An Estimate of Breeding Females and Analyses of Demographics For The Bathurst Herd of Barren-ground Caribou: 2012 Calving Ground Photographic Survey

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ABSTRACT

We conducted a calving ground photo survey of the Bathurst barren-ground caribou (*Rangifer tarandus groenlandicus*) herd from 3-8 June, 2012. 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 or not the herd had stabilized from the steep decline documented in the 2009 survey. Consistent with previous calving ground photographic survey methods, data from collared caribou and systematic reconnaissance surveys at ten km intervals in the calving ground 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. Unlike previous surveys, transect surveys were conducted at 5 km instead of 10 km intervals in the core calving area. Reconnaissance surveys revealed that the majority of breeding caribou were congregated in a relatively small (914 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 occurred on or about 5 June, 2012 and the photo plane survey was conducted on 6 June. Photo plane survey effort (transect spacing) was stratified into high and medium density blocks with the highest coverage (79.1%) in the high density stratum where the majority of breeding caribou were. The higher level of coverage allowed an adequate number of lines (22) to be placed in the stratum as a means of offsetting potential variance caused by clumped distribution of caribou. Survey conditions were ideal with zero cloud cover, minimal winds and minimal snow cover. Two lower density strata were also surveyed with visual strip-transect methods. Ground-based composition surveys were conducted from 6-8 June to estimate the proportion of breeding caribou in each of the strata. Survey results revealed that 87.4% of caribou on the core calving ground were within the high density stratum (914 km^2) with 8% occurring in the medium density stratum (644 km^2) and the rest in the two low density strata. The estimate of 1+ yr old caribou on the core calving ground was 24,166 (SE=1,853.6, CI=20,310-28,020) caribou. Using the results of the ground composition survey to adjust this number for breeding females, the estimate of breeding females was 15,935 (SE=1,407.2, CI=13,009-18,861). The estimate of breeding females was very precise with a coefficient of variation (CV) of 8.8%. Comparison of this estimate with the previous estimate of breeding females from 2009 of 16,649 (SE=2,181, 95% CI=12,188-21,110) suggests that the breeding female segment of the herd declined slightly, though not significantly. The rate of decline was much lower than between the 2006 and 2009 calving ground surveys. Results from a data-driven demographic modeling exercise suggest that adult female survival rate was 0.78 (CI range 0.75-0.82) in 2012, which is still below levels needed for a stable herd. A conservative bull-dominated harvest strategy with minimal cow harvest is recommended to minimize adult cow mortality. An increase in the number of radio collars on the herd would greatly assist in managing and monitoring this herd, including more reliable estimates of adult female survival rate.

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INTRODUCTION

The Bathurst caribou herd of barren ground caribou (*Rangifer tarandus groenlandicus*) was named based on its calving ground documented west of Bathurst Inlet since the mid-1990s (Sutherland and Gunn 1996). The Bathurst herd ranges from Bathurst Inlet with the calving range within Nunavut, summer range straddling the border between Nunavut and the Northwest Territories (NWT) and winter range in NWT 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.

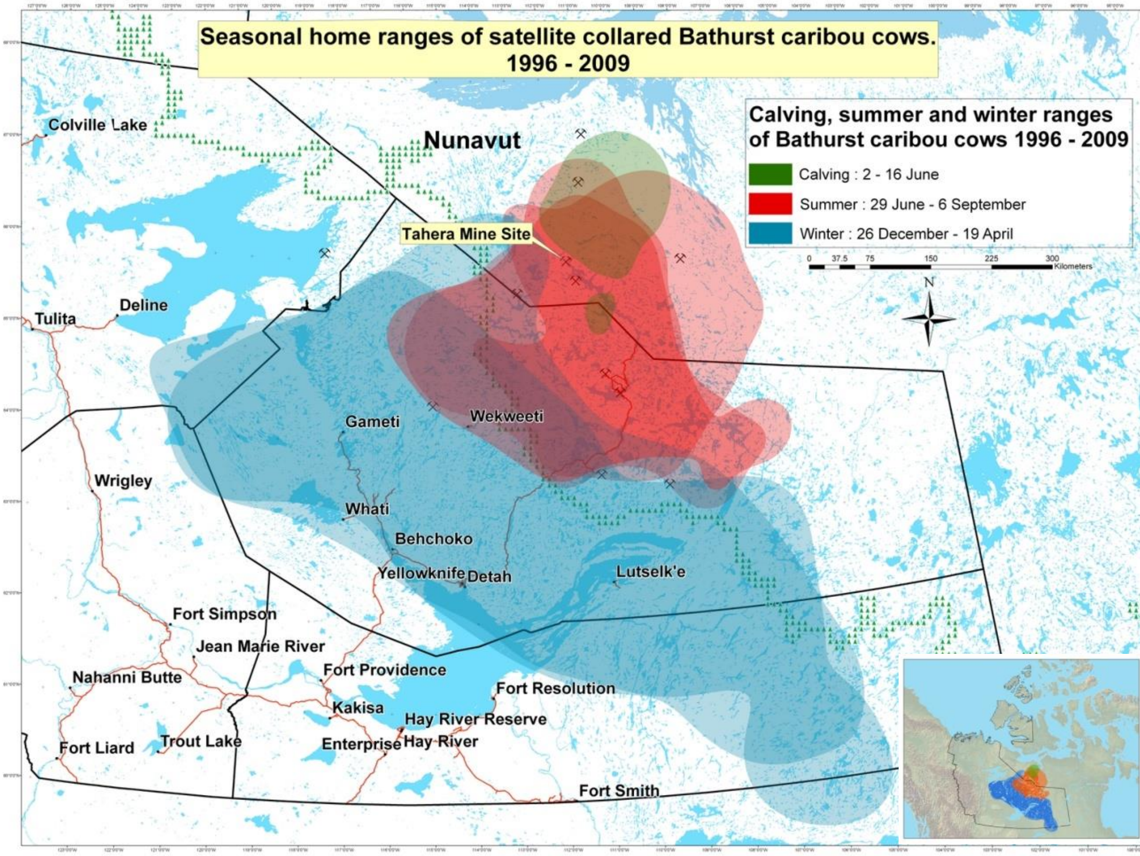

Figure 1: Calving, summer and winter ranges of the Bathurst herd, 1996-2009, based on accumulated radio collar locations of cows. Ranges were delineated using Kernel home range (Worton 1989) smoothing of seasonal radio collared cow locations (Nagy et al. 2011). The location of the Bathurst range relative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

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).

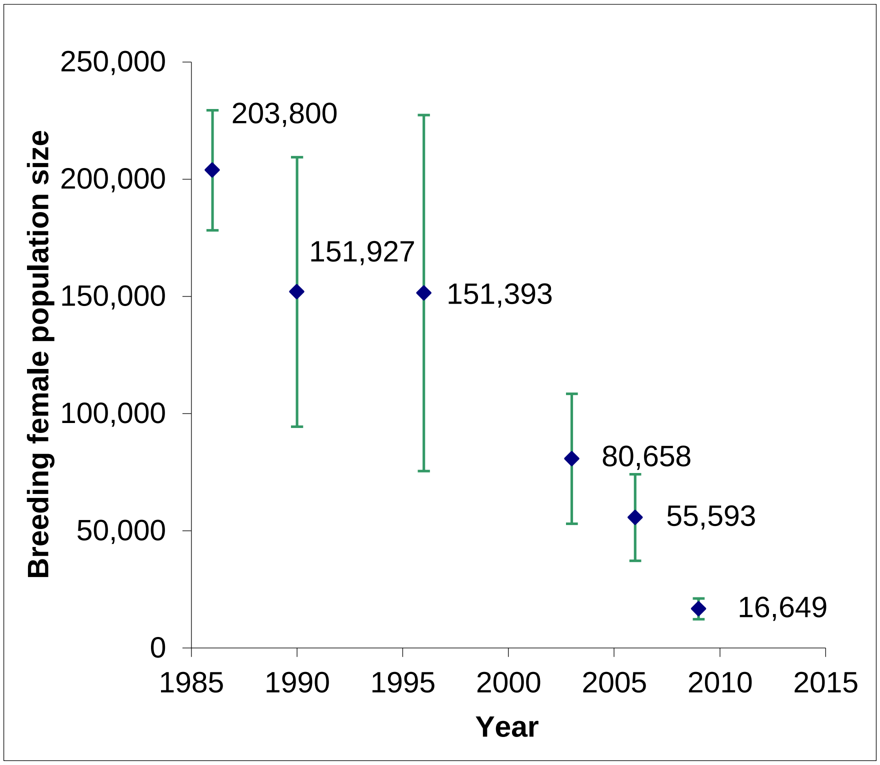

Figure 2: Trends of breeding female estimates for the Bathurst herd from 1986-2009.

This report presents estimates of breeding females and associated herd size for the Bathurst caribou herd from a calving ground survey conducted from 3-8 June 2012. 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). Therefore, 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 stabilization or potential herd recovery since the last survey in 2009.

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 in 10 km intervals were flown to determine areas where breeding females were concentrated (5 km intervals in the high density areas), 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.
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 ground-based composition survey was conducted using a helicopter that landed repeatedly within each stratum to determine the proportion of breeding caribou.

6. Using the estimate of total caribou within the strata and the estimate of proportion of breeding females within the strata, an estimate of breeding females was derived.
7. The breeding female estimate 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. In general, caribou movement rates are reduced to less than 5 km/day during the peak of calving and for an interval after calving (Gunn et al. 1997, Nishi et al. 2007, Gunn et al. 2008, Gunn and Russell 2008, Nishi et al. 2010). Status of calving was also verified on 3 June shortly after arrival at the base camp by flying the core calving area and by observing the proportion of cows with calves. This information was used to time the photo survey near the peak of calving, when caribou movement rates in the survey area would be lowest.

The relative dispersion of caribou, as indicated by successive minimum convex polygon areas (Mohr 1947), was also assessed to determine if caribou were clustered during the peak of calving compared to time periods immediately before or after calving. The minimum convex polygon method simply connects the outermost caribou locations to provide an index of the overall dispersion of caribou within the herd.

Reconnaissance surveys to delineate strata

As with previous surveys, visual transects were surveyed with 10 km spacing between lines in areas presumed to be the main calving area, as well as the surrounding areas. This resulted in survey ground coverage of 8% for the reconnaissance survey. As in 2009 (Nishi et al. 2010), the Tahera Mine was used to base survey operations (Figure 1). Two DeHavilland Turbo Beaver aircraft were used for surveys, each equipped with a radar altimeter to ensure consistent survey altitude. In visual surveys, caribou were counted within a 400 m strip on each side of the survey plane (800 m total, Gunn and Russell 2008). Strip width was defined by the wheel of the airplane on the inside and wooden doweling defined on the wing strut. Planes were flown at an average survey speed of 160 km/h at an average altitude of 120 m above the ground to ensure that the strip width of the plane remained constant.

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 communicated to ensure that groups of caribou were not double counted.

Caribou groups were classified by whether or not they contained breeding caribou. Breeding caribou were defined by female caribou with hard antlers or presence of calves. A female with 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. In most cases, each group was recorded individually, but in some cases groups were combined given that each plane only had a single data recorder. Data were recorded on a tablet computer by a single data recorder in the plane (Figure 3). As each data point was entered, a real-time GPS waypoint was generated, allowing geo-referencing of the survey data.

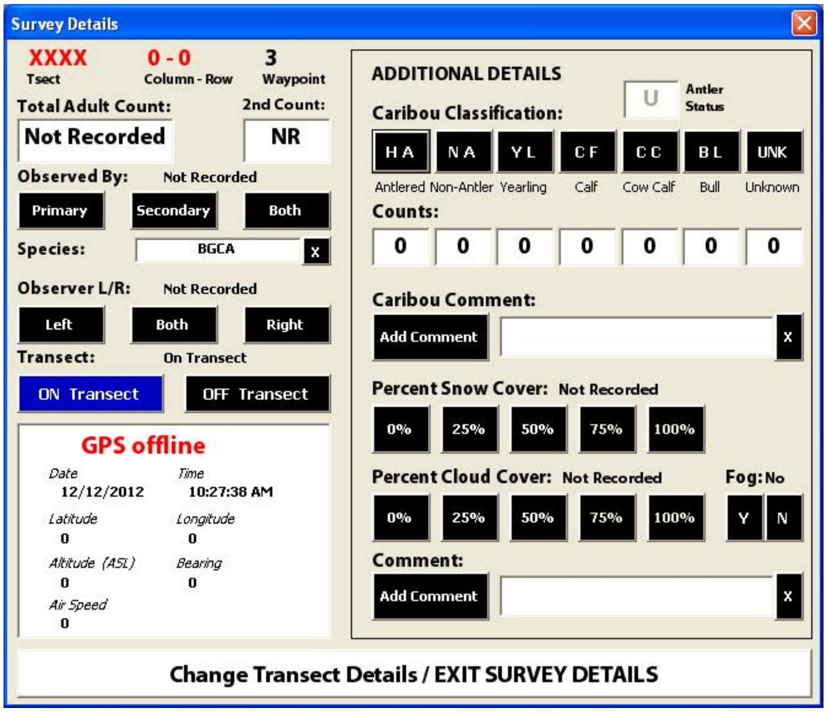

Figure 3: The tablet data entry screen used during reconnaissance surveys. A GPS waypoint was obtained for each observation, allowing efficient entry and management of survey data. In addition, the unique segment unit number was also assigned by the software for each observation to summarize caribou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

Transects were divided into 10 km north-south segments to summarize the distribution of geo-referenced caribou counts (Figures 3 and 10). The density of each segment was estimated by dividing the count of caribou by the survey area of the segment (0.8 km strip width x 10 km = 8 km^2). The segment was classified as a breeder segment if at least one breeding caribou was detected. Segments were then displayed spatially and used to delineate core calving ground strata based on the composition and density of the segments.

Unlike previous surveys, the core calving area, as indicated by higher densities of breeding caribou, was surveyed at 5 km 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 km transects was approximately 16%.

Areas that were to the far west and far east including points to the east of Bathurst Inlet were surveyed to ensure that no larger aggregations of breeding caribou were missed.

Stratification and allocation of survey effort

The main objective 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 neighbouring 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, with strata that had low densities being surveyed visually. Given that the objective of the survey was to estimate breeding females, only areas that contained breeding females were surveyed. Areas that contained non-breeders were not surveyed after initial reconnaissance since 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 in each stratum that would be sampled by the photo-plane, or visual estimate plane.

Two potential strategies for allocation were considered for the aerial survey. First, optimal allocation of survey effort was considered based on sampling theory (Heard 1987, Thompson 1992, Krebs 1998). Optimal allocation basically assigned more effort to strata with higher densities given that the amount of variation in counts is proportional to the relative density and size of caribou within the stratum. Optimal allocation was estimated using estimates of population size for each stratum and survey variance. In the case of this survey, enough photos were available to allow 2,405 km of photo surveys. In addition, it was determined that visual survey planes could survey 2,400 km of transects in a single day.

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 ten transects per stratum with closer to 20 transects being optimal for high density areas. In general, coverage should be at least 15% with higher levels of coverage for high density strata. In the context of sampling, increasing the number of lines in a stratum is “insurance” in that it minimizes the influence of any one line on estimate precision. As populations become more clustered, a higher number of transect lines is required to achieve adequate precision (Thompson 1992, Krebs 1998).

Estimation of caribou on the calving ground

For the photo strata, Geographic Air Survey Limited was contracted to fly aerial transects. They used a twin engine Aero-Commander aircraft with a camera mounted on the belly of the aircraft. The aircraft flew at an altitude of 1,100 m above the ground with altitude determined by a radar altimeter which resulted in photos at a scale of 1:4,000. Caribou detected on photos were counted by Derek Fisher, president of Green Link Forestry Inc., Edmonton, AB. The number of caribou counted was tallied by stratum and transect.

For visual surveys, the DeHavilland Turbo Beaver aircraft was used with two observers on each side of the aircraft and a data recorder on each side. The number of caribou sighted by observers was then entered into tablet computers and summarized by transect and stratum.

The counts of caribou by transect and stratum, the total survey area, the proportion of the stratum sampled and number of lines sampled were used to estimate the total number of caribou on each survey stratum using the formulas of Jolly (1969). The actual estimate of caribou in any given stratum is the total count of caribou seen on transects in the stratum divided by the proportional coverage of the stratum. Because calves were not counted, the estimate of caribou in each stratum pertained to 1+ yr old caribou. 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, a helicopter (ASTAR 350B2) from Great Slave Lake Helicopters was used to systematically survey groups of caribou allowing more in-depth classification of caribou by breeding status. Caribou groups were predominantly observed from the ground, with a few small groups classified from the air. 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 and bulls (Figure 4).

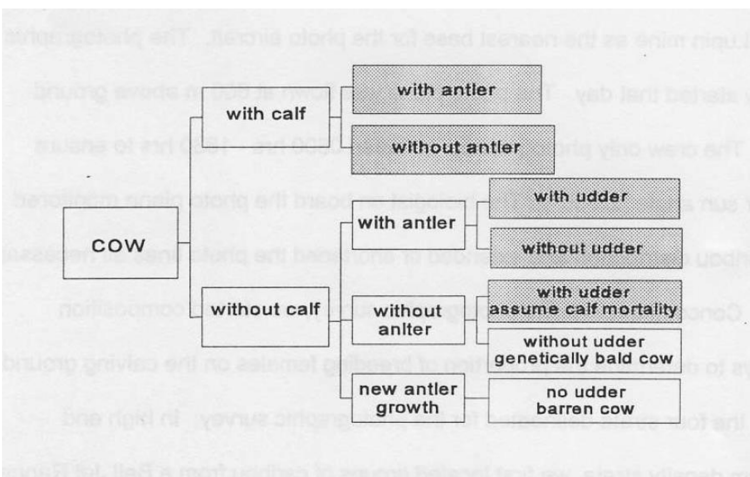

Figure 4: Classification of breeding females used in composition surveys. Shaded boxes were classified as breeding females [diagram from Gunn et al. (2005)].

The number of each group in Figure **2**4 was totalled as well as the number of bulls and yearlings (calves of the previous year) to estimate the proportion of breeding caribou on the calving ground. Bootstrap resampling methods (Manly 1997) were used to estimate proportions, standard errors and percentile-based confidence limits for the proportion of breeding caribou.

Estimation of breeding females

Breeding females were estimated by multiplying the estimate of total (1+ yr old) caribou on each stratum by the estimated proportion of breeding females in each stratum from composition surveys. This step basically eliminated the non-breeding females, yearlings and bulls from the estimate of total caribou on the calving ground. Each of these measurements has an associated variance and the delta method was used to estimate the total variance of breeding females under the assumption that the composition surveys and breeding female estimates were independent (Buckland et al. 1993).

Estimation of total herd size

Total herd size was estimated in a two-step process. First, the total number of adult (1.5+ yr old) females in the herd was estimated by dividing the estimate of breeding females on the calving ground by the assumed pregnancy rate of 0.72 [Dauphine (1976) and 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 2011 and 2012 to provide an estimate of total adult caribou in the herd (Heard and Williams 1991). Note that this estimate corresponds to adult caribou and will not include calves of the previous year that were yearlings on the calving ground. All of the estimates associated with herd size have standard errors and the delta method (Buckland et al. 1993) was used to combine variance for the entire herd estimate.

Trends in breeding females

The time series of 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. Two methods were used to assess trends.

Comparison of estimates with 2009 estimates

As an initial step, the 2012 estimate of breeding females was compared with the 2009 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. Two regression-based approaches were used to further explore trend.

Weighted regression

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.

The main question of interest in the regression analysis was whether the trend as indicated by the change from 2009 to 2012 was different than the longer-term trend indicated by previous analyses up to 2009. Previous analyses had indicated that the trend was negative and best described by a cubic polynomial term (Boulanger 2010). Hence, model building focused on comparison of the fit of this model to the newer data set compared to a model that had a breakpoint and new trend from 2009-2012. In addition, other linear and non-linear trend models were considered. The relative fit of models was evaluated using the sample-size-corrected Akaike Information Criterion (AIC_c) index of model fit (Burnham and Anderson 1998). The model with the lowest AIC_c score was considered the most parsimonious, optimizing the tradeoff between bias and precision (Burnham and Anderson 1998). The difference between any given model and the most supported (ΔAIC_c) was used to evaluate the relative fit of models when their AIC_c scores were similar. In general, any model with a ΔAIC_c score of ≤ 2 was considered to be supported by the data. Analyses were conducted with PROC GENMOD and PROC REG within SAS statistical package (SAS Institute 2000).

The population size was log transformed to partially account for the exponential nature of population change (Thompson 1998). 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 >1 indicate increasing and declining populations, respectively.

Monte Carlo simulation

We used a Monte Carlo simulation technique to provide an estimate of the variance in trend based on the breeding female estimates for each of the surveys (Manly 1997).

The basic question this simulation exercise asked was: "If these studies were repeated many times what would the estimated trends and associated variances be given the levels of precision of each of the individual surveys?" This analysis determined the maximal and most likely range of trend estimates that could be observed from this data set when the variance of each of the surveys was accounted for. The following procedure was used for simulations:

1. *The sampling procedure for each year was simulated using estimates of variance from each of the surveys*. The estimated mean and variance were used from each survey to generate random population sizes for each of the years of the survey. This is best explained in terms of confidence interval (CI) estimation. For a given estimate the 95% CI is the population estimate $\pm$ $t_{(\alpha=0.05,2,df)}$*SE. For each simulation a random *t*-distribution variate with associated degrees of freedom for each survey was generated. This random variate was then multiplied by the SE and added to the population estimate resulting in a random population size that followed the general probabilistic distribution of estimates. If done repeatedly, this procedure would create a distribution of estimates for each of the surveys that fell within the given CI. Formulas of Gasaway et al. (1986) were used to estimate degrees of freedom for *t*-statistics.

2. *The sampling procedure was simulated and trend estimates were estimated using regression analysis*. A random set of breeding female estimates were generated for each of the five sampling occasions using the process above and the parameters listed in Table 1. The most supported AIC_c regression model was used for estimation.

This procedure was repeated for 1,000 *pseudo* data sets that resulted in 1,000 estimates of trend.

3. *Estimates of trend from the pseudo data sets were analyzed.* Mean estimates and percentile-based CI based on successive changes in population size were estimated using the *pseudo* data sets.

Exploration of demographic factors influencing population trend

One of the most important questions 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) model 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 and 2012 breeding female estimates as well as calf:cow ratios, bull:cow ratios, estimates of proportion of breeding females, and adult female survival rates from collared caribou to estimate the *most likely adult female survival values* that would result in the observed trends in all of the demographic indicators for the Bathurst herd. The OLS model is a stage based model that divides caribou into three age classes with survival rates determining the proportion of each age class that makes it into the next age class (Figure 5). The details of this model are given in Boulanger et al. (2011).

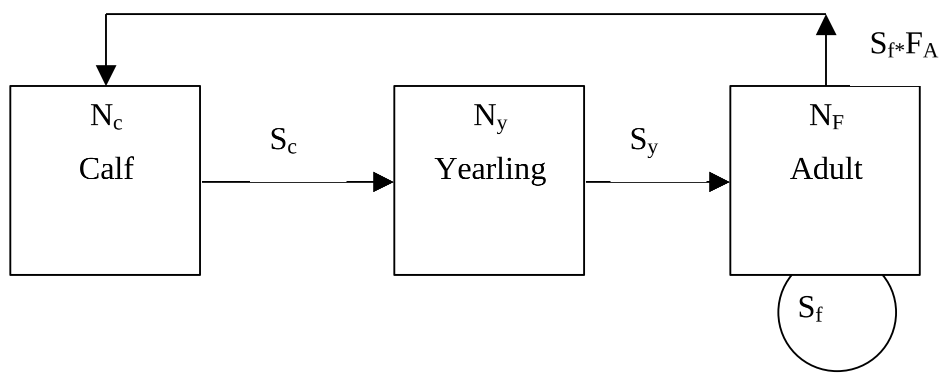

Figure 5: Underlying stage matrix life history diagram for the caribou demographic model. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (N_c), yearlings (N_y) and adult females (N_F). Each node is connected by survival rates of calves (S_c), yearlings (S_y) and adult females (S_f). Adult females reproduce dependent on fecundity (F_A) and whether a pregnant female survives to produce a calf (S_f). The male life history diagram was similar with no reproductive nodes.

An assumption of the OLS model is that net movement of Bathurst caribou to or from adjacent calving grounds (Bluenose-East and 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 using multi-state models (as detailed in Appendix 1), which found negligible net movement of radio collared caribou between adjacent calving grounds.

We restricted the data set for this exercise to survey results between 2007 and 2012. Using this approach ensured that past demographic values, that were recorded during the decline, 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 1). It was assumed that a 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 2007, 2008 and 2009 had the most direct bearing on the number of new breeding females on the calving ground that were not accounted for in the 2009 breeding female estimate. Calves born after 2009 would not have matured to be counted as breeding females and thus productivity for this time period was less relevant to the 2012 breeding female estimate.

Table 1: 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. The OLS model assumes that caribou are not capable of breeding in the fall rut until they are recruited into the adult class on the fall prior to the breeding ground survey. Productivity (calves born) in 2007-2009 had the most direct bearing on recruitment of breeding females counted on the 2012 survey (brown boxes). Calves born prior to 2007 were counted as breeding females in the 2009 survey and calves born after 2009 had not recruited into the breeding female segment and were therefore not counted. Surveys in 2006, 2009 and 2012 estimated breeding females.

Calf born	Status 2006	2007	2008	2009	2010	2011	2012
2006	calf	yearling	non-breeder	breeder	breeder	breeder	breeder
2007		calf	yearling	non-breeder	breeder	breeder	breeder
2008			calf	yearling	non-breeder	breeder	breeder
2009				calf	yearling	non-breeder	breeder
2010					calf	yearling	non-breeder
2011						calf	yearling
2012							calf

We used a sequential model building process where we first built a model that considered the dominant trends in productivity (calf survival) as indicated by calf:cow ratios. We then tested for trends in adult female survival and adult male survival. The main reason for testing the male survival models was to explore hypotheses regarding change in bull:cow ratios as opposed to a comprehensive analysis of male survival. Models were compared using information theoretic methods as for the breeding female trend analysis.

Estimates of adult female survival were then compared to levels of productivity to assess the demographic mechanisms for change in the relative numbers of breeding females. This same exercise was conducted for the bull segment of the population. Various adult female survival values were input into the most supported model to determine the relative influence of adult female survival on breeding female trend and on overall herd trend.

One potential bias in calf:cow ratios prior to 2009 was lowered over-winter survival of cows due to harvest after calves had weaned. In this case, the calf:cow ratio was potentially over-estimated as an estimate of productivity since the denominator (cow numbers) was reduced relative to the numerator (calf numbers). We conducted sensitivity analyses on this issue by considering models that estimated separate survival rates for the period prior to 2009 and by directly modeling the bias by introducing a term into calf:cow ratios that reduced adult survival rate, mimicking the potential bias.

While the OLS model uses the relative precision of field measurements as a means of weighting the influence of data sets in the model, it still is a deterministic population model. Thus the predictions of the model do not necessarily provide an assessment of uncertainty in OLS model prediction. We further considered how the OLS model predictions related to the point estimates of breeding female numbers, as well as the confidence limits of the breeding female estimate. This provided an indication of the range of adult female survival values that could occur within the range of the confidence limits of the 2012 breeding female estimate.

RESULTS

Survey conditions

Weather during the survey was ideal with temperatures between 10 and 20°C, low to moderate winds and minimal cloud cover. High temperatures prior to the survey resulted in low snow cover in the majority of the survey area compared to the 2009 survey. In general, snow cover was less than 5% (Figure 6) and sightability of caribou was optimal. The early spring was indicated by low snow cover as well as the Hood River being ice-free during the time of the survey.

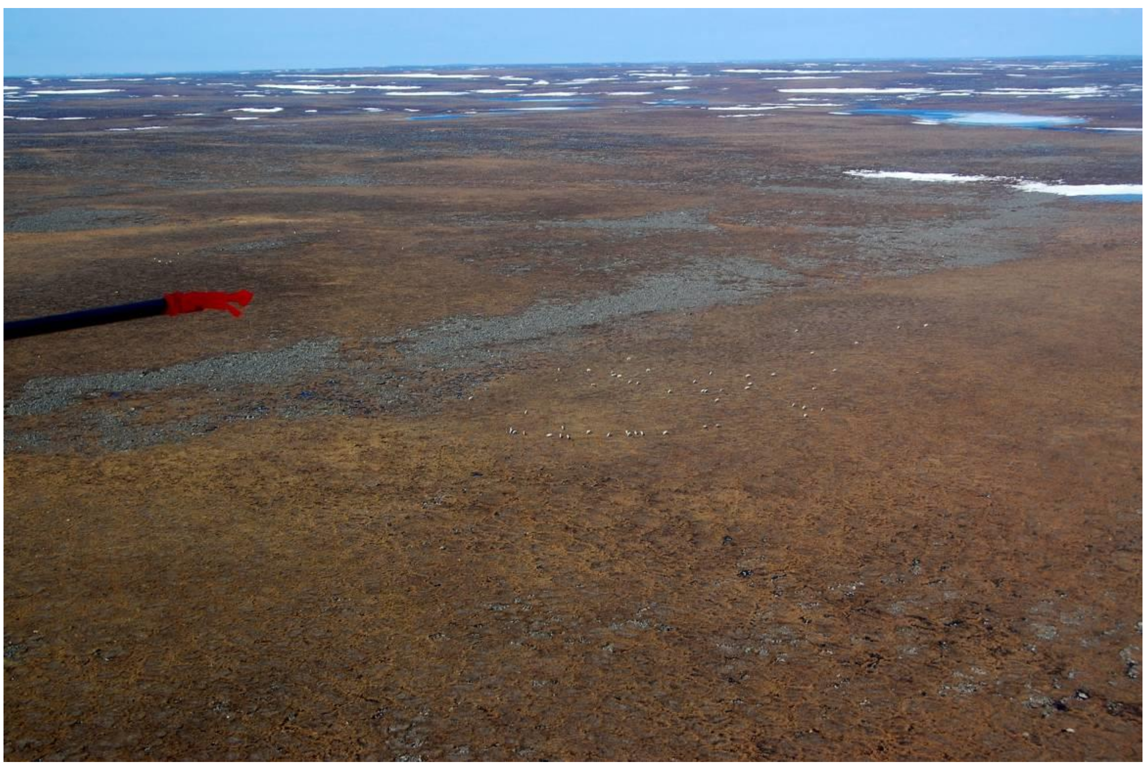

Figure 6: A group of caribou observed in the high density stratum on 5 June, 2012. In general, snow cover was minimal (<5%) for the core survey area with minimal cloud cover during surveys. The black-red bar is the survey strip marker.

Analysis of collared caribou data

Eighteen adult female caribou were tracked during the calving ground survey using GPS collars. The general path of movements to the calving ground was north-northeast (Figure 7). The date of arrival on the core calving area as delineated by crossing of latitude 66.4°N (which was the approximate southern boundary for survey strata in 2009 and 2011) for 17 of 19 collared caribou was 22 May, 2012. This contrasts with 2009 when 11 of 14 collared caribou did not pass this latitude until 2 June. We suspect that the early spring and snow melt improved travel conditions and led to a relatively early arrival of caribou on the calving ground.

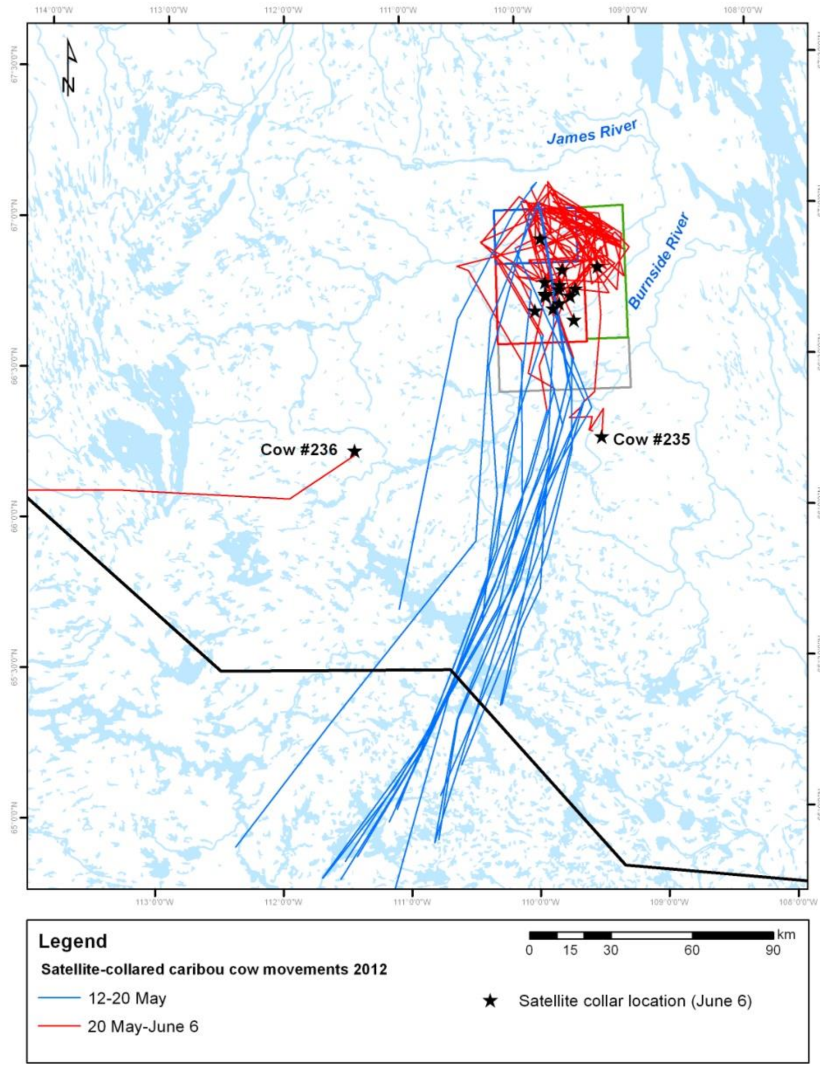

Figure 7: Movements of collared caribou to the calving ground area from 12 May to 6 June. Locations from 12-20 May are given as a blue line and locations from 21 May to 6 June are given as a red line. The location of caribou during the photo survey on 6 June is noted.

All collared caribou congregated in the core calving area except for a female that was approximately 17 km south of the core area (ID=235) and a female that was 58 km to the southwest (ID=236) (Figure 7). A survey plane flew in the general area of collared caribou 235 and spotted an isolated hard antler female caribou but did not detect any large congregations of breeding caribou or presence of calves. More exactly, no caribou were spotted on the segment closest to the collared caribou location and of the nine segments surrounding the location, only four hard antlered caribou were spotted (of 34 caribou seen total in the adjacent segments). Caribou 236 had arrived from the west in isolation from other collared caribou. Aerial survey in the vicinity of this caribou did not detect any clusters of breeding caribou and/or presence of calves. Both of these caribou appeared isolated from the main groups of breeding caribou to the north and were likely non-breeders.

Movement rate estimates (Figure 8) indicated that rates decreased until 5 June and stayed low until 13 June suggesting that the peak of calving started on 5 June with increased movement after 13 June which was likely when calves became more mobile.

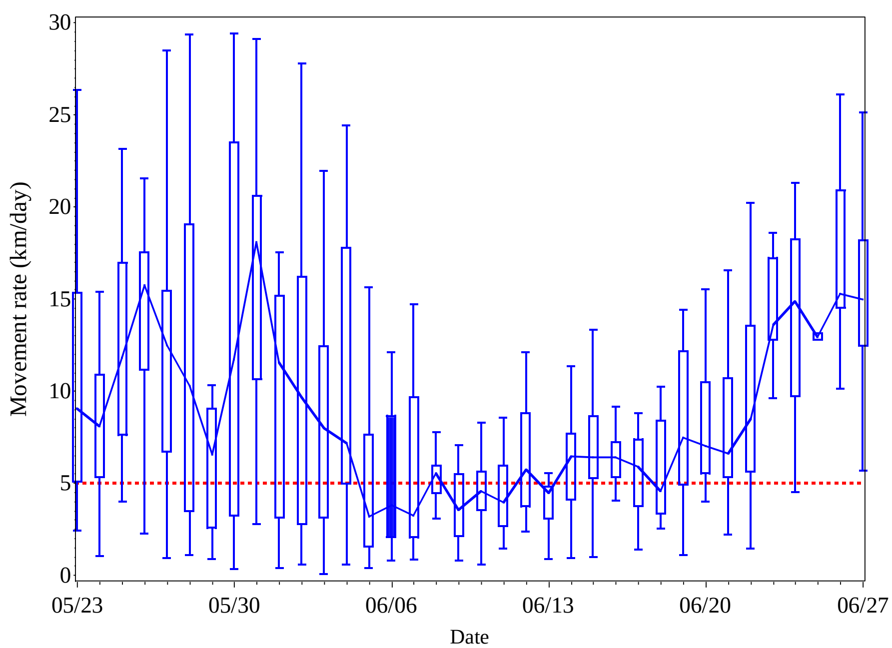

Figure 8: Movement rates (km/day) for Bathurst caribou before, during and after the calving ground survey. The distribution of movement rates is shown as box-plots with lines connecting median values, the boxes denote 25th and 75th percentiles and the whiskers denote the range of the data. The solid blue box indicates 6 June when the photo survey occurred.

A plot of minimum convex polygon area using locations of individual caribou by each date also revealed that the caribou congregated into a successively smaller area with the most notable decreases occurring in late May when caribou arrived into the vicinity of the calving ground (Figure 9). Areas were calculated with and without caribou 236 which was separated from the main group of collars and approached the calving ground from the west (Figure 9). On 6 June the core group of collared caribou (with caribou 236 excluded from the area estimate) were in an area of 1,050 km^2.

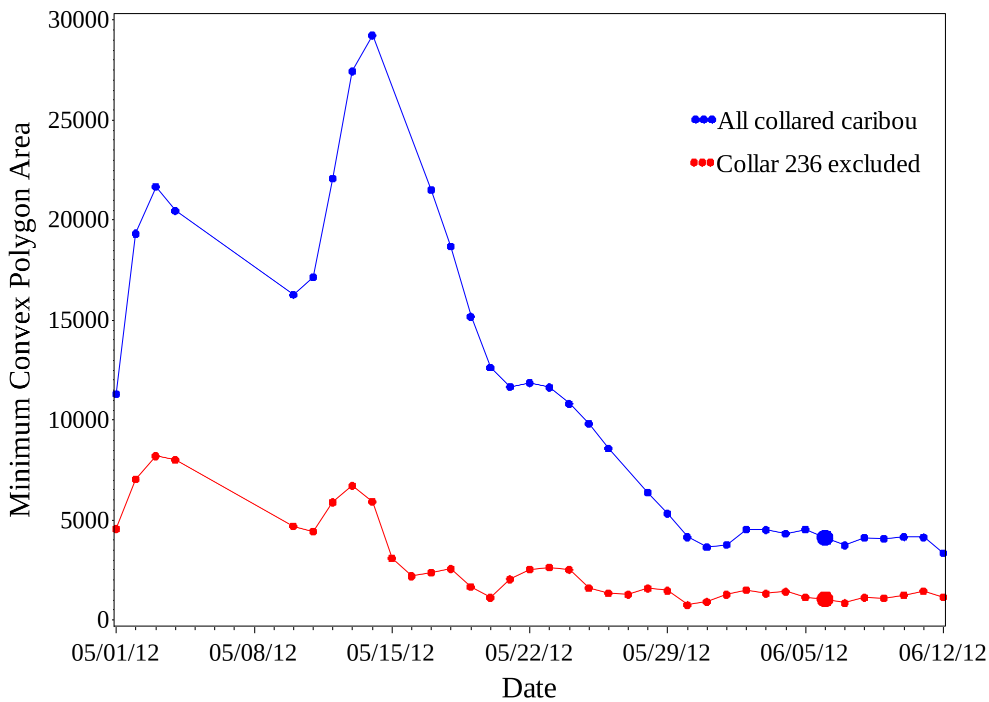

Figure 9: Minimum convex polygon area (km^2) by date for collared caribou in the vicinity of the Bathurst calving ground. Areas were produced with and without caribou 236 that was to the west of the calving ground (Figure 7)**.**

Reconnaissance surveys to delineate strata

Two DeHavilland Turbo Beaver aircraft flew reconnaissance surveys from 3-7 June to initially delineate the core calving area and then verify non-occupancy in areas surrounding the core calving area as summarized in Table 2. In total, 10,605 km of transect sampling were flown during reconnaissance and visual surveys. The results of systematic reconnaissance surveys revealed that the majority of breeding females were in a relatively small area of approximately 30 by 30 km. Few to no caribou were detected in areas to the west and to the east and areas to the south were composed mainly of non-breeding caribou (Figure 10). Low densities of breeding and non-breeding caribou were detected to the north.

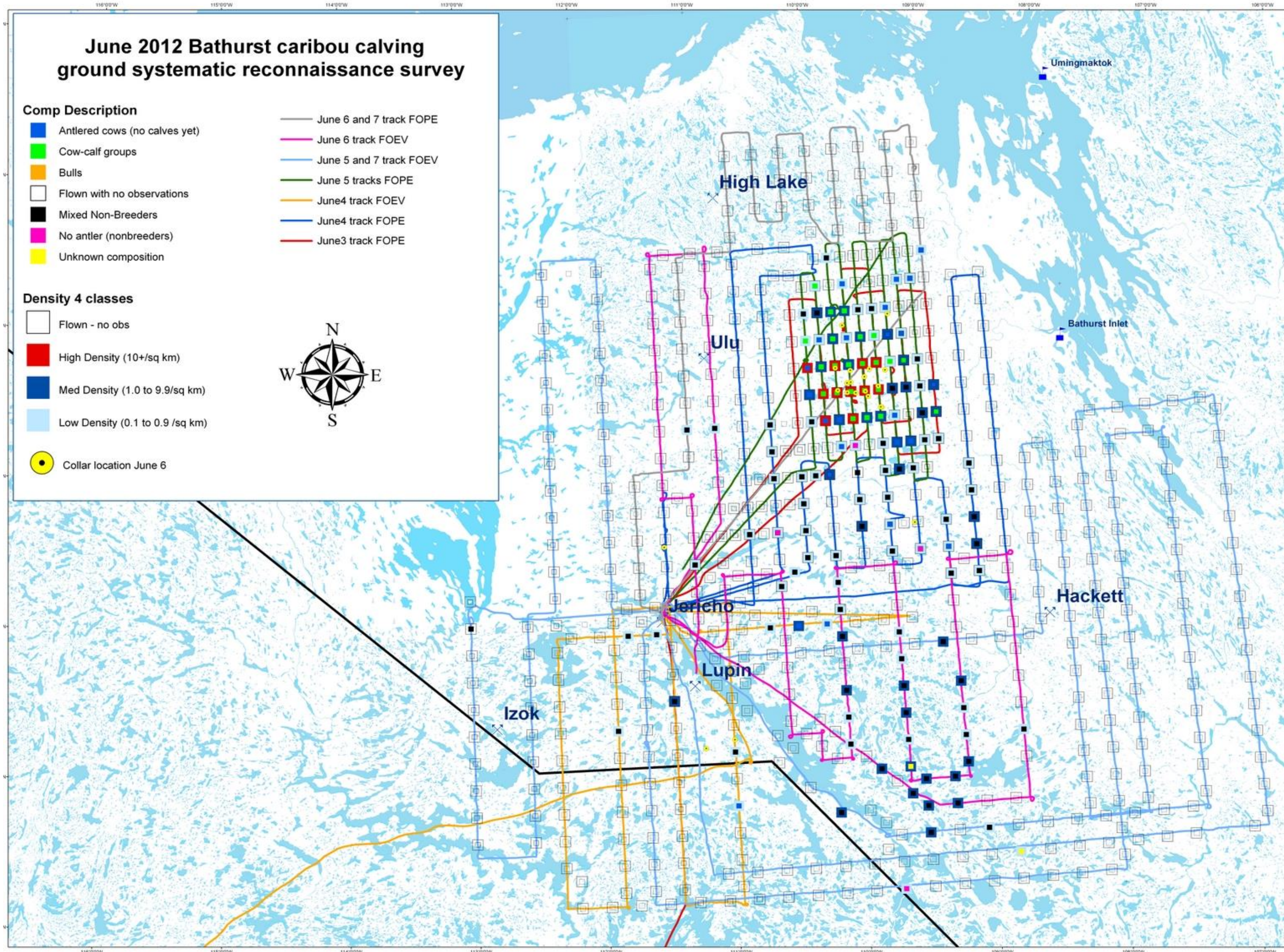

Figure 10: Reconnaissance survey coverage for two Turbo Beaver aircrafts (FOEP and FOEV) with flight lines by date.

Table 2: Summary of reconnaissance and visual survey efforts of the two Turbo Beaver aircraft during the 2012 calving ground survey as also summarized in Figure 10.

Date	Turbo Beaver 1 (FOPE)	Turbo Beaver 2 (FYOP)
3 June	• Yellowknife to Jericho • Preliminary delineation of core calving area and assessment of breeding status of caribou	• Yellowknife
4 June	• Segments immediately to the west, south and east of core calving area (delineated on 3 June)	• Yellowknife to Jericho • Segments to the southwest of Jericho
5 June	• Systematic reconnaissance and further delineation of core calving area	• Segments to the southeast of Jericho
6 June	• Visual survey of the Low East and Low South stratum • Further reconnaissance survey of areas to the west of core calving area to verify non-occupancy	• Areas to the northwest of core calving area to verify non-occupancy of breeding females.
7 June	• Survey of areas to the north and west of core calving area to verify non-occupancy of breeding females.	• Survey of area to the south of Bathurst Inlet to verify non-occupancy of breeding females.

In three segments to the south, single hard antlered caribou or small groups of hard antlered caribou were observed but in all cases these groups were small in size (segment group sizes of one, four hard antlered caribou in two segments to the south of the core calving area). To the north, a single hard antlered caribou was observed to the northeast of the core calving area but adjacent segments contained no caribou or non-breeding caribou (Figure 10, 11). We are confident that the stratified survey area included the core breeding female population.

Stratification and allocation of survey effort

The core calving area was initially surveyed on 3 June with the primary objectives of delineating the core calving area and to obtain a first assessment of how far calving had progressed. On 5 June, a systematic survey was conducted in which the core calving area was surveyed with 5 km spacing and the adjoining areas at the standard 10 km transect spacing

(Figure 11). From this, strata were defined based on gradients in density observed in reconnaissance surveys.

The area 20 km to the north of the proposed segments had single or small groups of antlered caribou spotted in four of the segments, but the actual densities in this area were low (average density=0.06 caribou/km^2). The actual survey coverage in this area was 16% given that transect lines spaced at 5 km intervals were sampled. If the segment densities were extrapolated to this area the resulting estimate of caribou was 56. Given the low densities of caribou, this area was not surveyed further.

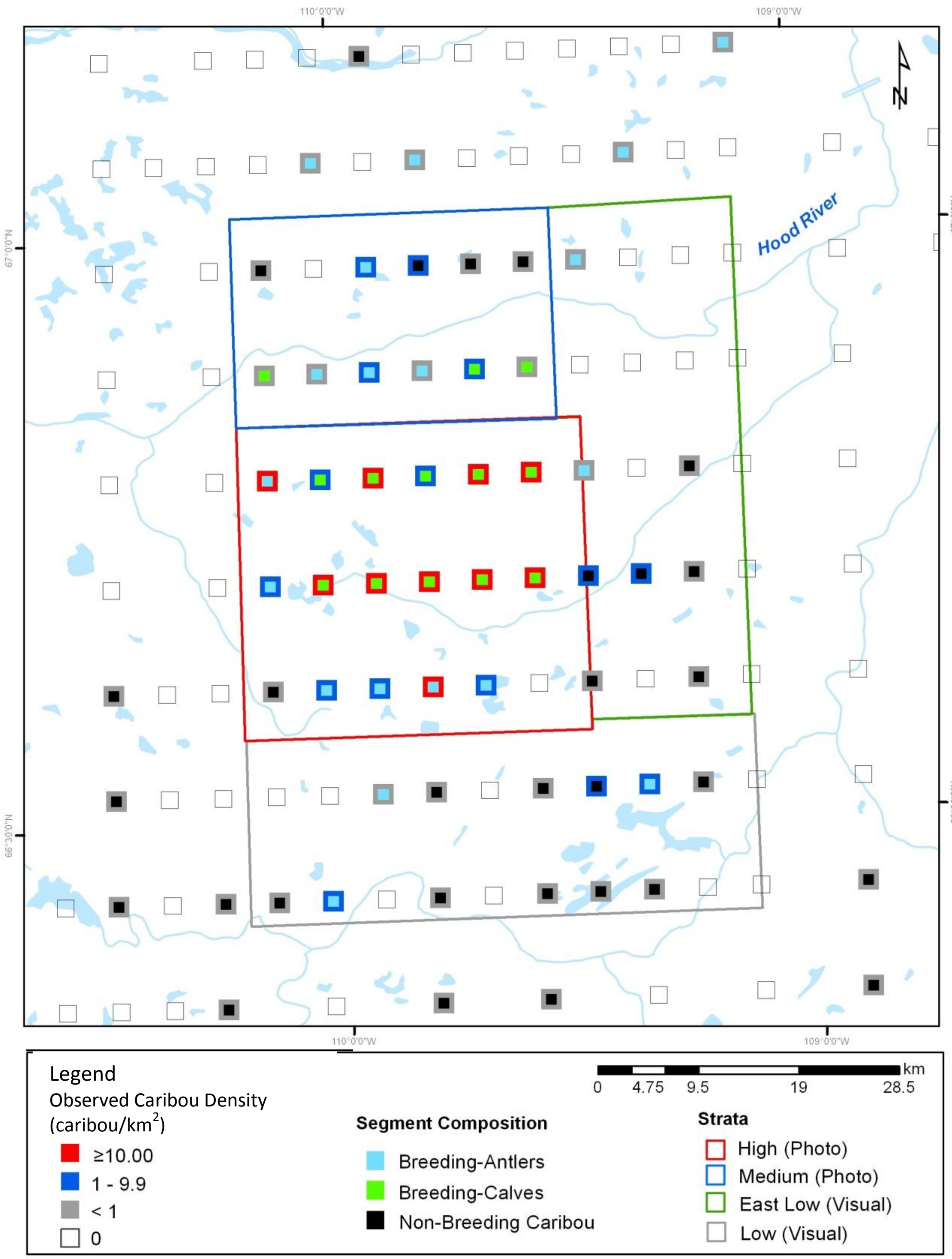

Figure 11: Segment densities and composition with sampling strata.

Comparison of the proportion of calves counted in the eventual medium and high density strata showed an approximate doubling (high stratum) to tripling (medium stratum) of the proportion of calves from 3-5 June, suggesting that the caribou were close to the peak of calving (Table 3). The estimates of proportion of calves will be conservative given lower sightability of newborn calves compared to adults. The estimated proportion of calves associated with peak of calving in 2009 was 27.1% (based upon eight segments) (Nishi et al. 2010) and percentages of calves were close to this on 5 June, 2012. Composition surveys on 6 and 7 June resulted in estimates of 49% (2,258 calves/4,612 1+yr caribou) and 60.9% (337 calves/553 1+ yr caribou) respectively. Overall, our data indicate that the peak of calving likely occurred 3-5 June and thus the photo survey occurred at or near the peak of calving.

Table 3: Summary of the number of total caribou observed, calves observed and proportion of calves for segments surveyed in the medium and high density strata. Only segments surveyed on both 3 and 5 June were included in the comparison to ensure the same general sampling areas were used to assess trends.

Stratum	Date	Total caribou counted	Total calves counted	Proportion of calves	Number of segments
High	3 June	888	112	12.6%	10
	5 June	1,582	378	23.9%	10
Medium	3 June	347	41	11.8%	6
	5 June	101	40	39.6%	6

Inspection of segment densities revealed higher densities in the core area with lower densities (<5 caribou/km^2) in all other strata (Figure 12). In particular, there were very high densities of caribou in the northeast corner of the proposed high stratum. Of the 19 collared caribou that were monitored, 15 were on the high stratum, one on the medium stratum, one on the Low East stratum and two to the south of calving ground sampling area on 6 June. The same numbers of collared caribou were present on each of the survey strata on 7 June suggesting little or no movement of caribou out of the strata during the photo survey.

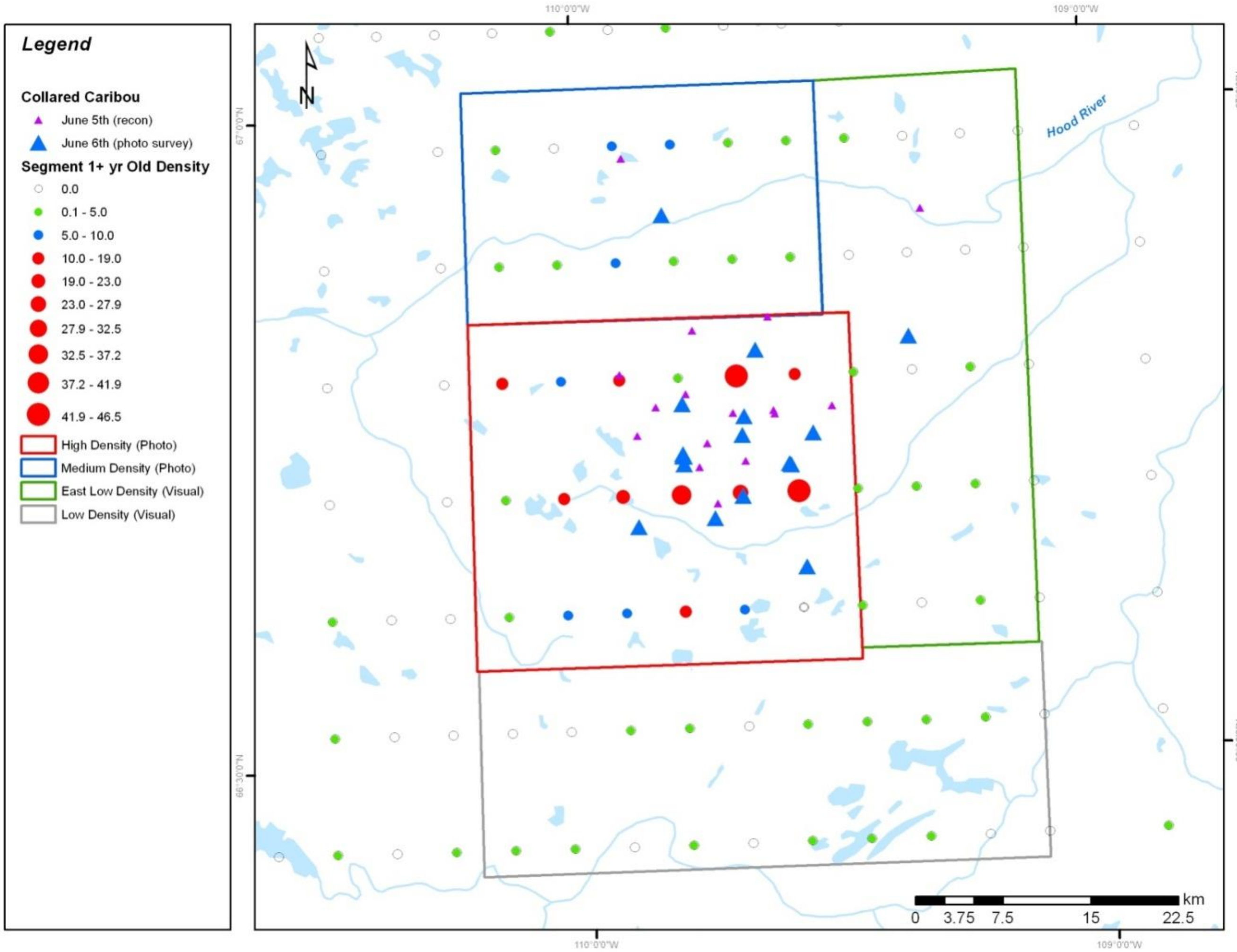

Figure 12: Segment densities as indicated by color coding and symbol size. Locations of GPS collared caribou during the reconnaissance survey of the core area (5 June) and during the photo and visual survey (6 June) are also shown.

Estimates from reconnaissance flying corroborated that the majority of breeding caribou were in the high density stratum area (approximately 86%) with 8.1% in medium density and the rest in lower density strata (Table 4). The estimates from the initial reconnaissance flights were not meant to provide precise estimates of caribou on survey strata.

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 ($\boldsymbol{\hat{D}}$) and stratum population size ($\boldsymbol{\hat{N}}$).

Stratum	Dimensions		Transects			Reconnaissance estimates			
	Area (km^2)	Baseline (km)	Max. possible	Sampled	Ave. width	$\hat{D}$	$\hat{N}$	$SE(\hat{N})$	% of sum of $\hat{N}$
High	914.24	28.2	32.6	6	32.7	15.20	12,313	2363.9	85.6
Medium	644.00	32.1	21.7	6	19.9	2.17	1,172	245.1	8.1
Low East	782.91	48.5	60.6	6	16.0	0.35	274	160.5	1.9
Low South	865.74	48.7	60.9	6	18.1	0.66	575	288.9	4.0

The large range of densities within the high strata created a potential issue of large variation in densities between survey lines which would result in lower precision of estimates (Figure 13). The relatively small area of high densities precluded further stratification of sampling given that the likelihood of larger-scale caribou movement between strata increases as strata size is reduced. For example, the relatively large size of the high density strata ensured that all of the collared caribou that were within the high strata on 5 June were still encompassed by this stratum on 6 June. If this stratum were smaller, it would be possible that caribou would move out of the strata between reconnaissance and photo surveys, or during photo surveys. This would increase possibilities for double-counting and compromise the population estimates.

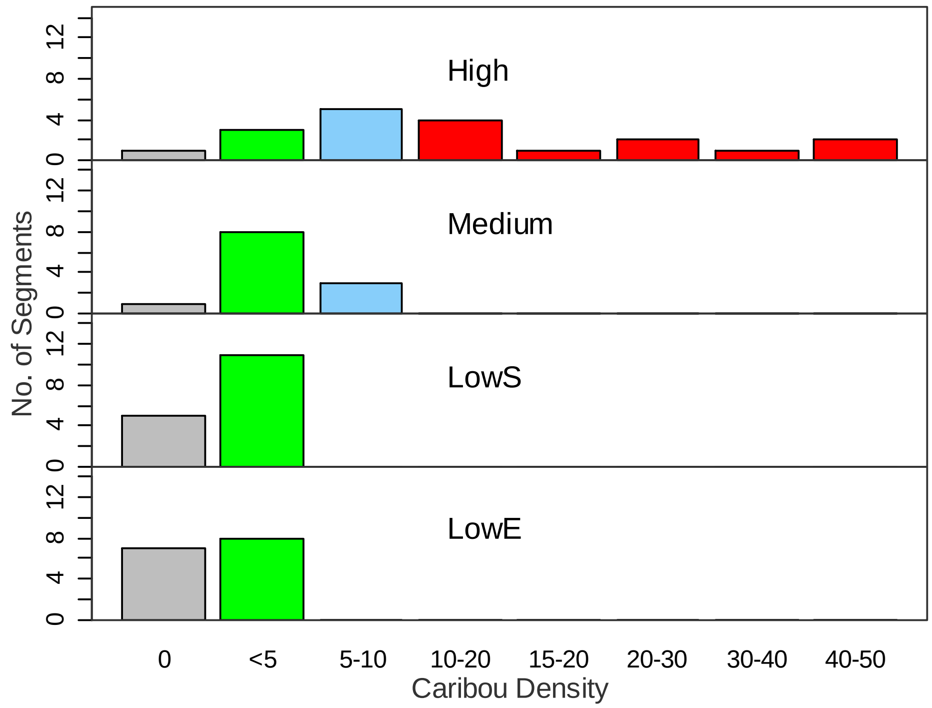

Figure 13: Frequencies of segments of different densities (caribou/km^2) observed during reconnaissance surveys for each stratum.

As a first step in planning transects within strata, estimates of caribou on each stratum were run through an allocation program to assess the proportional photo survey effort each stratum should receive to optimize estimate (Table 5). The program suggested that the high photo stratum receive most (90%) of the survey effort compared to the medium stratum. This amounted to more than 100% survey coverage if the entire number of photos available was used. We scaled this amount down to a number of transects (22) that would most likely ensure adequate survey precision. The resulting coverage (72%) was higher than high stratum had received in previous surveys. However, we felt higher coverage was justified as this area had a large range of caribou densities. Adding more lines and coverage was "insurance" against potential issues of low precision created by sampling this clustered distribution of caribou.

Table 5: Allocation of effort to photo strata based upon maximum km of photo transects possible (2,400 km).

Stratum	Based on population size	Based on variance	Km of transect	Coverage	Proportion survey effort
High	72	75	2,153.9	≥100%	0.90
Medium	13	8	251.1	37.2%	0.10

To further ensure adequate precision for the high stratum, we assessed spatial trends in segment densities to ensure that transects were sampled perpendicular to gradients in density. Transects in the high stratum were oriented East-West due to the gradient in density from East to West (Figure 14) and therefore transect sampling occurred against this gradient. In contrast, in the South to North direction, densities were highest in the middle of the strata with lower densities on the northern and southern sections.

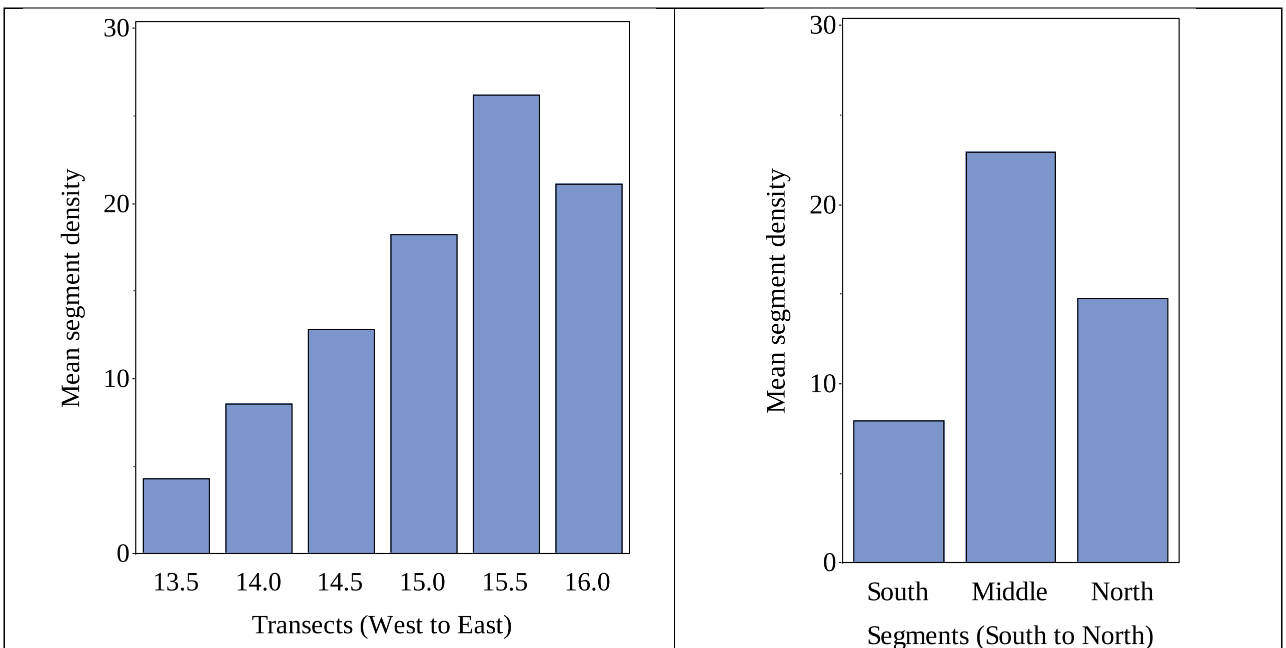

Figure 14: Segment densities from reconnaissance surveys (caribou/km^2) grouped West to East (left figure) and South to North (right figure) demonstrating the west to east density gradient in the high stratum. Transect lines were flown at 5 km intervals in the north to south direction resulting in six transects for this direction. For the South to North direction, segments were spaced at 10 km intervals, resulting in three segments.

The medium density stratum was sampled in a North to South direction due to its North-South gradient in density and received 14 survey lines. This amount of effort was close to that recommended by optimal allocation (Table 5).

The low strata had very low densities of caribou and contained mainly non-breeding caribou (Table 4). Therefore, these areas received enough coverage to ensure adequate estimates of precision, but did not require substantive survey effort. The final layout of strata had most of the survey effort occurring in the high and medium photo strata with less effort in the visual strata (Table 6). The final layout for transects is shown in Figure 15.

Table 6: Final dimensions and survey effort for each stratum. Sampling coverage is based upon transect area compared to total stratum area.

Stratum	Survey type	Maximum transects	Area of stratum (km^2)	Average transect width (w_i)	Base line width (l_i)	Transects sampled	Sampling coverage
High [A]	photo	30.8	914.2	32.7	28.2	22	71.9%
Medium	photo	35.1	644.0	19.9	32.1	14	39.6%
LowE[A]	visual	60.6	782.9	16.0	48.5	12	21.2%
LowS	visual	60.9	865.7	18.1	48.7	15	25.1%

[A]Stratum was flown in an East to West direction.

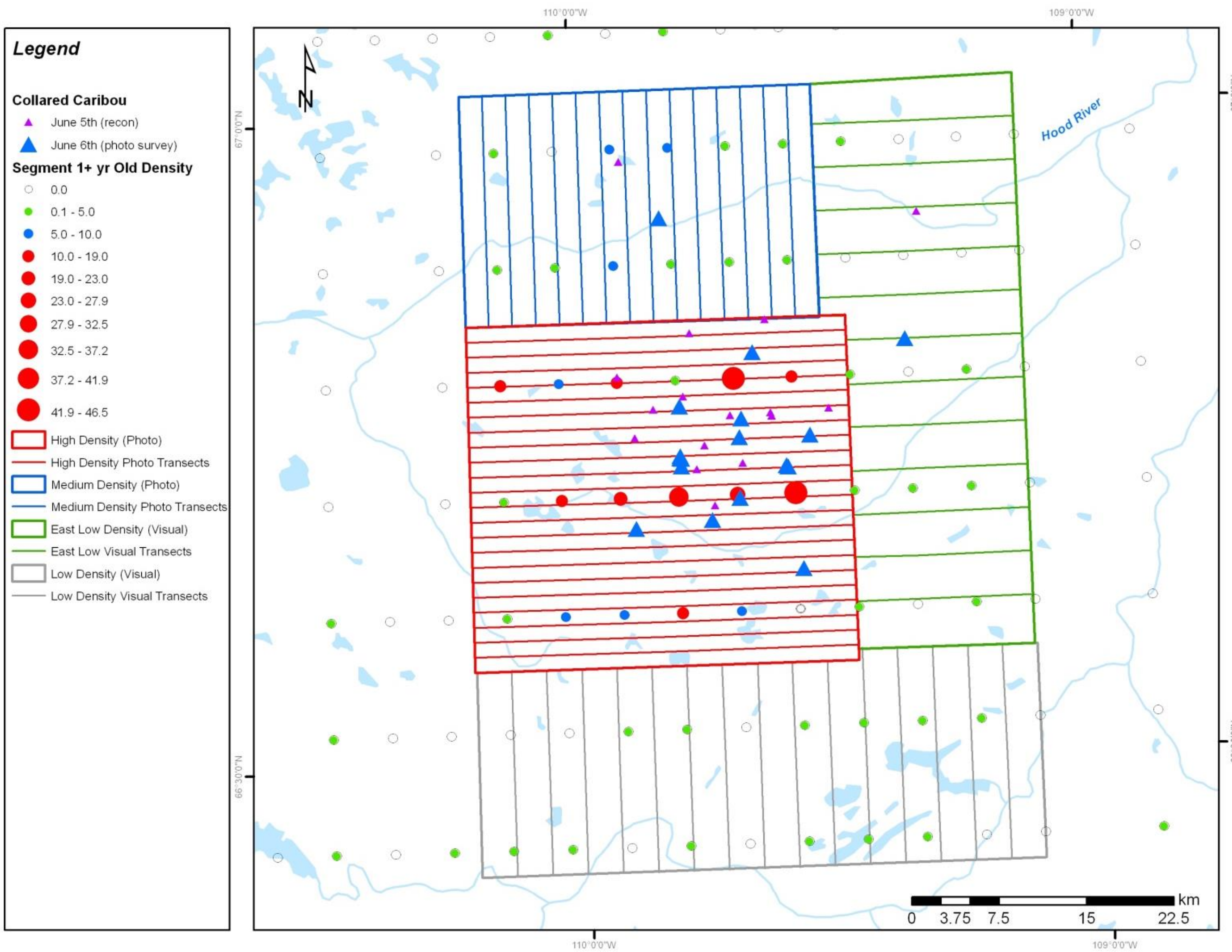

Figure 15: Final strata layout with transect lines, segment densities and collared caribou locations during the recon survey (5 June) and visual and photo survey (6 June).

Photo and visual survey

The high and medium photo strata were flown on 6 June with the majority of the photography completed by early afternoon and the medium stratum being surveyed during the later afternoon. The visual strata were surveyed on the same day with the Low East and Low South strata completed by early afternoon. Survey conditions were favorable with unlimited survey ceilings.

The majority of caribou (87.4%) were estimated to be within the high stratum with 8% occurring in the medium photo stratum and the remainder of caribou in the Low East (0.9%) and

Low South (3.6%) visual strata (Table 7). Coefficients of variation on estimates ranged from 0.08 for the high stratum to 0.46 on the Low East stratum. Because the majority of caribou were in the high stratum, the precision of the estimate from this stratum mainly dictated the precision of the overall estimate of one year old and older caribou on the calving ground (0.08). The resulting total estimate of 1+ caribou on the calving ground was 24,166 (SE=1,853.6, CI=20,310-28,020). CI were based upon a *t*-statistic of 2.08 with 21° of freedom.

Table 7: Estimates of the total number of caribou on the calving ground for each stratum. The standard error (SE), CV and percent of the total estimate is given for each stratum. Raw data for individual transects is given in Appendices 3-4.

Stratum Characteristics					Caribou Numbers in Survey Strata					
Stratum	Lines flown	Transect area	Stratum area	Coverage	Caribou counted	Average density	$\hat{N}$	SE	CV	% of sum of $\hat{N}$
Photo strata										
High	22	657.7	914.2	71.9%	15,201	23.1	21,129.6	1,750.5	0.08	87.4
Medium	14	254.8	644.0	39.6%	768	3.0	1,940.8	558.2	0.29	8.0
Visual strata										
Low East	12	166.1	782.9	21.2%	47	0.3	221.5	102.5	0.46	0.9
Low South	15	217.0	865.7	25.1%	219	1.0	873.6	222.4	0.25	3.6
Totals							24,166	1853.6	0.08	

Despite higher coverage, the actual km of photo transects flown in 2012 were 998 km in comparison with 5,156 km flown in 2009. This was due to the core calving area in 2012 being much smaller than in 2009 and thus high coverage could be achieved with less flying. For example the area of the high and medium strata in 2009 was 2,608.1 and 2,113.1 km^2 whereas the area of the high and medium for 2012 was 914.2 and 644 km^2 (Figure 16). The relatively small area for the high and medium in 2012 allowed the photo-plane to survey the high and medium density strata quickly and with high coverage.

A randomized re-sampling exercise was conducted to assess the relationship between survey coverage, estimates of caribou in survey strata and precision of estimates of caribou in survey strata. This exercise, which is presented in Appendix 2, demonstrated that higher coverage (n=20 lines with coverage=65%) was required in the 2012 survey to obtain estimates of higher precision (coefficients of variation of less than 10%) for caribou on the high stratum calving ground. Ground coverage of 49% (15 lines) would have resulted in a CV of 13.4%. The population estimate varied little with small changes in coverage.

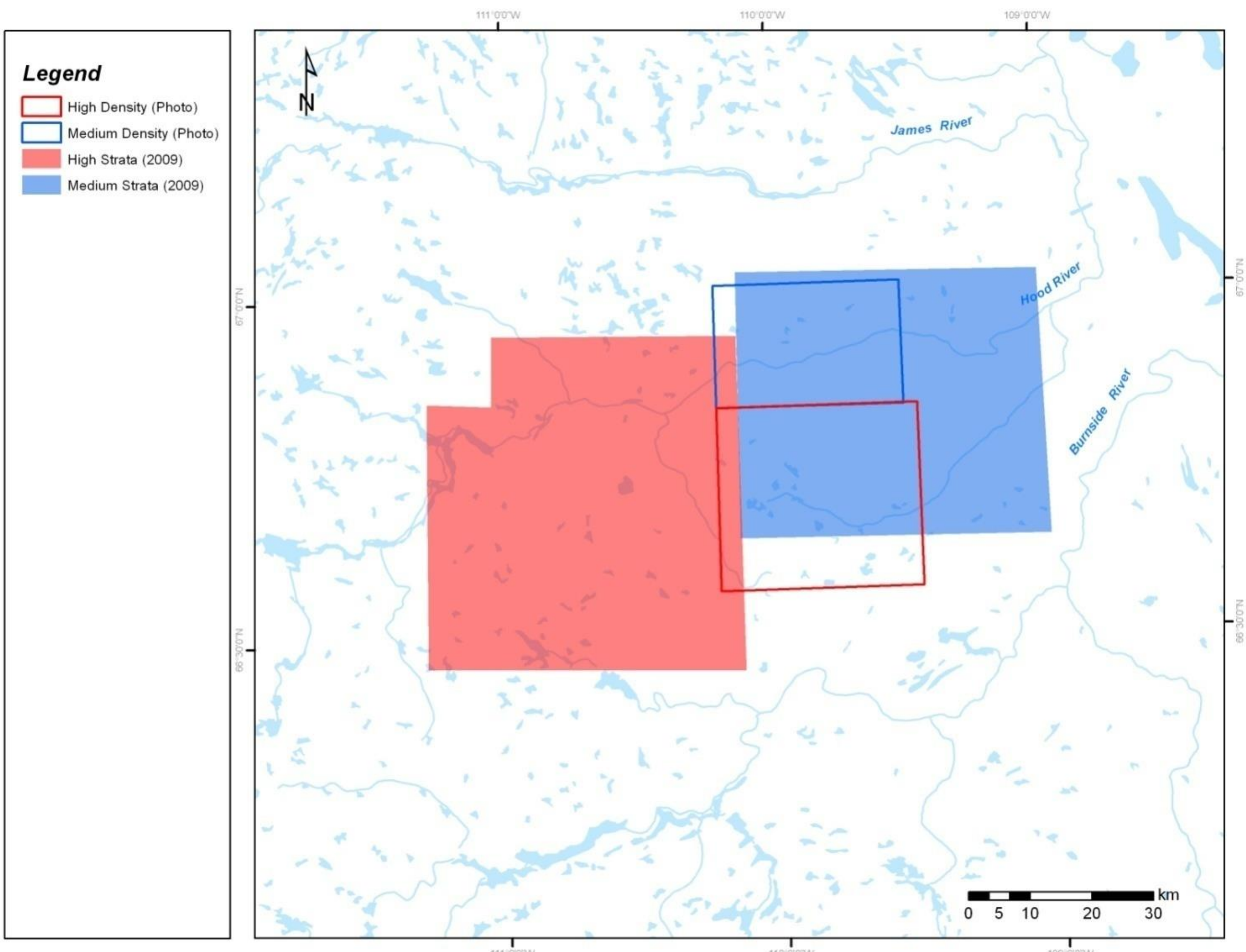

Figure 16: High and medium photo strata for the 2009 (coloured polygons) and 2012 (open polygons) Bathurst calving ground surveys.

Distribution of caribou densities on the high and medium strata revealed the highest densities in the middle lines of the strata suggesting that caribou were well delineated by stratum boundaries (Figure 17).

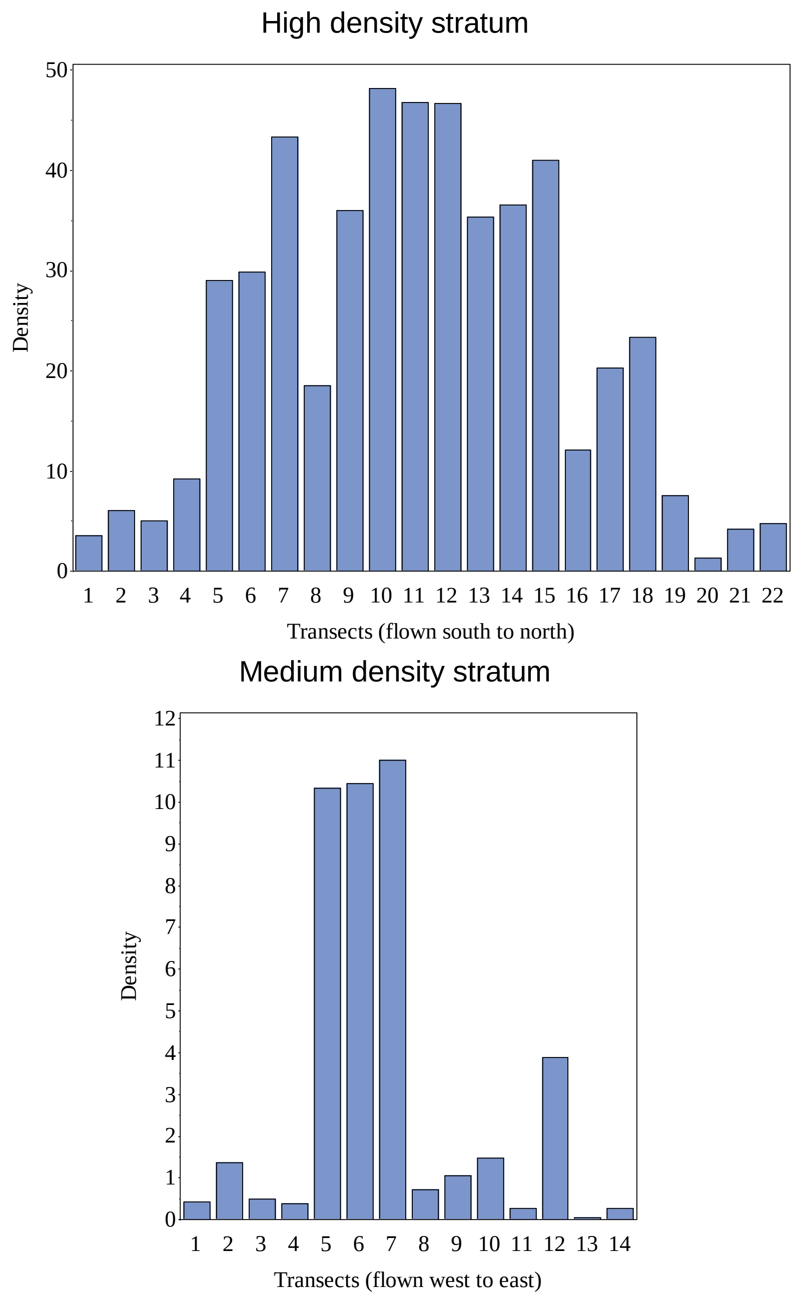

Figure 17: Densities of caribou on each transect line for the high and medium strata as estimated by counts of caribou on each stratum (from photos) divided by the area of each transect.

Composition on calving ground

Composition surveys were conducted on the High, Medium and Low South strata from 6-8 June. During this time, 86 groups and 5,245 caribou were classified with most groups (64) classified on the high density stratum (Figure 18).

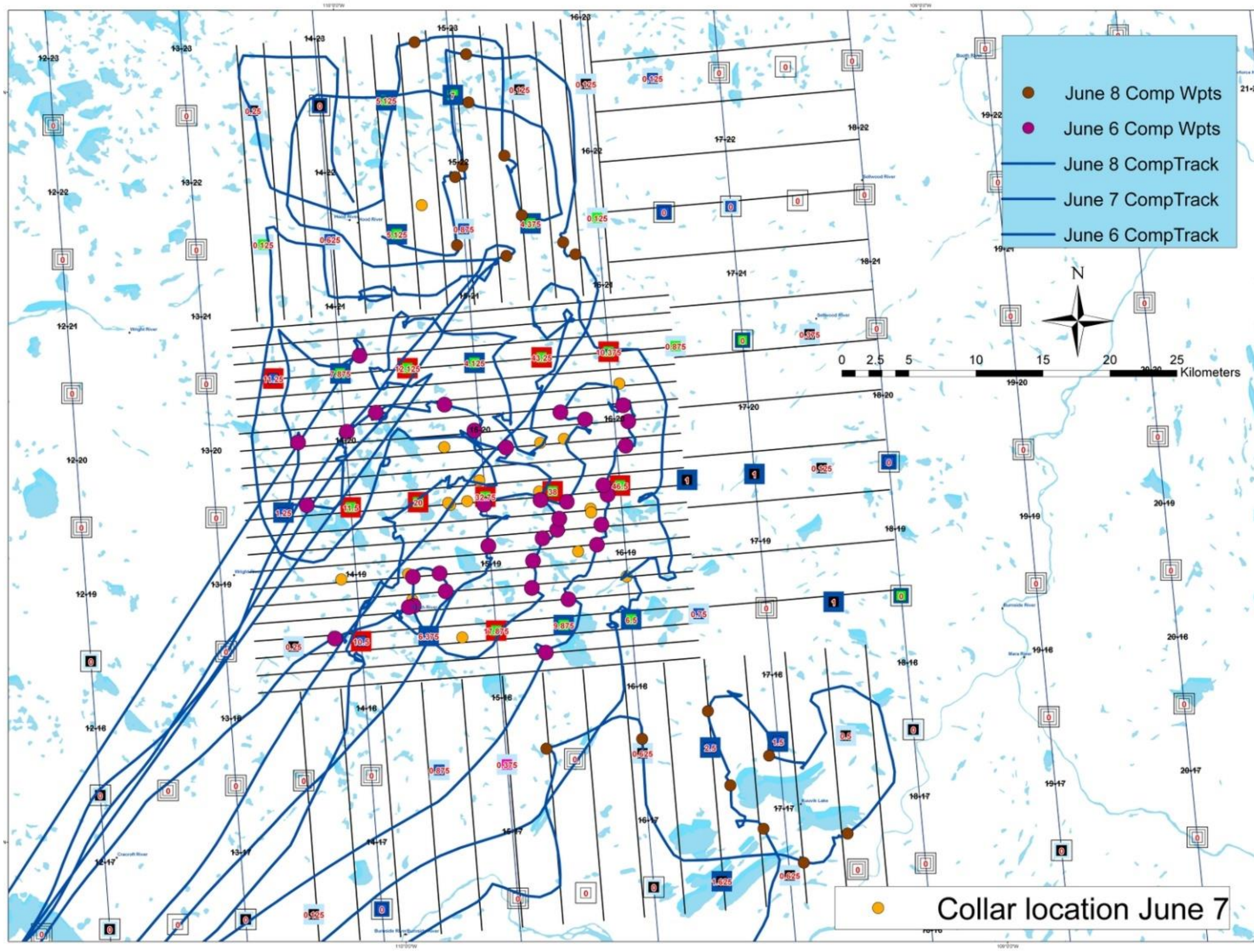

Figure 18: Flight tracks and waypoints for the composition survey. Waypoints for groups are missing for 7 June.

The proportion of groups and numbers of caribou classified roughly conformed to the proportion of caribou on each stratum (Table 8). Group sizes were much higher on the high density stratum than elsewhere. The Low East stratum was not revisited due to very low numbers of caribou during the visual survey. The proportion of calves estimated on the high and medium strata was 49% (2,258 calves/4,612 1+yr caribou) and 60.9% (337 calves/553 1+ yr caribou) respectively, further demonstrating that the photo survey occurred close to the peak of calving. A more exact estimate with non-breeders eliminated results in proportion calves of 71.2% (2,258 calves/3,171 breeding caribou) and 87.1% (337 calves/553 breeding caribou) for the high and medium strata respectively. This estimate corresponds best to the actual proportion of calves relative to breeding caribou, whereas the estimate with all caribou corresponds best to estimates that were derived during reconnaissance surveys (where detailed classification of caribou was not conducted).

Table 8: Summary of composition samples in the Low South, Medium and High strata. Raw data collected during surveys is given in Appendix 4.

Category		**Sum of counts**			**Mean group sizes**		
		High	**Medium**	**Low South**	**High**	**Medium**	**Low South**
Groups sampled		64	14	8			
Breeding females	Antler & udder	1,619	97	0	25.30	6.93	0.00
	No antler & udder	873	257	0	13.64	18.36	0.00
	Antler & no udder	679	33	5	10.61	2.36	0.63
Non-breeding	No Antler/udder	718	93	32	11.22	6.64	4.00
	Yearlings	720	73	43	11.25	5.21	5.38
	Bulls	3	0	0	0.05	0.00	0.00
Calves		2,258	337	0	35.28	24.07	0.00
All 1+ yr caribou		4,612	553	80	72.06	39.50	10.00

The proportion of breeding females was estimated by the ratio of the sum of the breeding females divided by the number of 1+ yr caribou observed (Table 9). Bootstrap resampling was used to estimate percentile based confidence limits, estimates of SE and bias-corrected point estimates.

Table 9: Estimates of proportion breeding females, SE, 95% CI and CV in the Low South, Medium and High strata using bootstrap resampling methods.

	Proportion breeding females				
Stratum	Proportion	SE	CI		CV
High	0.687	0.028	0.632	0.741	0.041
Medium	0.691	0.071	0.527	0.828	0.103
Low South	0.063	0.041	0.008	0.179	0.647

Estimation of breeding females

The estimated proportion of breeding females was multiplied by population estimates from each stratum to obtain estimates of breeding females and associated variances (Table 10). The total estimate of breeding females was 15,935 with corresponding 95% CI of 13,009-18,861.

Table 10: 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		
	$\hat{N}$	SE	CV	Proportion	SE	CV	$\hat{N}_{breedf}$	SE	CV
High	21,130	1,750.54	0.083	0.687	0.028	0.04	14,525	1,345.50	0.093
Medium	1,941	558.23	0.288	0.691	0.071	0.10	1,341	409.99	0.306
LowE	222	102.50	0.463	0.063	0.041	0.65	14	11.19	0.796
LowS	874	222.41	0.255	0.063	0.041	0.65	55	38.57	0.696
Total	24,167	1,853.64	0.077				15,935	1,407.15	0.088

Estimation of total herd size

Fall composition surveys

Fall composition surveys were conducted on 21-24 October, 2008, 23-26 October, 2011 and on 22 and 23 October, 2012. The main survey of interest was the 2012 fall composition estimate but the 2008 and 2011 surveys were also considered. In 2012, 33 groups and 4,272 caribou were classified (Table 11).

Table 11: Summary statistics for fall composition surveys conducted in 2011 and 2012.

Statistic	**Year**		
	2008	2011	2012
Number of groups	42	52	33
Mean group size	84.05	95.5	129.5
Total caribou	3,529	4,964	4,272
Total adults (1.5+ yr old)	2,868	4,105	3,710
Total cows	2,074	2,598	2,369
Total calves	661	859	562
Total bulls	794	1,507	1,341

Of most interest was the proportion of adult females in the composition surveys, which would then be used to estimate the proportion of adult females in the Bathurst herd. The bootstrap-based estimate of proportion of adult females (cows) for 2011 and 2012 was 0.631 and 0.638, respectively (Table 12). The 2012 estimate was used for the extrapolated population size estimate. The proportion of adult females decreased (and subsequently the proportion bulls increased) compared to the 2008 fall composition survey.

Table 12: Proportion cows and bull:cow ratios from 2008, 2011 and 2012 fall composition surveys. The proportion is based upon the total adults counted (excluding calves) as listed in Table 11.

Year	**Proportion cows**	**SE**	**CI**		**Bull:cow ratio**	**SE**	**CI**	
2008	0.723	0.013	0.697	0.750	0.383	0.025	0.334	0.435
2011	0.631	0.013	0.606	0.655	0.585	0.033	0.526	0.651
2012	0.638	0.014	0.610	0.664	0.567	0.035	0.505	0.640

Extrapolated estimate of total herd size

The extrapolated estimate of total herd size was derived in a sequential process. First, the estimate of breeding females was divided by the assumed pregnancy rate (0.72, Dauphine 1976) to estimate the total number of adult (1.5+ yr old) females in the herd of 22,132 (±6,140) caribou. This estimate was then divided by the proportion of adult females in the herd (Table 12) of 0.638 to estimate the total herd size of 34,690 (1.5+ yr old) caribou (Table 13).

Table 13: Extrapolated estimate of total herd size for 2012 using breeding female estimates (Table 10) and estimates of proportion of adult females in the entire herd from 2012 fall composition surveys (Table 12).

Survey data	Estimate	SE	CV	CI	
Number of caribou on the breeding ground	24,167	1,853.6	0.08	20,312	28,020
Number of breeding females	15,935	1,407.2	0.09	13,009	18,861
Proportion adult females in the entire herd	0.638	0.01	0.02		
Proportion 1.5+ yr females pregnant	0.72		0.10		
Total population estimate	**34,690**	**4,691.1**	**0.14**	**24,934**	**44,445**

One notable difference in the extrapolated estimate for 2012 is that it is based on an estimate of proportion adult females in the herd of 0.638, which was different than the estimate for the 2009 estimate of 0.723 (Table 12). If the 2008 proportion of cows estimate is used the resulting extrapolated estimate is 30,611 (CI=21,906-39,316). From this comparison it can be seen that that an apparent increase of 4,078 caribou is due to the change in estimated proportion of adult females in the herd. Of the two estimates, the estimate of 34,690 (CI=24,934-44,445) is preferred as it is based upon more recent ground composition survey data.

Table 14: Extrapolated estimate of total herd size for 2012 using breeding female estimates (Table 10) and estimates of proportion of adult females in the entire herd from 2008 fall composition surveys (Table 12).

Survey data	Estimate	SE	CV	CIL	CIR
Number of caribou on the breeding ground	24,167	1853.6	0.08	20,312	28,022
Number of breeding females	15,935	1407.1	0.09	13,009	18,861
Proportion females in the entire herd	0.723	0.0	0.03		
Proportion 1.5+ yr females pregnant	0.72		0.10		
Total population estimate	30,611	4185.8	0.14	21,906	39,316

We recognize that pregnancy rate varies in barren-ground caribou herds and consideration should be given to improving the estimate of pregnancy rate used to estimate extrapolated herd size by using values more reflective of the herd's conditions at the time of the survey. At this time, we have relied with the Bathurst herd on estimates of the number of breeding females as the key demographic segment of the herd; the calving photo survey measures this number with precision.

Trend in breeding females

Estimates of breeding females have varied from a high of 203,800 caribou in 1986 to the estimate of 15,935 in 2012. The relative difference (gross change) in breeding female population size between surveys was estimated by the ratio of successive estimates. This ratio was then scaled to the annual interval (Table 15). From this it can be seen that on an annual basis, the breeding female population size has declined between all surveys (except 1990 and 1996) with the largest decline between 2006 and 2009. Between 2009 and 2012, the rate of change is close to 1 suggesting that the rapid rate of decline observed between 2009 and 2012 has been reduced in magnitude.

Table 15: Breeding female estimates (N) used in the trend analysis and estimates of gross change (change in population size between surveys) and annual change (λ). Standard errors (SE) for change are based on the combined error of the two population estimates. The yearly interval (Int.) between surveys is also given.

Year						**Change**						
	N	SE	CI		CV	Gross	SE	Int.	Annual	SE	CI	
1986	203,800	12,695.7	178,197	229,403	0.062							
1990	151,927	25,805.0	94,430	209,424	0.170	0.75	0.13	4	0.93	0.07	0.80	1.06
1996	151,393	35,144.0	75,469	227,317	0.232	1.00	0.29	6	1.00	0.12	0.77	1.23
2003	80,756	13,167.1	52,878	108,438	0.163	0.53	0.15	7	0.91	0.06	0.80	1.03
2006	55,593	8,813.0	37,147	74,039	0.159	0.69	0.16	3	0.88	0.09	0.71	1.06
2009	16,649	2,181.0	12,153	21,056	0.131	0.30	0.06	3	0.67	0.04	0.60	0.74
2012	15,935	1,407.1	13,009	18,861	0.088	0.96	0.15	3	0.99	0.09	0.81	1.16

The general trend also can be seen with a plot of breeding female population size estimates (Figure 19) which illustrates the overall decline of estimates with an accelerated decline from 2006-2009 followed by minimal change from 2011-2012. Using a two-tailed *t*-test, there is no statistical difference in the 2009 and 2012 estimates (t=0.28, df=47, p=0.78).

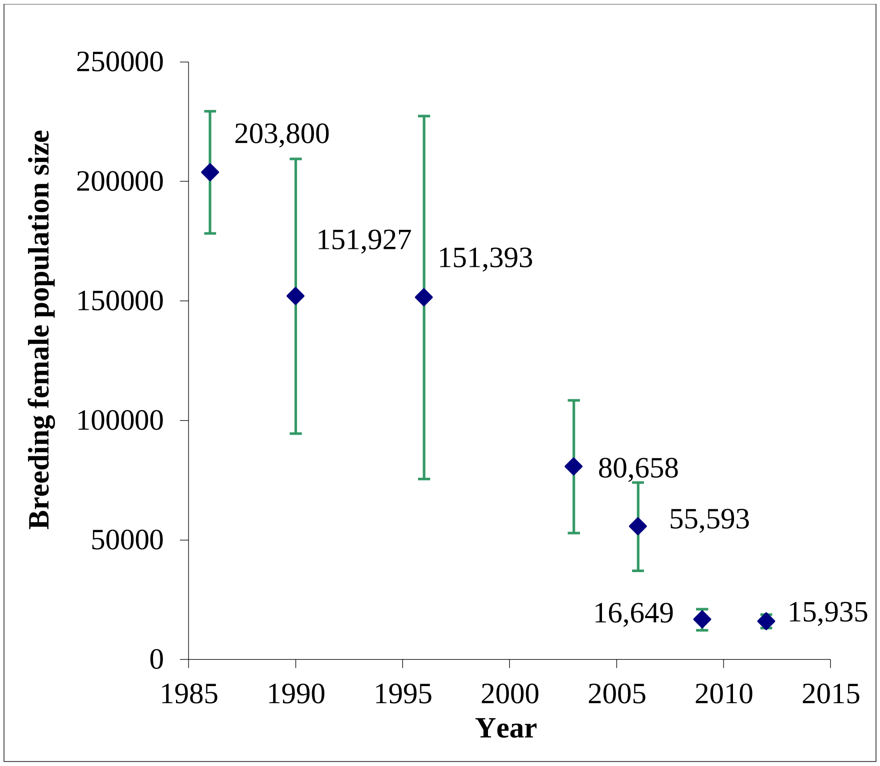

Figure 19: Breeding female estimates with associated CI used in the trend analysis.

Weighted regression

The main question addressed with regression analysis was whether the change in trend observed between 2009 and 2012 (Table 15) was statistically significant. In the analysis of the 2009 data set, Boulanger (2010) found that the downward trend of Bathurst herd was best described by a cubic polynomial model. The question therefore was whether this model of exponential decline still described the trend, or a model that assumed a cut-point (change) in trend was more supported.

Model selection results suggested that a model that assumed the cubic trend from 1986 to 2009 (yr^3), followed by a cut-point in 2009 (yr_{2009}) and a different trend from 2009-2012 ($T_{2009-2012}$) (Table 16, model 1) was most supported. This model was more supported than a model with quadratic and cubic terms (model 2) or the original cubic term model used in the 2009 analysis (model 3) or other trend models (models 4-7).

Table 16: Model selection results for trend analysis of Bathurst breeding cow estimates. 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), number of parameters (*K*) and log-likelihood (*LogL*) are presented.

Model No.	Model	AIC_c	ΔAIC_c	w_i	*K*	*LogL*
1	$yr^3 + yr_{2009} + T_{2009-2012}$	15.22	0.00	0.76	4	6.35
2	$yr^2\ yr^3$	17.28	1.98	0.11	3	-1.64
3	yr^3	17.69	2.39	0.07	2	-5.34
4	$yr\ yr^3$	17.79	2.48	0.06	3	-1.89
5	$yr + yr_{>06}$	29.69	14.39	0.00	3	-7.85
6	$yr\ yr^2\ yr^3$	31.24	15.94	0.00	4	-1.62
7	yr	33.48	18.18	0.00	2	-14.74

Parameter estimates from model 1 demonstrated that all parameters were significant (Table 17).

Table 17: Regression model parameter estimates and Chi-square test results.

Parameter	Estimate	SE	CI		χ^2	$P(\chi^2)$
Intercept	12.186	0.057	12.074	12.298	45,692.000	<.0001
yr^3	-0.141	0.016	-0.173	-0.109	74.450	<.0001
Yr_{2009}	-6.776	1.488	-9.691	-3.861	20.760	<.0001
$T_{2009-2012}$	0.261	0.062	0.141	0.382	17.94	<.0001

A plot of the regression line (back transformed to population size units) is shown in Figure 20. The grey lines are 95% CI around the trend line. The circles are data points. The CI are irregular as they are accounting for varying degrees of variance in each of the point estimates. For example, the 1986, 2003, 2009 and 2012 surveys had the best precision and therefore the CI are tightest around these points.

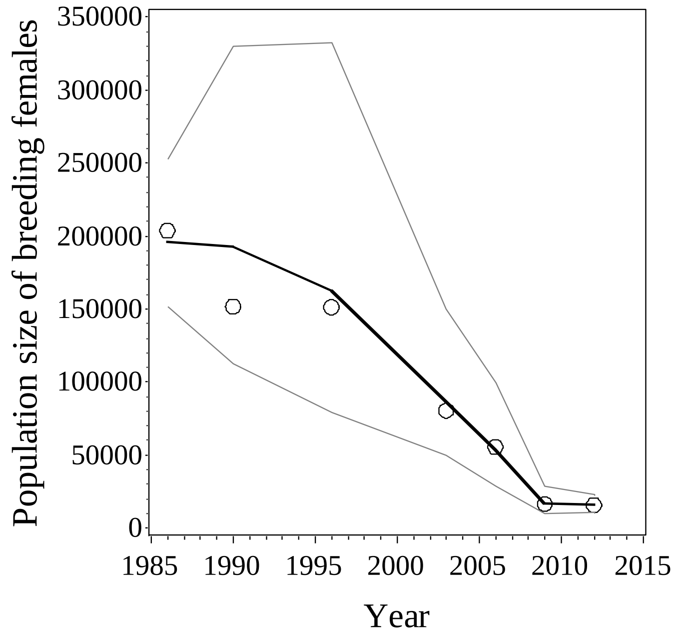

Figure 20: Predicted trend for breeding females from weighted least squares regression analysis. Grey lines are CI on predictions. Circles are estimates from each calving ground survey.

Monte Carlo simulation analysis of the regression model allowed an estimate of λ and associated confidence limits for the interval between 2009 and 2012. The estimates of λ from the Monte Carlo analysis for 2012 is 0.99 (SE=0.057, CI=0.86 to 1.08) with a corresponding r estimate of –0.010 (SE=0.058, CI=-0.143 to 0.086). The distribution of λ estimates was symmetrically defined around the point estimate of 0.97 (Figure 21). This estimate is higher than the λ from 2008-09 of 0.76 (SE=0.17, CI=0.74 to 0.80) with a corresponding *r* estimate of -0.26 (SE=0.027, CI=-0.31 to -0.22) (Boulanger 2010).

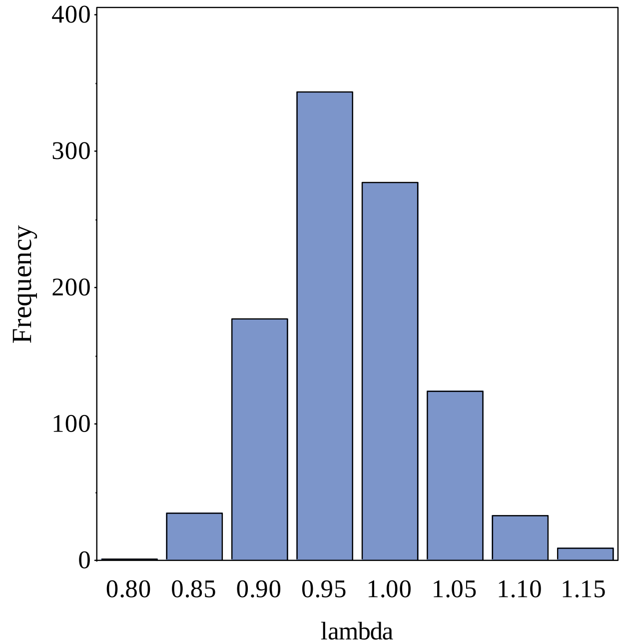

Figure 21: Distributions of population rate of change (λ) for 2012 generated using Monte Carlo simulation trials.

Analysis of demography

Twenty two 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 18). A model with yearly trends in calf survival and constant values for fecundity was most supported with an AIC_c weight of 0.999 (Table 18, model 1). Using the base productivity model, various cow and bull survival trend models were tested with none of the models showing substantial support. We used the most supported model with constant adult female survival rates to further estimate and explore demography of the Bathurst herd. Model averaging of estimates from candidate models was not required given the high level of support (AIC_c weight of 0.999) of the most supported model.

Table 18: AIC_c model selection for demographic analysis of Bathurst data (2007-2012). Akaike Information Criteria (AIC_c), the difference in AIC_c values between the *i*th and most supported model 1 (ΔAIC_c), Akaike weights (w_i) and number of parameters (*K*) and sum of penalties are presented. Trend models were indicated by a T (T-log-linear, T^2=quadratic, T^3=cubic), year-specific trends were indicated by a subscript under the T symbol. Yearly models allowed unique values for each year in the analysis. A constant model assumed the parameter was constant from 2007-2012.

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	Yearly	Constant	Constant	Constant	71.58	0	0.999	11	23.18
2	Yearly	T	Constant	Constant	78.42	6.83	0.001	12	19.75
3	Yearly	Constant	$T_{2007-2010}$, $T_{2011-2012}$	Constant	80.36	8.77	0.000	12	21.69
4	$T+T^2+T^3$	Constant	Constant	Constant	80.70	9.11	0.000	9	47.70
5	Yearly	Constant	$T_{2007-2008}$, $T_{2009-2012}$	Constant	81.28	9.70	0.000	12	22.62
6	Yearly	Constant	Constant	T	81.33	9.74	0.000	12	22.66
7	Yearly	Constant	T	Constant	81.83	10.25	0.000	12	23.17
8	Yearly	Constant	$T_{2007-2009}$, $T_{2010-2012}$	Constant	92.11	20.53	0.000	13	20.61
9	Yearly	Constant	T	T	81.85	10.26	0.000	12	23.18
10	Yearly	Constant	$T_{2007-2009}$, $T_{2010-2012}$	$T_{2007-2009}$, $T_{2010-2012}$	93.97	22.39	0.000	13	22.47
11	Yearly	Constant	$T+T^2$	Constant	93.34	21.76	0.000	13	21.84
12	T+T2	Constant	Constant	Constant	105.12	33.54	0.000	8	78.04
13	Yearly	Constant	Yearly	Constant	157.12	85.54	0.000	16	16.32
14	$T_{2007-2010}$, T_{2011}	Constant	Constant	Constant	243.93	172.34	0.000	7	221.93

Estimates of parameters from model 1 demonstrated temporal variation in calf survival and constant values for other parameters. Most notably adult female survival was estimated as 0.78. Yearling survival was estimated also at 0.78, adult male survival at 0.71 and fecundity at 0.84 (Figure 22). Calf survival varied from 0.68 in 2010 to 0.06 in 2012.

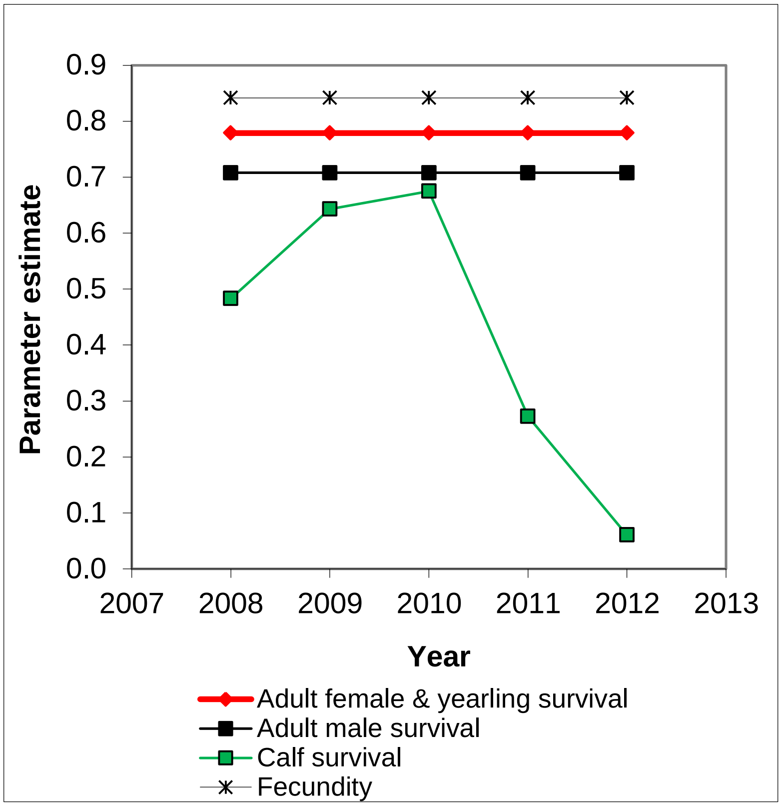

Figure 22: Estimate of demographic parameters from the most supported OLS model (Table 18, model 1).

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 23). Trends in spring calf:cow ratios suggested reasonably high productivity until 2012 when calf:cow ratios declined. Adult female survival estimates from collared caribou were very imprecise due to low numbers of collared caribou; hence determination of trend was problematic. Proportion of females breeding was within the confidence limits of field estimates. 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 9) as detailed in Boulanger et al (2012). Survival rates from collared caribou were low in 2010 and 2011 with the OLS model estimates being just within the upper limit of the confidence limits of the collar-based estimates.

OLS model predictions suggest a declining trend (yearly change λ=0.94) in breeding female numbers (Figure 23). This is lower than the estimate of λ from the weighted least squares regression of 0.99 (Figure 21). The trend in breeding females from the OLS model is based upon the combined inference from other data sources as shown by the fitted lines in Figure 23 and therefore may be a better estimate of change in the breeding female population. The predictions of the OLS model of breeding female population size fall well within the confidence limits of the breeding female estimates from the 2009 and 2012 surveys (Figure 23).

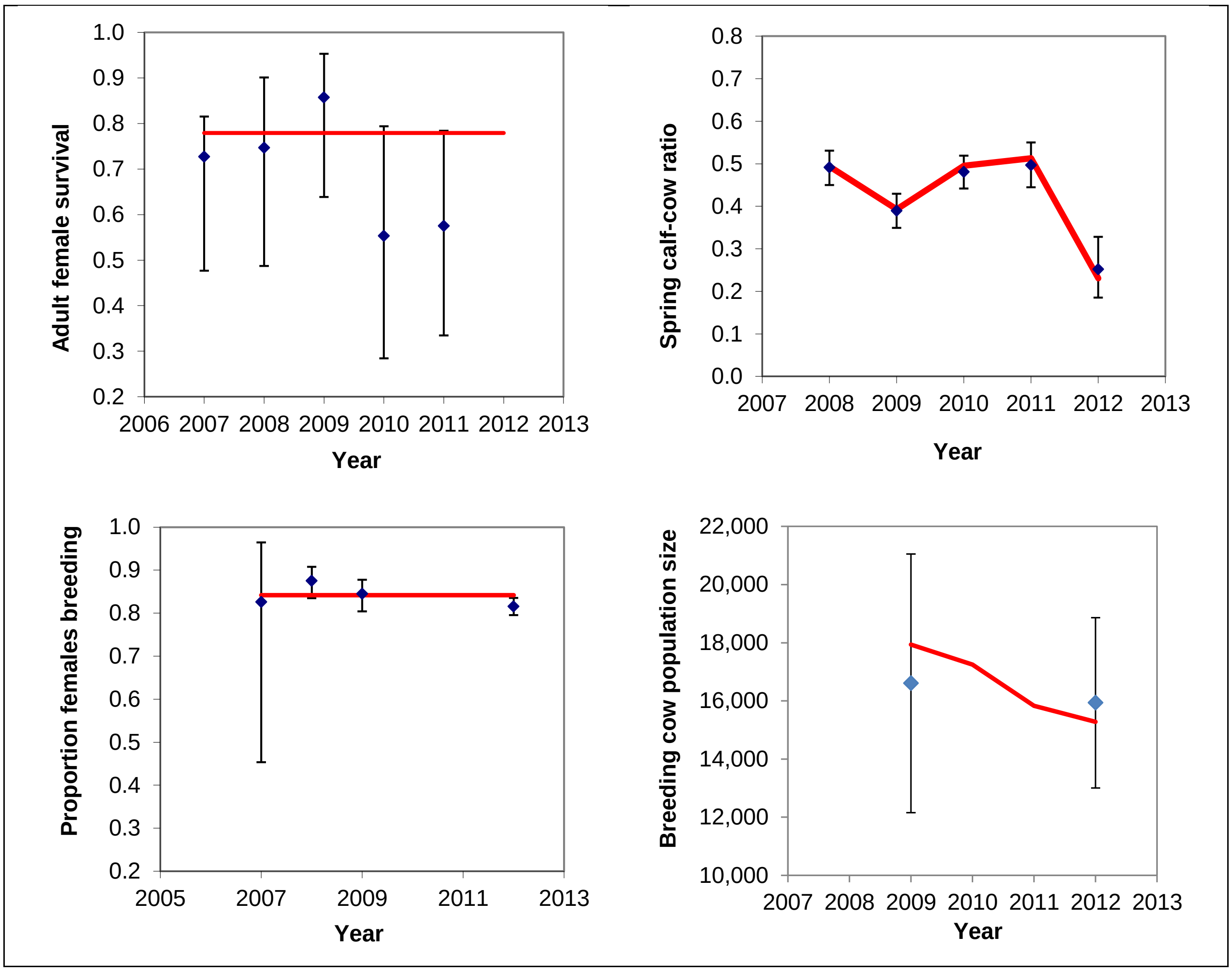

Figure 23: Estimates of adult female survival (from collared caribou), spring calf:cow ratios (from March composition surveys), proportion females breeding and breeding cow (female) population size estimates (from calving ground surveys). OLS model predictions are given as red lines (from model 1, Table 18).

The bull:cow ratio increased over the duration of the study. This was presumably due to higher levels of productivity, as explored further later in the report (Figure 24). 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.

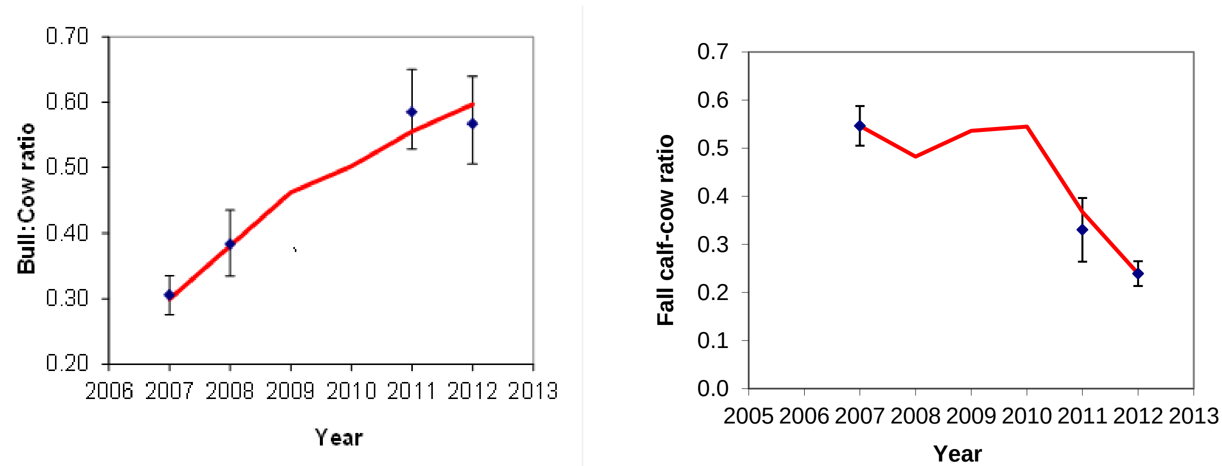

Figure 24: Estimates of bull:cow ratios and fall calf:cow ratios from fall composition surveys. The 2008 fall calf:cow ratio was not included into the analysis due to potential bias issues with this measurement. OLS model predictions are given as red lines.

Population size estimates for each of the age classes in the demographic model suggested a decline for adult females, calves and yearlings, but a slight increase in bulls. Assuming a pregnancy rate of adult cows of 0.72, we derived an extrapolated herd estimate using the OLS estimate of the bull:cow ratio for 2012 (0.60) of 33,887 which was close to the extrapolated estimate of 34,690 (CI=24,934-44,445) (Table 13). The main objective of the OLS model was to explore demography and not estimate herd size, however, the fact that these two estimates are similar is reassuring.

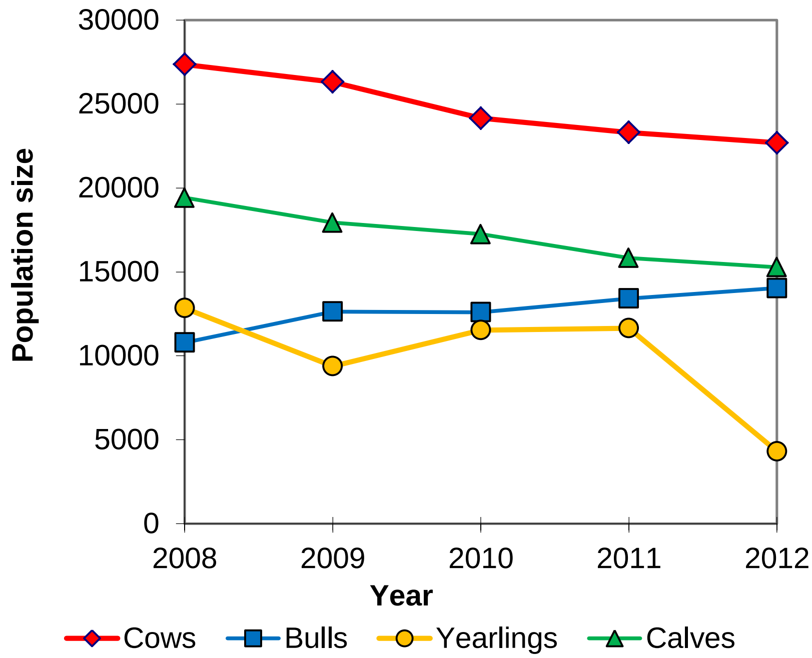

Figure 25: Estimates of population size for each age-sex class from the most supported OLS model (Table 18).

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 (Figure 25). In contrast, the recruitment of yearlings into the female segment, which is larger, is relatively low (Figure 26). Thus the bull segment of the population had a net gain (recruitment>mortality), whereas adult cows had a net loss (mortality>recruitment). This general trend also explained the increase in the bull:cow ratio observed in fall composition surveys (Figure 24).

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 slight increase in bull abundance. 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).

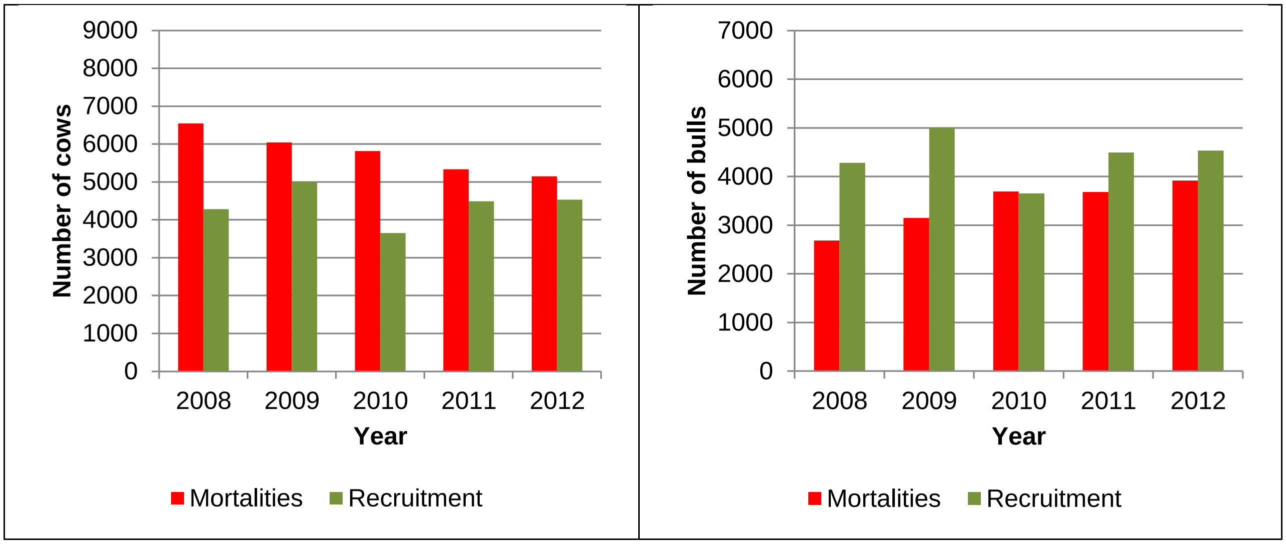

Figure 26: The estimated relative number of adult cows and bull mortalities compared to estimated recruitment into the bull and cow age class from the OLS model. Note that the number of recruits for bulls and cows is the same each year. This estimate assumes an equal sex ratio of yearlings so that equal numbers are recruited into the bull and cow age classes.

One potential issue with measures of productivity prior to 2009 was bias of calf:cow ratios due to reduced over-winter survival rates of cows and subsequent inflation of calf:cow ratios. If these ratios were positively biased, then estimates of adult female survival for 2012 from the OLS model would be negatively biased. We first considered models that had separate survival rates for the period prior to 2009 in model selection (Table 18; models 3 and 10). These models were not supported by the data [ΔAIC_c=8.77 (model 3) and ΔAIC_c=93.97 (model 10)]. This was most likely due to imprecise survival rates from the collared caribou and the fact that the decline prior to 2009 was not explicitly modeled. Estimates of adult female survival for 2007-2008 and 2009-2012 were 0.73 and 0.79 respectively (Figure 27). Thus the estimates of survival from this model were relatively close to that of the constant survival model (of 0.78 for 2012).

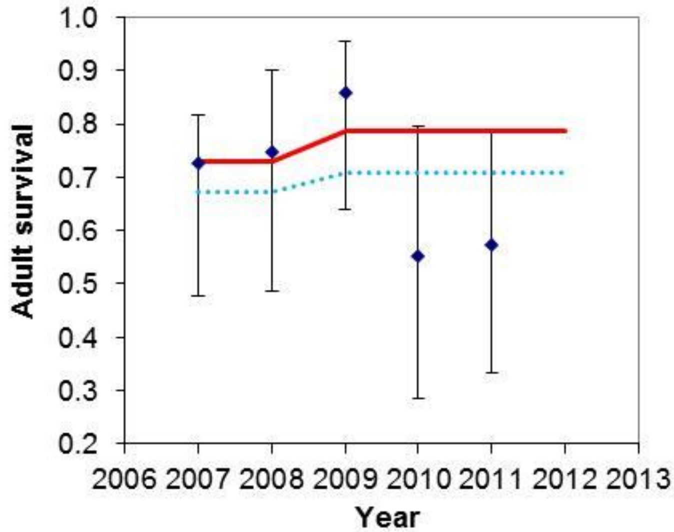

Figure 27: Estimates of adult female survival (red line) and adult male survival (blue line) from model 10, (Table 18).

To further explore potential bias caused by calf:cow ratios prior to 2009 we added a term that reduced female survival in the denominator of the OLS calf:cow ratio term. This reduced adult female survival to 0.67, which was equal to that estimated from the historic analysis of the Bathurst data up to 2009 (Boulanger et al. 2011). The resulting estimate of 2012 cow survival was 0.79. We therefore concluded that the general estimate of reduced adult female survival of 0.78 was reasonably robust to potential sampling issues with productivity estimates prior to 2009.

A potential issue with only using breeding female estimates from 2009 and 2012 was that the effect of the decline from 2006-2009 on productivity was not explicitly modeled. To investigate this we conducted additional runs that included the 2006 estimate and modeled the declining adult female survival rate during this interval. The resulting estimate of adult female survival for 2012 was 0.76 which suggested that the main effect of not including earlier data is a slight lowering of estimated 2012 adult female survival. The main conclusion from this exercise was that the estimate of adult survival of 0.78 would not be changed substantially and certainly not increased, by inclusion of earlier demographic data.

The OLS model is a deterministic model and it does not fully consider the level of variation and uncertainty in each of the demographic parameters. We were interested in how robust the estimated adult survival value was to the uncertainty in the 2012 breeding female estimate. In other words, if we assumed the base model for productivity, what would be the effect of varying adult female survival and what values of adult survival would be needed to cause the OLS model to predict higher breeding female population sizes? To explore this we used a range of values for adult survival and noted the corresponding estimate of breeding female size and trend in breeding female size. We also noted the AIC_c value that was generated that indicated how well a hypothesized adult survival value fit the model. Other productivity parameters were held constant and therefore the main factor influencing model fit was adult female survival.

Results of this sensitivity analysis suggested that adult female survival values of approximately 0.75-0.82 were possible with the corresponding OLS predicted breeding female size still occurring within the confidence limits of the field based breeding female estimate (Figure 28). The lowest AIC_c values corresponded to the point estimate of adult survival of 0.78.

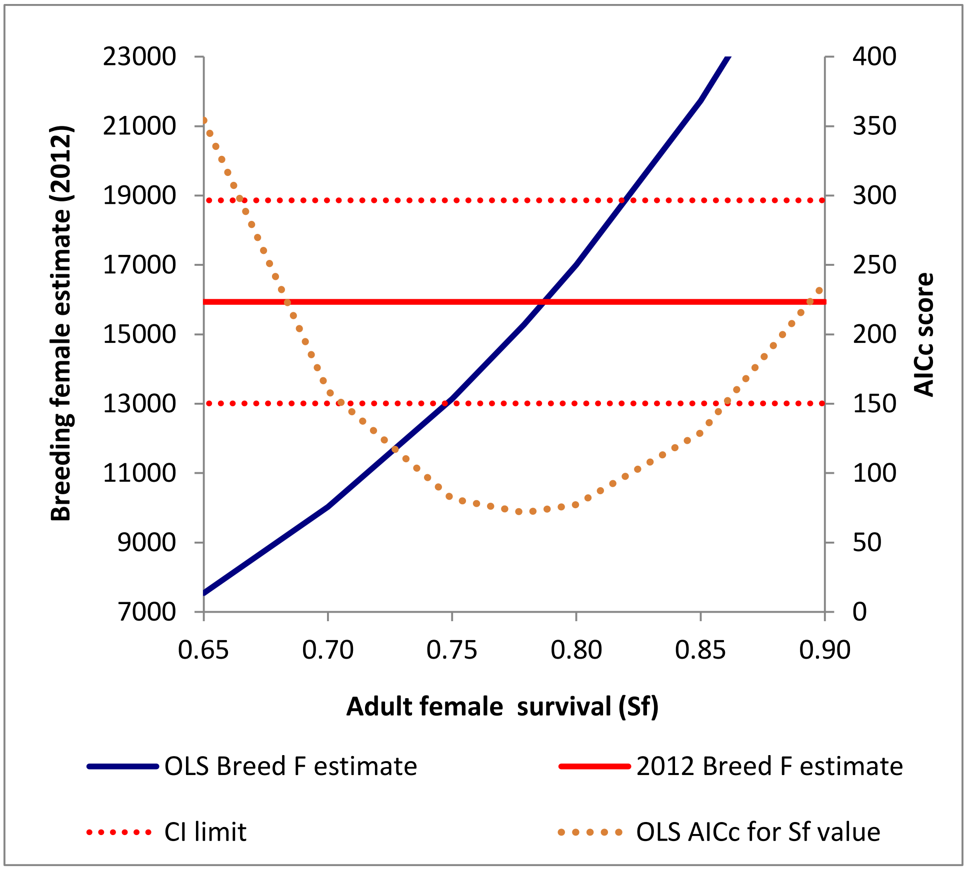

Figure 28: OLS model estimates of 2012 breeding female population size as a function of different values of adult female survival. The actual field estimate for 2012 is shown as a red line with corresponding confidence limits as dotted red lines. The predicted population estimate from the OLS model is shown as a blue line and the AIC_c score corresponding to the adult survival value is given as brown dotted line. Adult survival values with the lowest AIC_c score display the best fit to the data.

The sensitivity analysis demonstrates that if adult survival rates were at levels estimated in 2009 (0.67) the likely estimates of breeding females in 2012 would have been less than 9,000 caribou. If cow harvest levels of 3,000-5,000 caribou/yr would have continued then the adult survival value would have continued to decrease below 0.67 as that harvest would have been eliminating a successively higher proportion of the cow population (Boulanger et al. 2011). In this case, the number of breeding females would have been much lower than 9,000. Alternatively, if survival had increased to 0.85 the estimate would have been over 21,000 breeding female caribou.

In summary, the OLS model analysis suggests that the most likely level for adult female survival is lower than that needed for a stable herd. However, this result should be interpreted in the context of the overall uncertainty in the breeding female estimates (Figure 28) and the uncertainties in the modeling outcomes. 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).

DISCUSSION

The general results of this analysis suggest that the rapid rate of decline of the Bathurst caribou herd 2006-2009 has slowed substantially by 2012 (Figure 19). The relatively high precision of the breeding female estimate helps ensure that this result is robust to sampling variance. Compared to previous years, the core calving area was reduced in size (Figure 16), but densities of caribou within the calving ground were much higher. This allowed an efficient survey effort with relatively high coverage in the photographic strata. Given the high densities and variation in densities within strata (Figure 17), the higher coverage (71.9%) for the high density stratum provided high survey precision in the face of aggregated clusters of caribou within the survey strata.

The results of this survey likely reflect in large part the limited harvest strategy that was put in place after the 2009 survey. Prior to the 2009 survey 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). The OLS demographic analysis estimated that adult female survival rate was 0.78 [CI range=0.75-0.82 (Figure 28)] in 2012, as compared to the estimate based on the large decline from 2006-2009 of 0.67 (Boulanger et al. 2011). It is likely that one reason for the increase in survival rate is the reduction of harvest pressure. However, the adult survival rate is still not at levels estimated in 1986 (0.85) or as estimated based on the reduction of harvest of 0.87 (Boulanger and Adamczewski 2010).

One noteworthy difference between surveys was the much smaller extent of the calving ground core in 2012 compare to 2009 (Figure 16). The combined area of the high and medium strata for 2012 was 33% of the area of the 2009 high and medium strata (Nishi et al. 2010). However the average densities for the high and medium strata in 2009 were 6.76 and 2.49

caribou/km^2 compared to average densities of 23.1 and 3.0 caribou/km^2 in 2012 (Table 7). Caribou were basically congregated into a much smaller area at higher densities in 2012 compared to 2009. One potential reason for this is that there was virtually no snow cover and an earlier spring period in 2012, allowing easier travel conditions for caribou that may have resulted in increased congregation. Other factors, such as the influence of predators (that also would have had better travel conditions) may have resulted in increased aggregation as a response to predation. During the 2006 calving ground survey (Nishi et al. 2007), the average density in the high stratum (1,253.7 km^2) was 49.3 caribou/km^2 so the observed densities in the high density stratum in 2012 were similar during the two years. Densities in the range of 49 caribou/km^2 were observed on the central lines of the high stratum in 2012 (Figure 17). It could be argued that the relatively small size of the core calving area in 2012 was due to caribou exhibiting historic levels of aggregation, but the resulting area was smaller due to the lower overall population size of the herd.

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 one to three 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% [Kaminuriak, 1966 (Dauphine 1976)] to 48% [George River

Herd 1976-1982 (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 one to three years dependent on pregnancy rates of yearlings, two and three year olds. However, current trends in breeding females will reflect productivity for 2009 and years prior as well as relative survival rates for adult females up to the survey (Table 19). 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 19: A hypothetical timeline for a female calf that was born during the 2009 calving ground survey. Given that caribou do not breed until they are two to three years old the 2012 estimate of breeding females mainly reflects recruitment events that occurred in 2009 and years before. Pregnancy rates are based upon Dauphine (1976) and Bergerud et al (2008).

Group	**Year**				
	2009	**2010**	**2011**	**2012**	**2013**
Age class during survey	Calf	Yearling	2 year old	3 year old	4 year old
On calving ground?	Yes	maybe	maybe	More likely	Most likely
Classified/counted as a breeding female?	No	No	Less likely	**More likely**	**Most likely**
Bred in fall after c.g. survey? (*pregnancy rate*)	No (*0%*)	Less likely (*2-48%*)	More likely (*48-95%*)	Most likely (*82-96%*)	Very likely (*95-96%*)

The OLS model exercise provided a way to model the time-lags in productivity and assesses how this potentially affected the number of breeding cows in the 2012 survey. In the case of the OLS model, it was assumed that any caribou older than a yearling for the fall prior to a breeding survey had the potential to breed and the proportion of these adult female caribou breeding was estimated by the fecundity parameter. The data from 2007-2012 were considered in this analysis (Table 1) so that caribou that were calves in 2007 were available to be recruited into the breeding female age class for the 2012 survey. This analysis suggested that productivity had been reasonably good and that the estimated number of breeding females in

2012 was due partially to lower survival rates (0.78). If survival rates were higher then a larger number of breeding females would have been estimated. However, as noted earlier, the range of uncertainty in the 2012 estimate (as indicated by confidence limits) demonstrate that it is possible that adult survival was higher than that indicated by the point estimate of population size.

Management Implications and Recommendations

The results of the 2012 survey indicate that the herd size has somewhat stabilized when compared to the results of the 2009 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 1980s. Given this, 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 continued conservative, bull-dominated approach to caribou harvest would give the herd the best opportunity to recover. 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 an increase in number of collared caribou to 50-60, with some collars on bulls, to allow better determination of survival rates, which in turn will aid to determine how well the herd is recovering.

2. Continued monitoring of the number of breeding cows on 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.

3. The photo survey of the calving ground should be repeated in 2015 to allow for rigorous assessment of population size and trend.

The 2012 calving ground photo survey benefited from excellent survey and photographic weather conditions and resulted in one of the most precise surveys for this herd to date.

The results of the 2012 survey demonstrate that decline in population size of the Bathurst herd observed from previous surveys has been slowed. However, the current status of this herd is considered fragile given the fact that the number of breeding cows has not increased and that recruitment has been low in the past two years.

The future trend of the Bathurst herd is difficult to predict, 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 2013, 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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APPENDIX 1: Assessment of movement of collared caribou between the Bathurst, Ahiak and Bluenose-East calving grounds.

Records of movement of collared caribou from 2005-2012 were used to assess movements of adult cows between the Bathurst, Bluenose-East and Ahiak calving grounds. This analysis, originally conducted in 2010 (Adamczewski et al. 2009, Boulanger et al. 2011), used multi-state models (Hestbeck et al. 1991, Brownie et al. 1993, White et al. 2006) to estimate the probability of a cow "switching" calving grounds.

The question of movement between populations or areas has been addressed extensively as part of mark-recapture analyses of other wildlife species. In particular, multi-strata models (Hestbeck et al. 1991, Brownie et al. 1993) estimate emigration and immigration rates from different areas, which in the case of caribou are calving ground areas. Data for a multi-strata model is entered as a yearly encounter history with a caribou defined by what calving ground it was observed on. For example, say caribou 100 was seen on the Bathurst herd calving ground in 2000 but on the Ahiak in 2001, was not detected in 2002 and then detected in 2002 on the Bathurst. The data in the model would be entered as:

BA0B

where B denotes Bathurst herd, A denotes Ahiak herd and 0 denotes not observed. The model then uses this sequence to estimate the probability that a caribou that is on the Bathurst herd calving ground one year will be on the Ahiak calving ground the following year and vice versa. This is analogous to emigration/immigration rates between herds.

Multi-strata models estimate rates of movement (termed transition probabilities) between calving grounds, yearly survival and recapture rate. Yearly survival was not of interest in this analysis and we assumed that capture probability was 1. Namely, a caribou that had a collar had a probability of detection of 1 on the calving ground. Assumptions about herd-specific survival can affect movement estimates and so we investigated models that considered herd-specific and pooled survival rates. As part of program MARK (White and Burnham 1999), it was also possible to constrain multi-strata models to test particular hypotheses about movement between calving grounds. In particular, we investigated whether there was net emigration from the Bathurst calving ground that would be suggested if emigration rates from the Bathurst herd were distinctly different (larger) than immigration rates. There was no documented movement between the Ahiak and Bluenose-East and therefore movement rates between these two herds were fixed at 0. The fit of models was evaluated using the Akaike Information Criterion (AIC) index of model fit. The model with the lowest AIC_c score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). The difference in AIC_c values between the most supported model and other models (ΔAIC_c) was also used to evaluate the fit of models when their AIC_c scores were close. In general, any model with a ΔAIC_c score of <2 was worthy of consideration.

Records of radio collared caribou from 2005-2012 were considered for the multi-state analysis given that this period was most relevant to changes in breeding female population size between the recent (2006-2012) breeding female surveys. Two hundred eighty seven collared caribou were available for the analysis which extended from 2005-2012.

A summary of movement events (Table 20) was initially used to assess sample sizes in the data set. The previous and current strata summarized sequential movement events of caribou. For example, for the Bathurst calving ground, a caribou on the calving ground one year returned back to the calving ground the next year in 54 occasions. In three occasions, a caribou on the Bathurst calving ground occurred on the Ahiak calving ground in the following year. Caribou were only captured once and others were only captured once in (2012) and therefore could not contribute to estimation of movements. In general, there were few movement events where caribou switched calving grounds; fidelity to calving grounds was high.

Table 20: Summary of movement events from 2005-2012 for the Bathurst, Ahiak and Bluenose-East collared caribou.

Current stratum	Previous stratum			Other events		
	Ahiak	Bathurst	Bluenose-East	Detected once	First year of collaring	Totals
Ahiak	83	3	0	40	55	181
Bathurst	1	54	2	38	36	131
Bluenose-East	0	3	73	69	49	194
Totals	84	60	75	147	140	506

Model selection results suggested that there was not a detectable difference between emigration and immigration rates for the Bathurst-Ahiak or Bathurst-Bluenose-East (Table 21; model 1). Models that assumed that equal emigration rates of caribou to the Bluenose-East and Ahiak herd (model 2) and equal immigration from the Ahiak and Bluenose-East herds to the Bathurst herd, as well as model, that assumed equal immigration and emigration rates from adjacent herds (model 3) were also supported.

Table 21: Model selection results for multi-strata model analysis of movements between the Ahiak, Bathurst and Bluenose-East herds. Sample-size adjusted Akaike Information Criteria (AIC_c), difference in AIC_c between most supported and given model (ΔAIC_c), Akaike weight (w_i), the number of parameters (K) and deviance (an index of model fit) are given. Herds are symbolized by Bathurst (B), Ahiak(A) and Bluenose-East (E). Movement rates are symbolized by the ordering of herds. For example BA symbolizes movements from the Bathurst to the Ahiak.

No	Model	AIC_c	ΔAIC_c	w_i	K	Deviance
1	BA=AB=BE=EB, AE=EA	738.46	0.00	0.414	4	267.4
2	BA=BE, AB=EB, AE=EA	739.02	0.57	0.312	5	265.9
3	BA=AB, BE=EB, AE=EA	740.00	1.54	0.192	5	266.8
4	BA, BE, AB, EB, AE=AE	741.95	3.49	0.072	7	264.7
5	BA=AB=BE=EB=AE=EA	745.84	7.38	0.010	3	276.8

Model averaged estimates of probability of movement between herds suggested that rates of movement between calving grounds were low (<0.05) for all herds and that emigration and immigration rates were similar for herds adjacent to the Bathurst (Figure 29). There was a slight suggestion of higher rates of emigration than immigration for the Bathurst; however, this difference was not statistically discernible as suggested by overlap of confidence limits and support for a model that assumed equal rates of immigration and emigration for Bluenose-East/Bathurst and Bathurst/Ahiak calving grounds (Table 21; model 1).

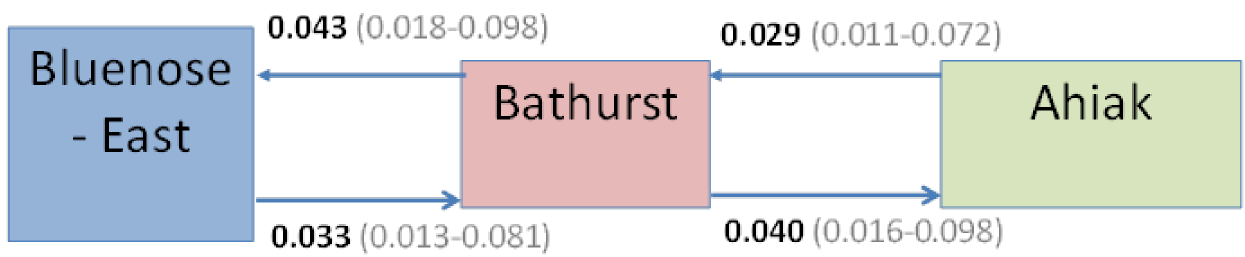

Figure 29: Model averaged estimates of movement from the multi-state model analysis (Table 21). Each arrow and associated estimate is the probability of directional yearly movement of collared caribou between adjacent calving grounds. Movement rates for the Bluenose-East to Ahiak and vice versa were estimated at 0 given that no movements of this type were observed (Table 20).

The general conclusion from this analysis was that net movement of caribou from the Bathurst to adjoining herds was very low. This finding and the fact that the relative population sizes of the Bluenose-East Herd and Ahiak herd are higher than the Bathurst, suggests that movement of caribou between calving grounds did not contribute significantly to the demographic variation within the Bathurst. This general finding of robustness of the Bathurst calving ground based on spatial affiliation of female caribou was also reported in the study of Nagy et al. (2011). The rates of exchange between neighboring herds in this study echo earlier results from Canadian caribou herds. Parker (1972) found that 20 of 442 (4.5%) ear-tagged Beverly caribou switched to the Qamanirjuaq range and 8 of 131 (6.1%) Qamanirjuaq caribou switched to the Beverly range in the 1970s. Similarly, Heard and Stenhouse (1992) placed 112 radio collars over four years on the Qamanirjuaq and neighboring herds and reported that four cows (3.6%) switched calving grounds. Elsewhere, just one of 175 cows (0.6%) radio collared between 1981-1990 switched calving grounds between the Mentasta and Nelchina herds in Alaska (Lieb et al. 1994).

APPENDIX 2: Effect of the number of transect lines surveyed and overall coverage on high density stratum estimates

The coverage for the high density stratum by the photo plane (71.9%) was higher than in previous Bathurst caribou surveys. The high degree of coverage was due to the relatively small size of the stratum and subsequent higher coverage resulting from the 22 lines sampled. Sampling 22 transect lines with resulting higher coverage ensured that a precise estimate would result given the highly clustered groups of caribou within the stratum.

To explore the effects of high coverage on survey precision and estimated caribou numbers (N), we randomly re-sampled transects from the high stratum and incrementally reduced the number of lines that went into the estimate of caribou. A bootstrap method was used where lines were resampled with replacement (Manly 1997). This method approximated precision and mean estimates if the stratum were sampled with a reduced number of lines and overall coverage. From this exercise, we found that we would have needed at least 20 lines (coverage=65%) to ensure a CV of less than 10% and at least ten lines (coverage=32%) to ensure a CV of less than 20% (Figure 30). A CV of 13.4% would have been obtained if coverage was 49% (15 transect lines). As expected, the actual mean estimate of N across re-samplings was approximately the same at different levels of coverage. The main effect of reducing coverage was reduced estimate precision.

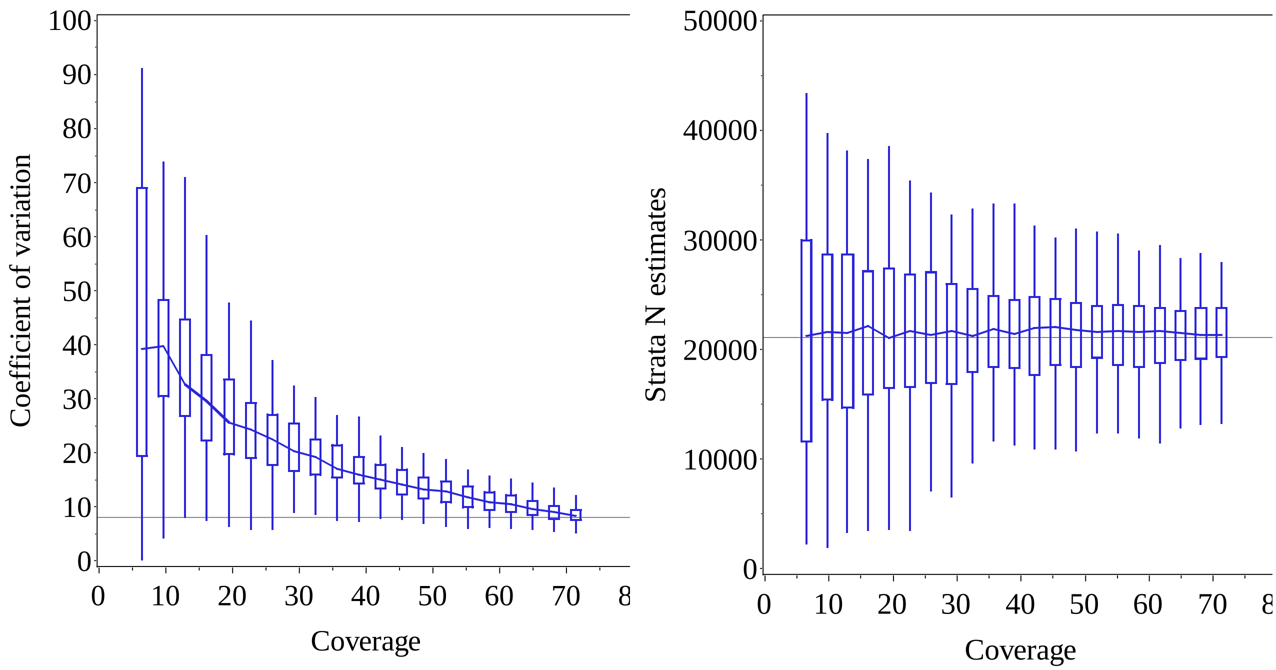

Figure 30: The effect of bootstrap randomized resampling of transect lines in the high photo stratum. The figure on the left shows the estimated CV as a function of coverage and the right figure shows the mean N estimate as a function of survey coverage. Each box delineates the 25th and 75th percentile and the upper and lower lines delineate the range of values observed in randomized resampling.

The main conclusion from this exercise was that there was not a noticeable asymptote in levels of precision at increasing coverage. This was most likely due to the clustered nature of caribou within the stratum (Figure 17). In general CV of 20% or less are required for management with optimal levels of precision at 10% or less for precise tracking of population trends as is needed for OLS model (Figure 22) and regression analyses (Figure 20). Therefore, our strategy of increasing coverage above 50% for the high stratum was justified in that it yielded a very precise estimate for the stratum. However, we emphasize that our sampling situation was unique in that caribou were situated in a relatively small area and therefore extra lines could be added with minimal cost compared to the usual sampling scenarios in which caribou are found within larger survey areas.

APPENDIX 3: Raw count data for photo and visual strata sampled on 6 June, 2012

Table 22: Count data for photo strata from surveys on June 6, 2012.

Stratum	Transect	Length (km)	Strip width (km)	Transect area (km^2)	Caribou (1+ yr) counted
High	1	32.65	0.9144	29.86	105
High	2	32.65	0.9144	29.86	181
High	3	32.65	0.9144	29.86	149
High	4	32.65	0.9144	29.86	275
High	5	32.65	0.9144	29.86	867
High	6	32.65	0.9144	29.86	891
High	7	32.65	0.9144	29.86	1,293
High	8	32.65	0.9144	29.86	553
High	9	32.65	0.9144	29.86	1,075
High	10	32.65	0.9144	29.86	1,438
High	11	32.65	0.9144	29.86	1,396
High	12	32.74	0.9144	29.94	1,398
High	13	32.74	0.9144	29.94	1,058
High	14	32.74	0.9144	29.94	1,095
High	15	32.74	0.9144	29.94	1,228
High	16	32.74	0.9144	29.94	362
High	17	32.74	0.9144	29.94	608
High	18	32.74	0.9144	29.94	698
High	19	32.74	0.9144	29.94	225
High	20	32.74	0.9144	29.94	38
High	21	32.74	0.9144	29.94	127
High	22	32.74	0.9144	29.94	141
Medium	1	19.98	0.9144	18.27	8
Medium	2	19.89	0.9144	18.19	25
Medium	3	19.89	0.9144	18.19	9
Medium	4	19.89	0.9144	18.19	7
Medium	5	19.89	0.9144	18.19	188
Medium	6	19.89	0.9144	18.19	190
Medium	7	19.87	0.9144	18.17	200
Medium	8	19.87	0.9144	18.17	13
Medium	9	19.87	0.9144	18.17	19
Medium	10	19.91	0.9144	18.21	27

Stratum	*Number*	*Breeding females*	*Non-breeders*	*Stratum*	*Number*
Medium	11	19.92	0.9144	18.21	5
Medium	12	19.94	0.9144	18.23	71
Medium	13	19.94	0.9144	18.23	1
Medium	14	19.94	0.9144	18.23	5

Table 23: Caribou counted in visual strata on 6 June, 2012.

Stratum	Transect	Length (km)	Strip width (km)	Transect area (km^2)	Caribou (1+ yr) counted
Low East	1	17.37	0.8	13.896	0
Low East	2	17.37	0.8	13.896	1
Low East	3	17.37	0.8	13.896	0
Low East	4	17.37	0.8	13.896	0
Low East	5	17.38	0.8	13.904	1
Low East	6	15.1	0.8	12.08	3
Low East	7	15.1	0.8	12.08	0
Low East	8	15.1	0.8	12.08	15
Low East	9	15.1	0.8	12.08	1
Low East	10	15.1	0.8	12.08	4
Low East	11	15.1	0.8	12.08	3
Low East	12	15.1	0.8	12.08	19
Low East	13	15.1	0.8	12.08	0
Low South	1	17.8	0.8	14.24	0
Low South	2	17.8	0.8	14.24	2
Low South	3	17.8	0.8	14.24	0
Low South	4	17.8	0.8	14.24	10
Low South	5	17.8	0.8	14.24	63
Low South	6	17.8	0.8	14.24	13
Low South	7	17.8	0.8	14.24	3
Low South	8	17.8	0.8	14.24	20
Low South	9	17.8	0.8	14.24	1
Low South	10	17.8	0.8	14.24	17
Low South	11	18.66	0.8	14.928	33
Low South	12	18.66	0.8	14.928	15
Low South	13	18.66	0.8	14.928	18
Low South	14	18.66	0.8	14.928	18
Low South	15	18.66	0.8	14.928	6

APPENDIX 4: Raw composition data for estimation of proportion breeding females

Table 24: Raw composition data from ground composition surveys on calving ground (6-8 June, 2012).

Stratum	*Number*	*Breeding females*			*Non-breeders*			
		Antlers/udders	No antler/udder	Antler/no udder	No antler-no udder	calves	yearlings	bulls
High	1	0	0	0	6	0	3	0
High	2	22	10	10	33	14	25	0
High	3	9	2	13	24	1	28	0
High	4	15	2	16	37	8	26	0
High	5	25	10	13	17	35	22	0
High	6	32	15	55	36	31	49	0
High	7	14	14	12	8	15	15	0
High	8	18	13	15	7	24	17	0
High	9	11	7	12	12	13	13	0
High	10	3	0	12	6	3	12	0
High	11	8	5	20	10	11	13	0
High	12	87	30	33	29	91	31	0
High	13	74	44	12	2	101	6	0
High	14	42	14	3	6	50	3	0
High	15	54	13	7	2	68	1	0
High	16	16	1	10	12	13	7	0
High	17	41	7	19	16	51	16	0
High	18	0	0	0	1	0	2	0
High	19	13	0	2	0	12	1	0
High	20	32	5	14	1	42	6	0
High	21	1	0	0	1	0	0	0
High	22	1	0	5	3	4	3	0
High	23	4	2	1	3	5	16	0
High	24	1	1	1	3	1	4	0
High	25	6	12	11	11	20	22	0
High	26	43	38	18	7	79	4	0
High	27	72	59	3	5	120	2	0
High	28	11	5	7	5	14	0	3
High	29	22	31	6	8	55	0	0
High	30	3	1	11	8	2	16	0
High	31	32	42	18	3	84	1	0
High	32	13	14	40	10	24	41	0
High	33	34	20	32	39	59	16	0
High	34	21	3	11	3	30	0	0

Stratum	*Number*	*Breeding females*	*Non-breeders*					
		Antlers/udders	No antler/udder	Antler/no udder	No antler-no udder	calves	yearlings	bulls
High	35	1	1	6	11	2	7	0
High	36	5	0	1	2	3	13	0
High	37	0	0	2	7	0	9	0
High	38	5	0	0	7	5	0	0
High	39	37	5	14	8	23	24	0
High	40	18	0	2	18	25	13	0
High	41	26	44	3	3	69	9	0
High	42	67	62	1	6	104	1	0
High	43	10	6	0	3	10	4	0
High	44	53	56	3	12	140	0	0
High	45	38	28	7	5	55	6	0
High	46	75	35	4	3	100	0	0
High	47	49	20	3	6	65	8	0
High	48	25	14	5	6	40	3	0
High	49	2	3	0	3	5	1	0
High	50	3	1	1	2	4	2	0
High	51	17	18	0	4	25	1	0
High	52	42	10	1	4	50	3	0
High	53	34	6	5	0	40	9	0
High	54	0	0	5	2	0	1	0
High	55	13	5	9	3	20	5	0
High	56	6	0	20	12	1	42	0
High	57	0	0	17	10	0	30	0
High	58	6	4	94	78	7	31	0
High	59	25	5	15	28	27	19	0
High	60	125	41	0	43	129	32	0
High	61	54	42	8	27	98	17	0
High	62	65	29	7	18	79	6	0
High	63	11	11	4	5	20	0	0
High	64	27	7	0	8	32	3	0
Medium	1	0	2	0	2	3	0	0
Medium	2	5	0	0	3	5	5	0
Medium	3	0	0	1	0	0	3	0
Medium	4	15	20	3	12	31	18	0
Medium	5	9	7	2	25	7	3	0
Medium	6	0	1	6	3	1	3	0
Medium	7	6	9	1	2	36	4	0
Medium	8	16	71	2	4	74	3	0
Medium	9	16	64	9	24	76	20	0
Medium	10	1	1	0	1	2	3	0
Medium	11	3	8	0	5	9	1	0
Medium	12	23	69	2	1	85	3	0

Stratum	*Number*	*Breeding females*	*Non-breeders*					
		Antlers/udders	No antler/udder	Antler/no udder	No antler-no udder	calves	yearlings	bulls
Medium	13	1	0	7	7	1	5	0
Medium	14	2	5	0	4	7	2	0
LowS	1	0	0	1	2	0	6	0
LowS	2	0	0	3	3	0	4	0
LowS	3	0	0	0	7	0	14	0
LowS	4	0	0	1	2	0	1	0
LowS	5	0	0	0	9	0	9	0
LowS	6	0	0	0	3	0	0	0
LowS	7	0	0	0	3	0	8	0
LowS	8	0	0	0	3	0	1	0