An Estimate of Breeding Females in the Bathurst Herd of Barren-ground Caribou, June 2009

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ABSTRACT

We used the calving ground photographic survey technique to estimate abundance and distribution of breeding females in the Bathurst herd of barren-ground caribou *(Rangifer tarandus groenlandicus)* in June 2009. In late May 2009, we started monitoring movements and locations of satellite collared Bathurst cows (n=11). We used Tahera Mine, located by the northwest end of Contwoyto Lake as our base of operations and started systematic aerial surveys on 4 June. The distribution of satellite collared cows provided the means of distributing survey effort during the initial systematic surveys. We then used observations of relative caribou density and composition (presence of hard antlered cows and/or newborn calves) to define the annual calving ground. Due to concerns regarding the declining trend of the Bathurst herd, we ensured that our systematic coverage was extensive so that large groups of breeding females were not missed. On 7 June, we delineated the annual calving ground a second time and stratified it into one high density (photographic) stratum, one medium density (photographic) strata and three low density (visual) strata. We initiated the photographic survey of the high density stratum on 8 June and completed photography of the medium density stratum on 9 June. Visual surveys of low density strata were flown with a fixed wing aircraft on 8 June. We used a helicopter to complete the composition surveys in high, medium and low density strata from 8 to 11 June. Based on the combined results of visual surveys in the low density strata and photographs of transects in the medium and high density strata, we estimated that there were 23,273 ±2,788 (SE) 1^{+}-year-old caribou on the annual calving ground. After adjusting this estimate by the proportion of breeding females observed during the composition surveys, we estimated that there were 16,650 ±2,181 (SE) breeding females in the survey area. The high density stratum contributed 76% of the

estimated number of total caribou and 72% of the breeding females. The proportion of breeding females in the high density strata was *ca.* 68% ± 4% (SE). The estimate of breeding females in June 2009 was relatively precise (CV = 0.13), and substantiates results of the June 2006 Bathurst caribou survey. The June 2009 survey confirms that the abundance of breeding females in the Bathurst herd has significantly declined since 1986; it also suggests an accelerated rate of decline since the June 2006 survey. If the observed rate of decline continues over the next several years, the estimated number of breeding females may decline to *ca.* 8,300 animals by June 2012, i.e. 50% of the June 2009 estimate.

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INTRODUCTION

The Bathurst herd is a population of migratory barren-ground caribou *(Rangifer tarandus groenlandicus)* that has traditionally calved near Bathurst Inlet in the Kitikmeot Region of Nunavut (Sutherland and Gunn 1996). The annual range of the Bathurst herd occurs mostly within the Northwest Territories (NWT) and Nunavut (NU), but also extends in some years into northern Saskatchewan (Figure 1). There are ten aboriginal communities on or near the range that rely on Bathurst caribou as a source of country food (Bathurst Caribou Management Planning Committee 2004). The Bathurst herd has also provided important economic opportunities for commercial harvesting by the guide/outfitting industry (Ashley 2000), and has been used extensively by resident hunters. Due to the proximity of Yellowknife to the winter range of Bathurst caribou and ready access from all-weather and winter roads, the Bathurst herd has been one of the most heavily hunted barren-ground caribou herds in the NWT (Case et al. 1996).

Regular calving ground surveys are a core monitoring action for Bathurst caribou, and survey frequency is tied to status and trend of the herd (Bathurst Caribou Management Planning Committee 2004). Recent surveys of the Bathurst herd were completed in June 2003 (Gunn et al. 2005) and June 2006 (Nishi et al. 2007) and showed that the estimated number of breeding females had declined significantly since 1986. Because of the declining trend and ongoing management concern regarding the low population numbers of the Bathurst herd, the Government of the Northwest Territories (GNWT) committed to conducting calving ground surveys at three-year intervals (GNWT 2006).

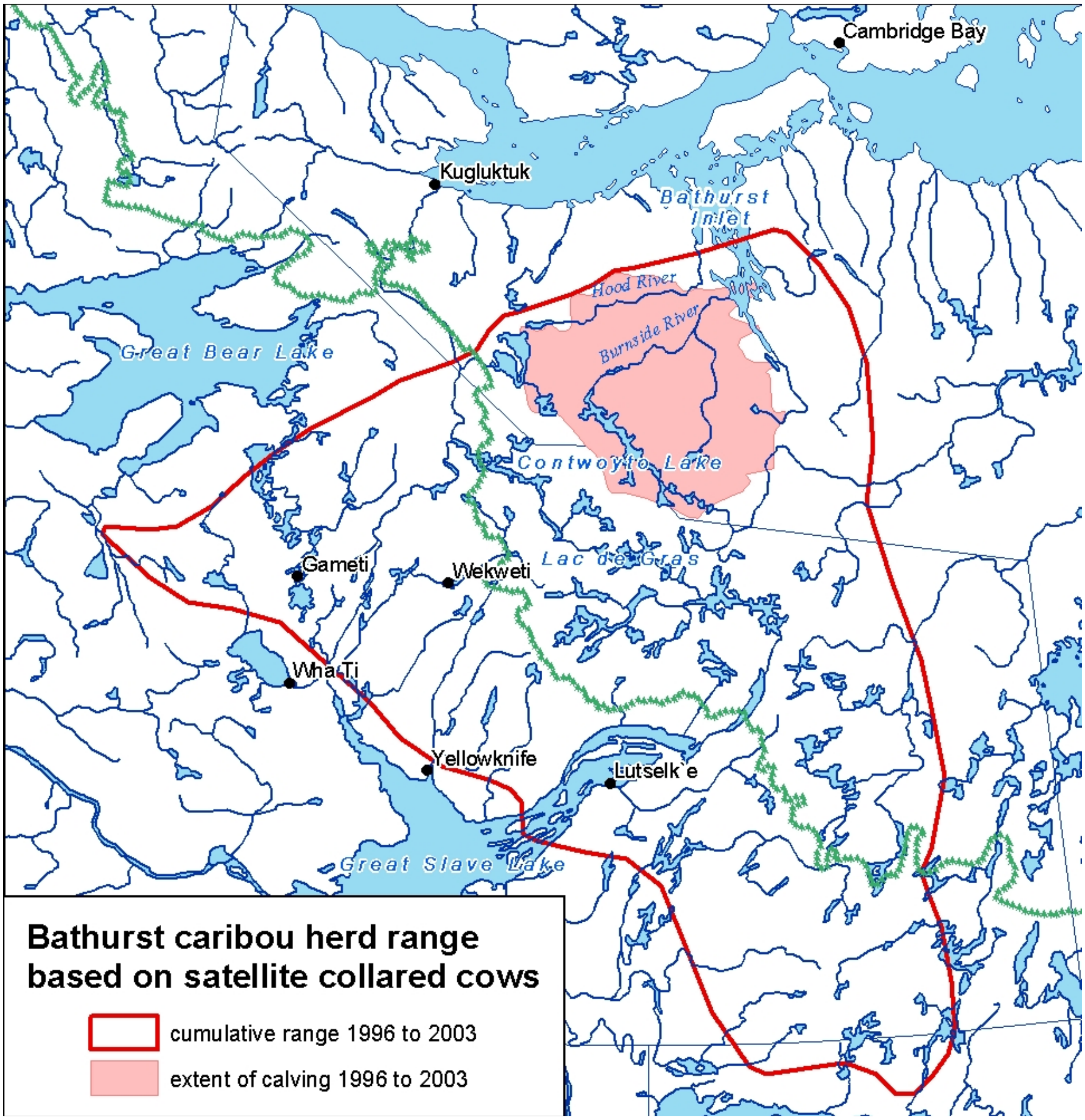

Figure 1. Herd range of Bathurst caribou based on satellite collared cows from 1996 to 2003 (p.8 in Bathurst Caribou Management Planning Committee 2004).

In this report, we describe the June 2009 calving ground survey of the Bathurst herd. To maintain comparability with previous surveys, we used the calving ground photographic survey method to estimate the number of breeding females on the annual calving ground. This technique was developed and tested in the early 1980s (Heard 1985, Heard and Williams 1990, Williams 1994) and has been used since for barren-ground caribou herds in the NWT. The rationale for using aerial photography was to reduce bias and increase accuracy of survey estimates. Mowat and Boulanger (2000) highlighted more recent discussions and recommendations to improve precision of calving ground surveys, and Gunn et al. (2005) described and implemented changes to survey design for improved precision starting with the June 2003 photographic survey of the Bathurst herd.

Our objectives for the survey in June 2009 were:

- To obtain an estimate for the number of breeding females on the annual calving ground with a coefficient of variation (CV) of $\leq$15%;
- To determine the trend in number of breeding females on the calving grounds;
- To estimate the ratio of breeding females to total females at the peak of calving as an indicator to pregnancy rates comparable to previous years; and
- To delineate the spatial extent of the annual calving ground.

METHODS

Study area

The study area was defined by the extent of calving for the Bathurst caribou herd over the past 10 years (Figure 1). Since 1996, the seasonal movements and annual range of the Bathurst caribou herd have been monitored using radio collars with satellite transmitters. Telemetry studies summarized by Gunn et al. (2001), Griffith et al. (2001), and Gunn and D'Hont (2002) as well as aerial surveys by Gunn (1996), Gunn et al. (1997 and 2005) and Nishi et al. 2007, have shown that the extent of calving has occurred west of Bathurst Inlet (Figure 1) since the mid-1990s. Previously it had been documented to the east.

Monitoring satellite collars and mobilization of field crews

We anticipated that the annual calving ground would be in or near the same area as in recent years – generally between the Hood and Burnside Rivers, west of Bathurst Inlet. Starting in early May 2009, we closely monitored the movements and observed locations of 11 satellite collared Bathurst caribou cows to track their progress (Figure 2) relative to the known extent of calving over the past 13 years.

On 3 June 2009, we mobilized field crews (JA, JB, BC, FC, ND, RF, GM, JN; see Appendix A) from Yellowknife using a Cessna Caravan (Appendix B). Our base of operations for the survey was Tahera Mine (66°01.2' N 111°28.2' W). A second survey aircraft – a Turbo Beaver – and additional field crew members (JB, KC, AK; see Appendix A) arrived on 6 June (Appendix B).

Aerial systematic reconnaissance surveys

We used a standardized methodology for visual strip-transect aerial surveys of barren-ground caribou; survey altitude was 120 m AGL, survey speed was *ca.* 160 kph, and total transect width was 0.8 km (400 m strip width per side). We used 50 cm lengths of wooden doweling (*ca.* 1.5 cm diameter) as markers to demarcate the outer edge of the strip-transect on the wing struts of survey aircraft. We used the methods outlined by Norton-Griffiths (1978) to position the strip markers and attached the dowelling to aircraft wing struts using black electrical tape and duct tape. We marked out 400 m from the southern end of the Tahera mine airstrip and had a service van parked temporarily at the marked distance after the survey aircraft was airborne. We checked the strip markers by having the pilot fly at survey altitude along a perpendicular axis to the airstrip with the aircraft positioned so that the southern end of the runway marked the inside of the transect and observers determined whether the parked van aligned with the strip markers on the wing struts. Left and right observers verified the strip marker positions on the wing struts against the distance markers on the ground, or adjusted them as necessary after the plane was back on the ground.

We used a systematic aerial survey design within the extent of calving to achieve three objectives:

1) delineate the annual calving ground based on relative densities and composition of caribou (see Appendix M);
2) at peak of calving (i.e. when >50% of calves are born) stratify the annual calving ground for a photographic survey of high and medium density strata and a visual survey of low density strata; and

3) survey an extensive area *ca*. 100 km beyond the annual calving ground to confirm that we did not miss any large groups of breeding females.

We used the methodology described by Gunn et al. (2005) and adapted from Williams (1994), in which a landscape level 10 km survey grid was applied to the known extent of calving for the Bathurst herd since the mid-1990s. Using the 10 km survey grid, we flew north-south transects with a coverage of *ca*. 8% (i.e. transects spaced at 10 km intervals).

We used navigation and data management techniques that combined portable Global Positioning System units with ESRI ArcView mapping software. Observational data were compiled and analyzed in Microsoft Excel to calculate densities within 10 km transect segments, and displayed in ArcView to produce maps that showed relative caribou densities, as well as the presence of antlered cows (indicating parturient females) and/or calves for each segment. On a daily basis we plotted survey data on digital maps of the study area to analyze observed patterns of caribou density and composition, and to plan subsequent survey tasks.

Our overall strategy for the systematic survey was to cover the known calving distribution since 1996 (Appendix M), and also include a large peripheral buffer to demonstrate clearly that we found the annual concentrated calving area – the area of relatively high use within an annual calving ground (*sensu* Russell et al. 2002) – and did not miss any substantial groups of calving caribou.

We started the systematic reconnaissance survey on the 4 June 2009 with the Cessna Caravan, and conducted the initial flight so that it encompassed the distribution of nine satellite collared cows that were located within the spatial distribution of calving.

This allowed us to survey the area that we initially thought would encompass the annual calving ground, and apply criteria on observed densities and relative composition of caribou to complete an initial delineation of the calving ground.

We selected the initial flight to cover the most recent locations of the satellite collared cows, and adapted the criteria described by Gunn et al. (2005) to end transects lines. As the northern distribution of the annual calving ground would have been a leading edge, our main criterion for ending a transect was the absence of caribou in the northern-most segment of a transect. As the southern ‘edge’ was more likely to reflect a trailing distribution, the absence of caribou in a 10 km segment was likely a less useful criterion because we expected to observe groups of non-breeders following the breeding females towards the calving grounds. Consequently, we used the criterion of <10 hard-antlered caribou within a southern-most segment unless a calf was present to determine whether to continue flying south. However, during the actual survey, we often continued flying south along transect until we saw no caribou in a 10 km segment; this conservative approach ensured that there was a clear break in the distribution of caribou.

We continued the systematic survey to progressively cover a larger portion of the extent of calving. From 6 to 8 June, a Turbo Beaver was also used to conduct the systematic survey. To determine whether we were approaching the peak of calving, we also estimated the proportion of calves in the concentrated area of calving, relative to observations from the systematic survey on 4 June. On 6 and 7 (a.m.) June, we re-flew some transect segments that had been surveyed on 4 June; observers counted or estimated the proportion of calves along with the group size of all 1^{+}-year-old caribou. Based on those observations we used two fixed wing aircraft to resurvey and delineate the annual calving ground on the afternoon of 7 June so that we could subsequently design the stratified photographic and visual survey.

Concomitant with the start of the photographic and visual survey of the calving ground, we used the Turbo Beaver to continue the systematic survey in the area northwest of the annual calving ground on 8 June. The Cessna Caravan resumed the systematic survey on 9 to 10 June to extend coverage to the south and east to Bathurst Inlet. On 17 June, the Cessna Caravan was used to extend coverage of the systematic survey to the area directly south and southeast of Kugluktuk, NU. The purpose of the survey was to ensure continuous systematic coverage between the eastern edge of the Bluenose-East calving ground distribution and the western extent of calving for the Bathurst herd, and to confirm that there were no large aggregations of breeding females between the two expected calving grounds.

Stratification of the annual calving ground for photographic and visual surveys

On the evening of 7 June, we delineated a single high density stratum with an adjacent medium density survey stratum. We also delineated three low density strata. Our stratified survey design for the annual calving ground was based on a combination of photographic survey methods for high and medium density strata, and standard visual aerial survey methods for low density strata. We used spatial patterns of breeding females and relative caribou densities within 10 km segments from aerial systematic reconnaissance surveys to delineate and stratify the annual calving ground. We delineated strata by enclosing adjacent segments that comprised breeding females (i.e. hard antlered females with or without calves and non-antlered females with newborn calves) of similar densities classes. We used density classes of high, ≥10 caribou/km^2; medium, 1.0–9.9 caribou/km^2; and low, 0.1–0.9 caribou/km^2).

As outlined by Gunn et al. (2005), we also specifically considered five issues in designing the survey and delineating strata on the annual calving ground:

1) Variance among observed caribou densities of transect segments within a stratum should be minimal.
2) In addition to observed densities, the presence of newborn calves and hard antlered cows within 10 km grid segments and the spatial dispersion of those segments were important factors in delineating survey strata.
3) Strata should be large enough to accommodate the anticipated movements of caribou between the time when the systematic reconnaissance survey and stratification are completed, to the time when transects in the strata are actually photographed by the photo plane.
4) The stratum baseline should be sufficiently long enough to allow for a minimum of 10 transects as a sample size.
5) Transect lines should be of similar length to minimize variance.

To minimize variance between numbers of caribou photographed / counted on transects, we oriented transects to run north-south so that we sampled along the predominant density gradient. We initially determined the allocation of survey effort, i.e. the number of available photographs, by estimating mean population size and variances for each stratum (Heard 1987). However, because of the small combined areas of the high and medium strata, we allocated effort to ensure that there were at least 10 transects in the medium strata (*ca.* 20% coverage), and maximized effort in the high density strata to achieve *ca.* 40% coverage, which required 22 transects.

Aerial photographic survey for estimation of caribou in high and medium density strata

We contracted Geographic Air Survey Ltd., Edmonton, Alberta (AB), to conduct the aerial photography. The survey aircraft was an Aero-commander equipped with a belly mounted camera (Wildle RC40 camera with forward motion compensator) and radar altimeter, and the crew consisted of a pilot and cameraman. The camera system was linked to a GPS navigation system that would fly the plane in an auto-pilot mode and permit the camera to take geo-referenced aerial photographs while on transect. In order for the pilot and cameraman to run their survey aircraft and camera, the aircraft GPS navigation needed to be pre-programmed with transect coordinates.

After completing the survey design, (i.e. delineation of strata and allocation of effort) we sent electronic files with stratum boundaries and start / end coordinates for all transects in the high and medium density strata to Geographic Air Survey's office in Edmonton, AB on the evening of 7 June. On the morning of 8 June, the aerial photography survey crew arrived at Tahera Mine to start the photographic survey. To ensure a proper sun angle (25-30°), aerial photography was conducted between 0800h–1830h. The intended scale of the aerial photography was 1:4,000, necessitating an approximate altitude of 1,100 m AGL. Approximate speed of the photo plane was 260 kph.

Aerial survey for visual estimation of caribou in low density strata

On 8 June, we used a Cessna Caravan with a pilot, navigator, left and right observers to survey the two low density strata and obtain a visual estimate of caribou numbers. Survey altitude was 120 m AGL, survey speed was 160 kph, and total strip width was 0.8 km (400 m strip width per side).

Sex and age composition survey

We started composition surveys on 8 June to estimate the proportion of breeding females within the high, medium, and low density strata. Due to time limitations on the helicopter, and the importance of collecting composition data on the same days of the photo and visual surveys, our main priority was to collect composition data from high and medium photographic strata initially. Remaining time was allocated for adjacent low density visual strata on 11 June. We used the midpoints of the 10x10 km segments within a stratum to distribute our search effort.

We used an Aerospatiale A-Star (AS350) helicopter with a three or four person crew [pilot, navigator, and observer(s)] to spot groups of caribou for classifying. The pilot approached caribou groups in a manner that minimized aircraft noise and landed 100-500 m away. A two (or three) person field crew would then approach caribou on foot. One person would classify caribou using binoculars or a spotting scope and the second person would record the data. To avoid double counting, the observer would scan and classify progressively from one side of their field of view to the other. The intent was to classify caribou as animals walked away slowly because this presented the observer with an optimal view of the hind end by which they could readily observe key characteristics of breeding females, (i.e. vulva patch and udder). In low density strata where groups were scattered and group sizes were usually smaller than 20, the front seat observer would classify caribou from the helicopter. For groups larger than 30, the helicopter would land and field crews would use the same ground-based techniques as those used in the high and medium strata.

We classified caribou into the following categories: breeding females, non-breeding females, yearlings, bulls, and calves (see p. 6 in Gunn et al. 1997). We identified breeding females (pregnant and post-partum) by the presence of hard antler(s) and/or a distended udder. Cows without hard antlers and without a calf at heel but with a distended udder were considered breeding females that had probably lost their calves. Non-breeding females were characterized by the absence of a distended udder and usually had new antler growth (although it is possible to observe a bald cow that would not have any antler growth). Yearlings were distinguished based on their relatively small body size and short faces. Bulls were easiest to classify consistently because of their relatively large antlers in velvet, large body size, and broad faces and muzzles.

Data analyses

Data from satellite collared cows

Location data from most satellite collared cows were available multiple times a day. We used successive locations at *ca.* 1500h to calculate daily distance travelled using the great circle distance (D):

$$\cos D = (\sin a \sin b) + (\cos a \cos b \cos|\delta\lambda|),$$

where a and b are the geographic latitudes of the two locations and $|\delta\lambda|$ is the absolute value of the difference in the two geographic longitudes (Robinson et al. 1995). We calculated daily distance travelled, by the distance between successive locations at 24 hour intervals (Appendix C). We then calculated the average distance travelled by all collared cows for which we had locations.

We used the Hawth's AnalysisTools © 2002-2006 Version 3.26 (Beyer n.d.) in ArcGIS to create minimum convex polygons (MCP) by date for the satellite collared cow locations.

Data from aerial surveys

We compiled observations of caribou for each transect within low density strata. Depending on whether transect lengths were the same, we used either the Jolly 1 or Jolly 2 method (Jolly 1969) for equal and unequal sample units, respectively. We used the program Aerial (Krebs 1992, Program 3.5) to calculate population estimates and variances.

We contracted Paul Roy (H.P. Roy, Ottawa, Ontario) to count all 1^{+}-year-old caribou on the photographs using a stereoscope. Caribou counts within each photograph were summed across all the photographs along a transect. We checked that the intended scale of 1:4,000 for the aerial photographs was correct by comparing distances on 1:250,000 scale maps to distances on the photographs. Population estimates for the high and medium density strata were calculated using the Jolly methods in the program Aerial.

Data from composition surveys

We calculated the mean proportion (and variance) of breeding females within each stratum by analyzing composition data using Cochran's (1977) jackknife method in a Microsoft Excel spreadsheet (Appendices H, I, and J). We estimated the number of breeding females on the calving ground by multiplying the mean population estimate for each of the strata by the mean proportion of breeding females calculated for each respective stratum. We were not able to collect compositional data from one low density strata (low-N) due to scarcity of caribou and time restrictions. Due to low densities of caribou in the low-SW and low-SE, we calculated the proportion of breeding females based on group observations pooled across the two strata, and also extrapolated that estimate to the low-N stratum.

Trend analyses

We incorporated the population estimate of breeding females from the 2009 survey into a longer term trend analysis on the Bathurst herd. We used three methods to estimate the trend in the estimated number of breeding females from 1986-2009 (see Appendix K):

1) For the two most recent surveys, we used methods described in Section 4.2.1.4 of Gasaway et al. (1986) to conduct a one-tailed t-test and determine whether the number of breeding females had declined since the last survey, i.e. was the estimate of breeding females in 2009 significantly lower than the 2006 estimate?
2) A weighted least squares analysis was used to estimate trend from the full time series of data (Appendix K).
3) Monte Carlo simulation techniques were used to estimate the variance in trend that resulted from individual variances of each of the surveys since 1986.

RESULTS

Satellite collared caribou cows

We monitored movements and locations of 11 satellite collared Bathurst caribou cows (Figure 2, Appendix C) from May through June. Cow # 212 was considered to be a non-breeder based on her location west of Contwoyto Lake and comparatively high rate of movement throughout the calving period (see Figure 2, Appendix C). It was not included in subsequent analyses. Sample sizes of collared cows used to determine daily locations and movement rates in May and June are shown in Figure 3.

The average daily movement rates of collared cows ranged from ~6-16 km/day during the first three weeks in May (Figure 4). Mean daily rate of movement increased and remained elevated (ranged from ~14.2-20.1 km/day) through the last 10 days of May, and then showed a constant rate of decline through early June. Average daily movement rates were less than 5.0 km/day from 8-15 June, with the lowest rate of movement, 2.0±2.7 km/day (SD), observed on 11 June 2009 (Figure 4). Subsequently, from mid-June to the end of June, average daily movement rates increased steadily.

The coefficient of variation in average daily movement rates did not exhibit an obvious pattern during the 8-15 June and ranged from a low of 0.17 on 10 June to a high of 0.36 on 12 June (Figure 5). Over a longer time frame, the CV in average daily movement rates showed a decrease in variance from 12-29 June (Figure 5).

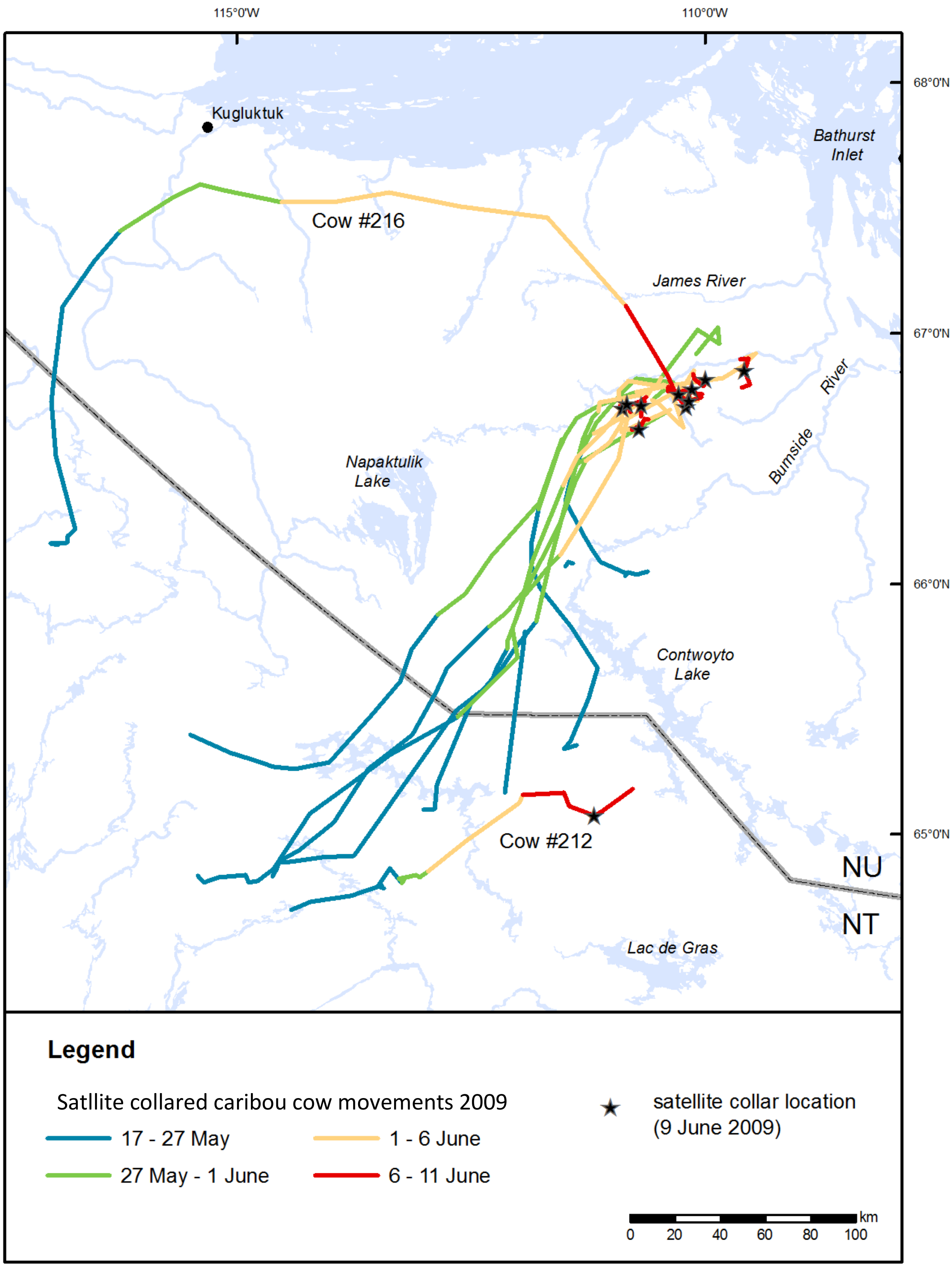

Figure 2. Movements of satellite collared Bathurst caribou cows from 17 May - 30 June 2009.

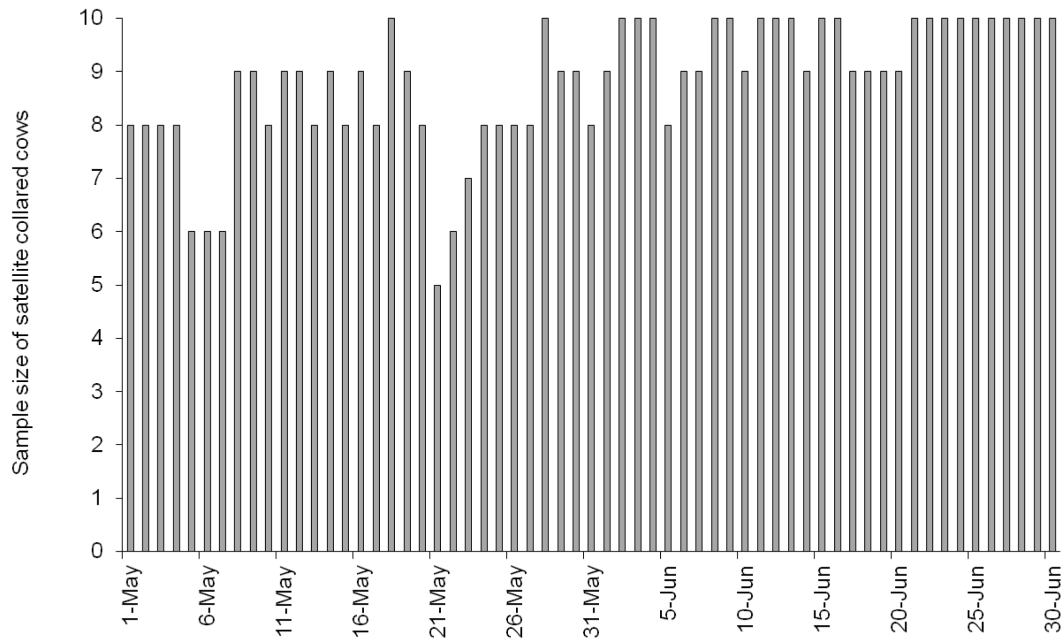

Figure 3. Sample sizes of satellite collared Bathurst caribou cows used to calculate daily movement rates and minimum convex polygons from May through June 2009. All cows presumed to be breeding females (see Appendix C).

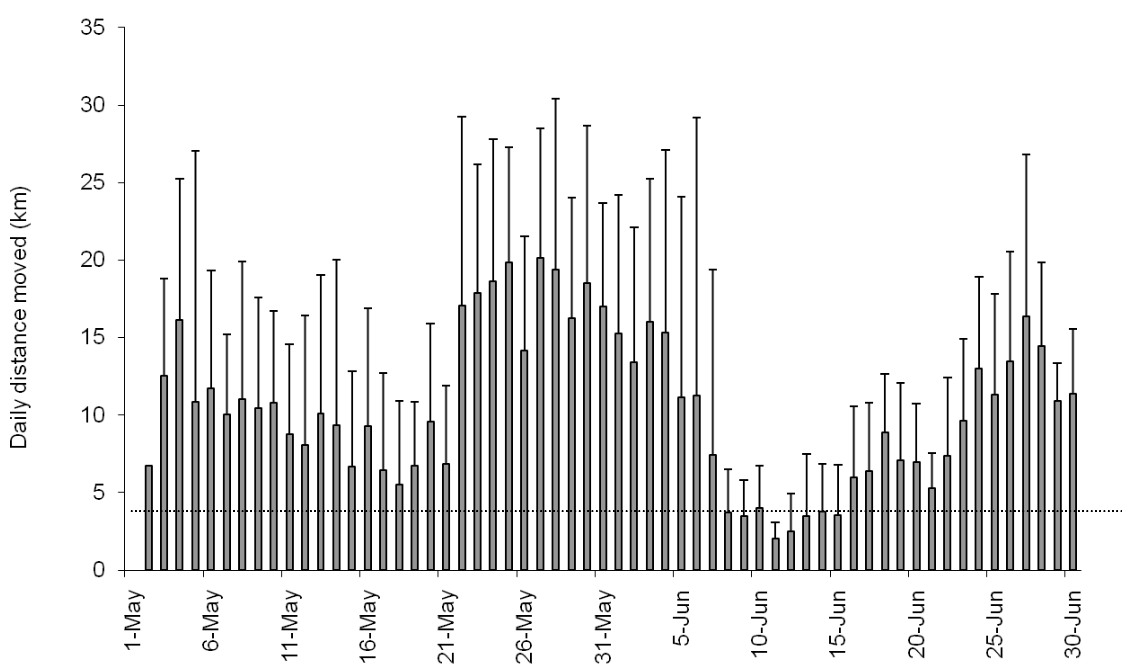

Figure 4. Average daily distance (km + 1 standard deviation) moved by satellite collared Bathurst caribou cows (presumed to be breeding animals) during May and June 2009.

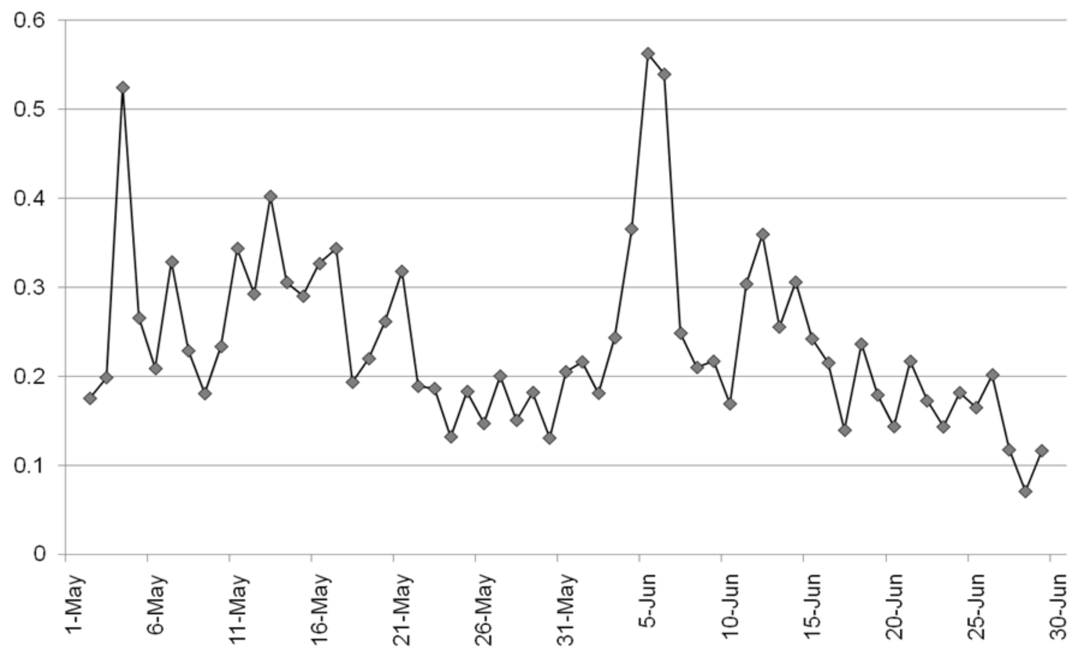

Figure 5. Trend in the coefficient of variation (CV) of daily distance movement rates of satellite collared Bathurst caribou cows (presumed to be breeders) from May through June 2009.

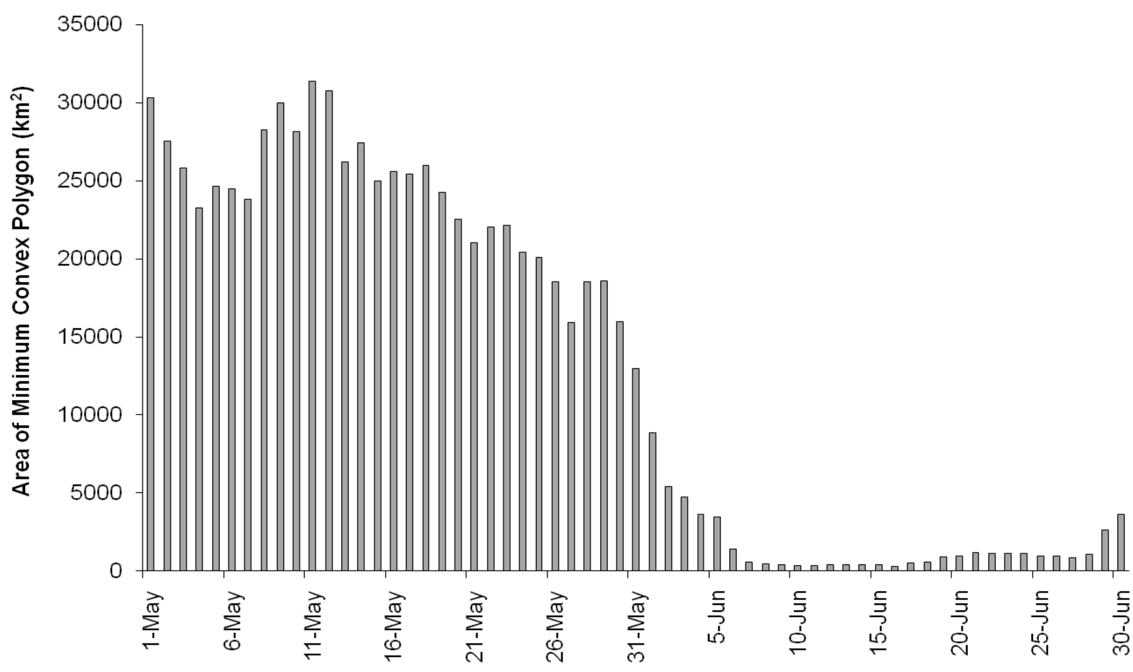

Figure 6. Area (km^2) of minimum convex polygons (MCP) for satellite collared Bathurst caribou cows (presumed to be breeding females) from May through June 2009.

The trend in dispersion of collared caribou was represented by the change in area of the minimum convex polygon (MCP) that enclosed ten satellite collared cows on any given day from 1 May - 30 June (Figure 6). Aggregation of breeding cows increased as area of MCP decreased; this spatial trend showed that the MCP enclosing the collared animals was steadily getting smaller and average distance between breeding females was decreasing as caribou cows travelled to and congregated on the annual calving ground. The first week of June showed a marked reduction in area occupied by the ten satellite collared cows, and MCP was strongly influenced by the location and movement pattern of cow #216 (Figure 2, Appendix C). Cow #216 showed a dramatic pattern of movement because she appeared to be displaying a movement pattern consistent with the spring migration of the Bluenose-East herd: in late May, she was *ca*. 20 km south of Kugluktuk but then over a six day period (2-8 June), she travelled quickly to the east and south and was on the concentrated annual calving ground of the Bathurst herd at about the peak of calving (Figure 2).

By 7 June the MCP of the ten collared cows had declined to 568 km^2, from a high of 31,400 km^2 on 11 May (Figure 6). From 8-16 June, the collared cows were enclosed by the smallest MCP values, which ranged from 282-465 km^2 (Figure 6).

Aerial systematic reconnaissance surveys

During the initial survey on 4 June, we covered an area that included the locations of nine satellite collared cows; cows 212 and 216 were not in the surveyed area (Figure 7). We flew 1,140 km of transects and counted 510 caribou and 25 calves (5%) across the surveyed area (Figure 8, 9). Of the (114) 10 km transect segments, 1 (0.9%) was high density, 17 (14.9%) were medium density and 27 (9%) were low density (Figure 8,

Appendix D). The high and medium density segments represented 17.5% and 68.0% respectively of all the caribou observed (Appendix D). The highest densities of caribou were within the central portion of the surveyed area somewhat above but mostly below the Hood River and along the Wright River Valley (Figure 8).

The aggregated distribution of caribou was well circumscribed within the initial surveyed area on 4 June, and there was a clear break in distribution along the western, southern, and eastern boundaries (Figure 7). A single high density transect segment was located in the north-central area of the aggregated caribou distribution, with medium and low densities of caribou observed in adjacent transect segments (Figure 7). Breeding females, i.e. cows with hard antlers, and cows with a newborn calves, were dispersed throughout the observed distribution of caribou (Figure 9).

In subsequent days (5-7 June), we extended the systematic survey to progressively cover the areas to the south, east, and north (Figure 10). We extended the survey south and southwest to determine whether breeding females may have been dispersed and travelling along the spring migratory corridor and to ensure that continuous systematic coverage was extended out to a previous location of a single satellite collared cow in vicinity of Point Lake (Figure 10). Survey coverage was also extended south to include all of Contwoyto Lake, east to the southern extent of Bathurst Inlet, and north to the coastline of Coronation Gulf (Figure 10).

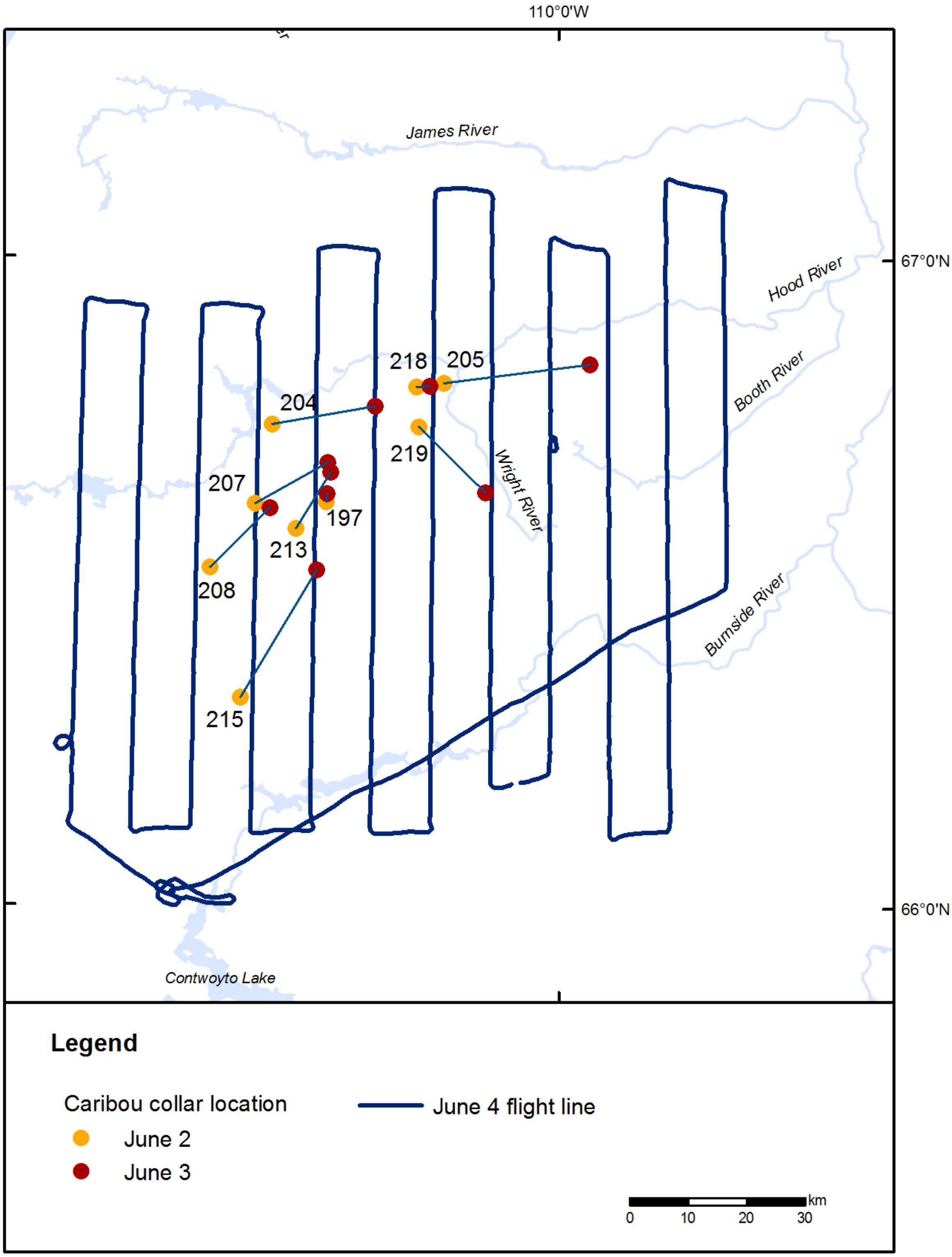

Figure 7. Locations of nine satellite collared caribou cows (presumed to be breeding females) in early June, prior to a systematic aerial survey that was flown on 4 June 2009 to delineate the annual calving ground of the Bathurst herd.

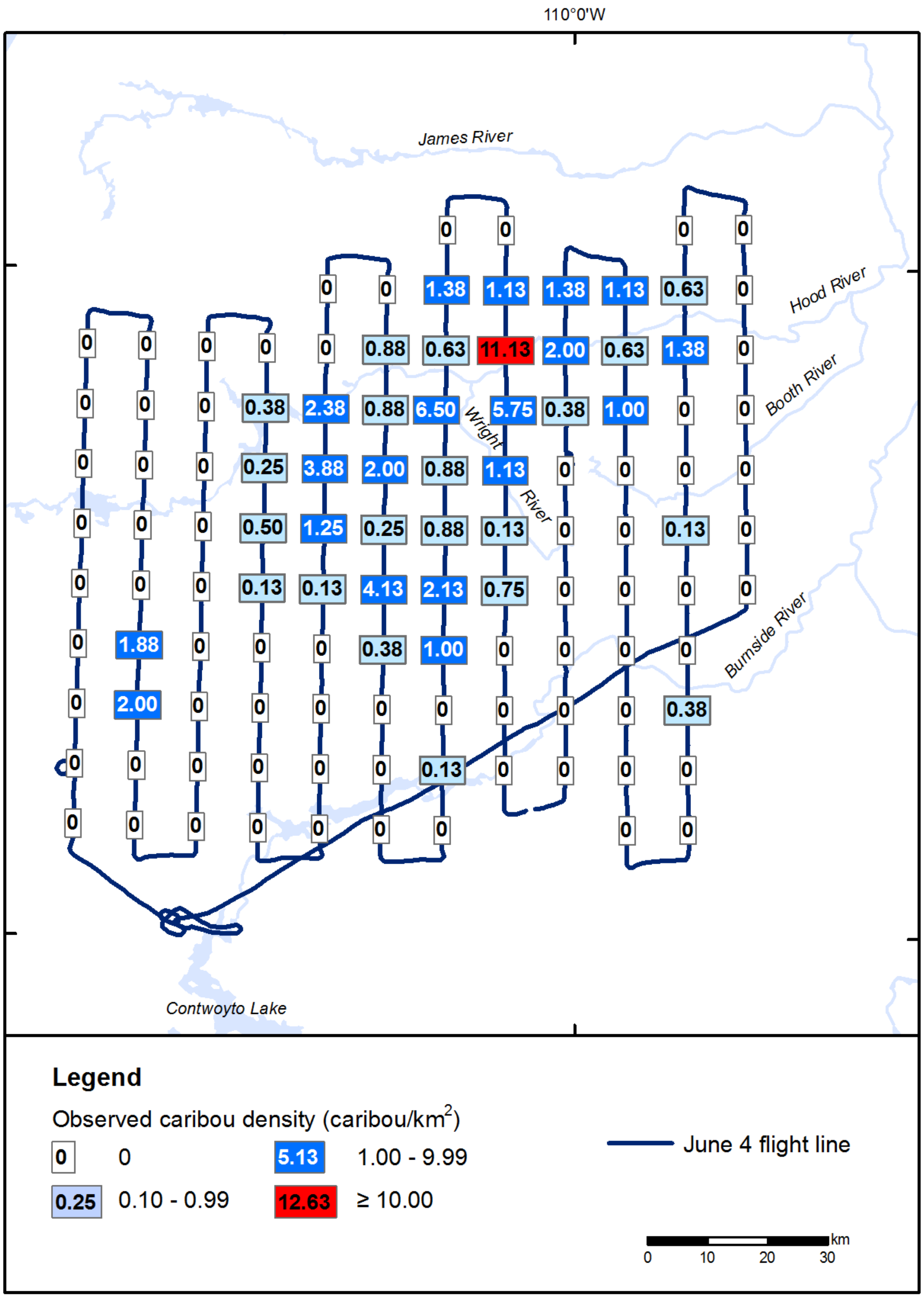

Figure 8. Observed densities of caribou within adjacent 10 km transect segments from a systematic aerial survey of caribou on the Bathurst calving ground, 4 June 2009. Label colours represent density classes: White = flown and no caribou observed, Light blue = 0.1-0.99 caribou/km^2, Dark blue = 1.0-9.9 caribou/km^2 and Red = ≥10 caribou/km^2. Numbers within cell represent actual caribou densities for each 10 km segment.

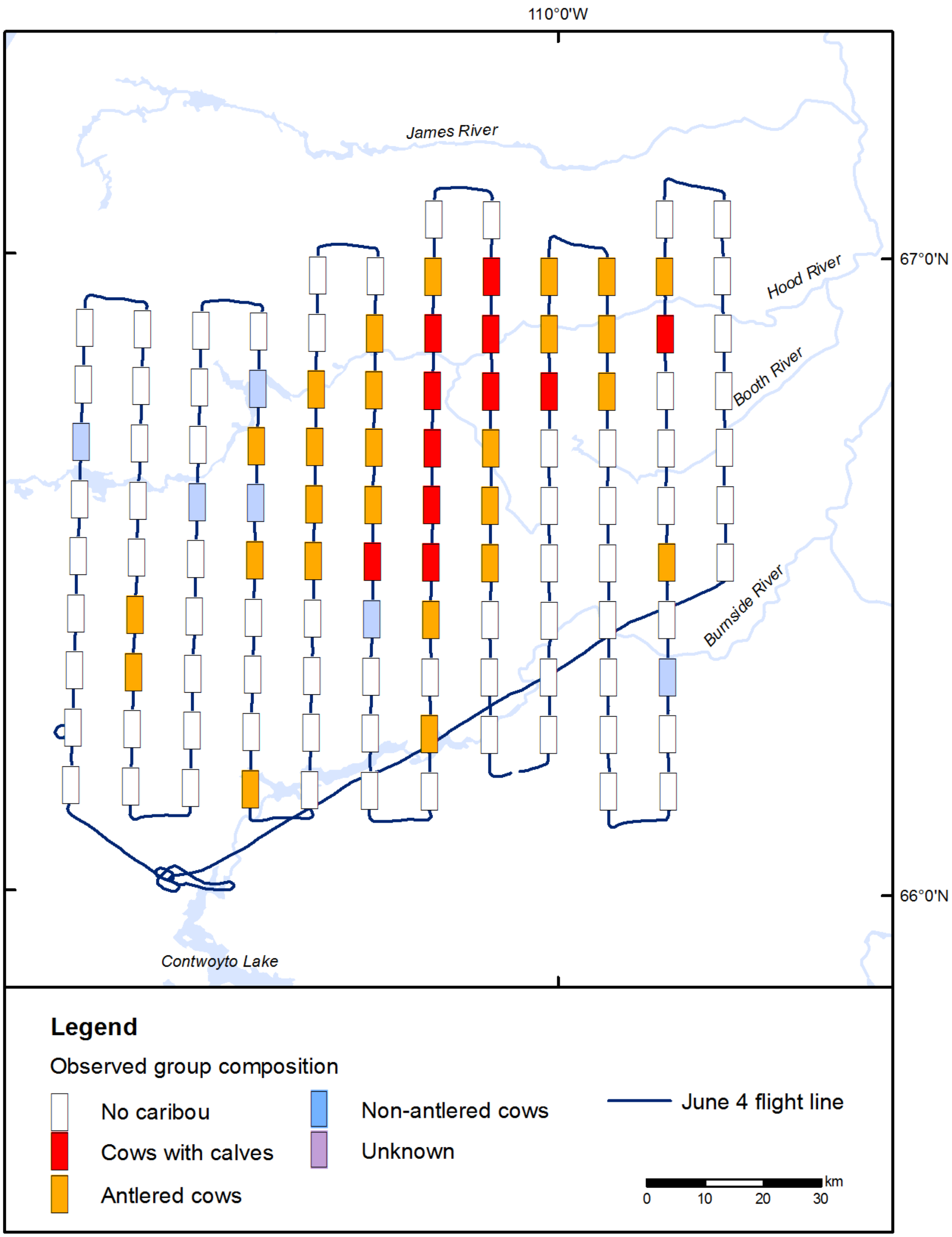

Figure 9. Observed composition of caribou groups during an initial systematic survey of Bathurst calving ground on 4 June 2009. Each cell represents an adjacent 10 km segment length (8 km^2) within a survey transect and cell colours represent composition classes: White = flown and no caribou observed; Red = cow-calf groups; Orange = cows with hard antlers; Blue = non-antlered caribou.

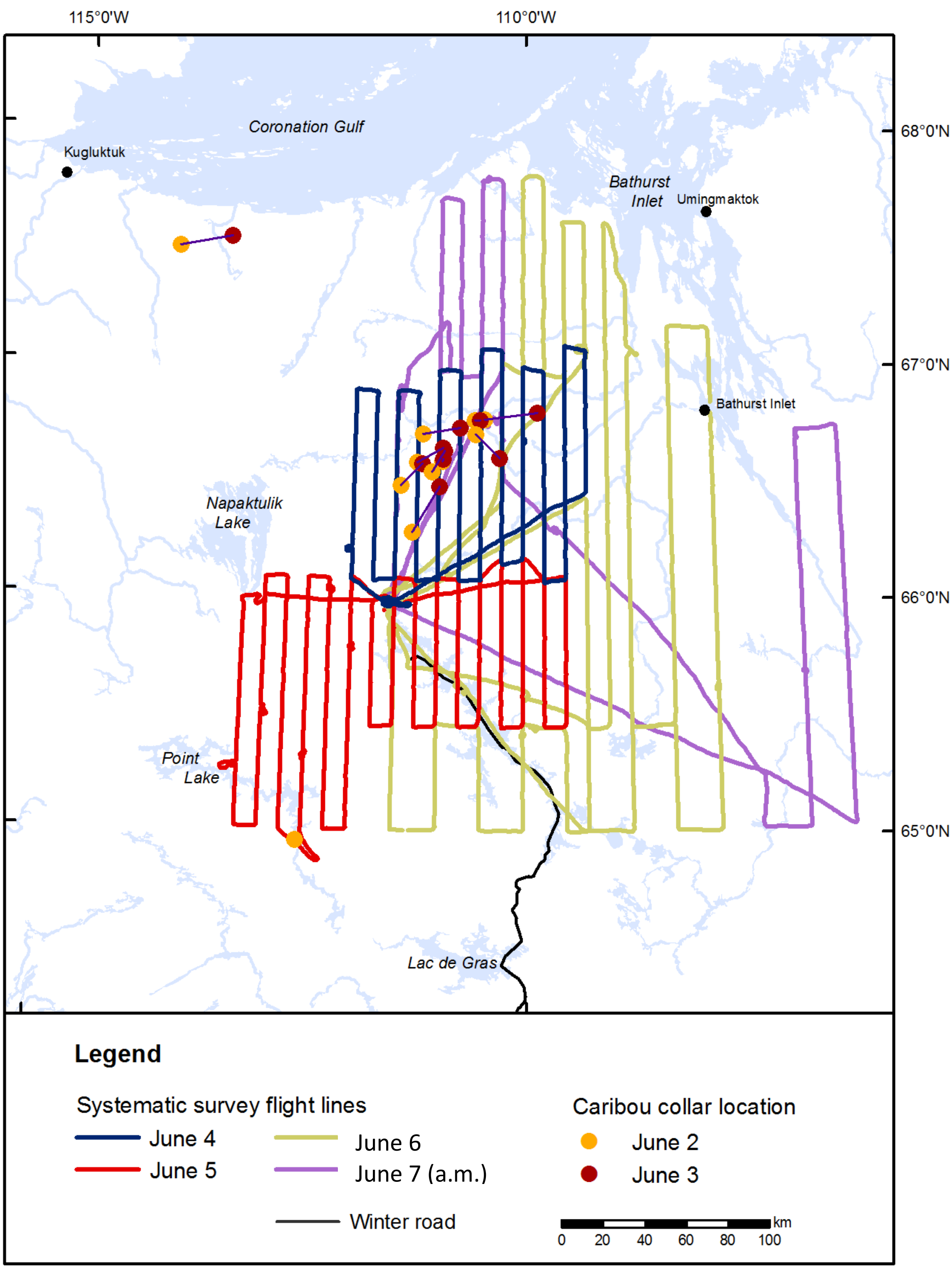

Figure 10. Flight lines from initial systematic survey to delineate annual calving ground for Bathurst caribou herd on 4-7 June 2009. Locations of satellite collared cows (n=10) on 2 and 3 June are shown by orange/red circles. Cow #216 is located north of Napaktulik Lake and about 20-30 km from the coastline of Coronation Gulf.

Although ten segments that had at least one antlered female were outside of the core aggregation of antlered cows and cows with calves, those peripheral segments were dispersed and isolated. We did not observe any large aggregations of breeding females during subsequent survey flights outside the concentrated area observed on the 4 June (Figure 11, 12).

During the systematic survey on the 6 and 7 (a.m.) June, we also flew some transect segments that had been previously flown on the 4 June to determine whether there may have been any observable changes in the proportion of calves, or a horizontal shift of the western boundary of the previously observed caribou distribution (Figure 13). A comparison of caribou observed on the same five transect segments showed that the proportion of newborn calves went from *ca.* 5.6-27.1% in a 48 hour period (Table 1).

While returning back to Tahera Mine after surveying on the morning of the 7 June, the survey crew in the Cessna Caravan checked the high density area previously observed on the 4 June, and observed three groups of caribou (see round symbols in Figure 13D), which totalled 29 caribou plus 16 calves. Additional unrecorded observations confirmed that the ratio of calves to 1^{+}-year-old caribou was *ca.* 50%; the pilot was instructed to gain elevation and return to base in order to minimize potential disturbance through the concentrated area of calving as it would be re-surveyed later in the day.

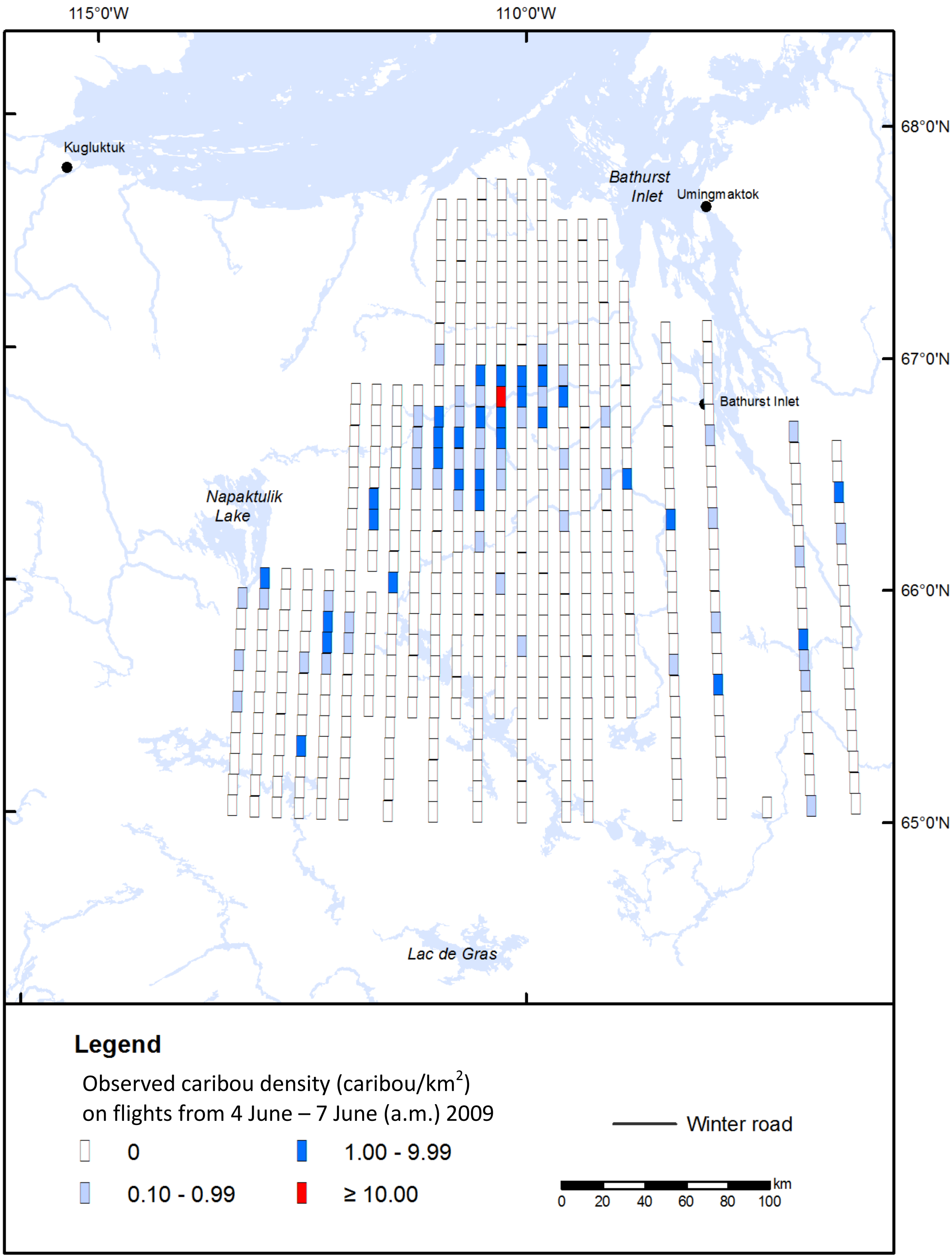

Figure 11. Observations of caribou densities within 0.8 km^2 transect segments, from systematic surveys of Bathurst calving grounds, 4-7 June, 2009 (a.m.). Label colours represent density classes: White = flown and no caribou observed, Light blue = 0.1-0.99 caribou/km^2, Dark blue = 1.0-9.9 caribou/km^2 and Red = ≥10 caribou/km^2.

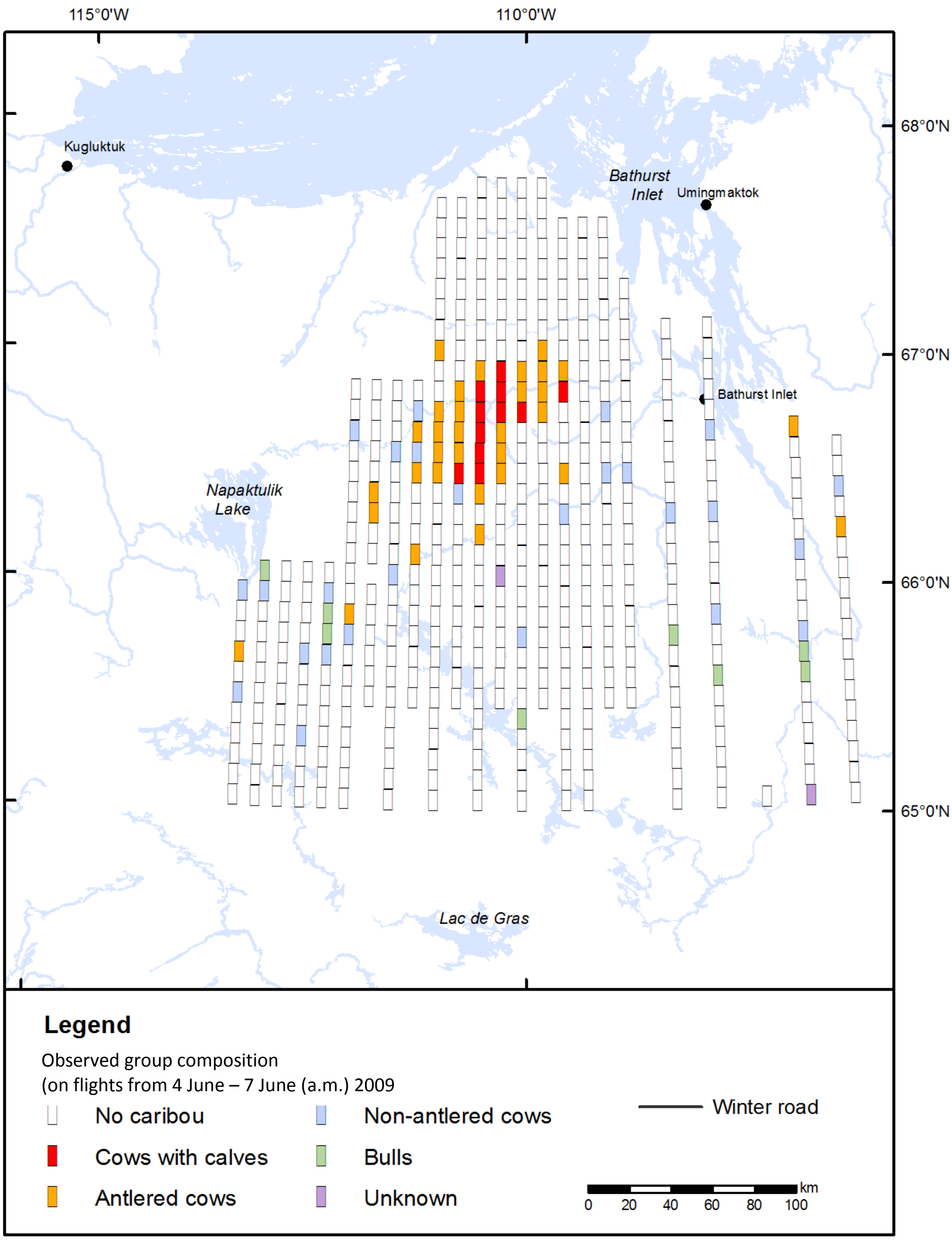

Figure 12. Observed composition of caribou within 0.8 km^2 transect segments, from systematic surveys of Bathurst calving grounds, 4-7 June, 2009 (a.m.). Each cell represents a 10 km segment of a survey transect and cell colours represent composition classes: White = flown and no caribou observed; Red = cow-calf groups; Orange = cows with hard antlers; Blue = non-antlered caribou; Green = Bulls; Purple = unclassified groups.

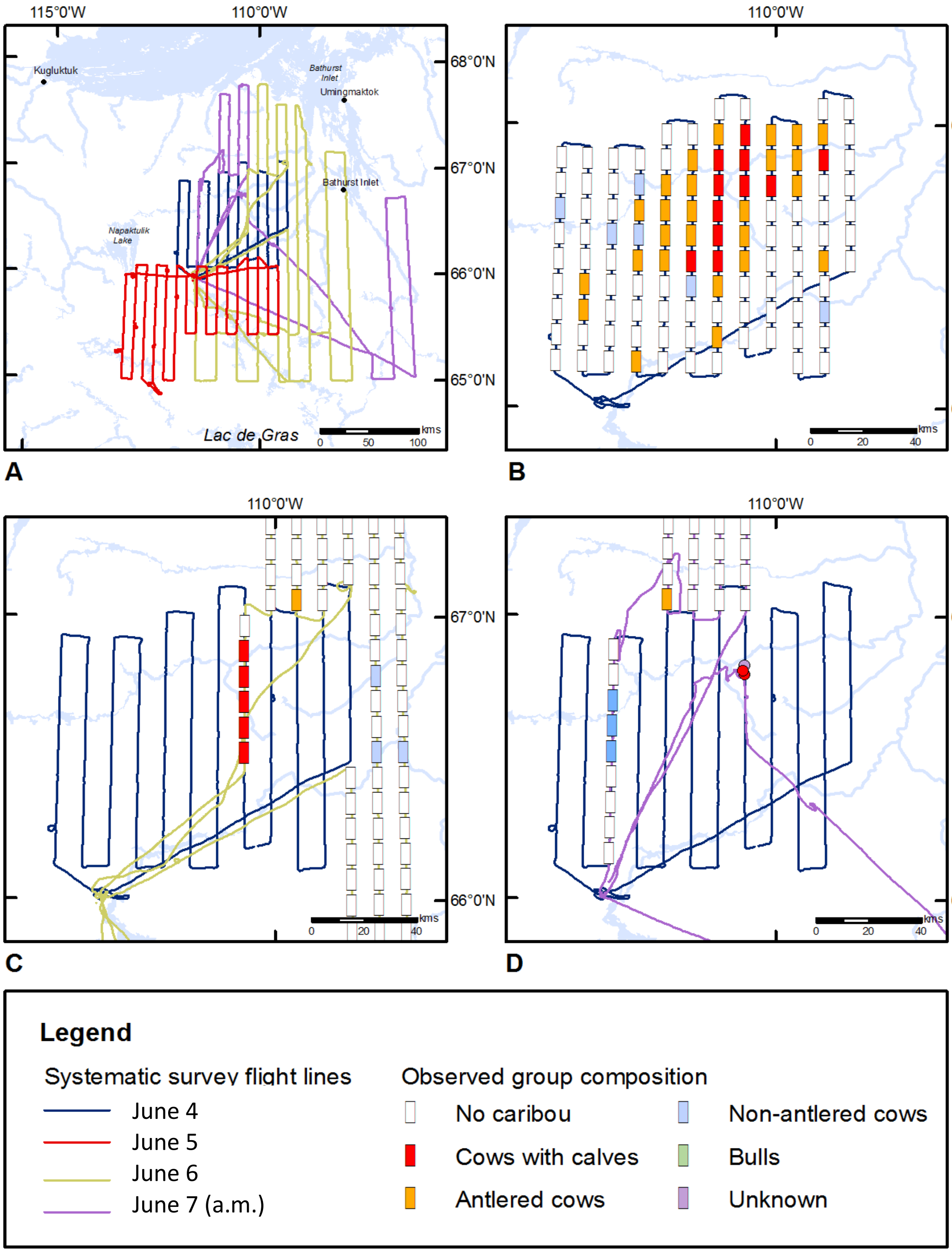

Figure 13. Comparison of systematic surveys flow on identical transect segments in subsequent days: A) all systematic transects flown from 4-7 June, 2009 (a.m.); B) relative group composition of caribou observed within 8 km^2 segments on 4 June; C) composition of caribou observed on transect segments (557-562) on 6 June; and D) composition of caribou observed on transect segments during a morning flight on 7 June along the western edge of the breeding female distribution.

Table 1. Survey of five (8.0 km^2) transect segments on 4 and 6 June 2009, to assess changes in proportion of caribou calves within the concentrated area of calving based on systematic reconnaissance surveys of the Bathurst calving ground.

Segment #	Caribou	# Calves	Density (caribou/km^2)	Density class
4 June				
562	9	1	1.13	Medium
561	89	3	11.13	High
560	46	5	5.75	Medium
559	9	0	1.13	Medium
558	1	0	0.13	Low
557	6	0	0.75	Low
	160	9		
	% Calves	5.6%		
6 June				
562	0	0	0.00	No Caribou
561	1	1	0.13	Low
560	52	14	6.50	Medium
559	13	2	1.63	Medium
558	3	1	0.38	Low
557	1	1	0.13	Low
	70	19		
	% Calves	27.1%		

Delineation and stratification of the annual calving ground

On the afternoon of 7 June (p.m.), we re-surveyed the main area occupied by breeding females during the initial systematic survey area on 4 June (Figure 14). We flew 920 km and counted 633 caribou and 106 calves (16.7%) on transect (Appendix D). We observed two horizontally adjacent high density segments in the west central portion of the annual calving ground, with segments of medium density caribou around the periphery interspersed with some low density segments (Figure 15). The pattern of segments that had at least one calf were dispersed more frequently in the east-central portion of the surveyed area, and associated more with medium and high density segments (Figure 16).

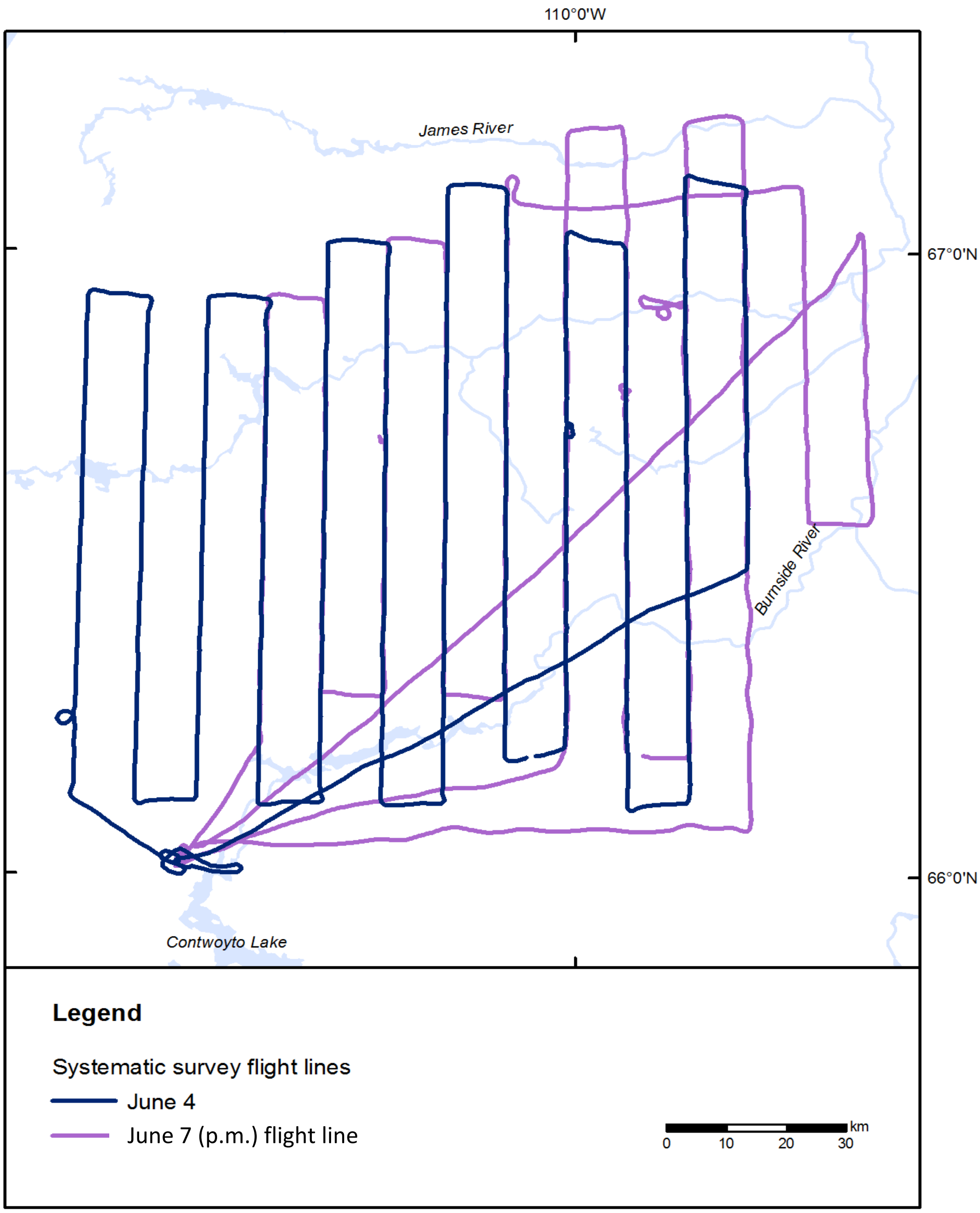

Figure 14. Flight lines from a) initial systematic survey to delineate annual calving ground and b) second systematic survey to delineate survey strata for combined photographic survey and visual survey of annual calving ground for Bathurst caribou herd, June 2009.

Based on the pattern of density and composition (Figure 15, 16), we delineated the annual calving ground and stratified it in to five survey blocks: a high (2,601.8 km^2) and medium density strata (2,113.1 km^2) for the photographic survey, and three low-density strata (low N, low SW and low SE were 13,10.9, 882.0, and 1,077.7 km^2, respectively) for estimation of 1^+-year-old caribou based on standard visual strip transect survey techniques (Figure 17).

We initially partitioned effort for the high and medium density strata based on the allocation formula by Heard (1987), but then re-adjusted the allocation to ensure a minimum sample size of ten transects in the medium density strata (19.1% coverage), and allocated sampling effort in the high density stratum to achieve *ca.* 40% coverage (n=22 transects; 40.6% coverage). For visual strata, we maintained coverage of *ca.* 17-18%, which ensured that we sampled at least ten transects in each of the smaller strata (Figure 17).

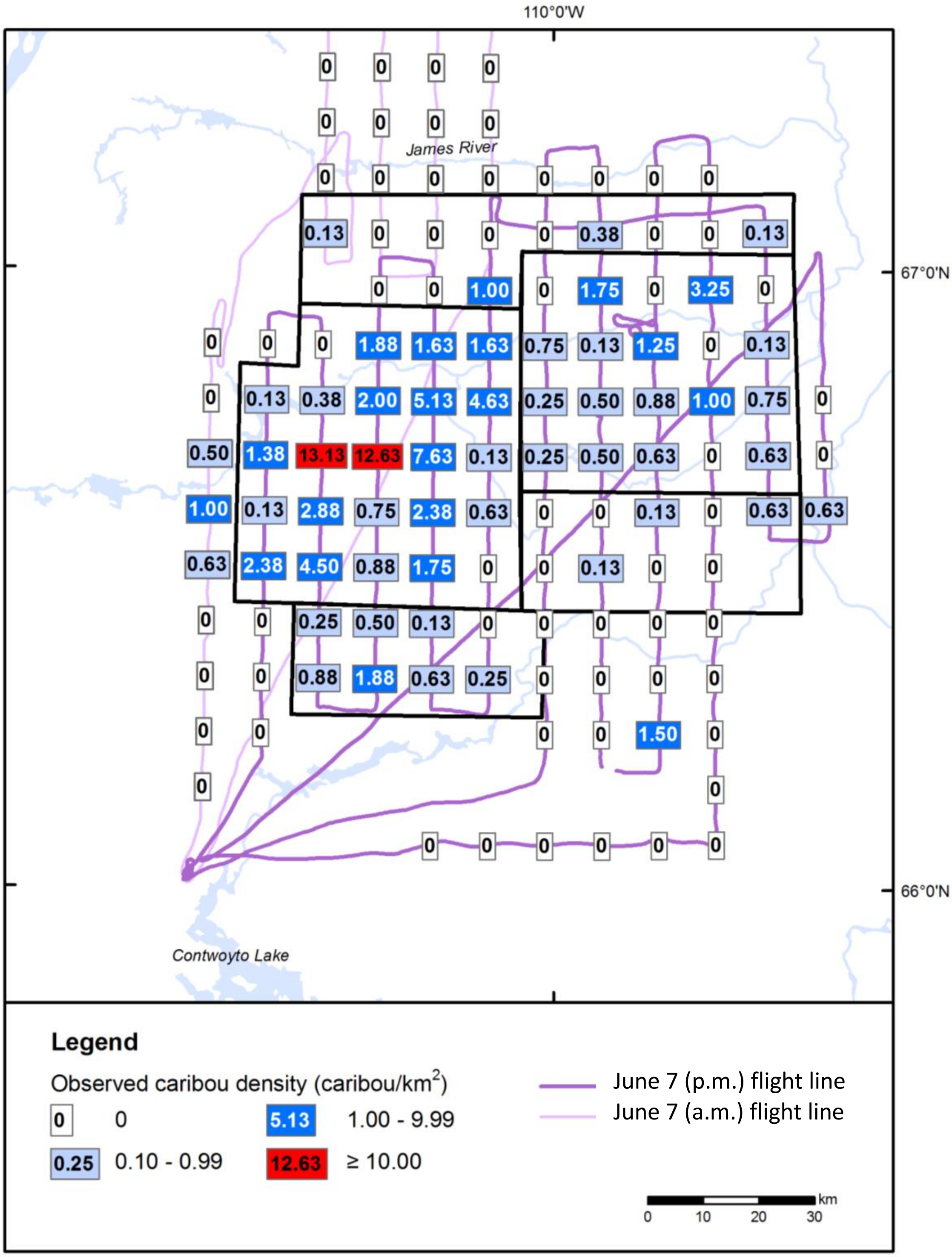

Figure 15. Flight lines and observed caribou densities within adjacent transect segments to delineate and stratify the annual calving grounds of Bathurst caribou, June 2009. Label colors represent density classes: White = flown and no caribou observed, Light blue = 0.1-0.99 caribou/km^2, Dark blue = 1.0-9.9 caribou/km^2 and Red = ≥10 caribou/km^2.

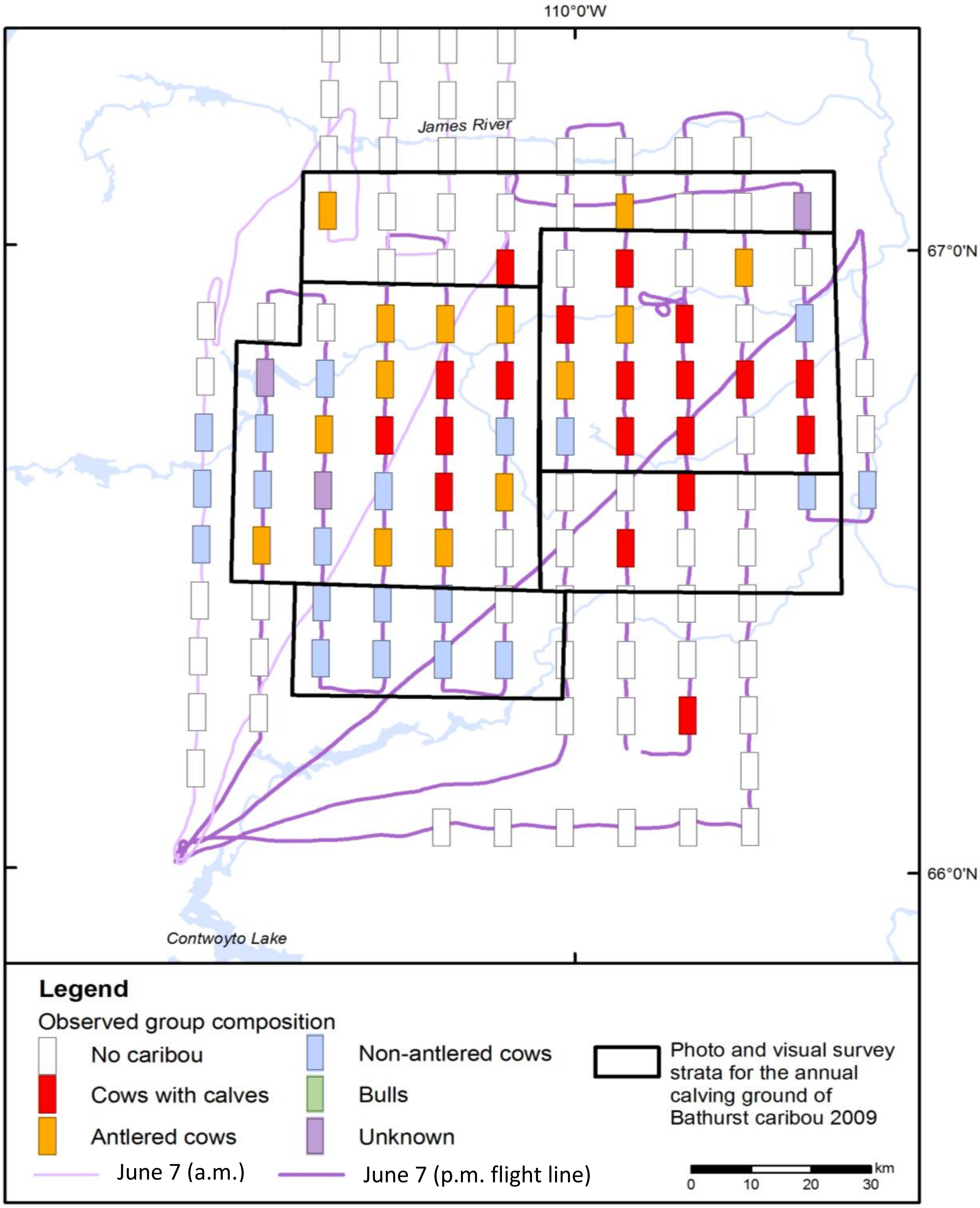

Figure 16. Observed caribou composition within adjacent transect segments flown to delineate and stratify annual calving grounds of Bathurst caribou, June 2009. Each cell represents a 10 km segment of a survey transect and cell colors represent composition classes: White = flown and no caribou observed; Red = cow-calf groups; Orange = cows with hard antlers; Blue = non-antlered caribou; Purple = unclassified groups; Green = bulls.

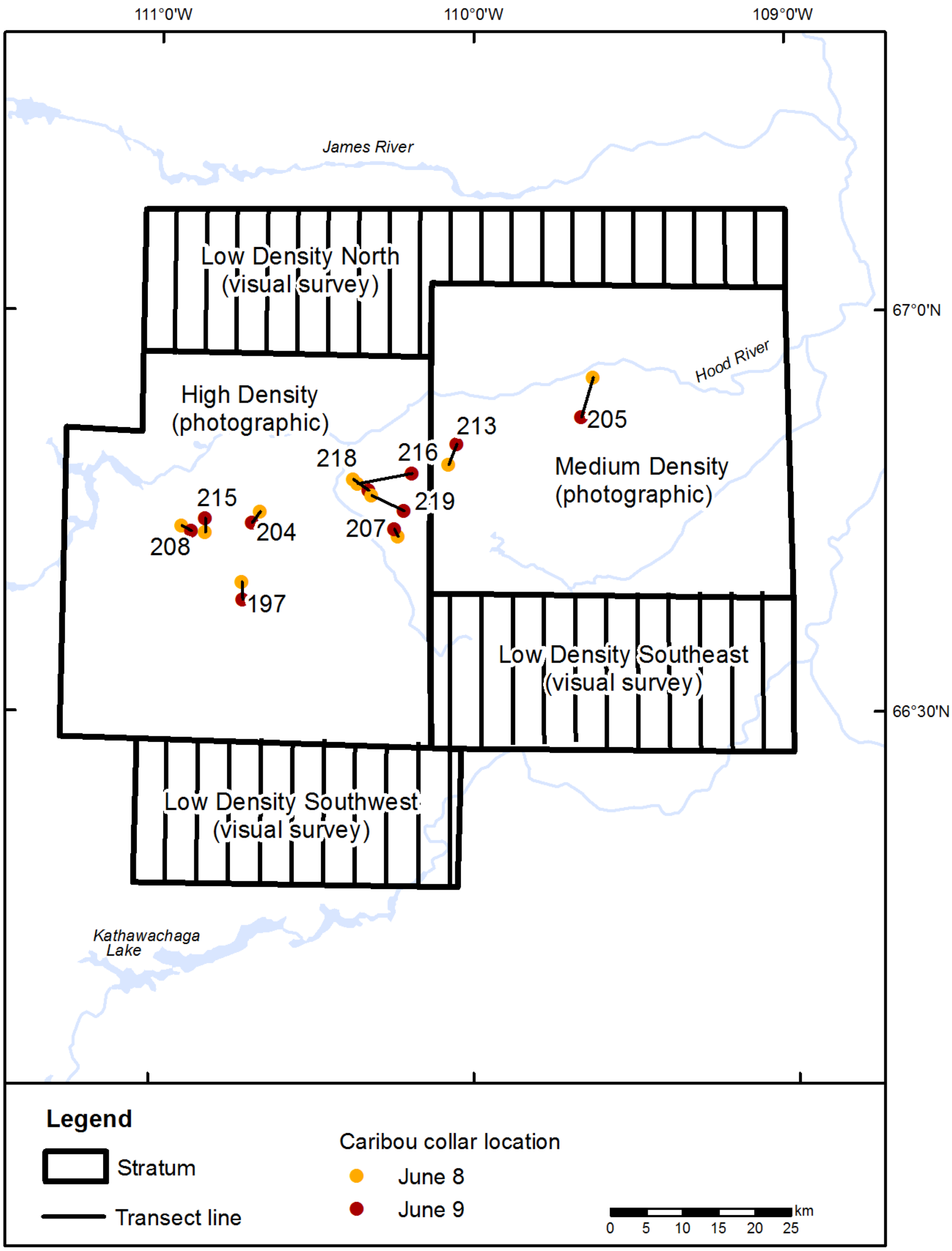

Figure 17. Final stratification for annual calving ground of Bathurst caribou herd, June 2009. The photo-plane surveyed the high and medium density strata. Standard visual strip transect surveys were conducted on the low density strata. Eight of ten satellite collared cows were located in the high density stratum, and two collared cows were in the medium density stratum. Transect numbers were sequential with number one starting in the west.

Survey of the annual calving ground

Photographic survey

The photographic survey of the calving ground was initiated on 8 June. Due to favourable weather and photographic conditions – morning temperature was 8^{o}C with excellent visibility, high scattered clouds (>8,000 feet AGL) and 50% snow cover – the photo-plane completed the high density strata on the first day of the photographic survey. However, due to the large number of transects in the high density stratum (n=22), we knew that the photographic aircraft would not be able to complete photography of the stratum during the morning flight, so we assigned priority to the first nine long lines (from west to east) followed by every other line until the aircraft had to return to base for fuel. The remaining lines were photographed on a second sortie later in the afternoon. The medium density stratum was photographed completely on 9 June. At the time of the photographic survey (8-9 June), we had excellent visibility. We encountered high scattered to high overcast conditions (8,000-10,000 feet AGL) which provided good contrast and lighting for aerial photography (D. Evans pers. comm.). The weather and snow conditions for the photographic survey were good for subsequent photo interpretation.

In the high density stratum, Paul Roy counted 7,140 1^{+}-year-old (adult) caribou, which resulted in an estimate of 17,593 adult caribou ± 2,413 (SE) and a density of *ca*. 6.76 adult caribou/km^2 (Table 2, Appendix E). In the medium density strata, Paul Roy counted 1,007 adult caribou. Caribou density in the medium strata was 2.49 adult caribou/km^2 and the estimate was 5,267±1,390 (SE) 1^{+}-year-old caribou (Table 2, Appendix F).

Visual survey

We surveyed all three low density strata on 8 June. We counted a total of 5, 53, and 15 1^+-year-old caribou in the low N, low SW and low SE strata respectively. This resulted in a combined estimate of 413 adult caribou for low density visual strata (Table 2, Appendix G). Densities within the low density strata ranged from 0.02-0.34 adult caribou/km^2. Of all the low density strata, stratum low SW, which was adjacent to the southwestern boundary of the high density stratum, accounted for 299±127 (SE, 72%) of all adult caribou within the three low density strata (Table 2). These observations likely reflected a trailing distribution of non-breeder caribou on to the calving ground.

Based on the combined photographic and visual survey estimates, the total number of 1^+-year-old caribou estimated on the calving ground was 23,273±2,788 (SE) (Table 2).

Table 2. Analysis of data from an aerial survey of the Bathurst calving ground, June 2009.

	Photographic		Visual			
	High	**Medium**	**Low N**	**Low SW**	**Low SE**	**Total**
Maximum number of transects (N)	57	55	112	57	63	
Number of transects surveyed (n)	22	10	20	10	11	
Stratum area, km^2 (Z)	2,601.8	2,113.1	1,310.9	882.0	1,077.7	
Transect area, km^2 (z)	1,055.9	404.0	234.2	156.4	188.3	
Number of 1+-year-old caribou counted (y)	7,140	1,007	5	53	15	
Caribou density, caribou/km^2 (R)	6.76	2.49	0.02	0.34	0.08	
Population estimate (Y)	17,593	5,267	28	299	86	23,273
Population variance (Var Y)	5,822,120	1,931,054	624	16,100	1,088	7,770,986
Standard error (SE Y)	2,413	1,390	25	127	33	2,788
Coefficient of variation (CV)	0.137	0.264	0.892	0.425	0.384	0.120

Sex and age composition surveys

We flew 28.4 hours in a helicopter (Appendix B) and classified 2,033 1^{+}-year-old caribou in 91 groups to estimate sex and age composition of caribou within high, medium, and low density strata (Table 3, Appendices H, I, and J). We sampled 65 groups in the high density stratum which accounted for 71% of our total number of groups classified; seventeen groups classified in the medium density photographic strata accounted for *ca.* 19% of sampling effort (Table 3).

Table 3. Sample sizes and proportion of breeding females in high, medium and low density strata of the Bathurst caribou calving ground, June 2009.

Stratum	Number of groups sampled	Number of breeding females	Number of 1^{+}-year-old caribou	Proportion of breeding females	Standard Error	CV
High density – photo	65	1,248	1,840	0.681	0.043	0.063
Medium density – photo	17	760	866	0.879	0.017	0.019
Low density - visual (South)	9	25	226	0.113	0.048	0.423
Sum	91	2,033	2,932			

Estimate for number of breeding females on annual calving ground

We adjusted the overall estimate of the number of 1^{+}-year-old caribou (summarized in Table 2) by the proportion of breeding females observed in each stratum during the composition surveys (Table 3). Due to low densities of caribou in the low N strata, we collected and pooled composition data from only the two low density strata in the south and extrapolated the observed proportion of breeding females (0.113) to all three low density strata. In summary, we estimated that there were a total of 16,650 ± 2,181 (SE) breeding females in the survey area (Table 4).

Table 4. Estimated number of breeding females in all high, medium and low density strata of the Bathurst calving ground, June 2009 based on composition counts and stratum population estimates (CV = coefficient of variation).

Stratum	Estimated number of 1+-year-old caribou on calving ground	Proportion of breeding females	Estimated number of breeding females	Variance	Standard Error	CV
High	17,593	0.681	11,973	3,257,447	1,805	0.151
Medium	5,267	0.879	4,630	1,499,906	1,225	0.265
Low N[a]	28	0.113	3	10	3	0.988
Low SW	299	0.113	34	410	20	0.599
Low SE	86	0.113	10	31	6	0.571
Total	23,273		16,650	4,757,804	2,181	0.131

[a]Composition data were not collected for stratum. Due to small sample sizes, composition data from stratum low SW and low SE were combined and the one estimate was used to derive the number of breeding females for all low density strata.

Trend of breeding females in Bathurst caribou herd, 1986-2009

The trend in estimates of breeding females since calving ground photographic surveys of the Bathurst herd were initiated in 1986 (Heard and Williams 1991) indicates that the herd has been declining (Figure 18). The estimate from June 2009 suggests an accelerated rate of decline between 2006 and 2009.

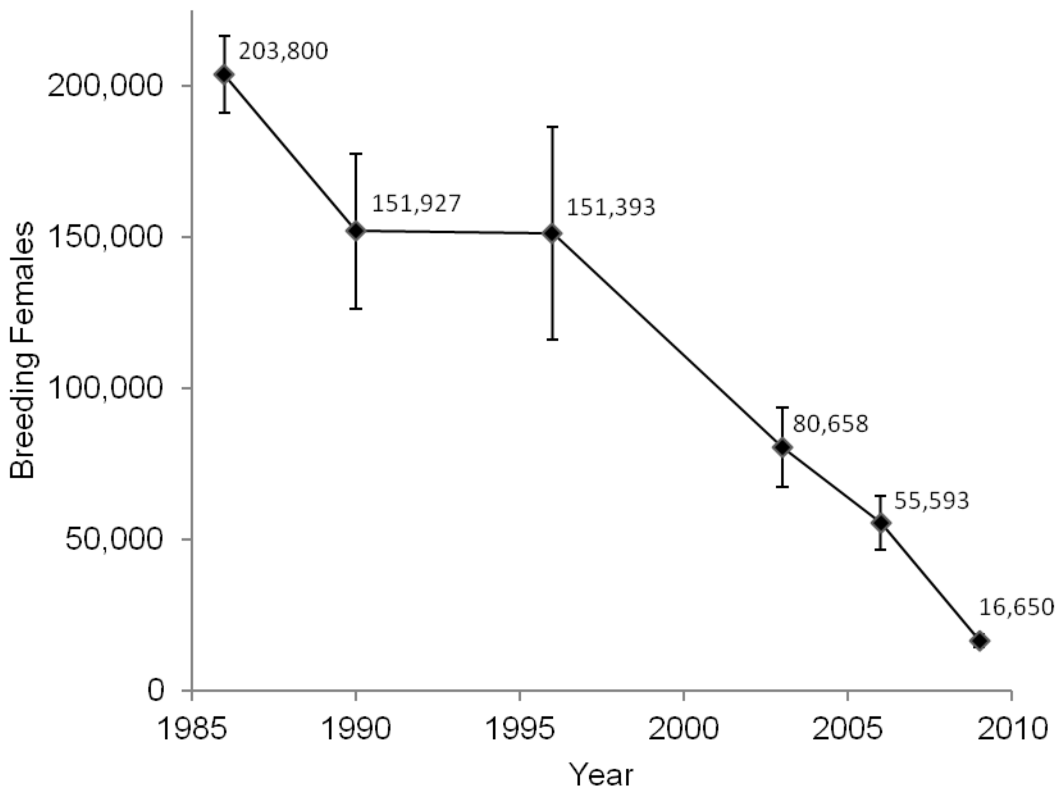

Figure 18. Trend in breeding females (estimate ± Standard Error) in Bathurst caribou herd, 1986-2009.

One-tailed t-test

Based on a one-tailed t-test, the estimate of breeding females in 2009 was significantly lower than the calving ground survey in 2006 (t=4.27, df=21, P<0.005). The exponential rate of change[1] between the 2006 and 2009 estimates of breeding females was r=-0.403 (SD=0.068) (Appendix L). The magnitude of this rate of decline corresponds to a halving time of *ca.* 1.7 years.

Weighted least squares regression

Model selection results suggested that a nonlinear trend best approximated by a cubic polynomial term was most supported (Table 5, and see Appendix K for detailed methodology on model selection analyses). This model showed strong support as indicated by an AIC weight of 0.95. A model with linear trends was not supported by the data.

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[1] The exponent *(r)* is the power to which *e* (the base of natural "Naperian" logs, taking the value of 2.71828) is raised such that $e^r=\lambda$; r is the exponential rate of increase. According to Caughley (1977), the exponential rate of increase is a more useful expression of population increase than λ for three reasons: 1) r is centered at zero, hence a rate of increase measured as r has the same value as an equivalent rate of decrease, apart from reversal of sign; 2) r converts easily from one unit of time to another, i.e. when r per year equals x, r per day equals x/365; and 3) doubling or halving time of a population can be easily calculated from r by 0.6931 / r. For example 0.6931/-0.403 equals a halving time of 1.7 years. Halving time refers to the number of years in which a population would be half of its size if it continued to decline at its present rate. Conversely, doubling time is the time in which a population would double its size if it continued to increase at its present rate.

The finite rate of increase (also termed the growth multiplier) is the simplest measure of a population's rate of increase; it is the ratio of numbers in two successive years. The Greek symbol lambda (λ) is used to represent the finite rate of increase. When λ>1 the population has increased between successive years; when >1, the population has declined.

Table 5. Model selection results for Bathurst trend analysis. Akaike Information Criteria (AIC_c), the difference in AIC_c values between the i^{th} and most supported model (ΔAIC_c), Akaike weights (w_i), and number of parameters (K) are presented.

model	AICc	ΔAICc	wi	logl
yr^3	2.82	0	0.995	2.59
$yr+yr_{>06}$	8.12	5.30	0.005	4.94
$yr^2\ yr^3$	11.58	8.76	0.000	3.21
$yr\ yr^3$	12.50	9.68	0.000	2.75
$yr\ yr^2$	17.68	14.86	0.000	0.16
$yr+yr_{>03}$	20.59	17.77	0.000	-7.29
yr	34.91	32.09	0.000	-13.46
$yr\ yr^2\ yr^3$	37.04	34.22	0.000	5.48
intercept	322.72	319.90	0.000	-159.86

Parameter estimates for the most supported model suggested that both the intercept and yr^3 terms were significant (Table 6).

Table 6. Regression model parameter estimates

Parameter	Estimate	S.E	C.I. low	C.I.high	t	P-value
Intercept	12.208	0.075	12	12.417	162.72	0
yr^3	-0.0002	0.000015	-0.0002	-0.0001	-13.45	0.0002

Figure 19 shows a plot of the regression line (back transformed to population size units). The 95% CI around the predicted trend are irregular because they reflect different levels of variance at each of the point estimates. For example, the 1986, 2003, and 2006 and 2009 surveys had the best precision and therefore the CI are narrowest around those points.

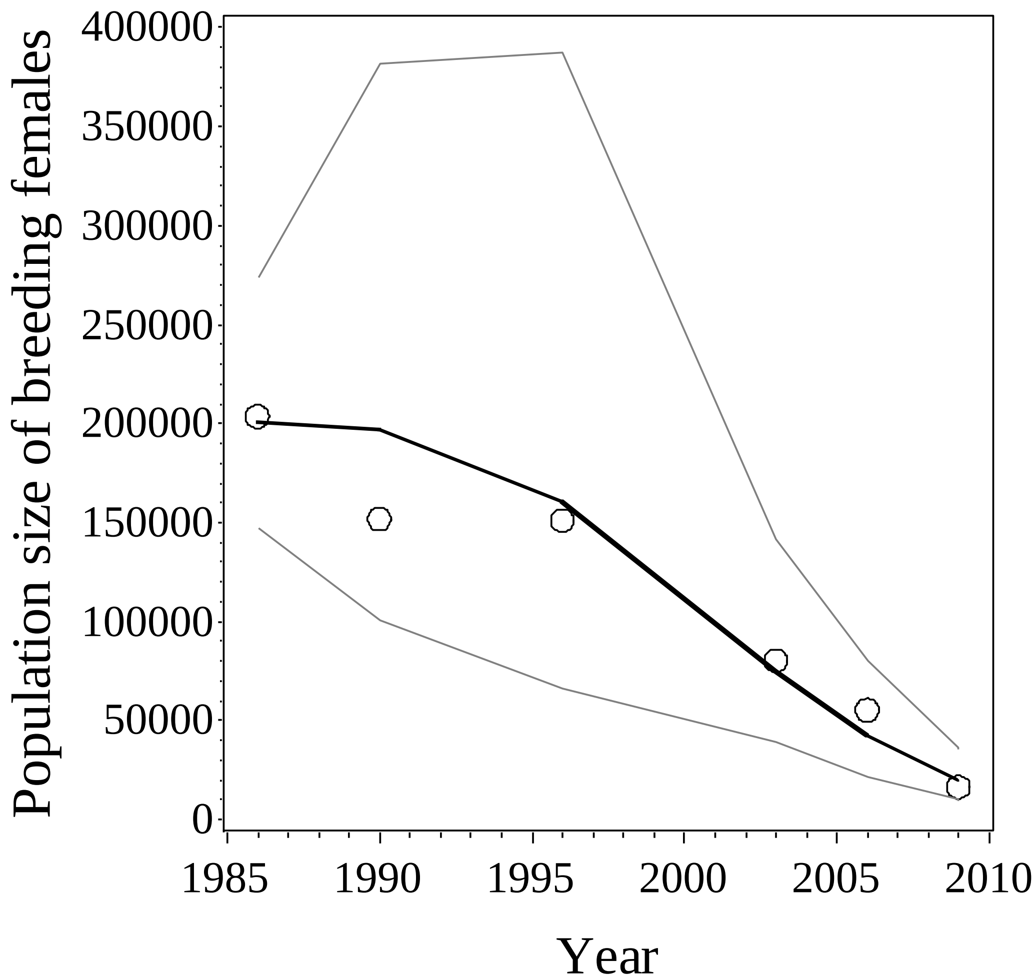

Figure 19. Predicted trend for breeding females of the Bathurst caribou herd using weighted least squares regression analysis. Thin grey lines are the 95% CI around the predicted trend. Circles are estimates of breeding females from calving ground surveys.

Monte Carlo simulation

Monte Carlo simulation results suggested that the trend was increasingly negative (i.e. indicative of a progressively faster rate of decrease) as shown by lower λ estimates for each year (Figure 20). The λ of 1 at the beginning of the simulations was an artifact of the fact that this was the first point in the simulation and therefore the most applicable estimates were for the latter part of the time series (i.e. after 2000).

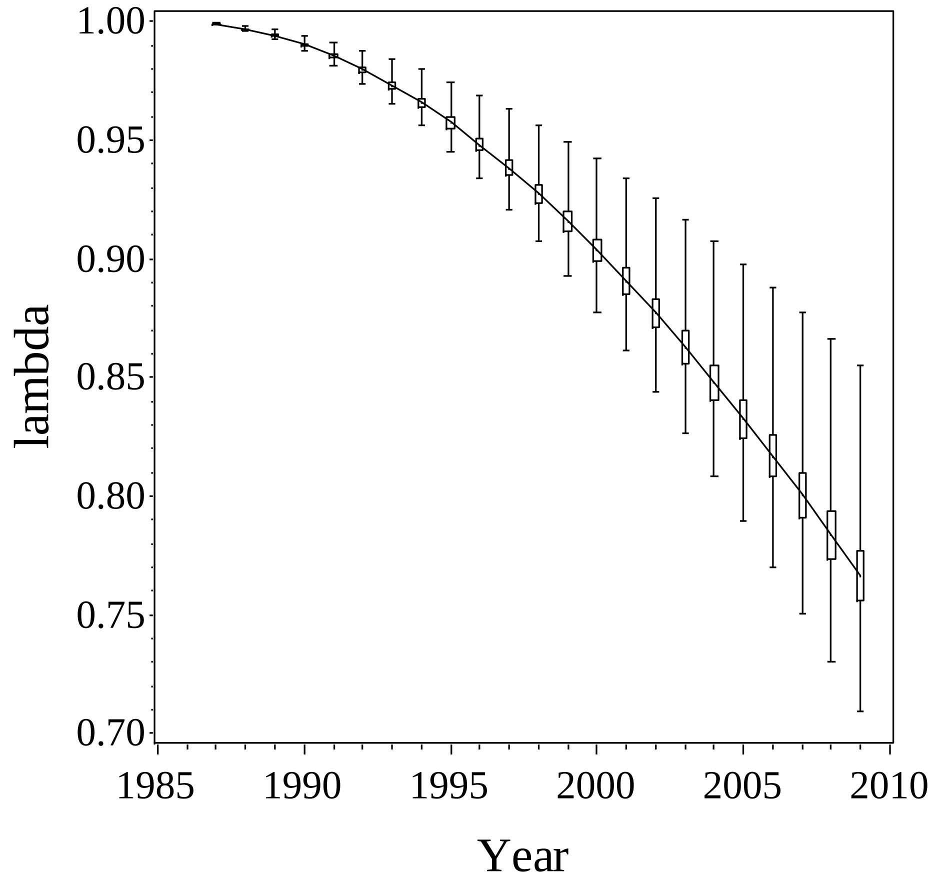

Figure 20. Simulated estimates of lambda (λ) as a function of year from Monte Carlo simulation analysis.

A histogram of λ estimates for 2009 shows that none of the values overlapped one suggesting there was no statistical chance that the population was stable (Figure 21).

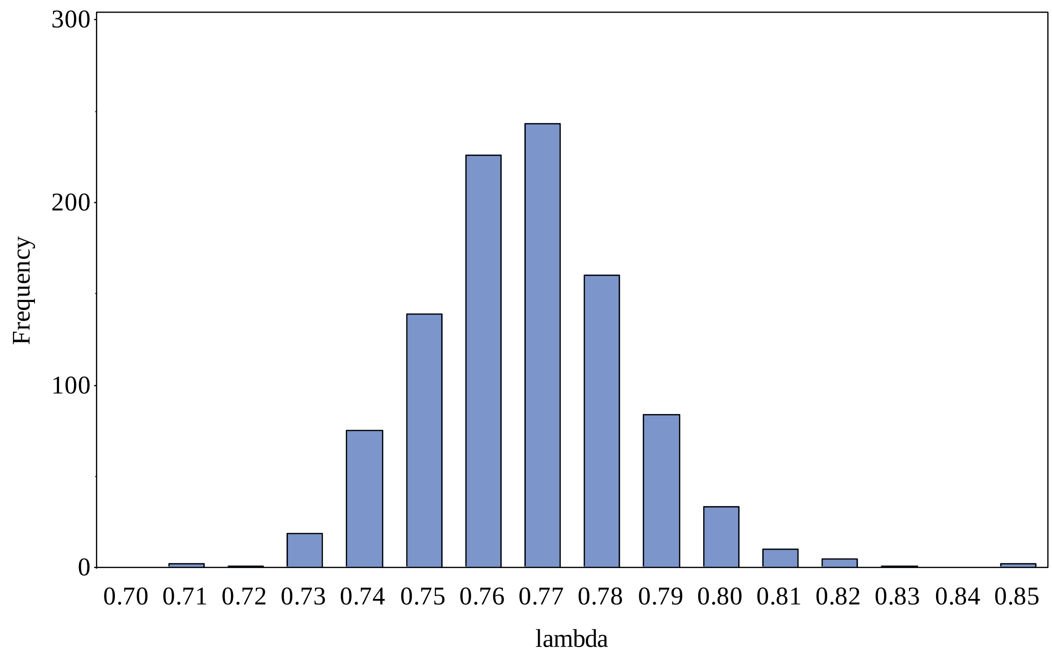

Figure 21. Distributions of population rate of change – lambda (λ) – for 2009 generated using Monte Carlo simulation trials on estimates of breeding females.

Estimates of λ from the Monte Carlo analysis for 2009 is 0.76 (SE=0.17, CI=0.74-0.80) with a corresponding *r* estimate of -0.26 (SE=0.027, CI=-0.31 to -0.22). The magnitude of this rate of decline corresponds to a halving time of *ca.* 2.7 years.

Additional systematic surveys

Once the photographic and visual surveys of the annual calving ground were initiated, we resumed the systematic survey to extend survey coverage and determine whether additional aggregations of breeding females may have been missed in adjacent areas. We completed the systematic survey on 8, 9, and 10 June (Figure 22). On June 17, we also surveyed the area west of Napaktulik Lake and northwest to Kugluktuk, NU (Figure 22) and observed low and medium densities of caribou that were mostly bulls and non-breeding females (Figure 23, 24, Appendicies D, M).

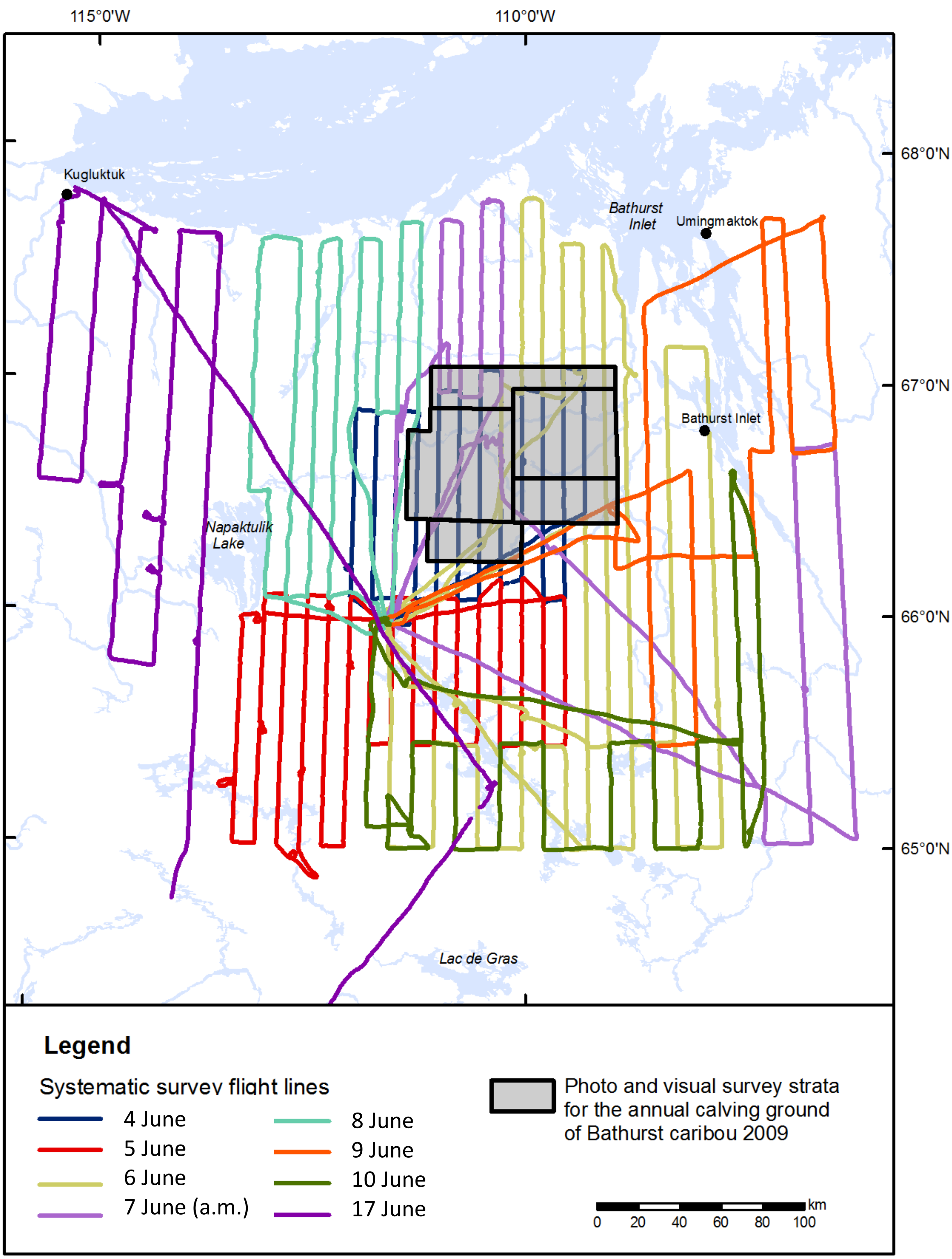

Figure 22. Cumulative coverage of extensive systematic surveys that were used to delineate the annual calving ground and determine final stratification for the Bathurst calving ground survey in June 2009.

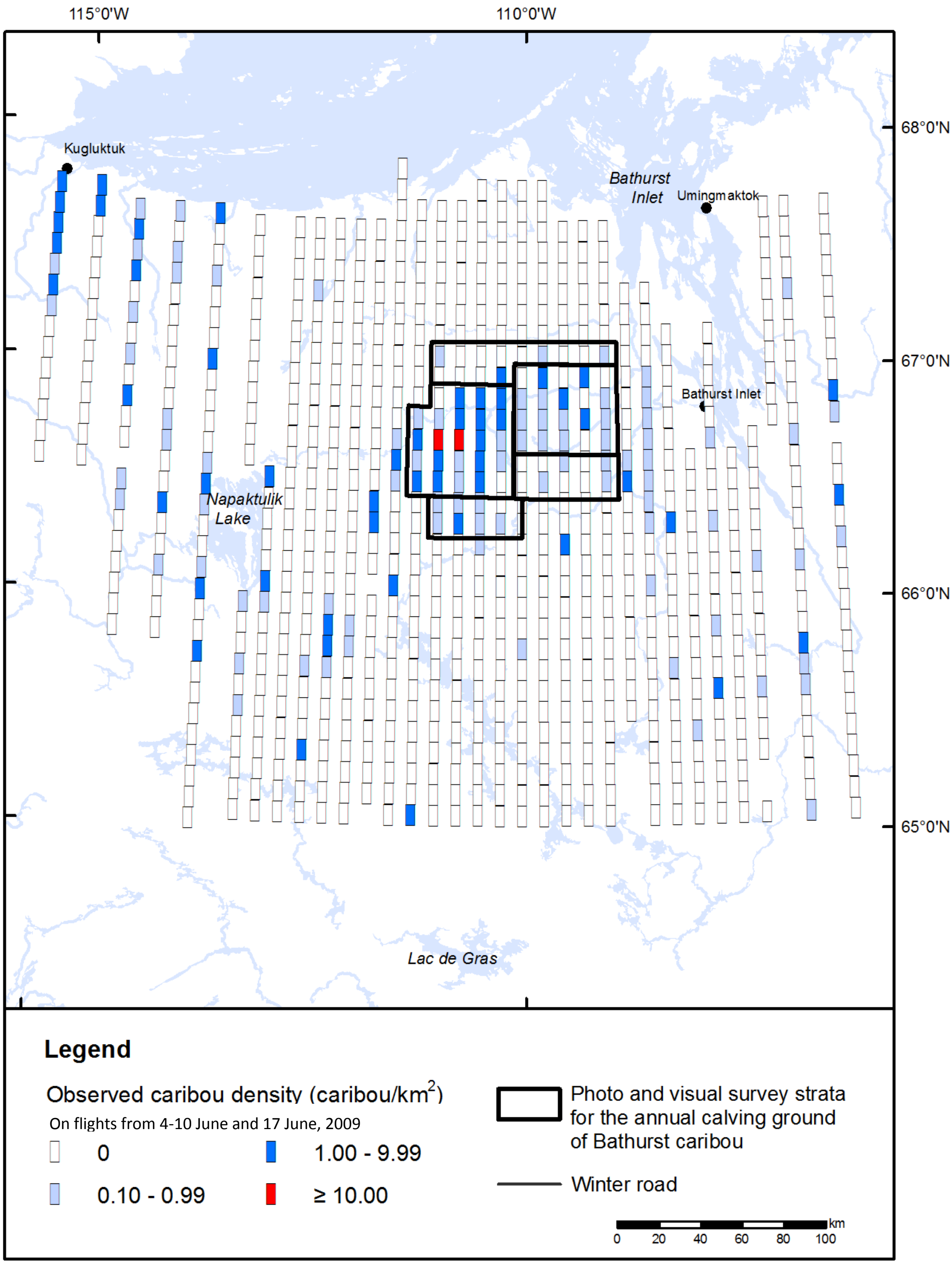

Figure 23. Observed caribou densities from extensive systematic survey of Bathurst caribou calving grounds, June 2009. Label colors represent density classes for 10 km transect segments: White = flown and no caribou observed, Light blue = 0.1-0.99 caribou/km^2, Dark blue = 1.0-9.9 caribou/km^2 and Red = ≥10 caribou/km^2.

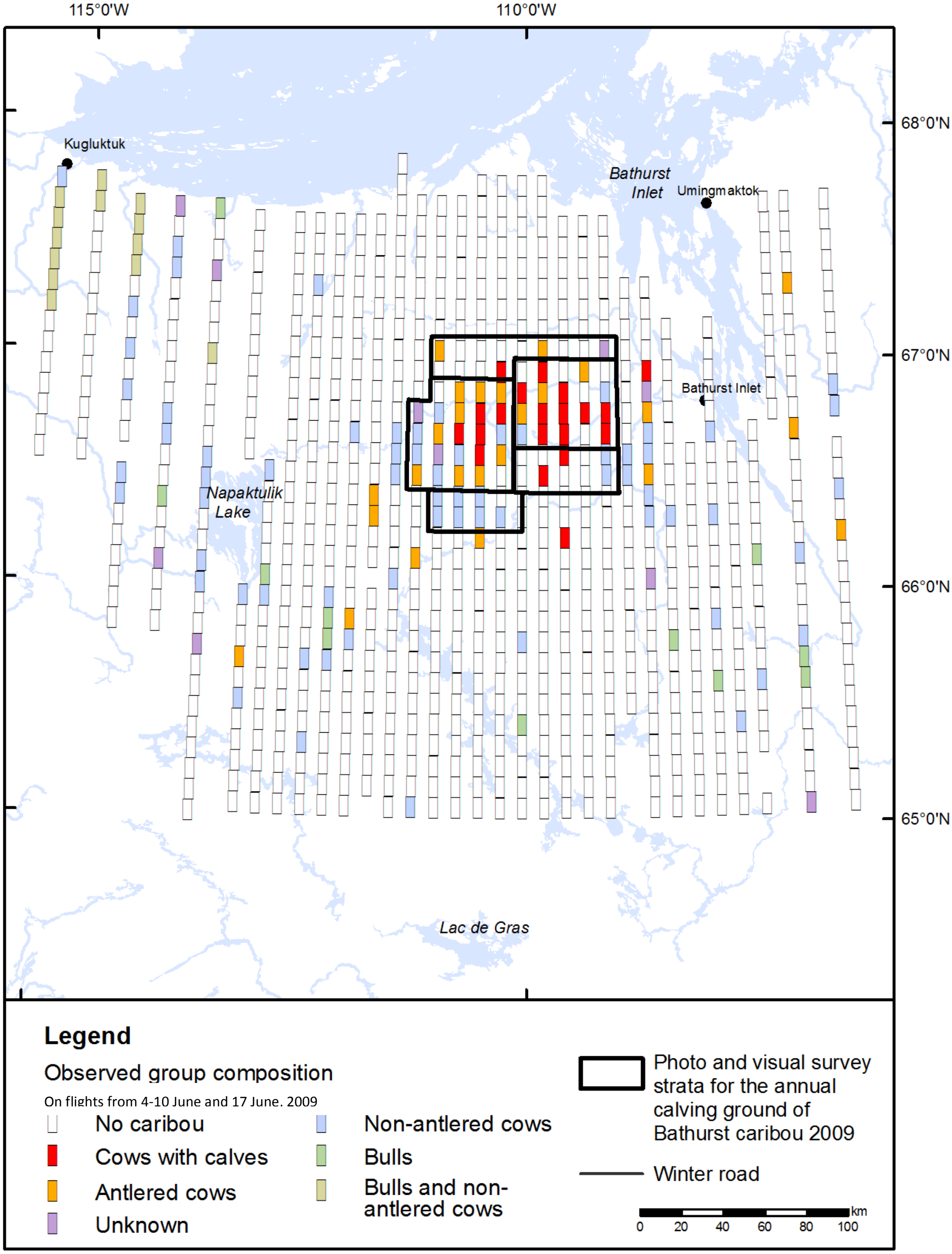

Figure 24. Observed caribou composition from extensive systematic survey of Bathurst caribou calving grounds, June 2009. Label colours represent composition classes for 10 km transect segments: White = flown and no caribou observed; Red = cow-calf groups; Orange = cows with hard antlers; Blue = non-antlered caribou; Purple = unclassified groups; Green = bulls.

Extrapolating the estimate of breeding females to total herd size

An estimate of breeding females can be used to extrapolate an estimate of total herd size, with the inclusion of two additional parameters: 1) the proportion of females in the population (i.e. sex ratio); and 2) the pregnancy rate of breeding females (Heard 1985). Thus, depending on the numerical estimates used for these two parameters, the derived estimate of total herd size can differ even though the estimate of breeding females is the same. Table 7 shows extrapolated population estimates for the Bathurst herd based on use of the same pregnancy rate, but with two different estimates of sex ratios. An extrapolated total population estimate of 38,388 ± 7,400 caribou is calculated (Table 7) when the average sex ratio of 66 males/100 females (i.e. 60.2% of females in the population) is used (Heard and Williams 1991, p. 35 in Gunn et al. 1997). If the sex ratio of 38.3 males/100 females (i.e. 72.3% of females in the population) is used, which is based on fall 2008 composition surveys (GNWT unpublished data; B. Croft pers. comm.), then the derived total population estimate is 31,982 ± 5,306 (Table 7).

Table 7. Extrapolation of breeding female estimate to total herd size.

Population Parameter	Parameter Value	Standard Error	Coefficient of Variation
a) Assumed proportion of females = 0.602 (66 bulls / 100 cows from Heard and Williams 1991, p. 35 in Gunn et al. 1997)			
Estimate of 1+ Yr Old Caribou	23,273	2,788	0.120
Estimate of Breeding Females	16,650	2,181	0.131
Proportion of Females in Population	0.602		0.100 *
Pregnancy rate of Breeding Females[#]	0.720		0.100 *
Extrapolated Population Estimate	38,388	7,400	0.193
b) Assumed proportion of females = 0.723 (38.3 bulls / 100 cows, 2008 composition data, p. 42 in Adamczewski et al. 2009, CV = 0.019 B. Croft unpub. data)			
Estimate of 1+ Yr Old Caribou	23,273	2,788	0.120
Estimate of Breeding Females	16,650	2,181	0.131
Proportion of Females in Population	0.723		0.019
Pregnancy rate of Breeding Females	0.720		0.100 *
Extrapolated Population Estimate	31,982	5,306	0.166

* no data, value is only a guess

[#] pregnancy rate from Heard and Williams 1991, p. 46 in Gunn et al. 1997

DISCUSSION

Results of June 2009 calving ground photographic survey of the Bathurst caribou herd were reliable, relatively precise, and met the survey's objectives. The estimate of breeding females was 16,650 (± 2,181 SE; with a CV of 0.131). The June 2009 estimate of breeding females was significantly lower ($p<0.005$) than June 2006 estimate of 55,593 (± 8,813 SE) (Nishi et al. 2007). The estimate of breeding females in June 2009 substantiates the results of June 2006 Bathurst caribou survey, and confirms the declining trend in abundance of breeding females since 1986.

A direct comparison of June 2009 estimate with the estimate of breeding females in June 2006, suggests that the number of breeding females has declined dramatically over the three year interval. The rate of decline (r=-0.402 (0.068 SD)) corresponds to a halving time of less than two years. A statistically rigorous Monte Carlo trend analysis suggested that the rate of decline has accelerated over the last few surveys, and that the abundance of breeding females is currently declining at a rate (r estimate of -0.26, SE=0.027, CI=-0.31 to -0.22), which corresponds to a halving time of less than three years. This means that if the number of breeding females continues to decline at the same rate (r=-0.26), by 2012 there may only be *ca.* 8,300 breeding females on the calving grounds (i.e. *ca.* 50% of 16,650).

A retrospective view of the pattern of movement and aggregation by ten satellite collared cows on to the survey strata suggests that our delineation of the annual calving ground and timing of the survey were effective (Figure 25). The design and execution of June 2009 calving ground survey was efficient, and we did not incur any major problems that could have seriously affected credibility of survey results. We also suggest that timing of the stratified photographic and visual survey coincided well with the peak of calving, which based on our observations during the systematic survey on 7 June, may have occurred by 8 June at the earliest. Reduced daily movement rates of satellite collared Bathurst caribou cows from 8-15 June coincided, with the initiation of the photographic survey. Data from composition surveys suggested that the peak of calving had occurred by 11 June; thus we conclude that peak of calving occurred from 8-11 June.

There were no logistic or weather-caused delays in timing between various phases of the calving ground survey including the systematic reconnaissance, stratification and completion of the photographic survey (and visual survey strata) and composition surveys on the annual calving ground. As the photographic survey was completed within two days following stratification, there was low potential for movements of breeding females across survey strata to bias the calving ground estimate. Occurrence of nine collared cows within the high and medium strata (Figure 7, 17) also supports our assertion that we had effectively delineated the annual calving ground and did not miss a substantial portion of breeding females outside the surveyed area.

In June 2009, we used two aircraft and flew 59.1 hours on survey (with an addition 33.6 hours of ferrying time) to complete extensive systematic surveys for delineating the annual calving ground and extending coverage well beyond it (Appendix B). In comparison, 35.0 hours (plus an additional 11.1 hours of ferry time) were flown in two aircraft to conduct the systematic survey in June 2006 (Appendix B in Nishi et al. 2007) and 22.2 hours were flown in one aircraft during the systematic surveys in June 2003 (Appendix B in Gunn et al. 2005). In summary, the relatively small area in which we observed breeding females, combined with the extensive area searched during systematic surveys, and the movement and distribution patterns of collared cows suggested that we accurately defined the Bathurst annual calving ground in June 2009. In addition, the declining trend observed in overall densities and relative frequency distributions of low, medium, and high densities observed through systemic reconnaissance surveys since 1996, suggests that annual reconnaissance surveys of annual calving grounds should be further refined, developed and reported as an annually monitored indicator especially when caribou populations (such as the Bathurst herd) decline to low numbers and management actions are implemented to assist in recovery (Appendix M).

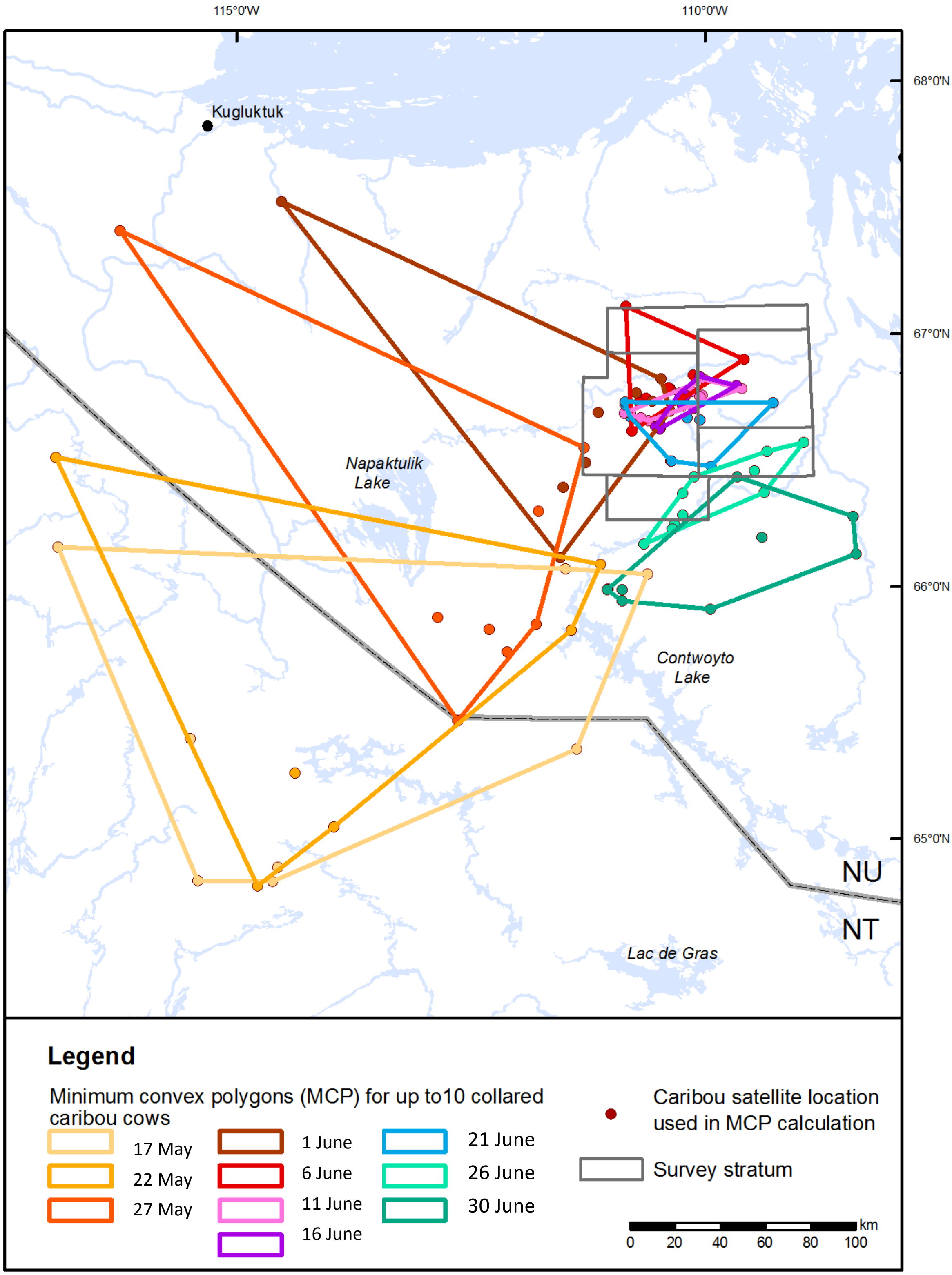

Figure 25. Minimum convex polygons enclosing locations of ten satellite collared Bathurst caribou cows at five day intervals from 17 May - 30 June, 2009.

Summary

We met the survey objective of obtaining a relatively precise estimate of the number of breeding females in the Bathurst herd (CV $\leq$15%). Optimal lighting conditions and use of aerial photography to count the number of caribou means that the estimate is accurate. Since the photographic estimate from the high and medium density strata represented over 98% of the total number of 1^+-year-old caribou on the calving ground, the overall contribution of observer bias (from the low density visual strata) to the survey results was inconsequential.

Our systematic reconnaissance covered an extensive area to reduce the likelihood of missing aggregations of breeding females. Indeed, we extended systematic coverage for approximately 100 km from the delineated boundary of the annual calving ground and extended our survey coverage west to the calving extent of the Bluenose-East herd, and east to the western calving extent of the Ahiak herd (Figure 4.8 in Adamczewski et al. 2009). Concomitant systematic surveys of the traditional calving grounds of the Ahiak and Beverly caribou herds further reduce the likelihood that large groups of breeding females from the Bathurst herd would have been missed (see Adamczewski et al. 2009). Furthermore, eight of ten satellite collared cows (that were presumed to be breeding females) were concentrated in the high density stratum; the other two animals were located in the medium density stratum, which also supports our assertion that we had included the entire distribution of breeding females. The 11th collared female, which was considered a non-breeder was located west of Contwoyto Lake (Figure 2, Appendix C) during the peak of calving and was associated with bulls, yearlings, and non-breeding females.

Based on our observations of caribou distribution, density and composition from extensive systematic reconnaissance (Appendix M), combined with locations and movement rates of collared cows, we suggest that the timing of the 2009 calving ground survey coincided well with the peak of calving, which likely occurred between 8 and 11 June. Finally, we experienced no major delays or technical challenges in conducting the calving ground photographic survey of the Bathurst herd in June 2009.

CONCLUSIONS

1. Results from the calving ground survey of the Bathurst caribou herd in June 2000 were reliable and relatively precise.
2. The estimate of breeding females in June 2009 (16,650 ± 2,181 SE) substantiates the results of June 2006 Bathurst caribou survey (55,593 ± 8,813 SE), and confirms that the abundance of breeding females has significantly declined since 1986.
3. The estimate of breeding females in June 2009 suggests that the number of caribou has declined significantly since 2006. If the observed rate of decline continues over the next several years, the estimated number of breeding females may decline to *ca.* 8,300 animals by June 2012, i.e. 50% of June 2009 estimate.

ACKNOWLEDGEMENTS

Funding for the calving ground survey was provided by the Department of Environment and Natural Resources (ENR), Wildlife Division, Yellowknife, NWT. The staff at Tahera Mine, Tahera Diamond Corporation generously provided us with a staging area and use of their airstrip along with meals, accommodations, flight services and office space at their site north of Contwoyto Lake.

Steve Blanchette and Adam Bourque (Air Tindi, Yellowknife) safely flew the survey crews in the Turbo Beaver and Cessna Caravan. Chuck Burke (Great Slave Helicopters, Yellowknife, NWT) piloted the A-Star for the composition surveys. We thank Geographic Air Service Ltd. (Edmonton, AB) for their excellent collaboration on the photographic survey; Wally Fiesel (pilot) flew the photo plane and Doug Evans (cameraman) took the photographs; Hilke Krey (manager) was patient and accommodating in our late night calculations of end points to photo lines. Beverly Archibald (TrueNorth Weather Services, Edmonton, AB), provided daily weather reports and forecasts which assisted us with planning field activities and anticipating weather conditions.

The data recording approach and data translations were developed by David Taylor and we appreciated his expertise. We thank Karin Clark (Wek'èezhìi Renewable Resources Board) for her participation and capable assistance throughout the survey. Adrian D'Hont (ENR, Yellowknife, NWT) provided timely updates on locations of collared cows, and helped with various logistics. Jennifer Bailey (ENR North Slave Region) provided assistance with GIS data and presentation, while Mika Sutherland (EcoBorealis Consulting Inc.) analysed satellite collar locations, and drafted all figures. Paul Roy counted caribou from all the aerial photographs. We thank George Mandeville, Ron Fatt, Frank Camsel, and Noel Doctor for participating in all aspects of field work and for sharing their insights on caribou. We thank Anne Gunn for advice on various aspects of survey design.

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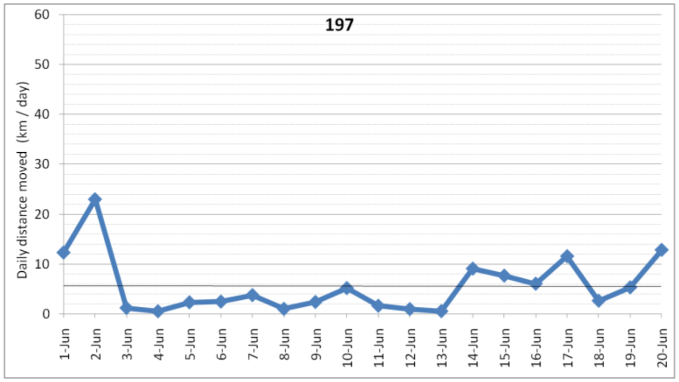
APPENDIX A. Field Crew for a Calving Ground Survey of the Bathurst Caribou Herd, June 2009

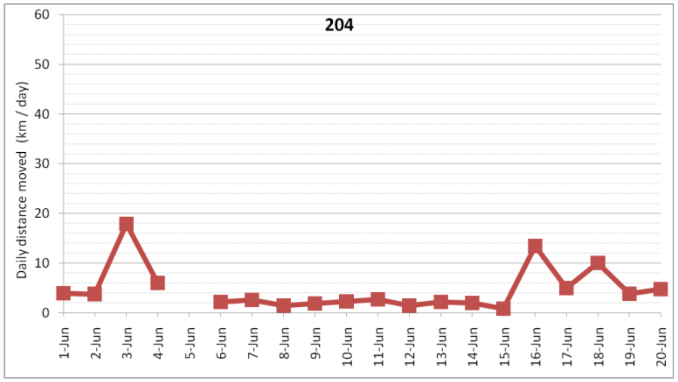
Team Member	Role	Affiliation
Jan Adamczewski (JA)	Biologist	Government of the Northwest Territories
Jennifer Bailey (JB)	GIS Technician	Government of the Northwest Territories
John Boulanger (JB)	Biometrician	Integrated Ecological Research
Steve Blanchette (SB)	Pilot (Turbo Beaver C-FOPE)	Air Tindi
Adam Bourque (AB)	Pilot (Cessna Caravan C-GATY)	Air Tindi
Frank Camsel (FC)	Observer & Community Representative	Tlicho Government
Karin Clark (KC)	Biologist	Wek'èezhìi Renewable Resources Board
Bruno Croft (BC)	Biologist	Government of the Northwest Territories
Noel Doctor (NC)	Observer & Community Representative	Yellowknife Dene First Nation
Doug Evans (DE)	Photographer (Challenger C-GEOS)	Geographic Air Survey Ltd.
Ron Fatt (RF)	Observer & Community Representative	Lutsel K'e Wildlife Lands & Environment Department
Wally Feisal (WF)	Pilot (Challenger C-GEOS)	Geographic Air Survey Ltd.
Allicia Kelly (AK)	Biologist	Government of the Northwest Territories
Chuck Burke (CB)	Pilot (A-Star G-ABX)	Great Slave Helicopters
George Mandeville (GM)	Observer & Community Representative	North Slave Metis Alliance
John Nishi (JN)	Biologist	EcoBorealis Consulting Inc.

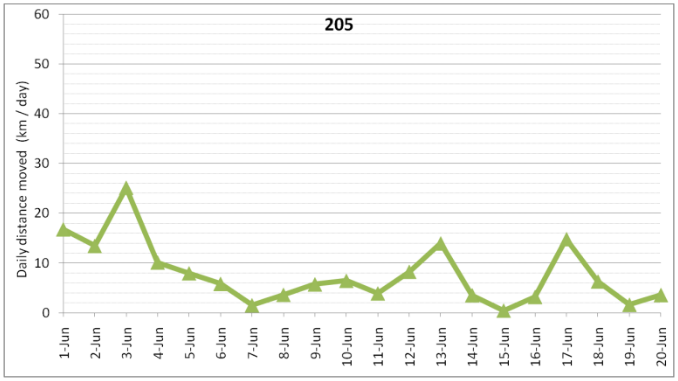
APPENDIX B. Daily Flight Log during Reconnaissance, Systematic, and Composition Surveys of Bathurst Calving Ground, 3-17 June, 2009

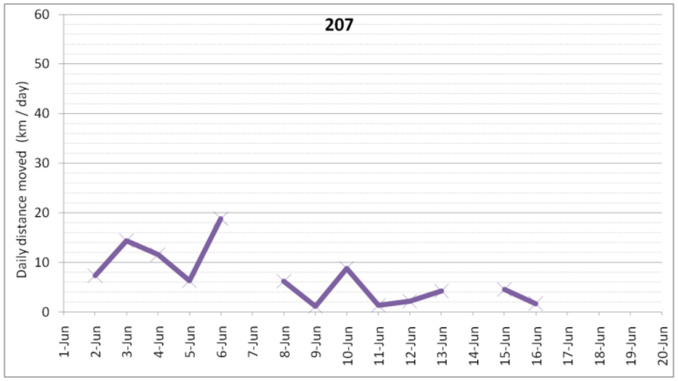
	Caravan		Turbo Beaver		A-Star Helicopter		
Date	Ferry time (hr)	Survey time (hr)	Ferry time (hr)	Survey time (hr)	Ferry time (hr)	Survey time (hr)	
03-Jun	8.0						
04-Jun	0.7	5.9					
05-Jun	1.0	8.0					
06-Jun	2.1	7.0	3.3	2.7			
07-Jun	2.9	5.5	2.2	5.8	3.0		
08-Jun	0.9	5.8	3.6	4.7		8.3	
09-Jun	2.0	4.2				8.9	
10-Jun	1.1	5.3				5.6	
11-Jun					3.0	5.6	
17-Jun	5.8	4.2					
Sum	24.5	45.9	9.1	13.2	6.0	28.4	
Total by Aircraft		70.4		22.3		34.4	127.1

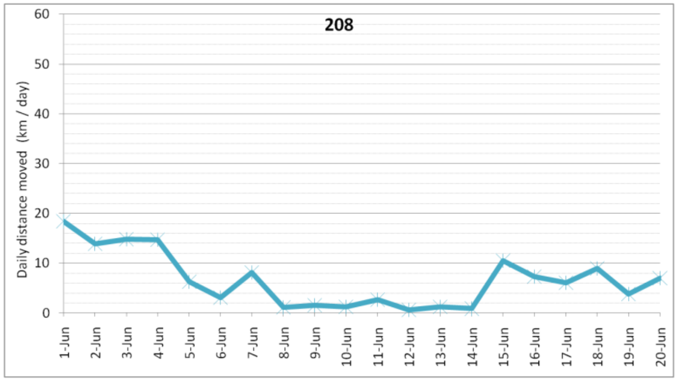
APPENDIX C. Daily Movements of 11 Radio Collared Bathurst Cows, 1-20 June, 2009







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Daily distance moved (km / day)
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7-Jun
8-Jun
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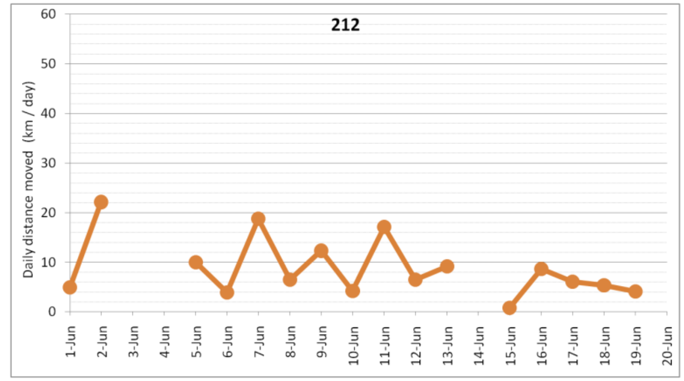
20-Jun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Daily distance moved (km / day)
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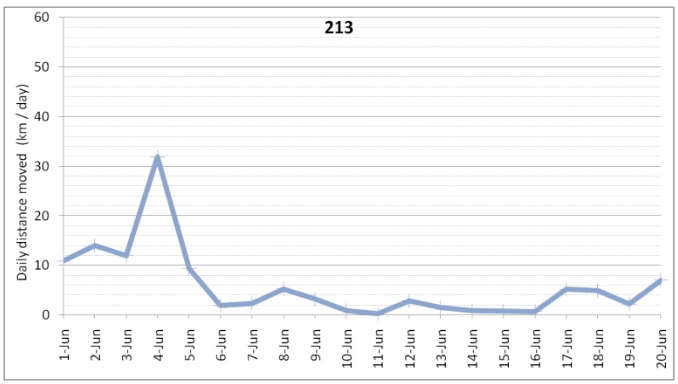
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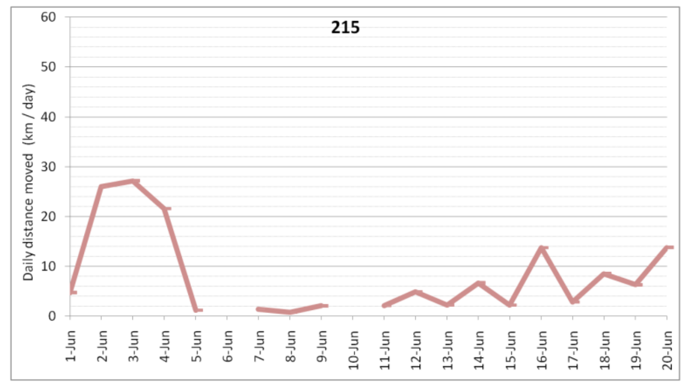
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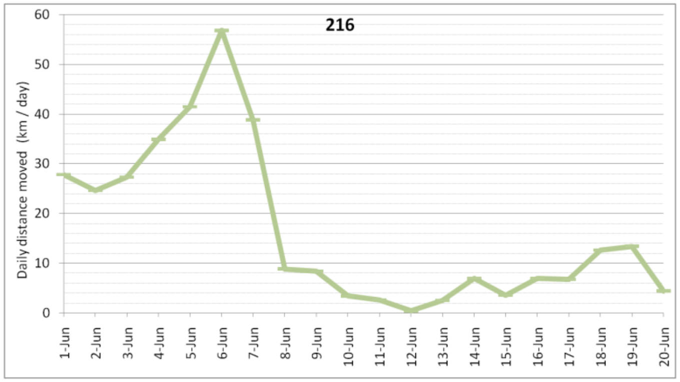
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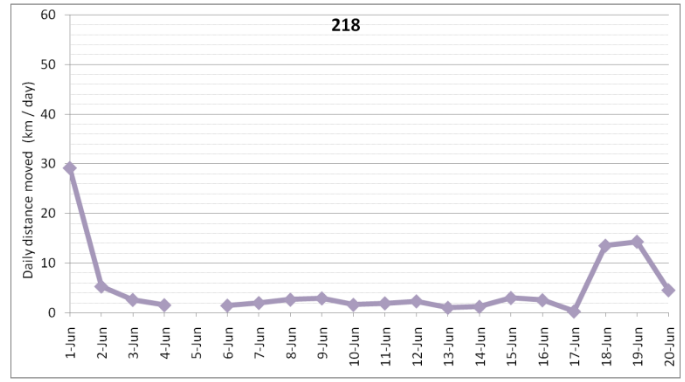
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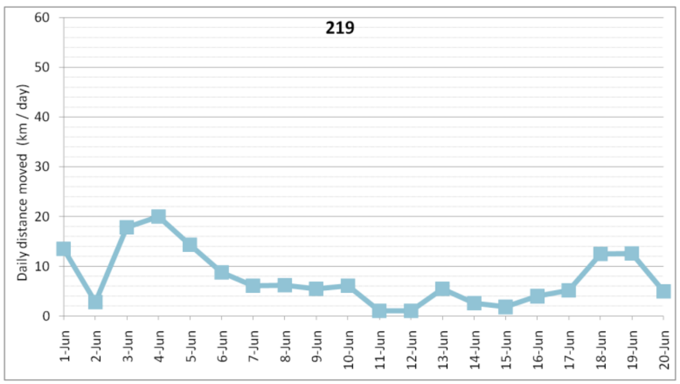
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Daily distance moved (km / day)
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APPENDIX C. continued.

Table C1. Likely breeding status of 11 radio collared Bathurst caribou cows based on location and trends in daily movement rates.

ID #	PTT #	Collar Type	On Annual Calving Ground	Daily distance < 2-3 km, for at least 2 consecutive days	Likely Breeding Status
197	73253	ARGOS	yes	yes	calved
204	73373	GPS	yes	yes	calved
205	73374	GPS	yes	no	uncertain
207	73376	GPS	yes	yes	calved
208	73377	GPS	yes	yes	calved
212*	73381	GPS	no	no	non-breeder
213	73382	GPS	yes	yes	calved
215	73384	GPS	yes	yes	calved
216	73385	GPS	yes	yes	calved
218	73387	GPS	yes	yes	calved
219	92147	GPS	yes	yes	calved

* Cow 212 was considered to be a non-breeder because it was a) located in an area east of Contwoyto Lake and away from the calving ground through the calving period, and b) it had a variable and comparatively high rate of movement. Cow 212 was not included in subsequent analyses of movement rates and dispersion of collared cows presumed to be breeders.

APPENDIX D. Caribou Densities Observed during Systematic Survey of the Bathurst Calving Ground, 4-17 June, 2009

Table D1. Transect segments surveyed and caribou counted during systematic reconnaissance surveys of the Bathurst calving ground, 4-17 June, 2009.

4 June	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	74	64.9%	0	0.0%	0	0.0%
Low	20	17.5%	74	14.5%	8	32.0%
Medium	19	16.7%	347	68.0%	14	56.0%
High	1	0.9%	89	17.5%	3	12.0%
Sum	114	100.0%	510	100.0%	25	100.0%
5 June	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	126	88.7%	0	0.0%	0	0.0%
Low	11	7.7%	33	28.4%	0	0.0%
Medium	5	3.5%	83	71.6%	0	0.0%
High	0	0.0%	0	0.0%	0	0.0%
Sum	142	100.0%	116	100.0%	0	0.0%
6 June	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	159	90.3%	0	0.0%	0	0.0%
Low	11	6.3%	27	12.3%	3	15.8%
Medium	5	2.8%	93	42.5%	16	84.2%
High	1	0.6%	99	45.2%	0	0.0%
Sum	176	100.0%	219	100.0%	19	100.0%
7 June (a.m.)	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	69	84.1%	0	0.0%	0	0.0%
Low	10	12.2%	21	35.6%	0	0.0%
Medium	3	3.7%	38	64.4%	0	0.0%
High	0	0.0%	0	0.0%	0	0.0%
Sum	82	100.0%	59	100.0%	0	0.0%

7 June (p.m.)	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	52	56.5%	0	0.0%	0	0.0%
Low	22	23.9%	78	12.3%	3	2.8%
Medium	16	17.4%	349	55.1%	85	80.2%
High	2	2.2%	206	32.5%	18	17.0%
Sum	92	100.0%	633	100.0%	106	100.0%
8 June (p.m.)	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	100	98.0%	0	0.0%	0	0.0%
Low	1	1.0%	3	27.3%	0	0.0%
Medium	1	1.0%	8	72.7%	0	0.0%
High	0	0.0%	0	0.0%	0	0.0%
Sum	102	100.0%	11	100.0%	0	0.0%
9 June	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	60	83.3%	0	0.0%	0	0.0%
Low	11	15.3%	32	62.7%	1	100.0%
Medium	1	1.4%	19	37.3%	0	0.0%
High	0	0.0%	0	0.0%	0	0.0%
Sum	72	100.0%	51	100.0%	1	100.0%
10 June	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	66	94.3%	0	0.0%	0	0.0%
Low	3	4.3%	10	47.6%	0	0.0%
Medium	1	1.4%	11	52.4%	0	0.0%
High	0	0.0%	0	0.0%	0	0.0%
Sum	70	100.0%	21	100.0%	0	0.0%
17 June	**10 km Segments**		**1+-Year-Old Caribou**		**Calves**	
Density class	(n)	(%)	(n)	(%)	(n)	(%)
No Caribou	1	2.6%	0	0.0%	0	0.0%
Low	18	47.4%	60	9.5%	0	0.0%
Medium	19	50.0%	569	90.5%	0	0.0%
High	0	0.0%	0	0.0%	0	0.0%
Sum	38	100.0%	629	100.0%	0	0.0%

APPENDIX E. Number of 1+-Year-Old Caribou Observed during an Aerial Transect Survey of High Density Photographic Strata (High), Bathurst Calving Ground, 8 June, 2009

High Density Photographic Stratum - High

Transect No.	Transect Length (km)	Transect Area (km^2)	1+-Year-Old Caribou Counted
1	43.55	39.82	71
2	43.55	39.82	39
3	43.50	39.78	51
4	43.45	39.73	51
5	54.49	49.82	81
6	54.49	49.82	79
7	54.49	49.82	158
8	54.49	49.82	130
9	54.49	49.82	192
10	54.49	49.82	391
11	54.49	49.82	220
12	54.49	49.82	580
13	54.49	49.82	494
14	54.49	49.82	661
15	54.49	49.82	479
16	54.49	49.82	643
17	54.49	49.82	624
18	54.49	49.82	1039
19	54.49	49.82	276
20	54.49	49.82	266
21	54.49	49.82	426
22	54.49	49.82	189
Total	1,154.80	1,055.95	7,140

APPENDIX F. Number of 1^{+}-Year-Old Caribou Observed during a Photographic Transect Survey of a Medium Density Stratum, Bathurst Calving Ground, 9 June, 2009

Medium Density Photographic Stratum – Medium

Transect No.	Transect Length (km)	Transect Area (km^2)	1^{+}-Year-Old Caribou Counted
1	44.18	40.40	118
2	44.18	40.40	296
3	44.18	40.40	195
4	44.18	40.40	30
5	44.18	40.40	68
6	44.18	40.40	113
7	44.18	40.40	97
8	44.18	40.40	63
9	44.18	40.40	17
10	44.18	40.40	10
Total	441.82	404.00	1007

APPENDIX G. Number of 1+-Year-Old Caribou Observed during a Visual Strip Transect Survey of Three Low Density Strata (Low N, Low SW, and Low SE), Bathurst Calving Ground, 8 June, 2009

Low Density Visual Stratum - Low N

Transect No.	Transect Length (km)	Transect Area (km^2)	1+-Year-Old Caribou Counted
1	19.63	15.70	5
2	19.69	15.75	0
3	19.75	15.80	0
4	19.81	15.85	0
5	19.88	15.90	0
6	19.94	15.95	0
7	20.00	16.00	0
8	20.06	16.05	0
9	20.12	16.10	0
10	9.92	7.94	0
11	10.01	8.01	0
12	10.09	8.08	0
13	10.18	8.15	0
14	10.27	8.21	0
15	10.36	8.28	0
16	10.44	8.35	0
17	10.53	8.42	0
18	10.62	8.49	0
19	10.70	8.56	0
20	10.79	8.63	0
Total	292.79	234.23	5

APPENDIX G. Continued

Low Density Visual Stratum - Low SW

Transect No.	Transect Length (km)	Transect Area (km^2)	1$^+$-Year-Old Caribou Counted
1	19.90	15.92	7
2	19.82	15.86	4
3	19.74	15.79	1
4	19.67	15.73	4
5	19.59	15.67	7
6	19.51	15.61	26
7	19.43	15.55	0
8	19.36	15.49	0
9	19.28	15.42	4
10	19.20	15.36	0
Total	195.50	156.40	53

Low Density Visual Stratum - Low SE

Transect No.	Transect Length (km)	Transect Area (km^2)	1$^+$-Year-Old Caribou Counted
1	21.40	17.12	0
2	21.40	17.12	2
3	21.40	17.12	2
4	21.40	17.12	0
5	21.40	17.12	3
6	21.40	17.12	0
7	21.40	17.12	2
8	21.40	17.12	0
9	21.40	17.12	6
10	21.40	17.12	0
11	21.40	17.12	0
Total	235.42	188.34	15

APPENDIX H. Composition of 1^{+}-Year-Old Caribou Classified in the High Density Photo Stratum, Bathurst Calving Ground, 8-11 June, 2009

Waypoint	Observation Number	Antlered With Udder	Antlerless With Udder	Antlered No Udder	Antlerless No Udder	Calves	Yearlings	Bulls	Sum All	Sum Breeding Females	Sum 1+ Yr Old Caribou	p	St	Pseudovalue
141	1	0	0	1	1	0	9	0	11	1	11	0.0909	0.67919	0.45146
142	2	0	1	1	3	1	6	0	12	2	11	0.1818	0.67865	0.48632
143	3	1	0	0	6	0	6	0	13	1	13	0.0769	0.67993	0.40406
144	4	0	1	5	3	5	11	2	27	6	22	0.2727	0.68055	0.36480
147	5	5	2	2	0	7	0	0	16	9	9	0.5625	0.67668	0.61239
148	6	9	7	1	0	16	0	0	33	17	17	1.0000	0.67268	0.86850
149	7	27	11	15	0	36	2	0	91	53	55	0.9636	0.66685	1.24130
150	8	3	0	1	2	2	4	0	12	4	10	0.4000	0.67719	0.57964
151	9	8	8	3	1	14	3	0	37	19	23	0.8261	0.67379	0.79706
152	10	0	0	1	2	0	9	0	12	1	12	0.0833	0.67956	0.42777
153	11	0	0	1	2	0	14	0	17	1	17	0.0588	0.68142	0.30894
154	12	0	0	0	16	0	33	0	49	0	49	0.0000	0.69410	-0.50282
155	13	0	0	0	6	0	16	0	22	0	22	0.0000	0.68384	0.15439
157	14	0	1	0	15	1	13	0	30	1	29	0.0345	0.68592	0.02108
158	15	0	1	0	3	1	6	1	12	1	11	0.0909	0.67919	0.45146
160	16	12	6	3	1	19	0	0	41	21	22	0.9545	0.67233	0.89083
161	17	80	25	15	15	101	10	0	246	120	145	0.8276	0.66275	1.50389
162	18	30	20	5	1	31	0	0	87	55	56	0.9821	0.66611	1.28894
163	19	16	10	9	1	26	4	0	66	35	40	0.8750	0.67128	0.95805
164	20	18	6	3	0	23	2	0	52	27	29	0.9310	0.67162	0.93637
165	21	6	2	2	0	7	0	0	17	10	10	1.0000	0.67392	0.78868
166	22	8	3	6	1	11	3	0	32	17	21	0.8095	0.67415	0.77420
167	23	12	4	11	5	15	4	0	51	27	36	0.7500	0.67421	0.77023
168	24	26	12	10	2	35	0	0	85	48	50	0.9600	0.66778	1.18197
169	25	13	1	3	1	14	0	0	32	17	18	0.9444	0.67305	0.84497
170	26	4	1	4	0	5	0	0	14	9	9	1.0000	0.67410	0.77732
171	27	6	5	3	0	13	0	0	27	14	14	1.0000	0.67321	0.83422
172	28	16	9	8	0	22	3	0	58	33	36	0.9167	0.67090	0.98227
173	29	32	5	4	1	39	2	0	83	41	44	0.9318	0.66944	1.07572
175	30	37	13	9	7	46	2	0	114	59	68	0.8676	0.66835	1.14528
176	31	48	6	1	5	42	4	0	106	55	64	0.8594	0.66910	1.09766
177	32	46	20	11	5	64	5	0	151	77	87	0.8851	0.66534	1.33805
179	33	4	1	5	0	4	13	0	27	10	23	0.4348	0.67873	0.48127
181	34	6	4	6	1	10	4	0	31	16	21	0.7619	0.67470	0.73915
182	35	3	1	1	14	3	16	0	38	5	35	0.1429	0.68598	0.01700

APPENDIX H. Continued

Waypoint	Observation Number	Antlered With Udder	Antlerless With Udder	Antlered No Udder	Antlerless No Udder	Calves	Yearlings	Bulls	Sum All	Sum Breeding Females	Sum 1+ Yr Old Caribou	p	St	Pseudovalue
184	36	10	4	4	2	16	2	0	38	18	22	0.8182	0.67397	0.78562
186	37	0	0	2	5	0	6	0	13	2	13	0.1538	0.67939	0.43895
187	38	12	3	1	3	13	5	0	37	16	24	0.6667	0.67581	0.66809
188	39	19	3	3	4	22	3	0	54	25	32	0.7813	0.67383	0.79480
189	40	13	0	0	0	11	12	0	36	13	25	0.5200	0.67783	0.53897
191	41	5	0	10	5	5	7	0	32	15	27	0.5556	0.67747	0.56163
193	42	8	1	4	5	8	7	0	33	13	25	0.5200	0.67783	0.53897
195	43	28	8	24	2	31	8	0	101	60	70	0.8571	0.66854	1.13315
196	44	22	8	14	7	19	5	1	76	44	57	0.7719	0.67263	0.87183
199	45	1	0	1	5	0	7	0	14	2	14	0.1429	0.67976	0.41523
200	46	7	0	6	5	11	6	0	35	13	24	0.5417	0.67745	0.56277
201	47	6	7	0	3	19	0	0	35	13	16	0.8125	0.67449	0.75220
202	48	4	0	4	0	5	0	0	13	8	8	1.0000	0.67428	0.76598
203	49	10	3	8	1	14	2	0	38	21	24	0.8750	0.67307	0.84362
204	50	3	1	3	5	3	3	0	18	7	15	0.4667	0.67740	0.56616
205	51	19	4	25	3	21	7	0	79	48	58	0.8276	0.67077	0.99086
207	52	7	8	2	3	14	3	0	37	17	23	0.7391	0.67489	0.72689
208	53	5	0	5	0	3	1	0	14	10	11	0.9091	0.67429	0.76519
209	54	3	0	2	4	3	10	0	22	5	19	0.2632	0.67998	0.40127
210	55	0	0	0	3	0	7	0	10	0	10	0.0000	0.67937	0.44028
212	56	0	0	0	9	0	0	1	10	0	10	0.0000	0.67937	0.44028
213	57	0	0	0	9	0	5	0	14	0	14	0.0000	0.68085	0.34540
214	58	2	0	1	8	2	7	0	20	3	18	0.1667	0.68070	0.35508
215	59	0	0	2	2	0	9	0	13	2	13	0.1538	0.67939	0.43895
217	60	0	2	6	16	2	4	0	30	8	28	0.2857	0.68169	0.29150
218	61	8	1	4	2	10	0	0	25	13	15	0.8667	0.67413	0.77577
219	62	7	1	5	0	10	0	0	23	13	13	1.0000	0.67339	0.82281
220	63	9	2	6	8	13	4	0	42	17	29	0.5862	0.67712	0.58434
221	64	1	1	3	2	1	10	0	18	5	17	0.2941	0.67923	0.44883
224	65	16	6	3	2	23	0	0	50	25	27	0.9259	0.67198	0.91328

APPENDIX H. Continued

n=	65				
Sum Breeding Females	1248	Sum Calves	892	Sum all caribou	2732
Sum 1+ Yr Old Caribou	1840	Ratio Calf:cow	0.7147		
Overall proportion Breeding Females	0.6783				

Tukey's Jacknife Method
(Cochran 1977, p. 178;
Krebs 1989, p. 464,
Sokal & Rohlf 1981, p. 796)

Proportion Breeding Females	
mean	0.681
variance	0.118
SD	0.343
SE	0.043
CV	0.063

Øi = nS - (n-1) St

Where:
Øi = Pseudovalue for jacknife estimate
n = Original sample size
S = Original statistical estimate
St = Statistical estimate when original value i has been discarded from sample
i = Sample number (1,2,3,…. n)

APPENDIX I. Composition of 1+-Year-Old Caribou Classified in the Medium Density Photo Strata (Med), Bathurst Calving Ground, 8-11 June, 2009

Waypoint	Observation Number	Antlered With Udder	Antlerless With Udder	Antlered No Udder	Antlerless No Udder	Calves	Yearlings	Bulls	Sum All	Sum Breeding Females	Sum 1+ Yr Old Caribou	p	St	Pseudovalue
225	1	1	1	39	6	3	4	0	54	41	51	0.8039	0.88221	0.80383
226	2	11	4	7	2	22	0	0	46	22	24	0.9167	0.87648	0.89542
227	3	15	3	2	2	16	1	0	39	20	23	0.8696	0.87782	0.87409
228	4	84	12	15	6	98	7	0	222	111	124	0.8952	0.87466	0.92456
229	5	7	9	3	2	16	2	0	39	19	23	0.8261	0.87900	0.85511
230	6	7	21	3	2	25	2	0	60	31	35	0.8857	0.87726	0.88307
231	7	30	30	1	8	60	1	0	130	61	70	0.8714	0.87814	0.86892
232	8	85	74	10	12	148	10	0	339	169	191	0.8848	0.87556	0.91028
233	9	22	28	2	0	47	1	0	100	52	53	0.9811	0.87085	0.98559
235	10	0	0	0	4	0	6	0	10	0	10	0.0000	0.88785	0.71356
236	11	0	3	2	1	3	1	0	10	5	7	0.7143	0.87893	0.85630
237	12	53	3	11	6	60	0	0	133	67	73	0.9178	0.87390	0.93682
238	13	21	18	1	3	32	2	0	77	40	45	0.8889	0.87698	0.88750
239	14	19	7	1	3	25	6	0	61	27	36	0.7500	0.88313	0.78905
240	15	12	10	5	0	19	2	0	48	27	29	0.9310	0.87575	0.90722
241	16	34	11	8	0	45	0	0	98	53	53	1.0000	0.86962	1.00527
242	17	10	1	4	0	10	4	0	29	15	19	0.7895	0.87957	0.84597

n=	17				
Sum Breeding Females	760	Sum Calves	629		
Sum 1+ Yr Old Caribou	866	Ratio Calf:cow	0.8276	Sum all caribou	1495
Overall proportion Breeding Females	0.8776				

Tukey's Jacknife Method
(Cochran 1977, p. 178;
Krebs 1989, p. 464,
Sokal & Rohlf 1981, p. 796)

Proportion Breeding Females

mean	0.879
variance	0.005
SD	0.070
SE	0.017
CV	0.019

Øi = nS - (n-1) St

Where:

Øi = Pseudovalue for jacknife estimate

n = Original sample size

S = Original statistical estimate

St = Statistical estimate when original value i has been discarded from sample

i = Sample number (1,2,3,…. n)

APPENDIX J. Composition of 1+-Year-Old Caribou classified in the Low Density Strata (Low-SW and Low-SE), Bathurst Calving Ground, 8-11 June, 2009

Waypoint	Observation Number	Antlered With Udder	Antlerless With Udder	Antlered No Udder	Antlerless No Udder	Calves	Yearlings	Bulls	Sum All	Sum Breeding Females	Sum 1+ Yr Old Caribou	p	St	Pseudovalue
243	1	0	0	0	8	0	15	0	23	0	23	0.0000	0.12315	0.01035
244	2	0	0	0	12	0	10	1	23	0	23	0.0000	0.12315	0.01035
245	3	3	7	2	14	2	18	2	48	12	46	0.2609	0.07222	0.41780
246	4	2	1	0	29	0	18	0	50	3	50	0.0600	0.12500	-0.00442
247	5	0	0	0	7	0	8	0	15	0	15	0.0000	0.11848	0.04771
248	6	3	2	0	12	3	1	0	21	5	18	0.2778	0.09615	0.22634
249	7	3	2	0	13	2	3	0	23	5	21	0.2381	0.09756	0.21509
250	8	0	0	0	15	0	4	0	19	0	19	0.0000	0.12077	0.02939
251	9	0	0	0	7	0	4	0	11	0	11	0.0000	0.11628	0.06534

n=	9				
Sum Breeding Females	25	Sum Calves	7		
Sum 1+ Yr Old Caribou	226	Ratio Calf:cow	0.2800	Sum all caribou	233
Overall proportion Breeding Females	0.1106				

Tukey's Jacknife Method
(Cochran 1977, p. 178;
Krebs 1989, p. 464,
Sokal & Rohlf 1981, p. 796)

Proportion Breeding Females	
mean	0.113
variance	0.021
SD	0.143
SE	0.048
CV	0.423

Øi = nS - (n-1) St

Where:
Øi = Pseudovalue for jacknife estimate
n = Original sample size
S = Original statistical estimate
St = Statistical estimate when original value i has been discarded from sample
i = Sample number (1,2,3,…. n)

APPENDIX K. Bathurst Caribou Breeding Female Trend Analysis 2009-DRAFT

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This short paper details analysis of trend for breeding females in the Bathurst caribou herd. It eventually will be incorporated into a larger more comprehensive report.

METHODS

Data set used for analysis

The data set of population estimates for breeding females is shown in Table 1 and Figure 1. I note that this is the most applicable data set for trend estimation since breeding females are the most biologically meaningful segment of the population. In addition, all parameters (i.e. counts of caribou and composition) are directly estimated for each year surveyed and therefore breeding female counts should most directly reflect changes in population size.

Table 1: Breeding female population estimates used for trend analysis

Year	N	SE	CV	t df	CI Min	CI Max
2009	16,604	2,176.42	0.13	29	12,153	21,056
2006	55,593	8,813	0.16	19	37,147	74,039
2003	80,658	13,149.1	0.16	17	52,916	108,400
1996	15,393	35,144.0	0.23	13	75,469	227,317
1990	151,927	25,805.0	0.17	10	94,430	209,424
1986	203,800	12,695.7	0.06	43	178,197	229,403

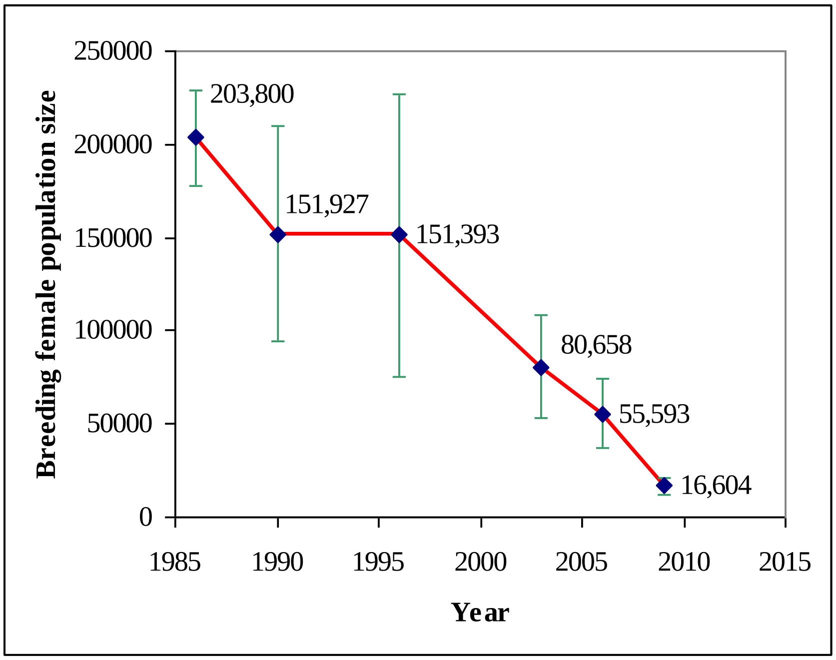

Figure 1: Population estimates of breeding females for surveys conducted in 1986, 1990, 1996, 2003, 2006, and 2009; 95% confidence intervals for estimates are shown as error bars.

Weighted regression

Weighted least squares analysis was used to estimate trend from the time series of data (Brown and Rothery 1993). Each population estimate was weighted by the inverse of its variance to account for unequal variances of surveys, and to give more weight in the estimation to the more precise surveys.

Unlike previous surveys, there was evidence of potential non-linear population trends as indicated by the substantially lower 2009 calving ground estimate. Given this, I conducted substantial testing for non-linear population trends using the sample-size-corrected Akaike Information Criterion (AIC_c) index of model fit (Burnham and Anderson 1998). The model with the lowest AIC_c score was considered the most parsimonious, thus optimizing the trade-off between bias and precision (Burnham and Anderson 1998). The difference between any given model and the most supported (ΔAIC_c) was used to evaluate the relative fit of models when their AIC_c scores were similar. In general, any model with a ΔAIC_c score of ≤2 is 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). Unlike previous analysis, it was not possible to estimate rates of change from λ given potential non-linear trends in the data set. However, λ could still be estimated using the ratio of successive predicted population sizes from the regression model. The per capita growth rate can be related to the population rate of change (λ) using the equation $\lambda = e^r = N_{t+1}/N_t$. If λ=1 then a population is stable. If λ is <1 then the population is decreasing, and if λ is >1 then the population is increasing.

Monte Carlo simulation

I used a Monte Carlo simulation technique to allow another estimate of the variance in trend that resulted from individual variances of each of the surveys (Manly 1997) and provide confidence interval for λ. The basic question this simulation asked was: "If these studies were repeated many times, would the estimated trends and associated variances be observed given the levels of precision of each of the surveys?" 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 estimation. For a given estimate the 95% confidence interval is the population estimate ± $t_{(\alpha=0.05,2,df)}$*standard error. 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 standard error and then 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 confidence intervals. 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 population sizes was generated for each of the five sampling occasions using the procedure documented in point 1 and the parameters listed in Table 1. The most supported AIC regression model was used for estimation. This procedure was repeated for 2000 pseudo data sets that resulted in 2000 estimates of trend. The most supported trend model was used to produce trend estimates.
3. Estimates of trend from the pseudo data sets were analyzed. Mean estimates and percentile-based confidence intervals based on successive changes in population size were estimated using the pseudo data sets.

Basically, 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.

RESULTS

Weighted regression

Model selection results suggested that a nonlinear trend best approximated by a cubic polynomial term was most supported (Table 2). This model showed strong support as indicated by a AIC weight of 0.95. A model with linear trends was not supported by the data.

Table 2: Model selection results for Bathurst trend analysis. Akaike Information Criteria (AIC_c), the difference in AIC_c values between the i^{th} and most supported model (ΔAIC_c), Akaike weights (w_i), and number of parameters (K) are presented.

Model	AIC_c	ΔAIC_c	w_i	logl
yr^3	2.82	0	0.995	2.59
$yr+yr_{>06}$	8.12	5.30	0.005	4.94
yr^2 yr^3	11.58	8.76	0.000	3.21
yr yr^3	12.50	9.68	0.000	2.75
yr yr^2	17.68	14.86	0.000	0.16
$yr+yr_{>03}$	20.59	17.77	0.000	-7.29
yr	34.91	32.09	0.000	-13.46
yr yr^2 yr^3	37.04	34.22	0.000	5.48
Intercept	322.72	319.90	0.000	-159.86

Parameter estimates for the most supported model suggest both the intercept and yr^3 terms are significant (Table 3).

Table 3: Regression model parameter estimates.

Parameter	Estimate	S.E	C.I. Low	C.I. High	t	P-value
Intercept	12.208	0.075	12	12.417	162.72	0
yr^3	-0.0002	0.000015	-0.0002	-0.0001	-13.45	0.0002

A plot of the regression line (back transformed to population size units) is shown in Figure 2. The gray lines are 95% confidence interval around the trend line. The circles are data points. The confidence intervals are irregular since they are accounting for varying degrees of variance in each of the point estimates. For example, the 1986, 2003, and 2006 and 2009 surveys had the best precision and therefore the confidence intervals are tightest around these points.

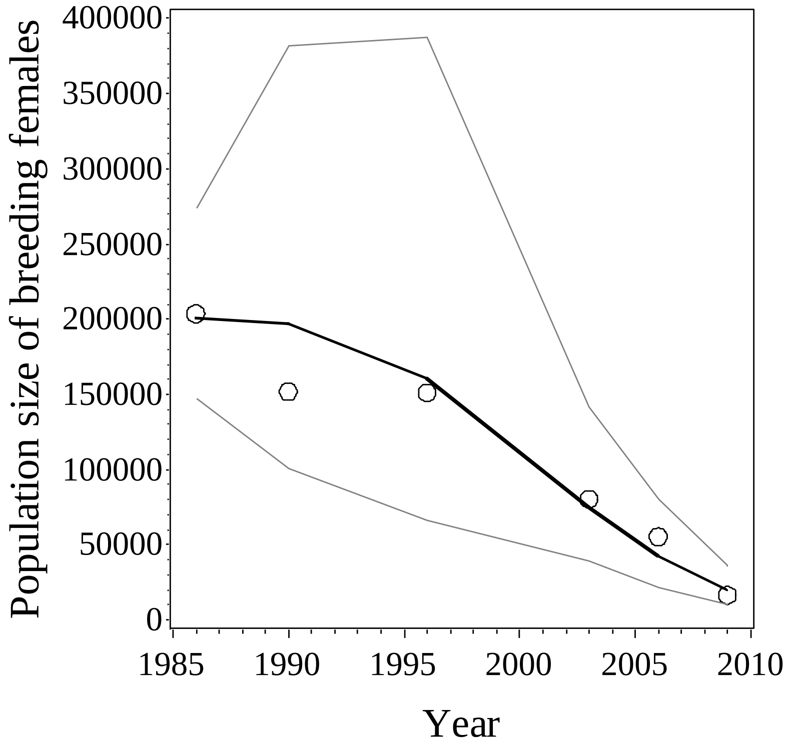

Figure 2: Predicted trend for breeding females from weighted least squares regression analysis. Thin grey lines are confidence interval on predictions. Circles are estimates for each year.

Monte Carlo simulation

Monte Carlo simulation results (Figure 3) suggested that the trend was increasingly negative as shown by lower λ estimates for each year. The λ of 1 at the beginning of the simulations was an artifact of the fact that this was the first point in the simulation and therefore the most applicable estimates were for the latter part of the time series (i.e. after 2000).

A histogram of λ estimates for 2009 (Figure 4) shows that none of the values overlapped 1 suggesting there was no statistical chance that the population was stable.

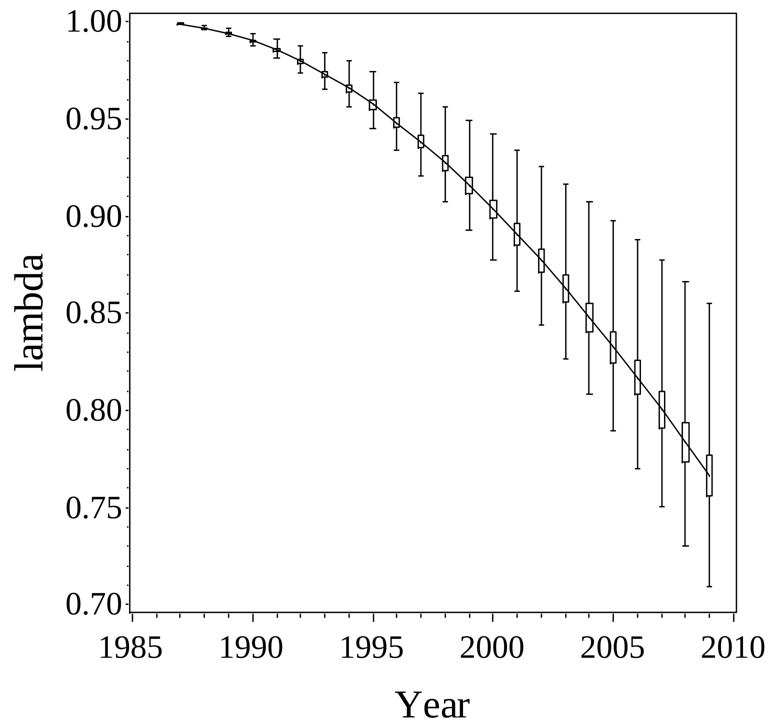

Figure 3: Simulated estimates of lambda (λ) as a function of year from Monte Carlo simulation analysis.

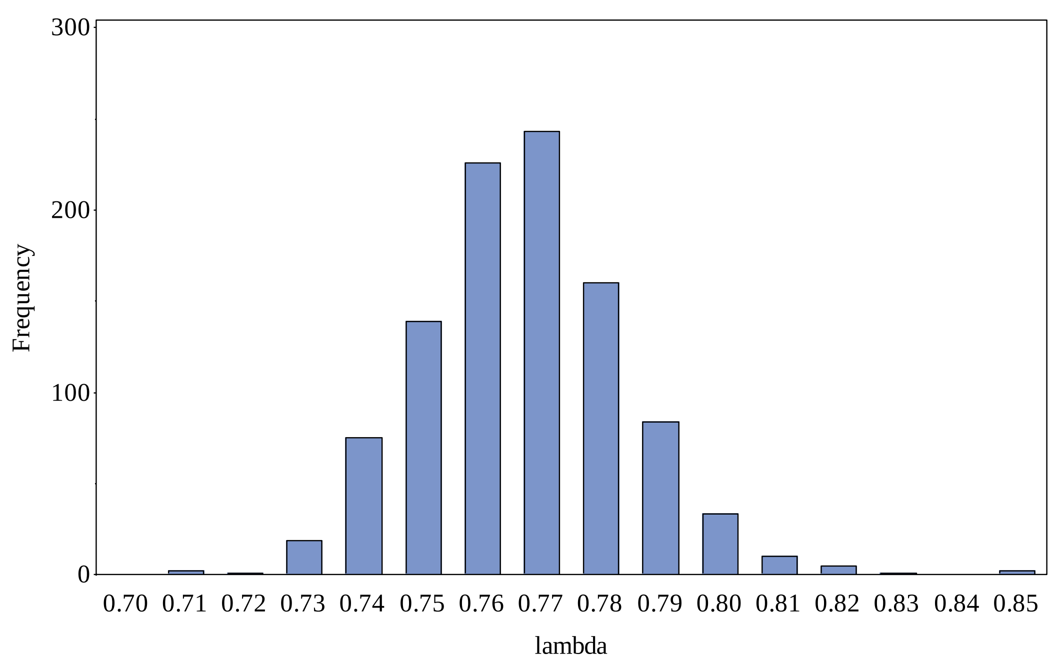

Figure 4: Distributions of population rate of change – lambda (λ) – for 2009 generated using Monte Carlo simulation trials.

The estimates of λ from the Monte Carlo analysis for 2009 was 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).

DISCUSSION

Both analyses suggest an increasing negative trend in the population size of breeding females in the Bathurst caribou herd. From inspection of Figure 1 it might be surmised that the population may have declined between 1986 and 1990 and then stabilized from 1990-1996 and then declined from 1996-2006 and then declined further from 2006-2009. The cubic polynomial trend model is the "best approximating model" in that it best summarizes the trends in population size using the least number of parameters as displayed in Table 2.

Regression methods that utilize multiple years of data provide potentially more inference regarding population trend and status compared to two sample t-tests of sequential population estimates. For example, regression-based estimates of r and λ express population change in yearly units. In comparison, t-tests of sequential estimates are will be influenced by the arbitrary period of time between successive surveys. For example, a two sample t-test will be more likely to detect a change in population size between surveys that are conducted at longer time intervals even if the population is changing at a constant rate. Estimates from regression are not influenced by survey interval, and they utilize data from all surveys conducted leading to higher overall power to detect change in population size. For this reason I recommend reporting trend estimates in terms of λ and *r*-values rather than the results of t-tests of sequential estimates.

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APPENDIX L. Exponential Rate of Increase between Estimates of Breeding Females on 2006 and 2009 Bathurst Caribou Calving Ground Surveys

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Rate of increase *(r)* between T_{2006} and T_{2009}

The rate of increase between the 2003 and 2006 estimates of breeding females was calculated in a spreadsheet using the formulas and methods in Section 4.3.1 of Gasaway et al. (1986). I estimated the value of *r* as well as the standard deviation and 95% confidence intervals for this parameter.

Table L1.

	T_{2006}	T_{2009}	Halving Time (years)
Year (t)	2006	2009	
Population Size (Nt)	55593	16649	
Variance	77667712	4757804	
$\log_e$ (Nt)	10.9	9.7	
Δt	3		
df	19	30	
a) Exponential Rate of increase *(r)* = $\log_e (T_{2009}) - \log_e (T_{2006}) / \Delta t$			
r =		-0.402	1.7
b) Variance of the Exponential Rate of Increase			
Var(L1)=		0.025	
Var(L2)=		0.017	
Var (r) =		0.00465	
Std Dev =		0.068	
Degrees Freedom =		42	
c) 95% Confidence Intervals: Upper		-0.264	2.6
Lower		-0.540	1.3

APPENDIX M. Potential for Systematic Surveys of Bathurst Caribou Calving Grounds to Contribute to Herd Monitoring

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INTRODUCTION

In this Appendix, I describe a trend analysis of data from systematic surveys of the Bathurst caribou calving grounds. I initiated the analysis in May 2009, prior to the June 2009 calving ground photographic survey. My goal was to review the systematic surveys that had been flown annually in 2007 and 2008, since the last photographic survey in 2006 (Nishi et al. 2007), in order to understand trend in area and density of the annual calving grounds, and anticipate those conditions for June 2009.

My rationale for the analysis was based on the premise that systematic surveys of traditional calving grounds are designed to delineate the annual calving ground based upon relative composition and density of caribou observed within 10 km long (or 8 km^2) segments of systematic transects. My objective was to delineate annual calving grounds retrospectively from systematic surveys in 2006, 2007, and 2008, and extrapolate observed densities within the delineated areas to area-weighted estimates of 1$^+$-year-old caribou. I thought this assessment would provide a directly comparable time series of data, which I could use to evaluate general trends, anticipate size of the calving ground and densities of caribou on the calving ground in June 2009.

Following the 2009 survey, I subsequently added the systematic surveys from 2003 and 2009 to evaluate trends and frequency distributions of caribou density observed during systematic surveys of annual calving grounds. I reviewed implications of this assessment and integrated those findings into the larger survey report.

METHODS

Data used for analyses

Estimates of 1^+-year-old caribou were available for systematic surveys and from completed calving ground photographic surveys in 1996 (Gunn et al. 1997), 2003 (Gunn et al. 2005b), 2006 (Nishi et al. 2007), and 2009 (this report). Systematic aerial reconnaissance surveys of the Bathurst calving grounds were conducted in 2007, 2008 (GNWT unpublished data), and 2009 (this report).

Data from systematic visual surveys were reported as caribou densities within adjacent transect segments (10 km long segments by 0.8 km wide) oriented along north-south oriented linear transects, within a systematic grid of transects spaced at 10 km intervals. For the 1996, 2006, and 2009 systematic survey data, I simply used the segment data from within the final stratification designs of the calving ground surveys. For the 2003 calving ground survey, I used the reconnaissance survey data collected mostly on 7 June, 2003 and the associated proposed calving ground delineation, rather than the final stratification which occurred following weather caused delay and stratum boundary flight on 13 June, 2003 (see Gunn et al. 2005). For 2007 and 2008 survey data, I delineated the annual calving ground based upon: 1) relative distribution and density of breeding females (with and without calves) from the composition categories, and 2) density values assigned to each of the 10 km segments during the systematic survey. Within the delineated annual calving ground, I extrapolated each observed density to an estimate of 1^+-year-old caribou in a 100 km^2 area (or adjusted it based on transect spacing) by multiplying the density value of a segment by 100. The sum of caribou counts within all

100 km^2 cells provided a coarse extrapolated estimate of 1^+-year-old caribou on the annual calving ground based on the systematic reconnaissance surveys.

Frequency distributions for caribou densities observed within all 10 km segments of an annual calving ground were plotted according to three broad densities classes, where low was >0 and $\leq$1, medium was >1 and $\leq$10, and high was >10 caribou/km^2. For visual presentation of histograms, I broke down the low, medium and high density classes further into two, three, and five sub-categories respectively.

RESULTS

The extrapolated estimates of 1^+-year-old caribou on the Bathurst calving ground were consistently lower, but showed a similar declining trend to that depicted by the caribou estimates derived from aerial photographic surveys (Figure 1M). The relative difference between the aerial photographic estimate and the extrapolated count was much greater when there were larger numbers of caribou on the calving ground. Extrapolated counts based on observed caribou densities from systematic reconnaissance surveys showed the decline from 2006-2009 on an annual time step.

The overall proportion of low, medium, and high density segments changed from 2003-2009, indicating a decrease in high density areas and corresponding increase in low density segments (Figure 2M). Relative to the 2003 systematic survey, all other surveys of annual calving grounds had lower proportions of medium density segments (Figure 2M).

In 1996, the caribou observed within the high density segments contributed *ca.* 91% to the extrapolated count of 1^+-year-old caribou on the annual calving ground. The proportion of caribou in high density segments varied between 76.8% and 80.0% between

2003 and 2007, but then declined to less than 30% in 2009 (Figure 3M). Since 2006, the relative contribution of high density segments declined, while more caribou were observed within medium and low density segments respectively (Figure 3M).

The decrease in number of high density segments and proportional changes to low and medium density areas from systematic surveys is shown in Figure 4M as an incremental leftward shift in the frequency distributions from high densities to medium and low. In 1996, there were 12 segments that had high caribou densities, of which three segments had caribou densities greater than 100 caribou/km^2, and comprised 28.6% of all transect segments on the annual calving ground (Figure 2M). In 2003, there were 11 high density segments, but none with densities greater than 100 caribou/km^2: High density segments represented *ca.* 23.4% of the total number of segments observed on the annual calving ground during the systematic survey (Figure 2M). By 2009, there were only two high density segments (<25 caribou/km^2) out of a total of 51 systematic transect segments (*ca.* 3.9% in Figure 2M) that covered the annual calving ground (Figure 4M).

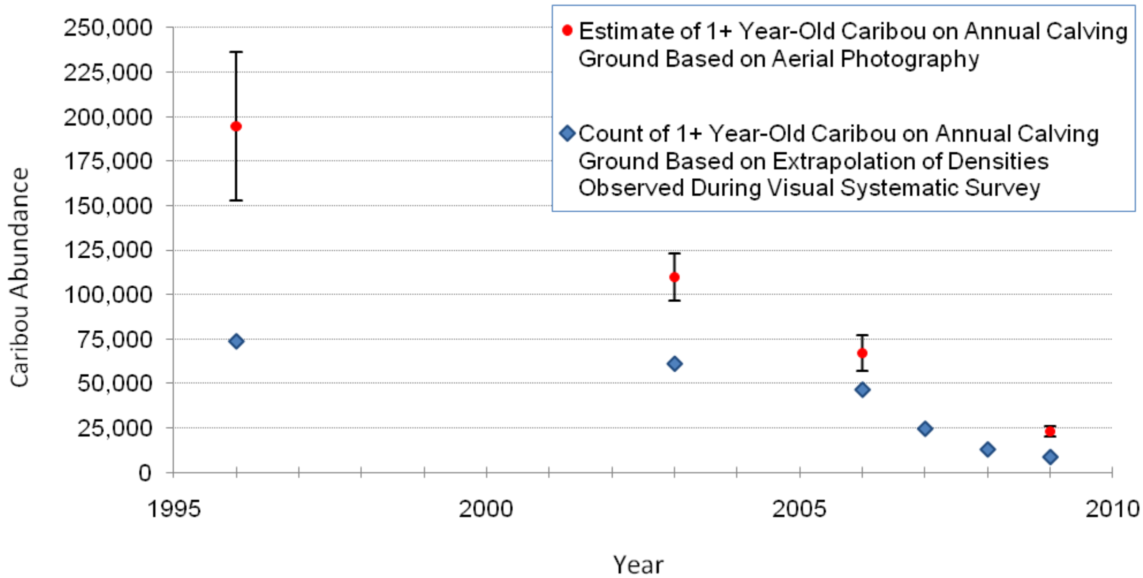

Figure 1M. Trend in estimates of 1^+-year-old caribou on Bathurst calving grounds based on aerial photographic survey results and extrapolation of caribou densities observed during visual systematic reconnaissance surveys.

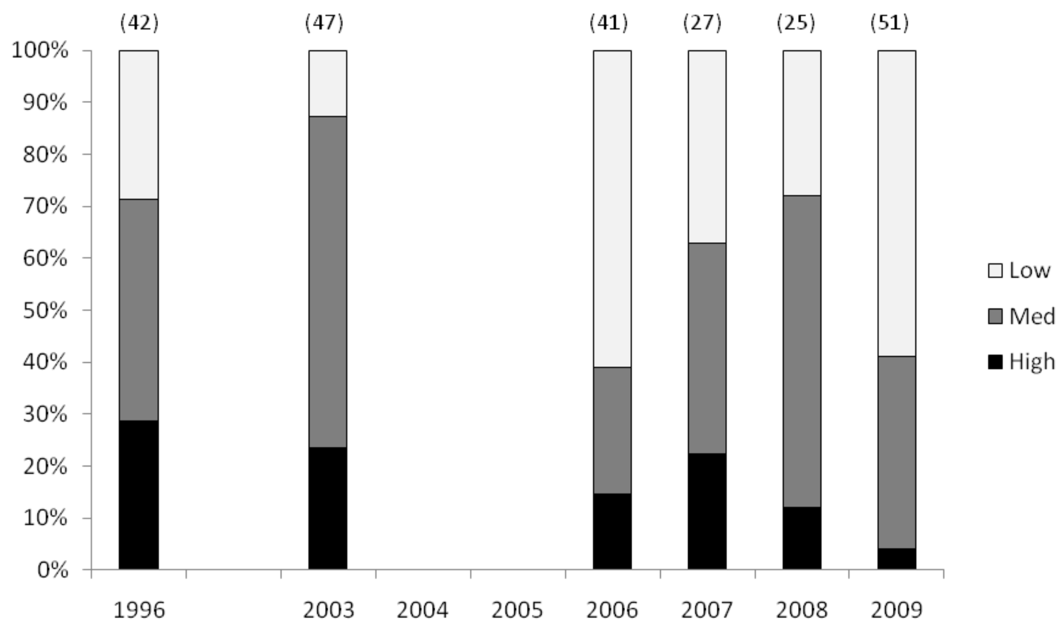

Figure 2M. Trend in proportion of low, medium and high density segments observed from systematic surveys of annual Bathurst calving grounds. Low density segments had >0 and $\leq$1, medium density had >1 and $\leq$10, and high density had >10 caribou/km^2. Total number of segments on the calving ground with at least one caribou are shown above the bars in parentheses.

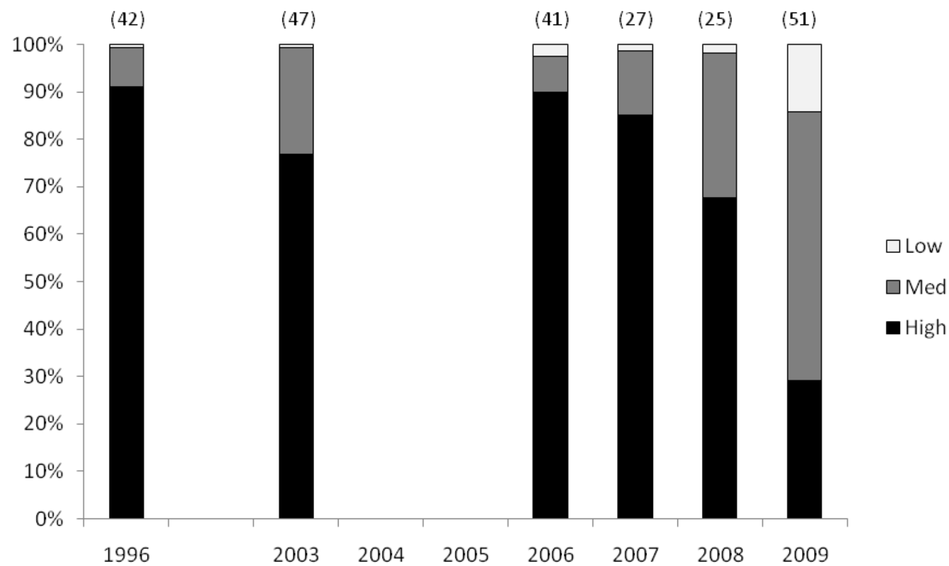

Figure 3M. Trend in relative contribution of high, medium and low density segments to extrapolated population counts from visual systematic reconnaissance surveys of Bathurst calving grounds.

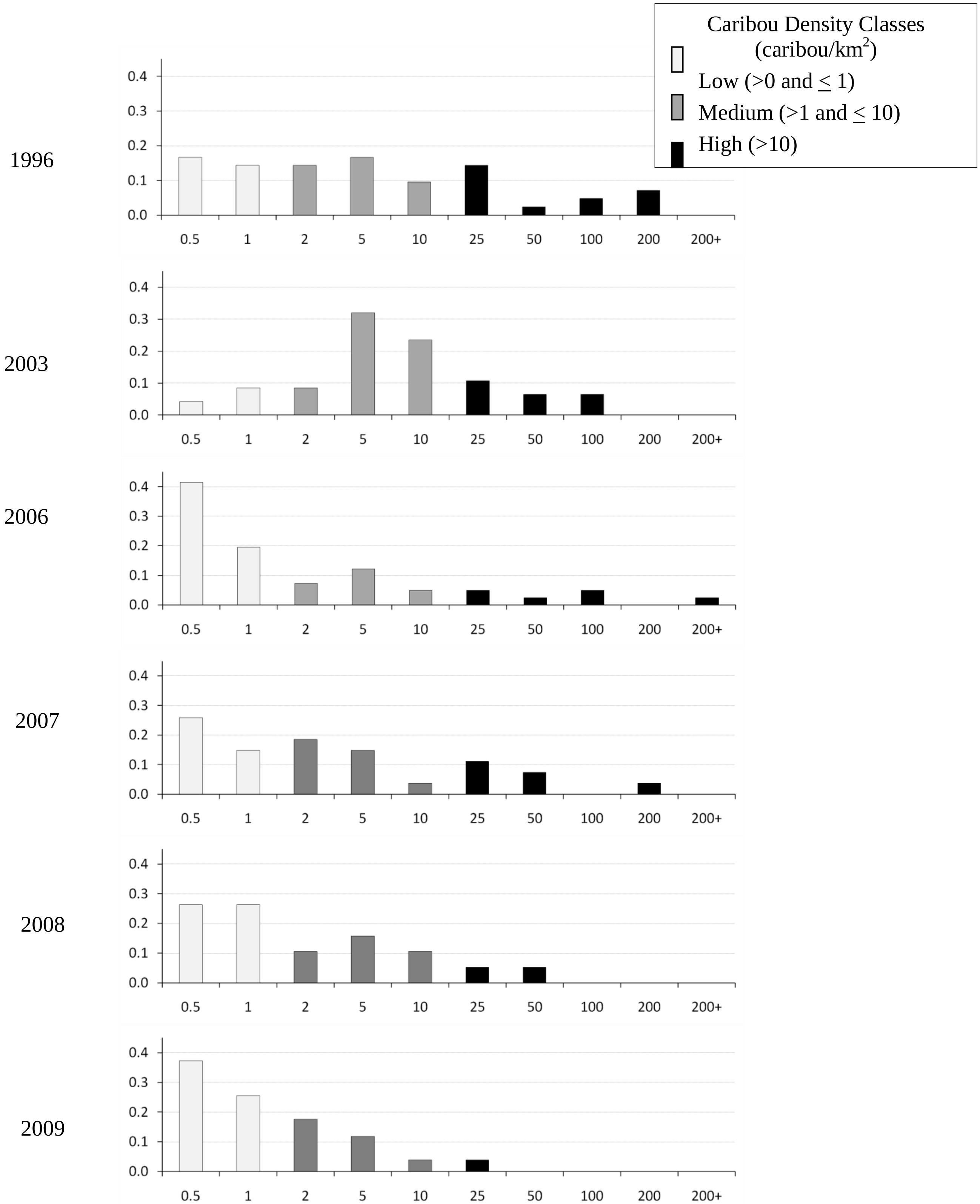

Figure 4M. Relative frequency distributions of low, medium and high density segments observed during systematic surveys of annual Bathurst calving ground. Numbers along x-axis represent upper density values for histogram bins.

DISCUSSION

Recent systematic reconnaissance surveys of the annual Bathurst caribou calving grounds are consistent with results from photographic surveys and suggest an accelerated rate of decline since 2006.

Systematic reconnaissance surveys appear to provide a potentially useful and comparatively economic way of monitoring trend of caribou on an annual calving ground, and allow managers to evaluate and anticipate trend during the intervening years between full-scale calving ground photographic surveys. In addition to monitoring abundance of 1^{+}-year-old caribou, results from systematic reconnaissance survey of caribou calving grounds can provide insight on trend in spatial extent of the annual concentrated calving area and associated spatial patterns of dispersion and changes in caribou densities.

However, observer bias associated with sightability[2] and counting error[3] will be a major source of uncertainty and variability that will affect precision and accuracy of this

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[2] "Visibility bias" results from animals being missed and is influenced by factors such as dense vegetation, bad weather conditions, and observer fatigue (Pollock and Kendall 1987). Sightability may be defined as the probability that an animal within an observer's field of search will be seen by that observer (Caughley 1974).

[3] Some potential sources of error in aerial survey are impossible to overcome because they result from limits in aircraft, human perception and brain function, and animal responses and interactions between them (Fleming and Tracey 2008). With respect to counting error, the physiological and psychological limitations of human perception and brain function ultimately limits an observer`s ability to accurately count large numbers of animals within short time periods. Counting error varies with animal density and may interact with other sources of bias under conditions where, a) observers are counting stationary and moving animals from a moving platform against a heterogeneous background with variable lighting, and b) pitch and roll of the platform imposes a variable boundary effect because strip transect markers are fixed to aircraft wing struts.

visual survey technique; counting error increases as overall densities on the annual calving grounds increase. Indeed, the calving ground photographic survey methodology was developed largely to address observer bias (Heard 1985) so it is important to recognize that there will be limits to precision and accuracy that we might expect from visual systematic surveys on high density areas of calving grounds. Nevertheless, careful and consistent standardization of survey methods, i.e. aircraft type and single versus multiple observers, and rigorous training of observers and navigators will help to improve the practical value of systematic reconnaissance surveys, especially under conditions where population size and densities on calving grounds are relatively low.

Another important source of bias is associated with the accuracy and repeatability of delineating the annual calving ground relative to the peak of calving. Careful attention will need to be applied to the continuous improvement and application of criteria used to delineate the annual calving ground from systematic surveys, especially during intervening years between full-scale calving ground photographic surveys. For example, using the systematic survey data, survey strata should be delineated as though the photographic survey were to be conducted on high and medium density strata. Similarly, allocation of sampling effort should also be determined, as well as an assessment of timing and movement rates by collared cows that are presumed to be breeders. Recommendations from each annual systematic survey should be summarized as an ENR File Report. In this way, technical staff will benefit from ongoing experience and training in calving ground survey design and execution; this should improve overall robustness and repeatability of surveys because they are based upon standardized criteria for relative density and composition of caribou, which are continually evaluated and improved.

Systematic reconnaissance surveys of annual calving grounds should be further refined and developed as an annually monitored indicator especially when caribou populations (such as the Bathurst herd) decline to low numbers and management actions are implemented to assist in recovery.

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