A Comparison of Calving and Post-calving Photo Surveys for the Bluenose-East Herd of Barren-ground Caribou in the Northwest Territories, Canada in 2010

J. Adamczewski[1], J. Boulanger[2], B. Croft[1], T. Davison[1], H. Sayine-Crawford[1], and B. Tracz[1]

[1]Environment and Natural Resources
Government of the Northwest Territories

[2]Integrated Ecological Research, Nelson, BC

2014

Manuscript Report No. 244

ABSTRACT

Two population survey methods have been used in Canada's Northwest Territories (NWT) and Nunavut (NU) to estimate herd size in migratory barren-ground caribou herds. The calving photo survey provides an estimate of the numbers of breeding females on the calving grounds in June. Survey strata with higher densities of cows are photographed from a fixed-wing aircraft, while lower density strata are counted visually. The estimated number of breeding females can be extrapolated to an estimate of overall herd size by adding in the bulls and non-breeding cows not on the calving grounds. The post-calving photo survey is carried out in July when warm and relatively calm weather and high numbers of biting flies can result in caribou forming dense aggregations of hundreds or thousands that can be photographed and counted. Prior to 2010, the two survey methods had not been compared within the NWT or NU. In 2010, we carried out a June calving photo survey and a July post-calving photo survey for the Bluenose-East (BNE) herd, which ranges between NU and NWT. We report here on results of the two surveys.

Based on reconnaissance survey flying at ten km line spacing in early June 2010 over the BNE calving grounds and adjacent areas, six strata were defined, including one high and one medium density stratum with mostly cow-calf caribou, two strata with low densities of caribou, and two low-medium density strata with predominantly non-breeding caribou (bulls, yearlings and non-breeding cows). The high and medium density strata were re-flown with the photo-plane on June 7 and 8, at ground coverage of 31.3% and 16.8%. The other four strata were re-flown visually at ground coverage between 14.2% and 28.2%. Five days of ground-based composition surveys were carried out to estimate the percentage of breeding cows in each stratum. The June survey resulted in an estimate of 51,757±11,092 [95% Confidence Interval (CI)] breeding females on the calving grounds. This estimate was extrapolated to an overall herd size of

102,704±39,965 (CI) caribou at least one year old using estimates of sex ratio and pregnancy rate. Because of the 43 radio collared cows and four radio collared bulls in the herd, we are confident that we located and surveyed a high percentage of the herd, including non-breeding caribou east of the Coppermine River. As all strata were surveyed either by photo-plane or by visual strip-transect, we derived a second June population estimate of 114,472±15,845 (CI) from the photographed and visually counted strata. This estimate is the preferred one for the June survey as it did not involve extrapolation and was based on the actual counts of survey strata.

The post-calving survey began in late June 2010 with a reconnaissance survey at ten km line spacing to provide an overall sense of caribou distribution. Thereafter, 47 collared caribou and associated caribou were monitored daily from the air with two fixed-wing aircraft. Spatially, the caribou were in three groups: the main group included over half the herd and was predominantly cows and calves in the Rae and Richardson valleys west of Kugluktuk, the northern group included lower densities of mostly cow-calf caribou northeast of Kugluktuk, and the southern group was primarily bulls, non-breeding cows, and bulls east of the Coppermine River. Caribou in the southern group were photographed on July 6 and on July 12, caribou in the main group on July 9, and caribou in the northern group on July 12. Daily monitoring of collar locations showed no mixing between these dates among the three groups. Counts of photographed caribou resulted in a total of 92,481 caribou at least one year old, counted in 39 groups. Using a Lincoln-Petersen estimator resulted in an estimate of 98,646±7,125 (SE) caribou at least one year old in the herd. We also used the estimator of Rivest, which produced an estimate of 122,697±16,202 (SE) caribou at least one year old. The Rivest-derived estimate is the preferred one for the July survey as the Lincoln-Petersen estimator tends to under-estimate herd size.

Overall, the preferred June estimate (114,472±15,845) and the preferred July estimate (122,697±31,757) showed overlap of confidence intervals as estimators of BNE caribou herd size in 2010. We believe the July estimate is likely the closest to true herd size as the June survey likely did not include all the bulls, yearlings and non-breeding cows in the herd.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Calving and Post-calving Photo Surveys for Barren-ground Caribou

Estimating population size in barren-ground caribou herds that range over vast remote areas is challenging even in the 21st century. Calving and post-calving photographic surveys have been used to estimate population size in migratory barren-ground caribou herds in northern Canada and Alaska. Calving photo surveys in June and post-calving photo surveys in July both take advantage of caribou aggregating spatially at a time when there is typically good separation between herds.

The calving photo survey is carried out near the peak of calving in June and provides an estimate of the number of breeding females on the calving grounds (Heard 1985, Gunn et al. 2005, Nishi et al. 2007, Campbell et al. 2010). Initial reconnaissance flying and radio collar locations are used to define strata or blocks on the calving grounds with higher and lower densities of caribou, and to determine whether these strata have a high proportion of breeding cows. A photo plane flies transect lines and takes strips of continuous photos over the higher-density blocks at ground coverage of 30-40% (Heard 1985, Gunn et al. 2005, Nishi et al. 2007) and caribou are counted on the photos. Usually 80-95% of the caribou found during the survey are in these photographed strata. Lower-density blocks are flown again visually and caribou counted in 400 m wide strips on either side of the aircraft. The photography and visual surveys are timed to be close to the peak of calving, when movement rates of collared cows that give birth are the lowest of the year; this minimizes movement within the survey area. A composition survey carried out largely from the ground in all strata provides a precise estimate of the proportion of breeding females and other classes of caribou, as this is difficult to assess precisely

from fixed-wing aircraft. The counts from photos and visual strata are combined with the composition numbers from each stratum to derive an estimate of the number of breeding females on the calving ground.

Because most of the bulls and substantial proportions of the yearlings and non-pregnant cows are not on the calving grounds in June, an extrapolation has been used to "add in" the missing caribou to derive an estimate of overall herd size. An estimate of sex ratio from fall composition surveys is used to add in the bulls, and an estimate of pregnancy rate is used to add in non-pregnant cows (Heard 1985, Gunn et al. 2005, Nishi et al. 2007, Campbell et al. 2010). The overall pregnancy rate in breeding cows tends to vary within a limited range; dividing by the pregnancy rate in breeding-age cows adds in the non-pregnant cows that are often largely on the periphery of the calving ground or south of it. The large variance on early surveys of this type and the extrapolation based initially on a fixed sex ratio and a constant pregnancy rate led some biologists (e.g. Rivest et al. 1998, Thomas 1998) to question the value of the calving photo survey as a method of counting caribou. Extrapolated herd size is usually nearly double the estimate of breeding female numbers. Over the years, however, careful attention to optimal allocation of survey effort (photographic and visual) has reduced the variance on estimates of breeding females (Mowat and Boulanger 2000, Nishi et al. 2007, Campbell et al. 2010). Extrapolation for bulls not on the calving grounds has changed from using a fixed sex ratio to a sex ratio based on one or more recent fall composition surveys for the herd surveyed (Campbell et al. 2010, Boulanger et al. 2014). Biologists using this survey have also emphasized that size and trend in the number of breeding cows are key demographic variables for the herd (Boulanger and Gunn 2008, Boulanger et al. 2011 and 2014).

The post-calving photo survey is carried out in early to mid-July when warm weather may lead caribou to aggregate in large groups that may number hundreds or thousands in response to biting flies. These groups can be photographed and the caribou counted on the photos (Valkenburg et al. 1985, Fancy et al. 1994, Patterson et al. 2004, Nagy and Johnson 2006). This survey includes all caribou in the herd that are at least one year old counted on photos; only the calves born a few weeks earlier in June cannot be counted reliably on photos as they may not always be clearly visible under or beside larger caribou. Figure 1 shows the annual ranges of migratory barren-ground caribou herds monitored by GNWT in the 2000s, and population survey methods in western and eastern herds.

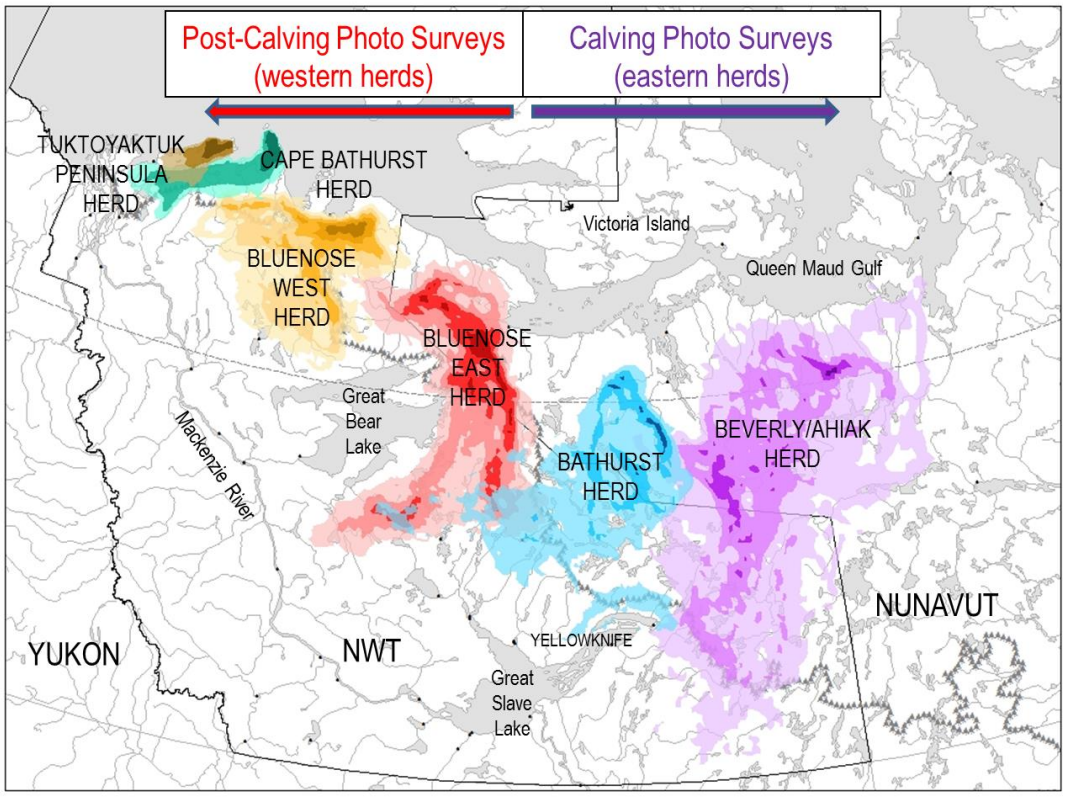

Figure 1: Annual ranges of migratory barren-ground caribou herds monitored by GNWT in the 2000s and population survey methods in western and eastern herds. Annual ranges are based on radio collar locations 2006-2010. Contours indicate the number of unique collared caribou found within each cell of a 10x10 km grid. Contours start at five individuals and increase in steps of ten. Darker colours indicate areas used by greater numbers of collared caribou. Map: GNWT/A. D'Hont, ENR.

Post-calving surveys, like calving photo surveys, have their limitations. Caribou may not aggregate tightly if the July weather has cool, wet or windy conditions when the biting flies to which caribou respond are not very active. If the caribou are well dispersed, photography is not feasible and the survey fails. Post-calving surveys were attempted for the Porcupine herd annually from 2004-2010 and failed due to weather and insufficient caribou aggregation (Porcupine Caribou Management Board, www.taiga.net/pcmb/population.html). A further limitation of this survey is that estimation of caribou groups missed during the survey is difficult. Groups of caribou with several collars are very likely to be found, but caribou groups with just one collar may not be found as readily, and groups with no collars are less likely to be found. An adequate sample of collars is essential to ensure that a high proportion of the herd will be found (Rivest et al. 1998, Rettie 2008). A reconnaissance survey with lines spaced at regular intervals can be carried out in June during calving to estimate densities and distribution of caribou when their movement rates are very low. Such a survey to find caribou has more limited value in July due to the clumped distribution of caribou and high daily caribou movement rates. In addition, the tightly gathered groups of caribou suitable for photos may sometimes not remain together for more than a few hours. The use of a Lincoln-Petersen mark-recapture estimator to derive a population estimate and associated variance used by, for example, Russell et al. (1996) for the George River herd was questioned by Rivest et al. (1998), as both population estimate and variance estimates will likely be negatively biased. Rivest et al. (1998) proposed an alternate way of estimating missed caribou groups and an alternate way of estimating population size and variance from post-calving surveys.

In the Northwest Territories (NWT) and Nunavut (NU) in northern Canada, community concerns over use of radio collars have generally been greater in more eastern communities, thus

the calving photo survey, which can be carried out with limited collar numbers, became the established method for eastern herds (Beverly herd: Heard and Jackson 1990, Williams 1995; Qamanirjuaq herd: Campbell et al. 2010; Bathurst herd: Gunn et al. 2005, Nishi et al. 2007, Boulanger et al. 2014). Acceptance of radio collars on caribou has generally been greater in more western communities of the NWT, and post-calving surveys that require substantial numbers of radio collars became the established method for herds in the western NWT (Bluenose-East (BNE) herd: Patterson et al. 2004; Bluenose-West (BNW) and Cape Bathurst herds: Nagy and Bucher 2007, Nagy and Johnson 2006). The post-calving survey is also the sole method used for Alaskan migratory tundra caribou (Fancy et al. 1994, Alaska Department of Fish and Game 2011). Once established, one or the other survey has been continued to maintain consistency of methods for particular herds. A side-by-side comparison of the calving and post-calving caribou surveys had not been carried out in NWT or NU prior to 2010. This was in part due to the substantial costs of both survey methods, and in part to maintain consistency of methods for individual herds. A calving photo survey somewhat modified from methods of Heard (1985) and a post-calving photo survey were carried out for the George River herd in 1993 (Couturier et al. 1996) and produced relatively similar estimates.

After an attempted post-calving survey of the BNE herd in July 2009 failed due to cool, wet and windy weather, both calving and post-calving surveys of this herd were planned for 2010. There was substantial concern as to the herd's size and trend in the late 2000s, given declines documented in all NWT herds in the 2000s (Adamczewski et al. 2009). Attempting both surveys increased the likelihood of securing an up-to-date population estimate. In addition, an independent review of the Government of NWT's barren-ground caribou program in 2008 by the Alberta Research Council (Fisher et al. 2009) had recommended a comparison of the two

population surveys. In this report, our objectives are to describe the results of the 2010 calving and post-calving surveys for the BNE herd and to compare population estimates from the two surveys. A preliminary version of our findings was presented in August 2011 at the Arctic Ungulate Conference in Yellowknife (Adamczewski et al. 2011).

METHODS

Detailed descriptions of calving photo surveys in NWT and NU were provided by Campbell et al. (2010), Gunn et al. (2005), Heard (1985), Nishi et al. (2007), and Boulanger et al. (2014). Similarly, reports by Nagy and Bucher (2007), Nagy and Johnson (2006), and Patterson et al. (2004) provide detailed methods on post-calving surveys previously carried out in the NWT.

Calving Photo Survey in June 2010

A. Reconnaissance Survey at Ten km Intervals

Reconnaissance flying by two Cessna Caravan fixed-wing aircraft based in Kugluktuk was carried out on June 3, 5, 6, and 7 over the calving ground and nearby areas of the BNE herd (Figure 2). Flight lines were spaced at ten km intervals in a north-south direction; survey elevation averaged 120 m above ground, and survey speeds averaged 150-160 km/hr, providing ground coverage of approximately 8%. Two observers and a recorder on each side of the aircraft recorded approximate numbers of caribou seen within a 400 m strip on either side of the plane. The presence of cows with calves, hard-antlered cows, bulls, yearlings, and non-breeding (non-antlered) cows was recorded. Precise classification from fixed-wing aircraft was not practical, hence was estimated separately from the ground later in the survey. The purpose of the initial classification was to determine areas where breeding cows were concentrated, and areas where non-breeding cows, yearlings and bulls were concentrated.

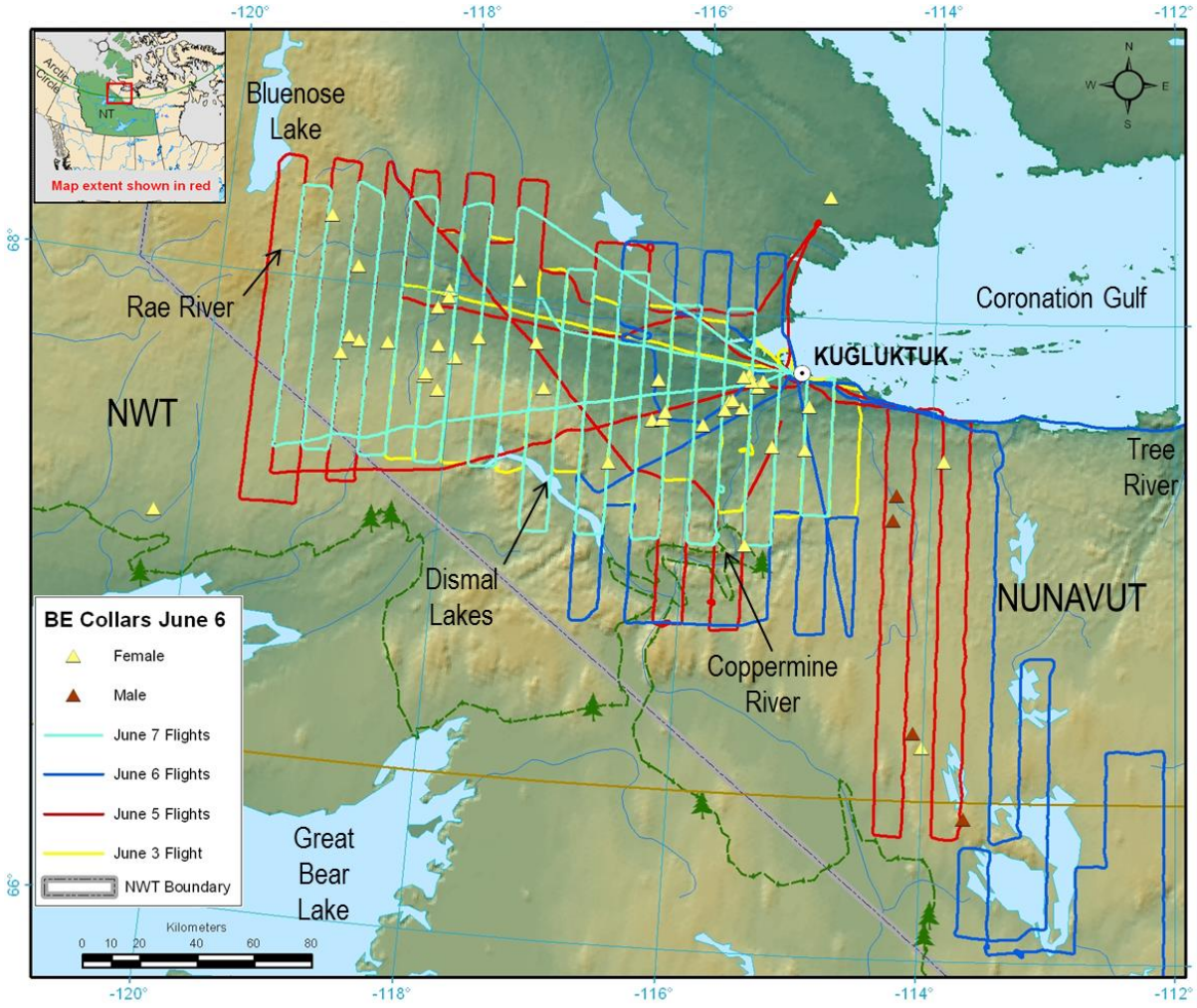

Figure 2: Reconnaissance flying over the BNE herd's calving ground and nearby areas at ten km intervals on June 3, 5, 6, and 7, 2010. Radio collar locations from 43 cows (red triangles) and four bulls (yellow triangles) for June 6 were also used to define the survey area. Map: GNWT/P. Spencer, ENR.

Observations from the reconnaissance flying were mapped in ten km segments as densities of adult caribou: more than 10/km^2 was high; 1.0-9.9/km^2 was medium; and 0.1-0.9/km^2 was low. In some segments no caribou were seen. Composition of caribou in ten km segments was mapped using the following classes:

(1) Cows with calves: if at least one new-born calf was seen or if hard-antlered cows were seen. Hard-antlered cows were considered breeding cows that had either calved recently or were about to calve, and had not yet dropped their antlers;

(2) Non-antlered cows: if antler-less cows were seen, but no calves or hard-antlered cows;

(3) Non-breeding caribou: if antler-less cows and yearlings were seen;

(4) Bulls: if bulls were seen; and

(5) Mixed non-breeders: if non-antlered cows, yearlings and bulls were seen.

In some peripheral areas, few caribou were seen and composition was recorded as unknown.

The study area was defined by previous surveys of this herd's calving ground in 2007 and 2008 (Poole et al. 2014); by review of radio collar locations for this herd in the late 2000s; and by locations of 43 radio collared cows and four radio collared bulls in June 2010 (Figure 2). These sources showed that the main cow-calf concentrations were consistently found in the Rae and Richardson valleys west of Kugluktuk, bounded in the west by Bluenose Lake.

In addition to the 47 known BNE collared caribou during the June and July 2010 surveys, one collared cow from the Bathurst herd (eastern neighbor of the BNE herd) died in mid-June 2010 north of the main BNE calving area. Two collared caribou from the Bluenose-West (BNW) herd (western neighbor of the BNE herd) were within the summer range of the BNE herd in 2010. One of these was briefly east of Bluenose Lake in June and early July and then returned to spend the rest of the summer well west of Bluenose Lake in BNW summer range. A second collared cow that calved on the BNW calving ground in 2009 was within the BNE summer range in June and July 2010, and calved on the BNE calving ground in 2011. Low rates of exchange of collared cows between neighbouring herds in NWT/NU and elsewhere have been known for many years (e.g. Gunn et al. 2008). These three collared caribou were considered as falling within this normal low rate of exchange and were not considered further in estimating population size.

Local knowledge and previous surveys indicated that bulls, non-breeding cows, and yearlings were often found east of the Coppermine River and south and east of Kugluktuk. The reconnaissance flying in early June 2010 confirmed previous information, as we found very few cows with young calves or hard-antlered cows east of the Coppermine River. Bulls, yearlings and non-breeding cows were observed consistently in this area. A few lines were flown further east to ensure spatial separation from Bathurst caribou. The area east of Kugluktuk towards the Tree River is very rugged and rocky with limited plant cover, and we saw no caribou and almost no sign (trails) of previous caribou use in this area.

B. Survey Strata and Coverage

The reconnaissance flying was used to define six survey strata or blocks (Figure 3). Strata included one high-density block (high in Figure 3) and one medium-density block (medium) with mostly cow-calf caribou, two visual low-density blocks with mostly cow-calf caribou (north and northwest), and two blocks flown visually with low-medium densities and mostly bulls, yearlings and non-breeding cows (east and south). The south stratum was extended south by ten km further than the initial reconnaissance flight lines due to the numbers of caribou seen at the southern ends of the lines during the reconnaissance flights.

An optimal-allocation algorithm was used to determine the number of transect lines and coverage for each of the six strata, depending on stratum size and densities of caribou seen during the reconnaissance flights. Following recommendations by Gunn et al. (2005), a minimum of ten transect lines were used for each stratum to reduce variance. Consistent with previous surveys of this type, the high and medium strata were re-flown on June 8 and 9 with a Commander aircraft (Geographic Air Survey Ltd., Edmonton) at an elevation of approximately

2,000 ft. taking continuous photo-transects to provide ground coverage of 31.3% and 16.8% (Figure 3, Table 1). A total of 7,000 photos were taken.

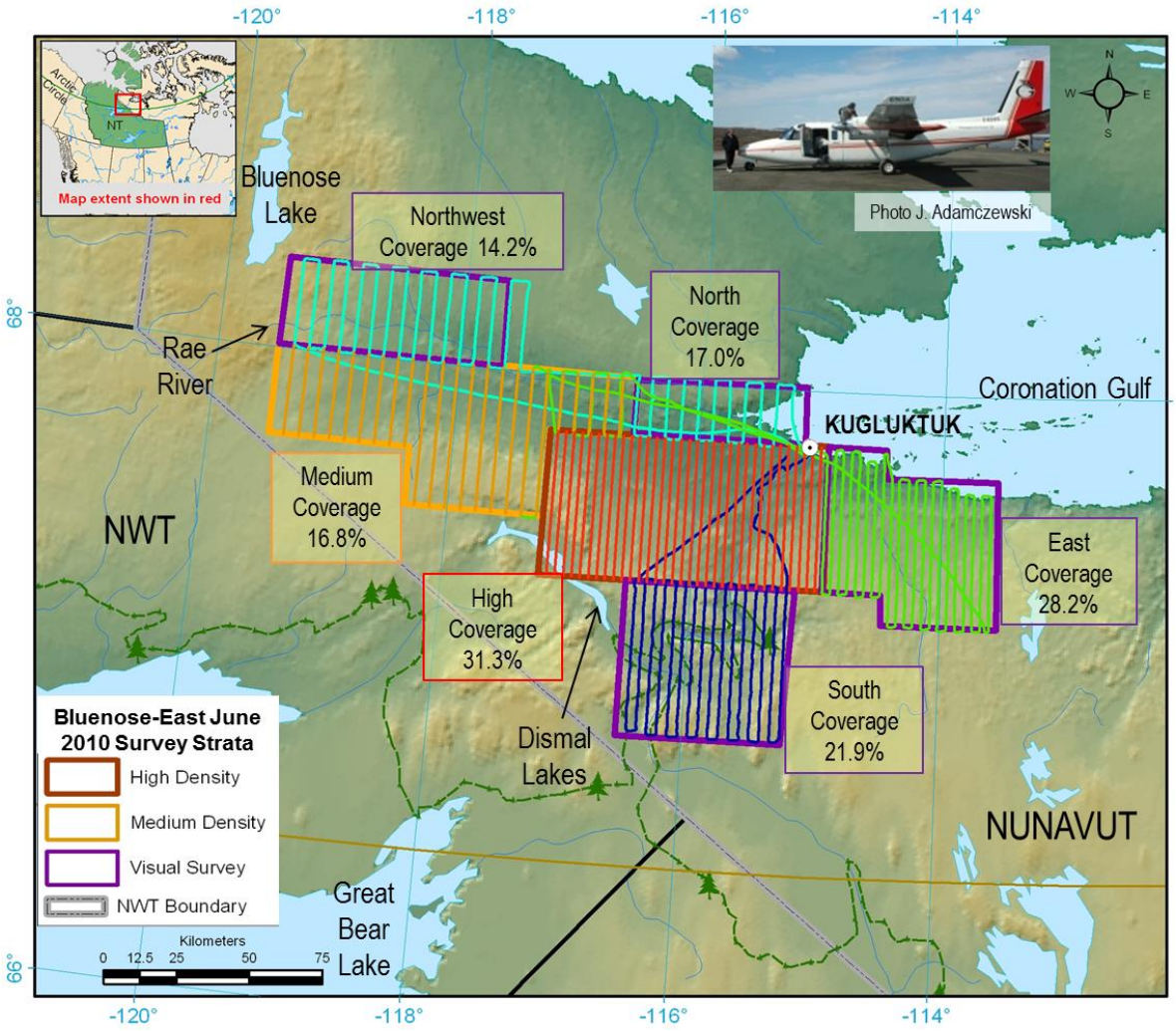

Figure 3: Survey strata, flight lines and coverage for the BNE June 2010 calving photo survey. The high-density and medium-density strata were flown with the Commander photo-plane (upper right corner above) and the four strata outlined in purple were re-flown visually, with the area coverage as shown for each stratum. Map: GNWT/P. Spencer, ENR.

Table 1: Transect sampling and size of strata during BNE June 2010 calving photo survey.

	Stratum						
Variable	**High**	**Medium**	**East**	**North**	**North west**	**South**	**Totals**
Count method	Photo	Photo	Visual	Visual	Visual	Visual	n/a
Area of stratum (km^2)	4,840.0	4,453.9	2,996.4	1,118.3	2,259.6	3,006.9	18,675.1
Lines flown	33	23	21	10	16	16	n/a
Area sampled (km^2)	1,517.2	749.9	844.6	158.5	383.5	658.7	4,312.4
Coverage (%)	31.3	16.8	28.2	14.2	17.0	21.9	23.1

The other four strata were re-flown on June 8 and 9 visually with ground coverage varying from 14.2-28.2%. Visual survey lines were flown at an elevation of 120 m and an average survey speed of 150 km/hr, with two observers and a recorder on each side of the aircraft. Wing struts were marked to define a strip of 400 m on the ground at 400 m above ground on either side of the aircraft, using methods originally described by Norton-Griffiths (1978), and followed by previous calving photo surveys of the Bathurst herd (e.g. Gunn et al. 2005, Nishi et al. 2007).

C. June Composition Survey

A composition survey was carried out June 8-12 to sample multiple caribou groups in each of the survey strata (Figure 4). Overall composition of caribou groups can be determined from fixed-wing aircraft, in terms of the presence and general proportions of cows with calves, bulls, yearlings and non-breeding cows, but precise percentages of sex and age classes are best assessed from the ground or by helicopter. The classification was carried out from the ground with a telescope and tripod to minimize disturbance to caribou, with a helicopter used to fly from one group of caribou to the next.

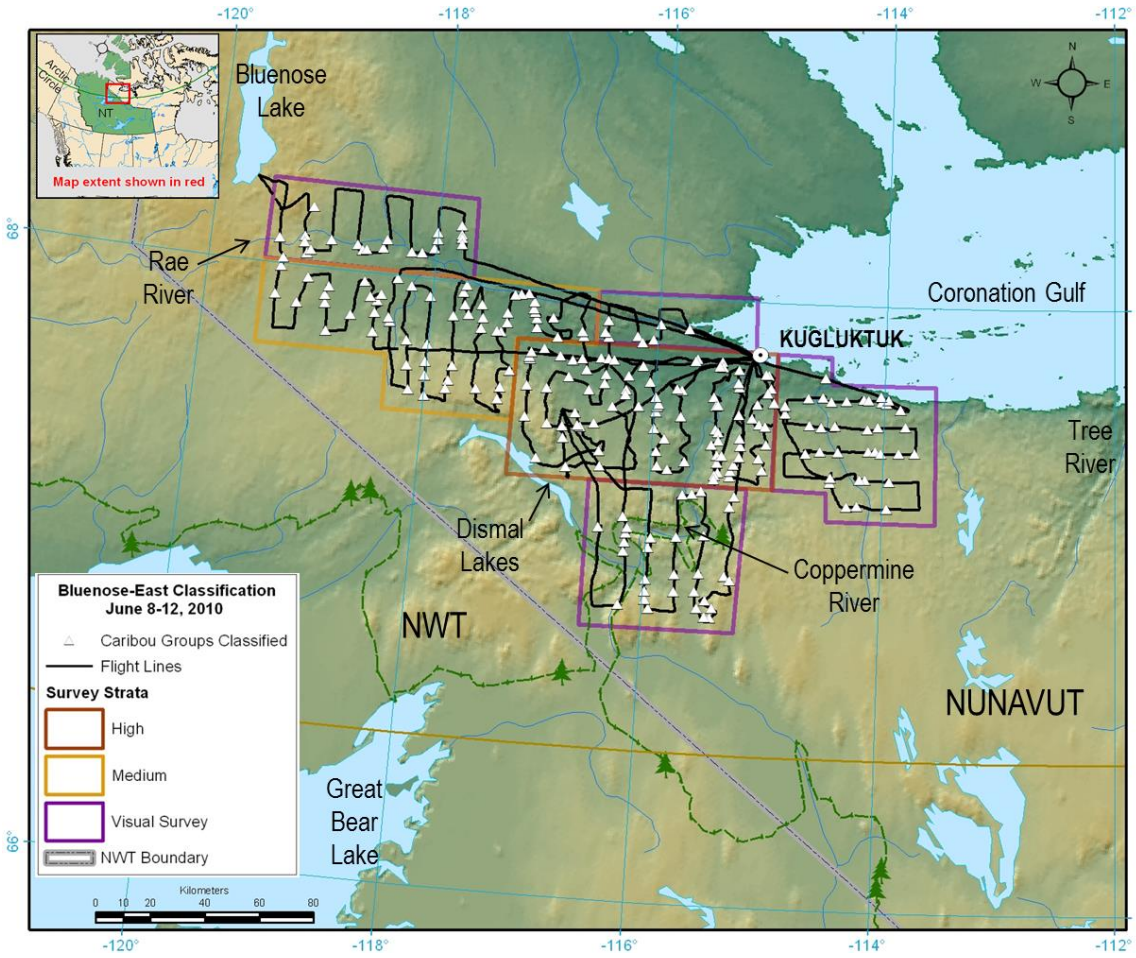

Figure 4: Locations (white triangles) and helicopter flight path (black lines) of caribou groups classified June 8-12, 2010 on or near the calving grounds of the BNE caribou herd. Map: GNWT/P. Spencer, ENR.

Caribou were classified as described by Gunn et al. (2005) and Nishi et al. (2007) as newborn calves, cows, yearlings, and bulls. Cows were further classified into the following categories: (1) antlered cows with distended udder; (2) antlerless cows with distended udder; (3) antlered cows without a distended udder; and (4) antlerless cows without a distended udder. The first two of these groups of cows were considered breeding cows based on the distended udder, and the third group was considered breeding cows that likely had lost their calves. The fourth group of cows was considered non-breeding females, characterized by the absence of a distended udder and usually by the presence of new dark antler growth. Yearlings were distinguished based

on their relatively small body size and short faces. Bulls were classified based on their relatively large antlers in velvet, large body size, and long faces and muzzles.

D. Fall 2009 Composition Survey

To extrapolate from the estimated number of breeding females on the calving grounds to overall herd size, an estimate of herd sex ratio has been used, as the fall rut in late October is the one time of year when all sex and age classes are mixed (Heard 1985, Gunn et al. 2005, Nishi et al. 2007). A composition survey was carried out in late October 2009 on the BNE range. The survey area was defined primarily by locations of 31 collared BNE caribou. In addition, a fixed-wing reconnaissance survey was flown on October 16, 2009 to verify that substantial numbers of caribou were associated with the concentrations of collared caribou. Caribou were classified from the front seat of a helicopter as bulls, cows, and calves of the year on October 19 and 20, 2009. A total of 4,531 caribou in 79 groups were classified.

E. Caribou Counting

Caribou at least one year old were counted on the June aerial photos by an experienced consultant (P. Roy) who had counted caribou on this type of aerial photo for several previous calving photo surveys of the Bathurst herd (e.g. Gunn et al. 2005, Nishi et al. 2007) and the Qamanirjuaq herd (Campbell et al. 2010). The caribou counted on photos could not be classified as cows, yearlings or bulls, only as caribou at least one year old. In this paper, we use the term “adult” caribou for any caribou at least one year old. In the four visual blocks, caribou seen by any of the four observers were recorded.

Post-calving Photo Survey in July 2010

A. Initial Reconnaissance Flying and Radio Collared Caribou

Reconnaissance flights over the BNE summer range were carried out June 29 - July 4, to gain an overall sense of caribou distribution and composition of caribou groups (breeding cows, non-breeding cows, bulls and yearlings; Figure 5). The survey area was defined based on past July surveys of this herd and based on the locations of 47 radio collared caribou (43 cows and four bulls, all either satellite or GPS-satellite) at the beginning of July. One crew was in a Helio-Courier equipped with Telonics RA-2AK dual antennae and an ATS receiver (Advanced Telemetry Systems Inc.) and the other crew was in a Cessna 185 equipped with Telonics RA-2AK dual antennae and a Telonics TR-5 Scanning-Receiver (Telonics Corp. Ltd), with all flights based in Kugluktuk, NU. After the initial reconnaissance flights, the two aircraft were used to check daily on collared caribou and caribou associated with them, except during poor weather. Locations of all collared caribou were received daily in the mornings and used to plan the day's flying. Several collars were located exactly every day by homing in on the VHF signal.

Overall, caribou groups made up mostly of cows with young calves were found west of Kugluktuk in the Rae and Richardson valleys and these areas had the largest numbers of caribou. Mostly cow-calf groups were also found in lower numbers north to the mainland coast (Figure 5). Bulls, yearlings, and non-breeding cows were primarily east of the Coppermine River and south-southeast of Kugluktuk, with a substantial area separating these groups from the cow-calf groups.

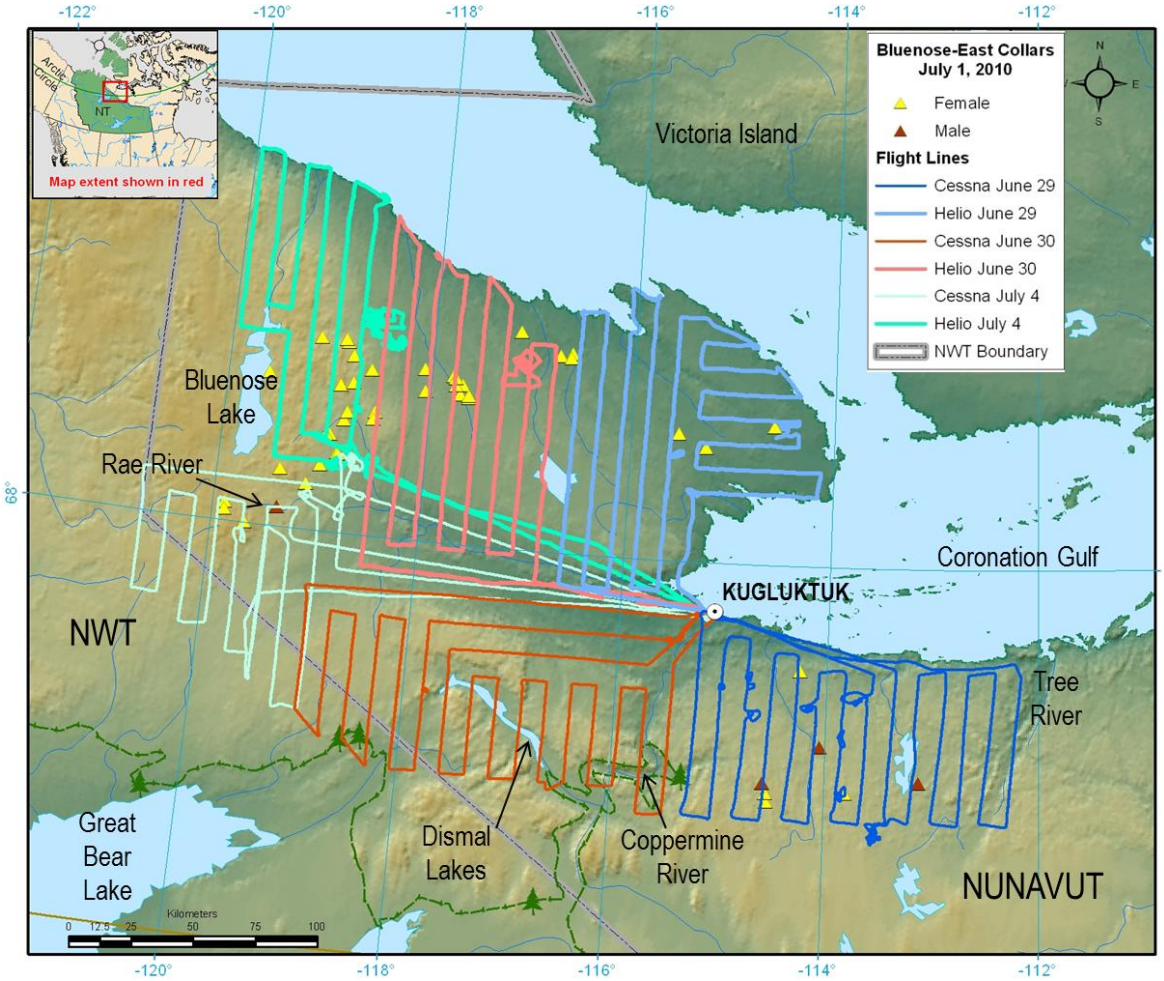

Figure 5: Initial reconnaissance flights at ten km intervals at start of July 2010 BNE caribou post-calving survey June 29 - July 4, 2010. Collar locations are from 43 cows and four bulls on July 1. Map: GNWT/P. Spencer, ENR.

B. Photos of Aggregated Caribou Groups and Caribou Counts

When caribou were seen to be forming groups of hundreds or thousands suitable for photography, every effort was made to account for all collared caribou and caribou associated with them in the area. Caribou groups found without collars were also photographed, and GPS locations of all groups were recorded. Multiple passes of either single photos of entire groups or multiple series of overlapping photos to cover larger aggregations were taken. Survey elevation was adjusted as needed. Photos were taken by 24 megapixel Nikon D3X cameras set for maximum resolution, through an open window of the aircraft (Cessna 185) or through a

"shooting window" on the right side of the Helio-Courier. Radio collar VHF signals from the 47 collars were monitored on all flights and the presence of individual collared caribou was double-checked to ensure that collared caribou in the photographed groups were identified.

At the end of each day when photos were taken, the photos were downloaded and reviewed on laptop computers, and the best images were chosen for each group of caribou. Digital images were imported into the desktop mapping program Ozi Explorer (© D & L Software Ltd.) and converted to map files. Caribou on these images were then marked one after the other by placing waypoints for each adult caribou. This method was developed by biologist J. Nagy and described in his survey reports (e.g. Nagy and Johnson 2006, Nagy and Bucher 2007). All caribou at least one year old were counted. Calves of the year were not counted as they could not be reliably identified under or behind larger caribou, particularly in more closely aggregated groups.

Caribou on each photo were counted at minimum by two of the authors independently (HS-C and JA). A third person independently counted a sub-set of the photos as a further check. On most photos, agreement among counters was close, with variation of totals well below one percent (e.g. totals of 915 caribou vs. 918 caribou for a single photo). On a few photos of larger, tightly aggregated groups taken from higher elevations, the two authors who previously counted all the photos together counted the photos again to arrive at a final total.

C. Estimation of Herd Size and Variance using Lincoln-Petersen Estimator

White and Garrott (1990) augmented the Lincoln-Peterson Index to apply to radio collared animals, which has been used in other post-calving surveys (Russell et al. 1996, Patterson et al. 2004, Nagy and Johnson 2006) to estimate population size. The formula is:

$$N = \left(\frac{(M+1)(C+1)}{R+1}\right) - 1$$

where:

N = estimate of population size during the census

M = number of radio collared caribou present in the herd (including all collars known to be active during the survey)

C = number of caribou in all aggregations observed during the survey

R = number of radio collared caribou observed in these aggregations during the survey.

The 95% confidence interval for the estimate is calculated as:

$$N_i = 1.96\sqrt{Var(N)}$$

where:

$$Var(N) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}$$

These calculations were applied to the results of the July 2010 BNE post-calving survey.

D. Estimation of Herd Size and Variance using Rivest Estimator

This section provides a basic summary of the Rivest approach; readers who want a more detailed statistical treatment are encouraged to read Rivest et al. (1998). All calculations were conducted using the R-package (R Development Core Team 2009) entitled "caribou" (Crépeau et al. 2012). The Rivest estimator considers the sampling of post-calving aggregations as a two phase sampling process. The first phase involves the initial collaring of caribou and how the collared caribou are distributed within the herd during the post-calving period. For this estimator it is assumed that *n* caribou are collared and that these caribou randomly distribute themselves into *m* groups during the post-calving period. The assumption in this case is that the radio-collared caribou are randomly distributed within the groups and a test of this assumption is provided as part of the estimation procedure. Given that collared caribou are used to estimate

detectability of groups, the Rivest estimator does not use data for groups of caribou that contain no collared caribou.

The second phase of sampling involves the actual aerial search for groups. For this phase various models are proposed as to how the collared caribou represent the groups, and how the collared caribou and associated groups are detected. Each model is summarized below:

(1) The homogeneity model: this model assumes that caribou groups (with collared caribou in the groups) are missed as a completely random event that is independent of the number of collared caribou in the group or other factors. Each group will have the same probability of being detected by the aerial survey;

(2) The independence model: this model assumes that each collared caribou in the group has the same independent probability of being detected and therefore the overall probability of detecting a group increases as a function of the number of collared caribou in the group. The assumption here is that the collared caribou are independent so that a simple probability model can be applied to detection of the group;

(3) Threshold model: this model assumes that all groups with more than a threshold level of collared caribou (symbolized by B) have a detection probability of 1. For example, it might be that once more than three collared caribou occur in a group the group will always be detected whereas groups with one or two collars are not always detected. For this model, all groups with three or more collared caribou get a detection probability of 1, and detection probability is estimated for groups with one or two collars.

Each of these models can potentially describe detection probability variation in the data set. As part of the estimation procedure a log-likelihood score is produced and the model with the highest log-likelihood is considered to best fit the data.

The estimate of herd size is then basically the summation of each group size divided by the probability of the observed group having at least one collared animal included in it. The probability of having at least one collared caribou is a function of the group size detection probabilities (which is associated with the underlying detection model described previously), the total group size of caribou counted relative to total herd size, and the overall number of collars employed in sampling. It is through an iterative likelihood-based optimization procedure that each of these parameters is estimated to produce estimates of herd size.

An assumption of this method is that the collared caribou are randomly distributed among the separate caribou groups that are photographed. This assumption can be tested by assessing the number of collared caribou relative to group sizes that are counted. It is possible to test this assumption using a test for over-dispersion of the Poisson probability distribution. Over-dispersion applies to a case when non-independence of collared caribou produces a distribution of collared caribou relative to group sizes that is different from that if the caribou were randomly distributed. If over-dispersion occurs then both estimates of population size and variance from the Rivest estimator will be negatively biased (Rivest et al. 1998).

RESULTS

Calving Photo Survey in June 2010

A. Densities and composition of caribou from initial reconnaissance

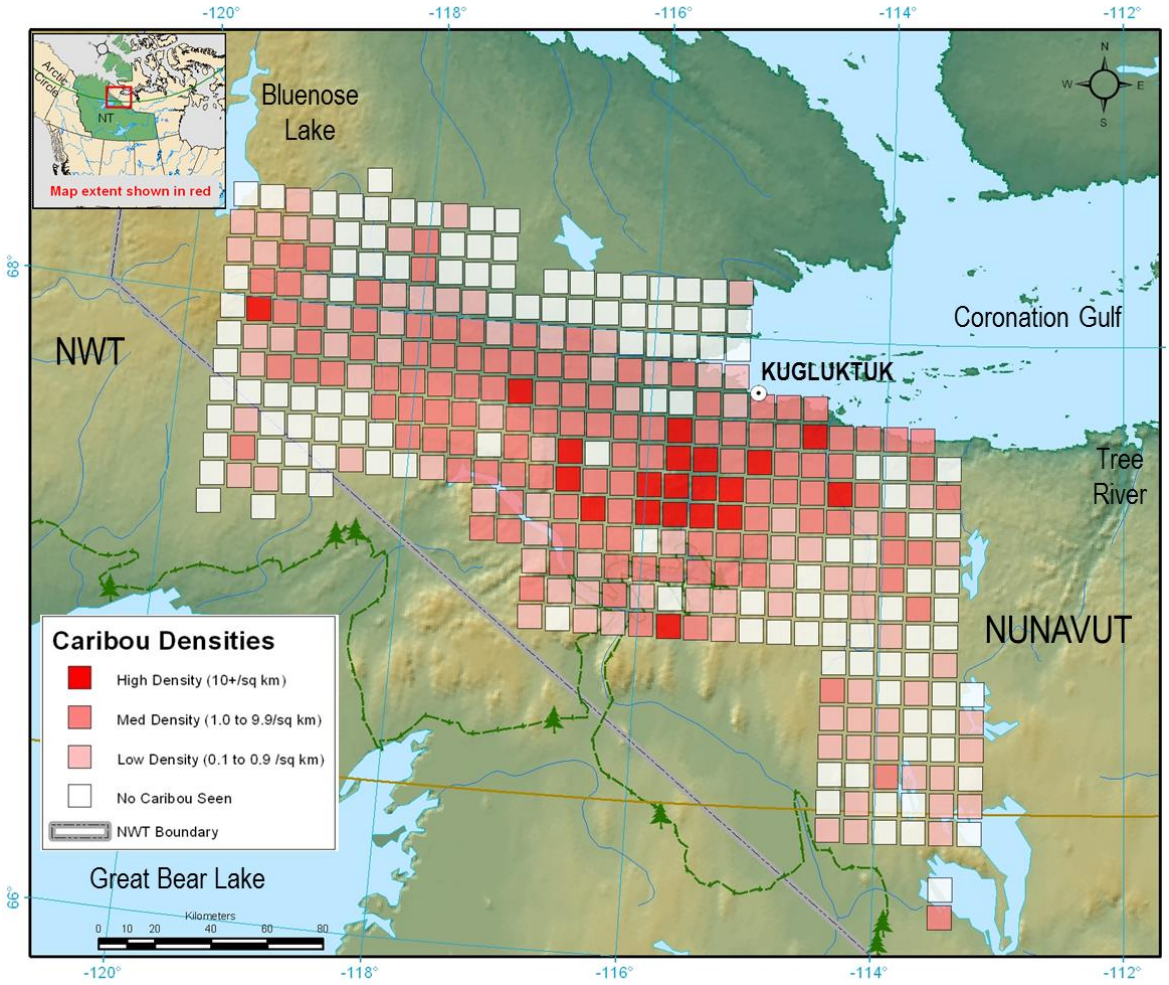

Figure 6a: Densities of adult caribou observed during June 2010 BNE caribou survey during reconnaissance flying June 3, 5, 6 and 7. No caribou were seen in white squares and increasing densities are shown as pink squares, with the highest densities of >10 caribou /km^2 in red. Squares represent ten km segments along flight lines. Map: GNWT/P. Spencer, ENR.

Caribou observations recorded during reconnaissance flying June 3, 5, 6 and 7, 2010 were mapped as squares along the flight lines, with each square representing a ten km segment, and darker red squares representing higher densities (Figure 6a). High (>10/km^2) and medium (1.0-

9.9/km^2) adult caribou densities were generally west, southwest, south, and southeast of Kugluktuk, with lower densities in more peripheral areas.

The composition of caribou groups seen in ten km segments was similarly mapped (Figure 6b). Cows with calves and hard-antlered cows were largely clustered in an elongated area in the Rae and Richardson valleys west of Kugluktuk. Further south and east in the survey area, non-breeding caribou predominated, with non-breeding cows and yearlings closer to the main cow-calf distribution and bulls in more peripheral areas south and southeast of Kugluktuk.

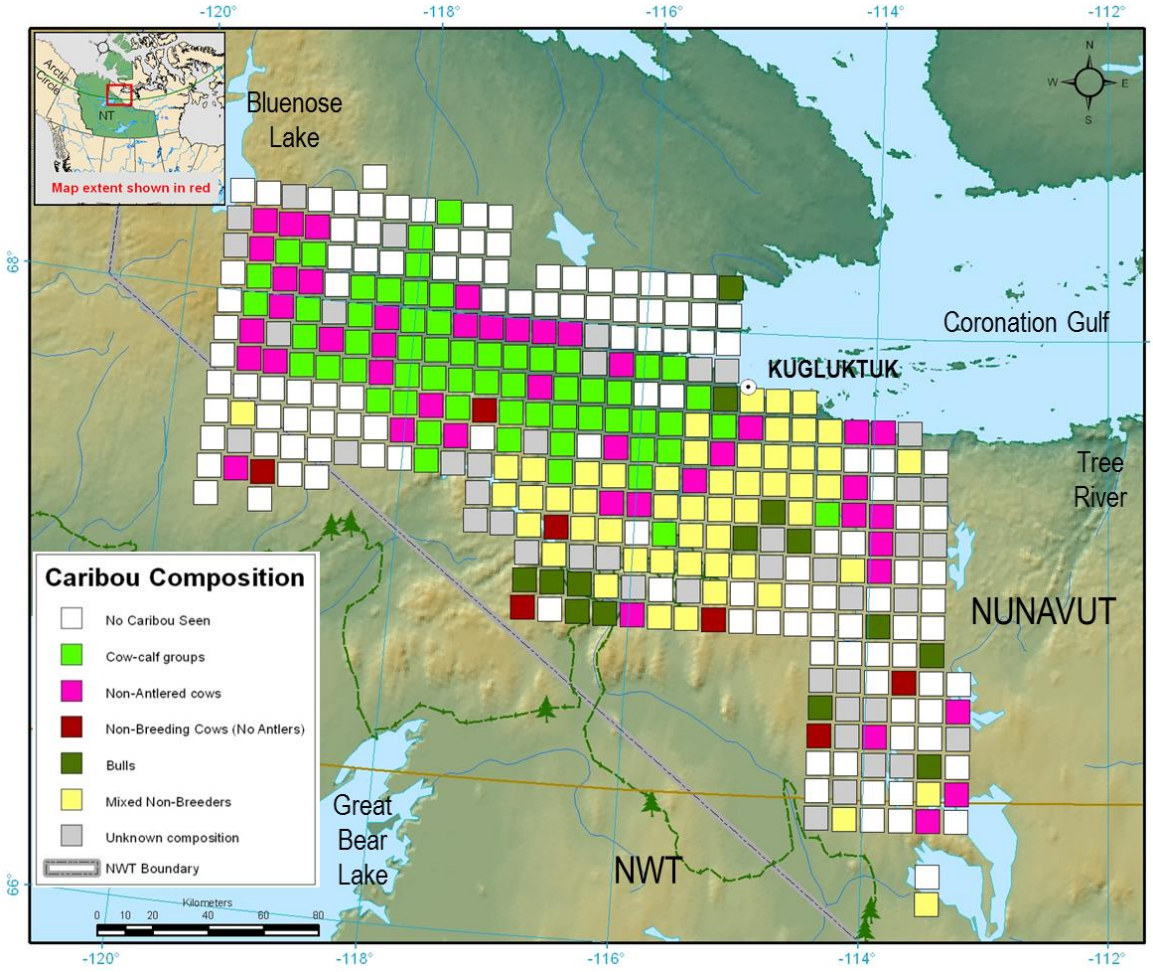

Figure 6b: Composition of caribou groups observed during June 2010 BNE caribou survey during reconnaissance flying June 3, 5, 6 and 7. The main cow-calf concentrations are light green squares, bull only areas are dark red and other types of caribou are as shown in the legend. Squares represent ten km segments along flight lines. Map: GNWT/P. Spencer, ENR.

B. Caribou Counted on Photos and in Visual Strata

Overall, the high and medium density strata that were photographed contained 77.3% of the 28,478 adult caribou counted in the six survey strata, and a similar 76.1% of the adult caribou estimated for the entire survey area (Table 2). These two strata also had the highest densities of adult caribou (10.5 and 8.2/km^2). The east and south strata had somewhat lower densities (3.7 and 3.9/km^2) and added proportionately to the overall total of caribou. The north and northwest strata had relatively low densities (0.9 and 1.5/km^2) of caribou. The total estimated number of caribou at least one year old was 114,472 (± SE 6,908).

Observations during the initial reconnaissance flights, along with composition recorded on the ground June 8-12 indicated that the peak of calving likely occurred June 6-9, with more than 50% of breeding cows observed after these dates having a calf at heel.

Table 2: Adult caribou estimates by stratum from BNE June 2010 calving photo survey.

	Stratum						
Variable	**High**	**Medium**	**East**	**North**	**North west**	**South**	**Totals**
Count method	Photo	Photo	Visual	Visual	Visual	Visual	n/a
Caribou counted	15,881	6,142	3,167	135	566	2,587	28,478
Density (caribou/km^2)	10.5	8.2	3.7	0.9	1.5	3.9	n/a
Estimated caribou in stratum (N)	50,661.2	36,477.4	11,236.3	952.6	3,335.0	11,809.6	114,472
SE[1](N)	4,768.0	4,442.4	1,468.9	256.7	1,005.2	1,421.5	6,908.2
CV[2](N) as %	9.4	12.2	13.1	26.9	30.1	12.0	6.0

[1] SE = Standard Error
[2] CV = Coefficient of Variation

C. June Composition Survey, Estimate of Breeding Females, and Proportions of Cows, Bulls and Yearlings

A total of 11,625 caribou in 205 groups were classified during the June 2010 calving photo survey (Table 3). The six strata showed strong segregation of sex and age classes consistent with the composition seen during the initial reconnaissance. The high and medium strata had predominantly cow-calf caribou, relatively few bulls, and variable numbers of yearlings, as did the lower-density north and northwest strata. The east and south strata had few or no newborn calves and breeding cows, and instead had mostly bulls, yearlings, and non-breeding cows.

Table 3: Composition survey results and estimates of breeding female numbers from BNE June 2010 calving photo survey.

	Stratum						
Variable	**High**	**Medium**	**East**	**North**	**North west**	**South**	**Totals**
Count method	Photo	Photo	Visual	Visual	Visual	Visual	n/a
No. groups classified	72	59	23	8	20	23	205
No. caribou classified	3,866	5,263	564	189	1,033	710	11,625
No. newborn calves	1,041	2,025	5	6	444	0	3,521
No. yearlings	497	157	99	40	12	132	937
No. bulls	230	23	219	10	3	353	838
No. cows	2,098	3,058	241	133	574	225	6,329
No. caribou 1+ years old	2,825	3,238	559	183	589	710	8,104
No. breeding females	1,211	2,493	4	7	506	0	4,221
Proportion breeding females (%)	42.9	77.0	0.7	4.2	85.9	0	n/a
SE (% breeding females)	5.0	3.0	0.6	2.4	3.7	0	n/a
CV (% breeding females as %)	11.6	4.1	78.4	57.9	4.3	0	n/a
No. breeding females	21,784.3	26,993.3	80.4	39.5	2,859.7	0	51,757
SE (breeding females)	3,258.8	3,464.7	63.9	25.3	870.7	n/a	4,836
CV (% breeding females)	15.0	12.8	79.5	63.9	30.4	n/a	9.3
Calves: 100 cows, breeding cows	86.0	81.2	125[3]	85.7[3]	85.9	n/a	n/a
Calves: 100 cows, all cows	49.6	66.2	2.1	4.5	77.4	n/a	n/a

[3] This value is based on a very small sample.

The proportion of breeding females among adult caribou was below 50% in the high stratum, indicating a high number of non-breeding cows. There were also substantial numbers of yearlings in the high stratum. The medium stratum, by contrast, had a much higher proportion of breeding females (77.0%) and relatively few yearlings. The calf:cow ratios for breeding females were high in the high and medium strata (86.0 and 81.2 calves:100 cows), but because of the large numbers of non-breeding cows in the high stratum, the calf:cow ratio was much lower (49.6 calves:100 cows) when all cows were included, and somewhat lower (66.2:100) in the medium stratum.

The proportions of breeding cows and estimates of adult caribou in each stratum were used to derive an estimate of 51,757 (± 4,836 SE) breeding cows for the survey area.

D. Fall 2009 BNE Composition Survey and Sex Ratio

A total of 79 caribou groups and 4,531 caribou, including calves of the year, were classified October 19 and 20, 2009 (Table 4, Figure 7). This resulted in estimates of 46.0 calves:100 cows (± 1.7 SE) and 42.9 bulls:100 cows (± 1.9 SE). At the time of the survey, there were 31 active collars on the BNE herd, of which 30 were within or near the survey area. There were also four collars from the neighbouring Bathurst herd to the north (Figure 7) but no caribou groups were classified among these collars.

Table 4: Composition survey results from October 19 and 20, 2009 for the BNE caribou herd.

No. groups classified	No. cows	No. calves	No. bulls	Totals
79	2,399	1,104	1,028	4,531
Calf:cow ratio ± SE	46.0 calves:100 cows (±1.7)	Bull:cow ratio ± SE	42.9 bulls:100 cows (±1.9)	

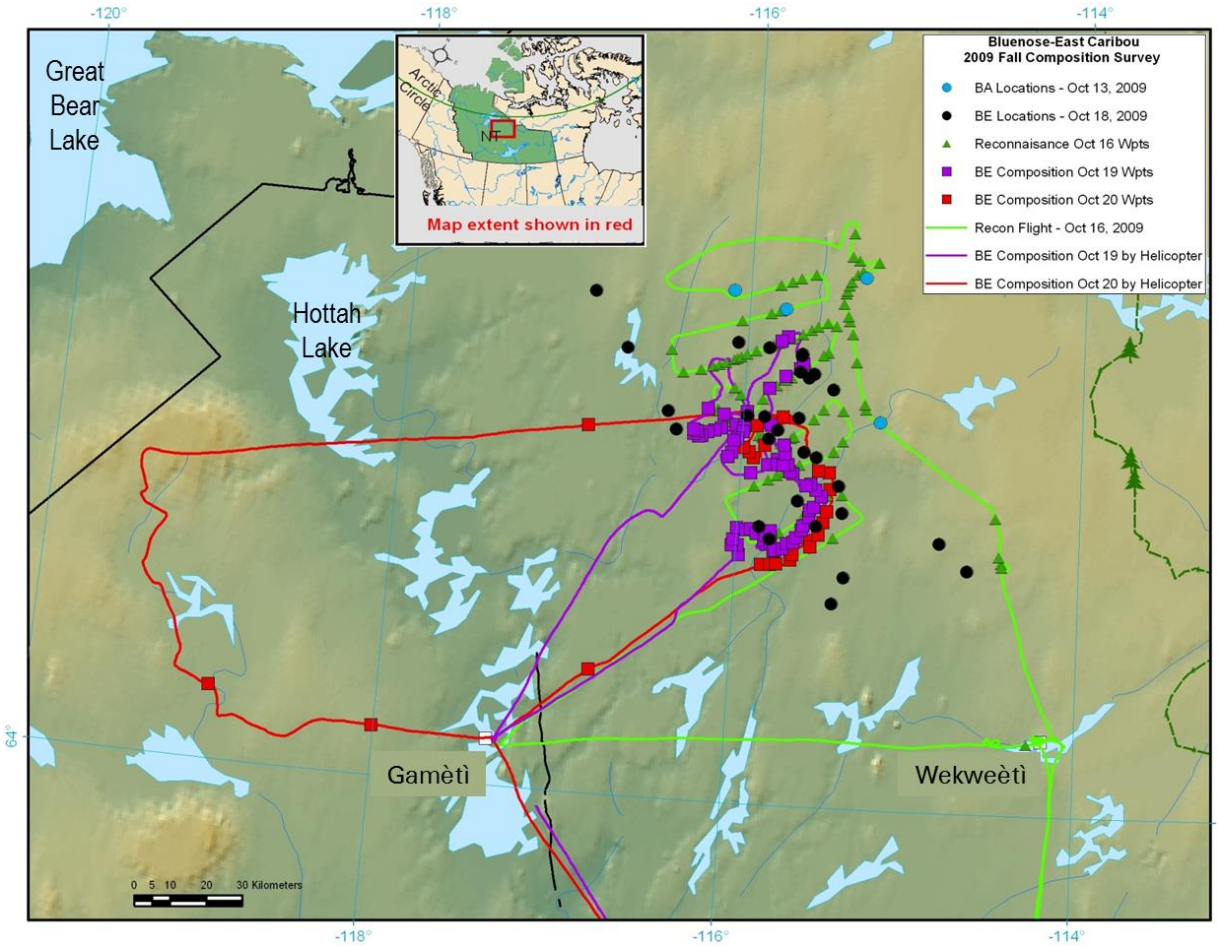

Figure 7: Composition survey flown October 19 and 20, 2009 in the range of the BNE caribou herd. BNE collar locations are black dots and Bathurst collar locations are in blue. Composition of caribou groups near Bathurst collars was not used for this survey. Map: GNWT/B. Croft and P. Spencer, ENR.

E. Estimated Population Size and Proportions of Cows, Bulls and Yearlings from June Survey

Two estimates of population size (number of caribou at least one year old) resulted from the June 2010 BNE calving photo survey. The estimated number of breeding females, 51,757±11,092 (CI), was extrapolated to an estimate of 102,704±39,965 caribou at least one year old (Table 5). The second estimate is the 114,472±15,845 caribou at least one year old from the two photo strata and the four visually counted strata.

Table 5: Estimated number of breeding females and extrapolated population estimate for the BNE herd in June 2010 using a sex ratio (42.9 bulls:100 cows, or proportion of females among adult population 0.70) from an October 2009 BNE fall composition survey, and an estimate of 72% pregnancy among breeding-age cows in the herd (Dauphine 1976).

Variable	Estimate	SE	CV as %	CIL[4]	CIU[5]
No. adult caribou on calving grounds and nearby areas	114,472	6,908	6.0	98,627	130,317
No. breeding females	51,757	4,836	13.0	40,665	62,849
Proportion of females in entire herd	0.70	n/a	4.0	n/a	n/a
Proportion of females ≥1.5 year old pregnant	0.72	n/a	10.0	n/a	n/a
Extrapolated adult population estimate	102,704	20,355	17.0	62,740	142,669

We used the numbers of adult caribou from Table 2 for each stratum multiplied by the proportions of cows, bulls, and yearlings in Table 3 to estimate the numbers of the three groups in the survey area in each stratum (Table 6).

Table 6: Estimated numbers of cows, bulls and yearlings in each stratum, based on estimates of adult caribou in each stratum (from Table 2) and composition (from Table 3).

	Stratum						
Variable	High	Medium	East	North	North west	South	Totals
Estimated number of caribou 1+ year old in stratum	50,661	36,476	11,237	954	3,336	11,808	114,472
Estimated number of cows in stratum	37,641	34,434	4,843	693	3,252	3,743	84,606
Estimated number of yearlings in stratum	8,916	1,750	1,989	209	67	2,196	15,127
Estimated number of bulls in stratum	4,104	292	4,405	52	17	5,869	14,739

Cows made up 84,606 of the 114,472 adult caribou (73.9%) estimated for the survey area, and yearlings (13.2%) and bulls (12.8%) made up the remainder. If the yearlings are presumed to

[4] CIL = Lower 95% Confidence Interval
[5] CIU = Upper 95% Confidence Interval

be divided equally among males and females (50:50 sex ratio), then the estimated numbers overall of adult females and males are 92,169 (80.7%) and 22,128 (19.3%). This is equivalent to a ratio of 24.0 bulls:100 cows.

Post-calving Survey in July 2010

A. Collared Caribou and Photography of Aggregated Caribou

Monitoring of collared caribou showed variable distances day to day, with substantial movements of up to 30-40 km by some individuals. The main concentration of collared cows in cow-calf groups was initially just east of Bluenose Lake (Figure 5) and later was concentrated further east and south (Figure 8).

Caribou in the southern group (seven collars) were photographed on July 6 and July 12. Caribou in the main group (30 collars) were photographed on July 9, and caribou in the northern group (ten collars) were photographed on July 12. The bulls, yearlings and non-breeding cows, and seven associated collared caribou east of the Coppermine River were separated widely from the cow-calf groups and 40 associated collars throughout the survey period. Collared caribou in the main and northern groups were monitored daily between July 9 and July 12, and collared caribou from the two groups remained entirely separate over this period.

Aggregation of caribou suitable for photography generally did not last more than a day. Caribou in the northern group were the least likely to aggregate; the collars and caribou in this area tended to remain scattered except for the one day when photos were taken. Caribou in the southern group were more likely to aggregate, which resulted in two separate sets of photos.

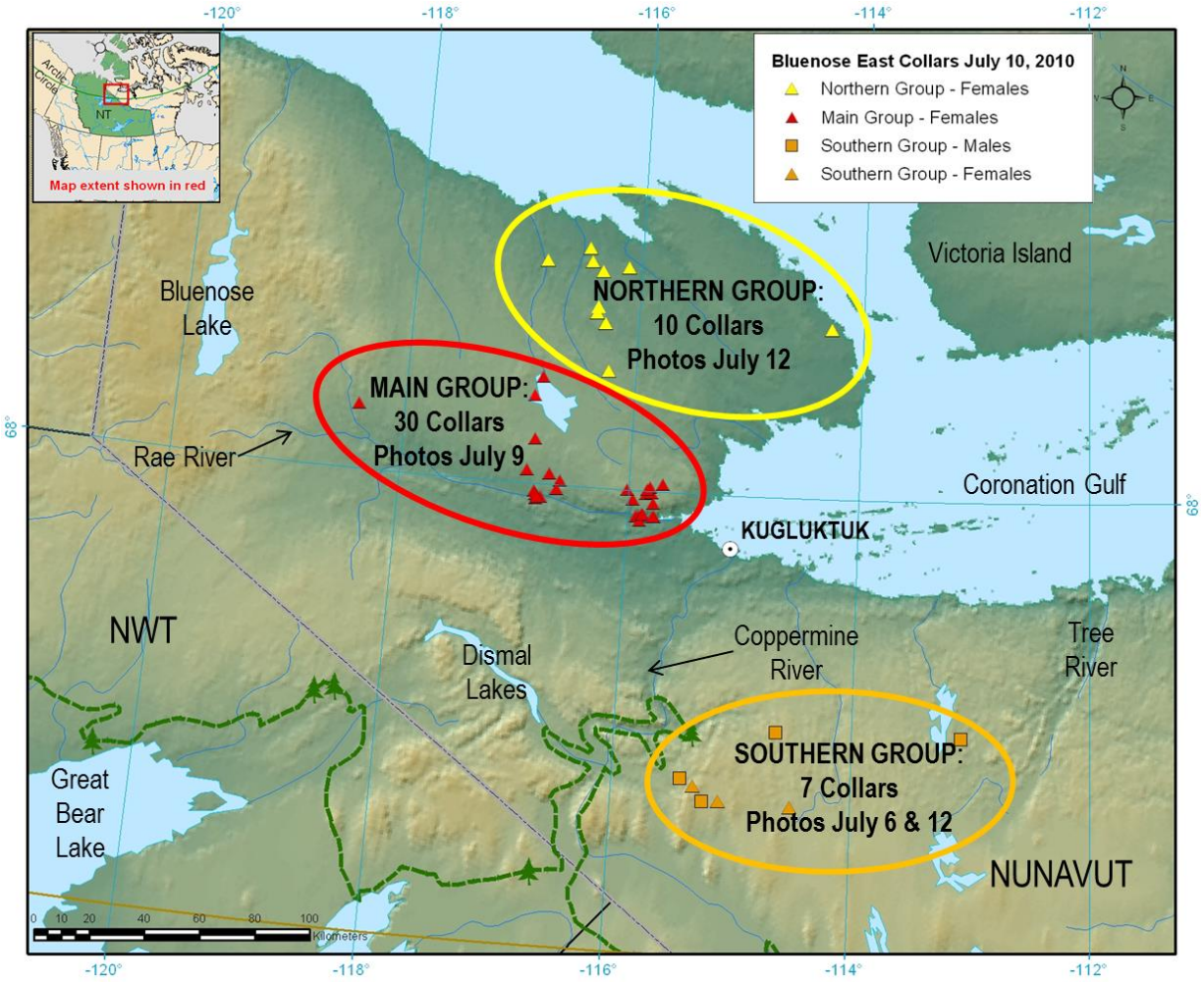

Figure 8: Locations of main, northern and southern groups of caribou photographed during July 2010 post-calving survey of the BNE herd. Collar locations are from July 10. Map: GNWT/P. Spencer, ENR.

B. Caribou Counted on Photos

A total of 40 groups of caribou and 92,481 adult caribou were counted on photos from the July 2010 BNE post-calving survey (Table 7). Two-thirds of these were in the main group that had 30 collars, with the remainder found in the southern and northern groups. The number of collars in caribou groups varied substantially.

Table 7: Groups of caribou, radio collars, and caribou counted on photos from July 2010 BNE post-calving survey.

Southern Group, photos July 6			**Main Group, photos July 9**			**Northern Group, photos July 12**		
Group No.	**Collars**	**Caribou**	**Group No.**	**Collars**	**Caribou**	**Group No.**	**Collars**	**Caribou**
1	1	11,461	1	8	11,652	1	3	5,999
2	1	4,080	2	3	8,327	2	2	1,106
3	1	804	3	2	7,585	3	1	760
4	1	385	4	5	7,528	4	1	115
5	1	5	5	1	7,365	5	1	14
6	1	3	6	4	4,989	6	1	3
7	0	175	7	2	4,942	7	1	1
8	0	2	8	2	1,943	8	0	3,870
9	0	2	9	1	1,014	9	0	914
Totals	6 of 7	16,917	10	0	2,263	10	0	268
(numbers used in estimate)			11	0	1,980	11	0	226
			12	0	1,523	12	0	175
Southern Group, photos July 12			13	0	670	13	0	6
Group No.	Collars	Caribou	14	0	242	14	0	2
1	2	5,711	15	0	79	Totals	10 of 10	13,459
2	2	4,629	16	0	2			
3	2	1,002	17	0	1			
4	1	1	Totals	28 of 30	62,105			
Totals	7 of 7	11,342						
(numbers not used in estimate)								
		Grand Total		**44 of 47**	**92,481**			

In the northern group the largest group photographed had three collars and nearly 6,000 caribou, but there was also a group of nearly 4,000 with a single collar. In the main group the larger groups generally had multiple collars. In the southern group on July 6, the largest group was over 11,000 caribou with just one collar, and another group of more than 4,000 also had only a single collar. Examples of small and large photographed groups of caribou are shown in Figures 9 and 10.

Figure 9: Small group of caribou cows and calves photographed during July 2010 post-calving survey (northern group) of the BNE herd. Photo: GNWT/B. Tracz, ENR.

The two sets of photos of the southern group resulted in two different counts. On July 6, six of seven collared caribou were found, nine groups were photographed, and 16,917 adult caribou were counted on photos. On July 12, seven of seven collared caribou were found, four groups were photographed, and 11,342 adult caribou were counted. We used the higher number of caribou counted on July 6 in the calculations of herd size. We assumed that the second set of photos was lower because the caribou had in the meantime formed different groups that resulted in a few thousand caribou without collars that were not found on July 12.

Figure 10: Group of approximately 5,000 caribou photographed during July 2010 post-calving survey (southern group) of the BNE herd. The group contained primarily bulls, yearlings and non-breeding cows. Photo: GNWT/B. Tracz, ENR.

Of the 47 collared BNE caribou in the survey area in July 2010, 44 were accounted for at the time of photos taken on July 6, 9 and 12. The other three were also active GPS-satellite or satellite collars for which locations were received daily. A few of the VHF transmitters during the survey sometimes functioned erratically, leading to homing-in flights that did not lead to caribou groups. On a few occasions homing in on the collars did not produce the usual very loud signals of transmitters close to the aircraft, and in effect led to "wild goose chase" flying. We have assumed that these three collared caribou and any caribou associated with them were in the survey area but were not found at the time of taking photos due to erratic functioning of VHF transmitters on the collars.

C. Estimated Herd Size and Variance using Lincoln-Petersen Estimator

An estimate of 98,646±13,965 (CI) caribou at least one year old in the BNE herd in 2010 was derived using the Lincoln-Petersen formula modified by White and Garrott (1990) described earlier. The upper and lower 95% CI were 112,611 and 84,681 caribou.

D. Estimated Herd Size and Variance using Rivest Estimator

Sample sizes of collared caribou were highest in the main group and lower in the northern and the southern groups. Percentages of collars were generally proportional to the counts of caribou (Table 8). In general, bulls were primarily found in the southern group, and there were four collared bulls and three collared cows in this group. Breeding cows predominated in the main and northern groups, and were represented by 40 collars.

Table 8: Numbers of caribou groups photographed and caribou counted during July 2010 post-calving survey of BNE herd.

Regional Group	Date	No. groups found (total)	No. groups with collars	No. collars detected	Caribou counted on photos	Percent of total groups	Percent of total collars	Percent of counted caribou
South	July 6	9	6	6 of 7	16,917	23.1	14.9	18.3
Main	July 9	17	9	29 of 30	62,105	43.6	63.8	67.2
North	July 12	14	10	10 of 10	13,459	33.3	21.3	14.6
Total		40	25	44 of 47	92,481	100.0	100.0	100.0

Of the 39 groups encountered, 21 contained radio collared caribou and 18 did not. Group sizes for groups that had no collared caribou were mainly between one and 2,000 with one group of 3,870 caribou. Groups with collars ranged from 1-11,652 caribou.

In general, group size increased with the number of collars (Figure 11) except for one large group (11,461 caribou) in the southern group that only had one collar. Only data for groups that had at least one collared caribou were used for the Rivest estimator.

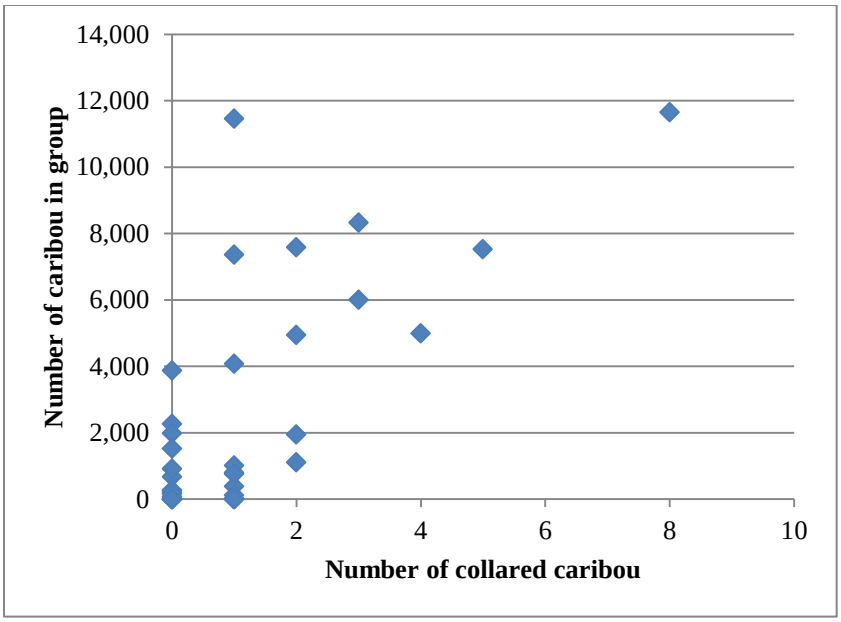

Figure 11: Number of caribou counted in individual groups as a function of the number of collared caribou in each group.

A suite of detection models was applied to the post-calving data set. As an initial step, a test for randomness of the distribution of collars in each caribou group was conducted using the independence, homogeneity, and threshold models (Table 9).

Table 9: Tests for randomness of collared caribou relative to group sizes from BNE July 2010 post-calving survey.

Model	Z value	P value
Independence	1.11	0.133
Homogeneity	0.97	0.165
Threshold B=2	1.13	0.128
Threshold B=3	1.07	0.142

In all cases, the null hypothesis of randomness was not rejected, suggesting that this assumption was reasonable for the BNE 2010 data set.

Table 10: Estimates of BNE adult caribou herd size in July 2010, based on detection models from Rivest estimation, ranked by log-likelihood. The Lincoln-Petersen estimate is given for comparison.

Detection Model	Log-likelihood	Detection probability	SE (Detection probability)	Estimated herd size $\widehat{T}$	Standard Error SE ($\widehat{T}$)	95% CI (±)	Coefficient of Variation
Threshold (B=5)	2.415	0.91	0.069	122,697	16,202	31,756	13.2
Homogeneity	2.412	0.94	0.066	120,495	15,673	30,720	13.0
Threshold (B=6)	2.409	0.92	0.067	121,702	15,934	31,231	13.1
Threshold (B=2)	2.364	0.81	0.098	127,841	18,361	35,988	14.4
Independence	2.363	0.83[A]	0.087	127,101	18,055	35,389	14.2
Threshold (B=4)	2.361	0.90	0.072	123,872	16,349	32,045	13.2
Threshold (B=3)	2.313	0.88	0.079	124,934	17,060	33,438	13.7
Lincoln-Petersen				98,646	7,125	13,965	3.7

[A] This estimate applies to a group with one collared caribou. Detection probabilities will increase as a function of group size for this model.

The independence, homogeneity, and threshold models (with thresholds of collared caribou ranging from two to five) were run and compared using log-likelihood scores. A threshold model that assumed that groups of caribou that had five or more collars had a detection probability of one had the highest likelihood score (Table 10). This model indicated the groups with a collar sample size of less than five had a detection probability of 0.91. A homogeneity model had a very close likelihood and in this case each group had a probability of 0.94 of being detected. The independence model had a lower likelihood. The probability of detection in this case corresponds to the individual collared caribou and therefore the probability of detecting a group depended on the number of collared caribou in the group. For this model the probability of detecting a group with one collar was 0.83 and the probabilities of detecting a group of three or more was very close to one (0.99).

The estimate of total herd size for the Threshold (B=5) model was 122,697 with 90,940-154,452 CI. The coefficient of variation of the estimate was 13.2%. Population size estimates for other models were reasonably similar to the threshold model, ranging up to 127,841 (Table 12). As a comparison, the Lincoln-Petersen estimate for this data set was 98,646 (±13,965).

DISCUSSION

Population Estimates for the BNE Herd from June 2010 Calving Photo Survey

The BNE June 2010 calving photo survey, the first for this herd, resulted in two estimates of herd size: the extrapolated estimate of 102,704±39,965 and the estimate of 114,472±15,845 based on counts of the six survey strata. The first of these was planned; the second was an unexpected outcome largely due to a substantial sample of collared caribou and a large June survey area. The June 2010 BNE calving photo survey was modeled after the Bathurst June calving photo surveys in the 1980s, 1990s, and 2000s (see Heard 1985, Gunn et al. 2005, Nishi et al. 2007, and Boulanger et al. 2014).

In the BNE June 2010 survey, the 43 cow collars and four bull collars, in combination with reconnaissance flying in early June, allowed us to map and survey the breeding cows on the calving grounds as planned. We believe that we also defined and surveyed a high proportion of the remaining portions of the herd, most of them in the south and east strata that had very few cows with calves. The composition surveys in the high and medium strata also showed that there was a substantial number of non-breeding cows on the BNE calving ground in 2010.

The estimate of 114,472±15,845 is the preferred of the two estimates as it is based on actual counts and did not involve extrapolation. The difference between the two estimates from the June 2010 survey is 11,768; we suspect that this difference is largely due to the yearlings in the survey area, which are not included in the extrapolated estimate (Heard 1985). The estimated number of yearlings in the survey area based on counts of strata and the composition survey in June (Table 6) was 15,127. Yearlings are not included in the extrapolation because the pregnancy rate for yearlings (which would be five-months old during the previous fall breeding season) is effectively zero, as caribou calves almost never breed in their first year and rarely as yearlings (Dauphine 1976). Mean pregnancy rate for a herd has been estimated by the ratio of caribou that

are pregnant divided by caribou that are capable of being pregnant (0.72, Dauphine 1976 *in* Heard 1985), and yearlings are almost never pregnant. If the proportion of yearlings present in the population were known, then the extrapolated herd estimate could be adjusted to include yearlings.

While the June calving photo survey has been designed to produce a relatively precise estimate of breeding females on the calving grounds, extrapolation to overall herd size is less precise and was termed a "rough estimate" of overall herd size by Heard (1985). The extrapolation depends on two ratios: an estimate of pregnancy rate in females at least 1.5 years old (to add in non-pregnant breeding-age cows) and an estimate of the bull:cow ratio based on one or more fall composition surveys (to add in bulls). The estimate of pregnancy that has been used is based on the Qamanirjuaq herd from the 1960s (Dauphine 1976) but pregnancy rates have varied in barren-ground caribou herds (Thomas and Kiliaan 1998, Beverly herd; Bergerud et al. 2008, George River herd). Sex ratios in migratory caribou herds also vary (e.g. Bathurst herd, Boulanger et al. 2011) and an accurate estimate of herd sex ratio depends on a spatially comprehensive fall composition survey. Both ratios introduce potential biases and error in the extrapolated herd estimate and the non-inclusion of yearlings is likely to lead to conservative estimation of the number of adults at least one year old in the herd.

The June calving photo survey was designed to provide a precise estimate of the number of a herd's breeding females, the core reproductive segment of the population (Heard 1985, Gunn et al. 2005, Nishi et al. 2007, Boulanger et al. 2011). Breeding female caribou are generally relatively stable over time and less influenced by annual variation in productivity, and these estimates from June calving photo surveys should be emphasized in monitoring herd trend where this survey is used (Boulanger et al. 2011). Assumptions in extrapolation of the breeding female

estimate to total herd size and (in earlier years) sometimes large variance on these estimates have reduced some biologists' confidence in this method as an overall estimator of herd size (Rivest et al. 1998, Thomas 1998). We concur with Heard (1985) that the extrapolated estimate from June surveys provides a "rough estimate" of total herd size. Our results for the BNE herd in 2010 suggest that the extrapolated herd size was a conservative estimate of adults in the herd defined as caribou at least one year old, particularly because yearlings were not accounted for in the extrapolation.

The estimate of 114,472 is likely an under-estimate of true herd size because bulls were under-represented within the survey area and the reconnaissance flight results suggested that we did not fully survey the "trailing edge" of bulls, yearlings and non-breeding cows often found south of a barren-ground caribou herd's calving grounds. The survey was not originally intended to define and count these and other non-breeding caribou concentrations of the herd. The bull:cow ratio calculated from June counts of strata and the composition survey (Table 6) was 24.0 bulls:100 cows, well below the 42.9 bull:100 cows estimated in October 2009 for this herd. Bulls tended to be found in the southernmost portions of the BNE June 2010 survey area (Figure 6b). In addition, there were just four bull collars on the BNE herd in June 2010, compared to 43 cow collars. Our results suggest that a modified June photo survey could be designed for this or other caribou herds that would include all segments of the herd, provided that collar numbers on cows and bulls were sufficient and that survey blocks could include the main calving concentrations as well as non-breeding cows, yearlings and bulls usually found south of the calving grounds at this time of year.

Population Estimates for the BNE Herd from July 2010 Post-calving Photo Survey

As with the June survey, the July 2010 Bluenose-East caribou survey resulted in two population estimates: 122,697±31,757 from the best model of the Rivest estimator and 98,646±13,965 from the Lincoln-Petersen estimator. All of the estimates from the Rivest models (Table 10) were similar and varied between 120,495 and 127,841.

The estimate of 122,697±31,757 from the Rivest estimator is the preferred population estimate of the two from the July 2010 Bluenose-East post-calving survey, as the Lincoln-Petersen estimate most likely under-estimates herd size and produces an unrealistically low estimate of variance (Rivest et al. 1998). Population estimates based on the Rivest estimator have become the standard means of estimating population size in Alaskan post-calving surveys (Alaska Department of Fish and Game 2011) and in Québec/Labrador. For surveys of the western Arctic herd, in particular, with 100 or more radio collared caribou, Rivest estimates often are very close to the total counts of photographed caribou groups (Alaska Department of Fish and Game 2011). The Rivest calculations use the groups with at least one collar as the sample units, consider the distribution of collars in those groups in relation to group size, and assess the probability of a group being detected as well as the probability of the group having at least one collar. These probabilities can be multiplied to get an estimate of detection probability of a group that has at least one collar in it. This becomes an estimate of the sample proportion that each caribou group represents relative to the total herd. The herd estimate then becomes the summation of the number of caribou in each group with at least one collar, divided by the detection probability of that group.

The Lincoln Petersen estimator assumes that all caribou groups and collared caribou have equal probabilities of detection so that the proportion detected will apply equally to all caribou in

the herd regardless of group size, or whether collared caribou are present within the group. These assumptions are most likely false: larger groups with more collars are more likely to be found, and groups with collars are more likely to be found than groups with no collars, and therefore estimates from the Lincoln Petersen estimator will be negatively biased in most circumstances. The Lincoln-Petersen estimator would lead to the conclusion that the entire herd had been surveyed if 50 of 50 collars had been found, but it would lead to the same conclusion if 10 of 10 collars had been found. In reality 10 collars would be insufficient to find all of a herd with the numbers and geographic range of the BNE herd in 2010. Analysis of detection probabilities for the current post-calving survey suggested that groups with several collars were indeed more likely to be detected than groups with a single collar; groups without collars are less likely to be found than groups with at least one collar. Some ad-hoc methods have been proposed to account for bias issues with the Lincoln-Petersen estimator (Russell et al. 1996), however, these are subjective and often result in the loss of data from smaller group sizes (Rivest et al. 1998).

The results we obtained for caribou in the southern group where the bulls, yearlings and non-breeding cows were concentrated suggest that the number of collars was somewhat low in this area, and that some caribou may have been missed. When photos were taken on July 6 in this area, the largest two groups each had respectively more than 11,000 caribou with just one collar and more than 4,000 caribou with just one collar; the other four groups with collars each had only a single collar. In total 16,917 caribou in nine groups were photographed. Six days later, all seven collared caribou in this area were found but the total number of caribou counted (11,342) in four groups was more than 5,000 caribou less. It is possible that the caribou in this area formed different groups on July 6 and 12, with several thousand caribou on July 12 having no

collars and not being found as a result. As we noted for the June survey, there were just four bull collars (all in the southern group) during the July survey of this herd, compared to 43 cow collars. A larger number of bull collars in closer proportion to the herd's bull:cow ratio would improve confidence in the population estimate from future post-calving surveys of this herd.

Post-calving survey methods with adequate cow and bull collar numbers can result in estimates of overall herd size that include all age classes of the caribou population at least one year old. We are confident that the BNE herd had at least 92,481 caribou at least one year old in 2010, as we counted them on photos. The Rivest estimator can produce robust population estimates provided collar sample sizes are adequate (Rivest et al. 1998, Alaska Department of Fish and Game 2011). The biggest challenge of the post-calving survey method remains the possibility of caribou not aggregating sufficiently for photos if the right weather conditions do not occur during the post-calving period. Insufficient aggregation of all parts of the Bluenose-East caribou herd has occurred repeatedly in attempted post-calving surveys of this population. In our experience, caribou in the northern sector are least likely to aggregate; in 2010 we only found adequate aggregation in this part of the herd's range on one day of flying (July 12). Trends in post-calving survey estimates may be influenced by yearly variation in productivity (variable numbers of yearlings included) that may not reflect trends in the core breeding female segment of the population.

Preferred BNE Population Estimate for 2010

The two preferred population estimates for the BNE caribou herd in 2010 had overlapping confidence intervals and differed by 8,225 caribou or 6.7% of the post-calving estimate. The correspondence of the two pairs of estimates suggests that both survey methods are fundamentally sound. Because we suspect that the June estimate of 114,472 caribou at least one

year old somewhat under-estimated the bulls, yearlings and non-breeding cows in the herd, we suggest that the July estimate of 122,697±31,757 adult caribou is likely closest to true population size (caribou at least one year old or older) for the BNE herd in 2010. The estimate of breeding females in the herd (51,757±11,092) from the June 2010 survey indicates that the herd's single most important demographic sector is substantial and was defined with good precision.

Future Population Surveys of the BNE Herd

June calving photo surveys may be the best option for future population surveys of the BNE herd. Several attempted post-calving surveys for this herd have been unsuccessful in the sense that nearly all the herd aggregated sufficiently for photos and produced a valid population estimate. The post-calving photo survey remains an option for this herd but the likelihood of success is relatively low. A June calving photo survey as carried out for the BNE herd in 2010 is much less likely to fail due to weather. The June survey provides a precise estimate of the herd's breeding females, the single most important demographic component of the herd. Tracking trends in breeding female numbers effectively monitors the demographic viability of the herd and is less influenced by annual variation in calf productivity and trends in bull numbers. Extrapolated herd size can be estimated from the estimate of breeding females, but the extrapolated estimates should be used with recognition of the potential biases and errors involved as rough estimates of herd size. With adequate samples of collared bulls and cows and adequate reconnaissance flying in June, it may be feasible to carry out a modified June survey that includes survey strata enclosing the non-breeding cows, bulls, and yearlings, as well as the concentrations of breeding cows.

ACKNOWLEDGEMENTS

Aerial surveys like the June and July 2010 Bluenose-East calving and post-calving photo surveys require months of planning, logistic support, careful field work, and analysis after the field work is complete. We would like to thank Adam Bourque and Monika Koetzle for capably piloting the Cessna Caravans during the June survey, Perry Linton and Brett Van Hearden for capably piloting the Helio-Courier and Cessna 185 during the July survey, and Jesse Pierce for flying the helicopter during the June composition survey. Mathieu Dumond, Jorgen Bolt and Allan Niptanatiak provided excellent logistic support in Kugluktuk. A very special thank you to Phil Spencer in Norman Wells for daily supplying the caribou collar locations during the surveys and for the fine maps he created for this report. Our thanks also to Jennifer Bailey for capable support with data entry and mapping during the June survey. Paul Roy once again meticulously counted photos from the June survey, as he has for these surveys for many years. Noel Doctor, George Mandeville, Kelvin Kotchilea, Joe Blondin, Nicole McCutchen, Kerri Garner, and Karin Clark were able observers during the June survey. Andrea Hrynkiw kindly assisted with the July field work and counting of caribou on July photos. Judy Williams provided her usual expert support with logistics and survey planning. Funding was largely provided by the GNWT, with an assist from the Government of Nunavut. These surveys represented collaboration among Inuvik, North Slave and Sahtú ENR regional staff and ENR headquarters staff. Alasdair Veitch in Norman Wells provided cheerful support during the surveys and organized a community observer tour at the end of the survey in July. We would also like to thank senior management staff in ENR, including Susan Fleck, Nicole McCutchen, Ernie Campbell, and Gary Bohnet for ensuring that we were able to carry out these surveys with the resources and support that these expensive, time-consuming surveys depend on.

LITERATURE CITED

Adamczewski, J., J. Boulanger, B. Croft, H.D. Cluff, B. Elkin, J. Nishi, A. Kelly, A. D'Hont, and C. Nicolson. 2009. Decline in the Bathurst Caribou Herd 2006–2009: A Technical Evaluation of Field Data and Modeling. Environment and Natural Resources, Government of the Northwest Territories. www.wrrb.ca/node/208 (accessed Oct. 2012).

Adamczewski, J., J. Boulanger, B. Croft, H. Sayine-Crawford, T. Davison, and B. Tracz. 2011. Post-calving Photo Surveys and Extrapolated Calving Photo Surveys for Barren-ground Caribou: A Comparison from the Bluenose-East Herd in June and July 2010. Presentation at 13th International Arctic Ungulate Conference, Yellowknife, NWT. August 2011.

Alaska Department of Fish and Game. 2011. Caribou Management Report of Survey-inventory Activities 1 July 2008 - 30 June 2010. P. Harper, editor. Juneau, Alaska. 345pp.

Bergerud, A.T., S. N. Luttich, and L. Camps. 2008. The Return of Caribou to Ungava. McGill-Queen's University Press, Quebec, Canada.

Boulanger, J., and A. Gunn. 2008. Exploring Possible Mechanisms for the Decline of the Bathurst Barren-ground Caribou using Demographic Modeling. Environment and Natural Resources, Government of Northwest Territories. Manuscript Report No. 175. 66pp.

Boulanger, J., A. Gunn, J. Adamczewski, and B. Croft. 2011. A Data-driven Demographic Model to Explore the Decline of the Bathurst Caribou Herd. Journal of Wildlife Management 75:883-896.

Boulanger, J., B. Croft, and J. Adamczewski. 2014. An Estimate of Breeding Females and Analyses of Demographic Indicators from the Bathurst Herd 2012 Calving Ground Photographic Survey. Environment and Natural Resources, Government of Northwest Territories. File Report No. 142. 91pp.

Campbell, M., J. Nishi, and J. Boulanger. 2010. A Calving Ground Photo Survey of the Qamanirjuaq Migratory Barren-ground Caribou (*Rangifer tarandus groenlandicus*) population, June 2008. Department of Environment, Government of Nunavut. Technical Report Series 2010 - No. 1-10. 129pp.

Couturier, S., R. Courtois, H. Crépeau, L.-P. Rivest, and S. Luttich. 1996. Calving Photocensus of the Rivière George Caribou Herd and Comparison with an Independent Census. Rangifer Special Issue 9:283-296.

Crépeau, H., L. P. Rivest, S. Couturier, and S. Baillargeon. 2012. Package "caribou" (R). *In* Université Laval, Quebec City, QC.

Dauphine, T. C. Jr. 1976. Biology of the Kaminuriak Population of Barren-ground Caribou. Part 4: Growth, Reproduction and Energy Reserves. Canadian Wildlife Service Report Series No. 38. Canadian Wildlife Service, Environment Canada, Ottawa, ON.

Fancy, S.G., K. R. Whitten, and D.E. Russell. 1994. Demography of the Porcupine Caribou Herd, 1983-1992. Canadian Journal of Zoology 72:840-846.

Fisher, J. T., L. D. Roy, and M. Hiltz. 2009. Barren-ground Caribou Management in the Northwest Territories: An Independent Peer Review. Alberta Research Council, Sustainable Ecosystems Unit, Vegreville, AB.

Gunn, A., J. Nishi, J. Boulanger and J. Williams. 2005. An Estimate of Breeding Females in the Bathurst Herd of Barren-ground Caribou, June 2003. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report No. 164. 75pp.

Gunn, A., J. Adamczewski, and J. Nishi. 2008. A Review of Concerns Expressed by Outfitters Between 2003 and 2007 About the Bathurst and Ahiak Herds. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report No. 178. 177pp.

Heard, D. C. 1985. Caribou Census Methods used in the Northwest Territories. Proceedings of the Second North American Caribou Workshop, Val Morin, Quebec, October 1984. McGill Subarctic Research Paper 40:229-238.

Heard, D. C. and F. J. Jackson. 1990. Beverly Calving Ground Survey, June 2-14, 1988. Renewable Resources, Government of the Northwest Territories. File Report No. 86. 38pp.

Mowat, G., and J. Boulanger. 2000. Summary of Caribou Calving Ground Survey Workshop, 7-8 November 2000. Resources, Wildlife and Economic Development, Government of the Northwest Territories. Unpublished Report, 10pp.

Nagy, J. A., and C. Bucher. 2007. Estimates of the Number of Barren-ground Caribou in the Cape Bathurst and Bluenose-West Herds Derived using Post-calving Photography, July 2000. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report 213. 46pp.

Nagy, J. A., and D. Johnson. 2006. Estimates of the Number of Barren-ground Caribou in the Cape Bathurst and Bluenose-West Herds and Reindeer/Caribou on the Upper Tuktoyaktuk Peninsula Derived using Post-calving Photography, July 2006. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report No. 171. 66pp.

Nishi, J.S., Croft, B., J. Williams, J. Boulanger, and D. Johnson. 2007. An Estimate of Breeding Females in the Bathurst Herd of Barren-ground Caribou, June 2006. Environment and Natural Resources. Government of the Northwest Territories. File Report No. 137. 107pp.

Norton-Griffiths, M. 1978. Counting Animals: Serengeti Ecological Monitoring Program Handbook No. 1. African Wildlife Leadership Foundation, Nairobi, Kenya. 110pp.

Patterson, B. R., B. T. Olsen, and D. O. Joly. 2004. Population Estimate for the Bluenose-East Caribou Herd using Post-calving Photography. Arctic 57:47-58.

Poole, K. G., A. Gunn, and J. Wierzchowski. 2014. An Operations Guide to Barren-ground Caribou Calving Ground Density, Dispersion and Distribution Surveys, Based on an Assessment of the June 2007 and 2008 Surveys, Northwest Territories and Nunavut. Environment and Natural Resources, Government of Northwest Territories, File Report No. 141. 104pp.

R Development Core Team. 2009. R: A Language and Environment for Statistical Computing. *In* R Foundation for Statistical Computing, Vienna, Austria.

Rettie, J. 2008. Determining Optimal Satellite Collar Sample Sizes for Monitoring Barren-ground Caribou Populations. Contract Report. Environment and Natural Resources, Government of the Northwest Territories. 31pp.

Rivest, L. P., S. Couturier, and H. Crepeau. 1998. Statistical Methods for Estimating Caribou Abundance using Post-calving Aggregations Detected by Radio Telemetry. Biometrics 54:865-876.

Russell, J., S. Couturier, L. G. Sopuck, and K. Ovaska. 1996. Post-calving Photocensus of the Riviere George Caribou Herd in July 1993. Rangifer 9:319-330.

Thomas, D.C. 1998. Needed: Less Counting of Caribou and More Ecology. Rangifer Special Issue 10:15-23.

Thomas, D.C., and H.P.L. Kiliaan. 1998. Fire-caribou Relationships: (I) Physical Characteristics of the Beverly Herd, 1980-87. Canadian Wildlife Service, Prairie and Northern Region, Edmonton, AB. Technical Report Series No. 309

Valkenburg, P., D. A. Anderson, J. L. Davis, and D. J. Reed. 1985. Evaluation of an Aerial Photocensus Technique for Caribou Based on Radio Telemetry. Proceedings of the Second North American Caribou Workshop, Val Morin, Quebec, October 1984. McGill Subarctic Research Paper 40:287-299.

White, G.C. and R.A. Garrott. 1990. Analysis of Wildlife Radio Tracking Data. Academic Press, London, U.K. 383pp.

Williams, T. M. 1995. Beverly Calving Ground Surveys June 5-16, 1993 and June 2-13, 1994. Renewable Resources, Government of the Northwest Territories. File Report No. 114. 46pp.