AN ESTIMATE OF BREEDING FEMALES AND ANALYSES OF DEMOGRAPHICS FOR THE BATHURST HERD OF BARREN-GROUND CARIBOU: 2015 CALVING GROUND PHOTOGRAPHIC SURVEY

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John Boulanger[1]

Bruno Croft[2]

Jan Adamczewski[3]

Dean Cluff[2]

Mitch Campbell[4]

David Lee[5]

Nic Larter[6]

[1]Integrated Ecological Research, 924 Innes, Nelson, British Columbia, V1L 5T2, boulange@ecological.bc.ca, www.ecological.bc.ca

[2]North Slave Region, Environment and Natural Resources, Government of Northwest Territories, P.O. Box 2668, Yellowknife, NT, X1A 2P9, bruno_croft@gov.nt.ca

[3]Wildlife Division, Environment and Natural Resources, Government of Northwest Territories, Box 1320, Yellowknife, NT, Canada X1A 2L9, Jan_Adamczewski@gov.nt.ca

[4]Department of Environment, Government of Nunavut ,Arviat, Nunavut

[5]Nunavut Tunngavik Inc., Rankin Inlet, Nunavut

[6]Department of Environment and Natural Resources, Government of the Northwest Territories, Fort Simpson, Northwest Territories, Canada

Abstract

We conducted a calving ground photo survey of the Bathurst barren-ground caribou (*Rangifer tarandus groenlandicus*) herd from June 2 to June 9, 2015. The main objective was to obtain an estimate of breeding females that could be compared to estimates from previous similar surveys that have been conducted since 1986. Of particular interest was whether the herd had changed in size since the 2012 survey. Consistent with previous calving ground photographic surveys, data from collared caribou and systematic reconnaissance surveys at 5 to 10 km intervals within the core area were used to delineate the core calving areas, 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. Reconnaissance surveys revealed that the majority of breeding caribou were congregated in a relatively small (1492 km^2) area with non-breeding caribou distributed in lower densities to the south. Based on collar movements and observed proportions of calves, it was determined that the peak of calving began around June 4th and the photo plane survey was conducted on June 6th. A single photo survey stratum was sampled with the highest coverage (54%) in addition to 3 lower density visual survey strata. The survey was conducted in a single day before a major weather system moved in to the survey area. Helicopter-based composition surveys were conducted from June 6th to June 9th to estimate the proportion of breeding caribou in each of the strata. The estimate of 1+ year old caribou on the core calving ground was 15,369 (SE=2615.9, CI=9,913-20,826) caribou. Using the ground composition survey results to adjust this number for breeding females only, the estimate of breeding females was 8,075 (SE=1650.3, CI=4,608-11,542). Comparison of this estimate with the previous estimate of breeding females from 2012 of 15,935 (SE=1407.1, 95% CI=13,009-18,861) suggests that the breeding female segment of the herd declined significantly, however, the degree of decline was affected by lower pregnancy rates in 2014 and subsequent higher proportions of non-breeding adult females on the calving ground. The annual rate of decline for breeding females between 2012 and 2015 was 20% (CI-8-31%) whereas the rate of decline of adult females (which includes non-breeding adult females) was 13% (CI=1-23%). The extrapolated herd size estimate (using direct estimates of adult females) was 19,769 (CI=12,349-27,189) 1.5+ year old caribou. Results from a data-driven demographic modeling exercise suggest that the adult female survival rate was 0.78 (CI=0.76-0.80) from 2009-15, which is still below levels needed for a stable herd. The low adult female survival rate in addition to low productivity of the herd (after 2011) has been the primary drivers for the observed decline in the herd. Switching of female caribou to adjacent calving grounds has been very low and is unlikely to account for the declining trend. Recent low calf productivity and continuing low cow survival suggest that further decline is likely, even with no harvest, and a very careful approach to management is needed.

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Introduction

The Bathurst herd of barren ground caribou (*Rangifer tarandus groenlandicus*) was named based on its calving ground documented west of Bathurst Inlet since the mid-1990's (Sutherland and Gunn 1996). The Bathurst herd ranges from Bathurst Inlet with the calving ground within Nunavut, summer range straddling the border between Nunavut and the Northwest Territories, and the winter range in Northwest Territories and northern Saskatchewan (Figure 1). Given its proximity to many communities, the Bathurst herd has been a principal country food and cultural resource for Aboriginal hunters from several groups. In addition, it was harvested by guided outfitter hunts and by NWT resident hunters until 2010.

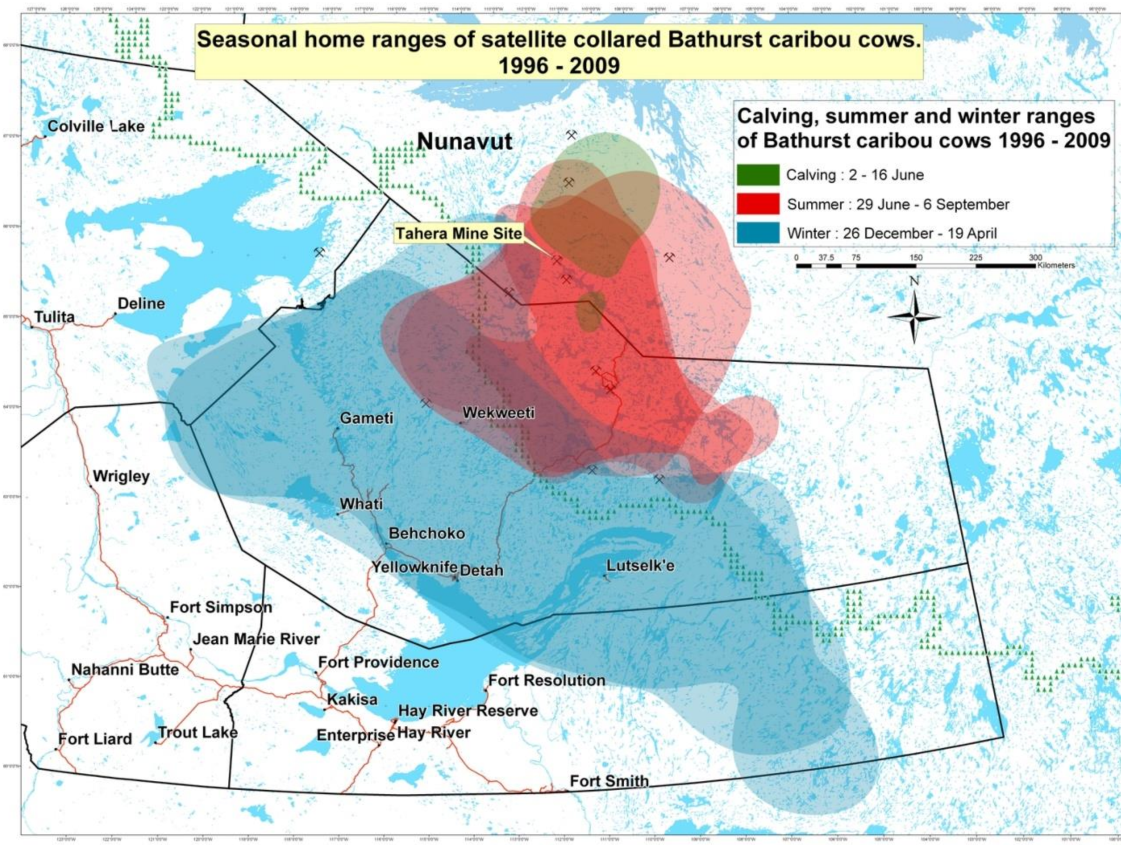


Figure 1: Calving, summer, and winter ranges of the Bathurst herd, 1996-2009, based on accumulated radio collar locations of cows. Ranges were delineated using Kernel home range (Worton 1989) smoothing of seasonal radio collared cow locations (Nagy et al. 2011). The location of the Bathurst range relative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

The Bathurst herd of barren-ground caribou was one of the largest of the migratory tundra caribou herds in northern Canada in the 1980s. Herd size was estimated from the number of breeding females, which declined from 203,800 (95% CI = 178,197 - 229,403) caribou in 1986 to 55,593 (95% CI = 37,147 - 74,039) in 2006 and 16,604 (95% CI =12,153 - 21,056) in 2009 (Heard and Williams 1991, Gunn et al. 1997, Gunn et al. 2005, Nishi et al. 2007, Nishi et al. 2010) (Figure 2). This rapid decline prompted a reduction of hunter harvest of over 90% as well as further investigation of causes of the decline of the Bathurst herd (Adamczewski et al. 2009, Boulanger et al. 2011). Estimates of breeding females appeared to have stabilized in 2012 suggesting that reduction of harvest and other measures had halted the large decline observed from 2006-2009. However, demographic analysis conducted as part of the 2012 survey analysis suggested a smaller scale decline that was within the confidence limits of survey estimates was potentially occurring due to lower adult female survival rates (Boulanger et al. 2014b).

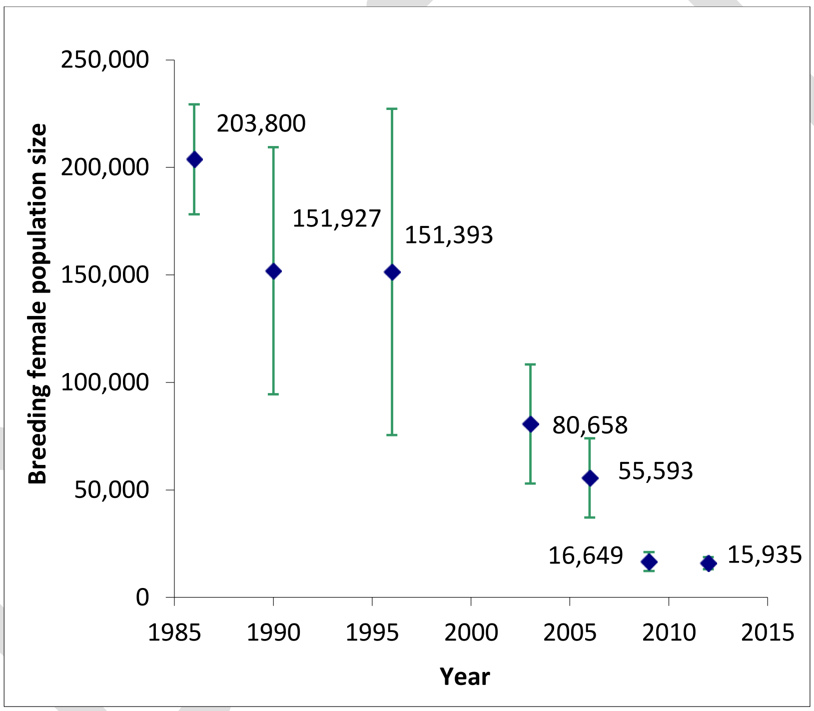


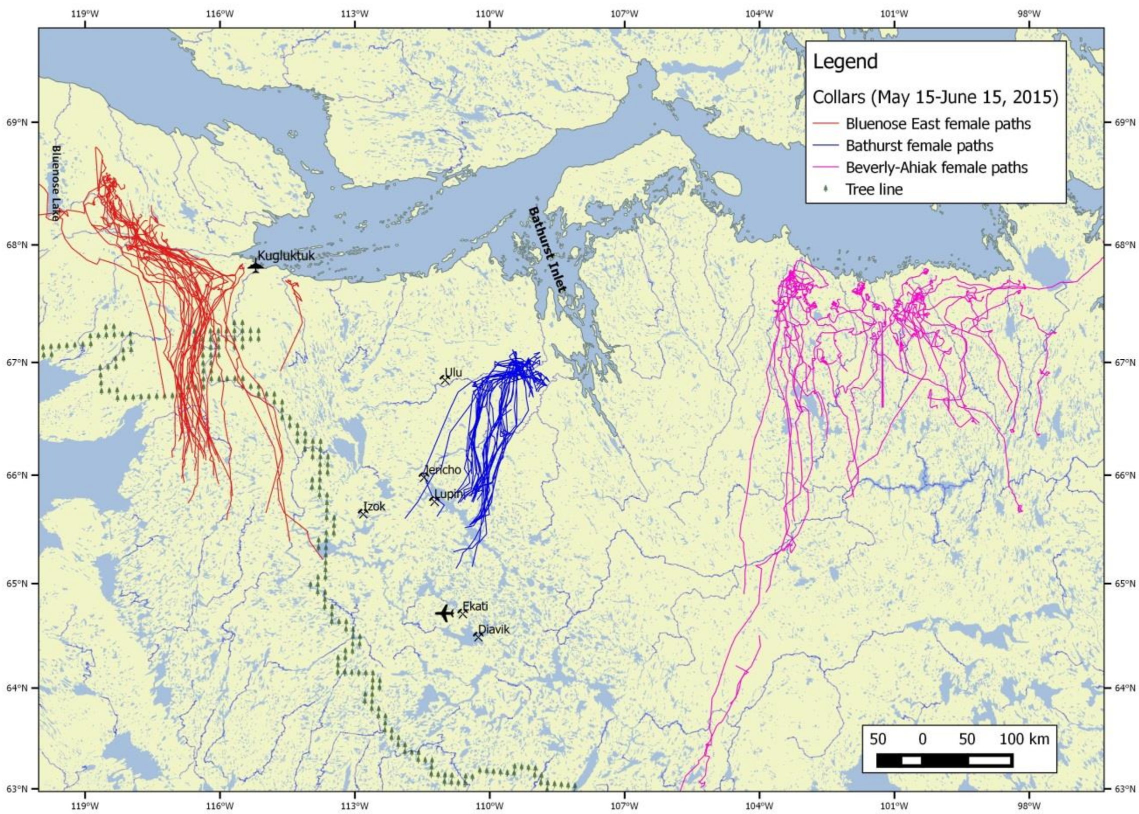
Figure 2: Trends of breeding female estimates for the Bathurst herd from 1986 to 2012

This report presents estimates of breeding females and associated herd size for the Bathurst caribou herd from a calving ground survey conducted from June 3 to June 9 2015. The Bathurst herd has been surveyed using the same calving ground methodology since 1986 (Gunn et al. 1997, Gunn et al. 2005, Nishi et al. 2007, Nishi 2010, Nishi et al. 2010, Boulanger et al. 2014b). An additional objective was the estimation of overall trend in the population size of the herd. The results from this survey will provide an indication of herd status and whether stabilization or potential herd recovery has occurred since the last survey in 2012.

Methods

Study areas

The Bathurst and Bluenose East calving grounds were surveyed concurrently in 2015. The majority of aircraft were positioned out of Kugluktuk, Nunavut with one plane and crew stationed out of the Ekati mine site (Figure 3).



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Previous surveys were based out of the Jericho or Lupin mine sites, however, these mines were not operational in 2015. Fuel for the survey aircraft was cached at the Jericho and Lupin mine airstrips.

Overview of methods

The calving ground survey was conducted as a sequence of steps.

1. Locations from collared caribou, historic records of calving ground use, and systematic aerial reconnaissance surveys of the Bathurst calving area were conducted to identify core calving areas in the general area to the southwest of Bathurst Inlet.
2. A systematic reconnaissance survey was conducted where transects were flown in 10 kilometer intervals to determine areas where breeding females were concentrated, as well as locations of bulls, yearlings, and non-breeding cows near the calving ground. How far calving had progressed was also assessed from the proportion of cows with newborn calves. Due to the relatively smaller size of the Bathurst calving ground, transects spaced at 5 kilometer intervals were flown in the core calving area.
3. Using data from the reconnaissance survey, geographic areas called strata were delineated for sampling by the photo plane with the most sampling effort dedicated to areas with the highest densities of breeding female caribou.
4. A photographic survey plane was then used to sample the higher density and medium density areas while visual strip-transect surveys were used to estimate caribou in lower density strata.
5. While the photo plane conducted the aerial survey, a helicopter-based composition survey was conducted within each stratum to determine the proportion of breeding caribou.
6. An estimate of breeding females was derived using the estimate of total caribou within the strata and the estimate of proportion of breeding females within the strata..
7. The estimate of breeding females was then used to estimate the total size of the herd, and trends in breeding females (Heard 1985, Heard and Williams 1990, Gunn and Russell 2008).

Each component is next described in detail.

Analysis of collared caribou data

Data from collared caribou were monitored during the survey to assess relative location of breeding females on calving ground areas. In addition, change in movement rates was assessed to determine the timing of calving. Generally , caribou movement rates are reduced to less than 5 kilometers per day during the peak of calving and for a short interval after calving (Gunn et al. 1997, Nishi et al. 2007, Gunn et al. 2008, Gunn and Russell 2008, Nishi et al. 2010). Information from collared caribou and observations during the aerial reconnaissance surveys was used to time the photo-survey near the peak of calving, when caribou movement rates in the survey area would be lowest.

Reconnaissance surveys to delineate strata

Since the 2012 Bathurst survey, the core calving area, as indicated by higher densities of breeding caribou, was surveyed with north-south transects at 5 kilometer line spacing. This approach allowed higher resolution in terms of defining caribou distribution, and more precise estimates of caribou density within the core calving area. The survey ground coverage for areas with 5 kilometer transects was approximately 16%. Areas peripheral to the core area were surveyed at 10 km intervals resulting in 8% coverage.

In visual surveys, caribou were counted within a 400 meter strip on each side of the survey plane (800 m total, Gunn and Russell 2008). Strip width was defined by the wheel of the airplane on the inside, and wooden doweling defined on the wing strut. Planes were flown at an average survey speed of 160 kilometers per hour at an average altitude of 120 meters above the ground to maintain a constant strip width.

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

Caribou groups were classified by whether they contained breeding caribou. Breeding caribou were defined by female caribou with hard antlers or presence of calves. A female with a hard antler potentially indicated that the caribou had yet to give 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 females. Data were recorded on a tablet computer by two data recorders in the plane (Figure 4). As each data point was entered, a real-time GPS waypoint was generated, allowing geo-referencing of the survey data.

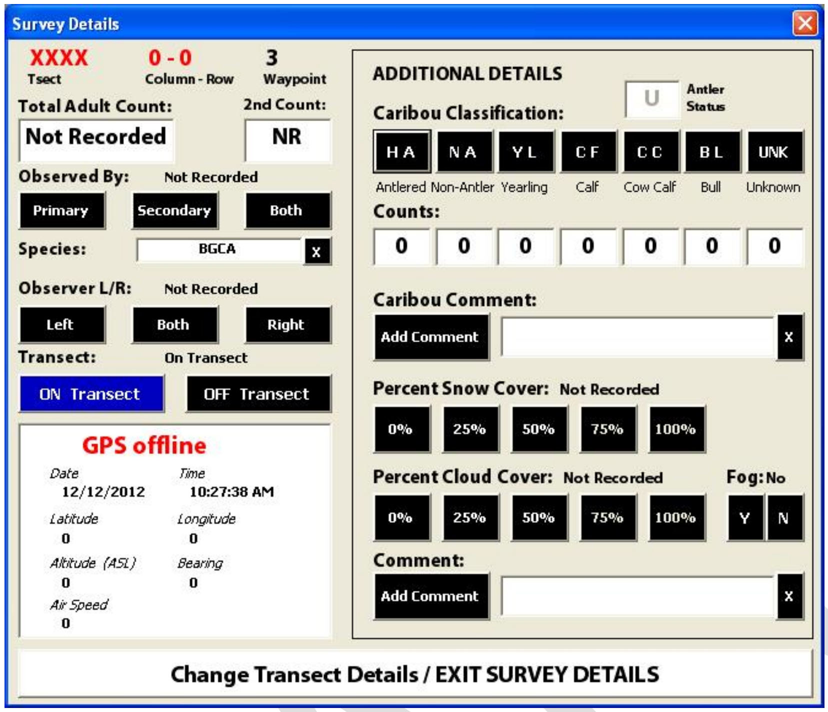

Figure 4: The tablet data entry screen used during reconnaissance surveys. A GPS waypoint was obtained for each observation, allowing efficient entry and management of survey data. In addition, the unique segment unit number was also assigned by the software for each observation to summarize caribou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

Transects were divided into 10 kilometer north-south segments to summarize the distribution of geo-referenced caribou counts. The density of each segment was estimated by dividing the count of caribou by the survey area of the segment (0.8 km strip width X 10 km = 8 km^2). The segment was classified as a breeder segment if at least one breeding caribou was detected. Segments were then displayed spatially and used to delineate core calving ground strata based on the composition and density of the segments.

Areas that were to the far west and far east including those to the east of Bathurst Inlet were surveyed at 10 or 20 km transect spacing to ensure that no larger aggregations of breeding caribou were missed.

Stratification and allocation of survey effort

The main goal of the survey was to obtain a precise and accurate estimate of breeding caribou on the calving ground. To achieve this objective, the survey area was stratified, a procedure in which neighboring segments with similar density were grouped into a contiguous area so that each stratum enveloped caribou distributions of similar 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 to estimate density. Strata that contained medium to high densities of breeding caribou were surveyed using the photo survey plane to ensure more accurate counts, with strata that had low densities being surveyed visually. Given that the objective of the survey was to estimate the number of breeding females, only areas that contained breeding females were surveyed. Areas that contained non-breeders were not surveyed after initial reconnaissance because they would not contribute to the breeding female population estimate.

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 to each stratum that would be sampled by the photo-plane, or by visual surveys.

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 assigns more effort to strata with higher densities given that the amount of variation in counts is proportional to the relative density and size 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 for each stratum. In particular, previous surveys suggested that there should be a minimum of 10 transects per stratum with closer to 20 transects being optimal for higher density areas. In general, coverage should be at least 15% with higher levels of coverage for high density strata. In the context of sampling, increasing the number of lines in a stratum is “insurance” in that it minimizes the influence of any one line on estimate precision. As populations become more clustered, a higher number of transect lines is required to achieve adequate precision (Thompson 1992, Krebs 1998).

Estimation of caribou on the calving ground

Photo surveys

Photo-surveys were planned for the higher-density stratum to ensure accurate counting of larger groups of caribou on the photo stratum. GeodesyGroup Inc. aerial survey company (Calgary, Alberta) was contracted for photo surveys. They used a Piper PA46-310P Jetprop DLX and a Cessna TI206D 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 expected cloud ceilings and desired ground coverage. Caribou detected on photos were counted by a team of photo interpreters and supervised by Derek Fisher, president of Green Link Forestry Inc, (Edmonton, Alberta) using specialized software that allowed three dimensional viewing of photographic images. The number of caribou counted was tallied by stratum and transect. The exact survey strip width of photos was also determined using the geo-referenced digital photos by Green Link Forestry.

Visual surveys using double observer methods

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

A double observer method was used to estimate the sighting probability of caribou during visual surveys. The double-observer method involves one "primary" observer who sits in the front seat of the plane and a "secondary observer" who sits behind the primary observer on the same side of the plane (Figure 5). The method adhered to five basic steps; 1 - The primary observer called out all groups of caribou (number of caribou and location) he/she saw within the 400 meter wide strip transect before they passed halfway between the primary and secondary observer (approximately at the wing strut). This included caribou groups that were between approximately 12 and 3 o'clock for right side observers and 9 and 12 o'clock for left side observers. The main requirement was that the primary observer be given time to call out all caribou seen before the secondary observer called them out; 2 - The secondary observer called out whether he/she saw the caribou that the first observer saw and observations of any additional caribou groups. The secondary observer waited to call out caribou until the group observed passed half way between observers (between 3 and 6 o'clock for right side observers and 6 and 9 o'clock for left side observer); 3 - The observers discussed any differences in group counts to ensure that they are calling out the same groups or different groups and to ensure accurate counts of larger groups; 4 - The data recorder categorized and recorded counts of caribou groups into "primary only", "secondary only", and "both", entered as separate records; 5 - The observers switched places approximately half way through each survey day (i.e. at lunch) to monitor observer ability. The recorder noted the names of the primary and secondary observer (Boulanger et al. 2010, Buckland et al. 2010, Boulanger et al. 2014a).

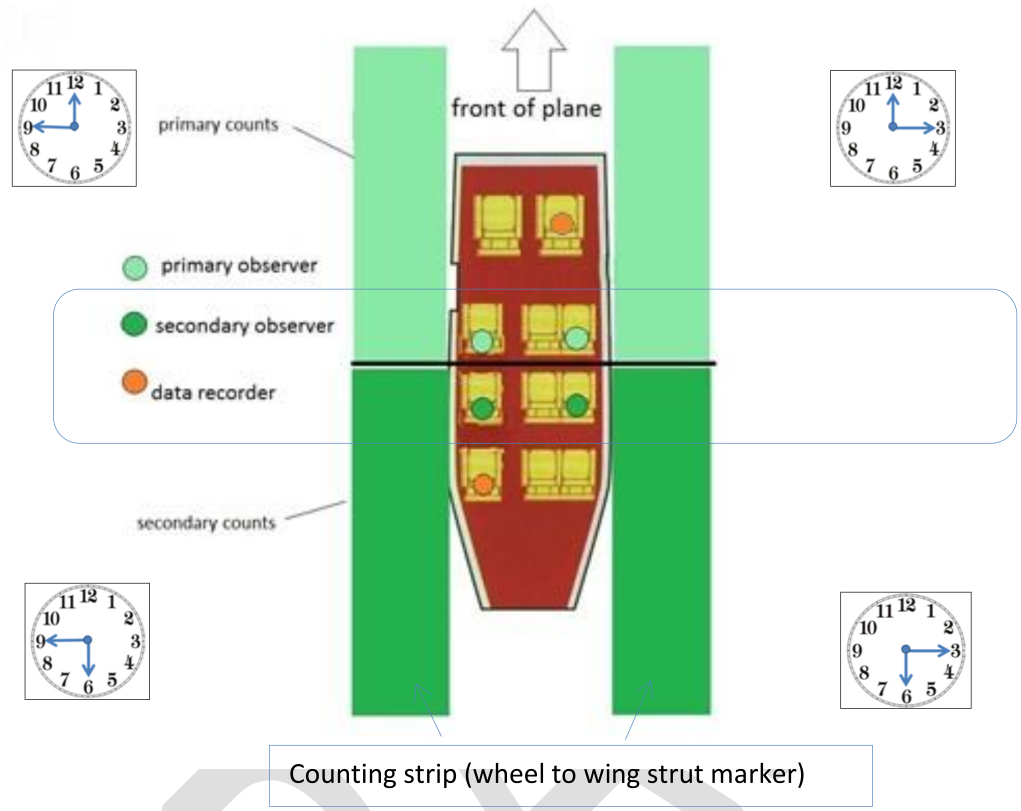

Figure 5: Observer position for double observer methods. The secondary observer calls caribou not seen by the primary observer after the caribou have passed the main field of vision of the primary observer. Time on a clock can be used to reference relative locations of caribou groups (i.e. "caribou group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

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

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

One assumption of the double observer method is that each caribou group observed had an equal probability of being sighted. To account for differences in sightability we also considered the following covariates in the MARK Huggins analysis (Table 1). Each observer pair was assigned a binary individual covariate and models were introduced that tested whether each pair had a unique sighting probability. An observer order covariate was modeled to account for variation caused by observers switching order. If sighting probabilities were equal between the two observers it would be expected that order of observers would not matter and therefore the confidence limits for this covariate would overlap 0. This covariate was modeled using an incremental process in which all observer pairs were tested followed by a reduced model in which only the beta parameters whose confidence limits did not overlap 0 were retained.

Data from both the Bluenose East and Bathurst herd calving grounds surveys was used in the double observer analysis given that most planes flew the visual surveys for both calving grounds. It was possible that the different terrain and weather patterns in each calving ground may affect sightability and therefore herd/calving ground was used as a covariate in the double observer analysis. Appendix 1 provides more details on estimation using double observer methods.

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

covariate	**acronym**	**description**
observer pair	obspair	each unique observer pair
observer order	obsorder	order of pair
group size	size	size of caribou group observed
Herd/calving ground	Herd (h)	Calving ground/herd being surveyed.
snow cover	snow	snow cover (0, 25, 75, 100)
cloud cover	cloud	cloud cover(0, 25, 75, 100)
Cloud cover*snow cover	Cloud*snow	Interaction of cloud and snow cover

The fit of models was evaluated using the Akaike Information Criterion (AIC) index of model fit. The model with the lowest AICc score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). The difference in AICc values between the most supported model and other models (ΔAICc) was also used to evaluate the fit of models when their AICc scores were close. In general, any model with a ΔAICc score of less than 2 was worthy of consideration. Further details on the double observer method are given in Appendix 1.

Estimation of caribou in stratum with varying strip widths

The photo survey plane was forced to change survey altitude during the photo survey due to variable cloud ceilings. As a result the strip width and survey area varied by transect in the photo stratum which could bias estimates due to non-random coverage of the stratum. To mitigate this issue, a method was used that estimated population size by equally weighting densities of caribou on each transect line regardless of strip width. More precisely, population size within a stratum is usually estimated as the product of the total area of the stratum (*A*) and the mean density $(\overline{D})$ of caribou observed within the strata $(\widehat{N} = \overline{D}A)$ where density is estimated as the sum of all caribou counted on transect divided by the total area of transect sampling ($\overline{D}$=caribou counted/total transect area). An equivalent estimate of mean density can be derived by first estimating transect-specific densities of caribou ($\widehat{D}_i = caribou_i/area_i$) were $caribou_i$ is the number of caribou counted in each transect and $area_i$ is the transect area (as estimated by transect length X strip width). Each transect density is then weighted by the relative length of each transect line (w_i) to estimate mean density ($\overline{D}$) for the stratum. More exactly, $\overline{D} = \sum_i^n \widehat{D}_i w_i / \sum_i^n w_i$ where the weight (w_i) is the ratio of the length of transect line (l_i) i to the mean length of all transect lines ($w_i = l_i/\overline{l_i}$.) and *n* is the total number of transects sampled. Using this weighting term accommodates for different lengths of transect lines within the stratum therefore ensuring that each transect line contributed to the estimate in proportion to its length. Abundance of caribou in the stratum is then estimated using the standard formula $(\widehat{N} = \overline{D}A)$. Estimates of variance were calculated using standard formulas that allow transects of different size and area (Jolly 1969). Confidence limits for estimates were based upon a t-statistic with degrees of freedom calculated using the number of lines surveyed in all strata and survey variances (Gasaway et al. 1986).

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

Immediately after photo and visual surveys commenced, composition sampling was undertaken on each of the survey strata. For this, helicopters were used to systematically survey groups of caribou allowing more in-depth classification of caribou by breeding status. Caribou were classified following the methods of Gunn et al. (2005) where antler status, presence of an udder, and presence of calf is used to categorize females by breeding status while also counting yearlings, bulls, and newborn calves (Figure 6).

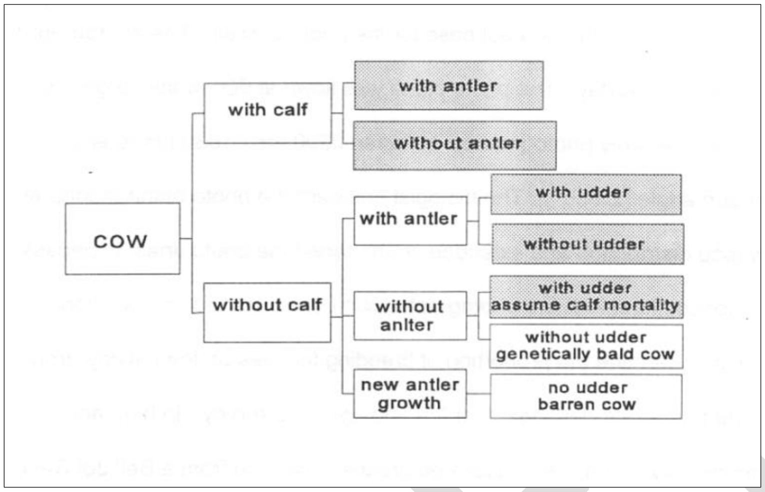

Figure 6: Classification of breeding females used in composition surveys. Shaded boxes were classified as breeding females (diagram from (Gunn et al. 2005)).

Groups classified were totaled and summarized 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 adult and breeding females

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. In addition the proportion of adult females, which includes non-breeding adult females, was estimated using composition counts. 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 adult sex ratio from fall composition surveys

The Bathurst herd was surveyed during the fall rut to estimate the bull-cow ratio and the proportion of adult females in the herd in 4 years between 2008 and 2014. Details of this approach are given in Cluff et al (2016). The observation data was mapped using pie-charts that indicated proportion bulls and cows in each sample as a way to assess spatial variation in bull-cow ratio using QGIS software (QGIS Foundation 2015). Estimates of variance and confidence limits were estimated using bootstrap methods as with other composition data.

Estimation of total herd size

Total herd size was estimated using two approaches. The first approach, used in historic calving ground surveys assumed a fixed pregnancy rate for adult females whereas the second approach used direct estimates of adult females in the surveyed area.

Estimation of herd size assuming fixed pregnancy rate

As a first step, the total number of adult (2+ year old) females in the herd was estimated by dividing the estimate of breeding females on the calving ground by the assumed pregnancy rate of 0.72 ((Dauphin'e 1976, Heard and Williams 1991)). The estimate of total females was then divided by the estimated proportion of females in the herd based on bull:cow ratios from fall composition surveys conducted in October of 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 at least 2 years old and will not include yearlings. This estimator assumes that all breeding females were within survey strata areas during the calving ground survey and that the pregnancy rate of caribou was 0.72 for 2014-5.

Estimate of herd size based upon estimates of adult females

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

Trends in herd indicators

Trends in calving ground size and location

The relative size and placement of the Bathurst calving ground was compared to determine relative trend and how this trend might relate to overall herd demography.

Trends in adult and breeding females

The time series of adult and breeding female estimates was used to assess overall trends in population size for the herd. Trends in breeding female estimates correspond best to the overall reproductive potential of the herd and therefore provide a good indication of overall herd status. However, estimates of breeding females will be affected by variation in reproductive rate and therefore the trend in adult females was also considered. Two methods were used to assess trends.

As an initial step, the 2015 estimate of breeding females was compared with the 2012 estimate to determine if the two estimates were statistically different, using a t-test (Zar 1996) with variances and degrees of freedom calculated using the formulas of (Gasaway et al. 1986). This comparison gave an initial indication of change in population size, but did not consider the survey interval between the two surveys.

Regression methods were used to estimate yearly rate of change of adult and breeding females. Weighted least squares analysis was used to estimate trend from the time series of data (Brown and Rothery 1993). Each estimate of breeding females was weighted by the inverse of its variance to account for unequal variances of surveys, and to give more weight to the more precise surveys. Estimates of trend of adult females were also conducted given that these estimates will be less sensitive to yearly variation in pregnancy rate.

The main question of interest in the regression analysis was whether the trend as indicated by the change from 2012 to 2015 was different than the trend from 2009 to 2012. As with double observer methods, information criteria (AICc scores) were used to evaluate the relative support of models. Analyses were conducted with PROC GENMOD and PROC REG within SAS statistical package (SAS Institute 2000).

Abundance estimates were log transformed to partially account for the exponential nature of population change (Thompson 1998). Annual population change (λ) was estimated using the ratio of successive predicted population sizes from the regression model. The per capita growth rate (r) was related to the population rate of change (λ) using the equation $\lambda=e^r=N_{t+1}/N_t$. If λ=1 then a population is stable; values greater or less than 1 indicate increasing and declining populations, respectively.

Trends in estimates of caribou on the calving ground from reconnaissance surveys

Annual reconnaissance surveys have been conducted on the Bathurst calving ground to assess trend in years between photo surveys . (Boulanger et al. 2014c) Estimates from the 2015 reconnaissance surveys was compared to earlier years and also estimates from photo survey years.

Exploration of demographic factors influencing population trend

Females switching calving grounds

Collar data for female caribou were compiled by GNWT Environment and Natural Resources staff for the Bathurst and neighbouring Beverly/Ahiak and Bluenose-East herds 2008-2015 . The locations of females during the peak of calving were used to assign each female to a herd calving ground. Data points were pairs of consecutive June locations where the cow either returned to the same calving ground or switched to a neighbouring one.

Survival rates of collared females

Collar data for female caribou were compiled for the Bathurst caribou herd by GNWT Environment and Natural Resources 2007 to 2015 to assess survival and mortality patterns. Fates of collared caribou were determined by assessment of movement of collared caribou with mortality being assigned to collared caribou based on lack of collar movement that could not be explained by collar failure or device drop-off. The data were then summarized by month as live or dead caribou. Caribou whose collars failed or were scheduled to drop off were censored from the analysis. Data were grouped by "caribou year" that began during calving of each year (June) and ended during the spring migration (May). Program MARK known fate models (White and Burnham 1999) were used to then estimate caribou-year estimates of survival rate from June 1996 to June 2015. Estimates from June 2007 to June 2015 were then used as an input into the demographic model described next.

Demographic model using multiple data sources

One of the most important questions to answer for the Bathurst herd was whether the breeding female segment of the population was increasing or stable. If the number of breeding cows is stable, then the herd has the potential to increase. The most direct metric 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 trend in breeding females. 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 further test hypotheses regarding breeding female status.

We used the ordinary least squares (OLS) demographic model (White and Lubow 2002) developed for the Bathurst herd (Boulanger et al. 2011) to further explore demographic trends in the Bathurst data. For this exercise, we used the 2009, 2012, and 2015 breeding female estimates as well as calf-cow ratios, bull-cow ratios, estimates of proportion breeding females, and adult female survival rates from collared caribou to estimate the *most likely adult female survival values* that would result in the observed trends in all of the demographic indicators for the Bathurst herd. The OLS model is a stage based model that divides caribou into 3 age-classes with survival rates determining the proportion of each age class that makes it into the next age class (Figure 7). The details of this model are given in (Boulanger et al. 2011).

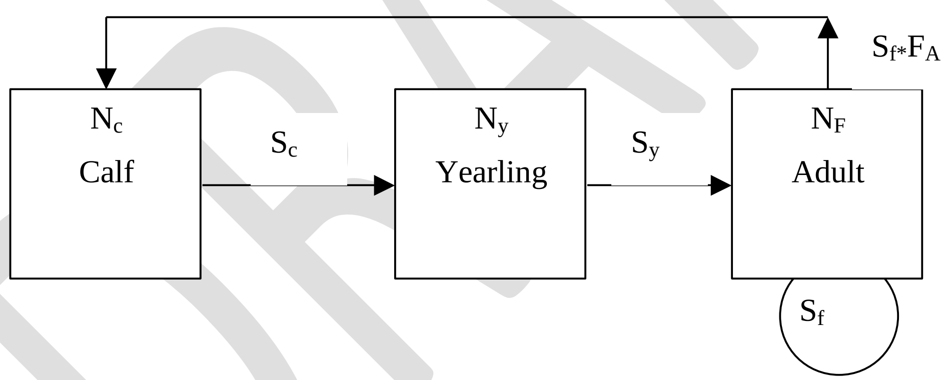

Figure 7: Underlying stage matrix life history diagram for the caribou demographic model. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y), and adult females (N_F). Each node is connected by survival rates of calves (S_c), yearlings (S_y) and adult females (S_f). Adult females reproduce dependent on fecundity (F_A) and whether a pregnant female survives to produce a calf (S_f). The male life history diagram was similar but with no reproductive nodes.

An assumption of the OLS model is that net movement of Bathurst caribou to or from adjacent calving grounds (Bluenose East and Beverly-Ahiak) is negligible so that the primary influence of change in population size is survival and recruitment of caribou within the Bathurst herd. This assumption was tested through evaluation of frequencies of collared caribou cows switching to or from neighbouring calving grounds (as described previously).

We restricted the data set for this exercise to survey results between 2007 and 2015. Using this approach ensured that past demographic values, that were recorded during the major decline 2006-2009, did not unduly influence the estimates for the principal time frame of interest (the interval between the 2009 and 2012 surveys). This interval basically covered potential recruitment into the breeding female class since any female calf born 2007-2009 had the potential to become a breeding female in 2012, and breeding females recruited prior to 2007 were accounted for by the 2009 calving ground estimate of breeding females (Table 2). It was assumed that a female calf born in 2007 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 2010. Given this time-lag, productivity (calves born) in 2010, 2011, and 2012 had the most direct bearing on the number of new breeding females on the calving ground that were not accounted for in the 2012 breeding female estimate.

Table 2: A schematic of the assumed timeline in the OLS analysis in which calves born are recruited into the breeding female segment (green boxes) of the population. Calves born prior to 2009 were counted as breeding females in the 2012 and previous calving ground surveys. survey. Calves born in 2010, 2011, and 2012 recruited to become breeding females in the 2015 survey.

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

We used a sequential model building process where we first built a model that considered the dominant trends in productivity (calf survival) as indicated by calf-cow ratios. We then tested for trends in adult female survival. Models were compared using information theoretic methods as for the breeding female trend analysis.

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

Results

Survey conditions

Weather during the survey was mixed with variable snow and cloud cover throughout the survey (Figure 8). Snow and cloud cover were summarized extensively using data from Trimble YUMA 2 tablet computers for the double observer analysis used in the visual survey conducted on June 6th. Fog and low ceiling prevented flying on June 5th. A weather system came into the survey area late on June 6th with fog and low ceiling grounding fixed wing aircraft from June 7nth to 9nth and helicopters used for composition on June 7nth.

Figure 8: Survey conditions during the June 6th visual and photo survey in the core survey area. In most cases cloud ceiling were high (left photo) with some pockets of lower cloud cover (right photo). Snow cover was generally less than 15%. Photos by David Lee .

Analysis of collared caribou data

Thirty one female and sixteen male Bathurst collared caribou were tracked during the 2015 calving ground survey. The caribou followed a usual migration path to the calving ground up to an area just north of the Hood River before heading south to the core calving area that occurred between the Burnside and Booth Rivers (Figure 9). Of the 31 collars monitored, 28 occurred in the high density photo stratum with the 4 other occurring in lower density visual strata to the south and west.

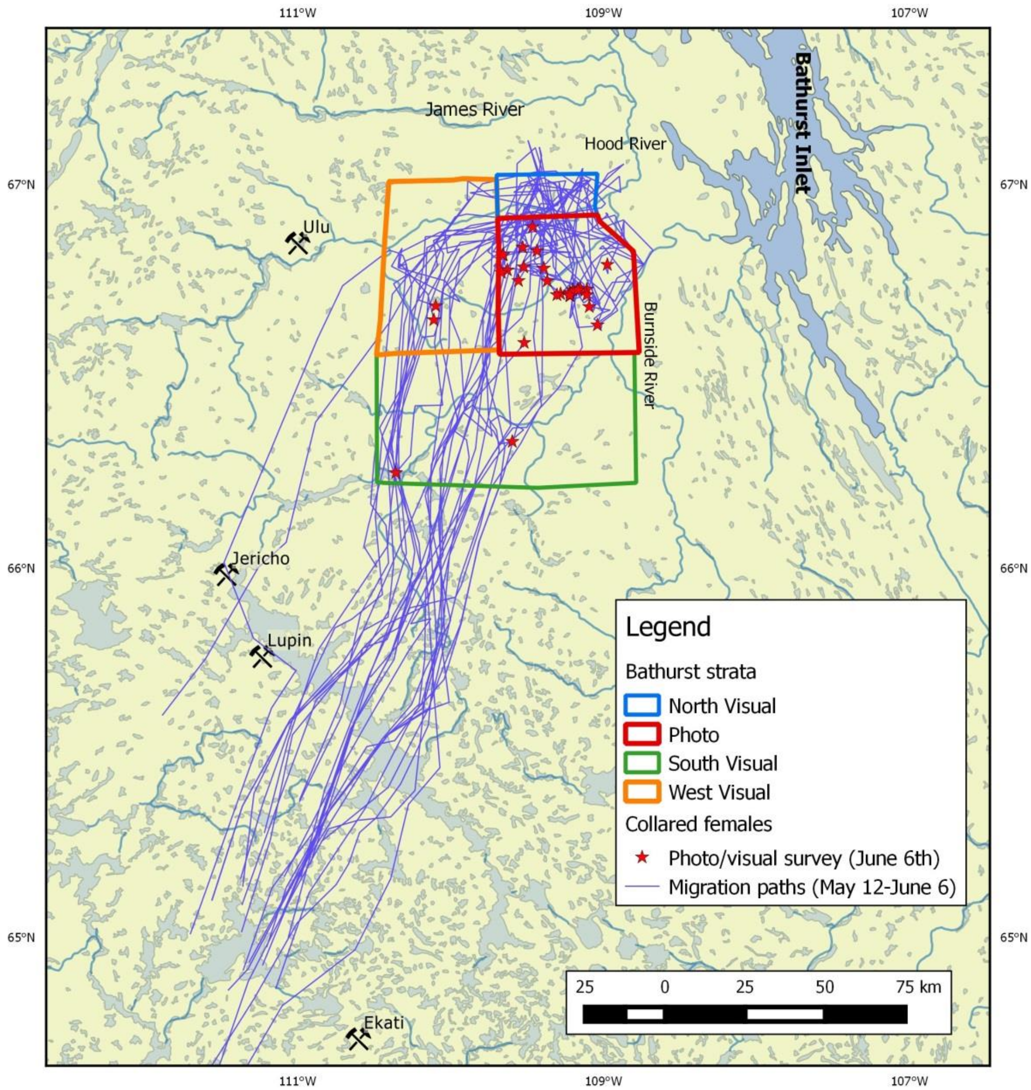

Figure 9: Movements of collared caribou to the calving ground area from May 12 to June 6. The location of caribou during the photo survey on June 6th is noted.

Movement rate estimates (Figure 10) indicated that rates decreased until June 4th and remained low until June 13nth suggesting that the peak of calving started on June 5th with increased movement after June 13nth which was likely when calves became more mobile.

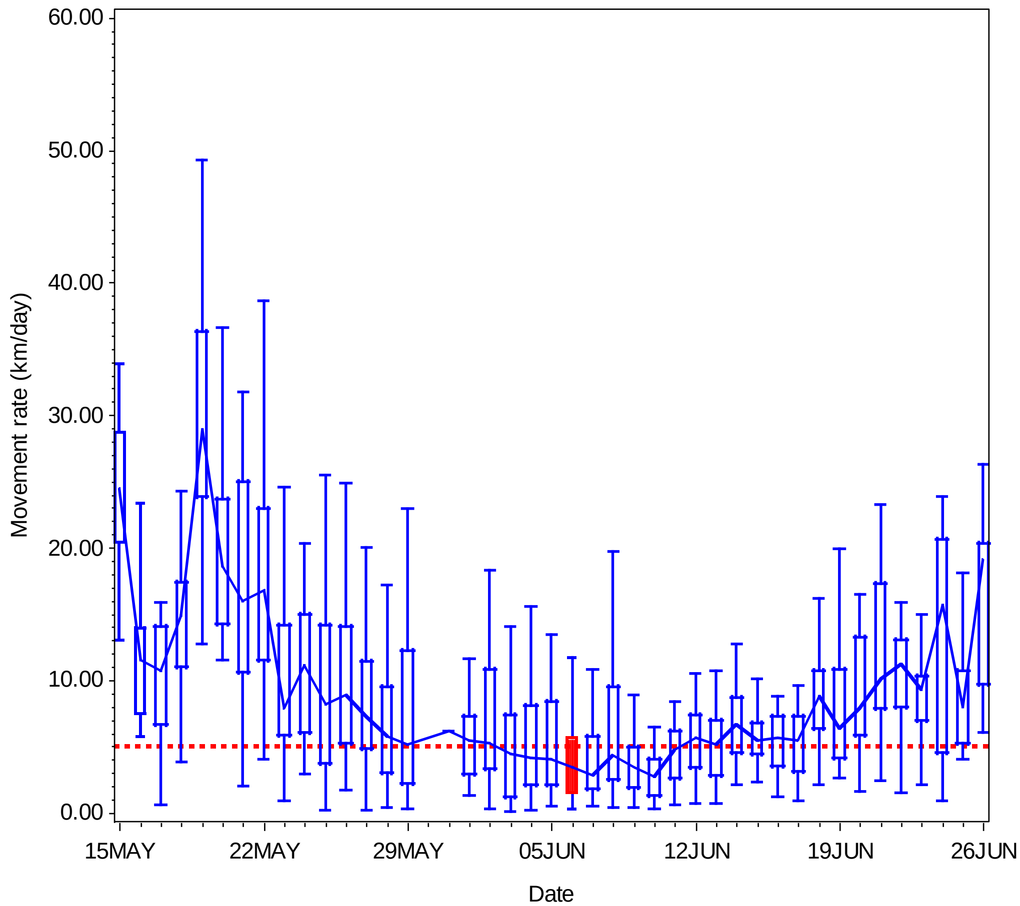

Figure 10: Movement rates (kilometers per day) for Bathurst caribou before, during, and after the calving ground survey (n=31 collared females). The distribution of movement rates is shown as box-plots with lines connecting median values, the boxes denote 25th and 75th percentiles, and the whiskers denote the range of the data. The solid red box indicates June 6th when the photo survey occurred.

Reconnaissance surveys to delineate strata

For the Bathurst survey one Caravan aircraft was based from the Ekati mine site to ensure that potential weather issues at the Kugluktuk airstrip did not prevent surveying of the Bathurst core area. This plane conducted reconnaissance surveys from June 2nd to 4th of the core area and surrounding area (Table 3). Another Caravan from Kugluktuk was also used to survey the core calving areas on June 3rd and 4th. For the visual surveys on June 6th, three survey aircraft from the Kugluktuk base were used to survey the primary core area with the Ekati-based caravan conducting further reconnaissance surveys.

Table 3: Summary of reconnaissance and visual survey efforts for the Bathurst calving ground survey. There was one plane primarily based out of Ekati mine site for the survey, and 3 planes that flew both the Bluenose East and Bathurst surveys based out of Kugluktuk.

Date	Caravan 1 Base: Ekati Mine site	Caravan 2 (and other planes) Base: Kugluktuk, Nunavut
June 2, 2015	Recon: Initial survey of core area	Bluenose East survey
June 3, 2015	Recon of areas south of core	Recon: Areas west of core
June 4, 2015	Recon of Core east to Bathurst Inlet	Recon: Core calving area
June 5, 2015	Grounded due to weather	Bluenose East survey
June 6, 2015	Recon: south and east of Bathurst Inlet	Caravan 2: Visual West and South strata Caravan 3: South stratum Pilatus porter: North stratum
June 7, 2015	Recon: North of core area	Bluenose East survey

The reconnaissance surveys identified a relatively small cluster of medium to high densities of caribou situated in the core calving area with a trailing edge occurring to the southwest (Figure 11). The observations of moderate to high densities coincided with the locations of female collared caribou which also were aggregated in the core area (Figure 11). The locations of collared bulls extended far to the south with intermittent lower densities of non-breeding cows and yearlings detected in this area.

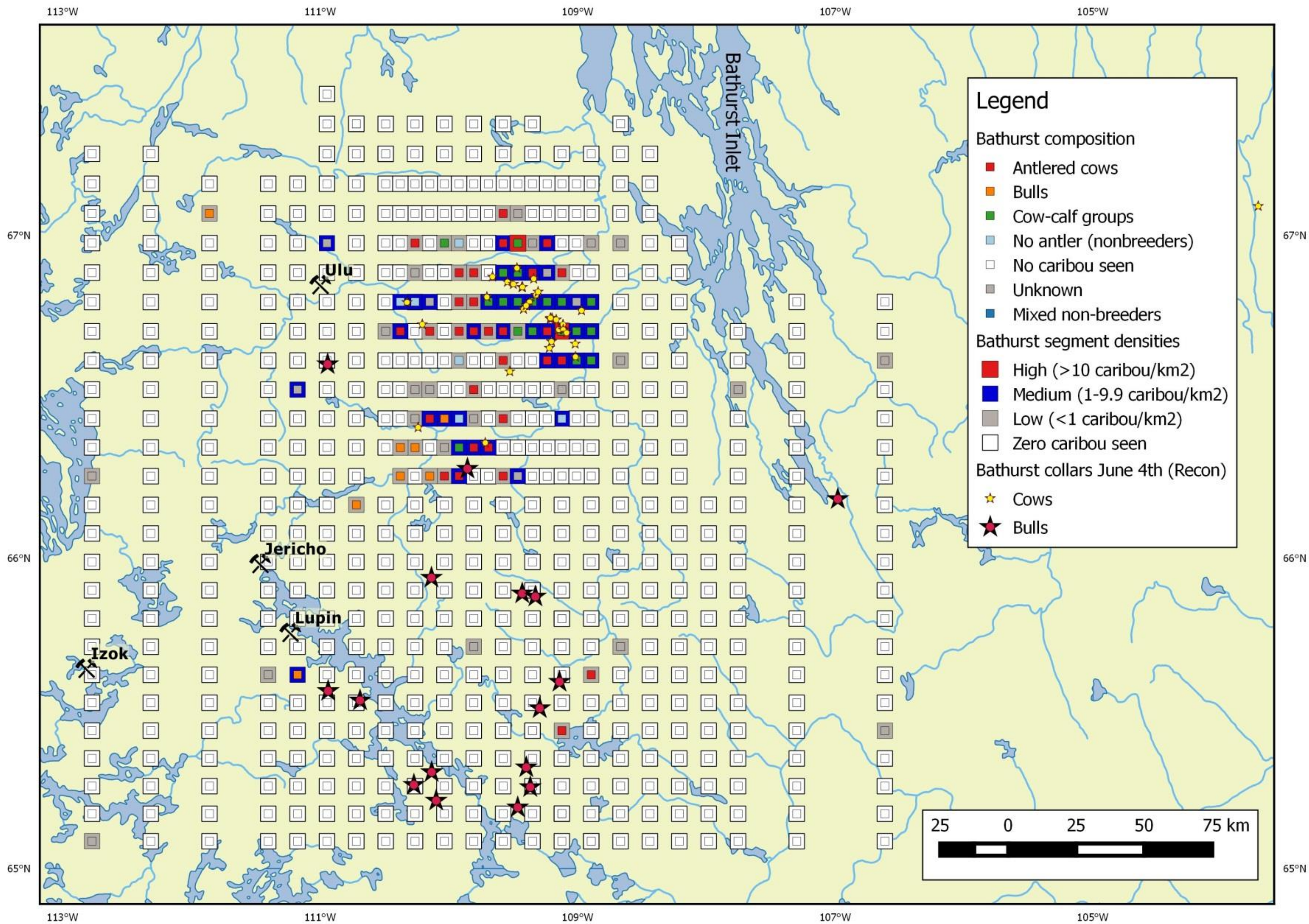

Figure 11: Reconnaissance survey coverage of Bathurst calving ground in 2015 with segment densities and composition.

Stratification and allocation of survey effort

The proportion of calves in the core area (as defined by the photo stratum) was 34.2% (std. dev.=34.9%, min=0, max=1, n=25) during recon flying on June 4th suggesting that the herd was close to the peak of calving. Newborn calves are small and often bedded or behind their mothers, thus are easily missed by observers from fixed-wing aircraft. The peak of calving was also indicated by reduced movements of collared cows beginning on June 4th (Figure 10).

Closer inspection of the reconnaissance data (Figure 12) revealed mainly medium density segments of caribou in areas between the Hood, Booth, and Burnside rivers with a few groups to the north of the Hood River. Overall, the density of segments was lower with only 2 high density segments in the entire core area. One of the northern segments was composed of a single group of 80 caribou 2 kilometers north of the Hood River. In addition, two hundred fifty seven caribou were observed in one high density segment between the Burnside and Booth Rivers which was also within the vicinity of many of the collared female caribou.

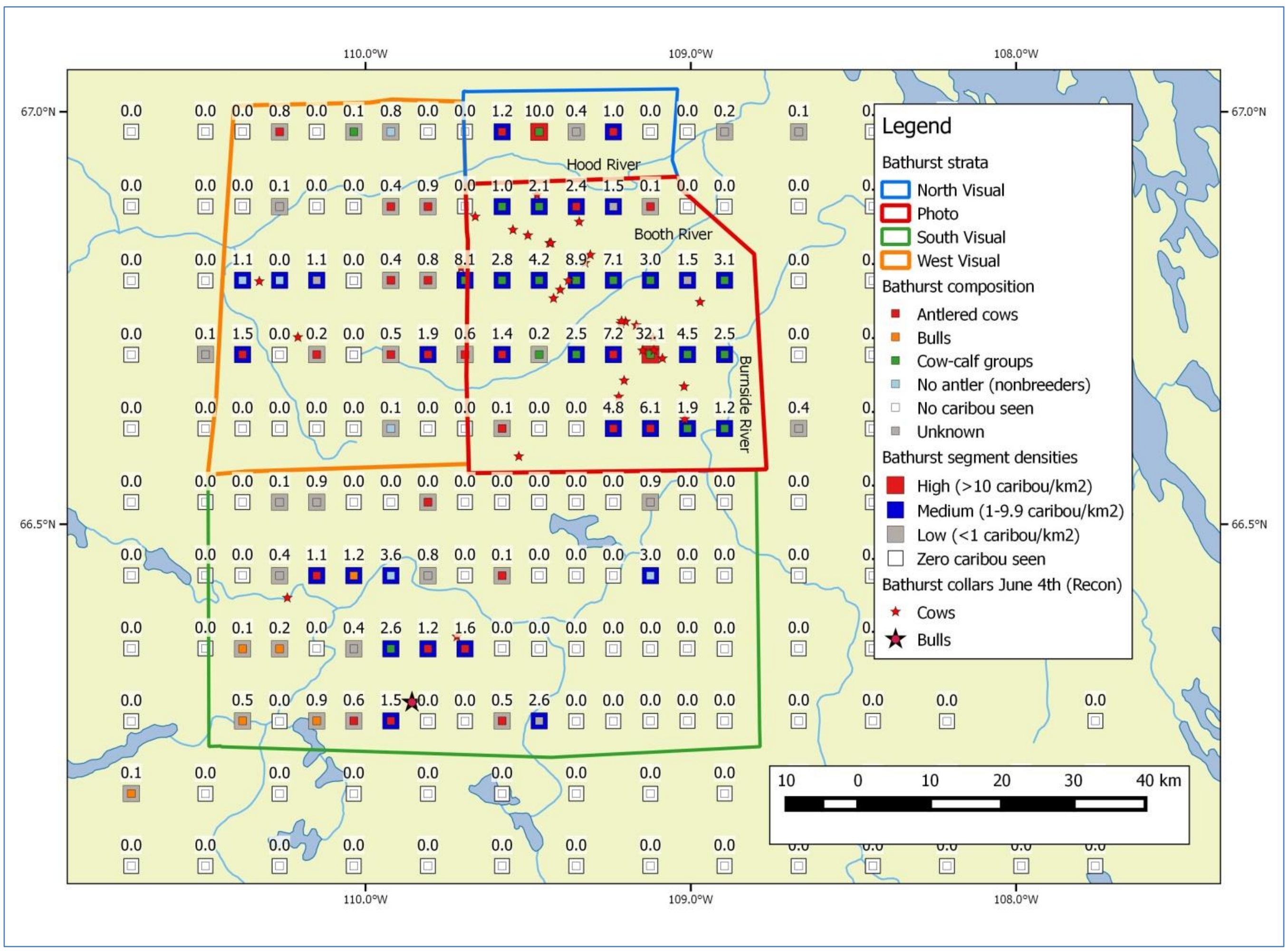

Figure 12: A closer view of segment with densities (caribou per km^2) shown above each segment.

One principal photo strata was defined which encompassed the majority of collared caribou and observations of medium to higher densities of breeding caribou. The northern stratum was low density except for a single group of caribou observed near the Hood River. For this reason this area was surveyed using visual methods. The south and west stratum were extended to include all the collared female caribou (Table 4).

Table 4: Summary of strata defined from reconnaissance survey with relative estimates of caribou numbers. Stratum and transect dimensions are given as well as reconnaissance-based estimates of stratum density ($\widehat{\boldsymbol{D}}$) and stratum population size ($\widehat{\boldsymbol{N}}$).

Stratum	Dimensions		Transects			Reconnaissance estimates			
	Area (km^2)	Baseline (km)	Max. possible	sampled	Ave. width	$\widehat{D}$	$\widehat{N}$	$SE(\widehat{N})$	CV
Photo	1492.5	38.6	48.3	7	38.1	3.59	5,365	1585.0	29.5%
North	339.9	28.6	35.8	4	12.1	3.16	1,083	603.1	55.7%
South	2906.5	75.0	93.8	5	38.0	0.91	1,540	824.0	53.5%
West	1623.6	49.0	61.3	14	33.2	0.68	1,838	242.9	13.2%
							9,827	1885.5	19.2%

One of the main challenges of surveying the core Bathurst herd was the large amount of transit distance (approximately 200 km) and time (approximately 1 hour) required for transit from base airstrips in Kugluktuk and Ekati Mine site (200 km) to the core calving area. Once at the core calving area it was possible to refuel at the Jericho or Lupin mine site airstrips. The other challenge was the weather forecast for the immediate survey window which indicated ground fog in the morning and mixed conditions for the Bathurst survey area. Given these constraints we planned the photo and visual surveys to occur in a relatively short survey window through the use of the 3 survey aircraft from the Bluenose East survey. Using this approach helped ensure that the survey could occur in one survey window rather than multiple survey windows and likely multiple survey days which would have introduced potential bias in estimates due to movement of caribou between strata boundaries.

For the photo stratum we estimated the total kilometers that the photo plane could fly within a single (8 hour) survey day (when considering transit time to the core calving area) and also considered the total number of photos (5000) within the survey budget. Given the limited weather window we also considered an alternative plan where both planes flew the photo stratum if we felt that a full survey day of flying was not viable given survey conditions. The actual number of kilometers that can be flown within a fixed number of photos depends partially on the survey altitude of the photo plane. If the plane can fly higher than it is possible to cover more survey area with less photos (Table 5).

Table 5: Range of survey altitudes and corresponding levels of coverage considered for the photo stratum. The altitude and focal length was different for the 2 photo planes. In all scenarios, the planes would fly 760 kilometers on transect for a total of 817 km of flying if a circular turning route is assumed between transects. Estimates of flying do not include ferrying from the Kugluktuk survey base (approximately 200 km).

Plane/Photo resolution (GSD)	Altitude (AGL)	Number of transects flown	Coverage	Approximate photos used
Cessna (LP Camera)				
5	1914	20	29.8	4810
6	2297	20	35.7	4000
7	2679	20	41.7	3423
8	3062	20	47.6	3004
9	3445	20	53.6	2667
Piper (XP Camera)				
4	2187	20	35.2	4199
5	2734	20	44.1	3363
6	3281	20	52.9	2804
7	3828	20	61.7	2398
8	4374	20	70.5	2100
9	4921	20	79.3	1867

On June 5th the entire Bathurst core area was enveloped in fog and it was not possible to conduct a photo survey. On June 6th, clearing was forecast for the afternoon with a potential storm front moving in the next day. For this reason, we decided to have both photo planes fly the photo stratum with each plane flying every other line to mitigate potential bias caused by a larger strip width for the plane with the XP camera compared to the plane with the LP camera. Using this plan, the coverage was still systematic and random given that the coverage systematically varied by every other line. The main penalty for this survey design was a slight reduction of precision, however, any bias was negligible given that the survey was still systematic random. We felt this approach was the best way to ensure the survey was completed within a single survey session.

For the visual stratum we allocated 1500 kilometers of survey transect flying with additional constraints for each stratum to ensure that they could be flown within a shorter survey window. Using estimates from the reconnaissance surveys (Table 4) effort was allocated to the 3 visual stratum using estimates of density and standard error (Table 6). The highest amount of coverage was allocated to the north stratum based on the higher density of caribou in this stratum. The south stratum had the lowest coverage. The number of lines was adjusted to allow coverage of the north stratum in a single flight with the rest of the effort allocated to the south and west strata.

Table 6: Allocation of survey effort for visual stratum using reconnaissance based estimates and adjustment of lines to meet minimal coverage and logistical considerations for each stratum.

Stratum	Optimal No. of transects		Coverage		Adjusted lines		
	Using N	Using SE	Using N	Using SE	transects	coverage	Km on transect
North	35.8	17.3	100.0	52.4	12	35.30%	144
West	13.9	26.4	21.8	41.4	18	29.30%	593
South	14.6	11.2	15.6	11.9	15	16.00%	580
Total							1317

The final dimensions of all of the strata are listed in Table 7 and shown in Figure 13. The actual coverage of strata changed due to variable altitudes of the photo plane as well as a lower survey altitude of the Pilatus Porter in the north stratum which was discovered during post-processing of the survey data. The lower survey altitude reduced the strip width to 540 meters (from 800 meters) with subsequent reduction of stratum coverage.

Table 7: Final dimensions and survey effort for each stratum sampled. Sampling coverage is based upon transect area compared to total stratum area. The intended and actual coverage of the North stratum is given separated by an arrow. The range of strip widths sampled is given for the photo stratum.

Stratum	Area (km^2)	Ave. transect length (w_i)	Base line length (l_i)	Strip width	Total transects possible	Area sampled	Transects	Sampling coverage (%)
Photo	1,492.5	38.1	38.6	1.057 (0.715-1.35)	36.5	816.8	20	54.7
North	339.9	12.1	28.6	0.80→0.54	53.1	78.0	12	35.3 →22.9
West	1,623.6	33.2	49.0	0.80	61.3	475.0	18	29.3%
South	2,906.5	38.0	75.0	0.80	93.8	464.2	15	16.0%

Photo and visual survey

Photo survey

Variable cloud cover and ceilings occurred during the photo survey and as a result the photo planes had to adjust survey altitude while in the photo stratum. In addition, the 2 planes had different cameras which created different strip widths. The differences in cameras were partially offset by having the planes fly every other line therefore ensuring that differences in coverage occurred systematically across the stratum (Figure 13).

Potential bias caused by different survey altitudes was negated through the use of special estimation formulas as described previously in the methods.

The movement of collars between the reconnaissance on June 4th and visual survey on June 6th was minimal with movement of most collars towards the center of the photo stratum (Figure 13). Most notable were movements of collars in the northern portion moving south to a large cluster between the Booth and Burnside rivers as also indicated by the longer time scale migration paths in Figure 9.

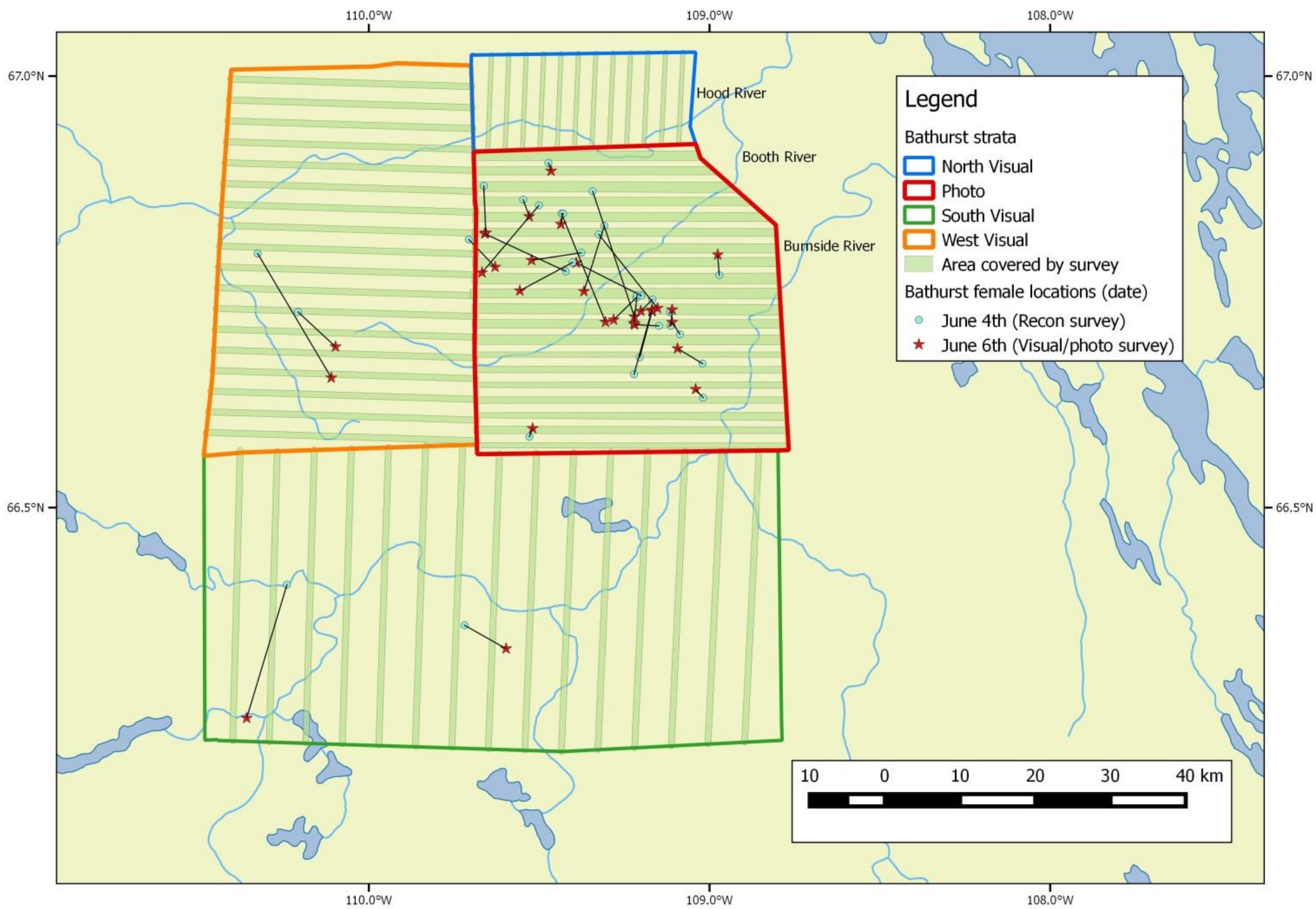

Figure 13: Final strata layout with actual transect area sampled and collared caribou locations during the visual/photo survey (June 6th). The strip width of surveys in the photo stratum varied due to differences in altitude (due to cloud cover) and camera types on the survey planes.

Visual surveys

Summaries of the double observer data showed that in most cases both observers sighted caribou when group size was greater than 1 to 2 caribou. Group sizes were 20 or less in most cases especially for the visual survey (Figure 14).

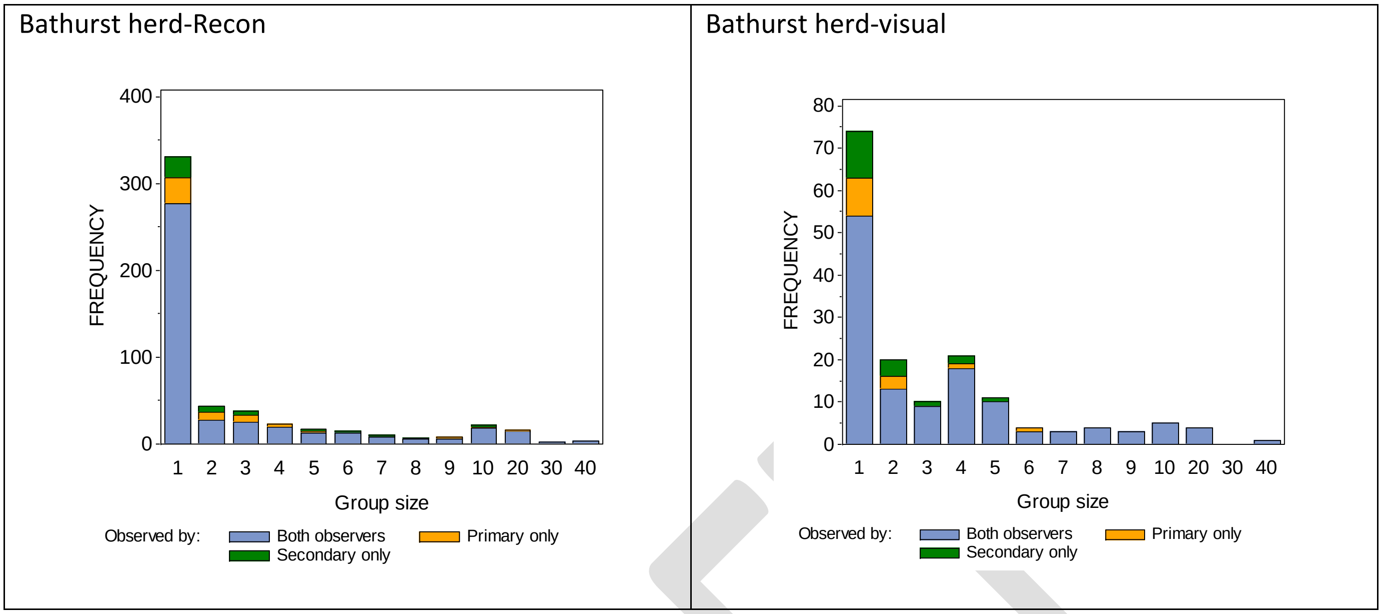

Figure 14: Group sizes of caribou observed as a function of whether observed by primary, secondary, or both observers

Snow and cloud cover was more pronounced during the reconnaissance surveys that occurred up to June 4th compared to the visual surveys that occurred on June 6th. Proportions of caribou only observed by a single observer were higher when cloud or snow cover was greater than 50% (Figure 15).

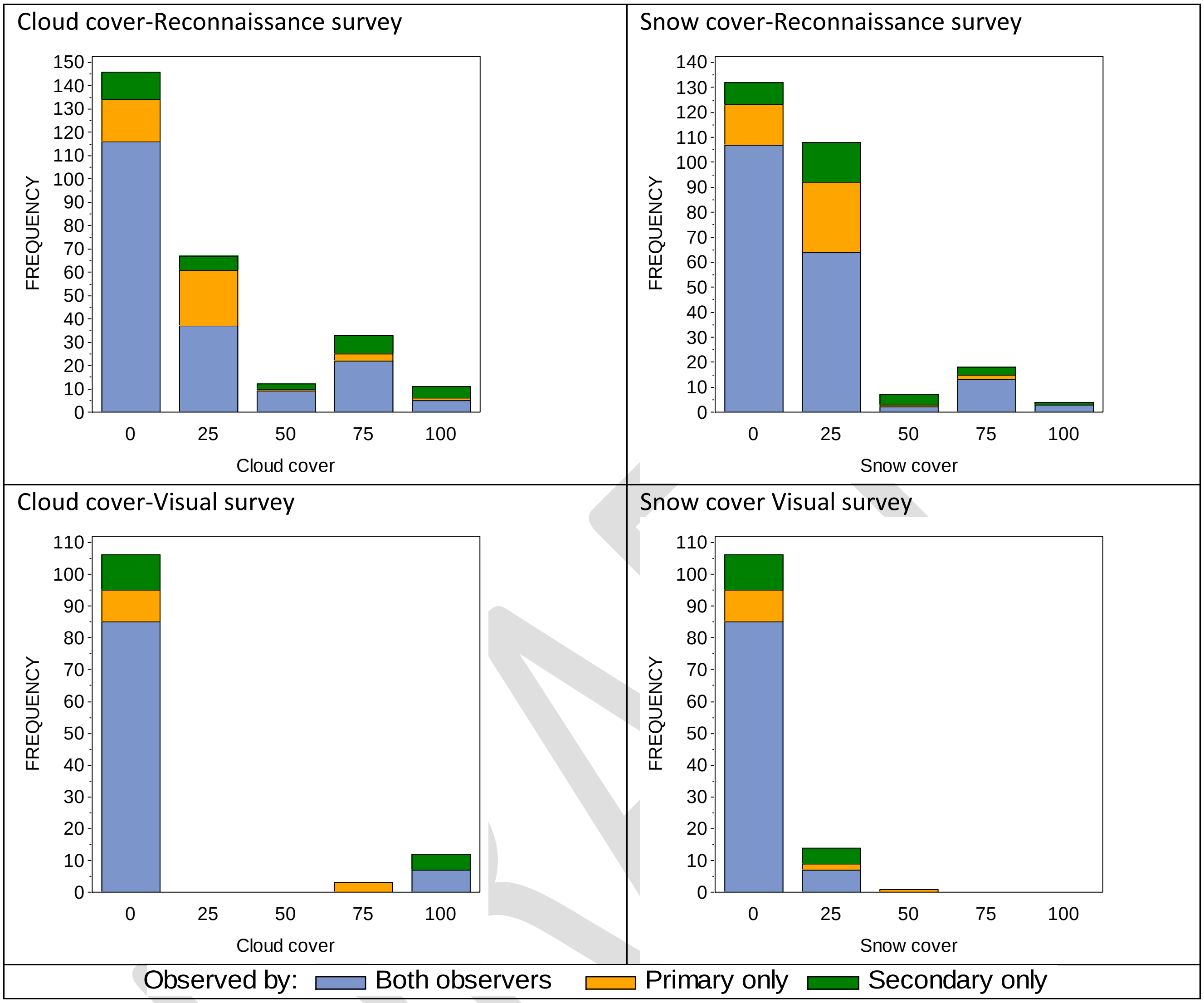

Figure 15: Snow and cloud cover in reconnaissance and visual surveys for the Bathurst herd

The double observer data were analyzed using the Huggins closed model in program MARK. Model selection focused on building a parsimonious model to describe variation in sightability caused by calving ground/herd (symbolized by h) ,group size, snow cover, cloud cover, phase of survey (reconnaissance or visual) and observer variability. An initial model with the log of group size (Table 8, Model 17) was substantially more supported than an intercept model (model 19). A model with all the observer pairs (Model 15) was also substantially more supported than models without observer pairs. A model that considered the order of observer pairs that had applicable sample sizes of observations (Model 14) was also more supported. The next set of models considered phase of survey, snow cover, and cloud cover. Survey conditions were appreciably different on the Bluenose East and Bathurst calving grounds. Cloud and snow cover was higher in reconnaissance but reduced in visual surveys for the Bathurst herd (Figure 15). This issue, and differences in topography made it possible that mean levels of sightability and relationships between sightability and cloud/snow cover could be different for the 2 calving grounds. A model that assumed similar relationships between sightability and snow/cloud cover between the 2 calving grounds (Model 11) was contrasted with models that considered herd-specific relationships (Models 1-8). Of the models considered, a model that estimated herd/calving ground specific relationships between cloud and snow cover was more supported than models that considered similar relationships for each calving ground (Model 1).

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

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

Plots of sighting probability (for the visual survey phases with other covariates at mean levels) as a function of group size for each observer pair illustrates that there are difference in sighting probability between observer pairs, but the main differences occur at smaller group sizes (Figure 16). The combined probability that a group of caribou was seen by at least one of the observers (p*=*1-(1-p)(1-p)* where p is the single observer probability) was close to 1 for most observer pairs when group size was greater than 5.

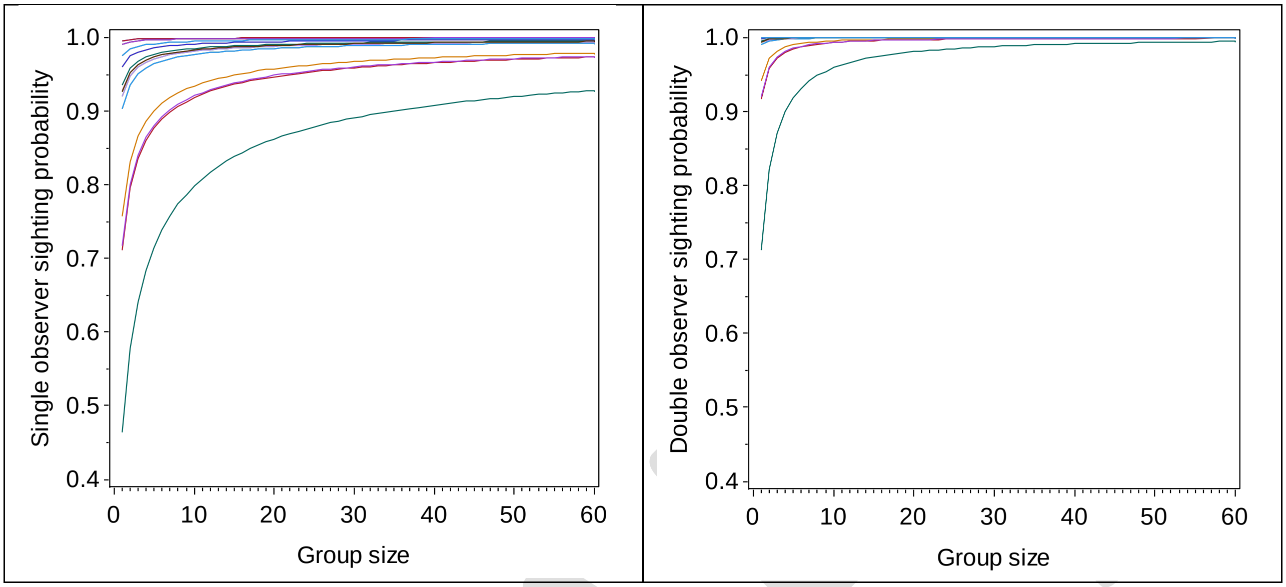

Figure 16: Predicted single and combined (double) observer sighting probabilities for the visual phase of the survey with other covariates set at mean levels.

The single and double observer sighting probabilities were affected by snow and cloud cover with high sightability if cloud and snow cover were <50% for single observer or less than 75% for double observers (Figure 17). Cloud and snow cover was mainly less than 75% for the visual survey (Figure 15) suggesting that sightability was high.

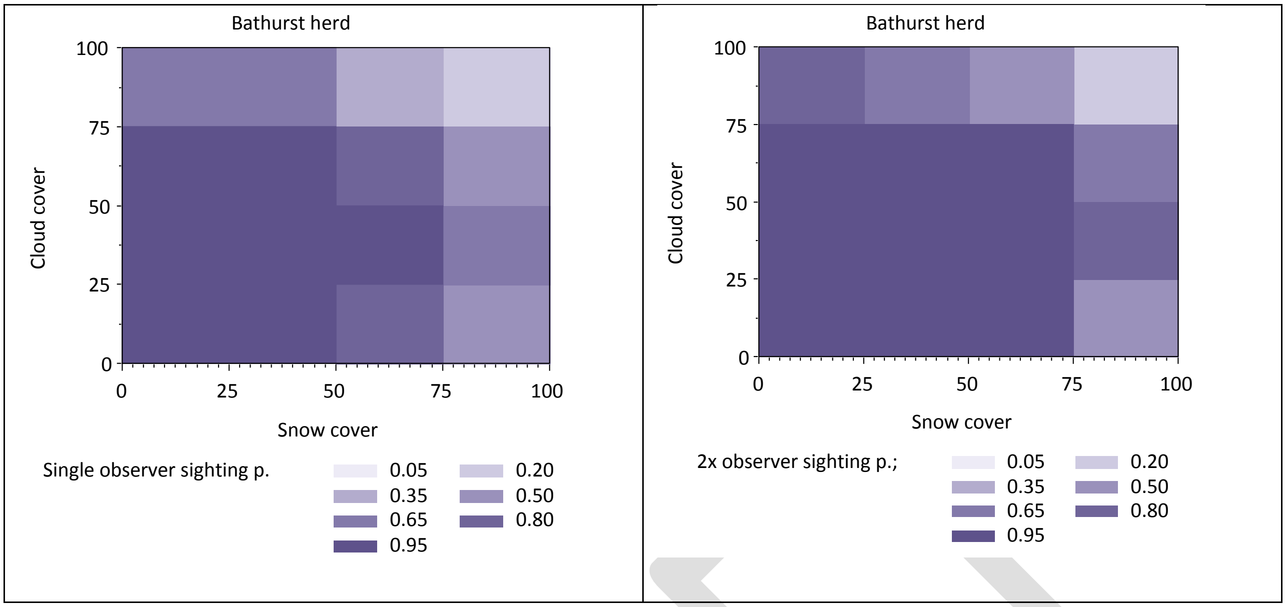

Figure 17: The estimated effect of cloud and snow cover on sightability of caribou for single and both observers combined (2x observer).

Overall, the mean double observer sighting probability estimates for reconnaissance and visual surveys was 0.87 (std=0.28, CI=0.1-1) and 0.99 (std=0.02, CI=0.92-1). The increase in sightability was due to better survey conditions as well as more attention to searching for groups in the visual component survey with less attention to classification of groups. In comparison, estimates of sightability for a single observer was 0.80 (std=0.29, CI=0.1-1) and 0.84 (std=0.71-1.00) for the reconnaissance and visual surveys. This general result demonstrates the increase in sightability with 2 observers searching for caribou per side of the plane compared to a single observer.

Estimates of caribou on the calving ground

The majority (85%) of the estimated caribou were in the photo stratum with relatively low densities in other strata (Table 9). The lower number of caribou counted in the north stratum was presumably due to southern movement of caribou between the reconnaissance and visual/photo surveys as suggested by collared caribou (Figure 13). The northern stratum was extensively surveyed during the composition survey with no caribou detected. The overall estimate of caribou was 15,369 (CI=9,913-20,826).

The estimate of total caribou on the calving ground without double observer correction was 15,341 (SE=2605.9, CV=17.0%) which was only 28 caribou less than the estimate with double observer corrections. The reasons for minimal difference between estimates was that the photo stratum (which did not use double observer correction) constituted most (85.1%) of the caribou estimated on the calving ground, and double observer sightability was high (0.99) during the visual survey.

Table 9: Estimates of the total number of caribou on the calving ground for each stratum. The standard error (SE), coefficient of variation (CV) and percent of the total estimate is given for each stratum.

Stratum Characteristics					Caribou Numbers in Survey Stata					
Stratum	Lines flown	Transect area	Stratum area	Coverage	Caribou counted	Average density	$\widehat{N}$	SE	CV	% of sum of $\widehat{N}$
Photo	20	816.8	1,492.5	54.7%	7157	8.76	13,076.9	2571.2	19.7%	85.1%
North	12	78.0	339.9	22.9%	17	0.22	74.1	31.6	42.6%	0.5%
West	18	475.0	1,623.6	29.3%	311	0.67	1,082.6	327.6	30.3%	7.0%
South	15	464.2	2,906.5	16.0%	180	0.39	1,135.8	351.2	30.9%	7.4%
Totals							15,369.4	2615.9	17.0%	

The precision of the overall estimate was lower than previous surveys; this was due to the aggregated nature of caribou in the photo stratum and logistical limitations on the level of coverage that could be achieved due to weather constraints in 2015. Inspection of transect-specific densities (Figure 18) revealed that high densities of greater than 10 caribou per km^2 were only found on 5 of the 20 lines surveyed, with lower densities on other lines. This large difference in densities resulted in lower precision of estimates. The distribution of transect densities does suggest the caribou numbers were well delineated by the stratum boundaries.

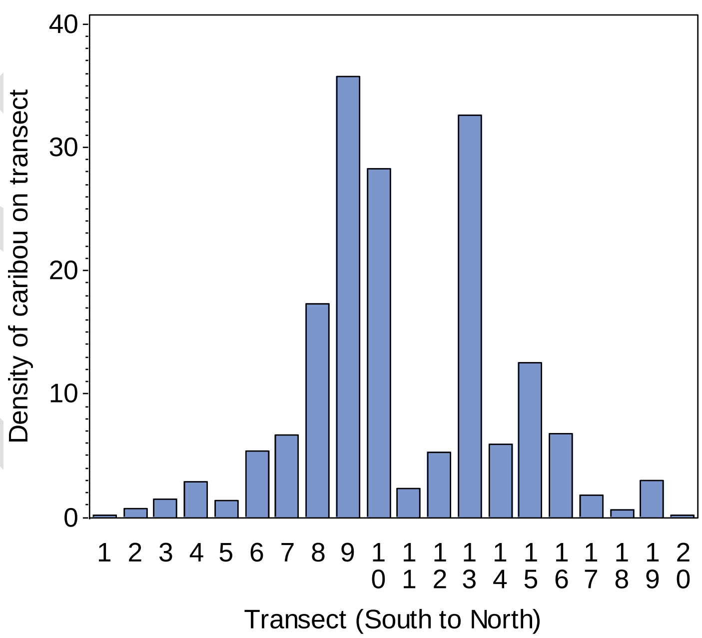

Figure 18: Densities of caribou on each transect line for the high photo stratum.

The distribution of caribou as summarized at 1 km intervals along transect lines in the survey area (Figure 19) was very aggregated with very high densities found in areas between the Booth and Burnside rivers with a very abrupt reduction in density in peripheral areas. The degree of aggregation and the relatively large scale of caribou clusters compared to potential caribou movements reduced the ability of stratified sampling to address this level of aggregation.

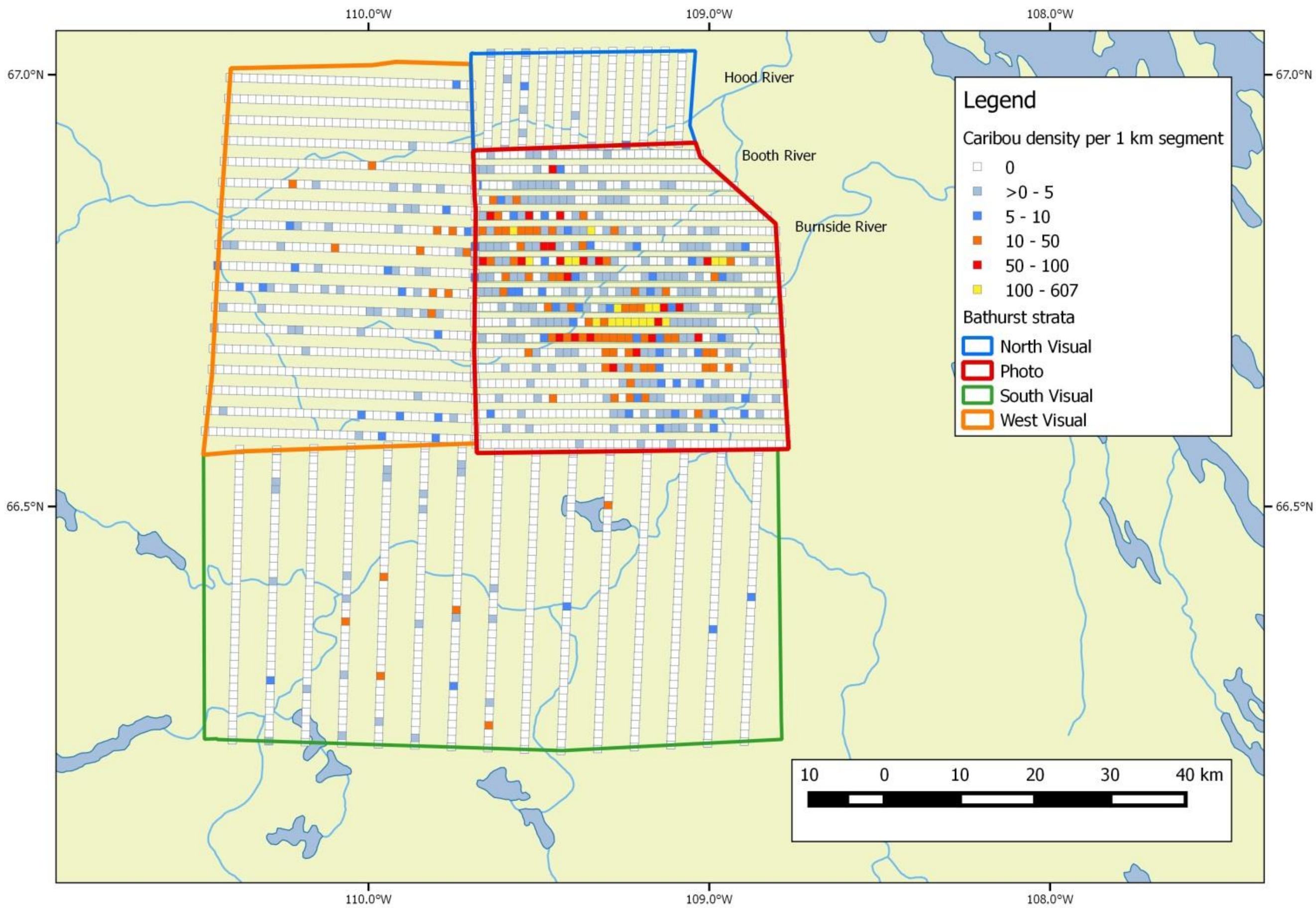

Figure 19: Spatial representation of caribou counted per 1km segment of transects. See Figure 13 for the actual area sampled by each transect.

Composition on calving ground

Composition surveys were conducted on June 6th concurrently with visual and photo surveys. Ground fog precluded sampling on June 7th with the sampling then occurring on June 8th and 9th. Movement of collars during this time was minimal (Figure 20) suggesting that composition samples on June 8th and 9th were still a good representation of composition within survey strata.

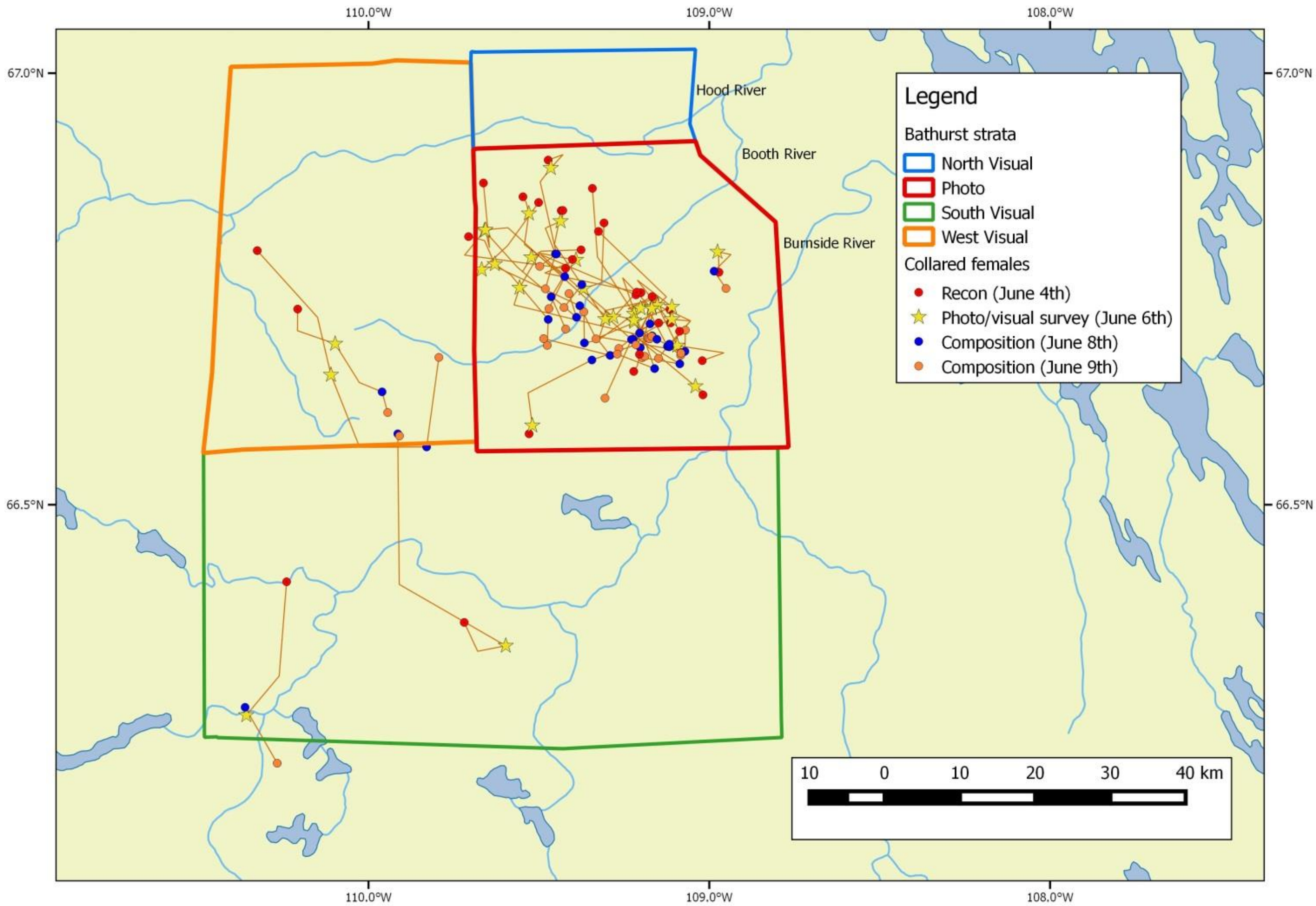

Figure 20: Movement of collared females between the primary reconnaissance survey (June 4th), photo survey and visual survey (June 6th) and composition surveys (June 6th, 8th and 9th).

The composition of each surveyed group revealed highly aggregated groups of breeding caribou in the central area of the photo stratum with non-breeding caribou to the immediate south of the main cluster of breeding caribou (Figure 21). Non-photo strata contained largely non-breeding caribou. No caribou were detected in the north visual stratum despite 3 flights that sampled the stratum from east to west, further verifying low densities of caribou in this stratum. For this reason, composition estimates for the photo stratum were used for the north visual stratum. The relatively low number of caribou estimated in this stratum (Table 9) and likelihood that caribou had moved south to the photo stratum (Figure 9) minimized the impact of this assumption on overall estimates.

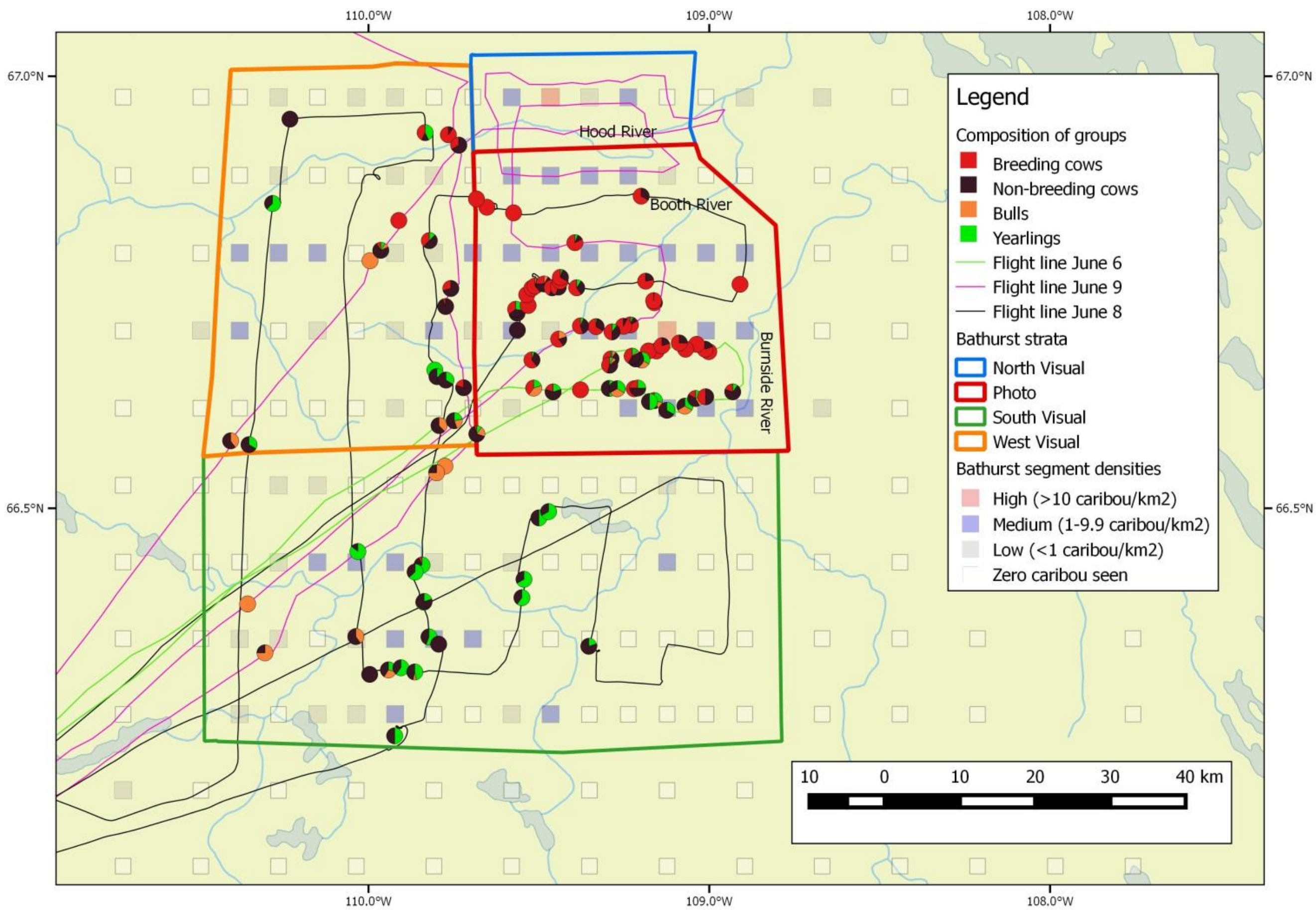

Figure 21: Flight tracks and waypoints for the composition survey. Each waypoint observation is given as a pie chart with proportion of each composition group delineated.

Counts of groups classified in each stratum revealed a relatively large number of non-breeding adult females (no antler or distended udder) in the photo stratum and the other strata (Table 10). The proportion calves to breeding adults was 58% suggesting that the survey occurred near the peak of calving.

Table 10: Summary of composition samples in each strata surveyed.

Category		**Sum of counts**			**Mean group sizes**		
		Photo	**South**	**West**	**Photo**	**South**	**West**
Groups sampled		58	24	17			
Breeding females	Antler & udder	323	0	14	5.57	0.00	0.82
	No antler & udder	114	1	3	1.97	0.04	0.18
	Antler & no udder	384	1	11	6.62	0.04	0.65
Non-breeding	No Antler/udder	426	91	70	7.34	3.79	4.12
	Yearlings	92	84	18	1.59	3.50	1.06
	Bulls	43	27	3	0.74	1.13	0.18
Calves		480	0	15	8.28	0.00	0.88
All 1+ yr caribou		1383	204	120	23.84	8.50	7.06

The proportion of breeding females was estimated by the ratio of the sum of the breeding females divided by the number of one-year-plus caribou observed (Table 11). The proportion of adult females was estimated as the sum of breeding females and non-breeding females (no antler/udder) divided by the sum of one-year-plus caribou). Bootstrap resampling was used to estimate percentile based confidence limits, estimates of standard error, and bias-corrected point estimates.

Table 11: Estimates of proportion of breeding females and adult females, standard error (SE), 95% confidence intervals, and coefficient of variation (CV) in the Photo/North, West, and South strata.

Stratum	Proportion	SE	Confidence Interval		CV
<u>Breeding females</u>					
Photo/North	0.594	0.047	0.51	0.69	7.9%
West Visual	0.233	0.076	0.10	0.39	32.6%
South Visual	0.010	0.006	0.00	0.02	60.0%
<u>Adult females (breeding and non-breeding)</u>					
Photo/North	0.902	0.022	0.846	0.936	2.4%
West Visual	0.456	0.047	0.372	0.546	10.2%
South Visual	0.817	0.064	0.630	0.912	7.8%

Estimation of breeding and adult females.

<u>Estimation of breeding females</u>

The estimated proportion of breeding females was multiplied by population estimates from each stratum to obtain estimates of breeding females and associated variances (Table 12). The total estimate of breeding females was 8,075 with a 95% confidence interval of 4,608 to 11,542.

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

Stratum	Total 1+ yr caribou			Composition proportion of breeding females			Estimated breeding females		
	$\widehat{N}$	SE	CV	Proportion	SE	CV	$\widehat{N}_{breedf}$	SE	CV
Photo	13,076.9	2571.2	19.7%	0.594	0.047	7.9%	7,768	1646.4	21.2%
North	74.1	31.6	42.6%	0.594	0.047	7.9%	44	19.1	43.4%
West	1,082.6	327.6	30.3%	0.233	0.076	32.6%	252	112.1	44.5%
South	1,135.8	351.2	30.9%	0.010	0.006	60.0%	11	7.4	67.5%
Total	15,369.4	2615.9	17.0%				8,075	1650.3	20.4%

Estimation of adult females

Another estimate of interest was the number of adult females (breeders and non-breeders) on the calving ground. For this the estimate of caribou on the calving ground was multiplied by the proportion of adult females (breeding and non-breeding) from the composition surveys (Table 13). The resulting estimate is 13,265 (CI=8,308-18,222).

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

Stratum	Total 1+ yr caribou			Composition proportion of adult females			Estimated adult females		
	$\widehat{N}$	SE	CV	Proportion	SE	CV	$\widehat{N}_{adultf}$	SE	CV
Photo	13,076.9	2571.2	19.7%	0.902	0.022	2.4%	11,795	2337.0	19.8%
North	74.1	31.6	42.6%	0.902	0.022	2.4%	67	26.1	39.1%
West	1,082.6	327.6	30.3%	0.456	0.047	10.3%	518	168.8	32.6%
South	1,135.8	351.2	30.9%	0.817	0.064	7.8%	884	276.5	31.3%
	15,369.4	2615.9	17.0%				13,265	2359.5	17.8%

Fall composition surveys

Fall composition surveys were conducted on October 21-24, 2008, October 23-26, 2011, October 22 and 23rd, 2012, and October 22, 2014. The main survey of interest was the 2014 fall composition estimate but the 2008 and 2011 surveys were also considered. In 2014, 34 groups and 2,927 caribou were classified (Table 14) mainly in the vicinity of Jolly Lake (Figure 22). Poor weather prevented more than one day of surveying. One group of 4 collars located 90 to 180 kilometers northwest of Ekati mine was not surveyed due to icing conditions (Cluff et al. 2016). The groups surveyed showed reasonable similarity, with cows forming greater than 50% counts in most groups surveyed.

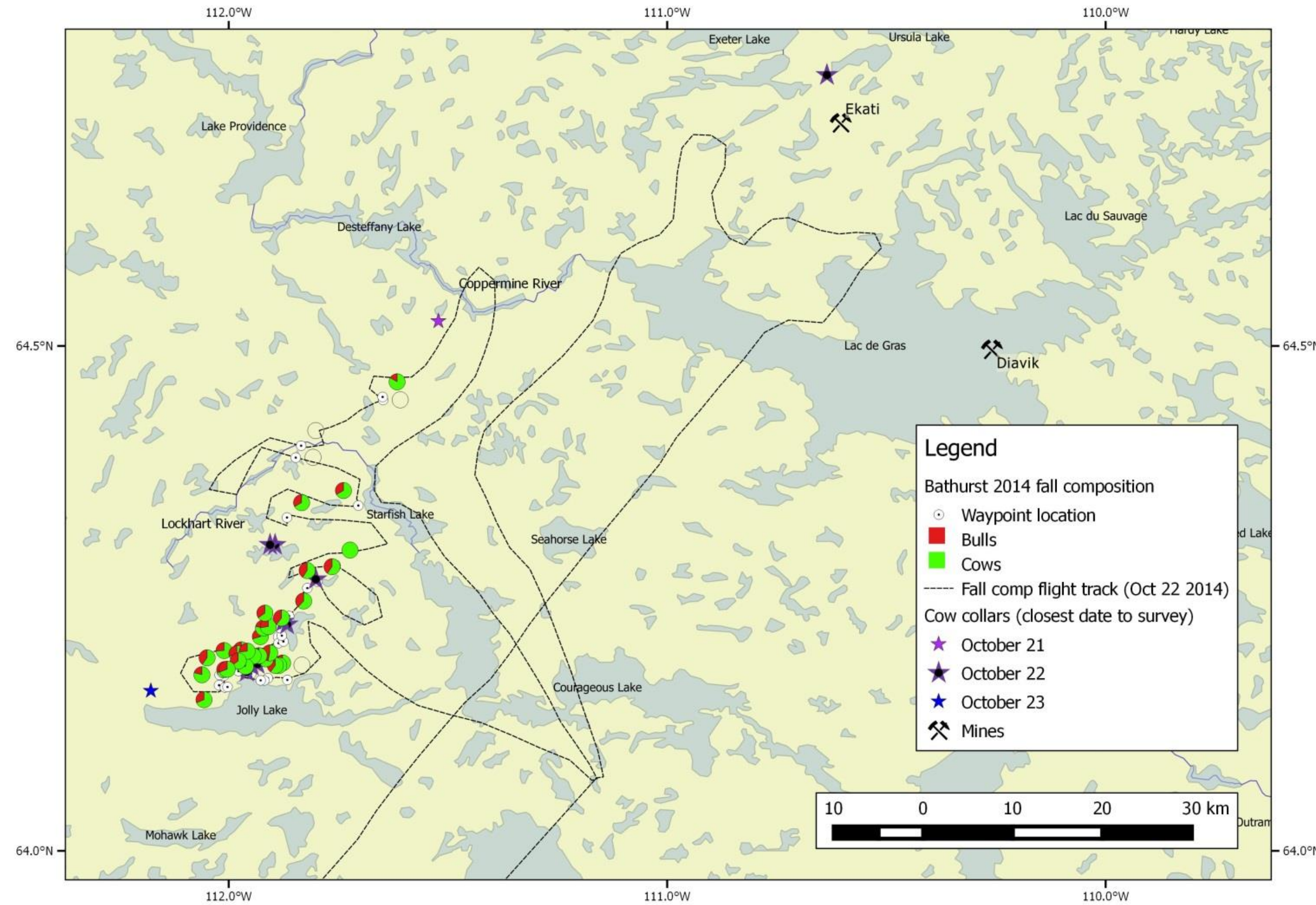

Figure 22: Fall composition survey waypoints and proportions of bulls and cows in each sample waypoint displayed as pie charts. The pie charts are staggered around waypoint to facilitate interpretation of closely spaced waypoints. Four collared females situated approximately 90 (1 collar) to 180 (3 collars) kilometers northeast of Ekati mine are not shown.

Sample sizes of caribou were slightly lower than in 2012 but similar to those in 2008 (Table 14).

Table 14: Summary statistics for Bathurst fall composition surveys conducted in 2008, 2011, 2012 and 2014.

Statistic	Year			
	2008	2011	2012	2014
Number of groups	42	52	33	30
Mean group size	84.05	95.5	129.5	73.6
Total caribou	3532	4964	4272	2927
Total adults (1.5+ year old)	2868	4105	3710	2502
Total cows	2074	2598	2369	1679
Total calves	661	859	562	425
Total bulls	794	1507	1341	823

Of most interest was the proportion of adult females (cows) in the composition surveys, which would then be used to estimate the proportion of adult females in the Bathurst herd. The bull-cow ratio in the herd decreased in 2014 compared to 2011 and 2012 with a subsequent increase in proportion of cows in the herd (Table 15).

Table 15: Proportion cows and bull-cow ratios from 2008 to 2014 fall composition surveys. The proportion is based upon the total adults counted (excluding calves) as listed in Table 14.

Year	**Proportion cows**					**Bull-cow ratio**			
	Estimate	SE	Conf. Limit		CV	Estimate	SE	Conf. Limit	
2008	0.723	0.013	0.697	0.750	0.018	0.383	0.025	0.334	0.435
2011	0.631	0.013	0.606	0.655	0.021	0.585	0.033	0.526	0.651
2012	0.638	0.014	0.610	0.664	0.022	0.567	0.035	0.505	0.640
2014	0.671	0.011	0.648	0.693	0.017	0.490	0.025	0.444	0.540

Extrapolated estimate of total herd size

<u>Using an assumed pregnancy rate</u>

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 11,215 (± 5361) caribou. This estimate was then divided by the proportion of adult females in the herd (Table 15) of 0.671 to estimate the total herd size of 16,714 (1.5+ year old) caribou (Table 16).

Table 16: Extrapolated estimate of total herd size for 2015 using breeding female estimates (Table 10) and estimates of proportion of adult females in the entire herd from 2014 fall composition surveys (Table 12).

Survey data	Estimate	SE	CV	Confidence Limit	
Number of caribou on the breeding ground	15,369	2615.9	17.0%	9,913	20,826
Number of breeding females	8,075	1650.3	20.4%	4,608	11,542
Proportion adult females in the entire herd	0.671	0.0112	1.7%		
Proportion 1.5+ year females pregnant	0.720		10.0%		
Total population estimate	16,714	3,813.1	22.8%	8,703	24,725

Using estimates of adult females

The alternative method to estimate herd size uses direct estimates of adult females in the herd from strata estimates and composition surveys (Table 13). Note that this estimate of 13,265 (Table 13) is greater than the estimate derived from breeding females and an assumed pregnancy rate (11,215) which further suggests that pregnancy rate was lower in 2014-2015 than the assumed 0.72 level. This estimate was then divided by the proportion of females in the herd to obtain an estimate of herd size of 19,769 caribou (Table 17).

Table 17: Extrapolated estimate of total herd size for 2012 using adult female estimates (Table 13 and estimates of proportion of adult females in the entire herd from 2014 fall composition surveys (Table 12).

Survey data	Estimate	SE	CV	Confidence Limit	
Number of caribou on the breeding ground	15,369	2615.9	17.0%	9,913	20,826
Number of adult females	13,265	2359.5	17.8%	8,308	18,222
Proportion adult females in the entire herd	0.671	0.0112	1.7%		
Total population estimate	19,769	3531.8	17.9%	12,349	27,189

Comparison of estimates of herd size

The applicability of the adult female-based herd size estimator depends greatly upon the extent of the survey (to estimate all adult females) as well as the degree of aggregation of adults during the given survey year. It is likely that it is less applicable to some survey years given that the Bathurst herd has been less aggregated relative to survey efforts. Figure 23 compares estimates using the adult female and pregnancy rate-based estimates for 2006, 2009, 2012 and 2015 (Gunn et al. 2005, Nishi et al. 2007, Nishi et al. 2010, Boulanger et al. 2014b). It can be seen that the pregnancy-rate based estimator was higher in 2006, 2009 and 2012 and then lower than the adult female-based estimate in 2015. For the June 2015 Bathurst survey, we suggest the estimate of 19,769 is the more appropriate estimate of caribou at least 1.5 years old or older in the herd.

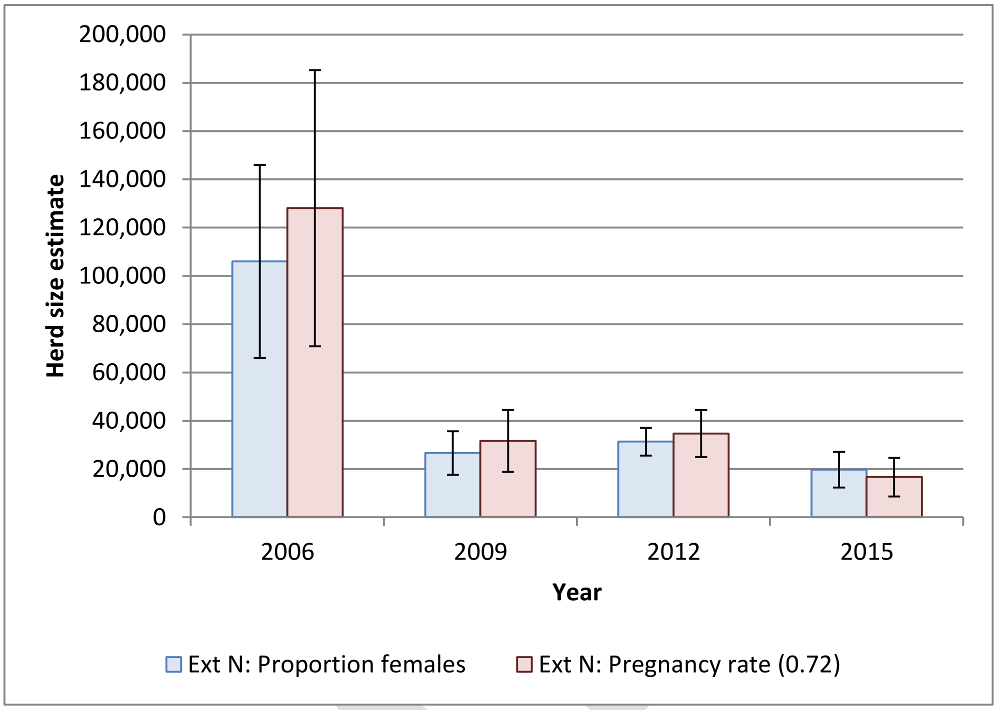

Figure 23: Extrapolated herd estimates using the pregnancy rate and adult female based estimation methods for 2009, 2012, and 2015.

There are a few potential reasons for the differences between pregnancy-based and adult female-based extrapolated herd estimates (beyond simple sampling variation). First, pregnancy rate was higher in 2006, 2009 and 2012 and therefore the pregnancy-rate based estimates were less likely to be negatively biased due to differences between the fixed pregnancy rate (0.72) and actual pregnancy rate. Second, it is likely that the degree of aggregation of caribou relative to the calving ground has increased from 2006 to 2015. For example, 93% (n=14 collared females)(Nishi et al. 2007), 81.8% (n=11 collared females), 83.3% (n=18), and 100% (n=31) of collared females were contained within survey strata for the 2006, 2009, 2012, and 2015 calving ground surveys. If the collars represent distribution of females overall then it is more likely that the majority of adult females were contained within the survey strata in 2015 compared to other years which would reduce bias with the adult female based extrapolation method. The evaluation of adult female distribution on the calving ground based on collared females is compromised by low sample sizes of collared caribou (especially for surveys prior to 2012).

Trends in indicators of herd status

<u>Trends in calving ground size and location</u>

The core calving area used by the Bathurst herd was reduced in size from comparison of survey extents in 2009 2012, and 2015 (Figure 24). The core area was reduced further in 2015 compared to 2012 especially when the highly aggregated nature of caribou in the 2015 photo stratum is considered (Figure 19). The core area has also shifted slightly eastward.

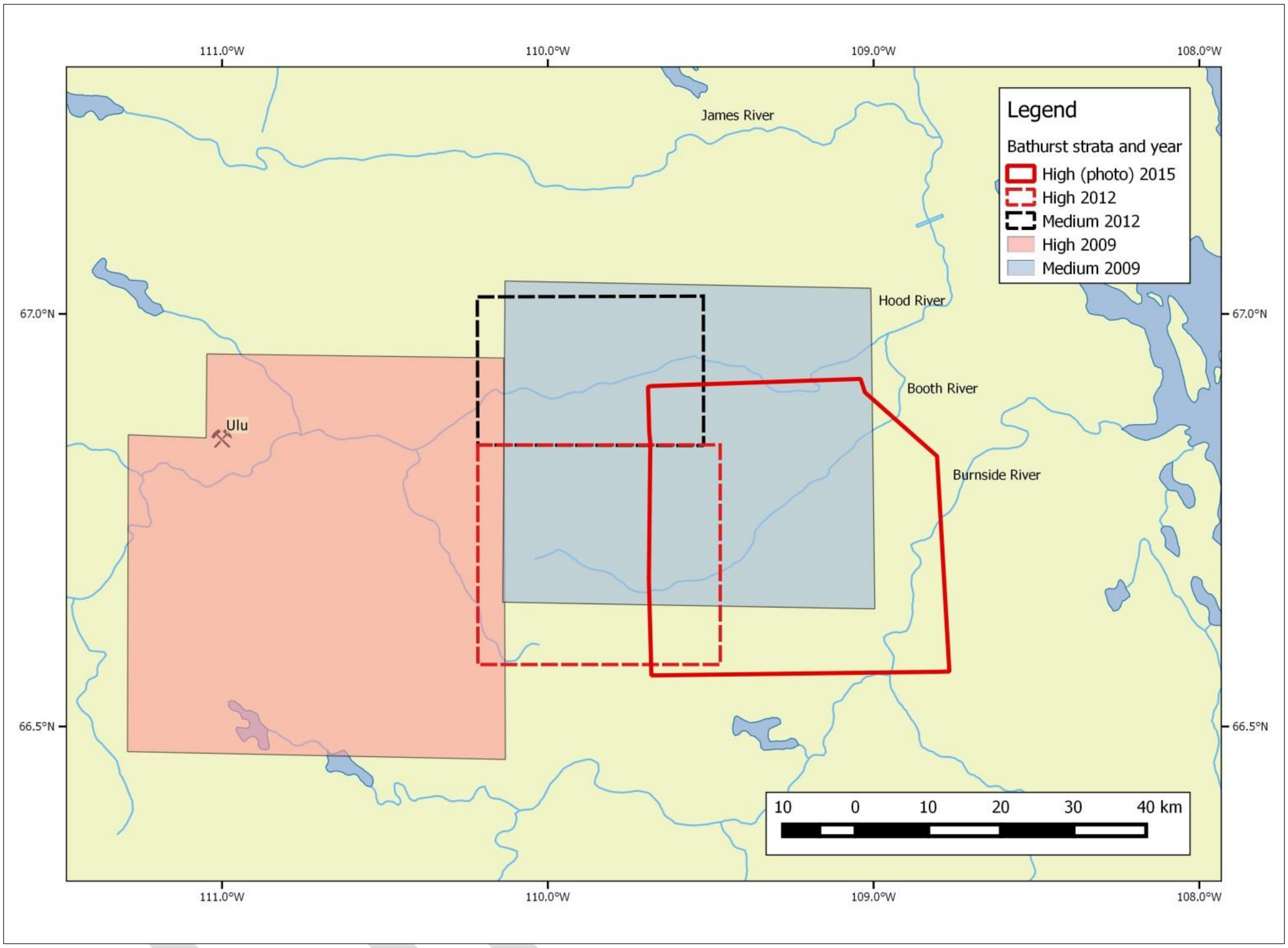

Figure 24: Location and relative size of calving grounds as defined by photo strata from 2009 to 2015

Overall, the relative size of the Bathurst calving ground has decreased substantially since 2006 as detailed further in Boulanger et al. (2014c). The size of the 2015 core calving area, as defined by the photo stratum, was roughly similar to previous calving grounds (Figure 25).

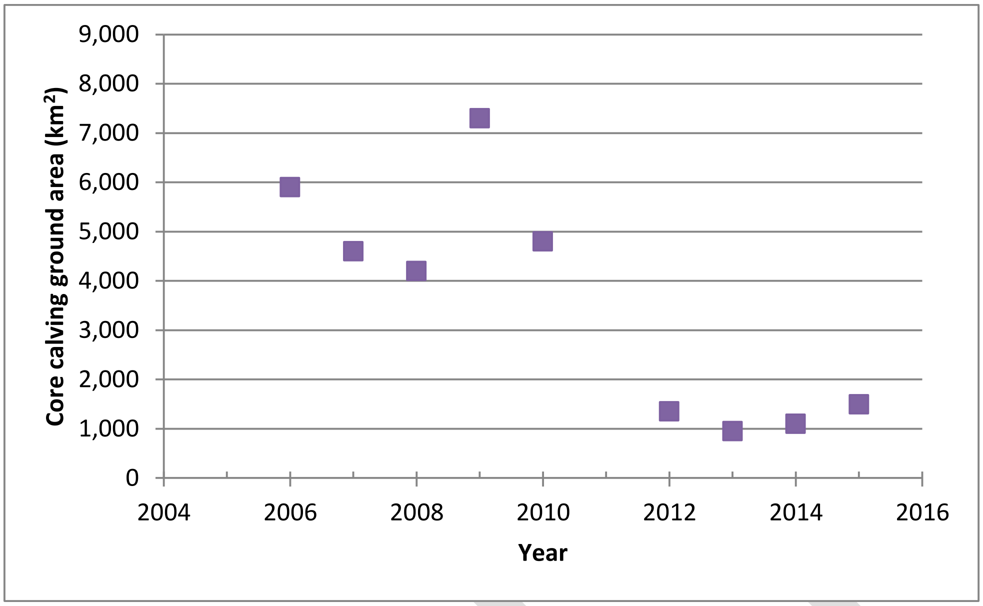

Figure 25: Relative size of the core Bathurst calving ground area as defined by areas where breeding caribou were detected (Boulanger et al. 2014c). The photo stratum area, where the majority of breeding caribou were present, was used for the 2015 data point.

Trends in adult and breeding females

The estimate of breeding females appeared to stabilize 2009-2012 with a further reduction as indicated in the 2015 survey estimate (Figure 26). The most pertinent question for 2015 is if the apparent decline from 2012 is significant and how it compares to previous estimates.

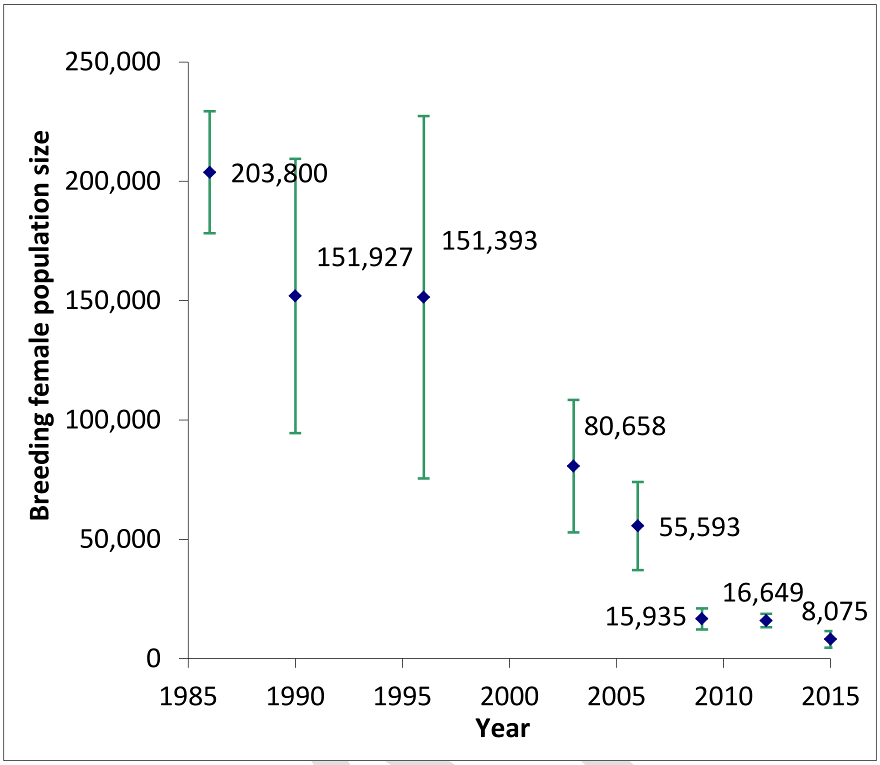

Figure 26: Estimates of breeding females in the Bathurst herd from 1986 to 2015.

A comparison of the breeding female estimate with estimates from the 2009 survey (Nishi et al. 2010) and 2012 survey (Boulanger et al. 2014b) shows a decline in breeding females since the 2012 survey (Figure 27). Despite slightly lower precision of the 2015 estimate, the difference in estimates is significant as indicated by non-overlap of confidence limits (t=3.62, df=38, p=0.0009).

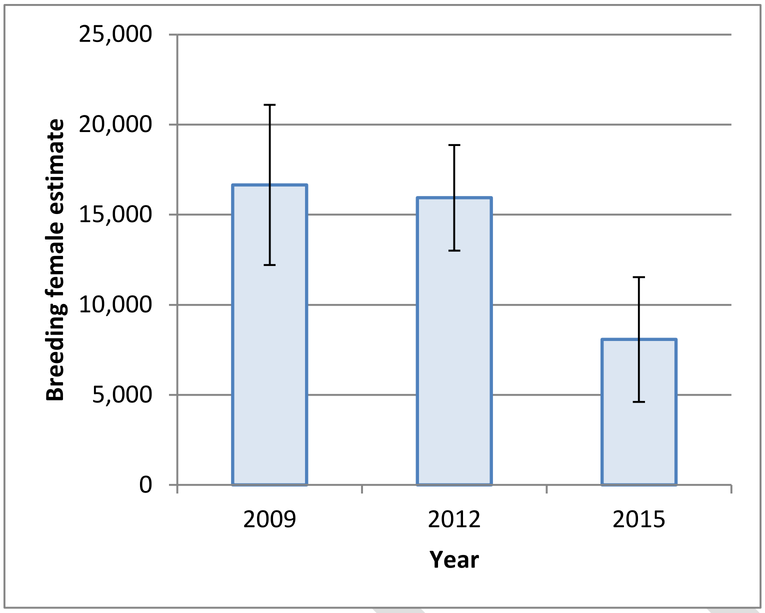

Figure 27: Comparison of 2015 breeding female estimate with estimates from the 2009 and 2012 calving ground surveys.

One important point to note is that the proportion of adult females that were breeding was lower in 2015 compared to previous surveys, which potentially further reduced breeding female estimates (Figure 28). Using estimates of total adult females (Table 13), it can be seen that the rate of decline in adult females is less than the rate of decline in breeding females and that there was a higher proportion of non-breeding females in 2015 compared to 2009 and 2012. The difference in the 2012 and 2015 adult female estimates is marginally significant (t=2.31, df=35,p=0.027).

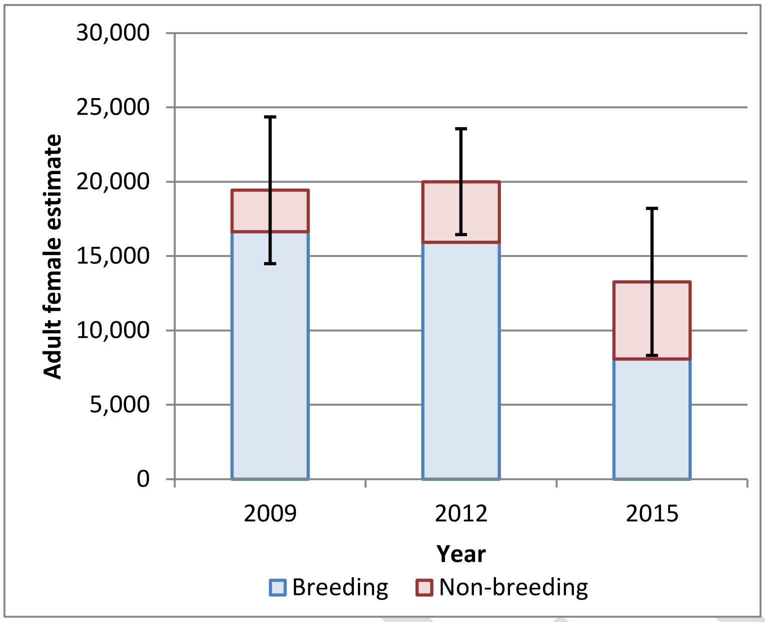

Figure 28: Estimates of total adult females subdivided by breeding status for 2009, 2012, and 2015. Confidence limits are for the total adult female estimate.

<u>Weighted regression</u>

The main question addressed with regression analysis was whether the overall trend in breeding females and adult females between 2012 and 2015 was significantly different than the trend since 2009, when the previous large-scale decline 2006-2009 was substantially reduced. Analyses were run for both breeding females and adult females.

For breeding females a model with separate slopes for 2009-2012 and 2012-2015 was more supported than a model that assumed a similar slope (ΔAIC=2.6) with resulting estimates of λ for 2009-2012 of 0.99 (CI=89-1.09) and 0.80 (CI=0.69-0.92) for 2012 and 2015. Both the 2009-12 and 2012-5 slope terms were significant in the weighted regression analysis (Table 18). The λ estimate for 2012-5 can be expressed as a rate of decline (1-λ) of 20% (CI=8-31%).

For adult females, which will be less influenced by differences in the proportion of females breeding, a model with the same slope for 2009 to 2015 was more supported than a model with separate slopes for 2009-12 and 2012-15 (ΔAICc=0.53). The estimate of overall slope for 2009 to 2015 was 0.95 (CI=0.89-1.02). The model with separate slopes was also supported by the data with λ estimates of 1.01 (CI=0.91-1.11) and 0.87 (CI=0.77-0.99) for 2009-2012 and 2012-2015 respectively. The estimate of the 2012-5 slope term was significant in the weighted regression analysis (Table 18). The lambda estimate for 2012-5 can be expressed as a rate of decline (1-λ) of 13% (CI=1-23%). We suggest that the adult female based estimate of decline is a better estimate of decline for the 2012-2015 interval. Table 18 provides estimates from the entire analysis including estimates of per-capita growth rate(*r*=ln(λ)).

Table 18: A summary of estimates of annual rates of population change from weighted regression analysis including significance tests for model terms.

Metric	Annual finite (λ)			Per-capita(*r*)				
Interval	λ	Conf. limit		r	Conf. Limit		χ^2	p(χ^2)
<u>Breeding females</u>								
2009-12	0.99	0.89	1.09	-0.01	-0.12	0.09	0.07	0.795
2012-15	0.80	0.69	0.92	-0.23	-0.37	-0.08	9.32	0.002
2009-2015	0.91	0.85	0.98	-0.09	-0.17	-0.02	5.72	0.017
<u>Adult females</u>								
2009-12	1.01	0.91	1.11	0.01	-0.09	0.11	0.04	0.846
2012-15	0.87	0.77	0.99	-0.14	-0.26	-0.01	4.33	0.037
2009-2015	0.95	0.89	1.02	-0.05	-0.12	0.02	1.91	0.167

<u>Comparison of photo survey to reconnaissance-based estimates of trend</u>

Reconnaissance surveys have been conducted annually on the Bathurst calving ground to determine relative status between years when photo surveys occur (Boulanger et al. 2014c). The estimate of caribou on the core calving ground from reconnaissance surveys also indicated a lower number of caribou in 2014 and 2015 (Figure 29). These reconnaissance estimates will contain breeding and non-breeding (bull, yearlings) caribou and therefore the best estimate of trend is from breeding females or adult females from photo and composition surveys. The estimate from photo surveys in Figure 29 is for total caribou in the core strata including non-breeders and should not be confused with the extrapolated herd estimates.

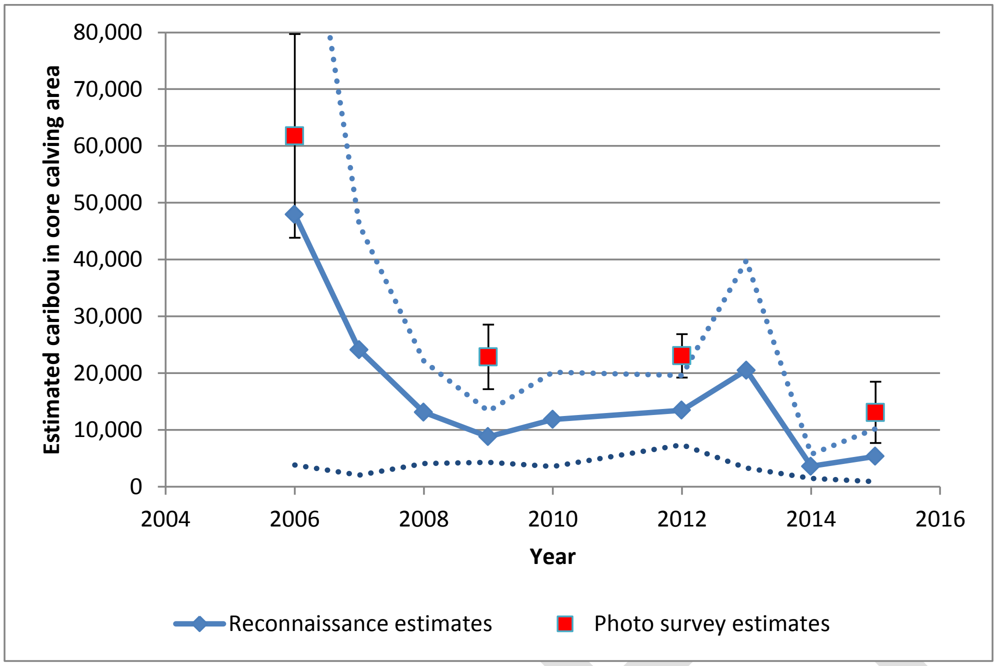

Figure 29: Trends in reconnaissance survey estimates of caribou on the core calving ground (Boulanger et al. 2014c) in comparison to the 2015 estimates. Estimates from the photo plane from surveys in 2006, 2009, 2012 and 2015 with confidence limits are shown for comparison as red squares. Confidence limits on reconnaissance survey estimates are given as dashed lines. The upper confidence limit for the 2006 reconnaissance survey estimate (119,161) is not shown.

Exploration of potential reasons for decline of the Bathurst caribou herd

Analysis of movements to other calving grounds

We assessed movements of collared cows between the Bathurst, Bluenose East, and Beverly-Ahiak caribou calving grounds from 2008 to 2015 determine if a significant number of female caribou switched calving grounds between years. The sample size of caribou for this analysis was the number of caribou monitored for 2 or more consecutive years so that fidelity to calving grounds could be assessed (Table 19). Note that this sample size will be lower than the actual number of collars for these herds, as the overall data sets will include collared caribou for which the accumulated tracking is shorter.

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

Year	Bluenose East	Bathurst	Beverly and Ahiak
2008	17	3	20
2009	17	7	23
2010	28	16	23
2011	23	10	13
2012	30	15	13
2013	26	10	11
2014	24	14	24
2015	19	13	22

Frequencies of movement events were assessed for caribou monitored for consecutive years and tabulated (Figure 30). For example, of caribou monitored 2 or more years in the Bathurst herd, 49 of them returned to the Bathurst calving ground in successive years. Two switched to the Bluenose East calving ground (in 2011 and 2013) and one switched to the Beverly and Ahiak calving ground (in 2009). Of caribou in the Beverly and Ahiak herd, one switched to the Bathurst (in 2010). Of caribou in the Bluenose East herd, one switched to the Bathurst herd calving ground (in 2010). Caribou showed fidelity to the Bluenose East and Beverly and Ahiak calving grounds (by returning back to the calving ground in successive years) 114 and 91 times respectively from 2008 to 2015.

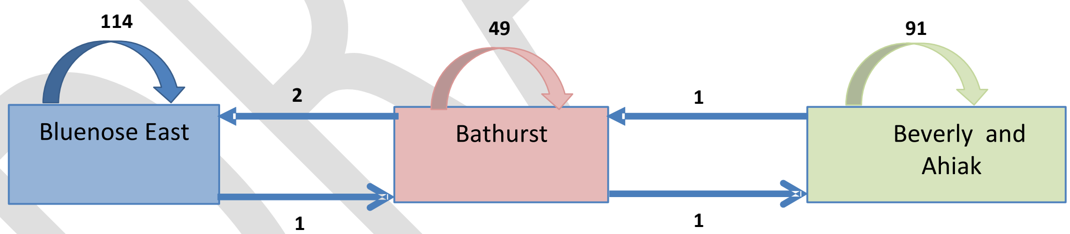

Figure 30: Frequencies of caribou movement events from 2008 to 2015 based on locations on calving grounds. The arrows above the boxes indicated the number of times a caribou returned to each calving ground for successive years. The arrows indicate movement of caribou to other calving grounds.

The main conclusion from this summary is that switching of cow caribou between calving grounds as estimated by collars is a rare event and cannot explain large changes in abundance of any of the three herds considered. More substantive multi-strata analyses have been conducted for past Bathurst survey data (Boulanger et al. 2011, Boulanger et al. 2014b) with similar conclusions. Davison et al. (2014) assessed rates of switching and fidelity in the Tuktoyaktuk Peninsula, Cape Bathurst, Bluenose-West and Bluenose-East herds based on collared cows 2005-2013 and found a similar low rate of 3.6% of cows switching (thus 96.4% fidelity) for these herds, with the low rates of switching between neighbours essentially canceling each other out.

Survival rate estimates from collared caribou

Survival rate estimates were obtained from collared caribou for input into the OLS demographic model. Sample sizes for 2007 up to June 2015, which was most applicable to the OLS model analysis ,varied from 7 to 32 collared caribou with a mean monthly sample size of 14.63 (std=2.65, n=96 months) collared females. Overall, the cumulative sample size of female caribou monitored from 2007-2015 was 108 caribou. Yearly estimates from this analysis are given as part of the demographic model results.

Analysis of demography using multiple data sources

Twenty nine field measurements were compared to OLS model predictions for the demographic modeling exercise. Initial model building focused on building a parsimonious model to explain variation in productivity (calf survival and fecundity) (Table 20). A year-specific calf survival model (Model 5) was more supported than polynomial trend calf survival models (Model 10). Model 5 estimated yearly calf survival with the exception of 2011 and 2012 which were pooled given missing spring calf-cow ratio data for 2013 (which would reflect calf survival from the 2012 calving ground). A model with a linear trend in proportion females breeding (fecundity; Model 1) was more supported than a model that assumed constant fecundity (Model 7). Using this model as a baseline, trends in adult female and adult male survival were tested with none of the trend models (Models 2,4,5, and 8) showing support from the data.

Table 20: AICc model selection for demographic analysis of Bathurst data (2007-2015). 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). A constant model assumed the parameter was constant from 2007-15. Twenty nine field estimates were used for model fitting and AIC_c calculations.

No	Calf survival (S_c)	Fecundity (F_a)	Cow survival (S_f)	Bull survival (S_m)	AIC_c	ΔAIC_c	w_i	K	∑Penalties
1	Year[A]	T	constant	constant	139.2	0	0.92	14	81.2
2	Year[A]	T	constant	T	144.9	5.7	0.05	15	78.0
3	Year[A]	$T+T^2$	constant	constant	148.1	8.9	0.01	15	81.2
4	Year[A]	T	T	constant	147.6	8.4	0.01	15	80.7
5	Year[A]	T	T	T	155.3	16.1	0.00	16	78.0
6	Year[A]	T	$T+T^2$	constant	157.4	18.2	0.00	16	80.0
7	Year[A]	constant	constant	constant	174.3	35.1	0.00	13	124.0
8	Year[A]	constant	T	constant	181.9	42.8	0.00	14	123.9
9	Year[A]	T	Year	constant	220.7	81.5	0.00	20	75.6
10	$T+T^2+T^3$	T	constant	constant	242.5	103.4	0.00	10	210.3
11	T	T	constant	constant	249.7	110.5	0.00	8	226.5
12	constant	T	constant	constant	280.5	141.3	0.00	7	261.1
13	constant	constant	constant	constant	629.3	490.1	0.00	6	613.4

[A]This models estimated yearly specific rates except for calf survival in 2012 which was assumed to be equal to 2011

Adult female survival was estimated as 0.78 (CI=0.76-0.80) from model 1 (Table 20). Yearling survival was estimated also at 0.78, adult male survival at 0.69 (CI=0.67-0.71). Calf survival and proportion females breeding (fecundity) varied yearly with subsequent yearly variation in productivity which is the product of fecundity and calf survival (Figure 32.

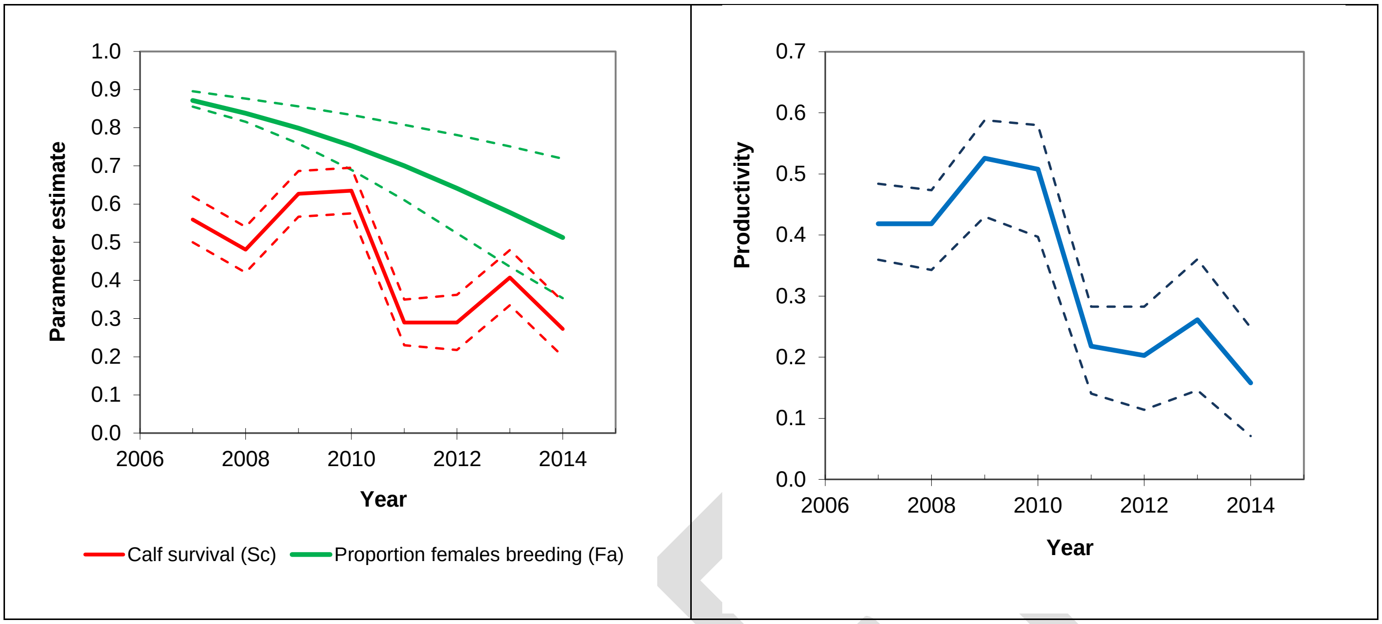

Figure 31: Estimate of demographic parameters from the most supported OLS model (Table 20, model 1). Productivity is the product of calf survival and fecundity. Confidence limits (95%) are given as dashed lines.

Comparison of field estimates and OLS model predictions suggested reasonable model fit with OLS predictions occurring within the confidence limits of field estimates in most cases (Figure 32). Naïve interpretation of collar-based survival estimates suggested a reduction, then an increase in survival rates. However, these estimates were based on low sample sizes of collared caribou and as a result the estimates were imprecise. Given this, a quadratic OLS model, which would fit this trend, was not supported (Table 20, Model 6). The OLS estimate of constant survival was within the confidence limits of collar-based estimates for all years except 2011 and 2012 (where it was close to the upper limit). In addition, the OLS model fit the overall trajectory of breeding female estimates with a constant level of survival.

A declining trend in proportion of females breeding is suggested by the OLS analysis based upon reduction in both calf-cow ratios and observed proportions of females breeding on the calving ground. Note that the proportion of females breeding estimated for the OLS model excluded yearlings and bulls and therefore was different (higher) than proportion breeding females on the calving ground used for breeding female estimates (Table 11) as detailed in Boulanger et al (2012). One assumption in this case is a directional trend in proportional females breeding so that it decreases evenly between calving ground surveys. The proportion females breeding is estimated with information from calf-cow ratios as well as estimates of proportion females breeding from the calving ground. Both of these field indicators suggest decreasing productivity from 2012 to 2015.

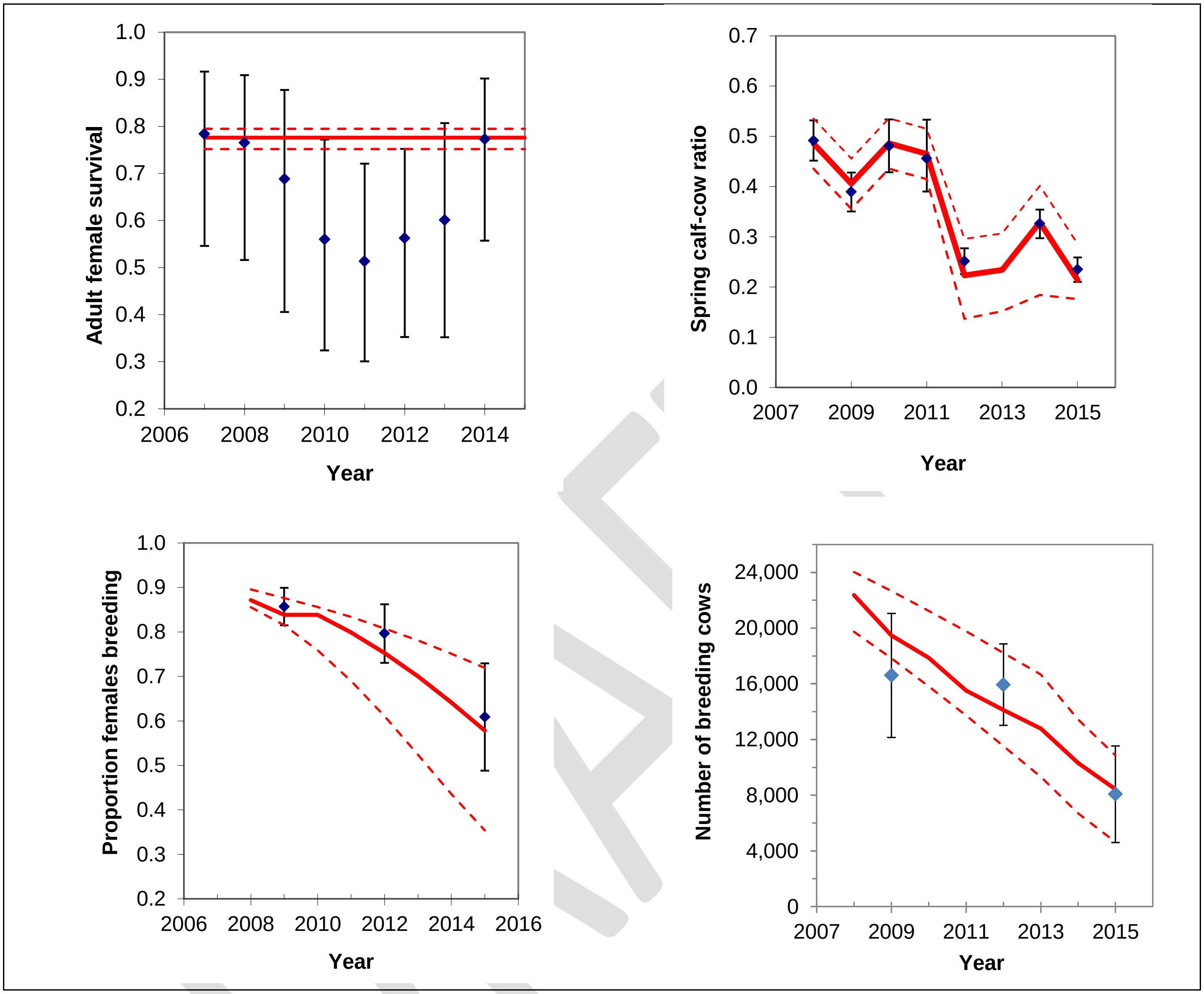

Figure 32: Estimates of adult female survival (from collared caribou), spring calf-cow ratios (from March composition surveys), proportion females breeding and breeding cow (female) population size estimates (from calving ground surveys). OLS model predictions are given as red lines (from Model 1, Table 20). Confidence limits (95%) are given as dashed red lines.

OLS model predictions suggest a declining trend (λ=0.79) from 2013-2015 in breeding female numbers which is similar to the estimate from weighted regression of field estimates (0.80; Table 18). The estimates of breeding females from the OLS model fall well within the confidence limits of the breeding female estimates from the 2009, 2012, and 2015 surveys (Figure 32). The estimate of trend in adult females from the OLS model (λ=0.86) for 2013-2015 was similar to weighted regression estimate based of 0.87 (Table 18). In both cases, the overall trend from adult females is higher than the trend from breeding females due to lower proportions of females breeding in 2014-5.

The bull:cow ratio increased then plateaued over the duration of the study (Figure 33). This was presumably due to higher levels of productivity up to 2010 followed by reduced productivity, as explored further later in the report (Figure 35). The OLS model-predicted fall calf:cow ratios displayed a similar trend to the spring calf:cow ratio. A calf:cow ratio from the fall of 2008 was not included (0.32) because its value was lower than the corresponding spring 2009 calf:cow ratio (0.39). This value was not likely given that the proportion of calves should decrease and not increase over the winter. This value created model-fitting issues with the OLS model and therefore it was excluded from the analysis. One potential reason for the increase in the calf-cow ratio was cow hunting mortality during the winter inflating the calf cow ratio. Previous analysis in the 2012 calving ground survey report (Boulanger et al 2014b) indicated that likely levels of hunting would not cause this magnitude of increase or substantial bias in OLS model estimates.

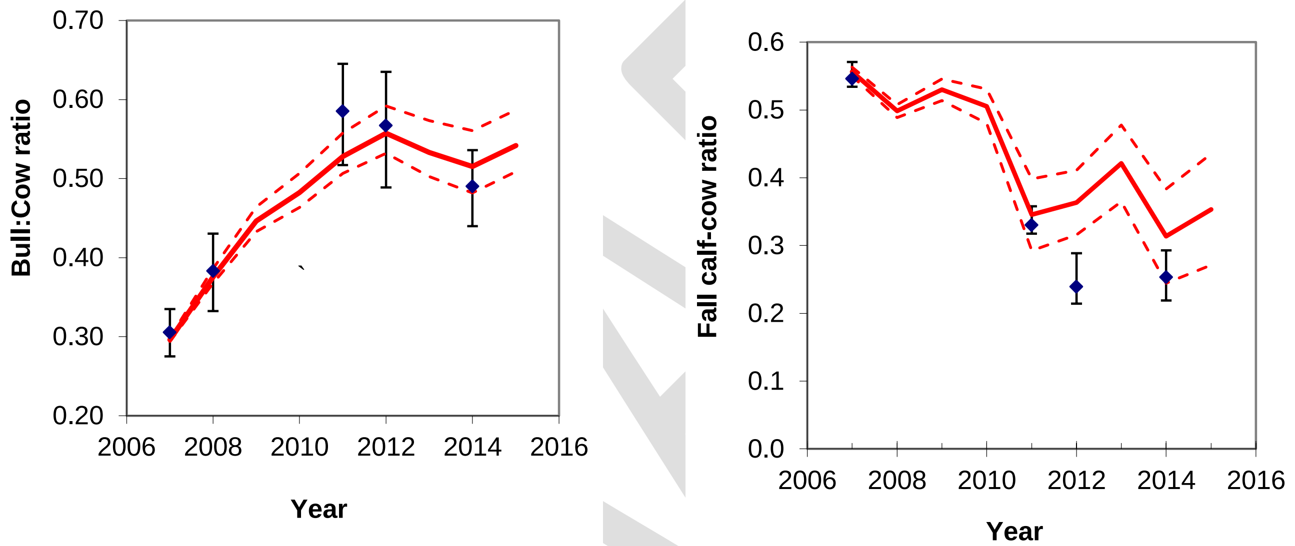

Figure 33: Estimates of bull cow ratios and fall calf-cow ratios from fall composition surveys from Model 1 (Table 20). The 2008 fall calf-cow ratio was not included into the analysis due to potential bias issues with this measurement. OLS model predictions are given as red lines. Confidence limits (95%) are given as dashed red lines.

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

Abundance estimates for each of the age classes in the demographic model suggested a decline for adult females, calves and yearlings, but a more stable trend for bulls followed by a decrease (Figure 34). The number of yearlings was low from 2012 to 2015 which means that few caribou are being recruited in to the cow and bull age classes.

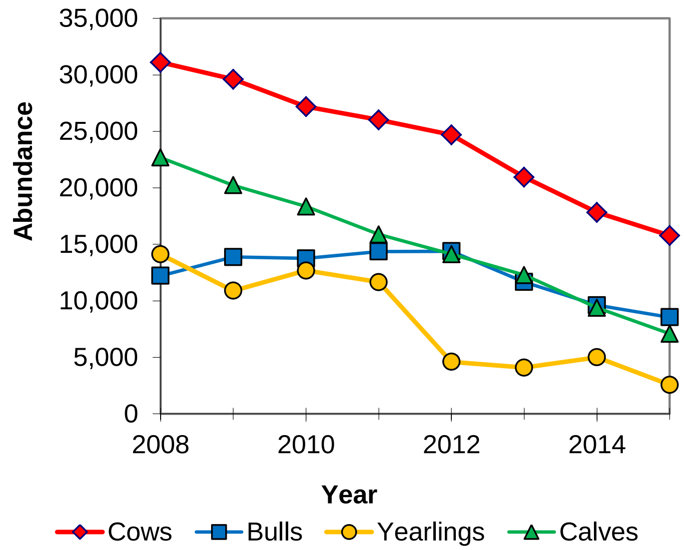

Figure 34: Estimates of abundance for each age-sex class from the most supported OLS model (Model 1, Table 20)

The increase in bulls may seem counterintuitive; however, the reason for this is that the amount of recruitment of yearlings into the bull segment was relatively high compared to the actual size of the bull population and subsequent level of bull mortality (Figure 35). In contrast, the recruitment of yearlings into the female segment, which is larger, was relatively low compared to the level of mortality (Figure 35). Thus, the bull segment of the population had a net gain (recruitment>mortality) up to 2011, whereas adult cows had a net loss (mortality>recruitment) across all years.

The estimated trends in bull and cow abundance (Figure 35) explained the increase in the bull:cow ratio observed in fall composition surveys (Figure 33). In general, an increasing bull:cow ratio is associated with improving population trend. But in the case of this analysis, the predicted OLS model increase in the bull:cow ratio, was partially due to a *decrease* in cow abundance with a more stable trend in bull abundance from 2008-12 (Figure 33). The increase in the bull:cow ratio of the Bathurst herd in this context further highlights why data from age ratios should be interpreted cautiously (Harris et al. 2007).

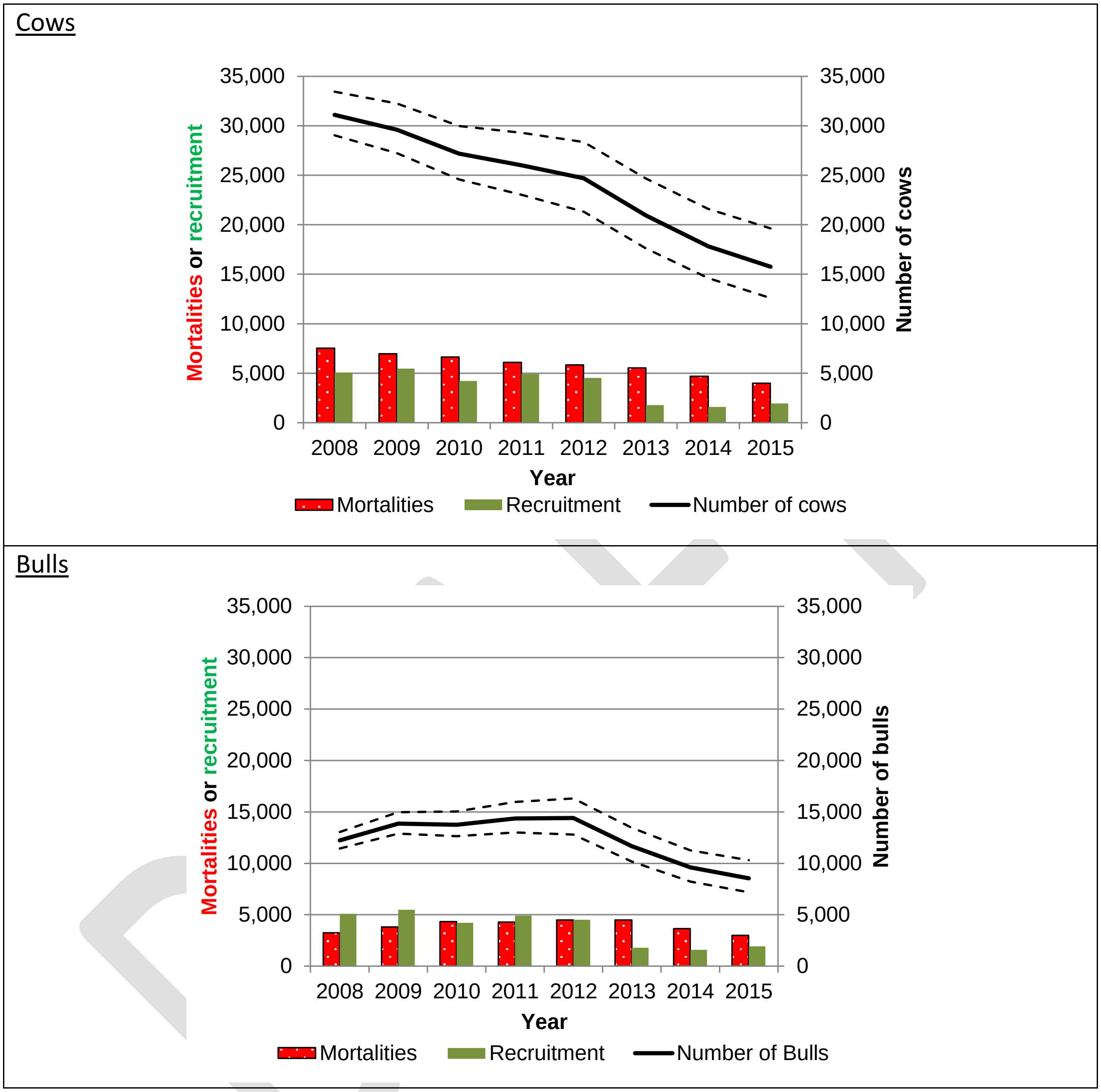

Figure 35: The estimated relative number of adult cows (upper plot) and bulls (lower plot) compared to estimated mortalities and recruitment into the bull and cow age class from the most supported OLS model (Model 1, Table 20). Confidence limits on bull and cow abundance estimates are given as dashed lines.

In summary, the OLS model analysis suggests that the most likely level for adult female survival in 2015 is similar to that estimated from the 2012 calving ground survey (Boulanger et al. 2014b) and is still lower than that needed for a stable herd. Regardless, we can conclude the adult cow survival has increased to about 0.78 since the level estimated for 2009 from the 1986-2009 analysis of 0.67 (Boulanger et al. 2011). However, the continued lower level of adult female survival combined with low productivity has resulted in a continued decline in overall herd size.

Discussion

General results

The general results of this analysis shows the Bathurst herd has declined since the previous survey in 2012 (Figure 25). The rate of decline as estimated by breeding females is higher than the rate of decline in adult females due to lower pregnancy rates in 2014 affecting the proportion of breeding females observed on the calving ground in 2015 (Figure 28). The rate of decline for adult females was 13% per year (CI=3-22%) from 2013-5 in contrast to a rate of decline of breeding females of 20% per year (CI=3 to 20%) for the 2013-5 period. Using adult females as a measure of overall herd status assumes that all adult females (breeding and non-breeding) were in the surveyed areas for all of the years considered. Switching of caribou between calving grounds was minimal for the Bathurst and the neighboring herds, suggesting that movement to other calving grounds is not a likely explanation for changes in numbers of caribou observed on the Bathurst calving ground.

Analysis of demography of the Bathurst herd using multiple data sources suggests that the observed decline in herd size is due to a lower adult female survival rate (0.78, CI=0.76-0.80) combined with relatively low productivity of the herd after 2010 (Figure 31), which reduced the number of female caribou recruiting to become breeding females (Figure 32). Low observed productivity levels after 2011 are of special concern given that the result will be lower levels of recruitment to the breeding female cohort (Figures 35) to offset lower adult female survival rates. As a result, the immediate prognosis for the herd is a continued decline unless adult female survival rates increase.

The demographic decline of the Bathurst herd was also suggested in analyses conducted during the 2012 calving ground survey report (Boulanger et al. 2014b). In this case the demographic model estimated a decline in the population trajectory that still fell within the confidence limits of the breeding female estimates; that is, there may have been a decline 2009-2012 that was not apparent from the actual survey estimates. It was for this reason that the Bathurst herd status was suggested to be “fragile” and deserving of careful and conservative management in 2012.

We note that the current estimate of adult female survival of 0.78 is higher than the estimated survival rate of 0.67 after the larger scale decline of the herd from 2006-2009 (Boulanger et al. 2011). Prior to the 2009 survey (Nishi et al. 2010), harvest levels of up to 3,000-5000 cows and 1,000-2,000 bulls were occurring on an annual basis (Adamczewski et al. 2009, Boulanger et al. 2011). If this harvest level had continued it is likely that the number of breeding females would have been less than 9,000 for the 2012 survey (Figure 28). It is likely that one reason for the increase in survival rate since 2009 is the reduction of harvest pressure. However, the adult survival rate is still not at levels estimated in 1986 (0.85) or high enough to allow stabilization and recovery of the herd.

The Bathurst calving ground was relatively small in 2015 compared to the 2009 survey and slightly smaller than the 2012 survey area (Figure 25). The high degree of aggregation within the 2015 calving ground was quite striking. For example, the relatively small size of the 2015 core area resulted in only one photo stratum (area of

1492 km^2) compared to two photo strata in 2012. Densities in the photo stratum in 2012 were 23.1 and 3.0 caribou per km^2 compared to a mean density of 8.76 caribou per km^2 in 2015. Inspection of segment densities (Figure 20) revealed relatively high densities of caribou within the 2015 photo stratum with an abrupt transition to areas of low or no caribou in surrounding areas. The composition data also revealed a sharp transition from breeding caribou in the core area to non-breeders in peripheral areas (Figure 22). This pattern may reflect an attempt to maintain the benefits of gregarious calving despite the much reduced numbers of cows in the herd; Griffith et al. (2002) demonstrated that calves in the Porcupine herd born in the interior of large groups of cows tended to survive at higher rates than calves in smaller groups or on the periphery of large groups.

The high levels of aggregation of caribou on the 2015 calving ground also created challenges to our ability to sample caribou on the calving ground especially in the reconnaissance and allocation phase of the survey. For example, despite relatively tight line spacing of 5 kilometers during the reconnaissance phase, only 2 segments of higher density of caribou were detected, of which 1 was based on a single group of caribou in the north stratum (Figure 12) and only one density segment was defined in the area of highest density of caribou (Figure 20). When populations are aggregated in a small area, it becomes more likely that larger groups of caribou will be detected on very few survey lines, reducing certainty and estimate precision. The effect of aggregation can also be seen in the photo survey results where only 4 of 20 lines detected caribou densities of over 10 caribou per km^2. To address this, we suggest that future surveys use an adaptive sampling design where the core area is first surveyed at 5 kilometer spacing. Once higher density segments are detected then the areas in the proximity of these should be surveyed at 2.5 kilometer spacing. This approach should ensure that core densities are sampled more adequately, which should allow for better reconnaissance estimates as well as more information to allow more precise stratification of photo strata.

The recent decline in proportion of females breeding could be due to reduced female condition due to poor summer range conditions (Chen et al. 2014) especially during the summer of 2014 which experienced low precipitation and high temperatures. In addition, variation in age structure of the adult female segment of the herd can create variation in reproductive rates (Dauphin'e 1976, Boulanger et al. 2011). Ongoing demographic analyses are being conducted to further assess the linkage between environmental covariates and caribou demography.

Interpretation of breeding female estimates.

The main target population for the calving ground surveys is 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 potential time lags between the production of calves and recruitment of these calves into the breeding female segment. In general, it takes females 1-3 years to mature and be capable of producing calves and most commonly females first have high pregnancy rates at 2.5 years of age (Bergerud et al. 2008). The actual pregnancy rate of yearlings has been shown to vary by herd. Dependent on whether the herd is increasing, stable or decreasing ,pregnancy rates of yearlings can vary from 2% (Qamanirjuaq, 1966

(Dauphin'e 1976)) to 48% (George River Herd 1976-82; (Bergerud et al. 2008)). Regardless, until a female caribou matures, it is not counted as a breeding female. Therefore, trends of breeding females will not reflect productivity events that occurred in the previous 1-3 years dependent on pregnancy rates of yearlings, 2 year olds and 3 year olds. However, current trends in breeding females will reflect productivity for 2011 and year's prior as well as relative survival rates for adult females up to the survey (Table 21). This is of great interest given that reduced survival of females was a primary cause for the rapid decline in breeding female population size that occurred between 2006 and 2009 (Adamczewski et al. 2009, Boulanger et al. 2011).

Table 21: A hypothetical timeline for a female calf born in 2011. Given that caribou do not breed until they are 2-3 years old the 2015 estimate of breeding females mainly reflects recruitment events that occurred in 2011 and years before. Pregnancy rates are based upon Dauphine (1976) and Bergerud et al (2008).

Group	Year				
	2011	2012	2013	2014	2015
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%*)

Estimates of extrapolated herd size

We adopted a new method to estimate extrapolated herd size based on adult females rather than using an assumed pregnancy rate. The reason for use of this estimator was increased variation in pregnancy rate in the 2015 survey (lower) compared to previous surveys, making it unlikely that estimates with an assumed constant pregnancy rate were unbiased and accurate. This estimator was developed during the 2014 Qamanirjuaq survey where similar lower pregnancy rates were observed (Campbell et al. 2016). This estimator assumes that all adult female caribou (breeders and non-breeders) as classified in composition surveys occurred within the core calving area as delineated by the survey strata. It does not make any assumptions about the distribution of yearling or bull caribou. The distribution of female collared caribou observed in 2015 suggests that this assumption was reasonable given that all of the 31 collared females were contained within the survey strata (Figure 13). It is more difficult to conclusively evaluate this assumption for previous years given lower sample sizes of collared female caribou. The direct estimate of adult females in the survey area (Table 13) of 13,265 (CI=8,308-18,222) is higher than an estimate based on breeding females (8,075, CI=4,608-11,542) divided by the assumed pregnancy rate 11,215 (±5361) caribou further suggesting that the actual pregnancy rate of the herd was lower than the assumed 0.72 level. As a result, the extrapolated estimate (adult females divided by proportion adult females in the herd from composition surveys) using the direct estimate of adult females (19,679, CI=12,349-27,189) is higher than the assumed pregnancy rate-based estimate (16,714, CI=8,703-24,725). Given this, we suggest the adult female-based estimate is most applicable for 2015. We note that estimates from both methods indicate a decline in herd size compared to 2012 estimates to less than 20,000 1.5+ year old caribou (Figure 23).

We do not suggest the adult female-based extrapolation method is as applicable to previous (pre 2006) survey data where the herd was much more dispersed over larger areas and therefore less likely to meet the assumption of all adult females being within the surveyed area. Low sample sizes of collared females in past surveys also challenge the testing of the assumption that all adult females are within the surveyed area. Future analyses will provide more comparison of the different extrapolation methods using past survey data.

Management Implications and Recommendations

The results of the 2015 survey indicate that the herd size has decreased since the 2012 survey. Further analysis of the demographic data suggests that the population of breeding females is “fragile” with estimated adult female survival rates still below levels needed for herd stability or levels estimated in the 1980’s. Of extra concern are recent levels of low productivity as indicated by spring calf-cow ratios since 2012. Unless these indicators change substantially in the near future, the herd is likely to decline further in the next few years. The herd in 2015 has declined by about 96% from peak numbers in 1986. Given these results, we make the following recommendations.

1. The herd’s ability to stabilize and increase depends most on breeding cows surviving in large numbers and producing calves, thus a very conservative approach to management, including harvest, would give the herd the best opportunity to recover.
2. One challenge of interpreting the demographics of the Bathurst caribou herd is imprecise survival rates from collared caribou given that in most years only 20 or less caribou have been collared. Low sample sizes of collared caribou also make it more difficult to delineate different herds on winter ranges. Given this, we suggest maintaining and considering an increase in the number of collared caribou for the Bathurst herd.
3. Continued monitoring of the number of breeding cows on the calving ground via annual reconnaissance surveys should occur with an emphasis on recommendations made in (Boulanger 2011) to strive for adequate precision. In addition, spring composition surveys should continue on an annual basis to monitor relative recruitment. An increased effort to assess annual pregnancy rates, e.g. via collection of fecal samples in late winter, should be considered.
4. The photo-survey of the calving ground should be repeated in 2018 to allow for rigorous assessment of population size and trend.

The future trend of the Bathurst herd is difficult to predict accurately, as migratory barren-ground caribou herds do not always return to high numbers on a predictable cycle, nor do they necessarily return to the same peak numbers (Bergerud et al. 2008). The Bathurst herd faces other stressors in 2015 and 2016, including climate change and the cumulative effects of development. A cautious overall approach to management of harvest and other human influences on this herd will provide this herd with its best opportunity to recover to larger numbers and higher productivity.

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Appendices

Appendix 1: Details on double observer estimation methods

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

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

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

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

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).

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

Estimates of herd size and associated variance were estimated using the mark-recapture distance sampling (MRDS) package (Laake et al. 2012) in program R program (R_Development_Core_Team 2009). In MRDS, a full independence removal estimator which models sightability using only double observer information (Laake et al. 2008a, Laake et al. 2008b) was used therefore making it possible to derive double observer strip transect estimates. For this component, program DISTANCE (Buckland et al. 1993, Thomas et al. 2009) was initially used to input data into program MRDS. Strata-specific variance estimates were calculated using the formulas of (Innes et al. 2002). Estimates from MRDS were cross checked with strip transect estimates (that assume sightability=1) using the formulas of Jolly (1969) as well as double observer estimates based on beta parameters in program MARK. Strip widths were adjusted for the Northern stratum given that it was flown at a lower altitude.

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