668.9	38.62	0.00	6	656.9
20	constant	670.4	40.11	0.00	2	666.4

Sightability curves for single and double observers were derived from Model 1 to illustrate the effect of group size, snow cover, and cloud cover on sightability. These curves demonstrated that using two observers increased sighting probabilities compared to a single observer. In general, once group size was >5, sighting probabilities were very high. Sighting probabilities were reduced in mixed snow and cloud cover but still remained relatively higher for two observers (Figure 14).

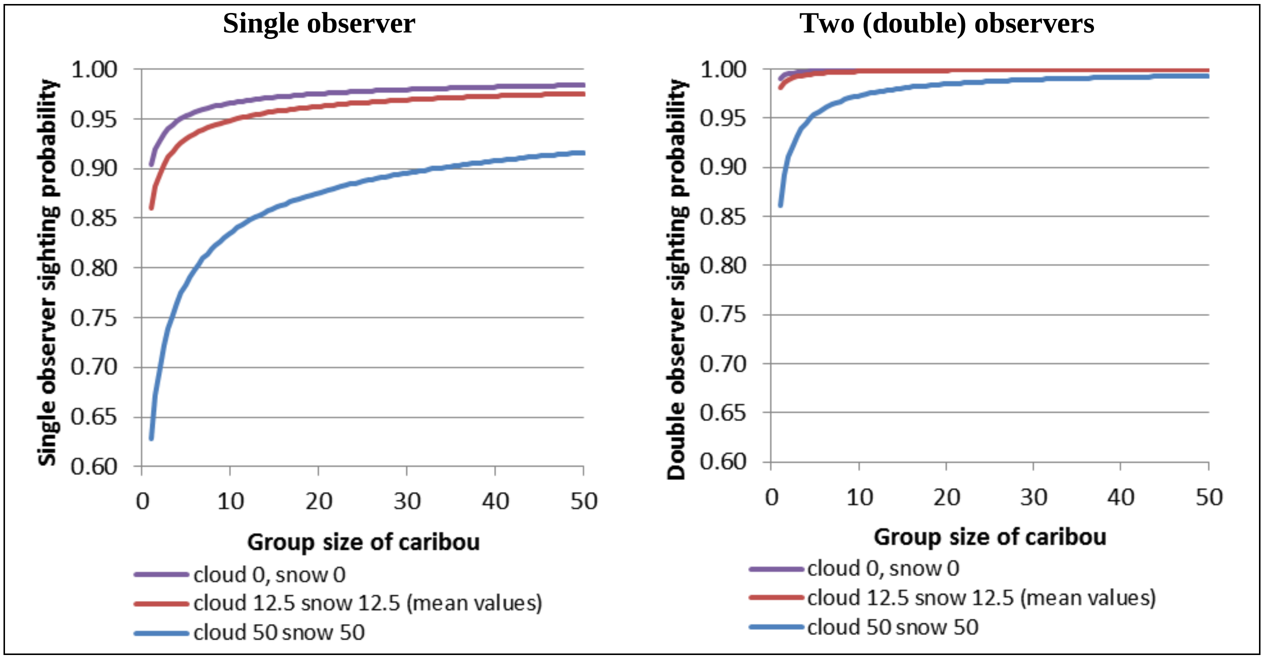

Figure 14: Single and double observer sighting probabilities from Model 1 (Table 7). Sighting probabilities from two observers are used for estimation.

The sightability curves obtained from the double observer analysis were applied to the visual survey data from all the survey strata. Distributions of group sizes were relatively similar for survey strata with larger group sizes generally observed in the high density (HD) stratum (Figure 15).

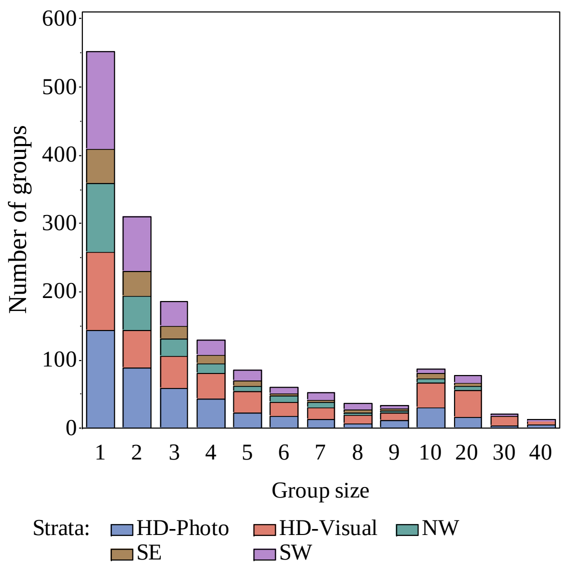

Figure 15: Distribution of group sizes observed in survey strata. The HD visual stratum applies to transect lines that were only surveyed using visual methods (and used for estimates) whereas the HD-photo applies to survey lines surveyed by both photo- and visual planes.

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 km segments of transects on the HD, NW and SW strata (Figure 16). The highest densities of caribou counted were observed in the HD stratum with the majority of HD groups counted in central regions of the HD stratum.

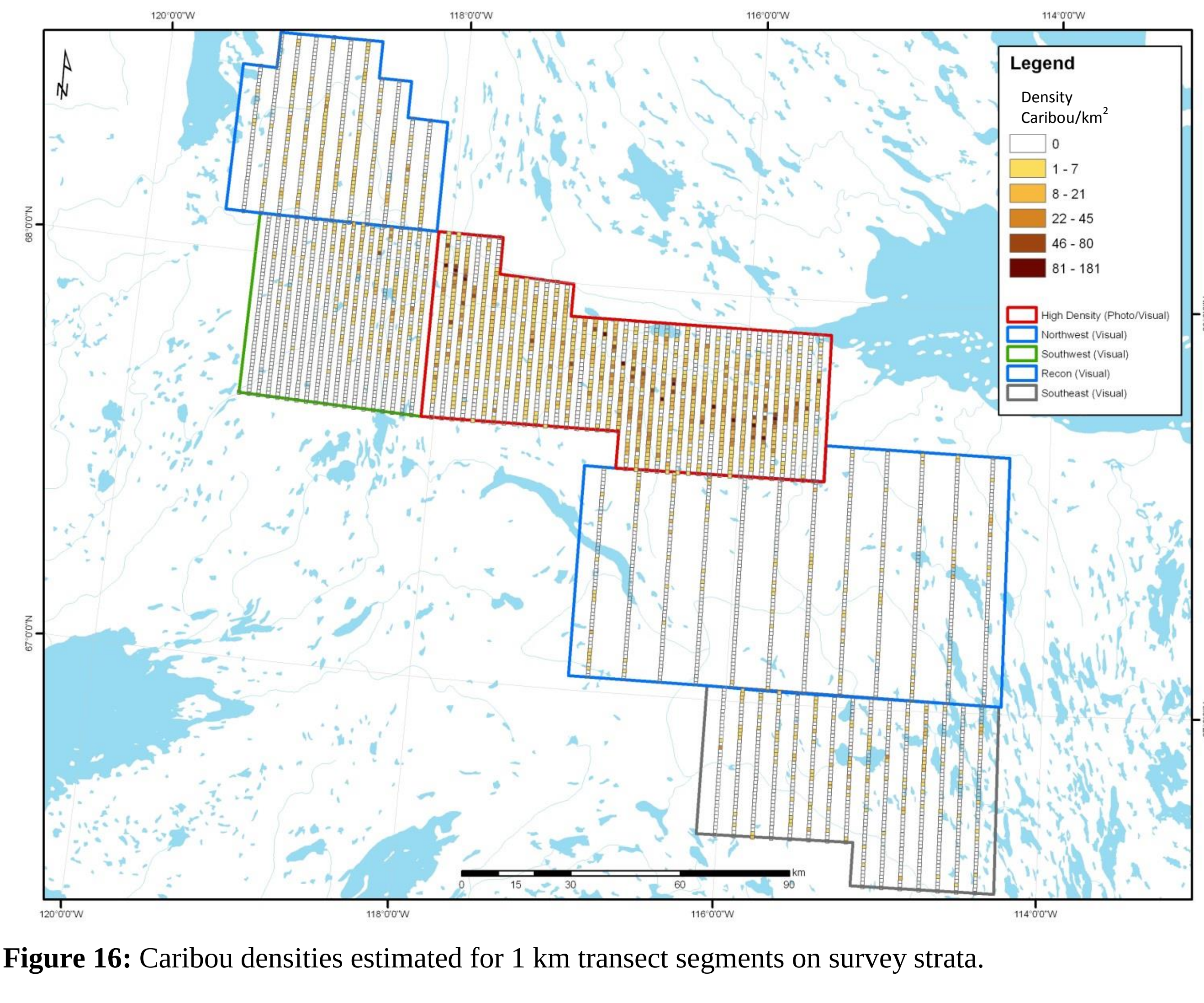

Figure 16: Caribou densities estimated for 1 km transect segments on survey strata.

Estimation of caribou on the calving ground.

Caribou on each stratum were estimated from photo and double observer visual estimates on the HD stratum and from double observer estimates on the other strata. The coverage for the HD stratum was reduced to 33.8% from 37.8% (Table 6) since the strip width of the visual plane (0.8 km) was less than the photo-plane (1.11 km) for the eight transects flown by the visual plane. The majority of caribou were estimated in the HD stratum (40,229 caribou) and the estimate had higher precision with a coefficient of variation of 5.4% (Table 8). The rest of the strata each had approximately 5,000 caribou. The total estimate of caribou at least one year old on the calving ground was 60,387 (CI=54,512-66,262).

Table 8: 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 HD stratum).

Stratum				Caribou Counted		Estimates			
Name	Transects	Transect Area	Coverage	Counted	Estimated (photo)	Density	$\hat{N}$	SE($\hat{N}$)	CV
HD	38	1,521.0	33.8%	2,873	2884.7 (10,705)[A]	8.93	40,229	2,166.4	5.4%
NW	11	378.2	15.2%	718	729.2	1.93	4,802	952.5	19.8%
SW	18	684.1	27.3%	1,340	1366.9	2.00	5,003	764.6	15.3%
SE	15	545.1	14.7%	543	787.1	1.44	4,985	526.5	9.8%
SR	12	554.7	7.6%	377	377.0	0.68	5,368	452.0	9.1%
						Total	60,387	2166.4	4.2%

[A]For the HD stratum, 10,705 caribou were counted on photos and 2,884.7 caribou were estimated from visual counts for a total count of 13,589.7 caribou on transect.

A plot of transect densities for the HD stratum revealed intermittent variation in density with transect densities varying between 3 and 13 caribou per km^2 (Figure 17). Density variation was intermittent with a slight East to West decreasing gradient in density across the stratum. However, no distinct gradients in density were observed, suggesting the single large stratum was appropriate. The intermittent variation in density and the larger number of lines resulted in higher precision of the population estimate for the stratum.

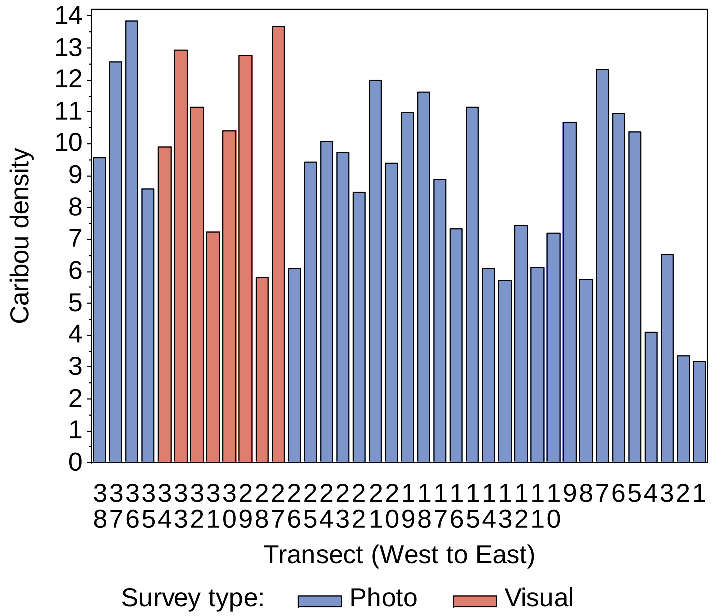

Figure 17: Densities of caribou (caribou per km^2) on transect for the HD stratum as a function of survey type. The visual survey estimates were based on the double observer analysis. Transects are ordered from West to East so that they are comparable to the maps of transect layout.

Composition on calving ground

Composition surveys were conducted on the HD, NW and SW stratum with the majority of groups sampled in the HD stratum. Breeding caribou were observed in the HD, NW, and SW strata (Table 9). Almost no breeding cows were found in the SE and the SR stratum was not surveyed for composition due to poor survey conditions and very low densities of breeding caribou. During visual surveys of this stratum, 126 groups composed of 380 caribou were observed. Of these, four cows with calves were observed on the border of the SR and HD strata further suggesting that this stratum contained negligible proportion (approximately 1%) of breeding caribou. The SE stratum was not sampled substantially due to low densities of caribou and poor survey conditions. During visual surveys, 192 groups were observed composed of 543 caribou. Of these, six cows with calves were observed also demonstrating that this stratum contained negligible proportion (approximately 1%) of breeding caribou.

Table 9: Summary of composition samples in the HD, NW, SE, and SW strata

Category		Sum of counts				Mean group sizes			
		HD	NW	SE	SW	HD	NW	SE	SW
Groups sampled		162	35	5	35				
Breeding females	Antler and udder	1,045	127	0	199	6.45	3.63	0.0	5.69
	No antler and udder	169	5	0	28	1.04	0.14	0.0	0.8
	Antler and no udder	1,063	181	0	173	6.56	5.17	0.0	4.94
Non-breeding	No Antler and udder	518	39	10	68	3.20	1.11	2.0	1.94
	Yearlings	579	17	8	54	3.57	0.49	1.6	1.54
	Bulls	21	0	31	2	0.13	0.00	6.2	0.06
Calves		1,164	155	0	215	7.19	4.43	0.0	6.14
All 1+ yr. caribou		3,395	369	49	524	20.96	10.54	9.8	14.97

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 10). Bootstrap resampling was used to estimate percentile based confidence limits and estimates of standard error.

Table 10: Estimates of proportion breeding females, SE, 95% confidence intervals (CI), and coefficient of variation (CV) in the Low and High strata.

Stratum	Proportion Breeding Females				
	Proportion	SE	Confidence Limits		CV
HD	0.66072	0.018	0.632	0.695	2.7%
NW	0.84824	0.027	0.781	0.891	3.2%
SR	0				
SE	0				
SW	0.76336	0.043	0.680	0.835	5.6%

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 10) during composition surveys (Table 11). Decimal places were kept on the stratum-specific caribou estimates to minimize rounding error. The majority of caribou were in the HD stratum and the proportion of breeding females was 0.661 leading to an estimate of 26,580 breeding females. The NW stratum had a higher proportion of breeding females; however, the actual estimate of 1+ year old caribou in this stratum was only 4,074.

No breeding females were detected in the SE or SR strata and therefore estimates from these two strata did not contribute to the overall estimate. The resulting estimate of breeding females (34,472, CI=30,109-38,836) was precise mainly due to the high precision of the HD stratum estimate (Table 11).

Table 11: Estimates of breeding females based upon estimates of caribou in each stratum and composition surveys.

Stratum	Total 1^+ year caribou			Proportion of breeding females			Estimated breeding females		
	$\widehat{N}$	SE	CV	Proportion	SE	CV	$\widehat{N}_{breedf}$	SE	CV
HD	40,228.7	2,166.4	5.4%	0.66072	0.018	2.7%	26,579.9	1,595.3	6.0%
NW	4,802.3	952.5	19.8%	0.84824	0.027	3.2%	4,073.5	818.50	20.1%
SW	5,002.9	764.6	15.3%	0.76336	0.043	5.6%	3,819.0	622.05	16.3%
SR	5,368.5	526.5	9.8%	0.000			0.0		
SE	4,984.9	452.0	9.1%	0.000			0.0		
Total	60,387	2,555.5	4.2%				34,472.4	1,897.88	5.5%

Fall composition surveys to estimate adult sex ratio

Surveys were conducted from October 20-24, 2013 to estimate the adult sex ratio for the Bluenose-East herd (Figure 18). A helicopter was used to sample caribou in the vicinity of collared Bluenose-East females and males.

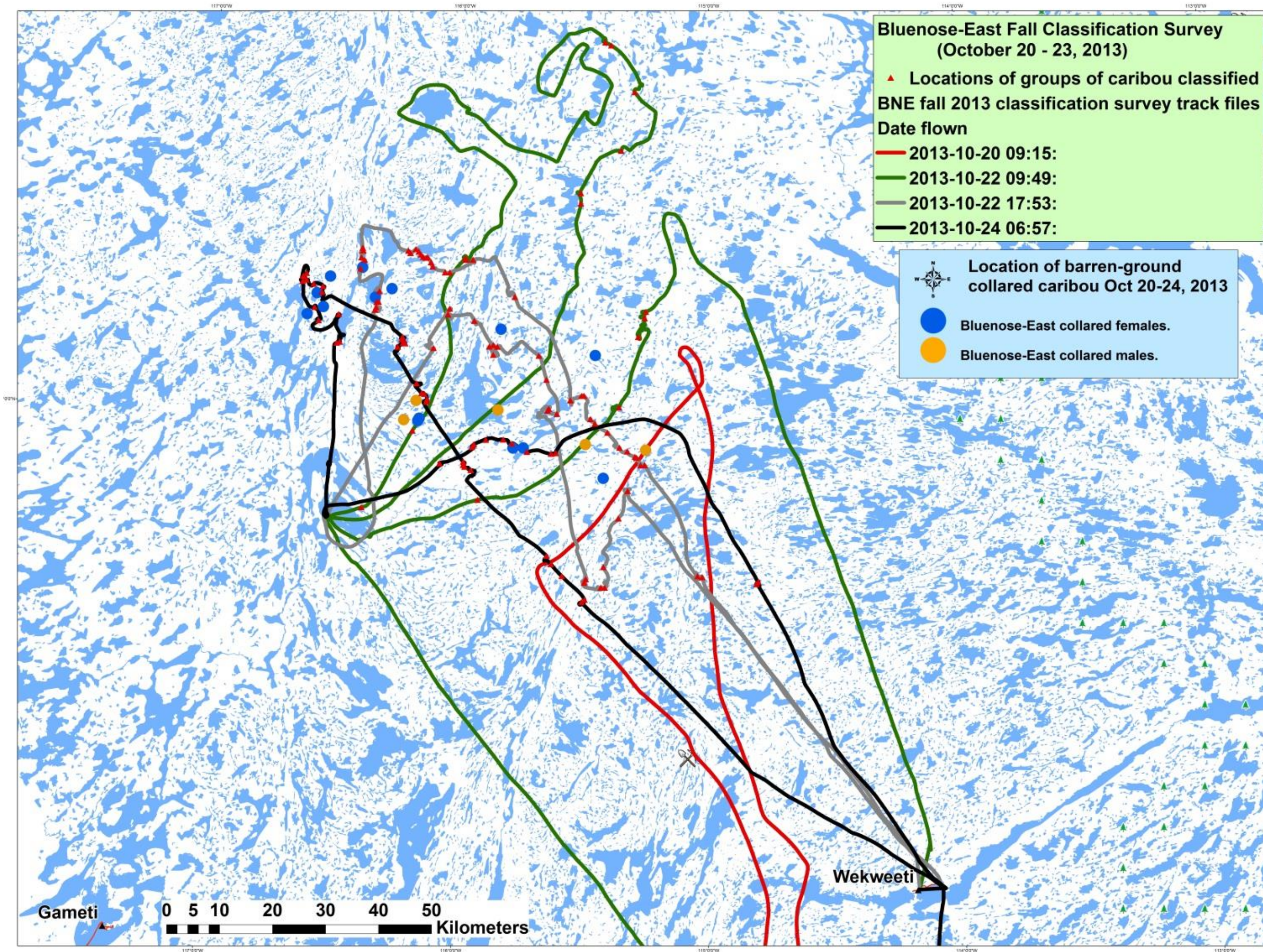

Figure 18: Flight path and groups sampled for fall 2013 composition survey conducted from October 20-23, 2013.

During this time, 117 groups composed of 5,381 individuals were classified with a mean group size of 36.7 individuals (Table 12). The sample sizes were similar to a fall composition survey conducted in 2009.

Table 12: Summary statistics for fall composition surveys conducted in 2009 and 2013.

Statistic	Year	
	2009	2013
Number of groups	79	117
Mean group size	43.38	36.73
Total caribou	4,531	5,381
Total adults (1.5+ year old)	3,427	4,297
Total cows	2,399	3,004
Total bulls	1,028	1,281
Total yearlings	0	12
Total calves	1,104	1,084

The estimated proportion of cows (0.70) and bull-cow ratio (0.426) were similar in 2009 and 2013 (Table 13).

Table 13: 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	CI		Bull-Cow Ratio	SE	CI	
2009	0.7000	0.008	0.684	0.716	0.429	0.017	0.396	0.463
2013	0.70105	0.009	0.685	0.720	0.426	0.019	0.389	0.461

Extrapolated estimate of total herd size

The extrapolated estimate of total herd size was derived in a sequential process. First, the estimate of breeding females was divided by the assumed pregnancy rate (0.72, Dauphine 1976) to estimate the total number of adult (1.5+ year old) females in the herd of 47,878 (±6,100) caribou. This correction adds in the non-pregnant breeding age cows, some of which may not be on the calving ground. This estimate was then divided by the proportion of adult females in the herd (Table 13; 0.70105) to estimate the total herd size of 68,295 (1.5+ year old) caribou (

Table 14). The estimate of proportion adults in the herd was extended to five decimal places to minimize issues with rounding error.

Table 14: Extrapolated estimate of total herd size for 2012 using breeding female estimates (Table 10) and estimates of proportion of adult females in the entire herd from 2012 fall composition surveys (Table 12).

Survey data	Estimate	SE	CV	CI	
Number of caribou on the breeding ground	60,387	2,555.5	4.2%	54,512	66,262
Number of breeding females	34,472.4	1,898.1	5.5%	30,109	38,836
Proportion adult females in the entire herd	0.70105	0.0091	1.3%		
Proportion 1.5^{+} year females pregnant	0.72		10.0%		
Total population estimate (1.5+ year old caribou)	68,295	7,847.1	11.5%	50,254	86,336

Trends in breeding females between 2010 and 2013

Comparison of 2010 and 2013 breeding female estimates

The estimate of breeding females for 2013 (34,472, CI=30,109-38,836) was 66.6% (CI=52.9-80.3%) of the 2010 estimate of 51,757 (CI=40,665-62,849). The difference in breeding female estimates was statistically significant (t=-3.386, df=80, p=0.0011). This amounts to an annual rate of decline of 12.6% (CI=7.0-18.9%) (Figure 19).

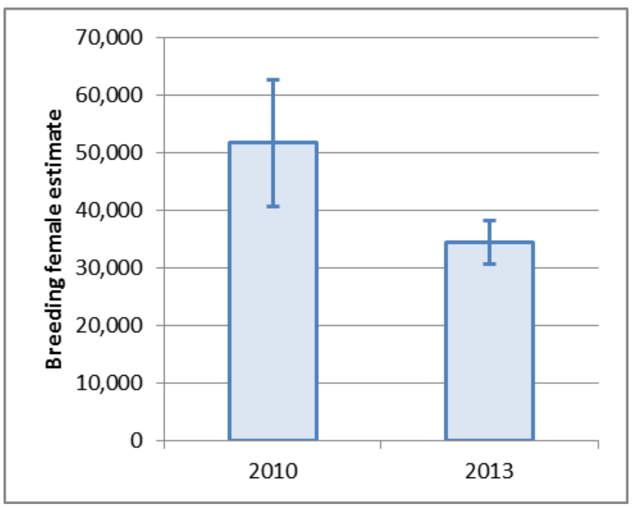

Figure 19: The 2010 and 2013 breeding female estimates with confidence limits.

Comparison of reconnaissance survey results

The estimates from the reconnaissance surveys in 2010 and 2013 were compared to assess if densities observed were similar to the breeding female estimates derived from the photographic and visual surveys. Segment densities from strata that contained breeding females from 2010 and 2013 were paired for this comparison. This comparison was not as robust as the breeding female estimate given that the sampling effort and coverage was less for reconnaissance surveys than the photo and visual surveys. In addition, it compared estimates of 1+ year old caribou, which include non-breeding cows, yearlings and bulls on the calving ground, not just the breeding females. However, it provided a secondary comparison of relative abundance between the two survey years, given similar flight lines and pairs of observers on each side of the aircraft in both years. Comparing the reconnaissance based estimates also provides a potential lower-cost method for estimation of trend for years in which a full photo survey was not conducted.

Comparison of segment densities revealed that there were less high density segments in 2013 and more segments without detected caribou (Figure 20).

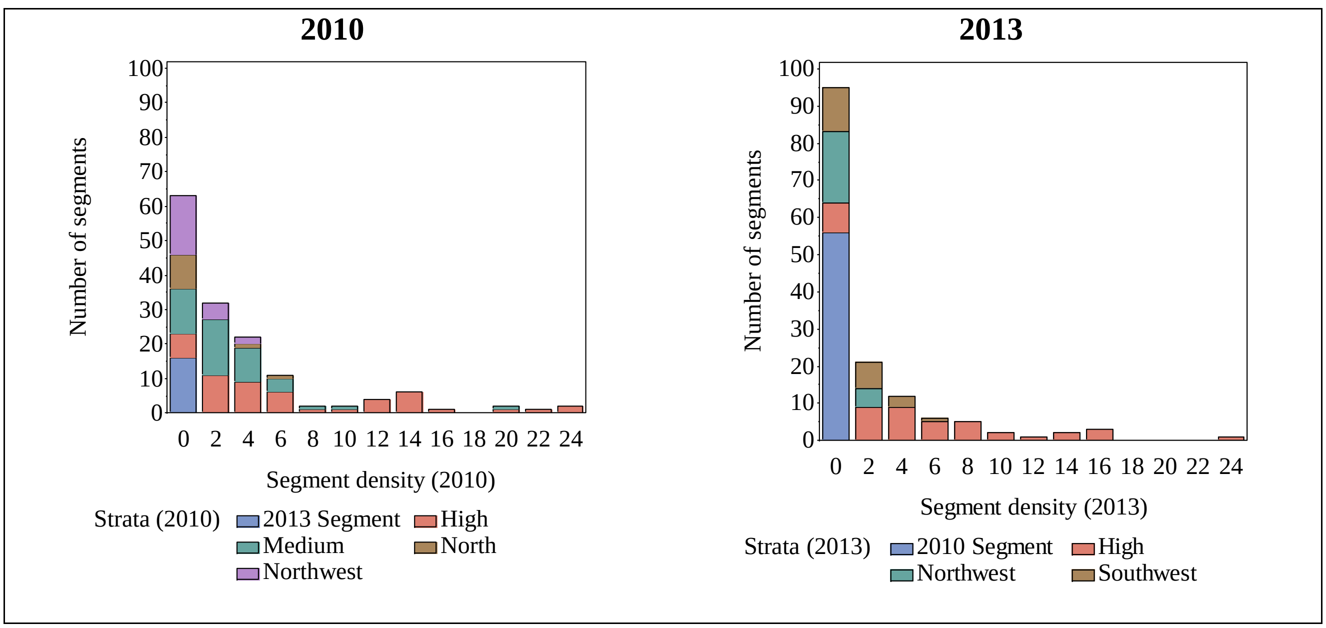

Figure 20: Distributions of segment densities from the 2010 and 2013 reconnaissance surveys.

A comparison of reconnaissance-based estimates of caribou on the calving ground from the 2010 and 2013 surveys revealed similar trends to the breeding female estimates with reconnaissance estimates for 2013 being 58.3% (CI=36.0-80.7%) of the 2010 estimates, which amounted to a 16.3% annual decline (CI=6.8-28.6%) (Figure 21).

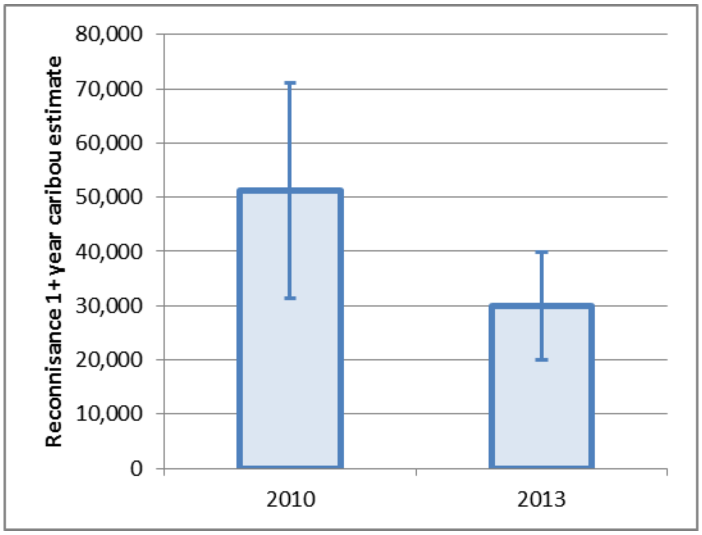

Figure 21: Comparison of reconnaissance-based estimates of 1+ year old caribou on the calving ground from the 2010 and 2013 surveys.

Exploration of potential biases in survey estimates

Because the 2013 Bluenose-East calving photo survey results suggested a substantial decline in caribou numbers, we assessed whether technical issues associated with the survey could have created errors or bias in estimates of breeding females or herd size. In particular, we considered whether movement of caribou within the survey area (among blocks) or into and out of the survey area might have affected results. In addition, we considered whether the altered flying of the high-density block (visual vs. photo-plane) due to field conditions might have biased the results of the survey.

Movement of caribou during sampling

After the commencement of the photo and visual survey, some of the collared caribou unexpectedly moved at a higher rate than the expected 5 km/day (Figure 22). The reason for this is uncertain but could have been due to a segment of the caribou population having a slightly later calving date of June 7th or later (when movements decreased again).

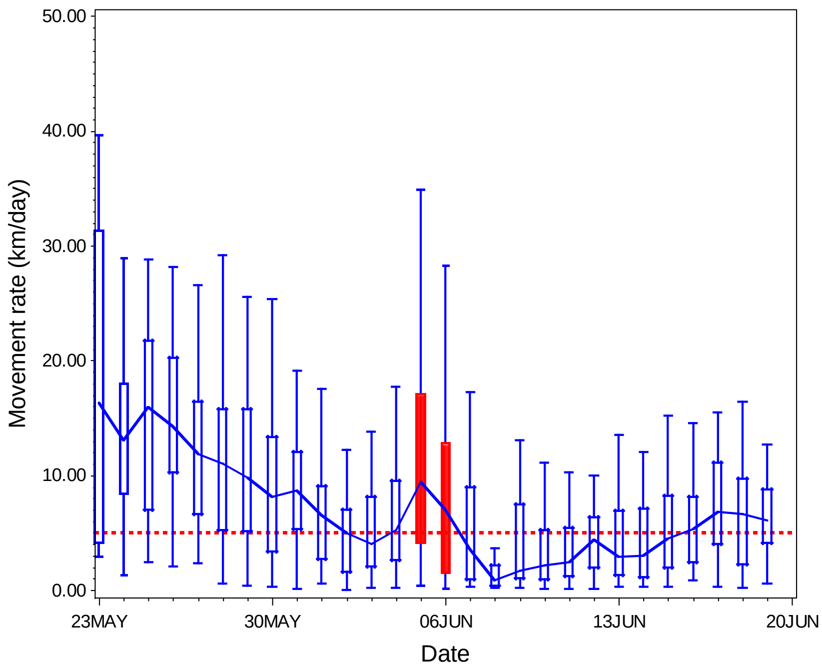

Figure 22: Movement rates (km/day) for Bluenose-East caribou before, during, and after the calving ground survey. The distribution of movement rates is shown as box-plots with lines connecting median values, the boxes denote 25th and 75th percentiles, and the whiskers denote the range of the data. The solid red boxes indicate June 5th and 6th when the photo survey occurred.

The movement of caribou during sampling, combined with sampling of different survey areas on different dates had the potential to create bias in estimates if there was significant directional movement into or out of survey strata or within strata (Figure 23). If movement is random relative to transects within a stratum then estimates will be unbiased even if some caribou are counted twice (Buckland et al. 1993). Bias mainly will occur if caribou change strata during sampling, so that they might be double counted in two strata, or if large scale directional movement causes a non-random sample of the distribution of caribou within a stratum.

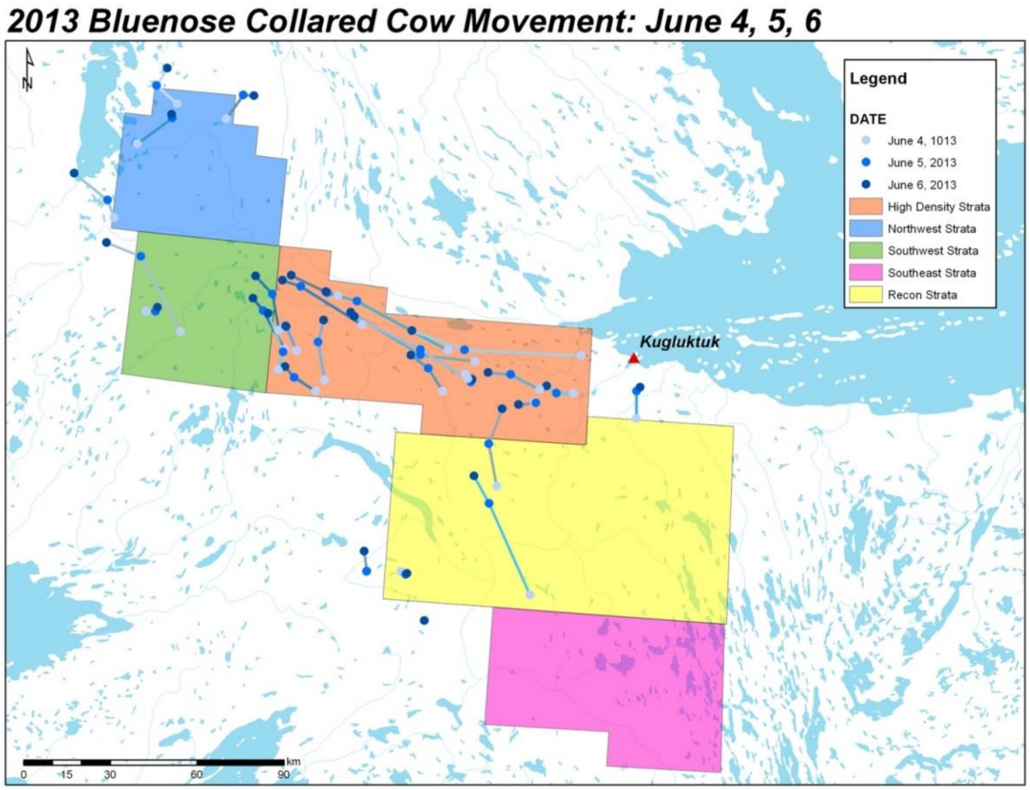

Figure 23: Collared caribou movement from the main reconnaissance survey (June 4th) and the visual survey (June 5th and 6th).

We used the data from female collared caribou to explore potential biases that may have been caused by the movements that occurred on June 5th and 6th. The main changes in movement of collared caribou occurred between the 4th and 5th when two collared caribou moved from the HD to the SW stratum and three collared caribou moved to the north of the NW stratum (Table 15).

Table 15: Numbers of collared caribou in each stratum during the initial reconnaissance survey (June 4th) and during visual/photo surveys from June 5-7th. The cells that indicate days when each stratum was surveyed are shaded. No collared caribou were present on the SE stratum.

Date (stratum)	North				South		
June	HD	SW	NW	Out	SR	Out	Total
4 (recon)	18	2	4	0	4	4	32
5 (HD,SW,NW)	16	4	1	3	3	4	31
6 (HD, SW,SR)	16	4	1	4	2	5	32
7 (SR)	10	6	0	4	1	5	26

At a finer scale, due to technical issues with the photo-plane, 74% of the HD stratum was flown on the 5th with the remainder flown visually on the 6th. In addition, the eastern half of the SW stratum was flown on the 5th and the eastern half flown on the 6th (due to a fog bank over the SW stratum on the latter part of June 5th). The main question was whether movement of caribou in the interval between the 5th and 6th potentially caused bias in estimates. For example, if caribou that were in the HD area sampled on June 5th moved to the area on June 6th then positive bias might occur. Conversely, if caribou in the HD area sampled on June 6th moved to the area sampled on June 5th then a negative bias might occur.

We tallied the number of collared caribou by location relative to visual and photo survey efforts to explore potential movement relative to survey efforts. For this exercise, the area sampled on June 5th is named Stratum 5 and the area sampled on June 6th is named Stratum 6. Initial summaries indicate that 13 collared caribou were on Stratum 5 on June 5th and 16 collared caribou were on Stratum 5 on June 6th whereas eight and six collared caribou were on Stratum 6 on June 5th and 6th respectively (Table 16).

Table 16: Summary of collared caribou numbers across strata as a function of area and survey date

Area	**June 5th**	**June 6th**
Stratum 5: Surveyed on 5th	13	15
Stratum 6: Surveyed on 6th	8	6

We also considered movements on the individual collared caribou level. Each daily location was summarized on the 5th and 6th. From this, we found that 11 caribou that were on Stratum 5 remained on Stratum 5 and two moved to Stratum 6 (Table 17). For Stratum 6, four stayed on Stratum 6 whereas three moved to the area surveyed on the 5th.

Table 17: Summary of movement events by collared caribou with potential bias scores. The sign on the score relates to whether a negative, positive, or 0 bias would be caused by the movement event.

Event	Effect	Frequencies	Score
Stratum 5 to Stratum 5	no bias	11	0
Stratum 5 to 6	positive bias	2	+2
out to out (in low density areas)	no bias	3	0
Stratum 6 to 5	negative bias	3	-3
Six to out	negative bias	1	-1
Sixth to Sixth	no bias	4	0
Totals		24	-2

Tabulating the number of movement events that lead to potential positive, negative, and no bias equaled two, four, and 18 events. This result, although limited by sample size, suggests that movements of caribou during sampling, as indicated by collared caribou, did not cause a high level of bias or movement between strata during the visual and photographic surveys.

The three collared caribou that were out of the survey strata for all of the sampling were on the extreme northern and western edge of the NW and SW strata. Of the 31 female collars monitored, four did not enter the core calving area (Figure 23). Of these, two of the caribou (BGCA12449 and 111006) displayed movement changes suggesting they were potential breeders, one caribou (11015) was later classified as a mortality, and one caribou was likely a non-breeder based on non-reduction of movement during calving. Of the two caribou that were potentially breeders (in the southwest corner of the SR stratum), reconnaissance surveys and visual surveys failed to detect substantial densities of breeding caribou (as indicated by antlers or calves) in the vicinity of these caribou. Therefore, it is likely that these were individual caribou or in small groups, and that large congregations of breeding caribou were not found nearby.

Visual survey of the high density stratum

The usual strategy with historic calving surveys was to use the photo-plane to estimate caribou in higher density survey areas with visual surveys in medium to lower density areas. Using this approach minimized bias due to sightability (the ability of visual observers to detect all caribou) and countability (the ability of observers to count larger groups of caribou once they were detected). For the Bluenose-East 2013 survey, portions of the HD stratum were visually surveyed with estimates derived using double observer methods to account for sightability bias (Table 6, Figures 13-14).

We compared densities for transects surveyed by both the photo- and visual planes to assess potential biases in visual survey estimates. All visual surveys were conducted on June 6th whereas the photo-plane surveyed lines 20-24 on June 5th and lines 25, 26, 35, and 36th on June 6th. Due to differences in survey timing, it would be more likely that movement would create differences in lines 20-24 due to caribou movement compared to lines 25, 26, 35, and 36 (which were surveyed on the same day).

The mean densities for the photo, double observer and raw visual transects were 9.73, 9.05, and 8.05 caribou/km^2 for all of the nine paired transects (Figure 24). The results of this comparison suggested that photo-based density estimates were 7.4% higher than double observer based estimates on average for all the transects. Using the four transects surveyed on June 6th (25, 26, 35, and 36), double observer estimates were 2% higher than photo estimates. Double observer estimates were 12.5% higher than raw visual estimates, which were due to sightability bias with uncorrected caribou counts.

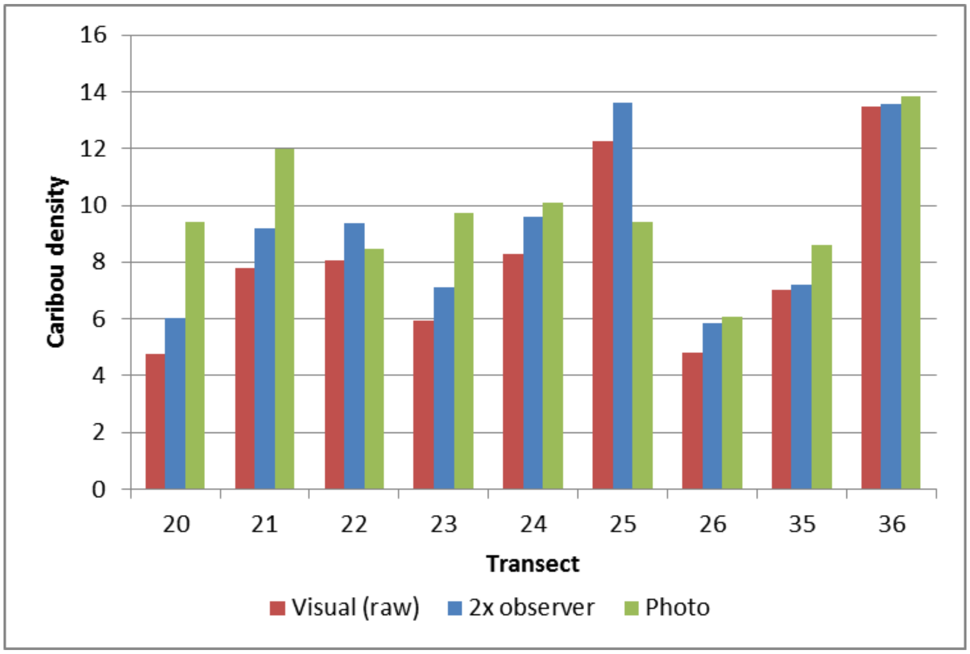

Figure 24: Comparison of transect densities for raw visual counts, estimates of caribou using double observer methods, and photo-based estimates for photo and visual surveys conducted on June 5th and 6th.

To assess the sensitivity of high density stratum estimates to potential bias in double observer we re-ran estimates for the HD stratum with the visual survey transect counts increased by 7.4% under the assumption that the difference between counts was due to countability bias. This analysis should be considered a sensitivity analysis rather than a method to correct an estimate since other factors, such as movement of caribou off transect lines, could have influenced differences between counts. The resulting estimate of the HD was 40,866 which was 638 caribou higher than the estimate derived for this stratum. The resulting difference in breeding female estimates would be 389 caribou.

The main conclusion from this sensitivity analysis is that a slight negative bias was potentially introduced by visual survey of the HD stratum due to countability bias. However, the relative magnitude of bias was negligible given that 30 of 38 lines were photo surveyed, and double observer methods accounted for sightability bias. At the higher population sizes recorded for the Bathurst and other herds in the 1980s and 1990s, visual estimates would likely not be suitable for calving ground surveys due to the difficulties of estimating larger groups of caribou (Heard and Jackson 1990), however at the relatively low densities on the Bluenose-East calving ground in 2013, visual surveys with double-observer methods appeared to produce density estimates very similar to photo-derived ones.

Exploration of potential reasons for decline in breeding females

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 2010-2012 to 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 two or more consecutive years so that fidelity to calving grounds could be assessed (Table 18).

Table 18: Sample sizes of caribou collared for two or more consecutive years, by year, for the Bathurst, Bluenose-East, and Bluenose-West caribou herds.

Year	Bathurst	Bluenose-East	Bluenose-West
2010	5	16	14
2011	7	21	13
2012	14	26	30
2013	10	21	28

Frequencies of movement events were assessed for caribou monitored for consecutive years and tabulated (Figure 25). For example, caribou that were on the Bluenose-East calving ground returned to the Bluenose-East calving ground 42 times. Two caribou that were on the Bluenose-West calving ground switched to the Bluenose-East calving ground and two caribou on the Bathurst calving ground switched to the Bluenose-East calving ground. In no cases did a caribou that was on the Bluenose-East calving ground switch to the Bathurst or Bluenose-West calving ground between 2010 and 2013. 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.

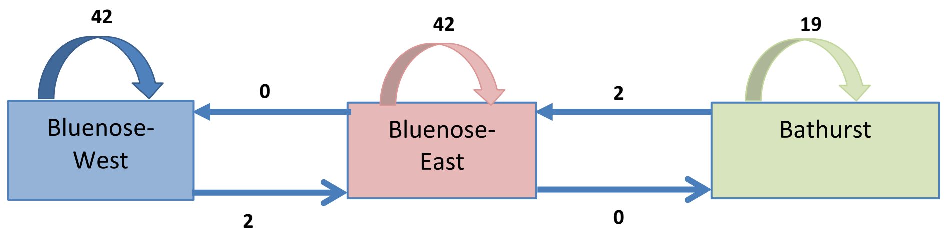

Figure 25: Frequencies of caribou movement events from 2010-2013 based on locations on calving grounds. The arrows above the boxes indicate the number of times a caribou returned to each calving ground for successive years. The arrows indicate movement of caribou to other calving grounds.

Changes in pregnancy rate and resulting fidelity of female caribou to the breeding ground

One assumption of caribou calving ground surveys is that a relatively constant proportion of females return to the calving ground each year. The primary biological driver for returning to the calving ground is for pregnant females to give birth there. In addition, gregariousness of caribou results in some non-breeding cows, yearlings and young bulls also travelling to the calving ground during the spring migration. If pregnancy rate was substantially lower than normal, then it would be possible that a proportion of females would not return to the core calving area. We tested for this effect by evaluating proportions of radio collared females that stayed south of the core calving area (as discussed previously), and by the proportion of pregnant females classified on the calving ground (as illustrated in Figure 5). Comparison of proportions of breeding females suggested that there were the same proportions of breeding caribou on the calving ground in 2010 and 2013. There was thus no indication of below-normal pregnancy in 2013 or a lower proportion of breeders in 2013 than in 2010 (Figure 26).

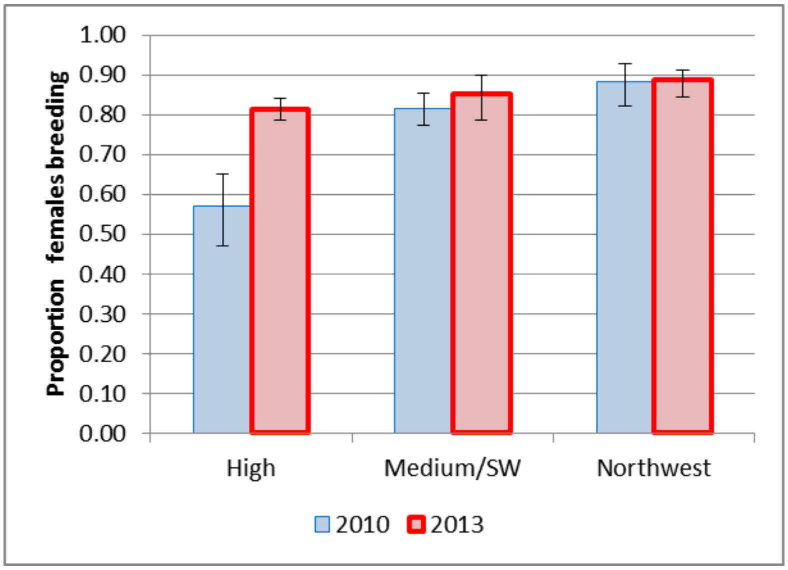

Figure 26: Proportion of adult females that were breeding as estimated by composition surveys on the 2010 and 2013 Bluenose-East calving grounds.

Estimation of survival rates and demographic trends in Bluenose-East herd

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 2013 when levels of productivity as estimated by calf-cow ratios are considered. Initial survival rate was estimated from 68 female caribou that were monitored from June 2010 to May 2013. The mean number of collared caribou monitored each month varied from 40.4 during the calving/summer season of 2012 to 6.7 collars during the fall/rut of 2011. The mean number of mortalities each month by season varied from 0-8 mortalities during May 2012. Yearly survival rates were estimated and then used 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 with constant adult female survival, bull survival, and fecundity levels (Table 19, Model 1). This model was more supported than models that allowed yearly variation in fecundity (Model 2), cow survival (Model 3) or with no variation in any parameters (Model 7).

Table 19: AIC_c 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. A constant model assumed the parameters were constant from 2008-13.

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	$T+T^2+T^3$	Constant	Constant	Constant	83.45	0.00	0.960	9	29.5
2	$T+T^2+T^3$	T	Constant	Constant	86.62	3.17	0.040	10	11.6
3	$T+T^2+T^3$	Constant	T	Constant	104.42	20.96	0.000	10	29.4
4	$T+T^2$	Constant	Constant	Constant	104.90	21.45	0.000	8	64.9
5	T	Constant	Constant	Constant	106.79	23.34	0.000	8	66.8
6	$T+T^2$	Constant	T	Constant	117.39	33.94	0.000	9	63.4
7	Constant	Constant	Constant	Constant	199.33	115.88	0.000	6	176.8

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 in calf-cow ratios was suggested as modeled by the cubic calf survival terms in Model 1.

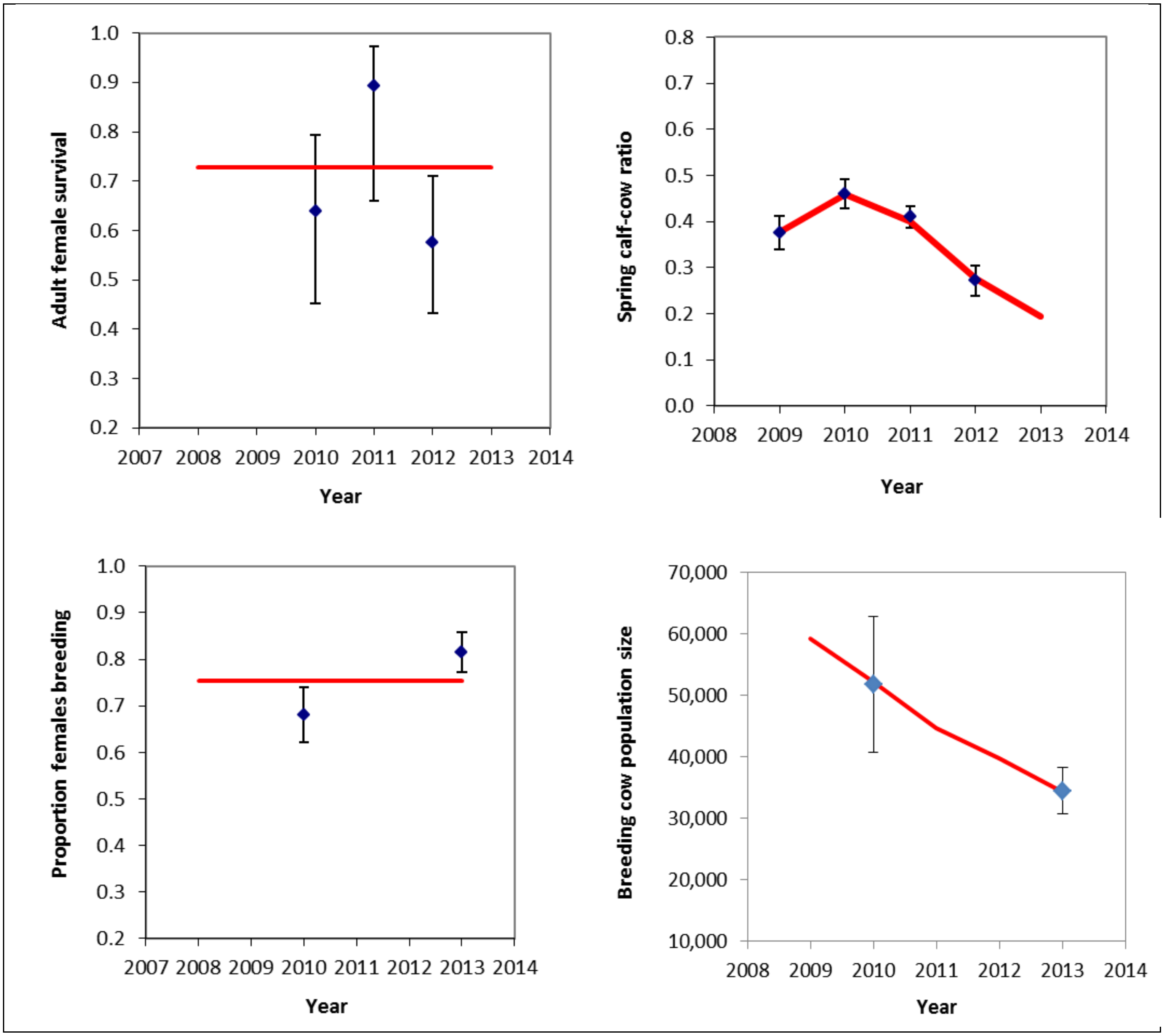

Figure 27: Estimates of adult female survival (from collared caribou), spring calf-cow ratios (from March composition surveys), proportion females breeding and breeding cow (female) population size estimates (from calving ground surveys). Confidence limits are shown on field estimates. OLS model predictions are given as red lines (from Model 1, Table 19).

Model estimates for fall composition surveys also suggested reasonable fit to bull-cow ratios and fall calf-cow ratios (Figure 28).

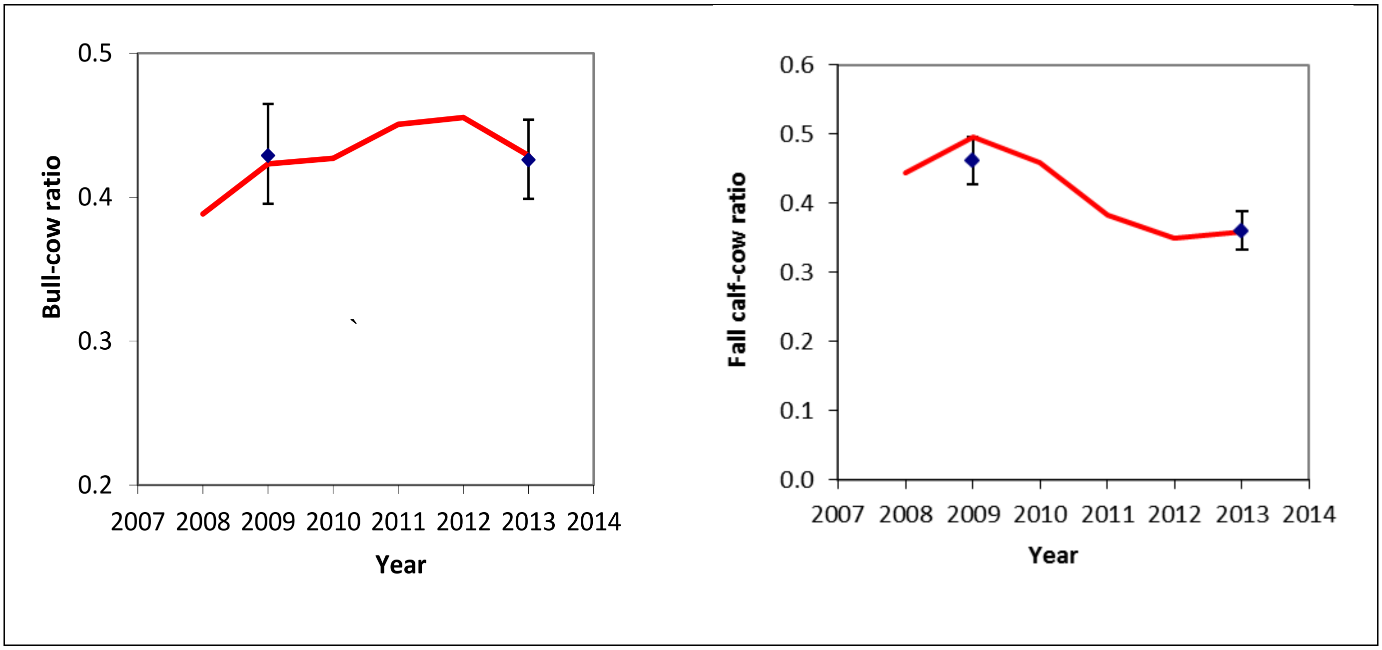

Figure 28: Estimates of bull-cow ratios and fall calf-cow ratios from fall composition surveys. Confidence limits are shown on field estimates. OLS model predictions are given as red lines (from Model 1, Table 19).

Demographic parameter estimates from the OLS model illustrated variation in calf survival and constant values for other parameters. Adult female and yearling survival was estimated at 0.73, bull survival at 0.59, and fecundity at 0.75 (Figure 29).

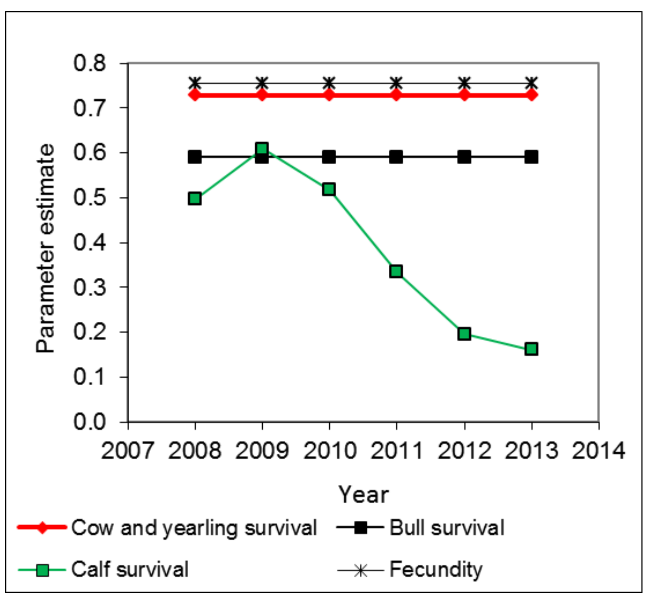

Figure 29: Estimate of demographic parameters from the most supported OLS model (Table 18, Model 1).

Population size estimates for each cohort demonstrated that all cohorts declined from 2008-2013 (Figure 30).

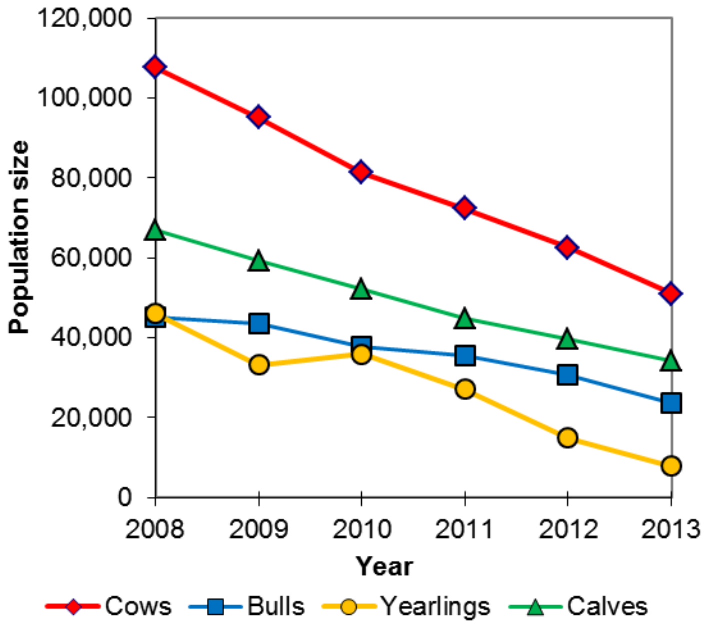

Figure 30: Estimates of population size for each age-sex class from the most supported OLS model (Table 19).

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 2,700 caribou, with the sex ratio likely 65% or more females (ENR unpublished data). Observations from harvest monitors and wildlife staff suggest that these figures are conservative and under-estimate the true harvest.

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. We ran simulations with the OLS model parameters from 2010-2013 (Figure 30) with varying harvest of cows and bulls, and varying natural survival rates. We tabulated combinations of the two values that resulted in breeding female estimates that were within the confidence limit of the 2013 estimate. For these simulations we assumed that 65% of the harvest was cows and 35% was bulls. Because the overall mortality rate (natural and harvest) remained the same, the higher harvest rates were associated with lower natural mortality rates. The results suggested that if harvest levels were as reported (average 2,000 caribou) then natural survival values were likely closer to 0.74 (Figure 31). If harvest levels were 4,000 then natural survival was 0.75. A harvest level of 6,000 would mean a likely natural survival rate of 76%. The general conclusion from these simulations was that harvest levels alone could not explain the lower survival levels indicated by the OLS model results. These simulations do not fully indicate the uncertainty in survival values given that the only source of variation considered was the confidence limit on the 2013 estimate.

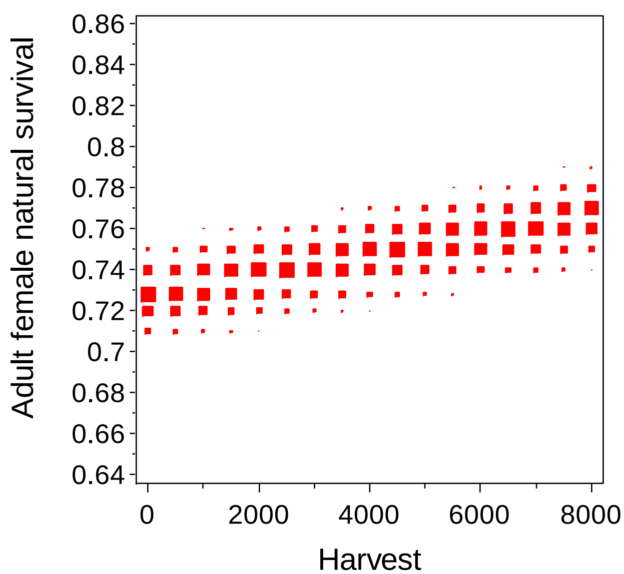

Figure 31: Estimated natural survival for adult females under a range of harvest levels. Harvest levels assume 65% cow-35% bull ratio of harvested caribou with demographic parameters from the OLS model. The range of squares represents harvest and survival levels that would result in breeding cow estimates that are within the confidence limit of the 2013 estimate. Largest squares were closest to the estimate.

DISCUSSION

Results from the Bluenose-East 2013 survey document a significant decline in breeding females and an overall decline in the herd. We assessed reasons for this decline including potential bias in survey estimates, followed by an exploration of demographic mechanisms.

Exploration of potential biases in survey estimates suggest that a small negative bias was possible due to movement of caribou during sampling, coupled with technical issues with the photo-plane causing a longer survey interval. However, the degree of bias was most likely negligible as indicated by movements of caribou relative to survey strata (Table 17). Another potential factor was the partial visual survey of the HD stratum with breeding females. However, the use of double observer methods minimized any potential bias as indicated by comparison of double observer estimates with photo-plane estimates for transects that were both surveyed in the HD stratum (Figure 24). The general change in estimates was also reflected in reconnaissance based estimates of caribou on the calving ground from the 2010 and 2013 surveys (Figure 21).

Exploration of demographic causes included assessment of movement of breeding females to other calving grounds 2010-2013, changes in pregnancy rate and potential fidelity to calving grounds, and survival rates including a multi-data source analysis of survival rate and the effect of potential harvest levels. The movement analysis revealed no documented cases of collared caribou emigrating or immigrating to the Bathurst or Bluenose-West calving grounds between 2010 and 2013 (Figure 25). Assessment of pregnancy rates as indexed by proportions of collared caribou on the calving ground and classification data (Figure 26) suggested similar pregnancy rates between 2010 and 2013. In addition, a high proportion of the collared caribou cows were on the calving ground as expected. Estimates of survival from collared caribou and the OLS model suggested that survival was relatively low [0.67

(collars) to 0.73 (OLS model)]. Demographic modeling suggested that a combination of relatively low natural survival and harvest was the likeliest explanation for the decline between 2010 and 2013.

Comparison of decline with other herds

The estimated yearly rate of decline of breeding females in the Bluenose-East caribou herd from 2010-2013 was -12.6% (CI=8.8-15.1%) (Figure 19). Rates of decline in the Bluenose-West and Cape Bathurst herds from 2000-2006 were also similar at 12-13% (Nagy and Johnson 2006). Similar yearly rates of decline were observed for breeding females in the Bathurst caribou herd from 2003-2006 (Annual rate of decline=-12% CI=-29% to +6%). Breeding females in the Bathurst herd continued to decline to 16,649 (CI=12,153-21,056) in 2009 which was caused in part by low recruitment and in part by a negative trend in survival rates (Boulanger et al. 2011). The decline in adult survival was partially the result of a relatively constant harvest level as the population declined (Boulanger et al. 2011). A similar annual 12% rate of decline was also experienced by the Rivière George caribou herd between 1991 and 1992 (Bergerud et al. 2008).

Interpretation of breeding female estimates.

The primary focus for calving ground photo surveys is to estimate the number of breeding female caribou. An inherent assumption of this method is that breeding females will congregate on the calving ground, allowing the photo survey to estimate this component of the herd. The breeding females are the most important component of the herd, given they produce calves and their numbers reflect the relative productivity and ability of the herd to increase. However, it is important to understand the time lags between the production of female calves and recruitment of these calves into the breeding female segment. Most commonly, females have consistently high pregnancy rates when they are 2.5 years old, with variable and often low pregnancy rates in 1.5 year old females (Bergerud et al. 2008). Thus female calves born in 2010 or earlier were likely to be breeding females in 2013, but females born in 2011 and

2012 were unlikely to contribute significantly to the breeding female segment of the herd in 2013 (Table 20).

Table 20: A hypothetical timeline for a female calf that was born during the 2010 calving ground survey. Given that caribou do not breed until they are 2-3 years old the 2013 estimate of breeding females mainly reflects recruitment events that occurred in 2010 and years before. Pregnancy rates are based upon Dauphine (1976) and Bergerud et al (2008).

Group	**Year**				
	2010	**2011**	**2012**	**2013**	**2014**
Age class during survey	Calf	Yearling	2 year old	3 year old	4 year old
On calving ground?	Yes	maybe	maybe	More likely	Most likely
Classified/counted as a breeding female?	No	No	Less likely	**More likely**	**Most likely**
Bred in fall after c.g. survey? (*pregnancy rate*)	No (*0%*)	Less likely (*2-48%*)	More likely (*48-95%*)	Most likely (*82-96%*)	Very likely (*95-96%*)

The OLS model exercise provided a way to model the time-lags in productivity and assesses how this potentially affected the number of breeding cows in the 2013 survey. In the case of the OLS model, it was assumed that any caribou older than a yearling for the fall prior to a breeding survey had the potential to breed, and the proportion of these adult female caribou breeding was estimated by the fecundity parameter. The data from 2008-2013 were considered in this analysis so that caribou that were calves in 2008 were available to be recruited into the breeding female age class for the 2013 survey. This analysis suggested that productivity had been reasonably good and that the estimated number of breeding females in 2013 was due partially to lower survival rates (0.73). If survival rates were higher, then a larger number of breeding females should have been estimated.

Comparison of estimates from 2010 and 2013 for the Bluenose-East herd

The Bluenose-East herd has been surveyed in the past using post-calving surveys in 2000 (Patterson et al. 2004, Nagy and Johnson 2006, Davison et al. 2014, Adamczewski et al. 2012 In Prep.). A calving photo survey had first been carried out in 2010 for this herd. Population estimates in 2010 from both the calving and post-calving surveys indicated a herd of just over 100,000 (Adamczewski et al. 2012 In Prep.). Given the differences in the way herd size is estimated between the calving and post-calving photo surveys, the most direct comparisons for the Bluenose-East herd between 2010 and 2013 are in the declines in breeding females from 51,757±11,092 (CI) to 34,472±4,363, and in the extrapolated estimates from 102,704±39,964 in 2010 to 68,295±18,040 in 2013. 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 In Prep.).

Management Implications and Recommendations

We suggest the following 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 three 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 two or three years should be conducted to re-assess herd status.

2. Proactive management of harvest levels with a shift from mostly cows to mostly bulls, and more reliable reporting of harvest levels. 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.

3. 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.

4. 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.

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APPENDIX 1: DOUBLE OBSERVER ESTIMATION METHODS

MARK produced estimates of sighting probability (*p*) and when possible re-sighting probability (*c*) for the secondary observer. The combined probability that a group of caribou was seen by at least one of the observers (p^*) is 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 two 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 *i*th 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). Two hundred and fifty resampling's were conducted and the standard deviation of the bootstrap resamples was used to estimate standard error of the strata population estimates. The number of bootstrap re-samplings (250) was suitable for obtaining parametric estimates of SE (Manly 1997). This procedure was conducted for the uncorrected estimates and the SE estimates were compared to the estimates using the Jolly (1969) formula.

APPENDIX 2: WEATHER FORECAST FOR JUNE 4TH

Weather briefing for Bruno Croft, M.Sc., Bathurst Caribou Biologist, GNWT, issued at 7:30 am MDT Tuesday June 4, 2013. Forecast valid for today and Wednesday with an extended outlook for five days.

TODAY (June 4th)

This morning the surface analysis shows an area of high pressure over eastern NU and a trough of low pressure to the west over the NWT. This will maintain the brisk, warm and dry southerly flow over the forecast region. The morning satellite picture shows generally clear skies throughout the forecast area. There are a few dissipating patches of scattered clouds over the western sections with local ceilings of about 6,000 ft. AGL. The fair weather pattern will continue through today. A very weak disturbance moving across the region may bring a few more patchy clouds with high cigs of 6,000 ft. AGL or more and the slight chance of a rain shower. Visibilities will stay good above 10 km. The warm and brisk southerly flow will boost temperatures into the mid to upper teens. There may be some highs getting close to 20, very much above the seasonal average of 6-7°.

WEDNESDAY (June 4th)

On Wednesday the weather pattern begins to change as a better defined upper system pushes over the region from the west through the day. This will bring more chances for broken cloud cover with still fairly high cigs of 4,000-6,000 ft. and the chance of a rain shower. Visibilities should stay good above 10 km. The system moves into the western half of the forecast region in the morning and then progresses to the eastern half in the afternoon. The cloud cover should not be completely extensive so scattered areas will be likely.

It is interesting to see that the air mass will become quite unstable so that there will actually be a chance of isolated thundershowers by afternoon. The best chances for these look to be through central sections and in the Kugluktuk area.

The brisk south-southwest flow will keep temperatures warm again in the mid-teens, although just a few degrees cooler than the very warm temperatures of Tuesday.

EXTENDED OUTLOOK

Significantly deteriorating conditions toward evening...

On Thursday the trend looks to be going along with the previous forecast scenario.

Most of Thursday looks to be broken cloud cover over the forecast region with cigs of 3,000-5,000 ft. expected. There will likely be some rain showers, but visibilities should stay good above 10 km. The cloud cover may not be extensive throughout the whole region so there will likely be some areas of scattered clouds. The winds will begin shifting to a northerly direction through the morning in the west and in the afternoon in the east. The northerly winds will begin to push the Arctic front back across the forecast region. Much cooler temperatures will result, dropping back down into the single digits later in the day.

By Thursday evening and into Friday morning two weather systems affect the region. One brings in moisture from the south while the Arctic front pushes across from the west. The combination of the two will bring more extensive cloud cover and light rain to many sections of the forecast region through the overnight and into Friday. Ceilings will likely be in the 3,000-4,000 ft. range with some lower patches forming in the precipitation of 1,000-2,000 ft. Visibilities of 6-8 km in could form in the rain. Near the coast the conditions will be worse in lower stratus and occasional fog in a northerly onshore flow. There will likely be a mix of rain and snow developing overnight as temperature drop near to zero. There is also a risk of freezing rain.

Poor conditions in store for Friday (June 6th)

On Friday a strong northerly flow will develop over the forecast area. Northerly winds of 30-40 km/h or more will usher in the true Arctic front from the west across the forecast regions. The front will push through western sections very early Friday morning and then through the eastern parts by around noon Friday. The timing of the front is difficult and it may come even earlier than expected. As is most often the case with Arctic fronts, behind the front the cloud cover in the northerly flow would become extensive with cigs of 2,000-2,500 ft. AGL common and occasional lower stratus 800-1,200 ft. cigs. The precipitation will be a mix of rain and snow through Friday with visibilities lowering to 4-6 km in rain/snow. There is a risk of freezing rain along the front. Along the coast, behind the front, expect the development of lower stratus 400-800 ft. and low visibilities 1-4 km in rain/snow/drizzle and local freezing drizzle to become more extensive. Temperatures will only be a few degrees above zero.

On Saturday the Arctic front will be well southeast of the forecast regions leaving a large Arctic high pressure area sitting over the forecast region. The brisk northerly flow will continue. The cloud cover which is brought in by the passage of the arctic front will be very slow to improve. Therefore it is likely that lower stratus will cover the forecast region through the day. Ceilings of 1,500-2,000 ft. will be common with areas of lower 800-1,200 ft. cigs. Along the coast expect low stratus to be more common with 400-800 ft. cigs and low visibilities in snow/drizzle/fog.

END/DUPILKA

APPENDIX 3: CROSS VALIDATION OF PHOTO COUNTS

Introduction

Cross validation of counts of caribou from digital aerial photography was conducted for the 2013 Bluenose-East caribou survey to test the assumption that all caribou on the photos are counted. This exercise was conducted to ensure that the newer digital photography-based method of aerial survey produced reliable counts of caribou.

Methods

The general methodology was for the second observer to count caribou on a subset of photos that have already been counted by the first observer. We first assessed the sample size of photos needed to verify that sightability is high. The sample size in terms of photos needed to verify that sighting probability is statistically equal to one depends somewhat on the actual estimate of sighting probability from the photo trials. The estimate of sighting probability can be conceptualized as a set of trials (with each photo as the sample unit) to estimate a proportion. The confidence limit of the proportion was therefore calculated using estimates of standard error for a proportion (Krebs 1998). A margin of error of at least 0.05 or less would be desirable with a margin of 0.02 or less being desirable. Using these guidelines, a sample size of 150 photos was chosen for the cross-validation exercise (Figure 33).

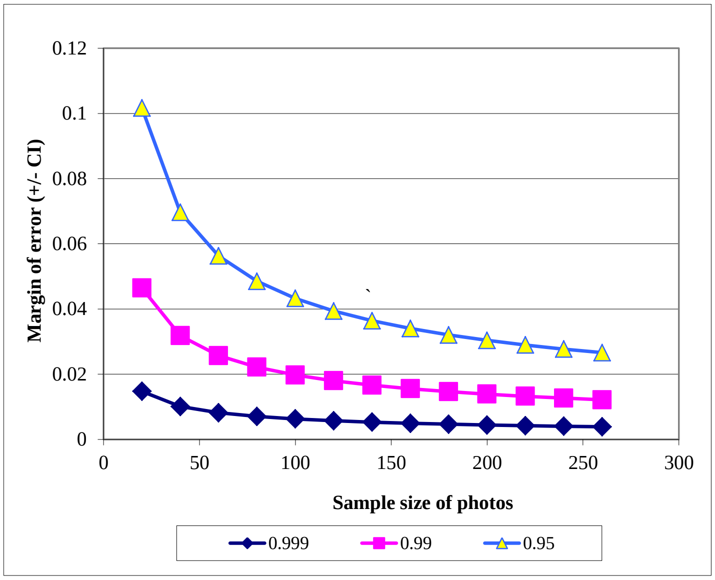

Figure 32: The effect of sample size of photos cross validated as a function of the actual sighting probability estimate. Each line represents a mean sighting probability estimated from the comparison of counts on photos.

The main design for cross-validation sampling ensured that a full range of caribou densities and ground conditions were sampled. The general procedure conducted is outlined.

1. The second observer (ENR) was trained to use the photo-interpretation equipment on photos that were not considered in the subsample procedure.
2. The second observer sampled a subset of photos that spanned observed numbers of caribou on photos as well as ground conditions. The second observer was not given any prior information on counts or caribou locations on photos.
3. The second observer counted caribou noting ground conditions or any other conditions affecting his ability to count caribou.
4. The number of caribou counted by the second observer was then tallied and compared to the first observer. The number of caribou counted by both observers was then tallied for each photo on a given line.

Results

One hundred and fifty one photos were recounted by the ENR technician and compared with the original photo counts. Of the 151 photos, 1,260 caribou were counted by the Greenlink technician and 1,288 were counted by the ENR technician suggesting that 97.8% of caribou were counted in the photos under the assumption that all the caribou counted by the ENR technician were correctly identified. Figure 34 provides an illustration of the correspondence of counts. Given the reasonable correspondence, subsequent analyses were not pursued.

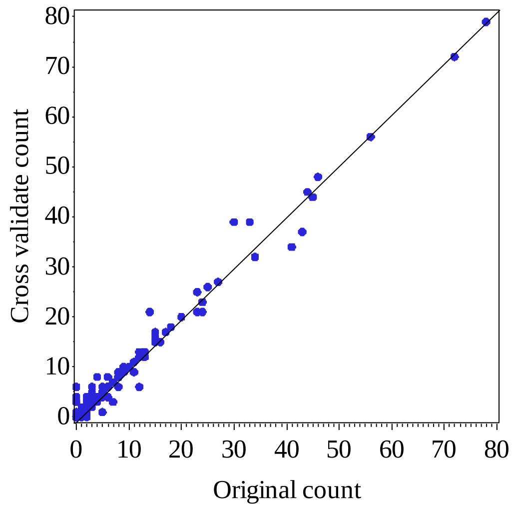

Figure 33: Correspondence of original counts of caribou on photos with secondary cross validation counts by an ENR technician.

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