Decline in the Bathurst Caribou Herd 2006-2009: A Technical Evaluation of Field Data and Modeling

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PREFACE (JA)

This report was prepared in late 2009 after a photographic calving ground survey in June that year documented a large and very rapid decline from more than 100,000 caribou in the Bathurst herd in 2006 to 31,980±10,853 adults in 2009, as described in this report. A technical meeting was held in September 2009 in Calgary with caribou biologists, statisticians and population modellers to assess the available evidence on the herd's apparent decline, and to try to understand what could have resulted in such a dramatic downturn in a herd that in 1986 was nearly half a million strong. The information reviewed at that meeting formed the main basis for the material presented in this report.

The June 2009 Bathurst survey led to management proposals from the Tłı̨chǫ Government (TG) and Government of the Northwest Territories (GNWT) to the Wek'èezhìı Renewable Resources Board (WRRB) in 2009 and 2010, and to two hearings in 2010 of the WRRB. Reports and recommendations that followed led to large-scale harvest restrictions, other management actions, and increased monitoring. Further declines in the Bathurst herd since 2009[1], further management proposals, and additional hearings and management actions have followed since 2010. Records of proposals, supporting documents, hearings and decisions from 2009-2019 relevant to the Bathurst herd in the NWT can be found on the WRRB public registry (https://wrrb.ca/public-information/public-registry) and for Nunavut on the Nunavut Wildlife Management Board (NWMB) registry from 2016-2020 (www.nwmb.com/en/public-hearings-a-meetings/public-hearings-1/2016-1/nwmb-public-hearing-to-consider-total-allowable-harvest-for-bathurst-caribou).

A version of this technical report in December 2009 was part of the material submitted to the WRRB to support of joint management proposals for the Bathurst herd in 2009 and 2010. The report has been quoted in a number of documents; however, it had not been finalized as a GNWT report. In 2020 the report from 2009 was finalized as a GNWT manuscript report. Because a draft version of the report has been in wide circulation for 10 years and is on the WRRB registry, changes were kept to a minimum. A few footnotes, updates and more recent references were added to provide context, but the basic content has stayed unchanged.

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[1] The most recent calving photo survey of the Bathurst herd in June 2018 resulted in an extrapolated herd estimate of 8,207 (CI 6,218-10,831) (Adamczewski et al. 2019).

EXECUTIVE SUMMARY

Barren-ground caribou herds across North America have undergone large changes in numbers over time for hundreds and likely thousands of years, based on scientific studies and knowledge of Indigenous elders. Variation in weather and forage quality and quantity on the calving and summer ranges are probably major factors affecting population trend in most barren-ground caribou herds, but the relationships are complex. Population trend and environmental trends may vary in neighbouring herds; thus, each herd has individual circumstances. A large part of the Bathurst herd's decline since 1986 is likely the result of this natural "cycle" as it parallels similar trends in other NWT/Nunavut herds, and more widely in migratory caribou/reindeer herds across the global north. This report is a review of information about the decline of the Bathurst herd from peak numbers in the 1980s and 1990s to the herd's estimated size in 2009 (31,980±10,853 adults, 95% Confidence Interval, CI), with the main focus on the rapid decline between 2006 and 2009.

Like other barren-ground caribou herds in the NWT, the Bathurst herd would most likely have declined in the early 2000s regardless of harvest, with a later peak of calving and low spring calf:cow ratios consistent with a declining herd from 2000 to 2006. Conditions for at least two other NWT herds (Bluenose-West and Cape Bathurst) were similar in these years, as evidenced by late calving and reduced June calf:cow ratios.

The overall pattern of decline followed by faster decline at lower herd size was similar in the Cape Bathurst, Bluenose-West and Bathurst herds. In the Cape Bathurst and Bluenose-West herds, estimated harvest rates in 2005 were large relative to herd size and included primarily cows. The switch from rapid decline to apparent stability from 2006 to 2009 in both herds followed harvest closure in the Cape Bathurst herd and harvest reduction (4% harvest with 80% bulls) in the Bluenose-West herd. These changes suggest that harvest had contributed significantly to decline in these herds, particularly at low numbers, and could have limited recovery if the harvest had not been restricted. Improved calf recruitment likely also contributed to a stabilizing trend in the Cape Bathurst and Bluenose-West herds.

The Indigenous harvest of the Bathurst herd was not well documented in all years but GNWT records of harvest by outfitters, resident hunters, winter road check-station data and model analyses suggested that a total harvest of about 4,000-5,000 cows/year and about 1,000-2,000 bulls/year was a reasonable estimate of annual harvest in recent years (2007-2009). Unlike earlier periods of low caribou numbers, the hunter harvest likely did not decline as the herd decreased, aided by easy access on winter roads to the communities and mines in the Bathurst range. A harvest of 5,000 cows would have been 2.4% of the herd's 210,300 adult cows in 1996, but it would be 21.7% of the herd's estimated 23,060

cows in June 2009. A lower harvest estimate of 3,000 cows would be 13.0% of the herd's cows in June 2009.

The recovery of the Bathurst herd would require a substantial increase in cow survival and good calf survival, with good fecundity. There is no level of calf recruitment that can compensate for estimated cow survival rates of 67-68% in 2008-2009 (mortality rates of 32-33%). If current cow survival rates, calf survival rates and fecundity continue unchanged, the herd could be lost or may reach extremely low numbers in four to five years. The smaller the herd becomes, the longer the expected period of recovery. Although bull harvest has less impact on caribou population trend than cow harvest, skewing the sex ratio strongly towards low bull:cow ratios should be avoided because of potential effects on population genetics, the importance of prime bulls to migration, and the value of breeding by prime bulls to temporally concentrated calving.

At a cow survival rate of 86%, calf survival would need to be 50-53% in the Bathurst herd to result in a stable herd, based on population modeling. At a cow survival rate of 91%, calf survival of 32-35% would be needed for a stable herd. These estimates are model projections, but they are similar to published estimates in other barren-ground caribou herds. Under optimal conditions, with no harvest, the Bathurst herd might stabilize and begin a modest increase in about five years. However, environmental trends, individual survival and normal year-to-year variation will occur in the real world, thus all model projections are indicators of likely trend under a particular set of assumptions, not predictions.

Poor recruitment in the early 2000s contributed substantially to the herd's decline in those years. Combined with higher recruitment in 2007-2009, this has led to an age structure with a slightly increased representation of older cows, a substantial representation of very young cows, and somewhat fewer middle-aged cows. In other caribou herds this kind of shift in age structure has contributed to declines if the older cows had lower productivity or survival rates. Given the very high cow mortality rates, good condition and high pregnancy rates in the Bathurst herd 2007-2009, this has probably not been a significant factor in the Bathurst decline. The high proportion of very young cows could slow the herd's recovery initially as these females may need another year or two to contribute young to the herd.

There is no scientific evidence that a significant proportion of Bathurst caribou cows switched to either of the neighbouring Bluenose-East or Ahiak ranges, given that the satellite collar data for the three herds showed continuing low levels of collared cow switching among these herds (1-3% of cows switching and about equally in both directions). These conclusions would be stronger with greater collar numbers on the Bathurst herd and a new population estimate for the Bluenose-East herd. Low rates of

exchange between collared cows on neighbouring calving grounds, as in these three herds, are consistent with results from Alaska, Labrador/Quebec, and other herds in NWT and Nunavut.

Although barren-ground caribou herds have been known to fluctuate in numbers over a wide range, they may sometimes remain at low numbers for extended periods. At very low numbers, predator-prey relationships may change, with the advantages of gregarious and temporally concentrated calving ("swamping" predators) lost or diminished. This could be the case for the inland-calving Beverly herd, which was at very low numbers 2007-2009, with high cow mortality rates, low calf:cow ratios and limited evidence of cows switching to the calving grounds of the more numerous Ahiak herd.

Environmental trends in the Bathurst range in recent years have included increasing temperatures and increases in precipitation, but less precipitation as snow. The plant growing season has grown longer and plant biomass has increased, but forage quality has shown a slow declining trend. Snowmelt on the calving ground was annually variable; 1998 and 2008 were two early years, and 2001 and 2005 were two late years. There has been a reduction in lichen-rich habitats on the winter range, largely as a result of forest fires. High pregnancy rates, good body condition in Bathurst cows 2007-2009, and higher spring calf:cow ratios than in the early 2000s suggest that environmental conditions for Bathurst caribou in 2007-2009 were improved over the early 2000s.

Although information on wolf and bear numbers in the Bathurst range is incomplete, annual surveys of wolf dens at the southern end of the Bathurst summer range since 1996 suggest that wolf numbers and productivity have fallen rapidly in recent years as the caribou herd has declined. With few alternate prey to sustain them, wolves can be expected to decline in numbers as their prey declines. This typically manifests through low pup survival and recruitment. Observations of wolves and bears on the Bathurst calving grounds have been limited. In about 14,000 km of survey flight lines on or near the Bathurst calving ground in June 2009, there were eight bear sightings and four wolf sightings. Although predator numbers may be reduced at a lower herd size, they may be having a proportionally greater effect on a smaller, declining Bathurst herd than on a large herd with good calf recruitment.

The diamond mines in the Bathurst summer range have resulted in reduced use by caribou within a Zone of Influence (ZOI) around the mines, to a distance of up to 14 km. This effect has been relatively small at the scale of the herd, with about 4% of the summer range affected by reduced use. Caribou may have also had increased energy costs (more time spent running or walking, less time feeding) if they were near the mines, but this effect has likely been relatively small, in part because caribou have avoided the mines. Overall, effects of the mines to date have been relatively limited and are unlikely to have

been a major contributing factor in the rapid Bathurst decline from 2006-2009. To date the largest effect of the mines is likely greater access for hunters on the additional winter roads.

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INTRODUCTION (JA)

A June 2009 survey of the Bathurst caribou herd's calving ground produced an estimate of 16,649±4,460 breeding females (±95% Confidence Interval, CI) and a population estimate of 31,980±10,853, a decline of 70% in three years (Figure 1). This herd had declined slowly in the 1990s but its rate of decline increased as the herd reached lower numbers. The accelerated decline and the importance of this herd to the Northwest Territories (NWT) communities led to a number of analyses, workshops and plans for management actions to allow the herd to recover. The WRRB asked for a joint management proposal for the Bathurst herd from the Tłı̨chǫ Government (TG) and Government of the Northwest Territories (GNWT) by the end of October 2009. Because the Bathurst range is large (*ca.* 350,000 km², Figure 2) and takes in portions of Nunavut, NWT and Saskatchewan, management of the herd needs to be coordinated across several jurisdictions and all communities that hunt the herd.
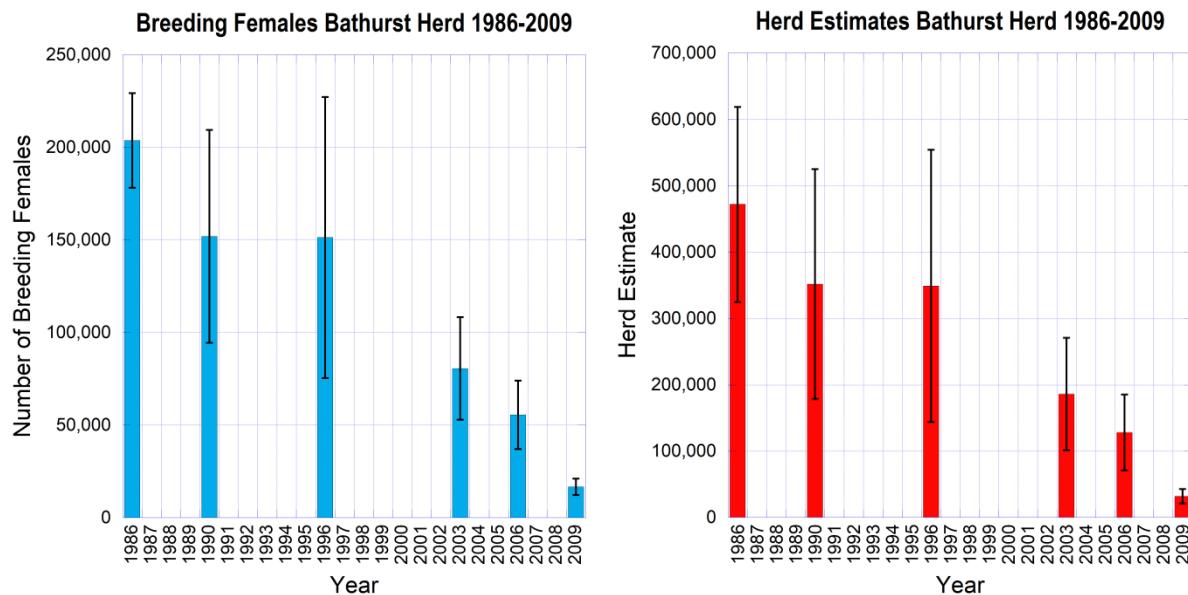
Figure 1. Estimated number of breeding females (left) and population size (right) of the Bathurst Caribou Herd, 1985-2009. All six estimates are based on calving ground photo-surveys. Error bars are 95% confidence intervals.
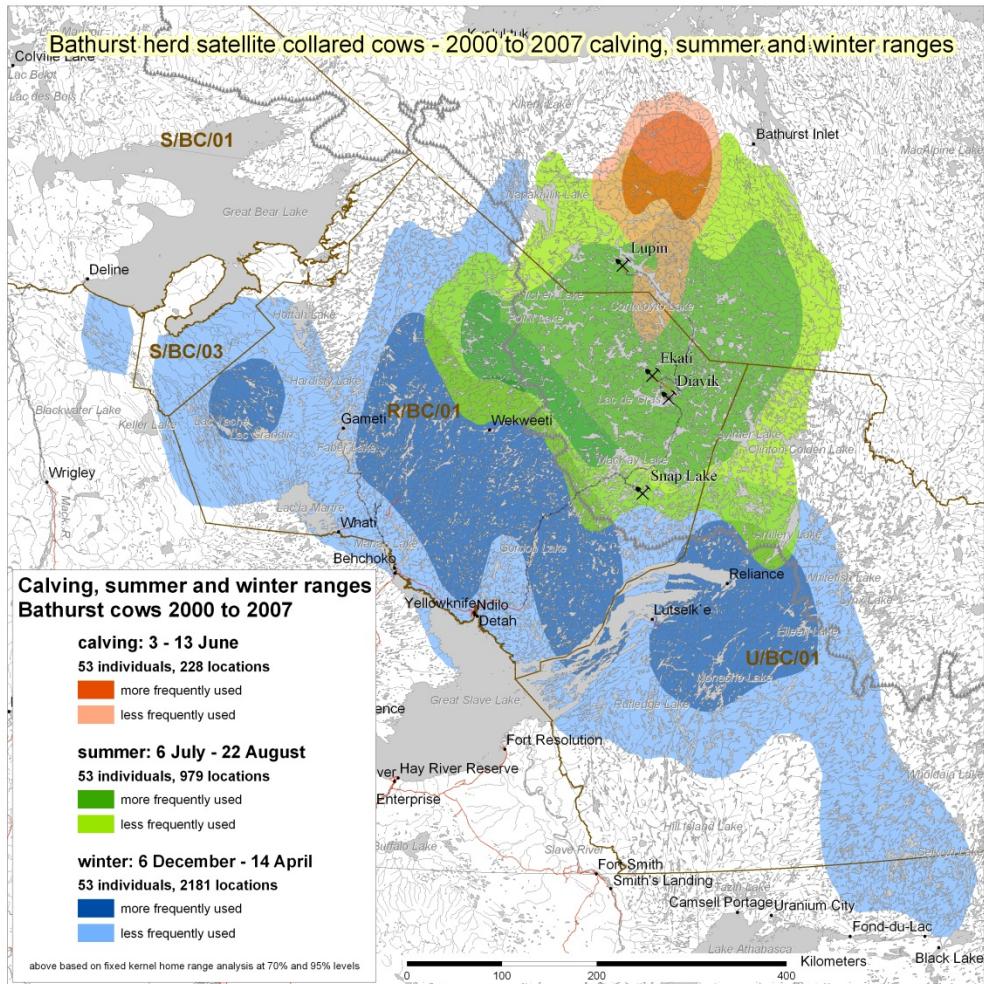
Figure 2. Calving, summer and winter ranges of the Bathurst caribou herd. Seasonal ranges are identified based on satellite collar locations of cows from 2000-2007. Outer polygons are based on 95% kernel contours and the inner ones are based on 70% contours. Winter roads to Gamètì, Wekweètì and the diamond mines at Ekati, Diavik and Snap Lake (active in 2009) are also shown.

As a supporting document for the management proposal to the WRRB, biologists with the GNWT submitted this technical report on the Bathurst decline. A technical meeting was held in Calgary on September 26 and 27, 2009 to review the information and follow-up analyses carried out by statistician and modeller John Boulanger in summer and fall 2009. In addition, a non-technical report on two workshop sessions on the Bathurst decline in Yellowknife on October 1 and 2, and October 5 and 6, 2009 was prepared by Nesbitt and Adamczewski (2013).

A number of graphs and images are common to the technical and non-technical reports. Detailed analyses and methods are included in the technical report, with some detailed material in appendices. To ensure that the report was sound, and interpretations of the data were valid, GNWT asked Don Russell (caribou biologist) and Jason Fisher (Alberta Research Council) to attend the September 2009 meeting in Calgary as outside experts familiar with the GNWT barren-ground caribou program.

The objectives of this report are:

1) To review information on the Bathurst herd decline with emphasis on the accelerated decline 2006-2009, including field observations as well as associated modeling;

2) To evaluate possible explanations for the accelerated decline; and

3) To evaluate the herd's prospects for recovery, using population models and studies of other caribou herds.

This report is a collaboration among several authors. Individual sections written primarily by one or more authors are identified by the person's initials at the beginning of the section.

Management Context for the Bathurst Caribou Herd

Management of the Bathurst caribou herd must take into account the size of the herd's range and the jurisdictions that share this herd. The herd's calving ground is in Nunavut and has been southwest of Bathurst Inlet since 1996 (Gunn et al. 2008a). The summer range is partially in Nunavut and partially in the NWT, much of the fall and winter range is in the NWT, and a portion of the herd has been found south of the 60th parallel in Saskatchewan in some winters (Figure 2). Within the NWT, portions of the herd's summer, fall and winter range lie within Wek'èezhìı, a land claim area established under the Tłı̨chǫ Agreement. The Wek'èezhìı Renewable Resources Board (WRRB) has key responsibilities for wildlife decision-making in Wek'èezhìı. The GNWT has wildlife management responsibilities throughout the NWT, including the responsibility to consult with all Indigenous groups that hunt the Bathurst herd. The Bathurst herd has been hunted by more communities than any other in the NWT. The four Tłı̨chǫ communities (Behchokǫ̀, Whatì, Wekweètì, and Gamètì) are within the herd's winter range. Hunters from Yellowknife, Dettah, N'Dilo and communities south of Great Slave Lake have also hunted the Bathurst herd. In recent winters, access to caribou has increased by winter roads to the Tłı̨chǫ communities Whatì, Wekweètì, and Gamètì, and roads to mines at Discovery, Diavik, Ekati, and Snap Lake.

Figure 3 identifies a sequence of actions and organizations involved in potential management of the Bathurst caribou herd in the NWT, primarily through processes under the Tłıchǫ Agreement. Proposed management may also affect the herds east and west of the Bathurst herd (Ahiak and Bluenose-East). Possible management actions in Nunavut would need to follow appropriate co-management processes in that territory. The expected process in 2009-2010 included the following steps:

1. Development of proposed management actions for the Bathurst herd through information-sharing meetings and workshops in summer and fall 2009.
2. As requested by the WRRB, a joint management proposal to be submitted by the Tłıchǫ Government and GNWT by October 30, 2009.
3. GNWT consultation on the proposal with other groups and Indigenous governments, some of whom do not have settled land claims.
4. WRRB call for a public hearing on total allowable harvest for the Bathurst herd in early 2010. Concerned communities and groups could make presentations as interveners at these hearings.
5. Decisions and recommendations from the WRRB on the herd's management[2].

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[2] Hearings under the WRRB occurred in March and August 2010, and a key outcome was a harvest limit in the NWT of 300 Bathurst caribou and 80% bulls (see WRRB website noted earlier).
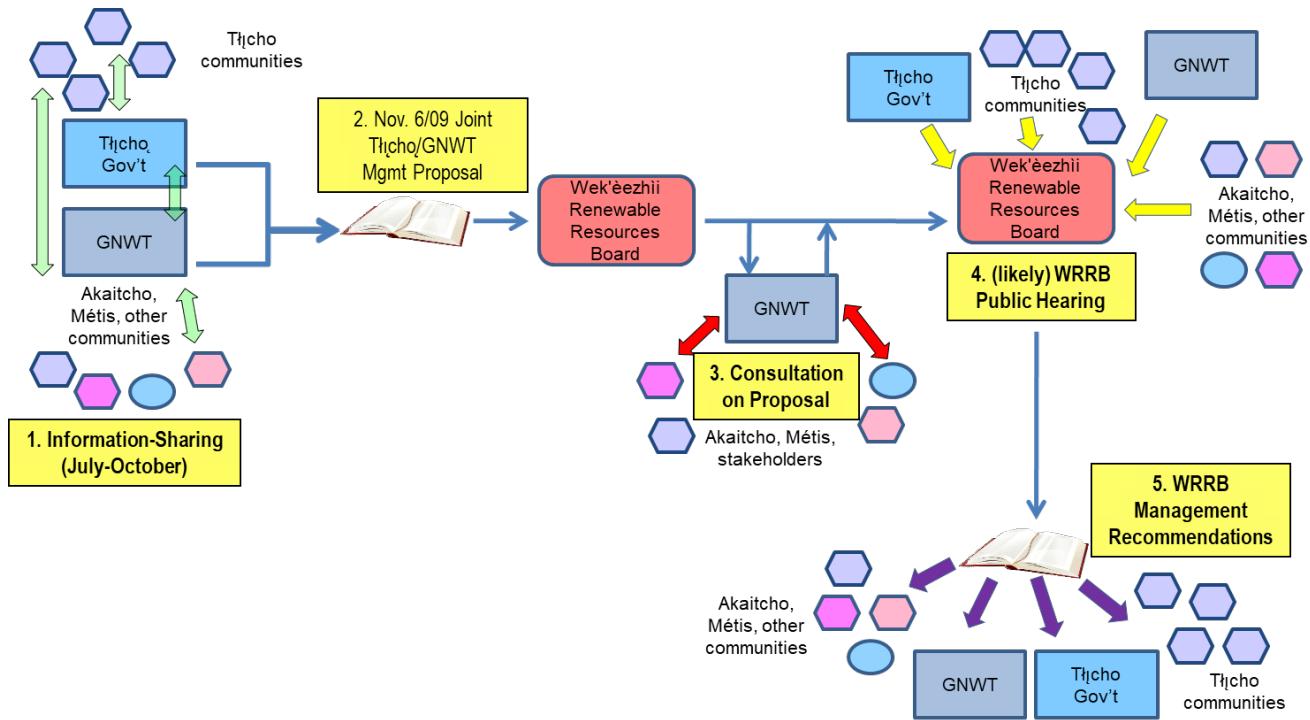
Figure 3. Management context for the Bathurst herd in 2009 in the NWT.

Status of NWT/Nunavut Barren-ground Caribou Herds Monitored by GNWT in 2009

Barren-ground caribou herds in the NWT and Nunavut are defined based on calving grounds to which breeding females return annually in June. The same approach is used throughout North America where these herds occur (Gunn and Miller 1986, Valkenburg et al. 2003, Gunn et al. 2008a). Biologists with the GNWT monitor several of these herds (Figure 4). Each annual range on the map is based on an accumulation of locations from satellite collared cows over time, using the 95% kernel contour to draw the outside boundary. The calving ground for each herd is shown as a solid polygon at the north end of the annual range and is likewise based on satellite collared cow locations. All the herds shown in Figure 4 declined over the period 1985-2008, some more rapidly than others.
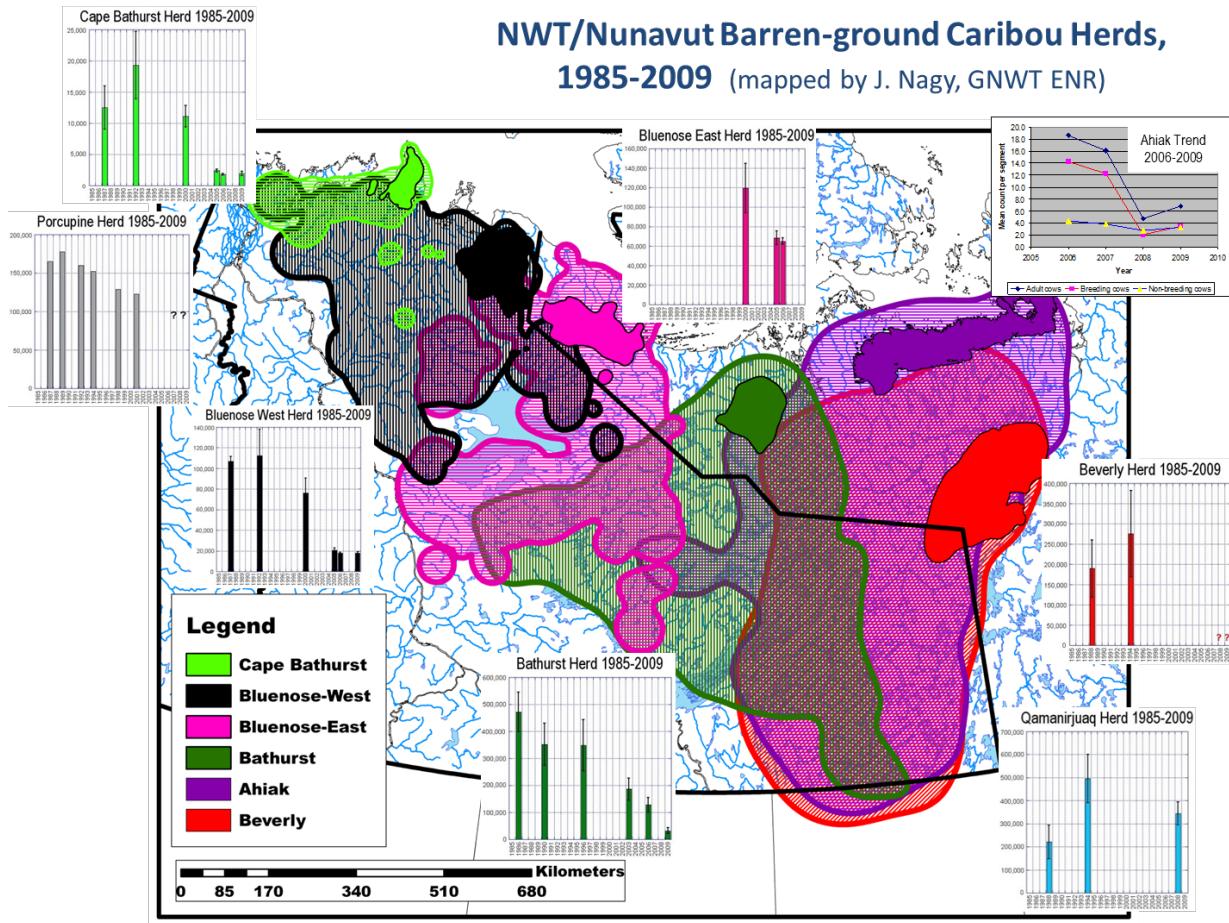
Figure 4. Annual ranges and population status of barren-ground caribou herds monitored by GNWT, 1985-2009. The Porcupine and Qamanirjuaq herds are monitored by Alaska/Yukon and by Government of Nunavut, respectively. These ranges are not shown on the map.

The Porcupine herd's range is not shown on the map. It is found to the west of the mapped area, in northern Yukon and Alaska. This herd was estimated at 178,000 in 1989 and then declined 1989-2003 to about 123,000 (survey information from website of the Porcupine Caribou Management Board, www.taiga.net/pcmb). Alaskan biologists have used post-calving photo surveys to estimate abundance for this herd. These surveys can provide population estimates with high precision (Valkenburg et al.1985, Rivest et al. 1998, Rettie 2017) but require relatively large numbers of satellite collars (Rivest et al. 1998, Rettie 2017) and rely on the caribou forming dense aggregations of hundreds or thousands in response to insect harassment in July. It is these dense aggregations that are photographed and counted. However, caribou may not aggregate sufficiently in cooler or windier weather, preventing photography and the subsequent derivation of a population

estimate. Post-calving surveys were attempted on the Porcupine herd annually from 2003 to 2009 but failed due to unsuitable weather. A population model used for this herd suggested that the herd numbered about 90,000 in 2009 assuming that the slow decline estimated after 1989 had continued though the 2000s[3]. Post-calving surveys have been used in the NWT for the Cape Bathurst, Bluenose-West and Bluenose-East herds (Figure 5).

Figure 5. Post-calving photo surveys used on the Cape Bathurst, Bluenose-West and Bluenose-East herds. Groups of caribou are photographed from a small aircraft, and caribou are counted digitally. A high proportion of caribou (>90%) are found in groups with at least one satellite collar. Large groups usually have several collars. (Photo credit: J. Nagy, ENR).

The Qamanirjuaq herd has been monitored since the creation of Nunavut in 1999 by biologists with the Government of Nunavut. Its range is not shown on Figure 4 and is to the east of the Ahiak range. This herd was estimated from a calving ground photo survey at about 500,000 in 1994 and has remained relatively abundant since that time, although the trend has been a slow decline[4].

The Cape Bathurst herd is one of the smaller barren-ground caribou herds in the NWT. It was estimated at 19,300±5,400 in 1992, and then declined to about 11,100±1,800 in 2000 and 2,430±260 in July 2005 (Nagy and Johnson 2006; Lincoln-Petersen estimates). Because the 2005 survey of this herd showed such a steep decline in five years, it was repeated in 2006 and the decline was confirmed with an even lower estimate (1,820±150;

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[3] Successful surveys of the Porcupine herd in 2010, 2013 and 2017 later showed that the herd had in fact increased after 2003 and reached an all-time high in 2017 of 218,000.

[4] The most recent Qamanirjuaq estimate since then is 288,244±46,123 (95% CI) in 2017 and the trend appeared to be a slow decline (Boulanger et al. 2018a).

Nagy and Johnson 2006). The preliminary estimate for a July 2009 survey of this herd was 1,930±350 (T. Davison, ENR Inuvik Region, pers. comm. October 2009).

The Bluenose-West herd is the Cape Bathurst herd's eastern neighbour and showed a similar population trend over the same period. From a peak herd size estimated at over 112,400±25,600 in 1992, this herd declined to about 76,400±14,300 in 2000, then declined at a higher rate to 20,800±2,040 in 2005 (Nagy and Johnson 2006; Lincoln-Petersen estimates). The low result in 2005 was confirmed a year later with a repeated post-calving survey and an estimate of 18,050±530 caribou (Nagy and Johnson 2006). The preliminary estimate for a July 2009 survey of this herd was 17,900±1,300 (T. Davison, ENR Inuvik Region, pers. comm. October 2009). The Cape Bathurst and Bluenose-West herds were in 2009 the only herds in Figure 4 with a stable trend[5]; all other herds showed a declining trend.

Population estimates for the Cape Bathurst and Bluenose-West herds from 2000 on are based on individual surveys for each herd. Previous post-calving surveys of the Bluenose herd in 1986, 1987 and 1992 were based on a single "Bluenose" herd. Population estimates for these two herds prior to 2000 are based on re-analyses of the earlier combined Bluenose herds, as described by Nagy (2009b).

Population estimates for the Bluenose-East herd were not available before 2000, when this herd was estimated at 119,600±25,400 (Nagy 2009; Lincoln-Petersen estimates). Like its western neighbours, this herd declined steeply to an estimated 70,100±8,100 in 2005 and 66,800±5,200 in 2006 (Nagy and Tracz 2005, 2006). The 2006 survey and estimate were repetitions of the survey and estimate a year earlier. A post-calving survey was attempted for this herd in July 2009 but failed because of cool weather and insufficient aggregation by caribou[6].

The Bathurst herd was estimated at 472,000±72,900 in 1986, was stable or declined slowly through the 1990s and then at a higher rate in the 2000s (Gunn et al. 2008a). The June 2009 calving photos survey resulted in an estimate of 16,649±4,460 breeding females (±95% Confidence Interval, CI) and a population estimate of 31,980±10,853, a decline of 70% in three years. Key steps in the calving photo survey in June 2009 are shown in Figure 6.

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[5] Further post-calving surveys of the Cape Bathurst and Bluenose-West herds showed that these herds were roughly stable 2006-2018, with the Cape Bathurst showing a modest increase 2015-2018 (Boulanger et al. 2018b, T. Davison unpublished data 2018). A transition was also made from using Lincoln-Petersen estimates of herd size from post-calving surveys to Rivest estimates (Boulanger et al. 2018b).

[6] In 2010, both a calving ground photo survey and a post-calving photo survey were carried out for the Bluenose-East herd after a number of attempted post-calving surveys of this herd failed due to weather and lack of aggregation (Adamczewski et al. 2017). Calving ground photo surveys in 2013, 2015 and 2018 showed a continuing decline in this herd (Boulanger et al. 2019).
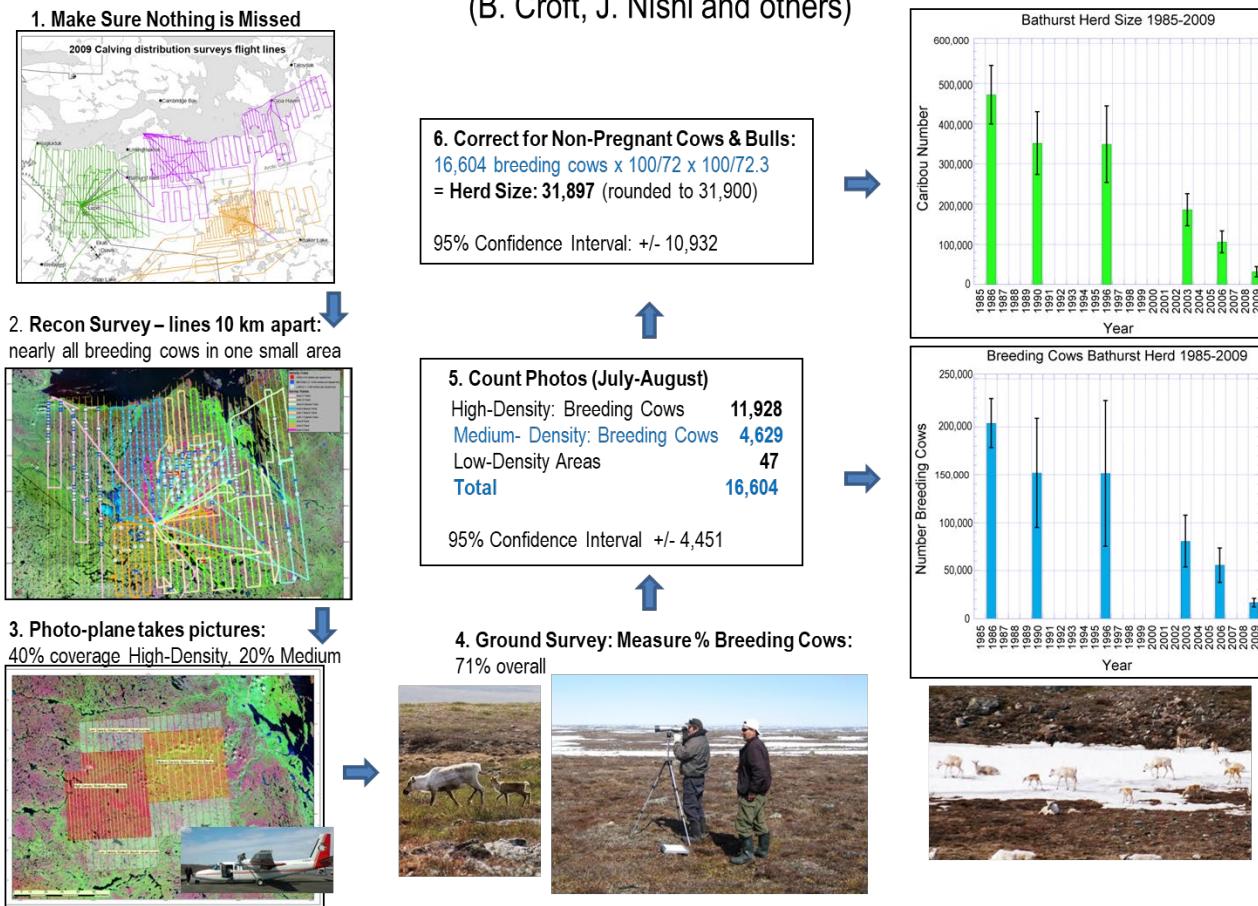
Figure 6. Key steps in the June 2009 Bathurst calving ground photo survey. Reconnaissance flight lines covered an area much larger than the actual calving ground, spanned Bathurst Inlet to the western end of the Ahiak calving ground and spanned an area to the west where the Bluenose-East calving ground would begin. The photo-plane took photos over 40% of the high-density area and 20% of the medium-density area. Less than 2% of the cows were counted visually on low-density areas. Extrapolation to overall herd size used a fall 2008 sex ratio of 38 bulls:100 cows.

To the east of the Bathurst range, the Ahiak herd has had generally less monitoring than other NWT herds, in part due to its remote range and in part because it is rarely accessible to NWT hunters. In recent years, satellite collars showed cows that calve on this elongated east-west calving ground south of the Queen Maud Gulf have a long north-south migration that takes some cows as far south as Saskatchewan. Preliminary analysis of satellite collar locations by J. Nagy showed collared cows that use the more easterly end of the Queen Maud Gulf area are tundra-wintering and have a pattern of movement somewhat different from that of the cows using the more westerly portion of the Queen Maud Gulf. A

population survey of the caribou in the Queen Maud Gulf area was planned as a cooperative effort between Nunavut and NWT biologists for June 2011[7]. Figure 4 includes a graph showing the average number of cows seen per 10 km transect on calving reconnaissance surveys from 2006 to 2009; this shows a strong downward trend over this four-year period (see population trend in the Ahiak herd).

The calving ground shown for the Beverly herd in Figure 4 is based on the traditional inland calving ground south of Garry Lakes defined by the Beverly and Qamanirjuaq Caribou Management Board, which was defined from previous surveys rather than satellite collar locations. Satellite collar locations for Beverly cows were limited, in part because community approval for satellite collars on this herd was not secured until 2006. In addition, calving reconnaissance surveys in 2002, 2007, 2008 and 2009 documented a decline of about 99% in numbers of caribou cows using this calving ground in June. The most rapid decline occurred between 2002 and 2007. Satellite collar locations of cows known to use the Beverly calving ground in June indicated that a few had switched from the Beverly to the Ahiak calving grounds, and outside of the calving period, the Beverly satellite collared cows do not appear to have distinct seasonal ranges. Mortality rates of the few Beverly collared cows in 2006-2009 have been exceptionally high. In June 2008, the calf:cow ratio near the peak of calving was 15 calves:100 cows, where calf:cow ratios would normally be 60-80 calves:100 cows at that time of year[8]. As a result, the Beverly range shown in Figure 4 is nearly the same as the Ahiak range. This is an exceptional situation with (to our knowledge) no precedent in Canadian technical studies of barren-ground caribou.

Calving and Post-Calving Surveys of Barren-ground Caribou in the NWT

GNWT biologists have used post-calving photo surveys for the more western barren-ground caribou herds (Cape Bathurst, Bluenose-West and Bluenose-East) and calving photo surveys for the more eastern herds (Bathurst and Beverly) since the 1980s. Nunavut government biologists have used calving ground photo surveys for the Qamanirjuaq herd. Both methods have some advantages and some disadvantages.

Post-calving photo surveys provide estimates of total herd size as cows and bulls are counted. These surveys require relatively large numbers of satellite collars because the collars are the primary cue to locations of caribou groups. A few additional groups of caribou without collars are usually found near groups that have collars, but usually well

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[7] Results of a large-scale survey of caribou in the Queen Maud Gulf region and regions to the east in June 2011 were described by Campbell et al. (2012).

[8] Calf-cow ratios, collar movements and related information were summarized by Adamczewski et al. (2015).

over 90% of the caribou found are in large groups with one or more collars. Re-analysis of 2006 GNWT post-calving surveys by Rettie (2017) suggested that satellite collar numbers for the Cape Bathurst, Bluenose-West and Bluenose-East surveys were sufficient in 2006, and he suggested that 2009 surveys of these herds should use 30, 60 and 40-60 collars, respectively, for these three herds. These recommendations were met or exceeded for all three herds in 2009. Post-calving surveys can provide population estimates with high precision, where nearly every adult caribou in the herd is counted from photographs (Valkenburg et al. 1985, Rettie 2017, Nagy 2009). However, photography may not be possible if the weather is cool and biting flies are not active enough to lead to dense aggregations of caribou, as in the Bluenose-East herd in 2009 and the Porcupine herd 2003-2009. In addition, large numbers of satellite collars are expensive to purchase, deploy and acquire locations from. There has been continuing opposition to the use of satellite collars in some northern Indigenous communities, based on concerns over the effects of the collars on caribou and concerns that handling animals is disrespectful to them. As a result, there have never been more than 20 satellite collars on the Bathurst herd[9] and approval for satellite collars on the Beverly herd was not obtained in Nunavut until 2006. A reliable post-calving survey of the Bathurst herd would not be feasible with less than 20 collars.

Calving ground photo-surveys in the NWT estimate the number of breeding cows on the calving grounds (Heard 1985). These surveys have generally been less vulnerable to weather, although the photo-plane does require one to two days of good weather in June as it flies at about 2,000 feet. In the 1980s, calving ground photo-surveys were carried out on the eastern Canadian herds with no satellite collars, as the reliability of breeding cows returning to calving grounds was high. However, exceptional spring weather may delay cows from reaching their normal calving grounds. In 2001 the Porcupine caribou cows calved far south of their usual coastal calving grounds (Griffith et al. 2002) and very few cows were on the normal calving grounds that June. Satellite collars allowed biologists to monitor the herd's movements and the unusual calving patterns that year. Without satellite collars, a calving ground with far fewer caribou than expected might be difficult to interpret. On Bathurst calving photo-surveys in the 1990s and 2000s, even the relatively low numbers of satellite collars used (10-20) provided some assurance that most of the herd's cows were part of the survey, as a high proportion during every June survey were in the higher-density areas on the calving grounds. Because some of the non-pregnant cows and nearly all the bulls are not on the calving grounds, the survey estimates number of breeding females and an extrapolation to overall herd size is needed (see field data from the June 2009 calving ground survey for calculations). There has been some concern with

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[9] In 2015, with the agreement of the Tłı̨chǫ Government, maximum collar numbers on the Bathurst herd were increased to 30 cows and 20 bulls. In 2019 maximum collar numbers were increased further to 50 cows and 20 bulls.

this extrapolation among some biologists (e.g. Thomas 1998) as it does tend to increase the variance or confidence interval around the population estimate.

A direct comparison of the post-calving and calving photo surveys was carried out with paired surveys of the George River herd in Quebec/Labrador in 1994 (Couturier et al. 1996). The population estimates in that case were very similar, providing some confidence that the two survey methods were fundamentally sound[10].

Barren-ground Caribou: Global Status and Population Cycles

On a global scale, caribou and reindeer populations across their range in North America, Europe, and Russia showed a largely declining trend in 2009 (Vors and Boyce 2009; Figure 7[11]). Of 58 caribou and reindeer populations, 34 were reported as declining, 8 were increasing, and for 16 there were no data or trend was uncertain (Vors and Boyce 2009). A few of the populations in Figure 7 are boreal woodland caribou in Canada and summations of multiple herds in Newfoundland, Norway and Sweden. The ecology of Scandinavian reindeer and Newfoundland caribou, with essentially no wolves, differs from that of most Canadian migratory caribou herds. However, most of the larger Russian, Alaskan and Canadian migratory caribou and reindeer herds were declining, even though monitoring, management of caribou and management of predators differ widely across this vast northern landscape. Vors and Boyce (2009) suggested that climate change and weather patterns are most likely the main drivers in the current declines. Generalization about caribou and reindeer herds must be done with caution, though, as there are exceptions, and conditions for individual herds may be unique. In Quebec/Labrador, the George River herd had been declining since the early 1990s, but its neighbour the Leaf River herd had initially increased over the same period (Bergerud et al. 2008). In Alaska the Porcupine and Western Arctic herds were declining while the Central Arctic and Teshekpuk herds were increasing. Overall, however, the declining trend in barren-ground caribou herds in NWT and Nunavut was consistent with a strong trend toward declines in migratory caribou and reindeer across their range in Canada, Alaska, Russia and Scandinavia.

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[10] A comparison of the post-calving and calving ground photographic surveys was later carried out by GNWT in 2010 for the Bluenose-East herd; although the surveys are quite different, similar population estimates resulted (Adamczewski et al. 2017). The extrapolation calculations from calving ground surveys have evolved, as detailed in this paper.

[11] The review by Vors and Boyce was published in 2009 but the overall trend of caribou and reindeer declines they documented has largely continued to 2020.
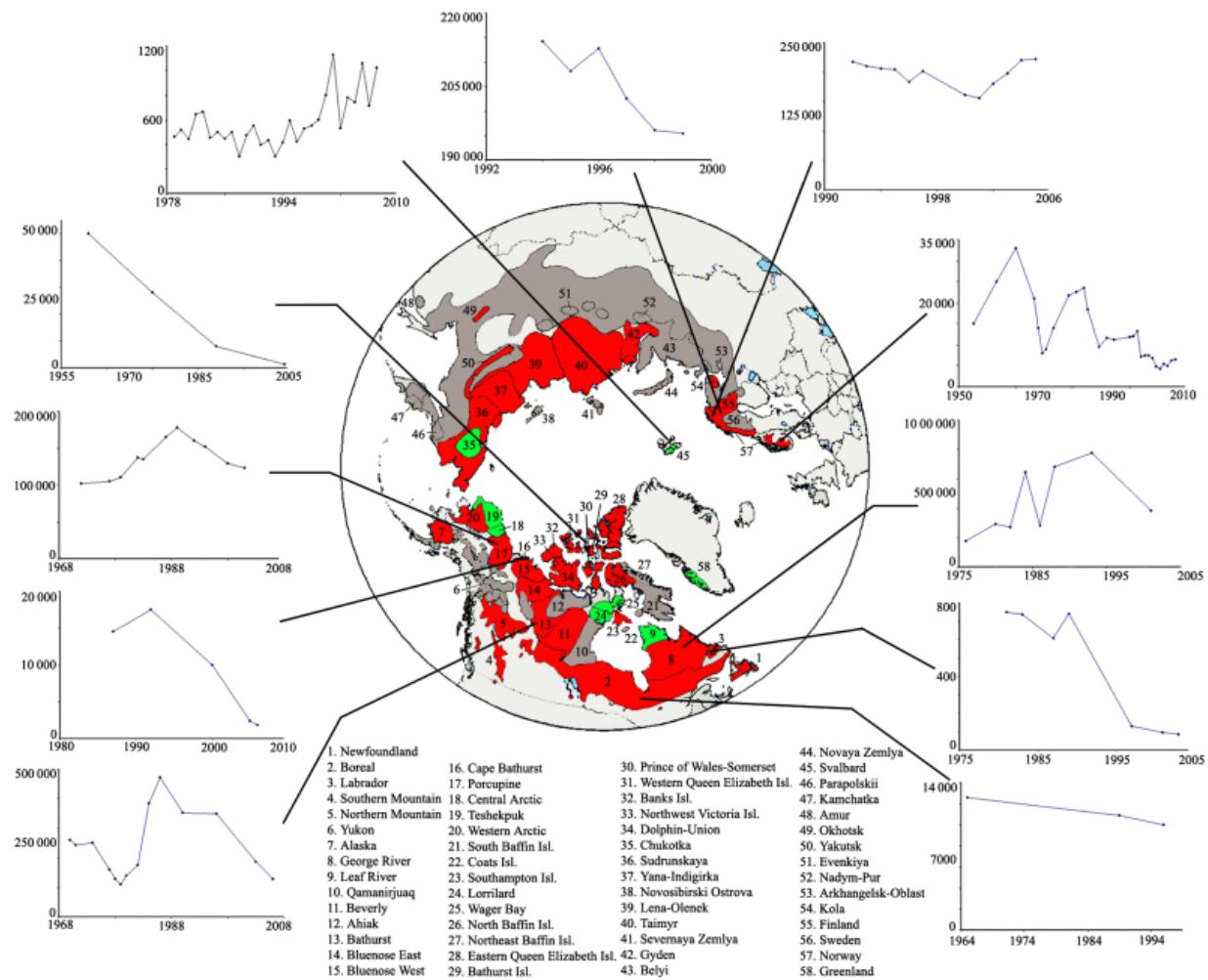
Figure 7. Population trajectories of 58 major caribou and reindeer herds worldwide. Herd ranges depicted in red are in population decline and ranges depicted in green are experiencing population growth. Population data are unavailable or uncertain for herd ranges illustrated in grey. Time series of population estimates for 11 caribou and reindeer populations are included to illustrate historical fluctuations in population size. The x-axis represents year of population estimate and the y-axis represents estimate of population size. (From Vors and Boyce. 2009. Global declines of caribou and reindeer, Global Change Biology 15: 2626-2633, with permission).

Traditional knowledge (TK) of Indigenous people in the NWT and studies by biologists have demonstrated that barren-ground caribou have fluctuated widely over time, going back hundreds and possibly thousands of years. A re-construction of a cycle in caribou numbers from D. Beaulieu's family and Chipewyan elders showed peaks and troughs every 30 years (Figure 8). The peaks occurred in years when caribou were very numerous near

Rocher River (southwest of Great Slave Lake, near the Taltson River)[12]. During the low periods in caribou numbers, hunters from Rocher River had to travel long distances to find caribou. Although the peaks have occurred on a 30-year interval, successive peaks have been lower and lower, possibly due to increased hunting and cumulative effects of development.
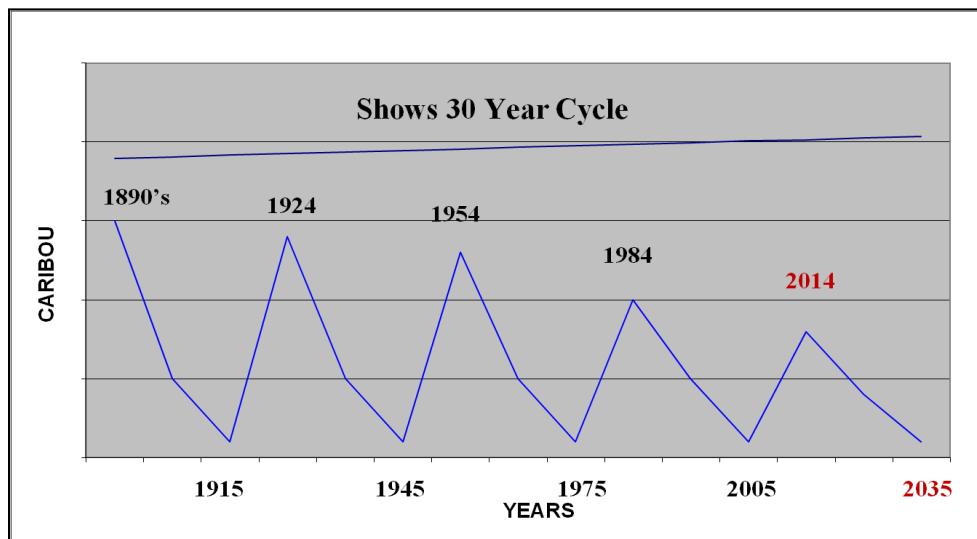
Figure 8. Cycles in caribou numbers over time based on traditional knowledge of Chipewyan elders and several generations of D. Beaulieu's family. (From D. Beaulieu, ENR, Yellowknife; later revised and published as Beaulieu 2012).

Long-time caribou biologist Tom Bergerud re-constructed a 200-year history for the George River herd in Quebec/Labrador from a number of sources (Figure 9). Some of the information was from Innu and Inuit oral history, including records of hunting at river crossings where people traditionally hunted caribou, and periods when people starved. In addition, biologists used scars on black spruce tree roots from caribou migration trails (Morneau and Payette 2000), calibrated against known population size for the George River herd from aerial surveys 1960-2000. The re-construction shows that population highs were sometimes separated by prolonged low periods, intervals between lows and highs varied in length, and successive peaks and lows sometimes fell increasingly lower.

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[12] This study was later published as Beaulieu (2012).
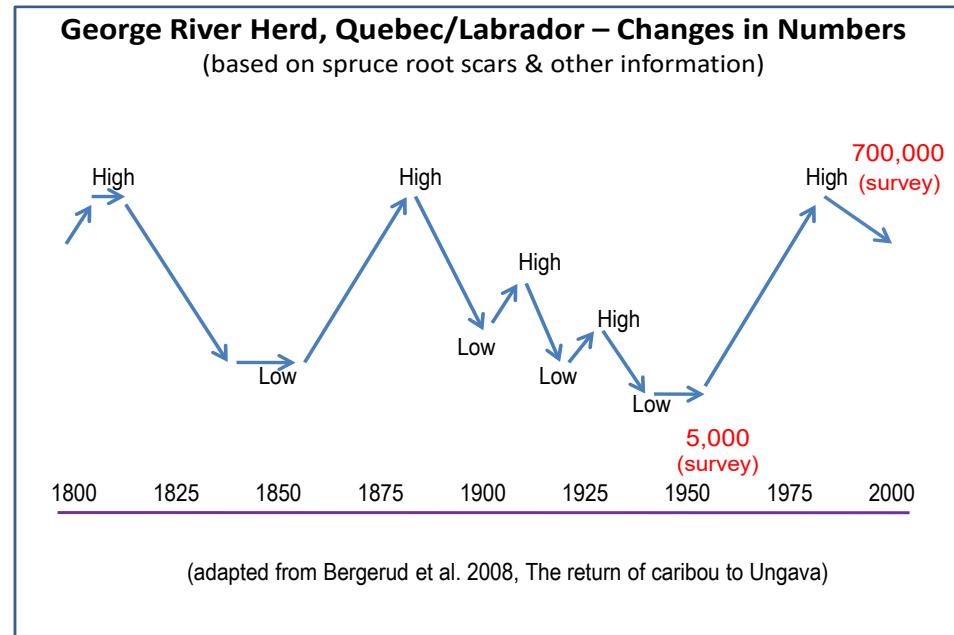
Figure 9. A 200-year re-construction of approximate abundance in the George River herd in Quebec/Labrador. Adapted from Bergerud, A. T., S. N. Luttich, and L. Camps. 2008. The return of caribou to Ungava. McGill-Queen's University Press, Montreal and Kingston, Ontario.

In an application of the spruce root scar method pioneered in Québec/Labrador (Morneau and Payette 1998, 2000), Zalatan et al. (2006) compared spruce root scars and Tłįchǫ elders' knowledge of Bathurst caribou abundance over a period from 1920-1980 (Figure 10). The spruce root scars and Tłįchǫ elders' knowledge both suggested a peak in caribou numbers in the 1940s. The spruce scar analyses detected the decline in the 1990s recorded from population surveys but suggested that the population peak may have occurred a few years before the peak population estimate from aerial surveys.
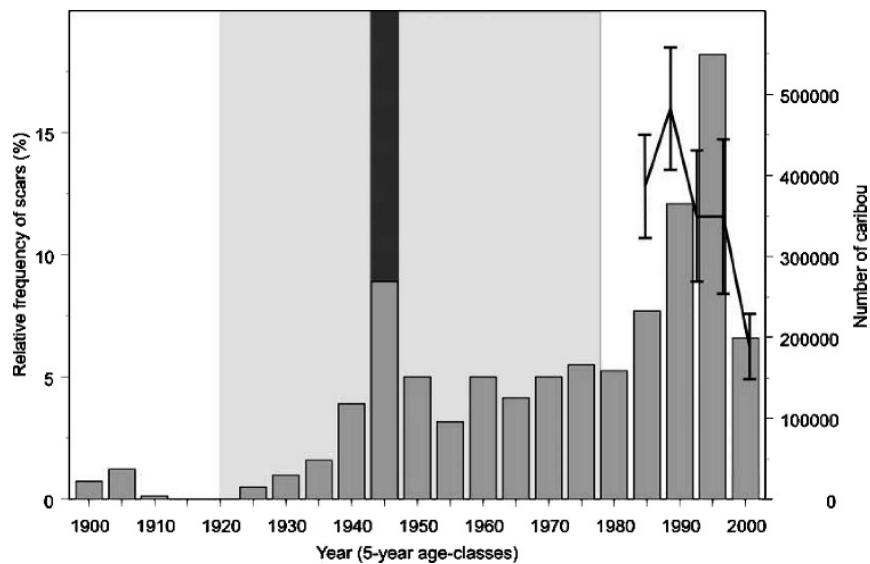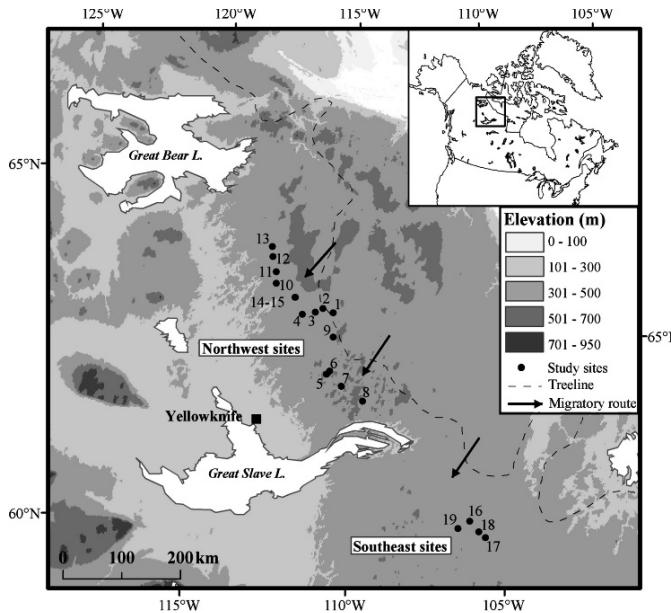
Figure 10. Locations of sampling sites in the summer/fall ranges of the Bathurst and Beverly herds (top) and spruce root scar frequency by year for the period 1900-2000 for the Bathurst range (bottom). The light grey period from 1920-1980 is the period over which Tłı̨chǫ elders provided their knowledge of Bathurst caribou abundance (from Zalatan et al. 2006).

In summary, the declining trend of the Bathurst herd, like those of other herds in NWT/Nunavut, is consistent with a global declining trend in most migratory caribou and reindeer herds. Large increases and decreases in numbers of Bathurst caribou and other herds have occurred in the past, based on TK, spruce root scars on caribou migration trails, and in the last 40 years, from aerial surveys. These fluctuations are most likely driven by

weather at a large scale, although the relationships are complex (Gunn 2003). Variation among neighbouring herds has occurred, though, including sometimes opposite trends, thus explanations for declines in particular herds must consider each herd's individual conditions.

LIKELIHOOD OF LARGE-SCALE EMIGRATION FROM THE BATHURST HERD (JB)

When biologists report that a caribou herd has declined, a question that is often asked is whether the missing caribou could have gone somewhere else. We addressed this question for the Bathurst decline by looking at satellite collar movements between the Bathurst herd and its neighbours to the east (Ahiak herd) and west (Bluenose-East herd), by evaluating population trend in these neighbouring herds, and by a brief review of the published literature of rates of switching among neighbouring barren-ground caribou herds. A brief review of caribou surveys flown in 2007, 2008 and 2009 suggests that there is little likelihood of the "missing" Bathurst caribou having been overlooked.

Satellite Collar Movements between Herds

Collared caribou from the Bathurst, Ahiak, and Bluenose-East herd have been monitored since the late 1990s; monitoring included tracking the calving grounds used every year by collared cows. Bull caribou have been satellite collared in the Bluenose-East herd (also in the Bluenose-West and Cape Bathurst herds), but most collars have been on cows and only data from cows were considered here. We used this data set to assess the rate of movements between calving grounds for the Bathurst, Ahiak, and Bluenose-East caribou herds. Although the satellite collars are used for various purposes by biologists and managers, they are not specifically intended to measure emigration or immigration. In mammals, emigration (and therefore immigration) most often occurs in juveniles, especially young males. A full discussion of emigration is beyond the scope of this report. However, adult cows almost invariably make up half or more of a barren-ground caribou herd and they are a high proportion of the caribou found on the calving ground in June. If the reduction in numbers of breeding cows on the Bathurst calving ground is to be explained, then the cows are the appropriate segment of the herd to investigate. We should expect some of the satellite collared cows to switch ranges if a substantial proportion of the herd's cows switch ranges.

To build the data set for the analyses, we classified each collared caribou from the Bathurst, Ahiak, and Bluenose-East herds in terms of which calving ground they occupied each year. The resulting data set contained 153 caribou. The actual number of caribou tracked varied yearly and by herd as shown in Figure 11.
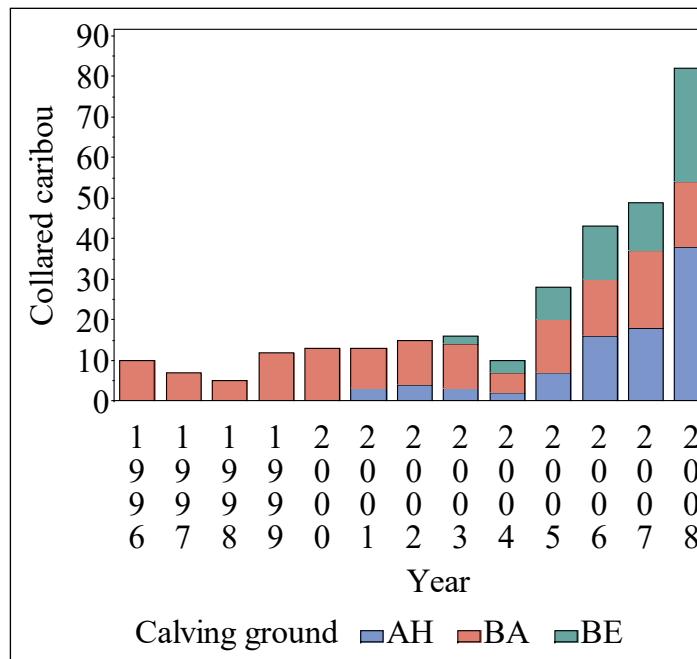
Figure 11. Yearly sample sizes of adult cow collared caribou used in the multi-strata analysis, from the Ahiak, Bathurst and Bluenose-East herds.

Of the 153 caribou, four occurred on both the Ahiak and Bathurst calving grounds in subsequent years, and three occurred on both the Bathurst and Bluenose-East calving grounds (4.5% of the total). In other words, 95.5% of the collared cows used only one calving ground in the time period monitored. No caribou occurred on both the Bluenose-East and Ahiak calving grounds.

We were further interested to determine if there was net movement between calving grounds, or if movement between calving grounds was random and non-directional so it could be assumed that the rate of movement from a calving ground (emigration) was equal to the rate of movement into a calving ground (immigration).

It is important to note that the caribou used in this analysis were mostly young or middle-aged cows and were not collared on the calving grounds. Because of the fidelity of collared cows to calving grounds, we believe most of these cows were born on the same calving grounds. Assessing life-long fidelity of caribou cows to calving grounds would require tracking them from birth through adult life. This analysis is limited to estimating yearly rates of movement between calving grounds. In addition, we assume similar rates of movement between age classes given that no age-class data were available to estimate age-specific yearly movement rates.

The question of movement between populations or areas has been addressed extensively as part of mark-recapture analyses of other wildlife species. In particular, multi-strata models (Hestbeck et al. 1991, Brownie et al. 1993) estimate emigration and immigration rates from different areas, which for this analysis of barren-ground caribou movements are calving grounds. Data for a multi-strata model are entered as a yearly encounter history with a caribou defined by the calving ground it was observed on in June that year. For example, if caribou #100 was seen in the Bathurst herd calving ground in 2000 but on the Ahiak in 2001, was not detected in 2002, and then detected in 2002 on the Bathurst calving ground, then the data in the model would be entered as BA0B, where B denotes Bathurst herd and A denotes Ahiak herd and 0 denotes not observed. The model then uses this sequence to estimate the probability that a caribou that is on the Bathurst calving ground one year will be on the Ahiak calving ground the following year, and vice versa. This is analogous to estimating emigration/immigration rates between herds.

Multi strata models estimate rates of movement (termed transition probabilities) between calving grounds, yearly survival, and recapture rate. Yearly survival was not of interest in this analysis and we assumed that capture probability was 1. Namely, a caribou that had a collar had a probability of detection of 1 on the calving ground. Assumptions about herd-specific survival can affect movement estimates and so we considered models that considered herd-specific and pooled survival rates. As part of program MARK (White and Burnham 1999), it was also possible to constrain multi-strata models to test particular hypotheses about movement between calving grounds. In particular, we were interested in knowing whether there was net emigration from the Bathurst calving ground. If emigration rates from the Bathurst herd were distinctly different (larger) than immigration rates, then we would expect that the net collar movement away from the Bathurst calving ground would be greater than the immigration rate. There was no documented movement between the Ahiak and Bluenose-East herds and therefore movement rates between these two herds were fixed at 0.

The fit of models was evaluated using the Akaike Information Criteria (AIC) index of model fit. The model with the lowest AIC_c[13] score was considered the most parsimonious, thus minimizing estimate bias and optimizing precision (Burnham and Anderson 1998). The difference in AIC_c values between the most supported model and other models (ΔAIC_c) was also used to evaluate the fit of models when their AIC_c scores were close. In general, any model with a ΔAIC_c score of <2 was worthy of consideration or plausible.

Model selection results suggested there was no detectable difference between emigration and immigration rates for the Bathurst-Ahiak or Bathurst-Bluenose-East (Table 1, model 1). A model that assumed similar emigration rates of caribou from the Bathurst to

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[13] The subscript "c" indicates an AIC score that is corrected for small sample sizes.

the Bluenose-East and Ahiak herds, and equal immigration from the Ahiak and Bluenose-East herds to the Bathurst herd, was also marginally supported (Model 2).

Table 1. Model selection results for multi-strata model analysis of movements between the Ahiak, Bathurst, and Bluenose-East herds. Sample-size adjusted Akaike Information Criteria (AIC$_c$), difference in AIC$_c$ between most supported and given model (ΔAIC$_c$), Akaike weight (w_i), the number of parameters (K), effective sample size (ESS), and deviance (an index of model fit) are given. Movement rates were estimated for the Bathurst-Ahiak and Bathurst-Bluenose-East, but not the Bluenose-East-Ahiak. Herds are symbolized by Bathurst (B), Ahiak (A), and Bluenose-East (E). Movement rates are symbolized by the ordering of herds. For example, BA symbolizes movements from the Bathurst to the Ahiak.

Model No.	Survival	Movement	AIC$_c$	ΔAIC$_c$	w_i	K	Deviance
1	pooled	BA=BE=EB=AB	10127.9	0.00	0.48	2	9810.7
2	pooled	BA=BE, EB=AB	10130.0	2.01	0.18	3	9810.7
3	herd	BA=BE=EB=AB	10131.0	3.10	0.10	4	9809.7
4	pooled	BA=BE,EB,AB	10131.1	3.12	0.10	4	9809.7
5	pooled	BA,BE, EB=AB	10131.8	3.86	0.07	4	9810.5
6	pooled	BA=BE, EB=AB	10132.9	4.98	0.04	5	9809.5
7	pooled	BA, BE, EB,AB	10134.2	6.27	0.02	6	9808.7

These results are best interpreted by looking at model-averaged estimates of movement which suggested that both emigration and immigration rates were about 0.03 (or 3%) for the Bathurst herd to the Bluenose-East and Ahiak calving grounds, with about equal movement rates in both directions (Figure 12).
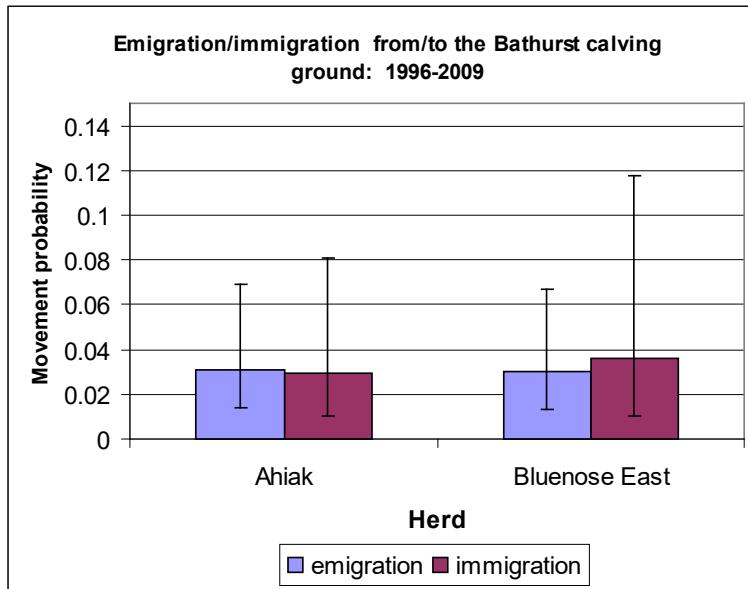
Figure 12. Model averaged estimates of emigration from the Bathurst calving ground and immigration to the Bathurst calving ground from the Ahiak and Bluenose-East calving grounds, 1996-2009.

Model averaged estimates suggest that emigration and immigration rates were low and similar, especially when the confidence limits on the estimates are considered. These estimates should be interpreted as the probability that a caribou on the Bathurst calving ground would switch to the Ahiak (emigrate) or the probability that a caribou on the Ahiak calving ground would switch (immigrate) to the Bathurst calving ground. These results suggest there was little or no net movement of caribou to or from the Bathurst herd calving ground to the Ahiak or Bluenose-East calving grounds.

We also evaluated whether movements between these three herds may have been greater in the past three years (rapid Bathurst decline 2006-2009) than in earlier years. During this three-year period, there were more collared caribou in the Ahiak and Bluenose-East herds, but the Bathurst collar numbers changed little. We therefore did an analysis that only considered data from 2006 to 2009. This analysis included 101 collared caribou. Of these, two were observed on both the Bathurst and Bluenose-East calving grounds, and four were observed on the Bathurst and Ahiak calving grounds. In other words, 94% of the cows were recorded on only one calving ground.

For this analysis a model that suggested similar emigration rates of caribou from the Bathurst to other herds, and similar immigration rates into the Bathurst from other herds was most supported (Table 2). This model was tied in terms of support (as indicated by ΔAIC_c values of <2) with a model that assumed that immigration equalled emigration (model 2), and a model that had unique emigration rates from the Bathurst but equal immigration rates (model 3).

Table 2. Model selection results for multi-strata model analysis of movements between the Ahiak, Bathurst, and Bluenose-East herds 2006-2009. Sample-size adjusted Akaike Information Criteria (AIC$_c$), difference in AIC$_c$ between most supported and given model (ΔAIC$_c$), Akaike weight (w$_i$), the number of parameters (K), effective sample size (ESS), and deviance (an index of model fit) are given. Herds are abbreviated as Bathurst (B), Ahiak(A) and Bluenose-East (E). Movement is denoted by order of herd abbreviations. For example, BE denotes movement of Bathurst to Bluenose-East and EB denotes movement of Bluenose-East to Bathurst.

Model No.	Survival	Movement	AIC$_c$	ΔAIC$_c$	w$_i$	K	Deviance
1	pooled	BA=BE, EB=AB	7,185.32	0.00	0.318	3	6,959.8
2	pooled	BA=BE=EB=AB	7,185.66	0.34	0.268	2	6,962.2
3	pooled	BA,BE, EB=AB	7,187.21	1.89	0.123	4	6,959.6
4	pooled	BA=BE,EB,AB	7,187.33	2.01	0.116	4	6,959.7
5	herd	BA=BE, EB=AB	7,189.09	3.77	0.048	5	6,959.3
6	pooled	BA, BE, EB,AB	7,189.25	3.93	0.045	5	6,959.5
7	herd	BA=BE=EB=AB	7,189.38	4.07	0.042	4	6,961.7
8	herd	BA,BE, EB=AB	7,191.03	5.71	0.018	6	6,959.1
9	pooled	BA, BE, EB,AB	7,191.39	6.08	0.015	6	6,959.5
10	herd	BA, BE, EB,AB	7,193.12	7.80	0.006	7	6,959.0

Inspection of model-average estimates suggests that emigration rates were slightly higher than immigration rates. However, overall immigration and emigration rates were relatively low, and based on a smaller sample due to the shorter time period (Figure 13). From a statistical point of view, it is not possible to conclude that emigration rates do not equal immigration rates given the overlap of confidence intervals of the immigration and emigration rates, and the support of model 2 which assumes equal immigration and emigration rates.
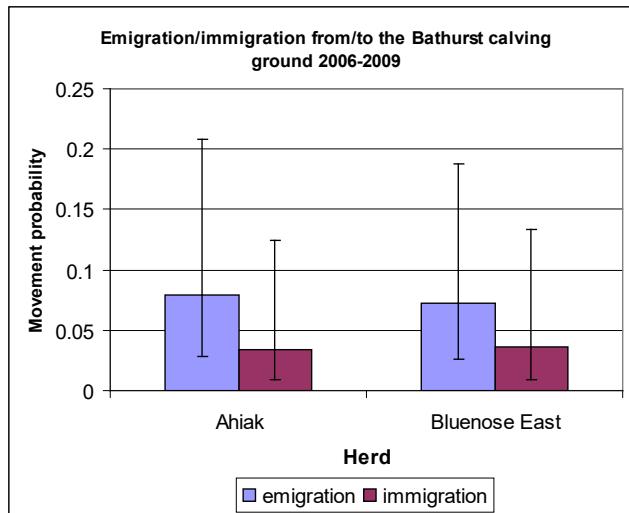
Figure 13. Model averaged estimates of emigration from the Bathurst herd and immigration into the Bathurst herd calving ground from the Ahiak and Bluenose-East caribou herds from 2006-2009.

In conclusion, data from collared caribou demonstrate there was some yearly movement between calving grounds with overall rates being low. Analysis of recent data suggests emigration rates are slightly higher than immigration rates; however, this difference is not statistically significant. Results from this analysis should be treated cautiously given the lower sample sizes of collared caribou used for estimates.

Population Trend in the Ahiak Herd

Reconnaissance surveys on the Ahiak[14] calving ground were carried out in 2006, 2007, 2008 and 2009, over the same period of the recent Bathurst decline (D. Johnson and A. Kelly, ENR unpublished data). The methods for these surveys were the same each year and involved visual counts within a defined transect flown at 400 feet above ground. These surveys do not provide a precise population estimate, but when done consistently, can give a clear indication of trend.

Preliminary analysis of the average number of caribou seen per 10 km survey segment on the Ahiak surveys suggests that the number of cows on the Ahiak calving ground in

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[14] At the time this report was written in 2009, caribou calving in the Queen Maud Gulf area were generally referred to as the Ahiak herd (Gunn et al. 2000), and we have retained that name in this report. In subsequent years there was evidence of collared cows that used the old inland Beverly calving grounds south of Garry Lakes and switched to the coastal Queen Maud Gulf calving grounds (2006-2009). Readers may want to refer to Nagy et al. (2011) and Adamczewski et al. (2015) for alternative explanations of these movements and how they affect more recent herd designations in this region.

2009 was about 40% of the number in 2006 (Figures 14 and 15). A substantial decline in Ahiak caribou from 2006 to 2009 makes it rather unlikely that there was a large movement of Bathurst caribou to the Ahiak range over this period.

The cause of the apparent Ahiak decline is not clear. An initial study of body condition in Ahiak cows in February 2009 (A. Kelly, ENR unpublished data) suggested that the caribou in this herd were leaner than Bathurst caribou assessed in March 2008, but pregnancy rates were normal. Of 28 caribou satellite collared in April 2008 on Ahiak/Beverly range, less than half were pregnant, which may suggest nutritional limitation that year (D. Johnson, ENR, unpublished data). If the low pregnancy rate was representative of the overall herd, then the low number of cows per transect segment in 2008 may in part reflect a higher than normal proportion of non-pregnant caribou cows not reaching the calving grounds that year. Non-pregnant cows are more likely to be on the periphery of a calving ground, or off the calving ground entirely, than breeding cows. We found that a number of Ahiak collared cows did not reach the calving grounds in June 2008, and several were on the periphery. We suspect that the total number of cows in Figure 14 for 2008 is an under-estimate, and that the increase from 2008-2009 is not real. The actual population trend from 2007-2009 was more likely a continuous decline.
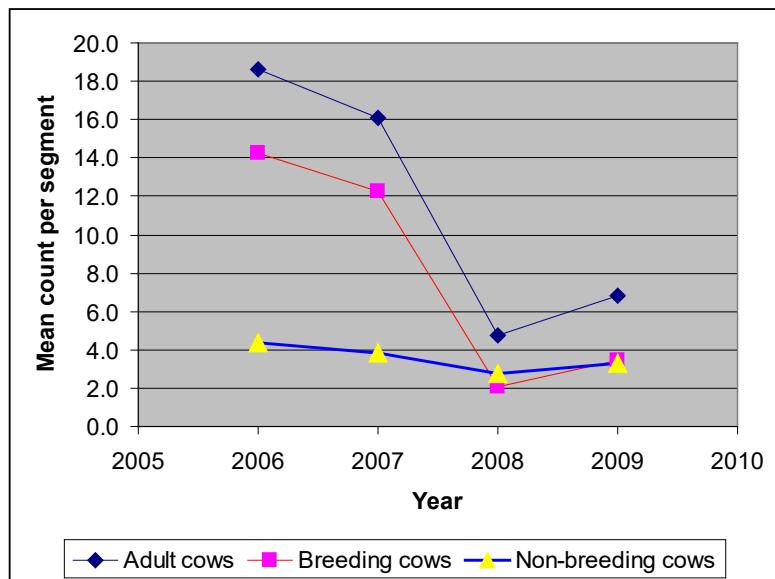
Figure 14. Average number of breeding cows, non-breeding cows, and adult cows (sum of breeding and non-breeding cows) observed per 10 km flight line segment on transect during calving reconnaissance surveys in June 2006, 2007, 2008 and 2009 on the Ahiak calving ground.
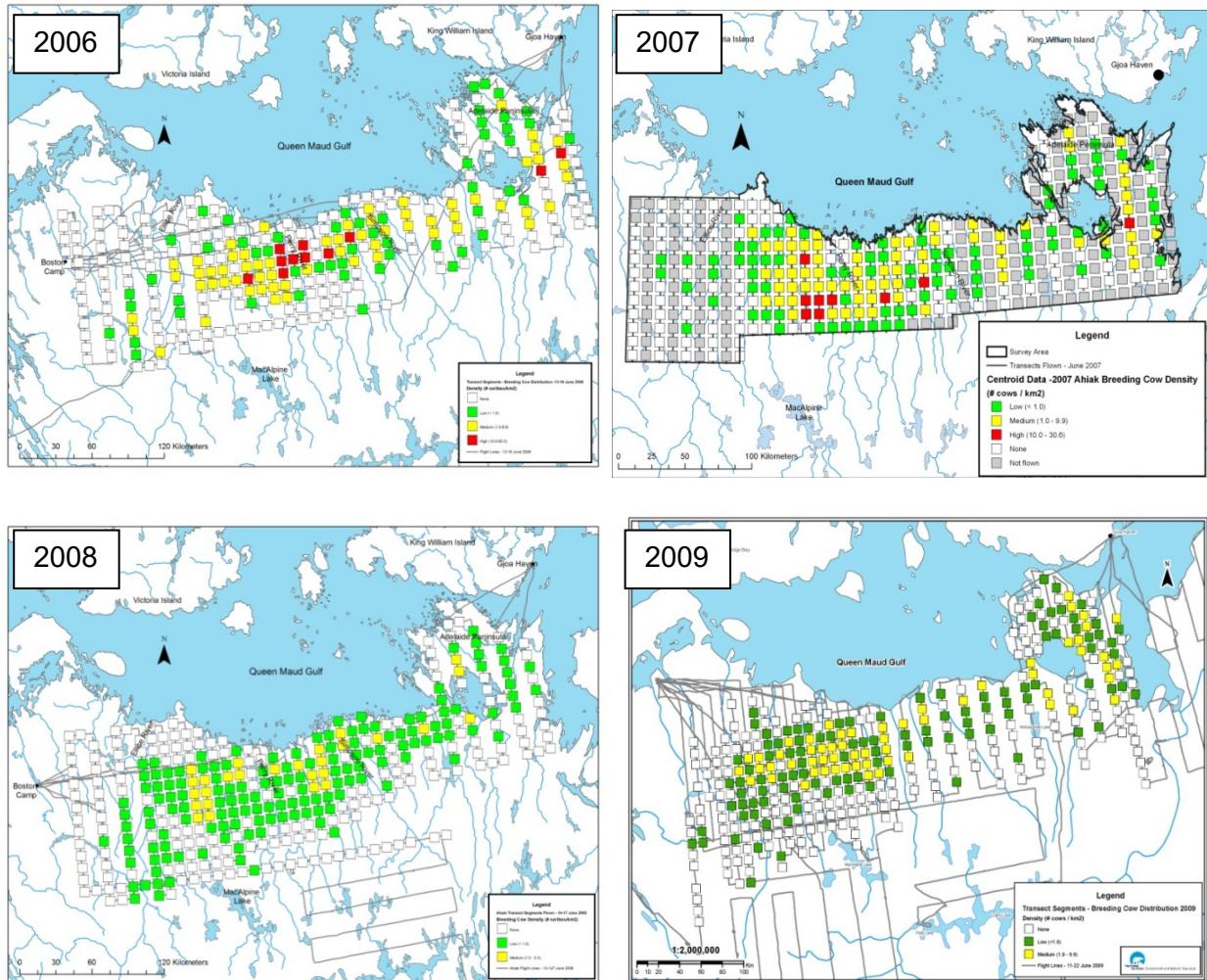
Figure 15. Map showing flight lines over the calving ground of the Ahiak herd in 2006, 2007, 2008, and 2009 (D. Johnson, A. Kelly, ENR, unpublished data). The squares are 10 km segments along flight lines. Red squares had at least ten breeding cows per km² (high density), yellow squares had 1-9.9 breeding cows per km² (medium density), green squares had <1 breeding cows per km² (low density), and white squares had no breeding cows. There were no red high-density segments in 2008 or 2009.

Population Trend in the Bluenose-East Herd

In 2000 this herd was estimated at 119,600±25,400 (Nagy 2009; Figure 16). From 2000-2006, its numbers dropped by nearly 50%, 70,100±8,100 in 2005 and 66,800±5,200 in 2006 (population estimates from Nagy and Tracz 2005, 2006, Nagy 2009; Lincoln-Petersen estimates). A post-calving photo survey of this herd was attempted in July 2009 but was unsuccessful because some of the caribou in the herd did not group up into tight groups suitable for photography.
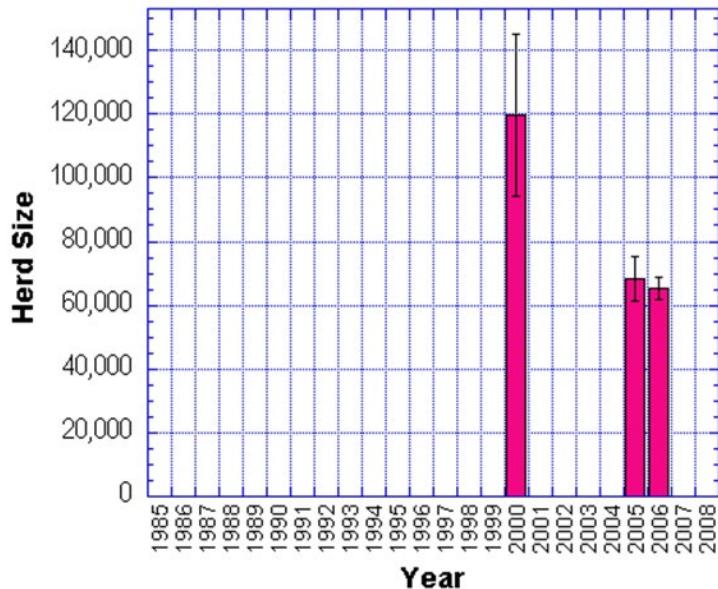
Figure 16. Population estimates for the Bluenose-East herd, 2000-2006, based on post-calving surveys and Lincoln-Petersen estimates.

Extent of Aerial Survey Coverage on GNWT Caribou Surveys in 2007, 2008 and 2009 (JA)

In June 2007 and June 2008, GNWT biologists flew the flight lines shown in Figures 17 and 18 near the peak of calving for each calving ground for the herds shown[15]. Flight lines were extended until no further groups of calving cows had been seen for at least 10 km. Additional lines were flown between calving grounds, and in the case of the Beverly inland calving ground, a second plane was used to fly areas north, south, east and west of the traditional calving ground to be certain that no significant groups of breeding cows were missed.

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[15] Results of these surveys in 2007 and 2008 were later mapped and analysed by Poole et al. (2014).
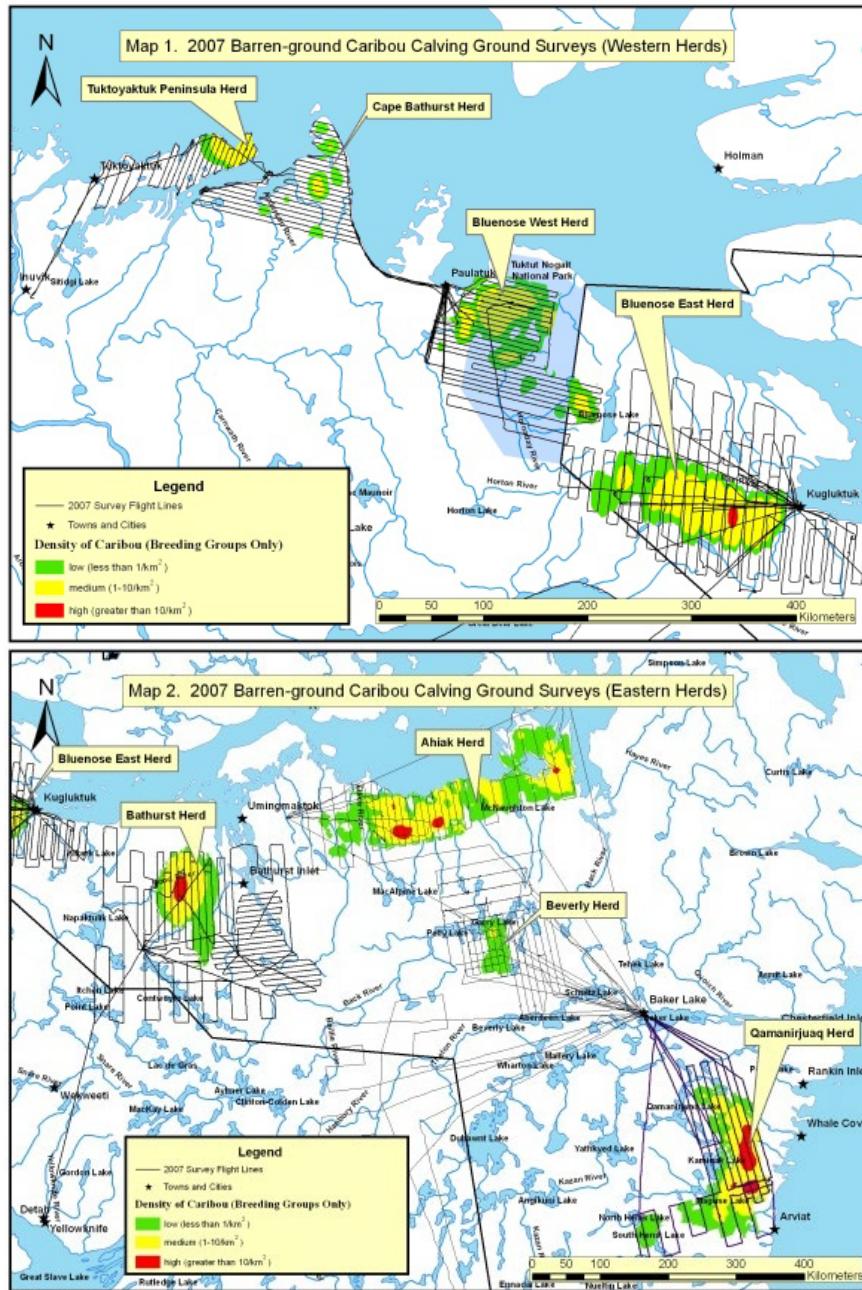
Figure 17. Survey lines flown by GNWT staff in June 2007 over calving grounds of the Tuktoyaktuk Peninsula, Cape Bathurst, Bluenose-West, and Bluenose-East herds (top); and Bathurst, Beverly, Ahiak and Qamanirjuaq herds (bottom).
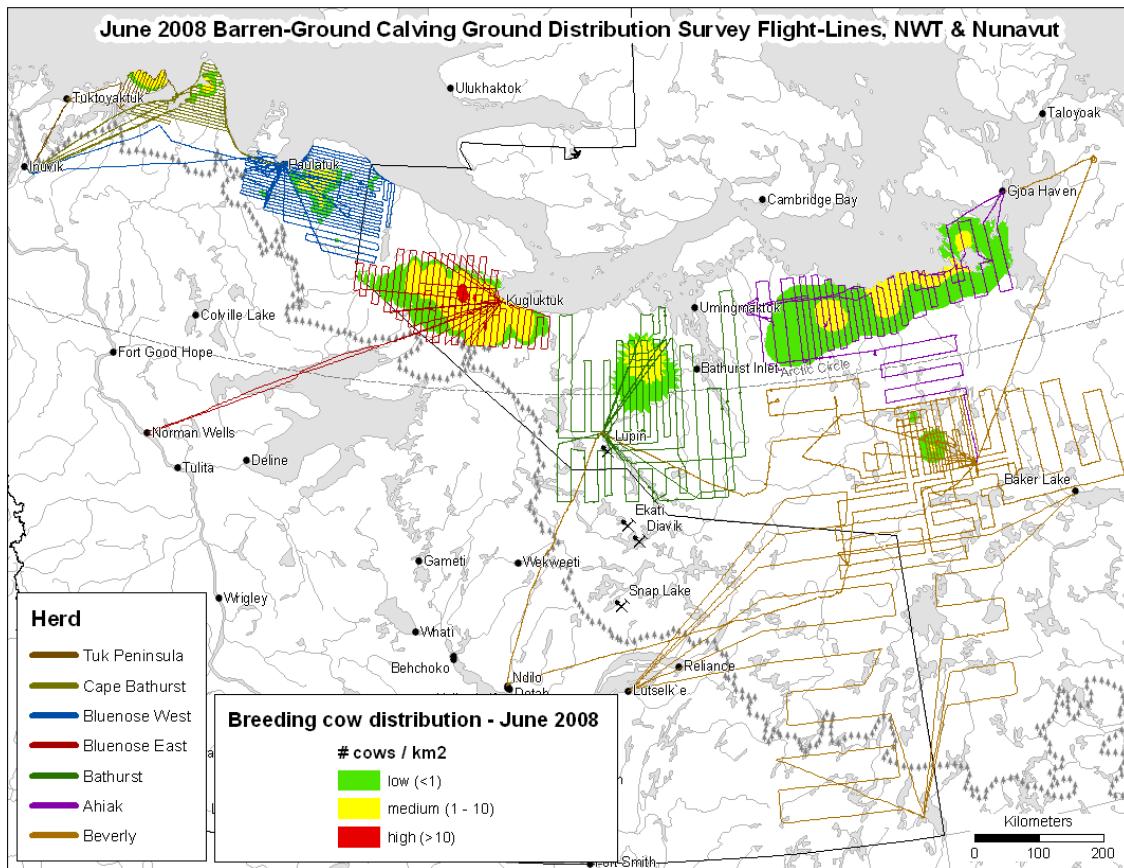
Figure 18. Survey lines flown by GNWT staff in June 2008 over calving grounds of the Tuktoyaktuk Peninsula, Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly and Ahiak herds.

In June 2009 (Figure 19), 59,000 km of flight lines were flown over the Bathurst, Ahiak, and Beverly calving grounds. Flight lines covered the area between the Ahiak and Bathurst calving grounds and were continued west from the Bathurst calving ground to the beginning of the Bluenose-East calving ground. Areas around the Beverly calving grounds were flown by a second survey aircraft. With this level of survey flying, and satellite collars confirming cows in each herd on their expected calving ground, the likelihood of missing large groups of calving caribou is low.
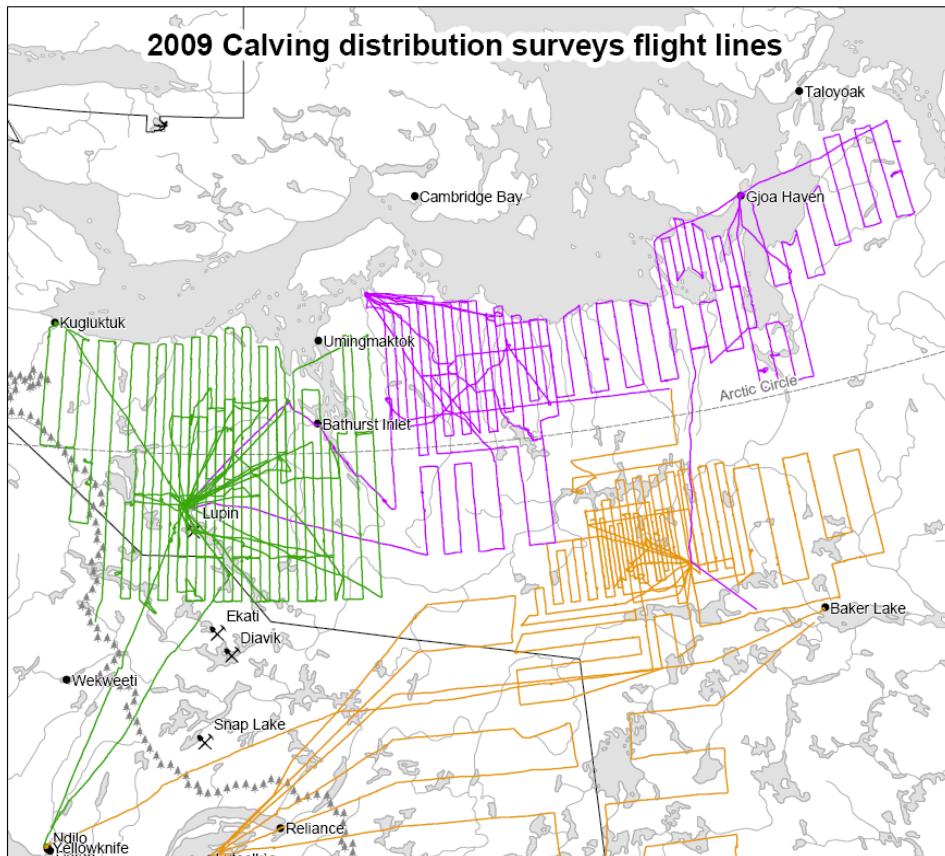
Figure 19. Aerial flight lines flown over the Bathurst, Ahiak, and inland Beverly calving grounds in June 2009.

Fidelity to Calving Grounds: Evidence from Other Herds (AG)

Fidelity to a calving ground is defined as the annual return of breeding cows to the geographic area used for calving in previous (recent) years. Fidelity to calving grounds is the basis of barren-ground caribou herd definition, which has a 40-year history across the North American range (Gunn and Miller 1986, Valkenburg et al. 2003, Gunn et al. 2008a). Fidelity to calving grounds is also the key assumption underlying the use of the June calving ground surveys to track the trend in breeding females. Annual evidence for fidelity of cows to the Bathurst calving grounds has been addressed in survey reports (Gunn et al. 2005b, Nishi et al. 2007).

Overall, the rates of collared cows switching between calving grounds for the Bathurst, Ahiak and Bluenose-East herds are similar to the rates recorded elsewhere between neighbouring herds. The low rate of switching between the Bathurst and neighbouring herds is similar to, for example, the Teshekpuk herd: Person et al. (2007) documented an annual apparent emigration rate of 0.07 ± 0.03 (five cows from 73 caribou years, 1990-2005). Only one of 175 satellite collared cows between 1981-1990 switched calving

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grounds between the neighbouring Mentasta and Nelchina herds (Lieb et al. 1994). Rates of switching were higher between the George River and Leaf River herds in northern Quebec and Labrador. Boulet et al. (2007) recorded that 14 of 149 satellite collared cows switched calving grounds (1986-2003). Most of the switches were George River cows moving to the Leaf River range for at least one calving season (whether they calved was not recorded). The annual rates of switching calving grounds were 6.6% and 0.9% of the George River and Leaf River collared cows, respectively. Six of 13 cows (one cow had only two calving locations) reversed and returned to their earlier calving ground. Two cows spent an equal number of years on either calving ground (six and eight years). Valkenburg et al. (2003) stated for Alaskan herds: "The last 20 years of data from satellite collaring and radio tracking caribou indicate that caribou herds can be considered closed populations for the purposes of population management."

Spatial fidelity (directed migration) is likely the mechanism whereby caribou maintain their associative (gregarious) calving. Combined with synchronous calving, gregarious calving helps reduce predation risk (Heard et al. 1996, Griffith et al. 2002, Bergerud et al. 2008) and allows nursing cows to take advantage of early appearance of green forage (Griffith et al. 2002, Post et al. 2003).

Reduction in geographic fidelity to a calving ground, or cows not returning to traditional calving grounds, has rarely been recorded. The conditions under which geographic fidelity is reduced include delay in pre-calving migration due to snow conditions. Under those conditions the calving ground is elongated along the main direction of pre-calving migration and this has been recorded for both the Beverly (1979) and the Qamanirjuaq herds (2005) (Gunn et al. 2007, 2008a) as well as the Porcupine herd in 2001 (Griffith et al. 2002). Calf survival under these circumstances is usually lower than normal, and much higher when caribou calve on their preferred calving grounds (Griffith et al. 2002).

On the Alaskan coast, three of five collared cows from the Teshekpuk herd calved on the neighbouring Central Arctic herd's range in 2004 but the preceding fall, severe icing conditions may have induced a third of the herd (including five collared cows) to migrate east. Then during spring migration in May 2004, Carroll (2005) reported that a combination of the Trans-Alaska Pipeline, the Dalton Highway and the flooding Savaganirktok River delayed the Teshekpuk migration. Two collared cows eventually continued migration west but calved before they reached the usual calving ground of the Teshekpuk herd. The other three collared cows calved on the Central Arctic herd's calving ground. In 2000 and 2001, spring break-up was late on the pre-calving ranges of the Western Arctic Herd in Alaska and 28% and 91%, respectively, of the breeding cows were south of the traditional calving grounds during the peak of calving (Dau 2003).

The persistence of geographic fidelity to traditional calving grounds varies between herds with some herds such as the Beverly and Qamanirjuaq showing a high degree of annually repeated use over decades (Gunn et al. 2007). The Bathurst herd showed two clusters of years with high geographic fidelity punctuated by a few years of lower geographic fidelity as the geographic location shifted from east to west of Bathurst Inlet (Gunn et al. 2008b).

Fidelity to calving areas is a relatively general phenomenon in many migratory large-bodied herbivores (Bolger et al. 2007) and in pelagic marine mammals. In caribou, the breeding cow's geographic fidelity is the consequence of the directional pre-calving migration (Bergerud et al. 2008). The strength of this can be seen in the satellite collared cows that abruptly change direction from heading to one calving ground to 'their' calving ground during pre-calving migration for the Bathurst herd (Gunn et al. 2013) and the George River herd (Bergerud et al. 2008).

Delayed pre-calving migration reduces geographic fidelity. Another cause of reduced geographic fidelity to calving grounds is also rare and is 'swamping' of one calving ground by cows from a neighbouring calving ground. The two published examples are from mountain caribou in Alaska. Between 1979 and 1987, the calving grounds of the smaller Yanert herd (500-1,000 caribou) and the larger Delta herd (4,000-8,000 caribou) were only 10-50 km apart after the Delta herd's calving ground had shifted (Davis et al. 1986). In the second example, the smaller Kilbuck herd's (*ca.* 4,000) traditional calving ground was within 25 km of the larger Mulchatna's (*ca.* 200,000) shifted calving ground in 1994 (Valkenburg et al. 2003, Hinkes et al. 2005) and the herds combined. The smaller mountain herds (Yanert and Kilbuck) had different calving strategies (scattered rather than gregarious) than the larger herds. The larger herds with gregarious calving expanded their winter and summer ranges and each overlapped a small neighbouring herd.

Analyses of the Ahiak and Beverly satellite collared cows since 2006 suggest a possible reduction in the fidelity of some cows to the traditional inland Beverly calving ground. Two related effects may be involved. The Ahiak herd's elongated east-west calving ground is directly north of the Beverly calving ground (see Figure 4) and thousands of Ahiak cows heading north may have passed near the Beverly calving ground or directly through it. It is possible that cows from both herds migrating to their calving grounds continued together on to the Ahiak calving ground. Given the generally high fidelity of cows to calving grounds, this is only likely to have happened if the Beverly herd had first reached very low numbers. It is possible that to maintain effective densities (gregariousness or predator swamping), some Beverly cows migrated to join the higher densities on the Ahiak calving grounds. If the densities on the Beverly calving grounds were below a density threshold for gregarious behaviour, this would be an example of an Allee Effect, which is a decline in survival or reproduction with declining density (Stephens and Sutherland 1999).

It is worth remembering that the primary reason barren-ground caribou herds are able to reach numbers in the tens and hundreds of thousands is that temporally concentrated calving in areas with limited predator numbers allows them to partially "escape" the limitation that predators (principally wolves) can exert over caribou (Heard et al. 1996). Woodland caribou, which never reach nearly the population size of barren-ground herds, are likely to be limited by predation across their usual densities (Seip 1991, Bergerud et al. 2008). The high mortality, poor calf survival and apparent shift to a calving ground with much higher numbers of cows by Beverly caribou may reflect the fact that at very low numbers, scattered numbers of cows and calves may be vulnerable to a limited number of predators.

The Fortymile herd's history can also serve as a cautionary tale. This Alaska/Yukon herd was estimated at 350,000-568,000 in the 1920s, when the herd took several days to cross the Yukon River. This herd declined to 46,000-60,000 by 1950, in part due to heavy harvests, then declined further to an estimated 5,000 in the 1970s (Davis et al. 1978, Alaska Board of Game 2006). By this point it occupied just a fraction of its former range. Between 1974 and 1990 the herd grew to about 23,000, and then remained at that level until 1995, in large part due to low calf survival (Alaska Board of Game 2006). After a period of predator control and low harvest rates, the Fortymile Herd increased to 43,000 by 2003. This may be another example of a herd that declined to such low numbers that the fundamental relationship with predators changed to one characteristic more of woodland caribou than of large migratory herds of barren-ground caribou. The Fortymile herd's history is also a reminder that declines in large caribou herds are not necessarily followed immediately by increases, and that periods of low numbers may last for decades.

BATHURST HERD DECLINE: FIELD DATA

In this section, we review the results of population surveys, other surveys and related studies carried out for the Bathurst herd.

Field Data from the June 2009 Calving Ground Survey (JN and BC)

Aerial photographic surveys of annual calving grounds have been the primary means of estimating abundance of breeding females for the Bathurst herd of barren-ground caribou since the early 1980s (Heard 1985). To maintain comparability with previous surveys, we used the calving ground photo survey technique and estimated the number of breeding females on the annual calving ground in June 2009; we briefly report results here and note that a full survey report was later finalized as Nishi et al. (2014).

Methods

Multiple aircraft and a relatively large field crew were coordinated to conduct and complete the June 2009 calving ground survey in a timely fashion (Appendix 1). The survey was initiated on the 3 June with mobilization of a field crew to the base of operations, which was the Tahera mine site at the northern end of Contwoyto Lake. We commenced the systematic reconnaissance survey on the 4 June using a Cessna Grand Caravan. A second fixed-wing aircraft (Turbo Beaver) and field crew arrived on the 6 June to assist with the systematic survey. By the 7 June, we had delineated the annual calving ground and determined boundaries and sampling effort for photographic and visual survey strata (Figure 20). Additional systematic surveys were conducted from the 8 to 10 June to expand survey coverage over a broader area of the extent of calving and to confirm that we had delineated the entire annual calving ground and not missed breeding females in adjacent areas (Figure 20). On 17 June, additional flight lines were added to the systematic survey coverage in the area to the west and north of Napaktulik Lake towards Kugluktuk (Figure 20).
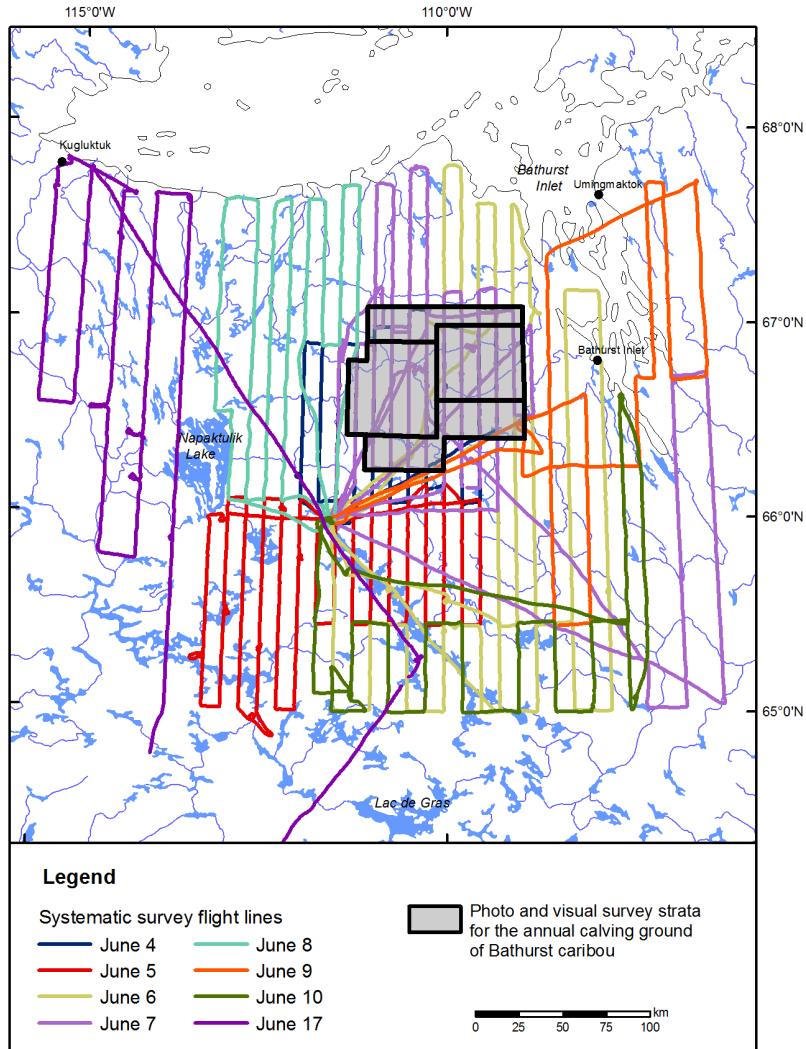
Figure 20. A systematic reconnaissance survey to delineate the annual calving ground of the Bathurst herd of barren-ground caribou, June 2009. Photo and visual strata are shown in grey.

Based on observed densities, composition of caribou (i.e., antlered cows with newborn calves), and relative abundance of newborn calves seen during the systematic survey, the annual concentrated calving ground was delineated into a high and medium stratum for aerial photography, plus three low density strata for visual estimation of caribou from fixed-wing aircraft (Figure 21). The photographic and visual surveys were initiated on the 8 June and completed on the 9 June.
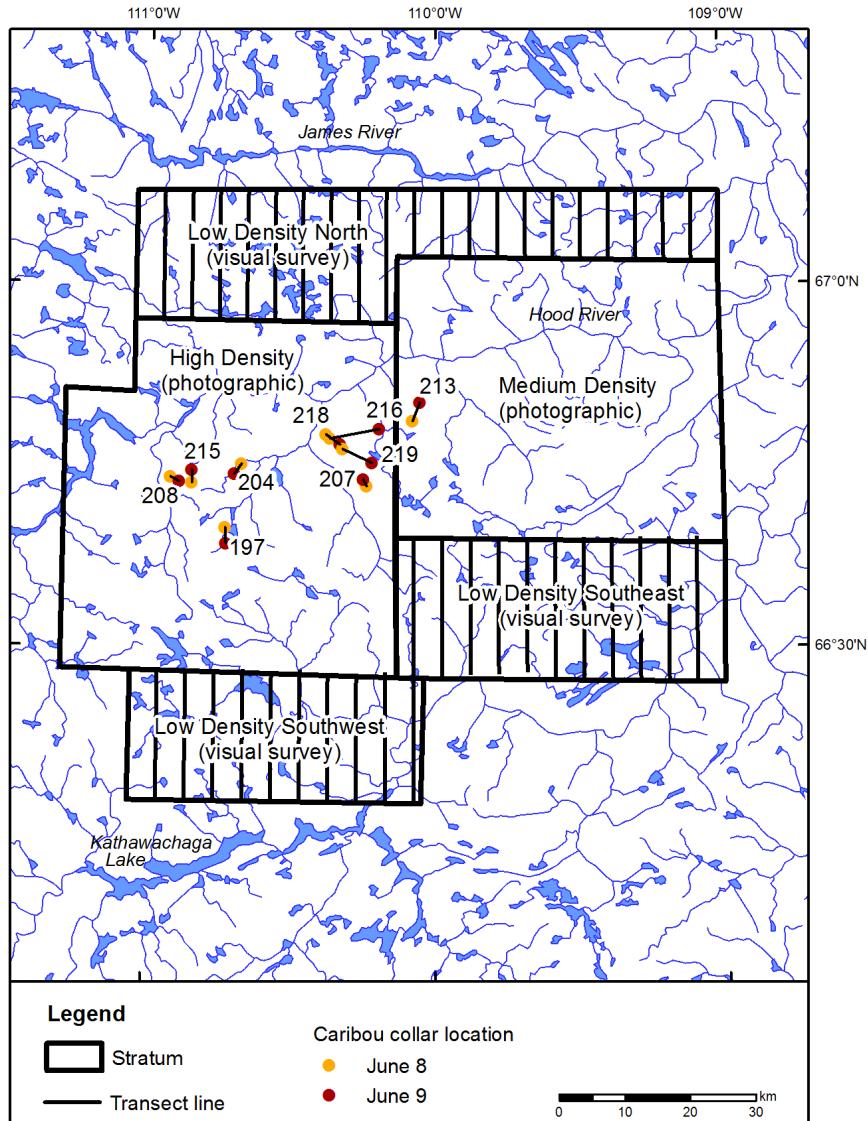
Figure 21. Photographic and visual survey strata delineated on the annual calving ground of the Bathurst herd of barren-ground caribou, June 2009. Locations of nine satellite collared cows are also shown within photographic strata on 8 and 9 June.

Aerial photography was conducted using similar methodology, aircraft, and camera equipment as previous surveys in 1996, 2003, and 2006 by Geographic Air Survey Ltd. Caribou on aerial photographs from the high and medium density strata were enumerated by H.P. Roy (Ottawa, ON.) using similar methodology from previous surveys (see Nishi et al. 2007), and counts of caribou were summed across all photographs along a transect. Composition surveys were initiated on the 8 June to estimate the proportion of breeding females in each of the survey strata and completed on the 11 June.

Results

The estimated abundance of 1+ year-old caribou on the annual calving ground of the Bathurst herd in June 2009 was 23,273 ($\pm$2,788 SE) (Table 3, Appendices B, C, and D). Approximately 98% of the estimated caribou on the calving ground occurred within the high (75.6%) and medium (22.6%) photographic strata, whereas the three visual strata comprised less than 2% of the estimate (Table 3).

Table 3. Analysis of data from an aerial survey of the Bathurst caribou calving ground, 8-9 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
95% Confidence interval	5,019	3,143	52	283	33	
% Coverage	40.6%	19.1%	17.9%	17.7%	17.5%	

During the composition survey, a total of 2,939 1+year-old caribou were observed within 91 groups across the survey strata (Table 4, Appendices E, F, and G). The proportions of breeding females in the high and medium strata were 0.678 ($\pm$0.043 SE) and 0.879 ($\pm$0.017 SE) respectively (Table 4). Given the low densities of caribou in the three visual strata, only nine groups comprising a total of 226 1+year-old caribou were classified in the low strata, resulting in a proportion of breeding females of 0.113 ($\pm$0.048 SE).

Table 4. Sample sizes and proportion of breeding females observed from composition surveys of high, medium, and low-density strata of the Bathurst caribou calving ground 8-11 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	1,847	0.678	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**	**2,939**			

After adjusting for the observed proportion of breeding females in the survey strata, the abundance of breeding females on the 2009 annual calving ground was estimated to be 16,605 ($\pm$2,176 SE) animals (Table 5).

Table 5. Estimated number of breeding females in high, medium and low-density strata of the Bathurst calving ground, June 2009, based on stratum population estimates and composition counts.

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	0.678	11,928	3,236,450	1,799	0.151
Medium	5,267	0.879	4,630	1,499,906	1,255	0.265
Low N	28	0.113	3	10	3	0.988
Low SE	299	0.113	34	410	20	0.599
Low SE	86	0.113	10	31	6	0.571
Total	**23,273**		**16,605**	**4,736,807**	**2,176**	**0.131**

Extrapolation of the abundance of breeding females on the annual calving ground to an estimate of total herd size is dependent on assumptions regarding a) sex ratio, and b) the pregnancy rate for breeding females. When the proportion of females in the population was set at 0.730 to reflect fall composition data from 2008, the extrapolated population estimate was 31,897 ($\pm$6,092). We include in Table 6 the extrapolated population estimate using the earlier sex ratio (38,245) but the lower population estimate is the appropriate one to use. It should be noted that in the extrapolated 2006 population estimate used previously, the proportion of females was set at 0.60, the average of several fall sex ratio results. However, since that time, results of fall surveys in 2004, 2006, 2007 and 2008

indicate that the Bathurst herd has had sex ratios lower than documented in the 1980s when the herd was increasing and adult and calf survival rates were high.

Table 6. Extrapolated herd size estimates using original Heard (1985) sex ratio and 2008 composition survey sex ratio. SE=standard error; CV = Coefficient of Variation; CIL = lower 95% confidence interval; CIR = upper 95% confidence interval.

Survey data	Estimate	SE	CV	CIL	CIR
With proportion females=0.603 (used in 2003 report)					
Number of caribou on the breeding ground	23,272.51	2,787.6	0.12	17,571	28,974
Number of breeding females	16,604.496	2,176.4	0.13	12,153	21,056
Proportion females in the entire herd	0.603		0.10		
Proportion 1.5+ yr females pregnant	0.72		0.10		
Total population estimate	38,245	7,374.5	0.19	23,163	53,328
With 2008 composition data= 37 bulls/100 cows=72 .3% cows					
Number of caribou on the breeding ground	23,272	2,787.7	0.12	17,571	28,974
Number of breeding females	16,604.496	2,176	0.13	12,153	21,056
Proportion females in the entire herd	0.723		0.03		
Proportion 1.5+ yr females pregnant	0.72		0.10		
Total population estimate	31,897	5,345.1	0.17	20,965	42,829

Discussion

The estimate of breeding females (16,605±2,176 SE) from the June 2009 calving ground photo survey of the Bathurst herd was relatively precise with a Coefficient of Variation (CV) of 0.129, and showed a significant decline (t=4.27, df=21, P<0.005) relative to the June 2006 estimate of 55,593 (±8,813 SE) (Nishi et al. 2007). The following section provides a more detailed assessment of the trend for the Bathurst caribou herd. The design and execution of the June 2009 calving ground survey was efficient, and we did not incur any major problems that could have seriously affected credibility of survey results. There were no delays in the timing between the systematic reconnaissance survey, stratification and completion of the photo survey and composition surveys of high and medium density strata. As the photo survey was completed within two days following stratification, there was minimal potential for movements of breeding females across survey strata to bias the calving ground estimate. Movement rates of satellite collared Bathurst caribou cows suggested that the peak of calving occurred on the 6-9 June 2009. Occurrence of those nine collared cows within the high and medium strata (Figure 21) 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.

Trend in Bathurst Caribou Breeding Females from Multiple Calving Ground Photo-surveys (JN)

In this section, we review changes in the numbers of breeding females in the Bathurst herd over time, with an emphasis on population trend, particularly between 2006 and 2009.

Data Set Used for Analysis

The data set of population estimates for breeding females is shown in Figure 22. The data on abundance of breeding females are 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. The survey methods were the same for all surveys.
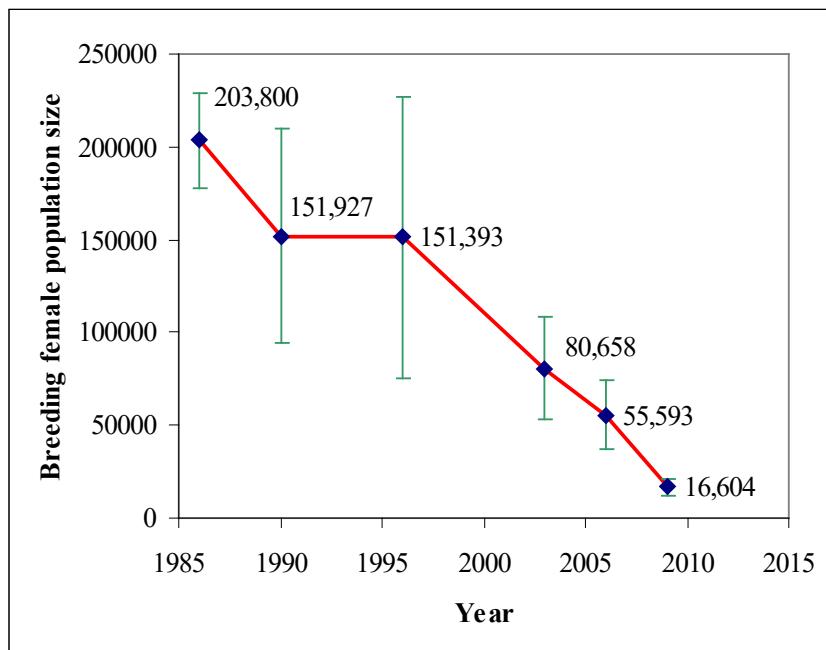
Figure 22. Population estimates of Bathurst breeding females for surveys conducted in 1986, 1990, 1996, 2003, 2006, and 2009. Ninety-five percent confidence intervals for estimates are shown as error bars.

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, we conducted substantial testing for non-linear population trends using the sample-size-corrected AIC (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 $\leq$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). 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 $\lambda = 1$ then a population is stable. If λ is <1, the population is decreasing, and if λ is >1, the population is increasing. Unlike previous analyses, 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.

Monte Carlo Simulation

We 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 survey. 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 $\pm t_{(\alpha=0.05,2,df)}$*SE. For each simulation a random t-distribution variate with associated degrees of freedom for each survey was generated. This random variate was then multiplied by the SE and 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 2,000 pseudo data sets that resulted in 2,000 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 non-linear trend best approximated by a cubic polynomial term was most supported (Tables 7 and 8). 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.

Table 7. Model selection results for Bathurst trend analysis. Akaike Information Criteria (AIC_c), the difference in AIC_c values between the ith 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

Table 8. Regression model parameter estimates for Bathurst trend analysis.

Parameter	Estimate	SE	CI low	CI 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

Parameter estimates for the most supported model suggest both the intercept and yr^3 terms are significant (Table 7).

A plot of the regression line (back transformed to population size units) is shown in Figure 23. 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.
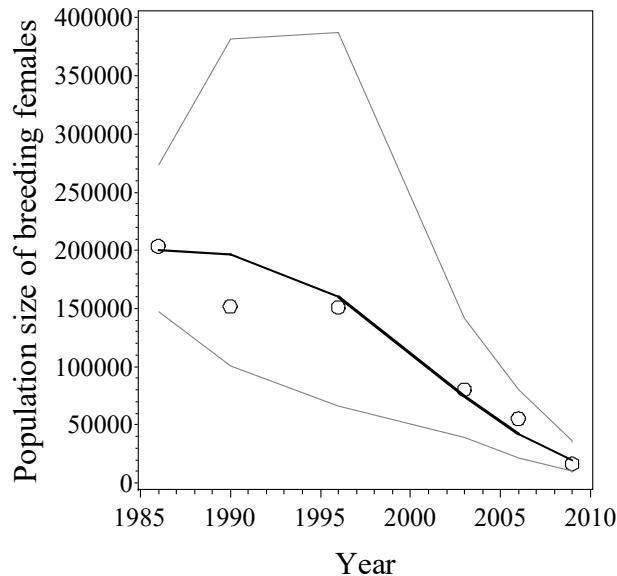
Figure 23. Predicted trend for breeding females from weighted least squares regression analysis. Grey lines are confidence interval on predictions. Circles are estimates of breeding females for a given year.

Results: Monte Carlo Simulation

Monte Carlo simulation results suggested that the trend was increasingly negative as shown by lower λ estimates for each year (Figure 24). The λ of 1 at the beginning of the simulations was an artefact 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.
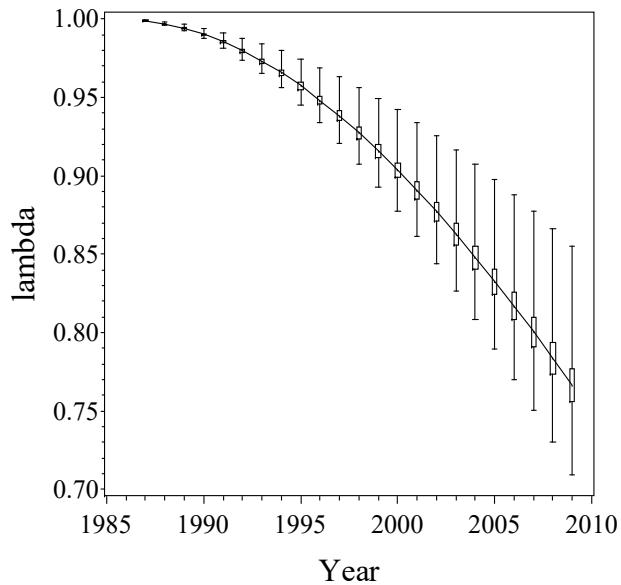
Figure 24. Simulated estimates of λ as a function of year from Monte Carlo simulation analysis.

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

A histogram of λ estimates for 2009 shows that none of the values overlapped 1, suggesting there was no statistical chance that the population was stable (Figure 25).
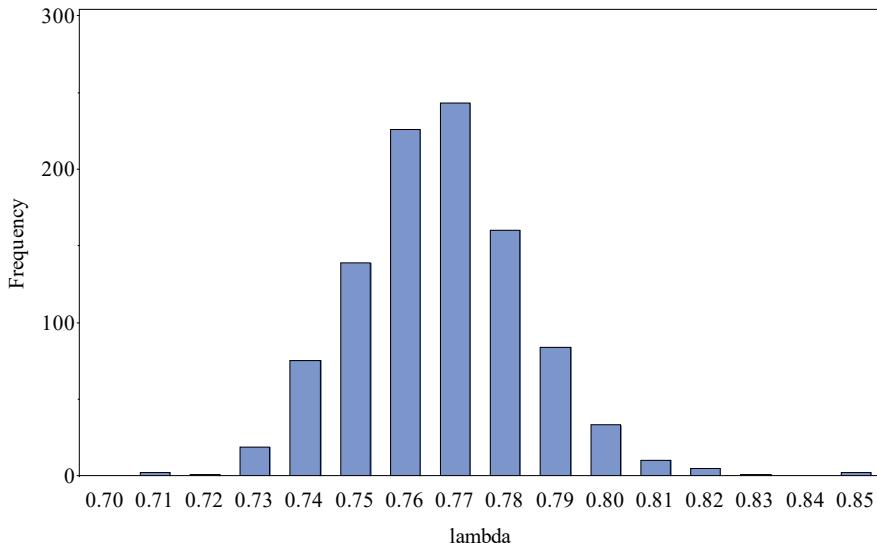
Figure 25. Distributions of population rate of change (λ) for 2009 generated using Monte Carlo simulation trials.

Discussion: Trend in Breeding Females in the Bathurst Caribou Herd

Both analyses reported here suggest an increasingly negative trend in the population size of breeding females in the Bathurst caribou herd. From inspection of Figure 22 it might be surmised that the population declined between 1986 and 1990, then stabilized from 1990 to 1996, then declined from 1996 to 2006, and declined further from 2006 to 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 7.

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 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, we recommend reporting trend estimates in terms of λ and r-values rather than the results of t-tests of sequential estimates.

Bathurst Calving Ground Distribution Surveys (JN)

The Bathurst calving ground photo survey starts with a systematic aerial reconnaissance survey to determine the relative composition and density of caribou and delineate the extent of an annual calving ground. Systematic aerial reconnaissance surveys are comparatively less expensive and can provide a useful comparative dataset to track trend in caribou densities on a calving ground. They can be conducted during intervening years between full-scale calving ground photo surveys. We briefly describe a comparison of caribou densities on the Bathurst calving grounds from systematic reconnaissance surveys and show that those data also indicate a dramatic decline in caribou density since 2003. Thus, systematic reconnaissance surveys provide an additional and useful index for trend of breeding females.

Methods

Estimates of 1+ year old caribou were available from completed calving ground photo surveys in 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 2003, 2006, 2007, 2008, and 2009 (GNWT unpublished data). Data from systematic surveys were reported as caribou densities within adjacent transect segments (0 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.

We delineated the boundaries of the annual calving ground based on composition and density of caribou observed during each systematic survey. We multiplied density estimates for each transect segment by 100 to extrapolate the observed density within a transect segment to a count of caribou within adjacent 10 km x 10 km cells of the delineated calving ground. The sum of caribou counts within all 100 km² cells provided a coarse extrapolated estimate of 1+ year old caribou on the annual calving ground based on the systematic reconnaissance surveys.

Results

The extrapolated estimates of 1+ year old caribou on the Bathurst calving grounds were consistently lower but showed a similar declining trend to that depicted by the caribou estimates derived from aerial photo surveys (Figure 26). Extrapolated estimates based on observed caribou densities from systematic reconnaissance surveys showed the decline from 2006 to 2009 on an annual time step.
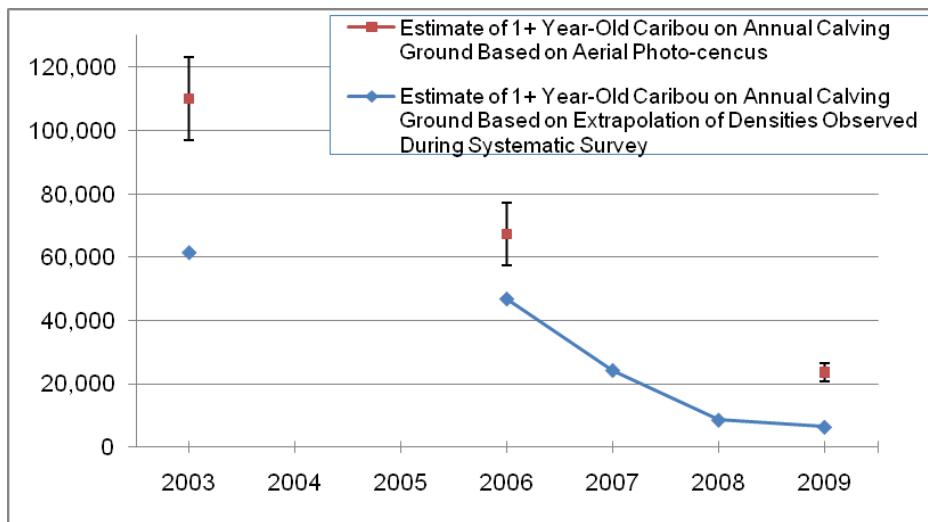
Figure 26. Trend in estimates of 1+ year old caribou on Bathurst calving grounds based on aerial photo surveys results and extrapolation of caribou densities observed during systematic reconnaissance surveys.

Discussion

Recent systematic reconnaissance surveys of the annual Bathurst caribou calving grounds are consistent with results from calving ground photo surveys and show a continued and dramatic decline in numbers of caribou on the calving grounds.

Systematic reconnaissance surveys provide a useful and comparatively economic way of monitoring trend of caribou on an annual calving ground and allow managers to anticipate trend during the intervening years between full-scale calving ground photo-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 and changes in caribou densities. However, observer bias associated with sightability and counting error will be a source of uncertainty and variability that will affect precision and accuracy of this visual survey technique. Therefore, careful and consistent standardization of survey methods and rigorous training of observers will help to improve the value of systematic reconnaissance surveys. Systematic reconnaissance surveys may be a particularly important annual monitoring tool when caribou populations (such as the Bathurst herd) decline to low numbers and management actions are implemented to assist in recovery.

Composition Surveys in the Bathurst Herd and Other Herds (DC and BC)

Biologists working with the Bathurst herd recorded spring or late-winter calf:cow ratios in the mid-late 1980s, early 1990s, and from 2001 to present (2009). In brief, each

survey is preceded by a systematic fixed-wing reconnaissance survey to verify where the main aggregations of caribou are. The locations of satellite collared females are helpful in guiding the reconnaissance survey. Areas of known overlap in satellite collars with neighbouring herds are avoided. Total numbers of caribou classified in the 2006-2009 surveys ranged from 4,346 to 10,121, and numbers of groups classified ranged between 97 and 286.

The calf:cow ratios recorded from 1985 to 2009 fall into three distinct periods: 1985-1995, with ratios between 30 calves:100 cows and 50 calves:100 cows; 2001-2006, with ratios at most of 30:100 and as low as 8.5:100 in 2006; and 2007-2009, with values between 37 calves:100 cows and 50 calves:100 cows.

For a wide range of caribou herds, Bergerud (2000) identified values around 30 calves:100 cows as indicative of stable herds, as a rough rule of thumb. However, modeling of the Bathurst herd (see stochastic simulations for the Bathurst herd) suggests that calf survival of 32-35% would be sufficient for stability at a cow survival rate of 91%, but at a lower cow survival rate of 86%, calf survival of 50-53% would be needed for stability.

Population surveys in 1986, 1990 and 1996 indicate that the herd was stable or declining slowly over this period. Calf:cow ratios of 30-50:100 might have been sufficient for a stable herd or one increasing slightly. However, if cow survival rates were around 86% or lower, these calves:cow ratios might not have been sufficient to maintain a stable herd.

The calf:cow ratios from 2001 to 2006 are less ambiguous: the herd would almost certainly have been declining over this period for natural reasons, regardless of harvest, with several weak cohorts, particularly in 2005 and 2006. Adult survival and calf survival tend to be correlated (Bergerud 2000), hence natural cow survival in the Bathurst herd might also have been low in these years.

The calf:cow ratios in 2007, 2008 and 2009 are similar to the values recorded for this herd in the 1980s and 1990s and may be an indication of improving environmental conditions. These ratios may be somewhat inflated due to high cow mortality rates from hunting: if large numbers of cows were shot and calves left alive, the calf:cow ratio might suggest better calf survival than actually occurred. However, calf:cow ratios in four other NWT herds (Ahiak, Bluenose-East, Bluenose-West, and Cape Bathurst) were all between 40 and 50 calves:100 cows in March/April 2008, possibly indicating a larger-scale improvement in environmental conditions (ENR unpublished data).

Spring calf:cow ratios recorded for the neighbouring Bluenose-East and Ahiak herds 2001-2009 are listed in Table 9. In the Ahiak herd, calf:cow ratios were high in 2008 as in other herds, but lower in spring 2009. These are the first spring composition surveys for

this herd. Spring calf:cow ratios were recorded for the Bluenose-East herd in 2001, 2004, 2007, 2008 and 2009. Calf:cow ratios in these years were generally similar to those in the Bathurst herd (Figure 27) or slightly higher. However, spring recruitment surveys were not carried out annually in this herd, so we do not know if the exceptionally low calf:cow ratios in the Bathurst herd in 2005 and 2006 also occurred in the Bluenose-East herd.

Table 9. Summary of spring (March/April) composition surveys for the Bluenose-East and Ahiak herds. Bluenose-East data from R. Popko, ENR Sahtu region (unpublished data); Ahiak data A. Kelly, ENR South Slave region (unpublished data). The % calves values do not always match the calf:cow ratio because of variable proportions of cows, bulls and yearlings recorded.

Herd	Year	Total caribou classified	Calves /100 cows	% calves in sample
Bluenose-East	2001	6,680	25.1	28.7
Bluenose-East	2004	5,517	51.6	29.3
Bluenose-East	2007	5,419	48.7	18.7
Bluenose-East	2008	5,604	48.3	27.2
Bluenose-East	2009	6,110	38.4	23.4
Ahiak	2008	11,163	48.3	25.8
Ahiak	2009	6,502	31.0	16.9
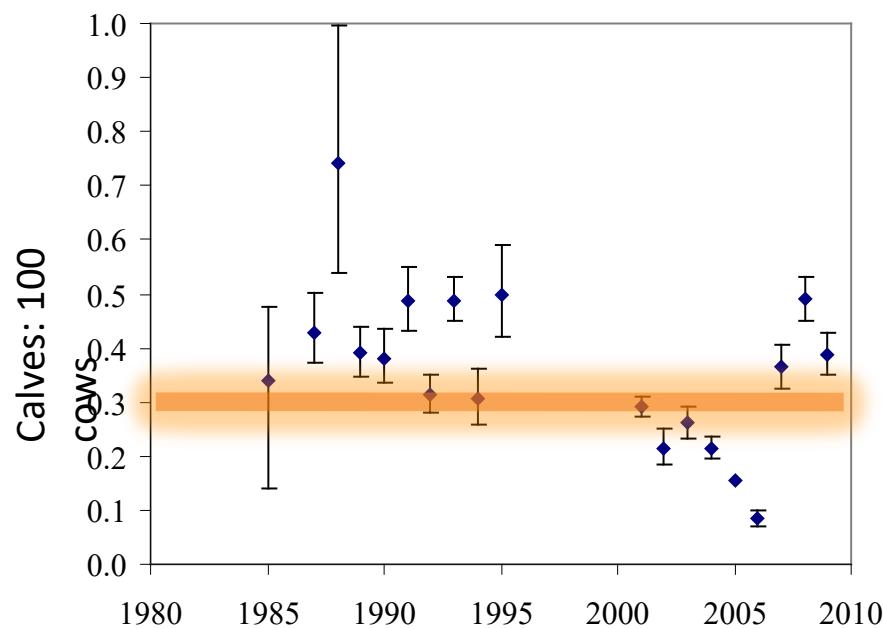
Figure 27. Spring (March-April) calf:cow ratios for the Bathurst herd, 1985-2009. As a rough rule of thumb, calf:cow ratios of about 30 calves:100 cows (orange bar) are associated with stable caribou herds, but demographic analysis has shown that this applies when cow survival rates are relatively high (Boulanger et al. 2011). At lower cow survival rates, higher calf:cow ratios are needed to result in a stable herd.

Fall composition surveys were carried out for the Bathurst herd in 2006, 2007 and 2008 (Table 10). These surveys are a necessary part of calculating a herd size estimate if June calving photo surveys are used, as very few bulls are found on the calving grounds. Carried out during the rut, these surveys provide the best opportunity to estimate the sex ratio, because all sex and age classes are mixed.

Table 10. Summary of fall (October) composition surveys, Bathurst herd 2006-2008, Bluenose-East herd 2008-2009, Bluenose-West herd 2009, and Ahiak herd 2009 (ENR unpublished data).

Herd	Year	Total caribou classified	Total groups classified	Calves /100 cows	% calves in sample	Bulls /100 cows
Bathurst	2006	5,610	69	40.2	22.7	36.2
Bathurst	2007	7,283	148	55.2	29.3	30.6
Bathurst	2008	3,532	42	31.9	18.7	38.3
Bluenose-West	2009	4,620	147	51.9	23.4	69.8
Bluenose-East	2009	4,531	79	46.0	24.4	42.9
Ahiak	2009	3,772	41	46.4	23.2	53.8

The sex ratio for the Bathurst herd was between 30.6 and 38.3 bulls:100 cows between 2006 and 2008 (Table 10). These sex ratios are lower than was found in most barren-ground caribou herds reviewed by Bergerud (2000) where ratios of about 50:100 were more common as an average value. Heard (1985) found bull:cow ratios over 60:100 in increasing NWT herds. A recent fall survey (October 2009) of the neighbouring Bluenose-East herd showed a sex ratio of 42.9:100 (Table 10). A fall count for the Bluenose-West herd showed a higher value of 69.8 bulls:100 cows, and a fall count of the Ahiak herd showed a sex ratio of 53.8:100. The low sex ratio in the Bathurst herd may in part reflect a declining natural trend in the early 2000s; males almost always have higher mortality rates than females, especially if environmental conditions are poor (Bergerud 2000). In addition, there has been a substantial harvest by outfitters from the Bathurst herd (see Hunter Harvest), a poorly documented Indigenous fall bull harvest, and a limited bull harvest by resident hunters. Mapped collar information suggests that the 2009 outfitter harvest was at least half from the Bluenose-East herd and some of the outfitter harvest in other years was likely also from this herd (see Hunter harvest).

Pregnancy Rate and Body Condition (BE and BC)

A separate report by B. Elkin and co-authors provides an overview of four field collections of Bathurst caribou in September 2007, March 2008, September 2008 and April 2009. These were carried out to assess condition, pregnancy rate (in winter), health, and

contaminant status of this herd. Here we have extracted portions of that report, focusing on cow body mass, condition (back fat and hunter condition score), and pregnancy rate, as the values most likely to affect population trend. Condition of caribou cows in the fall is strongly related to likelihood of pregnancy (Cameron et al. 1993, Russell et al. 1998, Kofinas et al. 2002) and reflects the accumulated nutrition of the cow over the summer and fall.

Samples were collected as follows:

1) Mackay Lake, September 7-13, 2007. Samples and measurements were taken from caribou harvested during a fall hunt by the Yellowknives Dene. A total of 51 caribou were sampled (17 adult cows, 17 adult bulls, three yearlings, and 14 calves).

2) Beaverlodge Lake, March 11-14, 2008. Samples and measurements were taken from 38 caribou harvested in conjunction with Tłı̨chǫ hunters (26 adult cows, two adult bulls, one yearling, and nine calves).

3) Lac de Gras, September 9-11, 2008. Samples and measurements were taken from 31 caribou harvested in conjunction with hunters from the Yellowknives Dene (12 adult cows, 13 adult males, one yearling, and five calves).

4) Strachan Lake, April 4-6, 2009. Samples and measurements were taken from caribou harvested in conjunction with Tłı̨chǫ hunters from Gamètì. A total of 30 caribou were sampled (28 adult cows, one adult bull, and one calf).

Measurements of body size and mass included full body weight, carcass weight, body length, chest girth, and foot length. Age was determined for each caribou using both a field estimate based on size and appearance, tooth wear, and laboratory tooth cementum analysis. Overall fatness/body condition were assessed by several methods, including depth of back fat, kidney fat weight, percent of fat in the bone marrow, and visual condition scores assessed by hunters (1 skinny, 2 not so fat, 3 fat, and 4 very fat). Cows estimated or aged as at least three years old were assessed as adults in this evaluation. In general, hunters took caribou as they were available, and we believe that the sampled animals were a fairly unbiased sample of the herd in that area.

Back Fat: In September 2007, back fat in cows averaged 3.75 mm (range 0-15), with greater fatness recorded in September 2008, with an average of 29.8 mm (range 25-39). In March 2008 the cows averaged 12.5mm of back fat (range 1.5-26) and 6.6 mm (range trace –23) in April 2009.

Body Mass: In September 2007, cow body mass averaged 86.3 kg (range 71-106) and was higher in September 2008 at an average of 94.9 kg (range 77-116). In March 2008,

average cow body mass was 85.9 kg (range 77-99) and a similar body mass of 84.2 kg (range 67-106) was found in April 2009.

Hunter Condition Score: Condition of cows was rated by hunters in March 2008, September 2008, and April 2009, but not in September 2007. The average score (1-4) was 2.9 in March 2008, 3.4 in September 2008, and 2.6 in April 2009. Numbers of cows rated in each category for the three collections are shown in Figure 28.

Hunter Condition Scores for Adult Females (% of animals in each category)
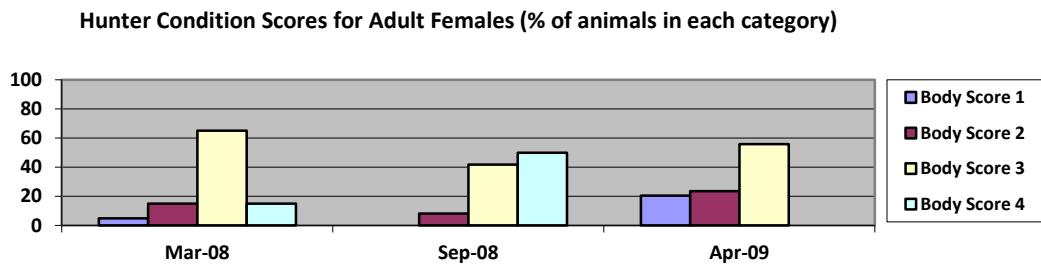
Figure 28. Percentages of cows rated by hunters on a 4-point scale (1 skinny, 2 not so fat, 3 fat, and 4 very fat) in assessing Bathurst caribou cows during three seasonal collections 2007-2009.

Pregnancy rate: In March 2008, 26 of 26 adult cows assessed as part of the condition and health assessment were pregnant. This field work was carried out at a camp near Beaverlodge Lake, north of Gamètì. In addition, a further 35 of 36 cows were pregnant, from a hunt carried out about a week later by hunters in the Bathurst range (E. Evans pers. comm. March 2008) at a different location 160 km away (near Indin Lake) but also in an area with wintering Bathurst caribou. In April 2009, 25 of 28 cows were pregnant during that collection. In 2008 and 2009, pregnancy rates in the two late-winter collections were added to Figure 29, which shows late-winter pregnancy rates in six previous condition and health studies of this herd. The lowest pregnancy rate recorded among these Bathurst collections was in March 1991 (60%), with other values generally between 80 and 100%.

Late Winter Pregnancy Rates (% Pregnant)
Adult Female Bathurst Caribou
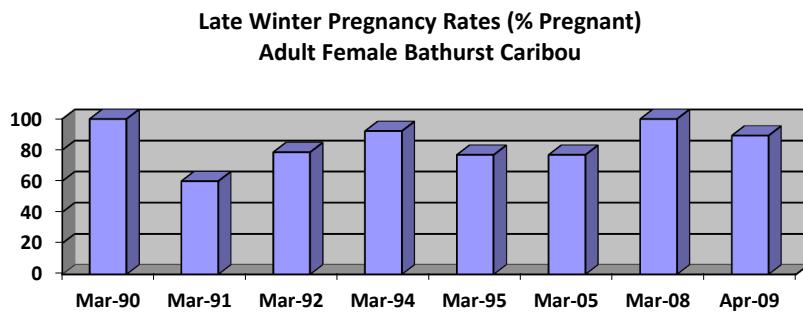
Figure 29. Pregnancy rates in Bathurst adult caribou cows assessed in late-winter hunts between 1990 and 2009.

Overall, the condition and pregnancy information for the Bathurst herd in 2007 to 2009, while based on limited sample numbers, suggests that the cows were in good or very good shape, with high pregnancy rates. Body mass and condition recorded by Dauphiné (1976) for Qamanirjuaq caribou in the 1970s were generally below the values recorded in these Bathurst collections. Body mass in autumn has been found to correlate strongly with pregnancy rate in caribou (Cameron et al. 1993, Russell et al. 1998), and the average Bathurst September body masses of 86.3 kg in 2007 and 94.9 kg in September 2008 should have translated to 80% and 90% pregnancy rates, respectively, in late winter 2008 and 2009, based on the relationships in those two papers. Actual pregnancy rates were 100% in March 2008 and 89% in April 2009. The scores from hunters for three collections also indicate that the cows were generally in good if not exceptional condition.

Environmental Trends (AG)

Weather can affect barren-ground caribou in a variety of ways. We provide some examples here, but this is not a full review of the subject. A late spring may mean that cows calve far from their preferred familiar calving grounds and summer calf survival is poor (Griffith et al. 2002) (Figure 30); summer forage may vary in quantity and quality (Chen et al. 2014); a hot dry summer may mean more fires on the winter range (Chen et al. 2013) or severe insect harassment in July (Helle and Tarvainen 1984); and above-freezing temperatures and rain may mean ice layers that make it difficult for caribou to reach their preferred winter forages (Chen et al. 2013)[16].

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[16] At the time of this report being written in 2009, use was made of two draft reports by W. Chen and co-authors, with those reports published later as Chen et al. (2013, 2014). A further relevant paper is Chen et al. (2018).
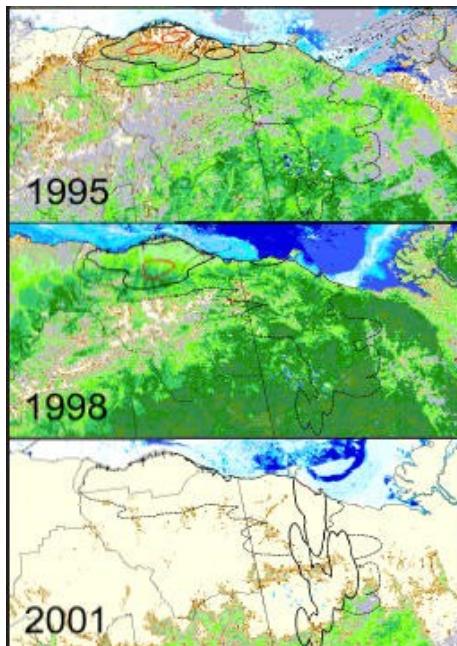
Figure 30. Satellite images of the Porcupine caribou herd's calving grounds in the first week of June in 1995, 1998, and 2001. Cows calved on their preferred calving grounds on the North Slope in 1998, with high calf survival. In 2001 cows calved in the mountains far from their normal calving grounds, with very poor calf survival (from Griffith et al. 2002).

The effects of environmental trends on caribou or other wildlife are difficult to evaluate because there is substantial variation at various temporal and spatial scales. One particular winter may be colder than average, but the trend over a five- or ten-year period may be warmer winters. Some regions may experience an unusual rain in December or January, but the effect may be limited in extent. The overall trends in the Bathurst herd's range, in recent years, have been warming temperatures and increases in precipitation, but less precipitation as snow. The plant growing season has grown longer and plant biomass has increased, but forage quality has shown a slight but non-significant declining trend. Snowmelt on the calving ground was annually variable; 1998 and 2008 were two early snowmelt years, and 2001 and 2005 were two late years. There has been a reduction in lichen-rich habitats on the winter range, largely as a result of forest fires. The period from 2006 to 2009 has not shown any major changes in environmental trends from the preceding years in the early 2000s. High pregnancy rates and good body condition in Bathurst cows 2007-2009 (see preceding section on composition surveys in the Bathurst herd and other herds), and higher spring calf:cow ratios (see Bathurst calving ground distribution surveys) than in the early 2000s suggest that overall environmental conditions for Bathurst caribou in 2007-2009 were improved over the early 2000s.

Trends for the Bathurst Calving Grounds and Summer Range

Based on satellite imagery for 1985-2006, there was essentially no green foliage biomass during the pre-calving period (21-31 May; Figure 31). During 1-10 June, only three of the 22 years had green foliage biomass >0.4 grams (1991, 1994, and 1998). The levels of green biomass during post-calving (11-30 June) varied annually and appeared to increase 55% from 1985 to 2006, but the high annual variation meant that the trend was not significant. The amount of green biomass correlates with the start date of plant growth – biomass was less when the date was later. The lichen vegetation classes decreased significantly from 1990 to 2000, from 44% to 22% of the total calving ground area, possibly due to shrub plants replacing lichens. The decrease in lichens relative to increase in vascular plants (Cornelissen et al. 2001) possibly is a result of competition for nitrogen, as nitrogen mineralization increases with warming temperatures (Epstein et al. 2004).
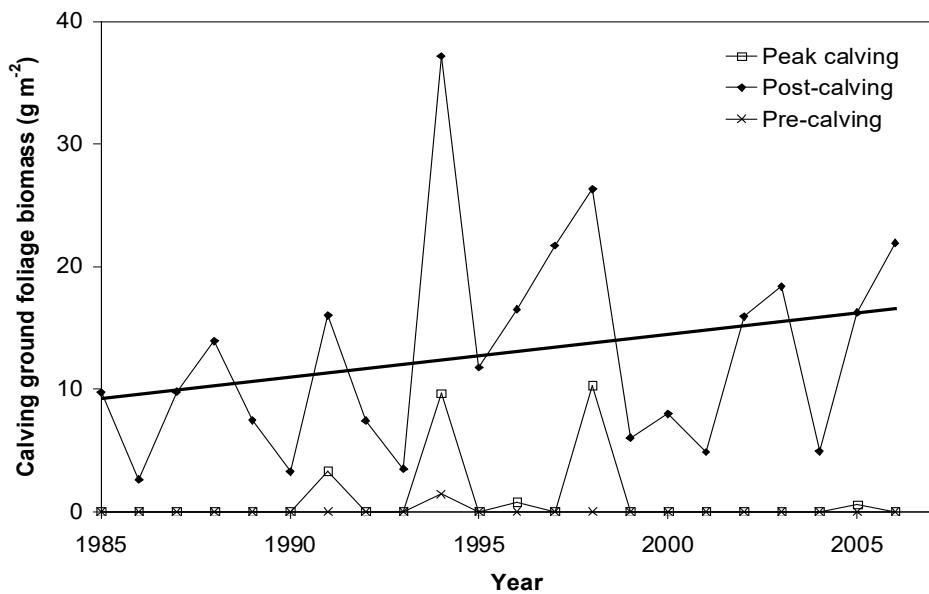
Figure 31. Green foliage biomass during pre-calving (21-31 May), peak calving (1-10 June), and post-calving (11-30 June) on the calving ground of the Bathurst caribou herd, 1985-2006 (adapted from Chen et al. 2014).

On the summer range (11 June to 20 September), mean foliage biomass showed a significant increasing trend despite high levels of annual variability (Figure 32). The longer the growing season, the greater the amount of biomass. However, an indicator calculated for forage quality, leaf nitrogen, decreased during 1985-1996, although the trend was not significant as annual variation was high. Leaf nitrogen was also negatively correlated with growing season length.
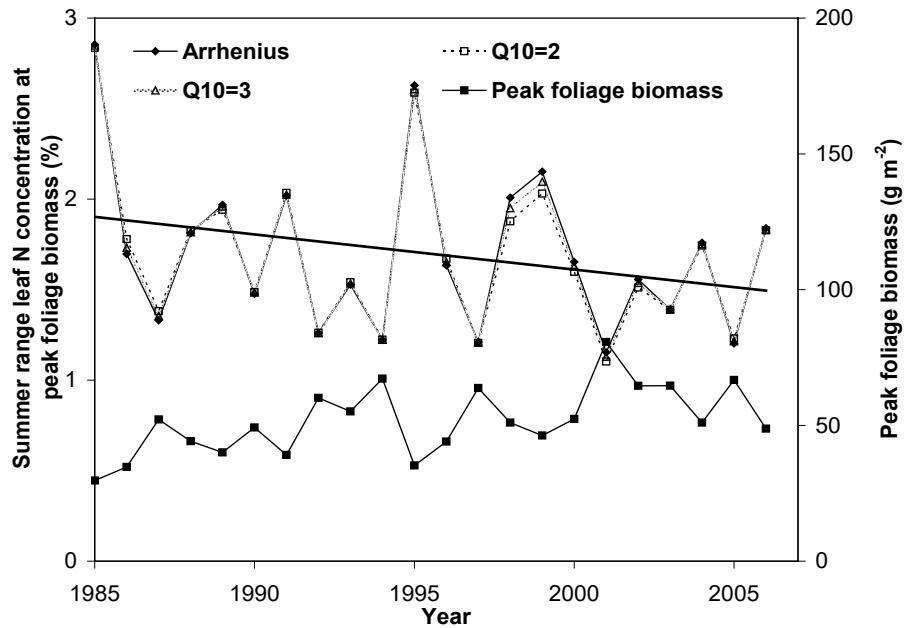
Figure 32. Summer forage availability indicator (foliage biomass), defined as the average foliage biomass from 11 June to 30 September in the summer range, for the Bathurst caribou herd, 1985–2006. The straight line represents temporal trend with R^2 = 0.29, F = 8.3, P = 0.009, and n = 22 (adapted from Chen et al. 2014).

Insects can affect caribou energy balance by interfering with feeding and by causing the caribou to run, walk and stand more than normal (Helle and Tarvainen 1984). The late 1970s and early 1980s marked the beginning of a global temperature increase. Based on this, the period of 1957-2005 was divided into two periods: 1957-1981, and 1982-2005. The number of "high" oestrid ratings was significantly greater in the 1982-2005 period than during the earlier time period (χ^2 = 18.68, df = 1, P < 0.01; Figure 33).
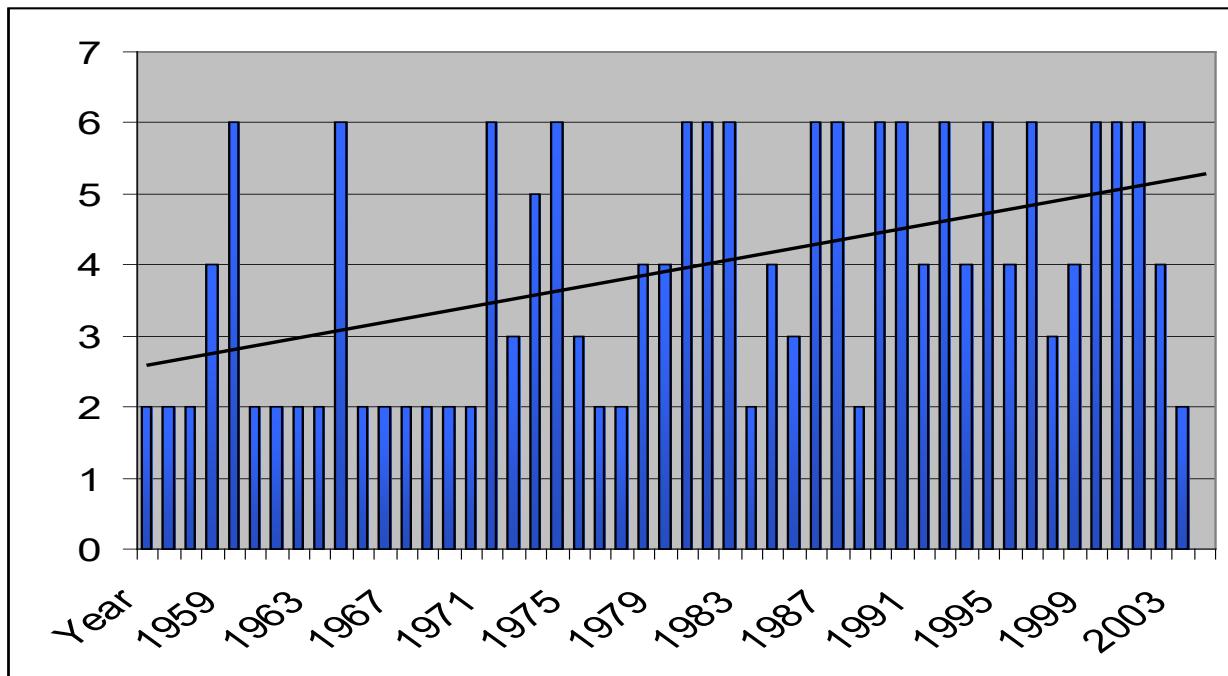
Figure 33. Trend line and annual scores for oestrid fly harassment (scored as 1 for low, 2 for moderate and 3 for high) based on 1957-2005 weather records for Contwoyto Lake, NU (from Gunn 2013).

Environmental Trends for the Winter Ranges

The area of lichen ranges as indexed by mature forests declined between 1959 and 2006, likely in part due to periodic forest fires (Figure 34). The area of forest burnt was significantly related to mean 1 June to 30 September temperatures over the winter range of the Bathurst herd during 1959-2006, and those temperatures have increased (Chen et al. 2013).
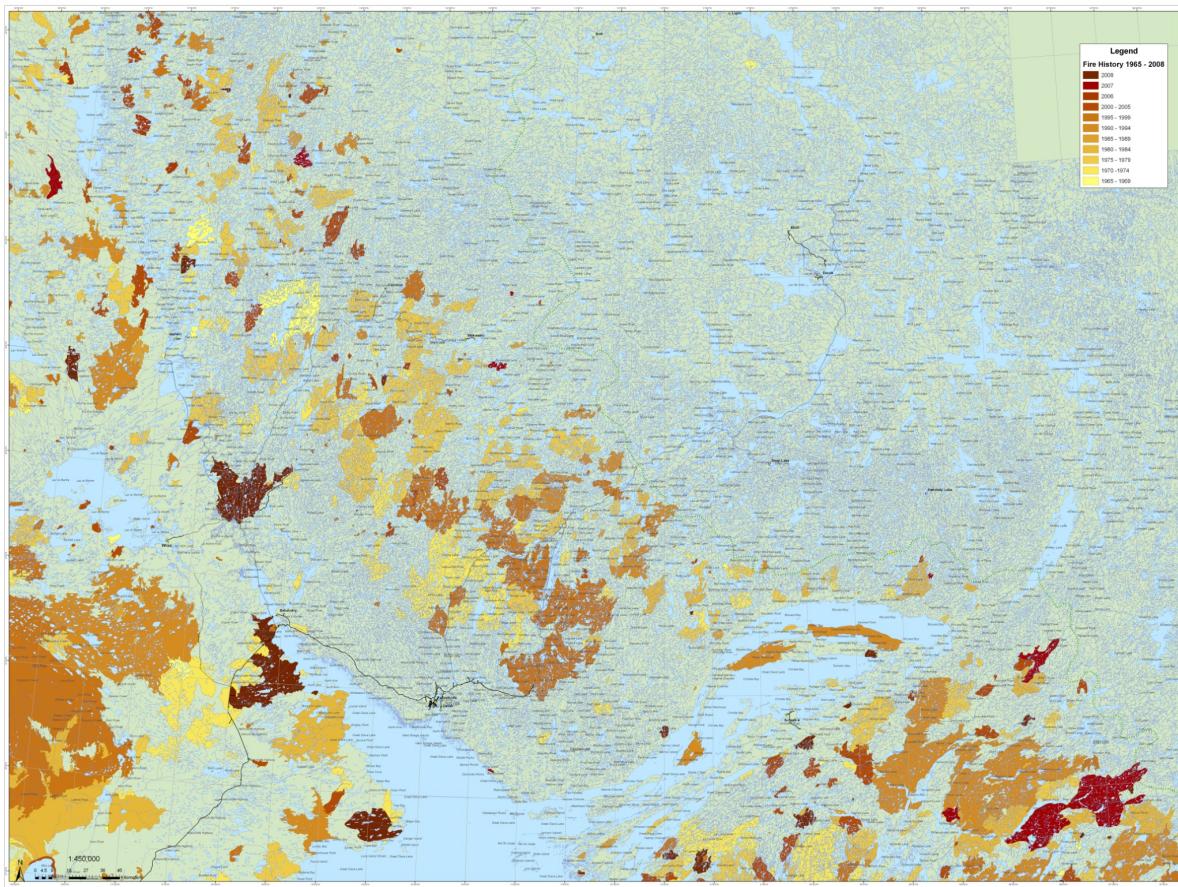
Figure 34. Map of fire history in the North Slave region of the Northwest Territories. Polygons of different colours identify fires of various ages from the 1960s to early 2000s. The darkest areas are for the most recent periods. The Bathurst herd's winter range covers a large area north and east of Great Slave Lake. Map provided by L. Schmidt, ENR.

Snow conditions influence the availability of forage for caribou. Two indicators are the annual maximum snow depth and ice content of the snow (Chen et al. 2013). A combined approach using data from the four weather stations on the Bathurst herd's winter range and remote sensing was necessary as snow conditions vary across the winter range. Maximum snow depth relates to October and April temperatures: a warmer October usually has less snow depth at the end of October, which contributed to less annual maximum snow depth. The trend toward warmer fall and late winter air temperatures reduced the annual maximum snow depth but increased the probability of thaw freeze events. The mean ice content in snow indicator may be caused by thaw-freeze events and rain on snow events and varies considerably between years and weather stations (1963-2006; Figure 35). The percent of years in which ice content in snow was >10 mm water equivalent increased from 14 to 43%, during 1960s to 2000-2006, respectively. Overall, the ice in snow indicator had a significant positive relationship with April-October air

temperature, indicating an increase in "hard" snow or icy crust in the snowpack under a warming climate (Chen et al. 2013).
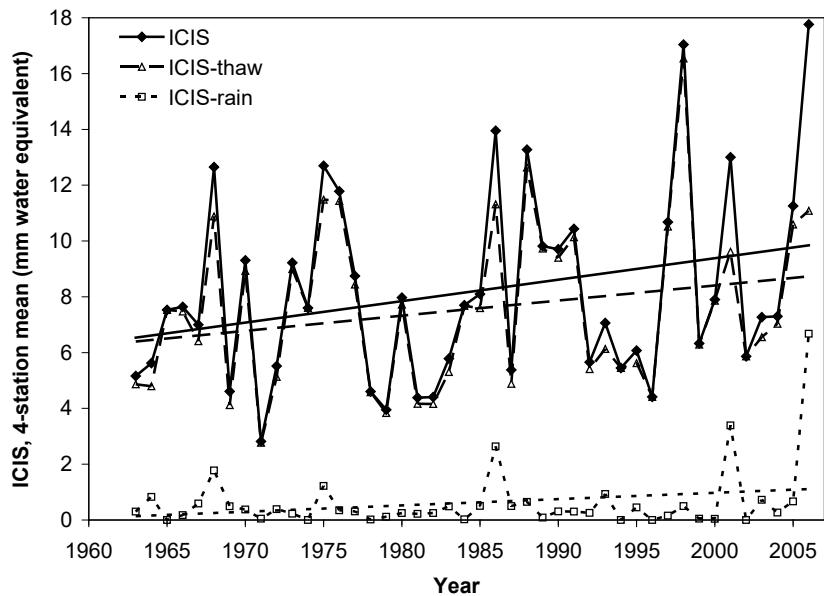
Figure 35. Mean ice content in snow (ICIS) for the winter range of the Bathurst caribou herd from 1963-2006, for Yellowknife, Reliance, Rae Lakes, and Uranium City climate stations. The straight lines represent temporal trends: for ICIS$_{rain}$ $y = 0.0225x - 44.065$, $R^2 = 0.06$, $F = 2.86$, $P = 0.1$, and $n = 44$; for ICIS$_{thaw}$ $y = 0.0544x - 100.4$, $R^2 = 0.06$, $F = 2.59$, $P = 0.12$, and $n = 44$; and for ICIS $y = 0.0769x - 144.48$, $R^2 = 0.08$, $F = 3.7$, $P = 0.06$, and $n = 44$ (adapted from Chen et al. 2013).

The average of snow presence/absence during pre-calving migration (16 April to 15 June) based on AVHRR imagery was annually variable, which prevents determining if there was a trend from 1982 to 2006 (Figure 36). Snow presence or absence during pre-calving migration was negatively correlated with 16 April to 15 June mean air temperature during 1982-2006.
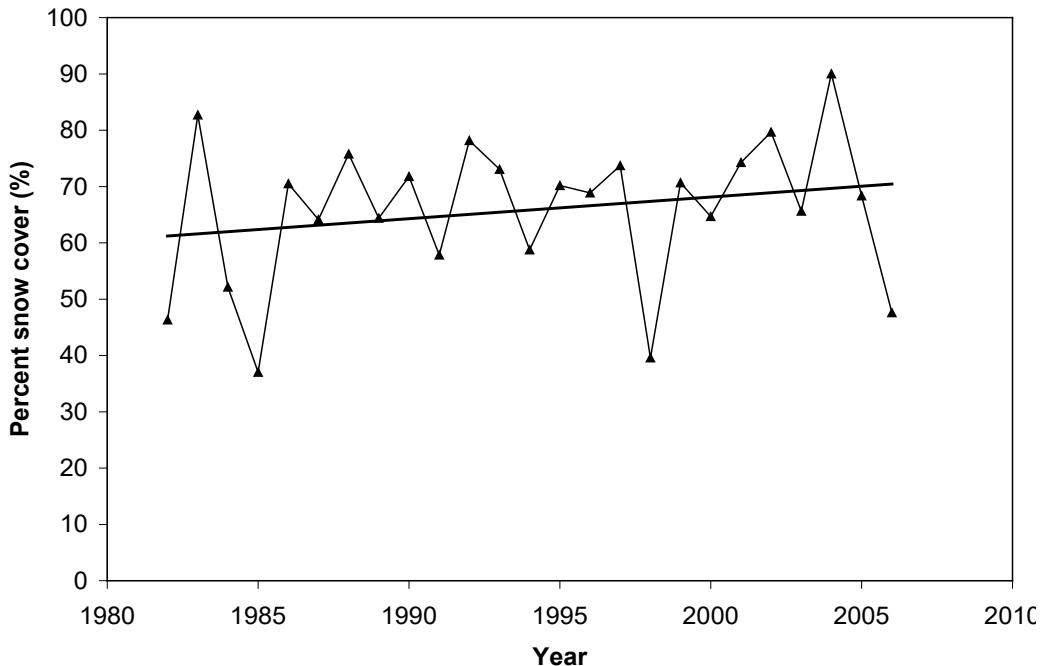
Figure 36. Percent snow cover averaged over the Bathurst caribou habitat during 16 April to 15 June from 1982-2006, derived from AVHRR Polar Pathfinder data. The straight line represents the temporal trend: $R2 = 0.05$, $F = 1.1$, $P = 0.3$, $n = 25$ (adapted from Chen et al. 2013).

On average, snowmelt took 20 and 23 days for snow cover at the Ekati mine site to change from 100% to 50% cover, and from 50% to 0% cover, respectively (Table 11, Figure 37). Year 2009 was noteworthy in that snowmelt was late as the 100 to 50% snow cover was the latest date recorded and took 36 days, but remaining snow disappeared quickly within five days, although not until 15 June. The rating of the years for whether snowmelt was early or late at Ekati generally correlated with the percentage of snow cover on the winter range (Chen et al. 2013) over the duration of pre-calving migration (Table 11). Years with lesser or greater snow cover had earlier or later snowmelt, respectively. On the calving ground (150 km north-northeast of Ekati) Croft (pers. comm. 2009) estimated that snow cover across the entire calving area in June 2009 was 50-80%, but once it began, snowmelt was exceptionally fast. Years 2007 and 2008 were actually a bit later as snow cover was consistently about 80% over the calving ground when the systematic reconnaissance surveys were done during the peak of calving for those two years.
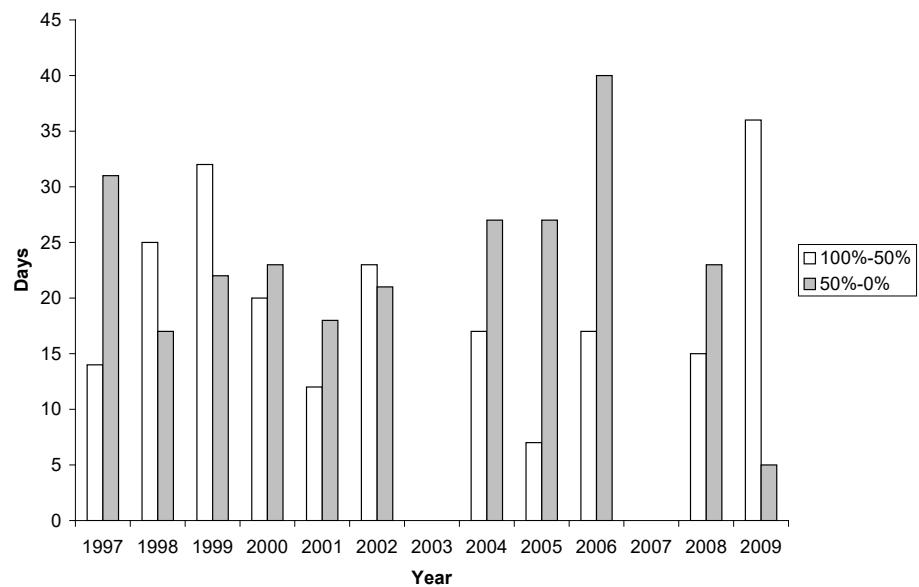
Figure 37. Number of days elapsed between the last day of 100% snow cover and the first day of 50% snow cover, and between 50% snow cover and 0% snow cover in the Ekati study area, 1997-2009 (calculated from Table 11).

Table 11. Timing of spring snowmelt in the Ekati study area, 1997-2009 (D. Abernathy, BHP Billiton, pers. comm.) and annual percentage snow cover averaged from 16 April - 15 June (data from W. Chen, pers. comm. 2009).

Year	100%	50%	0%	General timing	Percent snow cover	No. of days 100-0% snow cover
1997	16 May	30 May	30 Jun	Late	74	45
1998	16 Apr	11 May	28 May	Early	40	42
1999	27 Apr	29 May	20 Jun	Late	71	54
2000	3 May	23 May	15 Jun	Average	65	43
2001	21 May	2 Jun	20 Jun	Late	74	30
2002	1 May	24 May	14 Jun	Average	80	44
2003	2 May	-	28 Jun	Average[1]	66	57
2004	13 May	30 May	26 Jun	Late	90	44
2005	22 May	29 May[2]	25 Jun	Late	68	34
2006	20 Apr	7 May[3]	16 Jun	Early	48	57
2007	17 Apr[4]	-	12 Jun	Average		58
2008	17 Apr	2 May	25 May	Early		38
2009	5 May	10 Jun	15 Jun	Late		41
Mean	2 May	23 May	16 Jun			45

[1] Indications from the survey were that overall snowmelt was average
[2] Snow cover was 60%.
[3] Snow cover was 40%.
[4] Snow cover was 95%.

Peak of Calving and Entry of Satellite Collared Cows into the Calving Area

Dates of peak calving based on the movement data shifted about four days between the mid- to late 1990s (the first few years of the collaring program) to the years after 1999 (Table 12). The movement patterns indicated peak of calving in 2005 averaged about six days later than peak of calving during most of the remainder of the 2000s. With the exception of 2005, the peak of calving has remained stable (8-14 June) during the 2000s. The June 2009 calving ground photo survey provides an indication that the shift toward later calving may be reversing. The photo plane flew on June 8 and 9; a survey crew on those days recorded composition of calving caribou groups on these days and over half the cows had given birth by that point.

Overall mean dates for satellite collared cows crossing the outer and inner distance circles surrounding the centre of the Bathurst caribou calving ground were 21 May and 26 May, respectively. The trend in timing of arrival in the calving area was later between 1996 and 2005 (mainly due to the two earliest years being 1996 and 1998), but this trend does not appear to have continued over the past four years (Figure 38). Mean dates for crossing the outer and inner distances in 2009 were 23 May and 26 May, respectively. There

appears to be a pattern for alternate earlier and later years for six years then after 2003 the pattern changed.
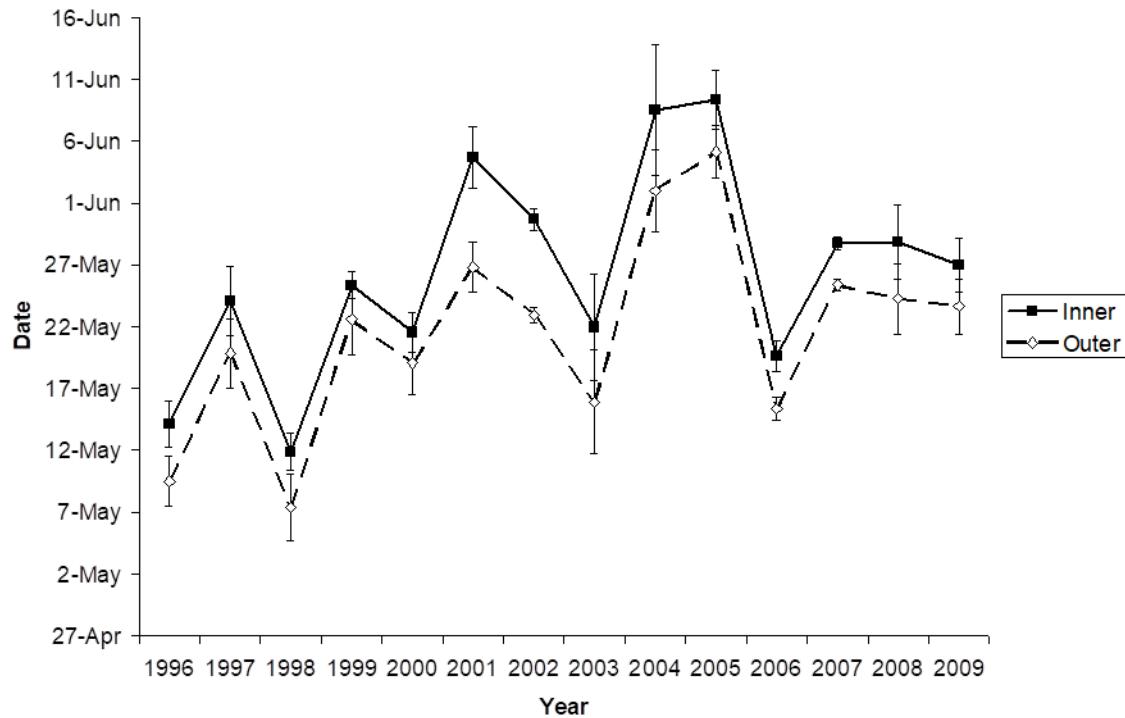
Figure 38. Mean (SE) dates of crossing of the outer (122 km radius) and inner (61 km radius) distance circles surrounding the centre of the Bathurst caribou herd calving grounds, 1996–2009.

With the exception of 2005, in all years only one to two collared caribou either did not enter the peak calving grounds or entered after the 10 June cut-off (Table 12). In all but four years this represented <8% of collared animals; on average 92% (±2.9% SE) of collared caribou entered the peak calving grounds prior to 10 June. Year 2005 was particularly unusual, as seven caribou (39%) entered the peak calving grounds late (13-30 June). These cows may not have been pregnant. Only one collared caribou did not enter the peak calving grounds in 2009; this animal stayed near the south end of Contwoyto Lake during early to mid-June, within the area covered by reconnaissance flights for the 2009 census (J. Nishi, pers. comm.). Observations in the field on the June 2009 survey suggested that the peak of calving had shifted slightly earlier in June. The photo-plane flew on June 8 and 9, while a helicopter-based crew carried out a composition survey. By June 8 and 9 over half the cows had a calf at heel, indicating that the peak of calving was likely June 6-9.

Table 12. Peak of calving for the Bathurst herd and proportion of collared caribou that reached the peak calving grounds (CG) by 10 June 1996-2009, as determined from satellite collar data (Gunn et al. 2008b and updated to 2009). Primarily GPS/satellite collar data were used in 2009. Determination of calving was based on changes in movement rates.

Year	Peak of calving	No. of caribou available for assessment	No. of caribou (%) that reached the CG by 10 June	Comments
1996	4-10 Jun	9	9 (100)	
1997	4-10 Jun	7	7 (100)	
1998	4-10 Jun	10	10 (100)	
1999	8-14 Jun	14	13 (93)	1 never entered CG
2000	8-14 Jun	13	12 (92)	1 never entered CG
2001	8-14 Jun	13	11 (85)	1 never entered CG; 1 late arrival; did not calve
2002	8-14 Jun	11	11 (100)	
2003	8-14 Jun	12	11 (92)	1 late arrival; did not calve
2004	8-14 Jun	6	5 (83)	1 late arrival; did not calve
2005	14-20 Jun	18	11 (61)	7 late arrivals; 2 calved, 5 did not
2006	8-14 Jun	14	14 (100)	
2007	8-14 Jun	19	19 (100)	
2008	7-10 Jun	12	10 (83)	2 late arrivals; did not calve
2009	6-9 Jun	13	12 (93)	1 never entered CG

Indirect Measures of Environmental Trends

Overall, the trends in environmental indicators point to changes over time on the calving, summer and winter ranges of the Bathurst herd, but there do not appear to have been major changes since 2006 that would identify a reason for the accelerated decline of the Bathurst herd after 2006. The higher recruitment, good condition of the cows (see sections on composition surveys in the Bathurst herd and other herds and pregnancy rate and body condition) and tendency in 2009 toward an earlier peak of calving, all suggest that the Bathurst herd was experiencing improved environmental conditions in 2007-2009 over 2000-2006. High calf survival is usually correlated with high adult natural survival rates in adult caribou (Bergerud 2000).

Age Structure (JB and AG)

In the Bathurst herd, years of low calf survival (2001-2006) led to changes in the herd's age structure. In particular the 2005 cohort was small as calf survival was especially low, and other cohorts from that period will also have low representation in the herd. Weak cohorts and a shift in age structure could influence both the decline and potential recovery of the Bathurst herd.

For migratory tundra caribou, changes in age structure are relatively little discussed in the context of changes in abundance. This is partly because age specific data are often lacking, or sample size is low. Yet in other long-lived mammals, the importance of age structure relative to census data for detecting declines is well-recognized, for example, in marine mammals (Holmes and York 2003) and in other large-bodied herbivores (Festa-Bianchet et al. 2003, Coulson et al. 2004). Coulson et al. (2004) commented that cohort performance is under-estimated as a factor in demography. They reported that a deductive construction using density-dependent age- and sex-specific survival and recruitment functions with climate, explained 90% of the variation in population growth of Soay sheep. Their model captured important, persistent differences in the contribution of different cohorts to the population dynamics of the sheep.

The role of weak cohorts rather than a sustained trend in low recruitment was a factor in the decline of the Alaskan Nelchina herd (Eberhardt and Pitcher 1992). These authors described age structure reconstructed from 2,800 hunter-contributed mandibles (1954-1971). The reconstruction revealed three years (1964-1967) when recruitment was extremely low, and those weak cohorts were a driving factor in the herd's decline.

The second aspect of age structure apart from weak cohorts is that reduced recruitment in a sequence of cohorts will shift the overall age structure from middle-aged to older females. Bergerud et al. (2008) used mandibles from hunters and found that in the George River herd, the mean age of females increased from the increasing phase to the decline phase (1974-1993) by 13 months (Bergerud et al. 2008). One effect of a shift to older females is older females having reduced condition and greater frequency of breeding pauses. A second effect is that in large-bodied ungulates, survival decreases with senescence. For example, estimates of adult survival have to include senescence to avoid serious errors (Eberhardt 1985).

Bathurst Data

Female age specific-survival data with ages based on cementum annuli were available through the CARMA database for 1990 (12); 1991 (50); 1992 (35) provided by D. Heard and M. Williams (details in Gunn et al. 2005a). A second dataset is available from 2007-2008 collections (data from B. Elkin and B. Croft, ENR, September 2009). In September 2007 and March 2008, year classes were available for 44 females (data from September 2008 and April 2009 had not been received).

The early 1990s data were obtained when the Bathurst herd was at its peak and suggest a small shift in age classes toward an older age structure in the late 2000s (Figure 39). Interpretation is limited by small sample sizes in the year classes, especially the first three cohorts. Further analyses could be considered when the 2008 and 2009 age assignments are available. With overall cow mortality rates estimated at 32% in 2009 (see Assessment

of the impact of harvest on trends in adult survival) it is likely that relatively few cows reached advanced ages at which poor condition might affect survival and reproduction.
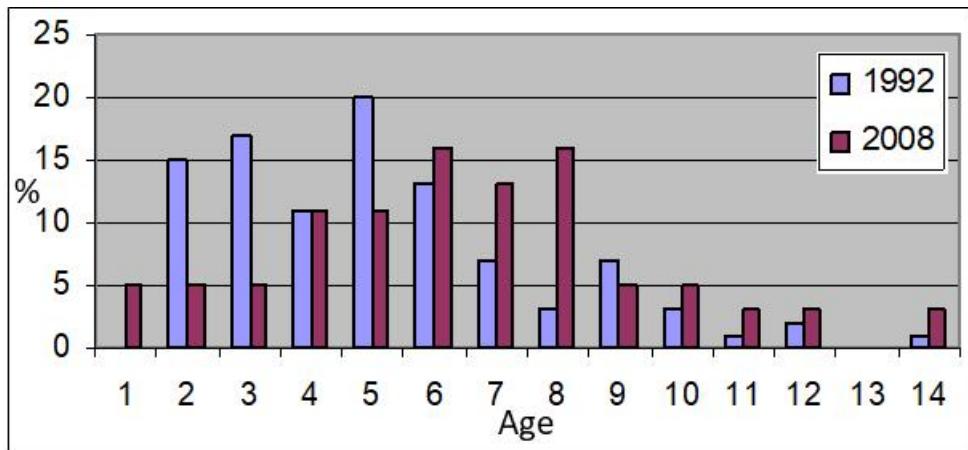
Figure 39. Distribution (%) of ages at death of female Bathurst caribou from condition studies in 1992 (n=97) and 2008 (n=38). The herd was at high numbers and stable/declining slightly in 1992 and had a greater representation of young cows than in 2008.

One of the outcomes of the OLS modeling (see Bathurst herd decline: modeling outcomes using OLS models) was a re-construction of the Bathurst herd's likely age structure from 1986-2009 (Figure 40). This is not based on empirical data but also suggests that by 2009, the age structure of the herd's cows would have a high proportion of young cows from the increased recruitment 2007-2009, and a higher representation of older cows than in the 1980s. The large proportion of very young females could mean a delayed recovery as these females would need another year or two to reach breeding age. If many older females had a lower reproductive output or lower survival, this could have contributed slightly to the herd's decline in the late 2000s.
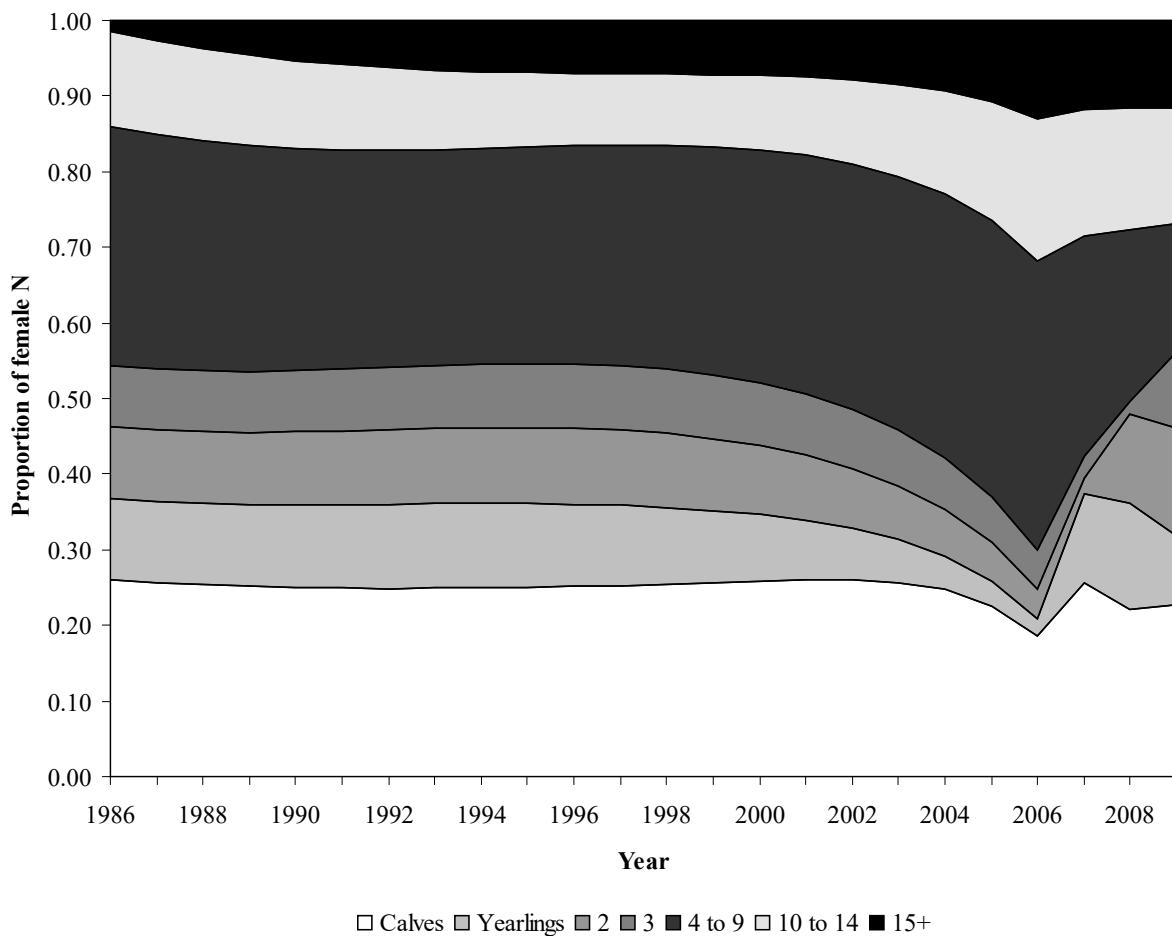
Figure 40. Trends in (modeled) estimated proportion of age classes (females only) based on reconstruction of age classes. Estimates are from the most supported OLS model. Caribou aged four to nine are usually considered to have the highest level of reproductive output (fecundity and calf survival).

Hunter Harvest

Accurate and up-to-date harvest reporting is one of the key information gaps for the Bathurst herd, and for other NWT caribou herds, particularly when the herds are declining and at low numbers. Some of these herds range over large areas and harvest from all sources must be considered. In this section we report the information that is available on harvest of Bathurst caribou.

Indigenous Harvest of Bathurst Caribou (JB and BC)

Reporting of Indigenous harvest of barren-ground caribou in the NWT has varied over time, although all estimates and reported data indicate that it has been the main part of the harvest for this herd. In the Inuvialuit, Gwich'in and Sahtú Settlement Areas, harvest studies mandated by land claims agreements have produced five or more years of

information on Indigenous harvest of caribou and other wildlife. However, those harvest studies ended several years ago and harvest information since then has been incomplete.

A study of Indigenous harvest in the Tłı̨chǫ region was carried out for six years from 1988-1993 (Table 13). We assume that most of this harvest was Bathurst caribou, however recent satellite collar studies indicate some overlap in winter with Bluenose-East caribou to the west and Ahiak caribou to the east. In the late 1980s and early 1990s the Bathurst herd was estimated at about 350,000. The average number of Bathurst caribou taken annually was estimated at 15,864, with slightly more than half (8,380) being cows. This would be about 4.5% of a herd of 350,000. Some observers have suggested that the numbers are substantial over-estimates, and that the harvest in more recent years was well below these totals (pers. comm. Earl Evans, Ft. Smith, 2009).

Table 13. Numbers of caribou hunted annually 1988-1993 in the Tłı̨chǫ region from the Bathurst herd, based on the Dogrib harvest study. From Boulanger and Gunn (2008).

Year	Number of bulls taken	Number of cows taken	Total caribou taken
1988	4,606	3,318	7,924
1989	3,855	4,730	8,585
1990	8,970	8,450	17,220
1991	10,073	11,626	21,699
1992	9,685	9,046	18,731
1993	7,712	13,107	20,819

The North Slave ENR regional office in collaboration with the Tłı̨chǫ Lands Protection Department operated a check-station on the winter road to Gamètì and Wekweètì in winters 2007-2008 and 2008-2009, to monitor the caribou harvest. In addition, hunters from Whatì, Gamètì and Wekweètì were interviewed to determine numbers of caribou harvested during the two years of the project from hunters of those three communities (Figures 41, 42). The totals reported in the last two winters were 1,690 and 2,712 caribou respectively, with more than half being cows (B. Croft and T. J. Rabesca, ENR, unpublished data). However, these totals are under-estimates for the following reasons:

(1) Not all active hunters were interviewed each year and no correction or adjustment factor was applied to account for missing hunters.

(2) Some of the hunters interviewed very likely under reported their harvest for fear of consequences to their subsistence harvest rights.

(3) Some hunters did not recall exact numbers of caribou harvested given the time lag between the harvest and the interview date; this also applied to the sex ratio in the harvest.

(4) There was a high turnover rate of staff at the check station, at times leaving the station unattended when south-bound hunters were driving by.

(5) Some hunters did not stop to report their harvest at the check station.

(6) Wounding losses would not be picked up by the check-station or the interviews.

Doubling the results of this reporting project, as suggested by wildlife officers in the field, would add up to 3,380-5,424 caribou, primarily cows, and the total winter harvest may have been higher in some years.
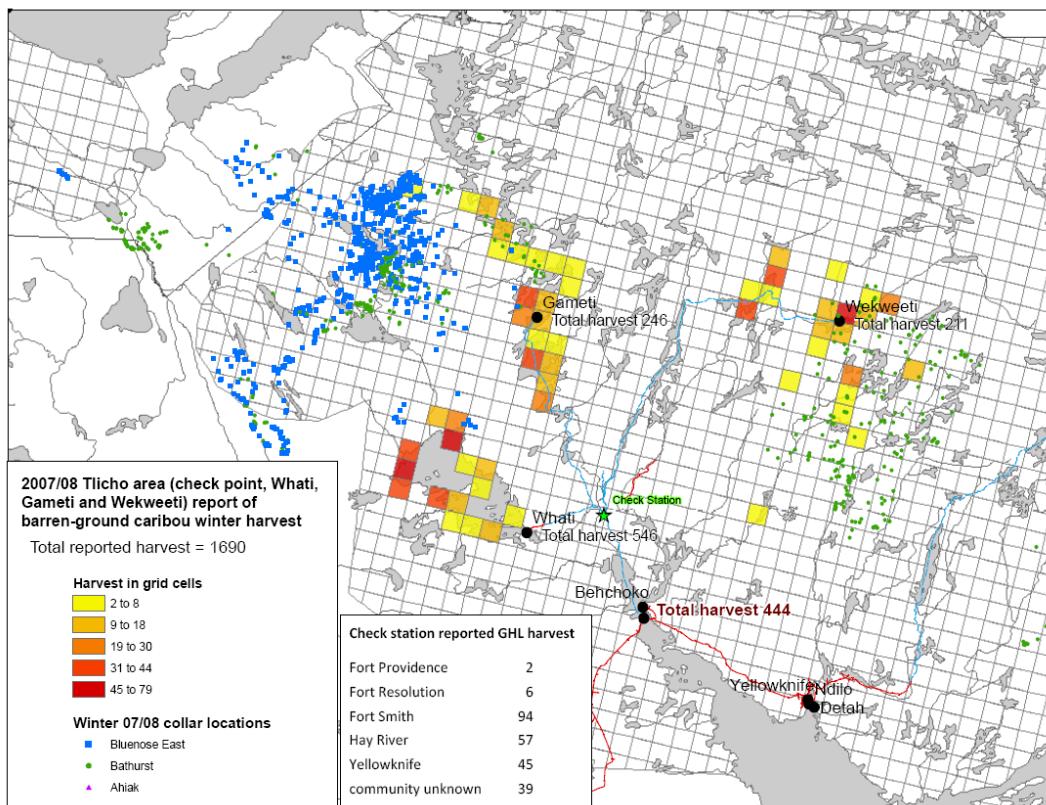
Figure 41. Map showing harvest of caribou in winter 2007/2008 near Tłįchǫ communities north of Yellowknife. The squares are 10x10 km blocks and the colour scheme reflects relative numbers of caribou taken. Blue dots are winter satellite collar locations of Bluenose-East caribou and green dots are Bathurst satellite collar locations. There were generally more Bluenose-East collar numbers than Bathurst, which accounts for the greater number of blue dots.
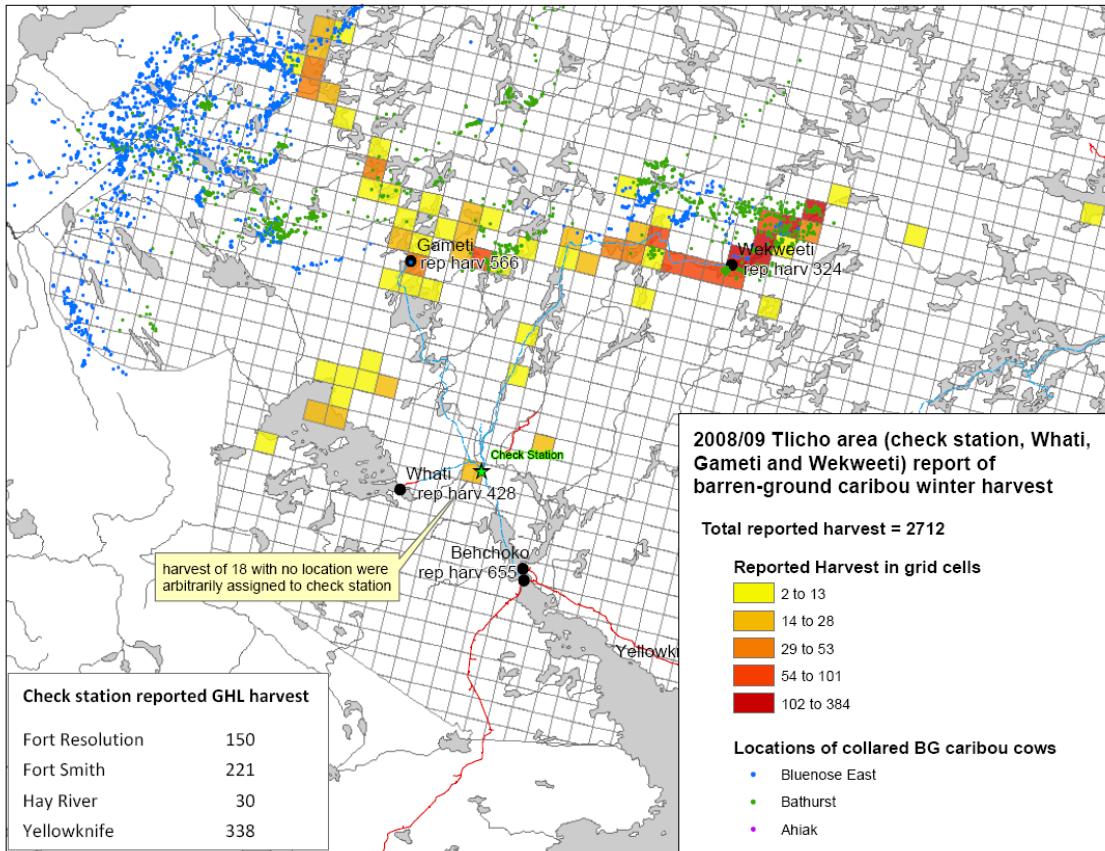
Figure 42. Map showing harvest of caribou in winter 2008/2009 near Tłı̨chǫ communities north of Yellowknife. The squares are 10x10 km blocks and the colour scheme reflects relative numbers of caribou taken. Blue dots are winter satellite collar locations of Bluenose-East caribou and green dots are Bathurst satellite collar locations.

The population modeling by J. Boulanger provided an opportunity to derive an approximate estimate of the cow harvest (see assessment of the impact of harvest on trends in adult survival) by back-calculation from survival rates. We emphasize that this is a model approximation of a harvest that is a reasonable fit with other demographic indicators, not an empirical estimate. The model estimated cow survival rate at 0.86 in the 1980s when the effects of harvest were very low relative to herd size. If this survival rate is used as an estimate of natural cow survival, then the difference between 0.86 and the model-estimated survival rate in 2008-2009 of 0.68 should be roughly equal to hunting mortality of cows. This translates approximately to an annual harvest of 5,000 cows (see assessment of the impact of harvest on trends in adult survival). This estimate is based on the assumption that relative natural mortality levels, movements and other factors affecting apparent survival did not change appreciably over the time period studied. A similar back-calculation by C. Nicolson using the Bathurst Caribou Calculator suggested

that the estimated annual harvest included about 4,000-5,000 cows, i.e. that harvest fits well with other indicators. In some winters (but not in recent years) satellite collared Bathurst caribou have wintered in northern Saskatchewan and Indigenous hunters from communities in the northern part of the province likely took some Bathurst caribou. The numbers of caribou taken by hunters from those communities are not well documented.

Table 14 was reported by Nesbitt and Adamczewski (2013) as a summary of how Indigenous hunting practices have changed in the last 30-40 years, based on observations by W. Bayha, J. Rabesca, M. Rabesca, D. Beaulieu and others at a workshop on caribou population models and hunter harvest in May 2009 in Yellowknife. During earlier periods of caribou scarcity, hunters shifted to other game or fish, and some regions remained remote. This most likely helped caribou herds to recover at times of low numbers. In the present day, however, access during winter is much greater due to winter roads to the communities and diamond mines north of Yellowknife, and there are many more trucks and skidoos than in the 1970s when caribou were last at low numbers. Hunters from many communities north and south of Great Slave Lake hunted the Bathurst herd in recent years (up to 2009).

Table 14. Comparison of traditional hunting practices and present-day Indigenous hunting in the NWT (from Nesbitt and Adamczewski 2013).

Traditional hunting	Current hunting
Done with snowshoes / dog-team / slower snowmobiles with small wooden toboggans	Fast, wide-track snowmobiles with large teflon and fiberglass toboggans. People even hunt from trucks and vans on the winter roads.
Good organization / Community / Social event	Many small groups / often strangers
Open scope. Less accuracy. Fewer animals taken	High powered rifles with scopes – shoot from a distance; shoot many quickly
Taking your time	Done quickly
Part of the lifestyle	Done for sport
Selecting healthy animals from herd	No selection of healthy animals
Leaving most of group / herd alive	Killing all of a group.
Letting the leaders pass	Killing the first animals through
Conservation education built into lifestyle	No awareness of conservation ethic
Selecting sex based on use/need	Killing indiscriminately
Taking only what was needed	Killing more than is needed
Sharing meat	Selling meat. Stories of dump trucks coming from other communities to take caribou away.
Using all of the animal	Wasting meat
Taking elders along	Not practiced as much now
Asking permission to use the land	People coming from everywhere
Easy to track how many animals taken	Very difficult to track number of animals taken
Leaving the bones / remains to rest on the land	Carcasses at the dump or left on ice roads
Caribou weren't always accessible. Successful harvest depended on their migration route	Hunters access caribou wherever they are – regardless of migration pattern. Airplanes, roads, fast snowmachines, etc.
People lived with/ followed caribou population cycles - harvest decreased when numbers were low	Even during low population cycles, harvest stays high because people can always access the animals.

Satellite collar locations of caribou from the Bluenose-East, Bathurst and Ahiak herds for 2005-2009 in winter are shown in Figure 43. These maps demonstrate the year-to-year variation in areas used by the three herds in winter, as well as the degree of overlap between neighboring herds. Overlap between neighbouring herds is common in winter. In 2005 Bathurst caribou (green) were scattered across a big area north of Great Slave Lake, with some overlap with Bluenose-East caribou (red). In 2006 the Bathurst collars were mostly east of Great Slave Lake and overlapped with Ahiak collars (purple). Tłįchǫ hunters would have been hunting mostly Bluenose-East caribou.
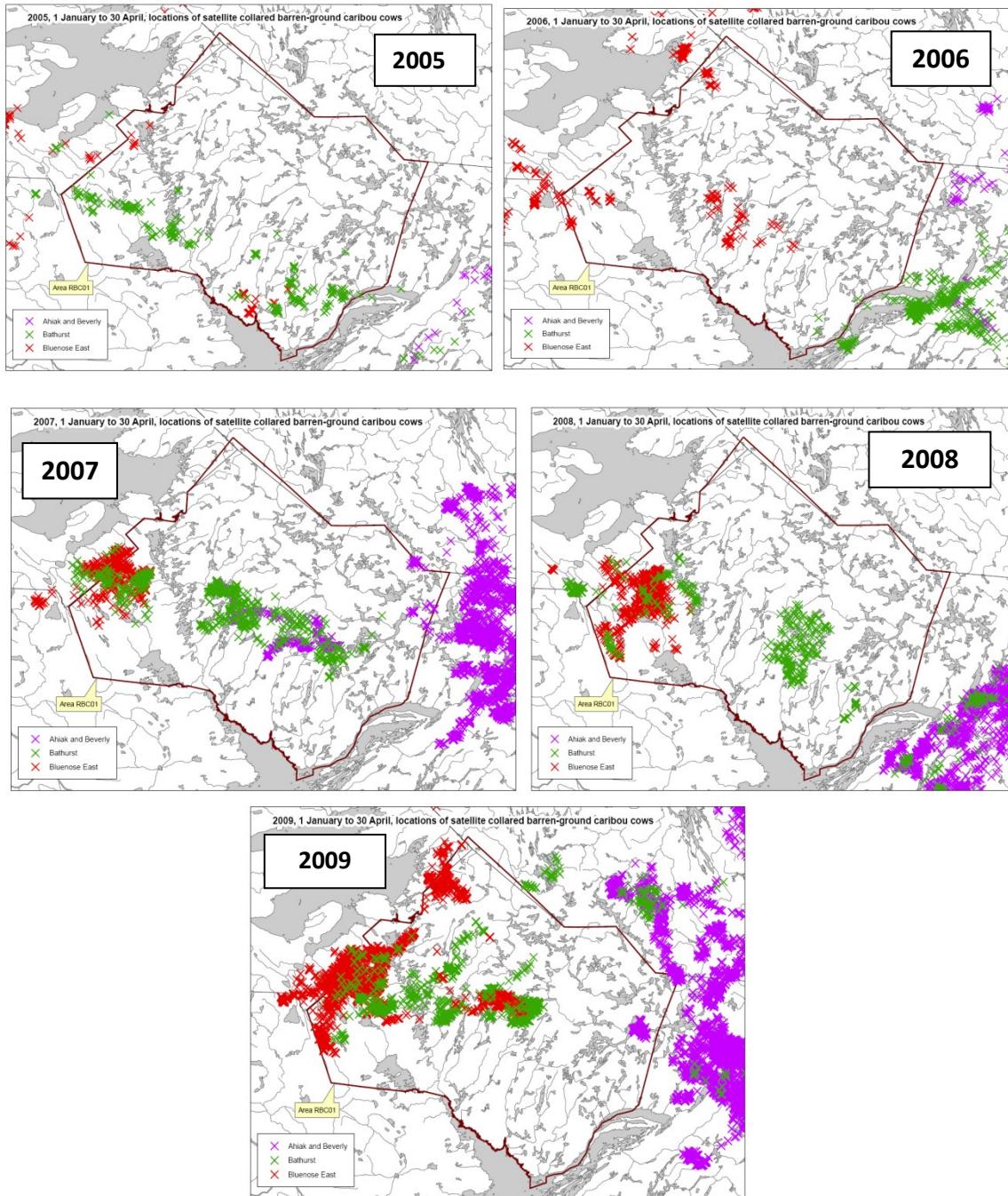
Figure 43. Satellite collar locations in winter of Bathurst, Bluenose-East and Ahiak caribou, 2005-2009. Numbers of collars were variable among herds, with generally the lowest numbers of collars in the Bathurst herd.

In 2007 the Bathurst collars were back north of Great Slave Lake and overlapped extensively with Bluenose-East caribou south of Great Bear Lake. In 2008 the collar locations were generally similar to the previous year. In 2009 many caribou wintered north

of treeline in all three herds, possibly because of shallow snow on the tundra. Bathurst collars again overlapped extensively with Bluenose-East collars in that year.

Resident Harvest of Bathurst and Other Barren-ground Caribou (JA)

The reported harvest of barren-ground caribou by resident hunters in the NWT is shown in Figure 44 from 1983/1984 to 2007/2008. Since 2006, NWT residents have been limited to bull-only hunting. Resident hunters from the Inuvialuit, Gwich'in and Sahtú Settlement Areas hunted primarily Cape Bathurst, Bluenose-West and Bluenose-East caribou. Resident harvest in these three land claim areas was reduced to 0 in 2006-2007. Resident hunters from Yellowknife and the North/South Slave regions hunted primarily Bathurst caribou and possibly some Bluenose-East caribou in the fall and winter due to overlap on these ranges.
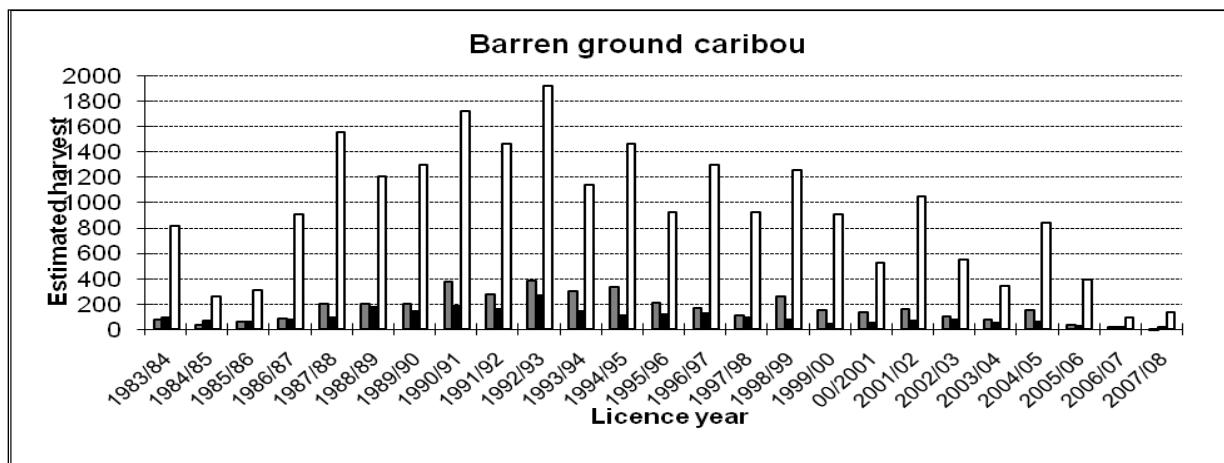
Figure 44. Reported annual resident harvest of barren-ground caribou in the NWT from 1983/1984 to 2007/2008. White bars are Yellowknife hunters, grey bars are hunters in Inuvialuit, Gwich'in and Sahtú Settlement Areas, and black bars are North Slave (except Yellowknife) and South Slave regions. (S. Carrière, ENR, Yellowknife)

The largest numbers of barren-ground caribou taken by resident hunters were in the early 1990s. Over 2,000 caribou were taken in 1992/1993 by residents. The resident harvest of caribou has declined since those years and by 2006/2007 and 2007/2008 was less than 200 caribou from all herds. Since 2006 only bull caribou can be taken by resident hunters, and the sex ratio (females to males) declined to 0 by 2007 (Figure 45).
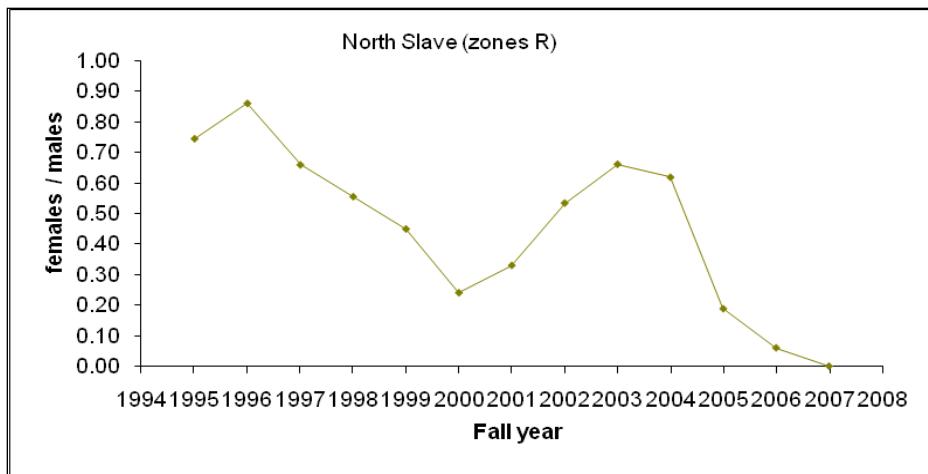
Figure 45. Sex ratio (females: males) in barren-ground caribou taken by resident hunters in the North Slave region 1994-2008. (S. Carrière, ENR, Yellowknife)

Outfitter Harvest of Bathurst Caribou (JA)

The total harvest of caribou bulls by outfitters from 1997-2009 is listed in Table 15. The average annual harvest was 828 bulls, with the highest total in 2001 at 1,166 bulls, and declining harvest totals from 2005-2009. Maps of satellite collared Bathurst, Ahiak and Bluenose-East caribou indicate that the outfitter camps accessed primarily Bathurst caribou in August and September in most years, with some access to Bluenose-East caribou from the more western camps (Figure 46). The exception was in 2009 when most of the collared cows and bulls near outfitter camps were from the Bluenose-East herd. Collared Ahiak caribou were not near the outfitter camps in any year for which we have collar information.

Table 15. Total number of caribou bulls taken by caribou outfitters in Wildlife Management Unit R, from records kept by North Slave ENR regional staff.

Year	Numbers of tags issued	Number of bulls taken
1993	586	517
1994	485	309
1995	651	574
1996	770	684
1997	900	717
1998	959	784
1999	1,118	943
2000	1,147	960
2001	1,342	1,166
2002	1,425	1,150
2003	1,252	910
2004	1,163	912
2005	1,211	850
2006	1,241	730
2007	691	605
2008	610	419
2009	503	223
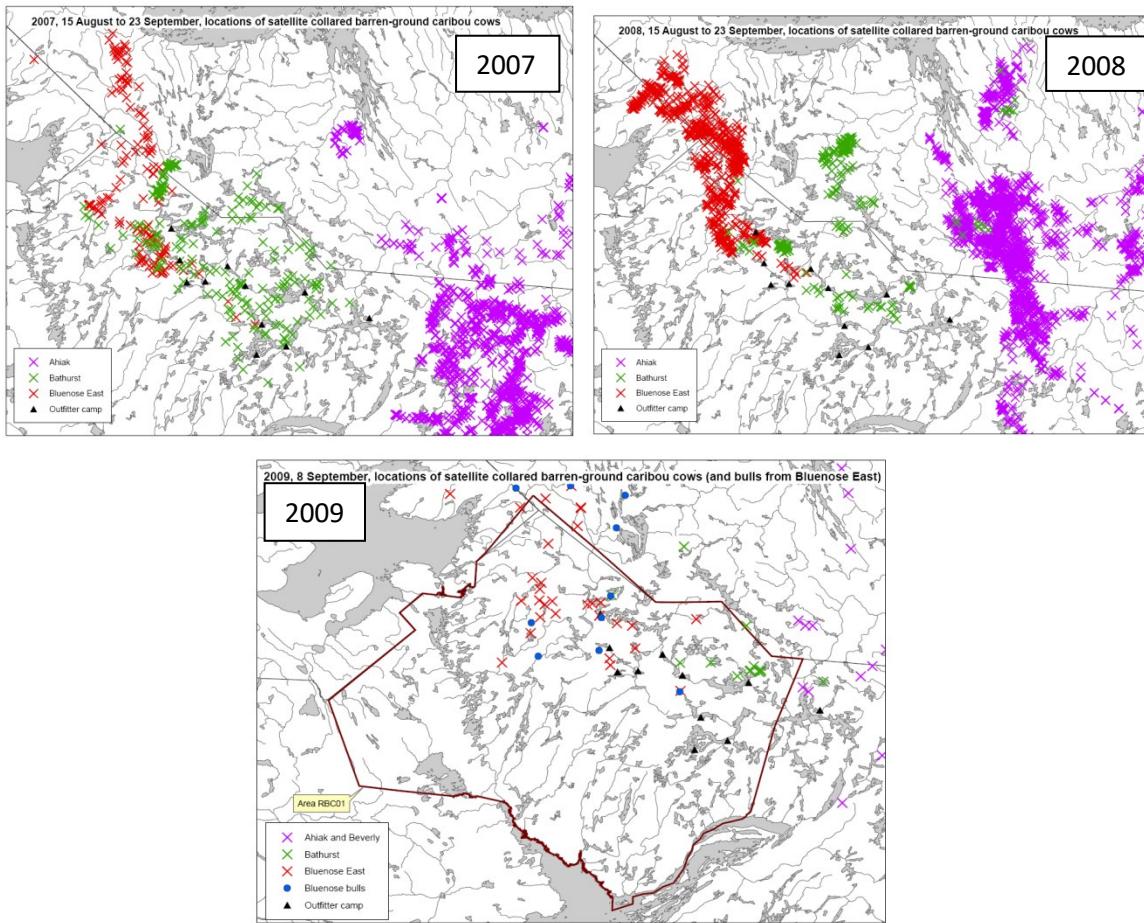
Figure 46. Satellite collar locations of caribou from the Bluenose-East (red), Bathurst (green) and Ahiak (purple) herds in fall 2007 (above left), fall 2008 (above right), and in early September 2009 (bottom left). Camps used by outfitters are black triangles. Blue dots are satellite collared Bluenose-East bulls.

Total Hunter Harvest 2006-2009

With an average total of 415 bulls taken annually by outfitters (2006-2009), 100-200 caribou, primarily bulls, taken annually by resident hunters, and an approximate estimate of 4,000-5,000 cows and 1,000-2,000 bulls taken by Indigenous hunters, the total Bathurst harvest was likely in the range of 4,000-5,000 cows and 1,000-2,000 bulls/year in the last three years. Harvest totals likely varied from year to year, depending on weather and accessibility of caribou from roads and communities.

Wolves in the Bathurst Range (DC)

Population sizes of wolves (*Canis lupus*) are difficult to estimate because wolves range over vast areas, exist at relatively low densities, have secretive behaviour, and limit their activity during daylight hours. Wolves that follow migratory barren-ground caribou add to

the difficulty by having increased annual home range sizes. Wolf populations are composed of packs and lone individuals. Pack size usually varies seasonally while most lone wolves are only temporary situations (Mech and Boitani 2003). Consequently, counting wolves can be a complex and costly effort easily susceptible to biases and errors. Standardized, accurate, and cost-effective methods of assessing wolf distribution and abundance are lacking and need to be identified and implemented (Fuller et al. 2003).

What constitutes a wolf population can also be problematic. A wolf population can have a geographic, ecological or genetic basis (Fuller et al. 2003). Population assignment studies have not been done in the north although wolves are generally classified as boreal, tundra, or Arctic wolves. Tundra wolves are also genetically distinct from wolves associated with prey resident in the boreal forest regions, therefore tundra and boreal forest wolves do not mix significantly during the breeding season (Musiani et al. 2007).

Wolf Den Site Monitoring

If trend (increasing, stable, and decreasing) in the wolf population is sufficient for management then an index of wolf abundance can be used. An index of population size requires a measurable variable correlated with density (Caughley 1977). Tundra-denning wolves show a strong fidelity to a denning area and often return to the same site each year. Consequently, den site occupancy should be a suitable parameter for such an index. The assumption would be that with more wolves there would be more dens, ideally in a linear relationship. The treeless tundra and extended daylight hours allow wolves to be observed from the air which is usually not feasible in forested areas further south.

Wolves den throughout the range of the barren-ground caribou, especially on the tundra and treeline areas where caribou can be expected during spring and summer. However, the distribution of wolf dens is not uniform and is influenced by habitat features and caribou movement patterns (Heard and Williams 1992). Wolves denning on the tundra tend to select areas on or near eskers and other similar landforms that resulted from melting glaciers (Mueller 1995, McLoughlin et al. 2004). The distribution of eskers on the tundra reflects the pattern of glacial retreat and was not uniform. Because wolves incorporate esker distribution at the home range scale (McLoughlin et al. 2004), an index tracking wolf abundance must consider esker density in the survey design.

Wolves are territorial animals and normally defend an area as a pack (Mech and Boitani 2003). Wolves that hunt migratory barren-ground caribou do not appear territorial in winter but likely are in summer (Walton et al. 2001, Cluff et al. 2002, Frame et al. 2007). Therefore, an active wolf den at one site likely means that there is not another one nearby. From 1996-2006 surveys, the mean distance between the next closest active den was 13.0 km (SD=5.5 km, n=11 years) with a range of 5.5-23.8 km.

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The wolf den survey area in the North Slave Region includes Aylmer and Clinton-Colden lakes to the east, the Nunavut boundary to the north, Point Lake and Jolly Lake to the west, and Lockhart and Fletcher lakes to the south (Figure 47). In 2009, the survey study area was divided into 744 grid cells encompassing over 74,400 km².

Den Survey Methods

Wolf den sites tended to be discovered opportunistically but in 1996, eskers on the central tundra of the Bathurst caribou range were systematically inventoried to locate dens. This inventory was part of a West Kitikmeot Slave Study Society (WKSS) baseline study examining the relationship of wolves and esker habitat (Cluff et al. 2002, McLoughlin et al. 2004). The search effort also benefitted from revisiting den sites found previously (Williams 1990, Heard and Williams 1992, Mueller 1995). While most wolf dens were expected to be located on or near eskers, other survey opportunities have allowed other habitat types to be flown to test if wolves could have denned elsewhere. From 1997 to 2004, wolves were captured and radio collared (Walton et al. 2001, Cluff et al. 2002, Frame et al. 2007) and their movements also confirmed the preponderance of eskers as denning locations. Since 1996, some eskers continued to be surveyed for dens but in an *ad hoc* manner while navigating between sites. However, in 2008, a 10 km x 10 km grid cell approach was formally adopted to better quantify den site occupancy. Sites of wolf dens surveyed in May-June 2009 are shown in Figure 47 and the numbers of active dens at that time are shown in Figure 48.
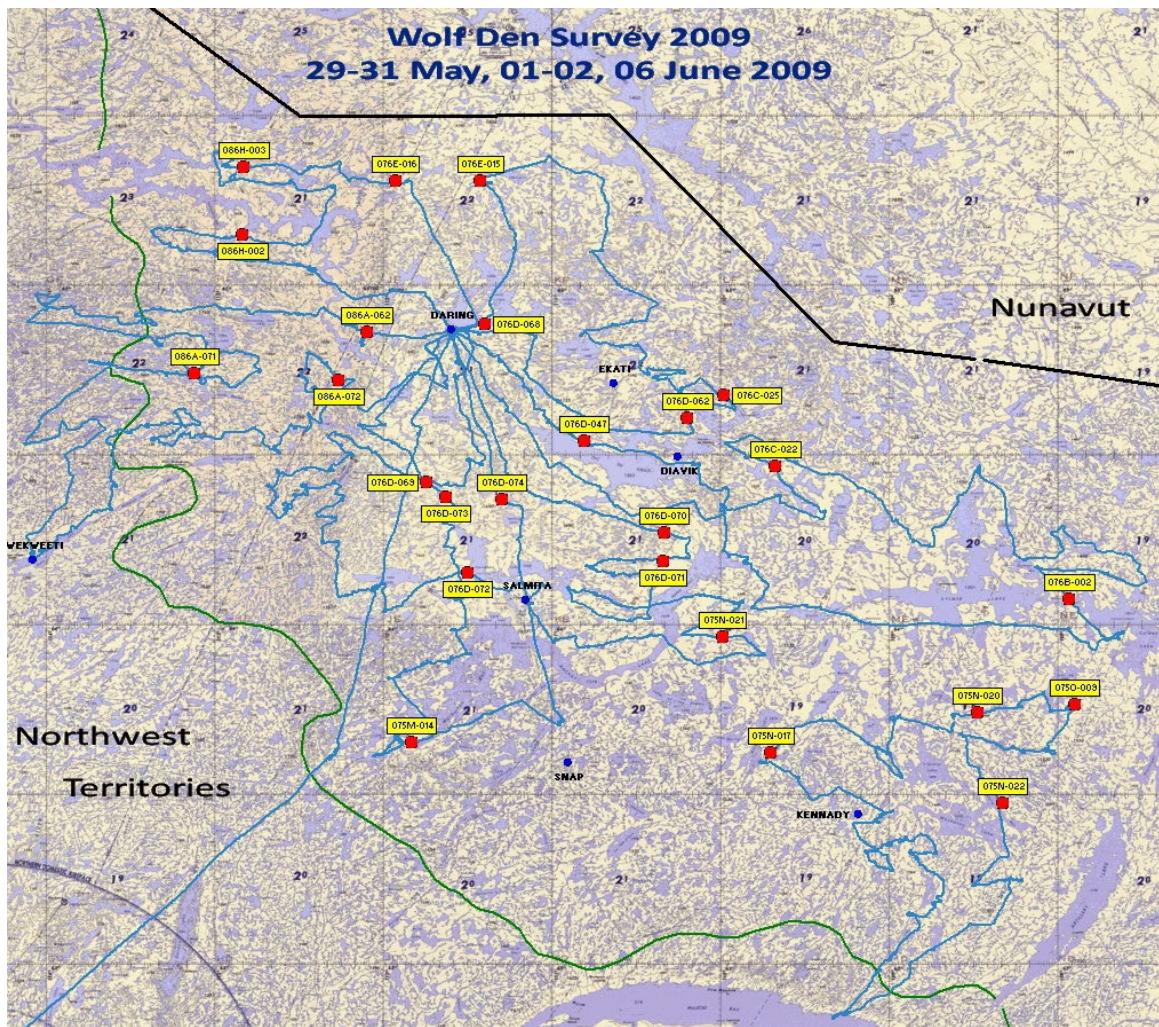
Figure 47. Wolf den survey in the summer/fall range of the Bathurst herd, May-June 2009. Blue line shows the flight path.
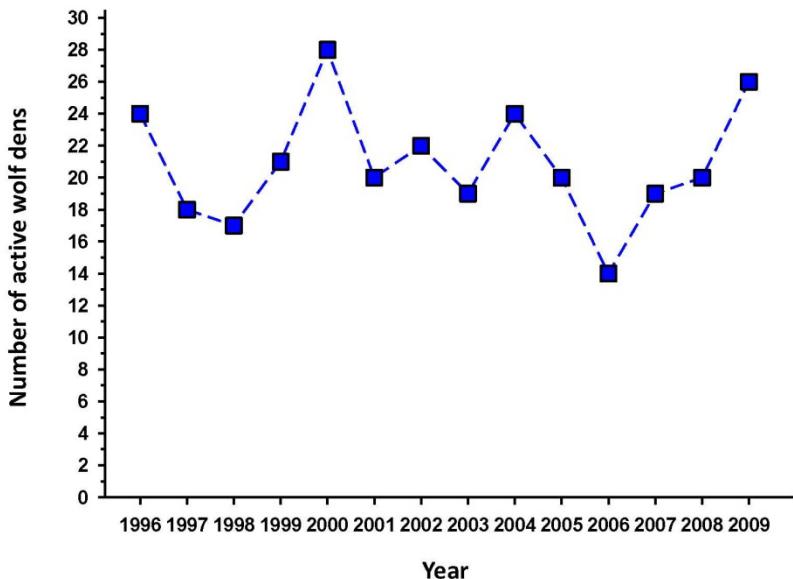
Figure 48. Number of active wolf dens on the Bathurst caribou summer range in early summer (May-June) 1996-2009.

A wolf pup survey was also conducted in late summer to estimate recruitment. Ideally early fall is best when the pups travel with the adults. However, once wolves leave the den, they are not easily found without radio collars. Therefore, den sites that were active in the June den survey were re-visited in early to mid-August to count pups. Because wolves can relocate their den, move to a rendezvous site, or an entire litter can fail, not all dens from the June survey remain active and the sample size for the August pup survey was invariably smaller than in the June survey. In 2009, a follow-up den survey was initiated in early July as a way to get an early count of pups and more precisely determine if early pup mortality or entire litter loss was occurring.

Den Survey Results

Since 1996, 292 active wolf dens were recorded for an average of 20.5 dens each year (SD=3.5, range 14-28, n=14 years, Figure 48). The search effort and geographical extent varied over the years, complicating the trend analysis of wolf abundance if only dens are considered. However, a grid cell approach was implemented as of 2009 and a retrospective analysis since 1996 was underway using flight tracks as a way to measure search effort and survey coverage. This will allow trend analysis of active den sites with variable survey effort among years as an index of wolf abundance.

In June 2009, only 40 wolves were sighted from the 25 active dens observed on the NWT tundra portion of the Bathurst range. Most dens had one or two wolves present while one den had three wolves, one had four wolves, and one had five wolves. When only one

wolf is observed at the den, a second wolf is assumed. Therefore, at an active den, the minimum number of wolves present would be the breeding pair (i.e., two wolves). The number of non-pup wolves (>1 year of age) observed at den sites has decreased since a peak during the late 1990s (Figure 49). For example, in 2000, one den had nine adults and 15 pups, the most ever recorded in the NWT. At that time, it was common to observe many wolves at a den site in June; however, more recently sightings typically consisted of seeing only one or two wolves at a den.
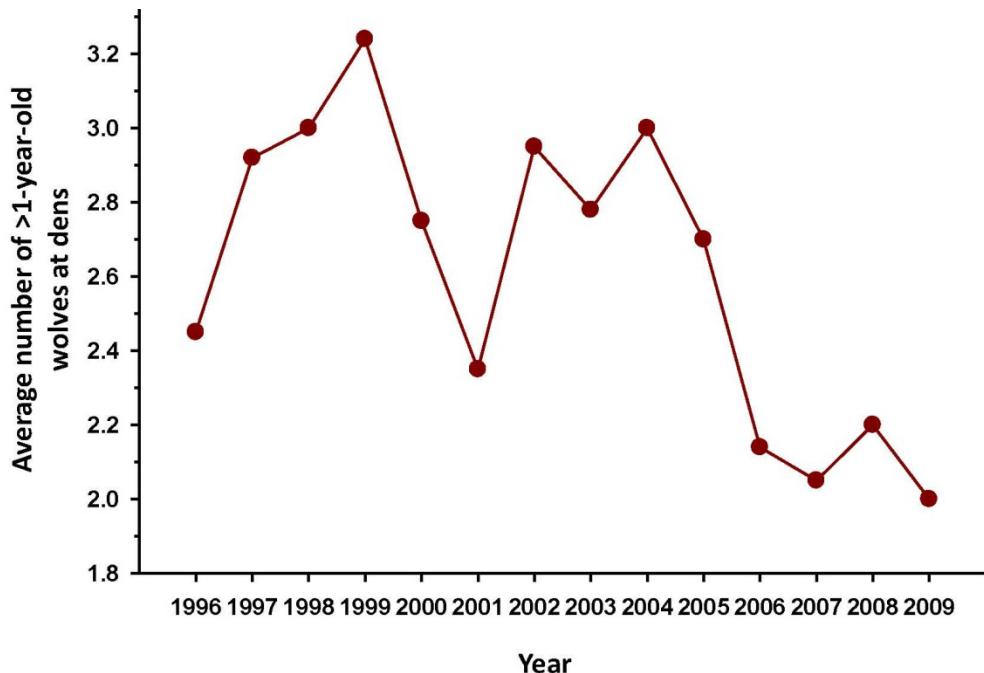
Figure 49. Average wolf sightings per den on the Bathurst caribou summer range, 1996-2009.

The average number of pups has not shown much change over 14 years although the number of wolf dens active in June that remain active in August has plummeted (Figure 50). Although wolves can relocate their pups from dens to rendezvous sites, not many did so in the late 1990s and early 2000s. Wolves recently were either experiencing complete litter loss more often or were relocating pups to rendezvous sites much further away from the natal den. Since 2004, wolves were no longer radio collared so we could not locate the breeding pair to confirm if pups are still alive. However, the follow-up den survey we initiated in early July 2009 to count pups indicated only half of the dens were still active after a month. While some wolves may have moved their pups this early, pup mortality may also have increased. This would be consistent with the recent decline in caribou numbers.
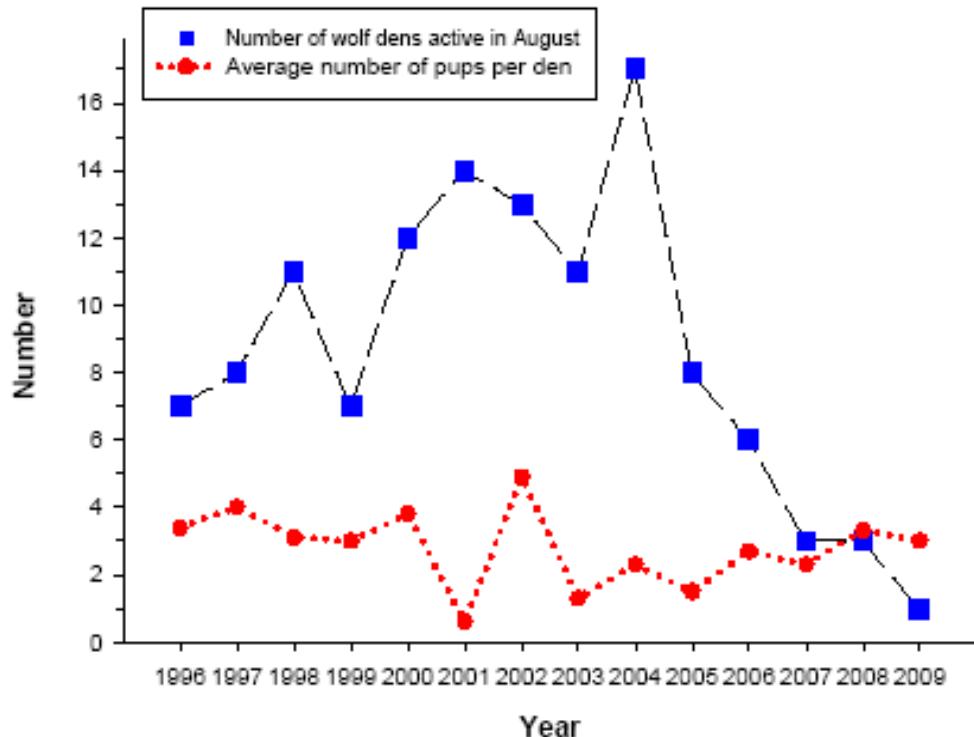
Figure 50. Number of dens still active in August and average number of pups per den, in wolf dens surveyed in the Bathurst range, 1996-2009.

Detecting Change

If the number of active wolf dens corresponds linearly to wolf population fluctuations, then more active dens would mean more wolves. Similarly, few active dens would suggest a decline in the population. However, survey effort would have to be large to overcome local influences in wolf den activity. For example, if one or both members of a breeding pair are shot or trapped in the annual fur harvest, their den will not likely be active the following spring. Survey results must be robust to slight variations. However, if many wolves are harvested, then this mortality factor would likely be observed as reduced den occupancy over a greater area. Human-caused mortality is a significant factor for wolves and these tundra-denning wolves have been killed over 400 km from their den in the boreal forest during winter (Walton et al. 2001, Cluff et al. 2010). That harvest mortality of wolves can occur long distances from where wolves den is an important consideration for wolf ecology and management. In recent years, wolf harvest has been low.

The number of adult wolves observed per den site will likely fluctuate with population size. Often yearlings and two-year-old wolves will remain at the den as associates and help raise their younger siblings. As the average number of adult wolves per den approaches 2.0 (e.g. Figure 49), population numbers are likely declining. Counts of pups may also provide

supporting documentation of changes in wolf population numbers. Incidence of multiple breeding, whether from capture evidence or inferred, will also be useful to assess the abundance of food (prey) available.

Aerial Surveys

Wolf Abundance in Late Winter

In February/March 2006, a stratified random survey was conducted to estimate the number of caribou and wolves on the Bathurst caribou winter range (Mattson et al. 2009). That year, Bathurst caribou were wintering in the Artillery Lake and Łutsel K'e area. Survey cells were stratified as high or low caribou density over a total area of 494,000 km^2 based on the distribution of satellite collared caribou at that time. Those cells were further stratified by lichen occurrence and snow-water equivalence. Using those count data, 41,000±8,430 caribou and 211±66 wolves were estimated on the winter range study area (Mattson et al. 2009). Only six wolf-killed caribou were observed. The density estimates for both caribou and wolves were lower than expected and may have been influenced by having only 14 collared caribou available for the stratification technique. Also, that winter 104 wolves were harvested by a trapper from Fort Reliance.

Wolf Sightings during Aerial Surveys for Caribou

The Department annually conducts a number of aerial surveys to assess caribou composition and distribution. On many surveys, wolves are sighted. The Department recently examined if there are trends in wolf sightings and if relationships exist between number of wolves seen and survey search effort and number of caribou seen (Frame and Cluff 2009 *in prep.,* later finalized as Frame and Cluff 2011). Infrequent surveys for some herds and inconsistent methodologies limited the analysis to the North Slave area and from 1987-2008.

The number of wolves seen from year to year was variable with no clear patterns for either late winter or autumn surveys. In some years many wolves were observed, such as in 1991 or 2008, but then few wolves were observed the following year, and sightings increased the year after that. Interpreting such results is difficult by itself but becomes more uncertain when we consider that Bathurst caribou numbers were generally high from 1987-1995. It appears there was a weak pattern of wolf observations fluctuating from low to relatively high and back to low every few years, however because there are no estimates of wolf abundance for those years for comparison, we cannot state that those observations were representative of the wolf population and therefore do not necessarily represent trends in abundance. There was also no significant relationship between the number of wolves seen and the distance or time searched. This was not surprising because aerial caribou surveys also include areas where caribou are scarce or absent while they delineate current caribou winter range boundaries.

We also plotted flight track logs, caribou and wolf observations from late winter and fall caribou composition surveys for the Bathurst caribou herd for 2006, 2007, and 2008. We buffered these flight paths by 400 m on each side to reflect the standard range of view by observers in these surveys. We analyzed these locations based on several ecological features and did the same for five random points for each wolf location to look at sightability patterns of wolves from the air. The ecological features we examined were habitat type, cover classification, distance from wolf sighting to a lake, distance from the wolf sighting to caribou, and the local caribou abundance. Some of these features are interrelated and we looked for these patterns in our development of a sightability model.

We use AIC, adjusted for small samples sizes (AIC$_c$) to test nine models (Frame and Cluff 2009 *in prep.*). The best fitting model included proximity to lake, proximity to caribou, and local caribou abundance. Neither proximity of the wolf sighting to lakes or local caribou abundance on their own contained any useful information differentiating wolf observations from random points. Proximity to caribou influenced all the models even when tested alone (Frame and Cluff 2009 *in prep.*). Not surprisingly, wolves selected for areas where there are caribou, especially where caribou were abundant, and were more readily seen in open areas such as lakes than elsewhere.

Conclusions

Overall, our data on wolf dens and wolves indicate that abundance and productivity have in the last five years (2005-2009) fallen rapidly[17]. Annual wolf den site occupancy is likely a reasonable index of population size, and therefore can be considered a measurable variable correlated with density (Caughley 1977). Indices are useful to draw comparative inferences about populations at different times and/or locations. However, because the exact relationship between an index and true population size is usually not known, there is typically uncertainty about the validity of the comparisons made (Lancia et al. 2005). Efforts to locate all active dens within a given area may offer a coarse estimate of population size.

Aerial surveys for wolf abundance would be feasible if they occurred in late winter and stratified by caribou abundance, specifically immediately after a composition survey for caribou. A grid-based survey stratified by this detailed level of caribou abundance would have the best chance of seeing wolves in all habitats and thus reduce the influence of sightability factors. However, because of the difficulty sighting wolves in forested areas, aerial surveys that do not include a measure of detection probability would be flawed. Typically, a detection rate would be needed using radio collared wolves present during the

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[17] A graduate thesis study of wolves on the Bathurst summer range resulted in papers on wolf-caribou dynamics and denning sites (Klaczek et al. 2015, 2016) that confirmed reduced wolf densities and low pup recruitment from den surveys to 2013.

survey and this detection rate applied to the population estimate from the stratified random survey for a more unbiased estimate of wolf numbers. Because such a survey would estimate wolf and caribou density, a predator/prey ratio could be calculated which would also provide a meaningful measure of wolf abundance.

Mining and Other Development (JB and JA)

The cumulative effects of active mines and associated roads and traffic on the Bathurst caribou herd have been studied by biologists, staff and consultants at the mines from the early 2000s to the present day (2009; Figure 51). We include here a summary of a draft report by J. Boulanger and co-authors in 2009 on a Zone of Influence (ZOI) around the diamond mines[18]. In addition, ENR has had a demonstration project underway that uses a combination of modeling approaches to assess effects of the diamond mines on the Bathurst herd on its summer range. The project has not been completed but we include a brief summary on initial trends[19].

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[18] This report was later published as Boulanger et al. (2012).
[19] This work resulted in a book chapter by Gunn et al. (2011) and a GNWT report edited by Nishi and Gunn (2016).
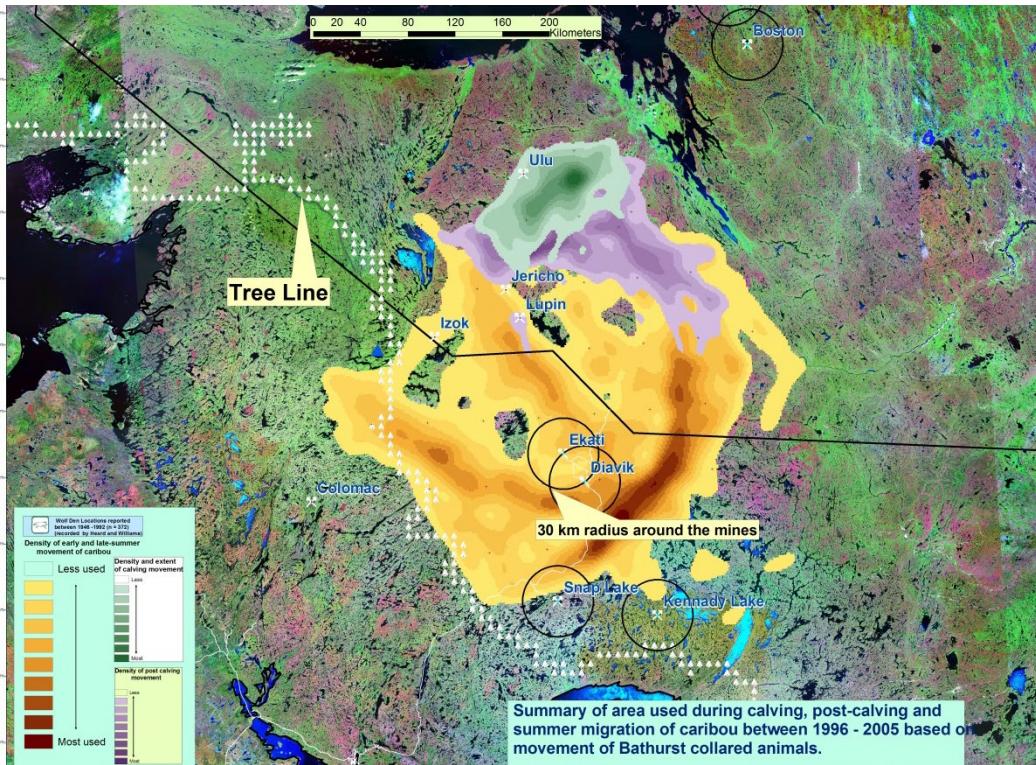
Figure 51. Calving and summer ranges of the Bathurst caribou herd, 1996-2005, with 30 km radius around the active mines. The map shows the calving (green), post-calving (purple) and summer (yellow) ranges of the Bathurst herd, based on satellite collar caribou locations from 1996-2005. Darker areas had greater use by caribou. The Ekati and Diavik diamond mines are in the summer range and the Snap Lake mine is on the edge of the summer range. Map by: B. Croft, ENR.

A study by Johnson et al. (2005) first reported avoidance of the active diamond mines in the Bathurst summer range, based on spatial analysis of the summer habitat and satellite collar locations. Since then, further analyses by consultants to the mines (Golder 2008a and b) and Boulanger et al. (2009) have evaluated use by caribou of areas within 30 km of the mines using satellite collar data and data from systematic aerial surveys of caribou by mine staff.

Boulanger et al. (2009) used data from aerial surveys and locations of satellite collared female caribou as inputs to a model to account for patterns in habitat selection. They then constrained the zone of influence curve to asymptote, such that the average distance from the mine complex where caribou habitat selection was not affected by the mine could be estimated. Around the Ekati-Diavik mine complex during the operation period for both mines, they detected a 14 (CI=12-15.5) km zone of influence from the aerial survey data, and a weaker 11 (CI=1-17) km zone from the satellite collar locations. From the aerial

survey data, it was estimated that caribou were 4.18 (CI=3.6-4.9) times more likely to select habitat at greater distances from the mine complex than within the zone of influence.

Boulanger et al. (2009) also used data from the CALPUFF (Rescan 2006) dust deposition model to explore if ZOI was associated with dust or total suspended particles (TSP) deposition. The CALPUFF model generates isopleths of dust deposition, which predicted that TSP declines rapidly >2 km from mine development and was indistinguishable from background deposition rates at a distance of 14-20 km from the Ekati-Diavik mine complex (Rescan 2006). Results of analyses suggested that TSP was a significant predictor of caribou occurrence, and furthermore suggested that caribou would avoid areas with even low levels of TSP which can occur up to 14-20 km from mine areas. These results should be interpreted cautiously given that this was a study of association rather than a controlled study. For example, it was likely that other anthropogenic factors beyond TSP influenced caribou distribution in the immediate proximity of mine areas. Low-frequency noise from heavy machinery and blasting could contribute to avoidance by caribou.

Boulanger et al. (2009) estimated that the area of reduced caribou occurrence from the Ekati-Diavik mine complex is ~6.7% of the 33,000 km² core and ~4.2% of the high use area of summer range of the Bathurst herd. Cumulative impacts from other sources of disturbance on the landscape (Johnson et al. 2005) could have wider implications to the ecology and health of the herd. Boulanger et al. (2009) were unable to estimate the proportion of the herd that is affected by development, and thus the population-scale costs are unknown (Wolfe et al. 2000). However, these results depict clear separation of the effects of development from natural variation in habitat use.

Further analyses by C. Johnson (pers. comm.) and Daniel et al. (2009) added further perspective on the effects of the diamond mines on the Bathurst herd. Spatial analysis by C. Johnson indicates that the habitat within the ZOI is not unique and that the 96% of the summer range not within the ZOI has an abundance of the habitat types within the ZOI. In addition, Daniel et al. (2009) used an energetics model developed for Porcupine caribou by Russell et al. (2005) to assess whether caribou that came within close range of the mines might be adversely affected by feeding less or expending more energy on running or walking. The analysis thus far suggests that these effects have been limited, in large part because caribou avoid the mines, as described earlier, and a relatively small proportion of the herd comes near the mines. Further, caribou are most likely to come into the mines' proximity during spring and fall migration, when they tend to maintain strong directional movement, thus further limiting their potential exposure to noise or traffic that might affect their behaviour.

Overall, the studies to date of the effects of the diamond mines on the Bathurst herd show a clear avoidance of the active mines to a distance of 14 km or possibly at longer distances. This affects only a small proportion of the herd's current summer range. Behavioural effects on caribou feeding or energetics have been limited, in large part because caribou avoid the mines and are on the move when they are most likely to be near the mines. Although the disturbance effects of the mines on the Bathurst caribou herd appear thus far to be limited, they should not be trivialized: human infrastructure can at some scale of intensity lead caribou or reindeer to abandon an area altogether and linear corridors can become partial or complete barriers to movement (Nellemann et al. 2003, Cameron et al. 2005). The greatest effect of the diamond mines in recent years on the Bathurst herd has been increased road access for hunters.

Declines in Other NWT/NU Herds (JA)

Three NWT barren-ground caribou herds experienced similar patterns in decline in recent years: the Cape Bathurst, Bluenose-West and Bathurst herds all declined relatively slowly, then declined at an accelerated rate at lower herd size (Figure 52).

The Cape Bathurst herd declined at about 4% per year from 1992 to 2000, then at a rate of 14% per year from 2000 to 2006. The Bluenose-West herd similarly declined by about 4% per year from 1992 to 2000, then at a faster 13% per year from 2000 to 2006. The Bathurst herd declined at about 5% per year from 1996 to 2006, then by 22-23% per year from 2006 to 2009.

Trends in the three herds are considered in greater detail on the following pages.
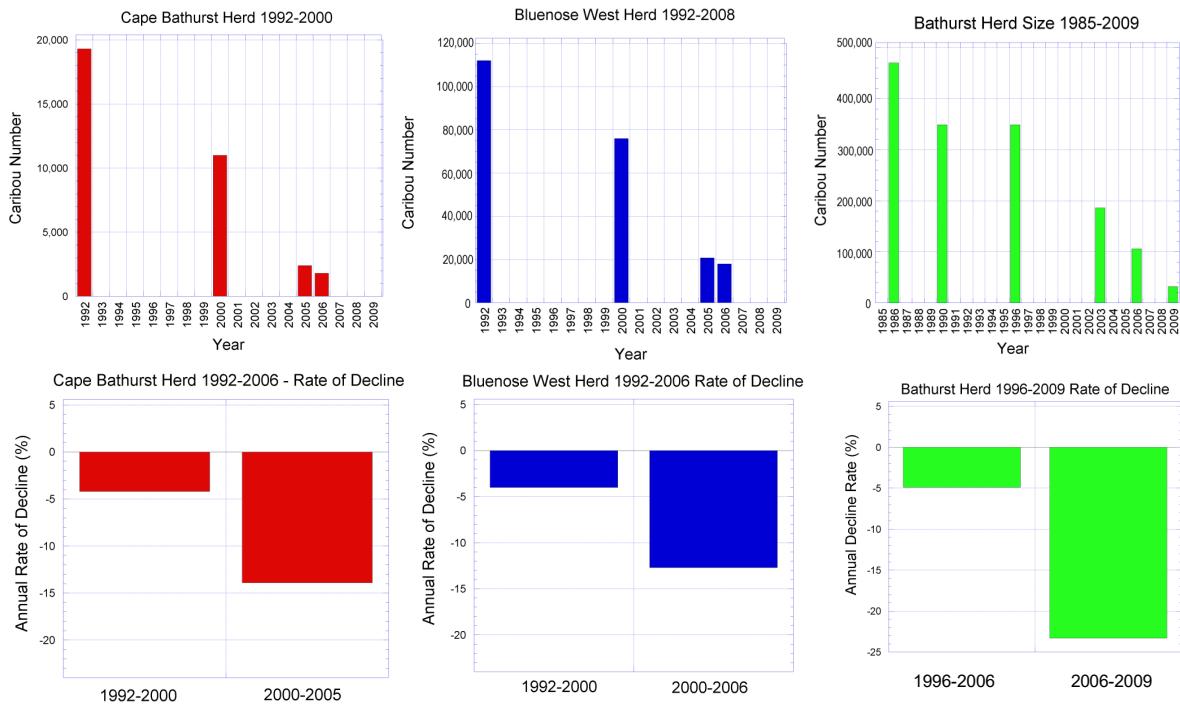
Figure 52. Comparison of declines in estimated population size and annual rate of decline in the Cape Bathurst, Bluenose-West and Bathurst herds in the 1990s and 2000s.

Decline and Harvest Management in the Cape Bathurst Herd

In the early 2000s, late calving and low calf:cow ratios were recorded on the calving grounds of the Cape Bathurst herd (J. Nagy, ENR, unpublished data; Figure 53). These observations would indicate that the caribou were nutritionally limited, and likely would have been declining naturally without hunting. The estimated hunter harvest for the Cape Bathurst herd was around 730 caribou in 2005 (primarily cows; J. Nagy unpublished data). If this harvest was about the same in earlier years, then 730 caribou would be about 3% of the herd in 1992, about 7% in 2000, and about 30% in 2005. This harvest would have accelerated the herd's downward trend from natural factors. By recommendation of the Wildlife Management Advisory Council (NWT) (WMAC-NWT) and implemented by ENR, all harvest on this herd was closed in 2007. A July 2009 survey of this herd indicated a stable trend from 2006-2009 (Figure 54). This result suggests that the harvest contributed significantly to the herd's earlier decline, particularly at low numbers. Stabilization also benefitted from improved calf recruitment.
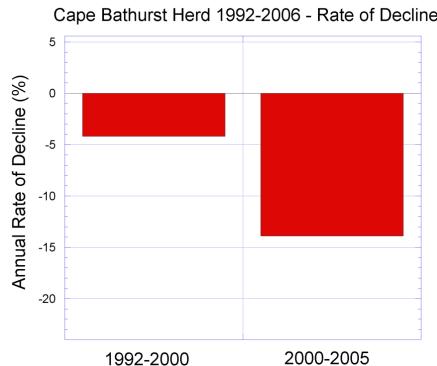
Figure 53. Rate of decline (top left), harvest as a % of herd size (bottom left), estimated 2005 harvest, and population trend indices for the Cape Bathurst herd 2000-2006 (top right).

Cape Bathurst Herd 1992-2009
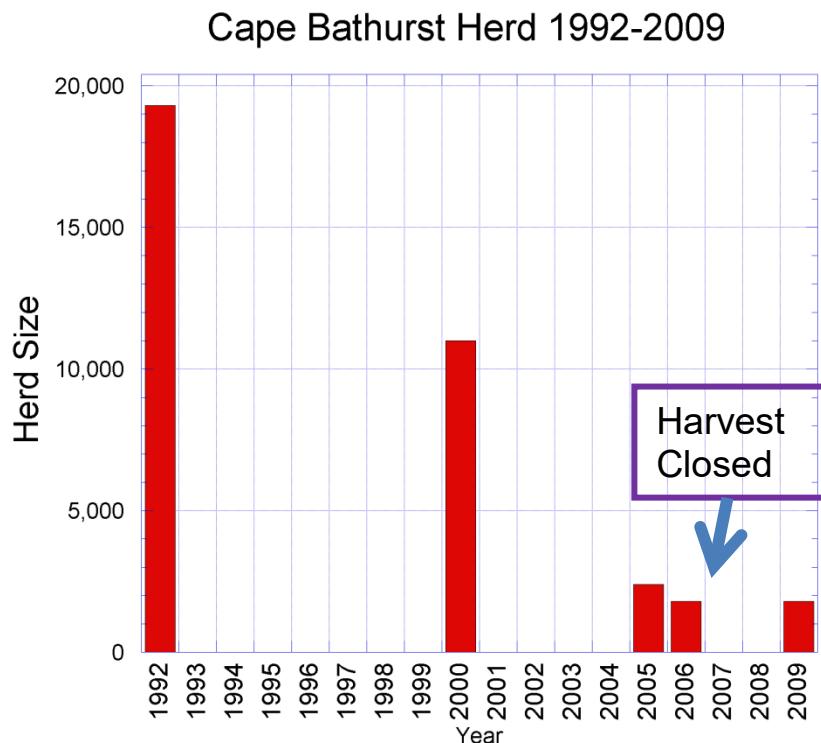
Figure 54. Trend in the Cape Bathurst herd 1992-2009. All harvest was closed on this herd in 2007.

Decline and Harvest Management in the Bluenose-West Herd

Patterns of decline in the Bluenose-West herd in the early 2000s were similar to those in the Cape Bathurst herd. Late calving and low calf:cow ratios on the calving ground indicate that the caribou were nutritionally limited, and likely would have been declining naturally without hunting (J. Nagy, ENR, unpublished data; Figure 55). The estimated hunter harvest for the Bluenose-West herd was around 1,900 caribou in 2005 (primarily cows; J. Nagy unpublished data). If this harvest was about the same in earlier years, then this harvest would be about 2% of the herd in 1992, about 3% in 2000, and about 9% in 2005. Evaluation of the decline by C. Nicolson suggests that the harvest may have been higher than 1,900/year in the 2000s, assuming that natural mortality rates of cows were at the lower end of the range reported elsewhere. By recommendation of WMAC-NWT and the Gwich'in and Sahtú Renewable Resources Boards, a total allowable harvest was set at 720 caribou (4% of the herd), with at least 80% bulls in 2006-2007. A July 2009 survey of this herd indicated a stable trend from 2006 to 2009 (Figure 56). As with the Cape Bathurst herd, this change suggests that the harvest had contributed significantly to the decline in the early 2000s, especially at low numbers. In 2009, the Bluenose-West and Cape Bathurst

herds were the only barren-ground herds monitored by GNWT with a stable trend[20]. Stabilization likely also resulted in part from improved calf recruitment.
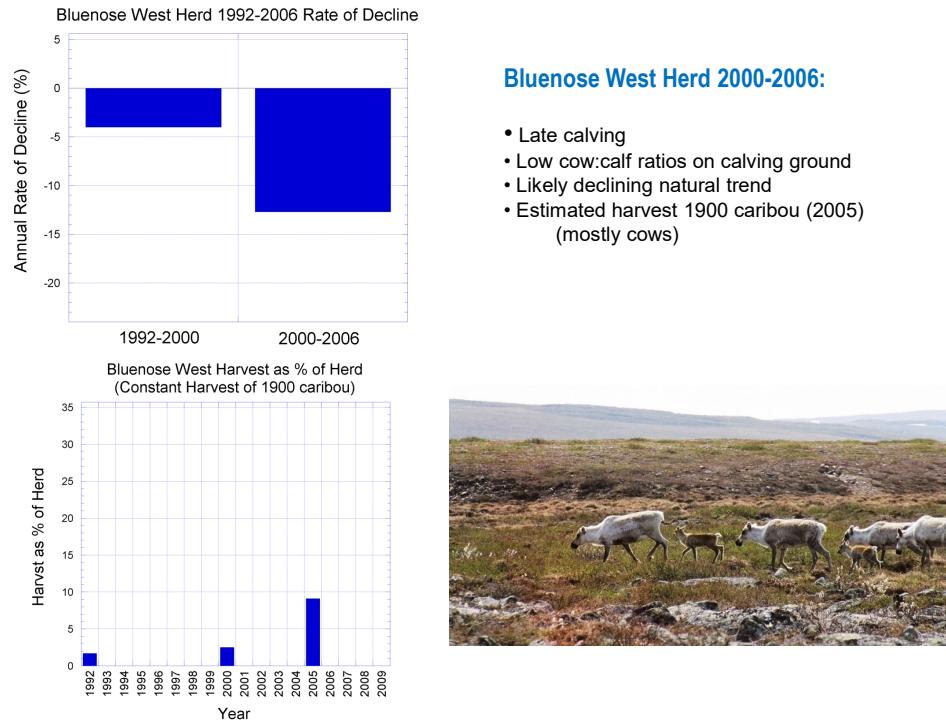
Figure 55. Rate of decline (top left), harvest as a % of herd size (bottom left), estimated 2005 harvest, and population trend indices for the Bluenose-West herd 2000-2006 (top right).

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[20] As noted earlier, the Cape Bathurst herd was roughly stable 2006-2015 (Boulanger et al. 2018a) and showed a modest increase 2015-2018 (T. Davison, unpublished data). The Bluenose-West herd was roughly stable 2006-2018 (Boulanger et al. 2018a, T. Davison unpublished data). Harvest restrictions for both herds remained in place in 2020.
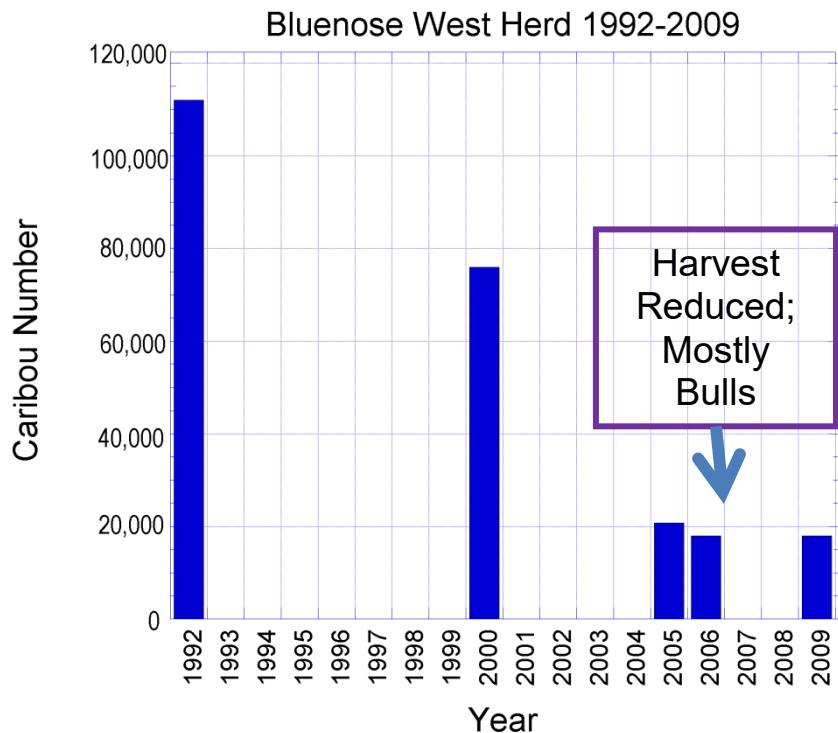
Figure 56. Trend in the Bluenose-West herd 1992-2009. Harvest was reduced to 4%, mostly bulls, in 2007.

Decline and Harvest in the Bathurst Herd

An evaluation of the decline of the Bathurst herd shows similarities to the declines of the Cape Bathurst and Bluenose-West herds. Between 1996 and 2006 the herd declined at an average rate of 5% per year (Figure 57). Spring calf:cow ratios in the early 2000s were low, indicating that the herd was most likely nutritionally limited and would have declined naturally, without hunting, over this period. From 2006 to 2009 the herd declined at a very rapid 22-23% per year.

Bathurst Herd Size 1985-2009

Bathurst Spring Calf:Cow Ratios 1985-2008
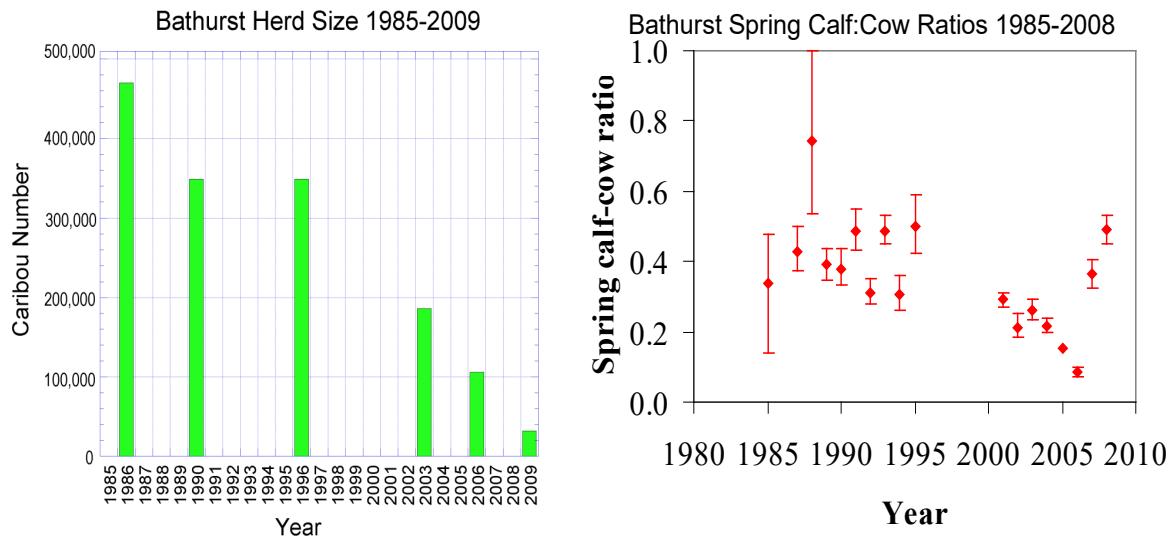
Bathurst Caribou Herd Trends 2000-2008

(Estimated harvest 16,000 caribou/year
Dogrib harvest study, early 1990s)

Figure 57. Herd size (top left), spring calf:cow ratios (top right), population trend indices, and estimated hunter harvest (bottom) in the Bathurst caribou herd, 1985-2008.

The hunter harvest has not been well documented in all years for the Bathurst herd, but an estimate of 7,000 caribou/year (5,000 cows, 2,000 bulls) is probably realistic (see earlier section on Hunter Harvest). These totals are well below the 16,000/year for this herd estimated by the Dogrib harvest study in the early 1990s. As with the other two herds, this harvest would have been barely 2% of the herd in 1996, increasing to 4% in 2003, 7% in 2006, and 22% in 2009. A lower harvest of 3,000 caribou produces a similar result, with 15.6% of the herd taken in 2009 (Figure 58).

The Bathurst herd has been hunted by more communities in the NWT than any other. With winter roads to the communities and diamond mines, access by truck and skidoo has increased and the caribou have been accessible even at very low numbers.
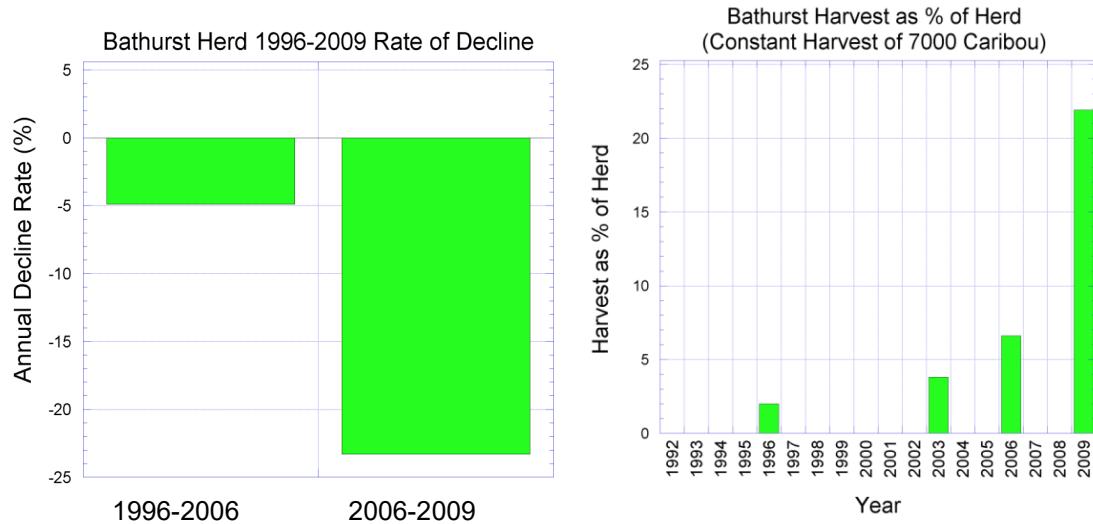
Figure 58. Rate of decline (% of herd lost per year) in the Bathurst herd 1996-2006 and 2006-2009 (left), and harvest of 7,000 caribou per year as % of herd in 1996, 2003, 2006 and 2009 (right).

Bathurst Herd Decline: Modeling Outcomes using OLS Models (JB)

Boulanger and Gunn (2008[21]) used a data-driven demographic model to explore potential causes of the Bathurst decline. This approach used all the direct data (e.g. estimates of breeding cow numbers) and indirect data (calf:cow ratios, bull:cow sex ratios, and measures of fecundity from the breeding ground) to estimate demographic parameters as well as test biological hypotheses regarding causes of the Bathurst decline.

It is beyond the scope of this report to provide all the details of the model methodology and we suggest readers interested in these details should consult Boulanger and Gunn (2008). We will, however, provide a synopsis of how this method was applied and the main outcomes of the modeling effort.

The main challenge with fitting demographic models to the Bathurst caribou herd, and, indeed, to most barren-ground caribou herds in Canada, is the lack of direct estimates for demographic parameters. For example, although direct estimates of survival for adult females were available from satellite collars, sample size was low. Most information on the demographics of the Bathurst herd came from indirect sources such as composition counts in June (calving), late October (fall rut) and March or April (late winter) that produce calf:cow and bull:cow ratios.

To deal with the lack of direct demographic rate estimates we adopted a model that considers multiple data sources developed for deer and elk by White and Lubow (2002). The main distinction and advantage of this approach is that both direct and indirect sources of demographic information are used to produce model-based estimates of demographic parameters, thus relaxing the need for direct (individual satellite collared based) estimates. In addition, this approach allows the evaluation of multiple hypotheses regarding temporal variation and trends in herd demographic parameters (White and Lubow 2002, Phillips and White 2003) using information theoretic methods of model evaluation (Burnham and Anderson 1998).

The basic demographic modeling exercise had the following steps. First a base demographic model was formulated which divided caribou into three separate cohorts as described in Figure 59. This model was based upon the population of caribou that calve on the Bathurst calving ground each year. It was assumed that there was no net movement of caribou to other calving grounds (as tested with multi-strata models in earlier section on likelihood of large-scale emigration from the Bathurst herd). We only

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[21] This report was updated in 2009-2010 and published in 2011 as Boulanger et al. (2011). In further years of calving ground photo surveys of the Bathurst herd, demographic modeling has been updated and a Bayesian model was adopted in 2019 (see Adamczewski et al. 2019 and Boulanger et al. 2019).

had indirect estimates of adult survival and population size of adults. However, information regarding fecundity (the proportion of females giving birth) could be estimated from calving ground composition surveys. Calf:cow ratios contained information about calf survival, fecundity, and adult survival since all these components related to the number of cows and calves observed on the calving ground. Therefore, it was possible to also mathematically formulate and model data from composition surveys to further inform the demographic model.
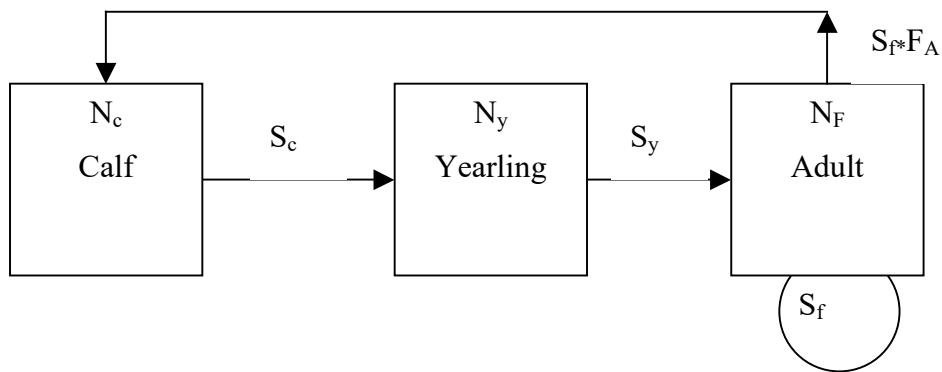
Figure 59. Underlying stage matrix life history diagram for the caribou demographic model. This diagram pertains to the female segment of the population. Nodes are population sizes of calves (Nc), yearlings (Ny), and adult females (NF). Each node is connected by survival rates of calves (Sc), yearlings (Sy) and adult females (Sf). Adult females reproduce dependent on fecundity (FA) and whether a pregnant female survives to produce a calf (Sf). The male life history diagram was similar with no reproductive nodes.

The demographic model generated predictions of population size, demographic parameter values (i.e. survival, fecundity) as well as prediction of corresponding field measurements (i.e. calf:cow ratios). Therefore, it was possible to supply a set of initial values of population size, survival rates, and fecundity rates and then assess how close model predictions were to those observed in the field. We formally assessed the difference between field measurement and model predictions using a penalty term.

$$Penalty = \left[\frac{(Model\ prediction - Field\ observation)}{SE\ of\ Field\ observation} \right]^2$$

The penalty term expressed the difference between model predictions and field observations in units of standard error (SE) of the field measurements. This accomplished two objectives. First, it standardized the difference between field measurements (i.e. population size, calf:cow ratios, survival rates) into SE units therefore allowing easy comparison of estimates even though the original units of measurement were different. Second, it considered the level of precision of field measurement so that

differences between model and field estimates, based upon precise (low SE) units of measurement would receive a lower penalty term than comparisons based upon imprecise (high SE) measurements. For any run of the model, it was then possible to add up all the penalty terms from each of the field and model comparisons to arrive at a total penalty score which indexed the overall fit of the model to the field data.

Using the penalty-term approach, we were able to propose a set of assumptions about demography and test how well the resulting predictions from the model fit the data as indexed by the penalty terms. The next step was then estimating the most likely parameter values given the set of underlying assumptions about demography. For example, we might test a model that assumed that adult survival, fecundity, and calf survival were all constant from 1985 to 2009. We had estimates of adult survival from 1996 to 2009 from limited numbers of cow collars but not for other years. Therefore, some parameters had to be estimated based upon the underlying demographic model used. To accomplish this, we used an optimization algorithm. This computer algorithm essentially iteratively varied all the parameters within the model within the constraints set by the underlying assumptions (i.e. all parameters constant from 1985 to 2009) so that the resulting penalty term from the model was minimized. By doing this it estimated the most likely set of parameter values based upon the set of assumptions proposed about caribou demography. We then used this approach to test a set of assumptions about caribou demography. For example, all parameters did not vary, or only survivals declined linearly through time, and estimate the most likely parameter values based upon these assumptions, as well as assess the model fit based on penalty terms.

Our main objective with the demographic model exercise was to formulate the simplest demographic model that adequately explained the observed trends in Bathurst caribou demography. In general, a model that has a large set of assumptions (and parameters) may exhibit lower penalty terms and therefore "fit" the data better than a simpler model. For example, a model that estimated a model parameter for every field measurement would have a penalty term of 0 but this model would not tell us anything about overall demographic trends. The best model therefore balanced the complexity, or the number of assumptions about demography (as reflected in the number of estimated terms or parameters), with the fit of the model to the data as partially dictated by the sample size of field measurements available.

This topic has been theoretically formalized by the AIC or AIC_c score. Briefly, the AIC_c score considers the fit of a model (as indicated by the penalty term) and model complexity (as indicated by the number of parameters). A lower AIC_c score suggests the most parsimonious model which balances bias (model fit) and precision (model complexity) (Burnham and Anderson 1998). The basic formula for the AIC is the sum of penalties plus two times the number of model parameters. So, the AIC score further penalizes the penalty

score by two times the number of parameters. The difference in AIC_c values between the most supported model and other models (ΔAIC_c) was also used to evaluate the fit of models when their AIC_c scores were close. In general, any model with a ΔAIC_c score of <2 was worth considering. In addition, the proportional support of each model, or AIC_c weight (w_i) was considered in evaluating the support of each model. The AIC weights, or "weight of evidence" add up to one for all models considered. All parameter estimates were model averaged using AIC_c weights to account for model selection uncertainty.

Model Outcomes for the Bathurst Herd

We proposed a suite of models that considered variation in calf survival, fecundity, and adult female survival. Male survival was held constant for all models due to the lack of field measurements pertaining to the male segment of the population. Variation in adult female survival was modeled using polynomial regression terms and "broken stick" models, however, for the sake of brevity we provide a verbal description of models in Table 3 in Boulanger et al. (2011) and encourage readers to consult the full paper for more details. In short, models in which adult survival declined were most supported by the data as indicated by lower penalty terms as well as lower AIC_c scores (Table 16). This result suggests that based upon all of the field measurements available, the decline of the Bathurst herd was associated with a directional decline in adult female survival coupled with declines in calf survival and fecundity. The hypothesis that the decline was due to just variation in productivity and a constant survival rate was less supported (Model 3) by the available field data (Boulanger et al. 2011).

Table 16. A synopsis of AIC$_c$ model selection results from OLS deterministic caribou model as further detailed in Boulanger et al. (2009). Sample-size adjusted Akaike Information Criteria (AIC$_c$), difference in AIC$_c$ between most supported and given model (ΔAIC$_c$), Akaike weight (w_i), the number of parameters (K), effective sample size (ESS), and sum of penalties (ΣPen) are displayed. Effective sample size (the number of model and field estimate comparisons used to estimate ΣPen) was 56 for all models. Trends were not modeled in yearling and adult male survival due to lack of corresponding field data for these parameters.

No.	Model	AIC$_c$	ΔAIC$_c$	w_i	K	ΣPen
1	➢ Adult female survival declined linearly from 1985 to 2009 ➢ Productivity (calf survival/fecundity) declined until a lowpoint in 2005, rebounded in 2006, then declined.	391.32	0.00	0.46	15	349.3
2	➢ Same as model 1 except adult female survival declined steeply after 2007	391.44	0.12	0.40	16	345.5
3	➢ Same as model 1 but adult female survival was constant (did not decline)	401.46	10.14	0.00	14	363.2
4	➢ All parameters were constant	1,371.78	980.46	0.00	8	1,352.7

The best way to consider these results is through model-averaged parameter estimates (Figures 60, 61). Model averaged parameters are estimates based upon all models in the analysis with weight given to models that were most supported by the field data. It can be seen that adult female survival rates declined steadily until 2007 after which the decline was accelerated. Calf survival was relatively constant until 1995 after which it declined until a rebound after 2006 followed by a decline. Fecundity declined to a low point in 2005, then increased and then remained constant. Productivity (the product of fecundity measured on the calving ground times calf survival) suggested that productivity declined in unison with calf survival, rebounded in 2006 and then declined.
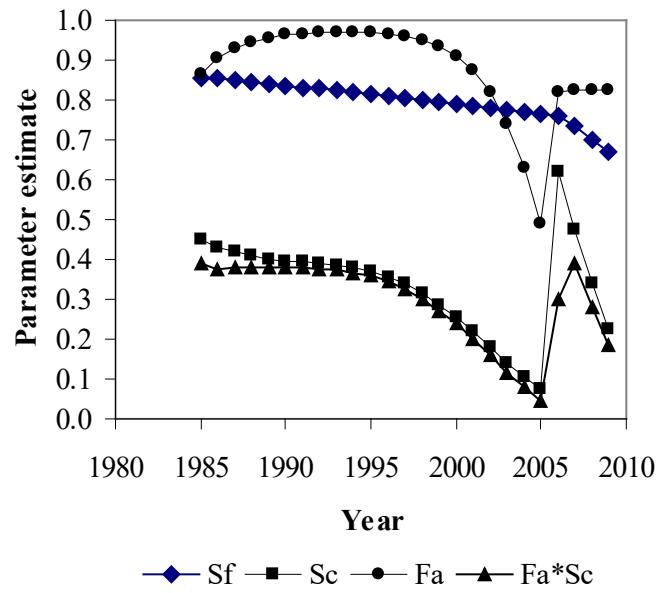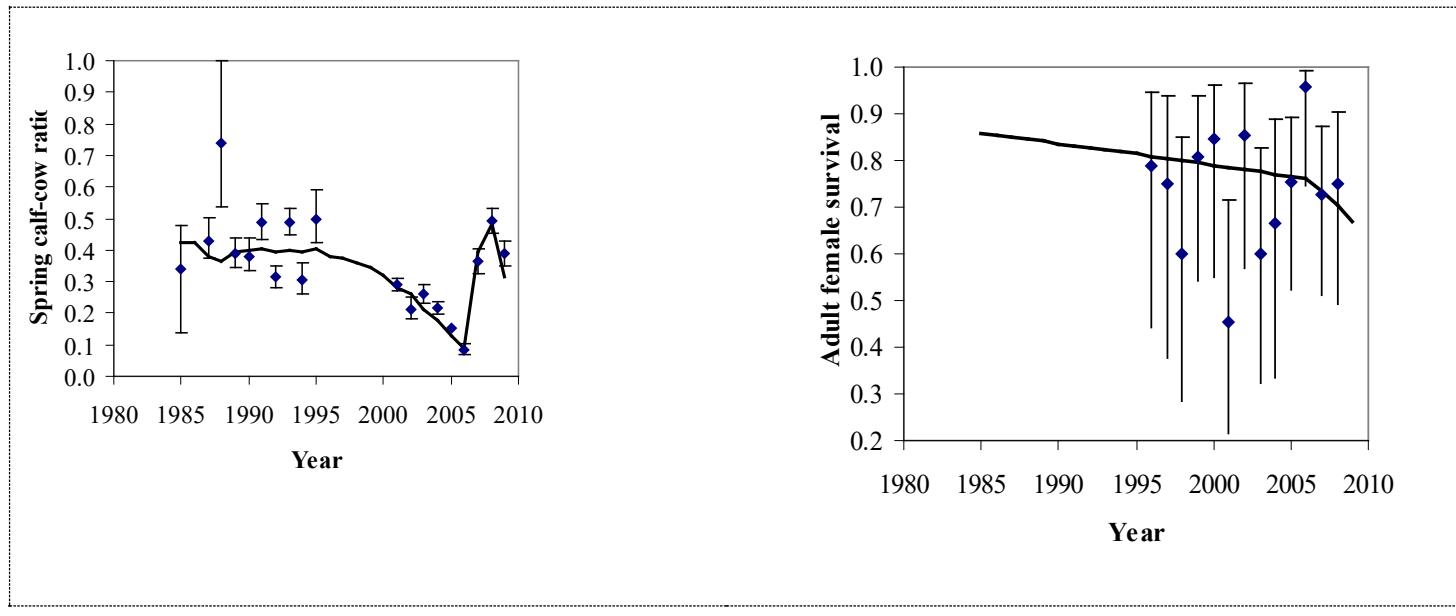
Figure 60. Trends in model-averaged estimates of parameter values from models in Table 16. Productivity as estimated by fecundity times calf survival is given for reference. Adult male survival (S_m) was 0.64 and yearling survival (S_y) was 0.86 for all years because temporal trends were not simulated in these parameters.
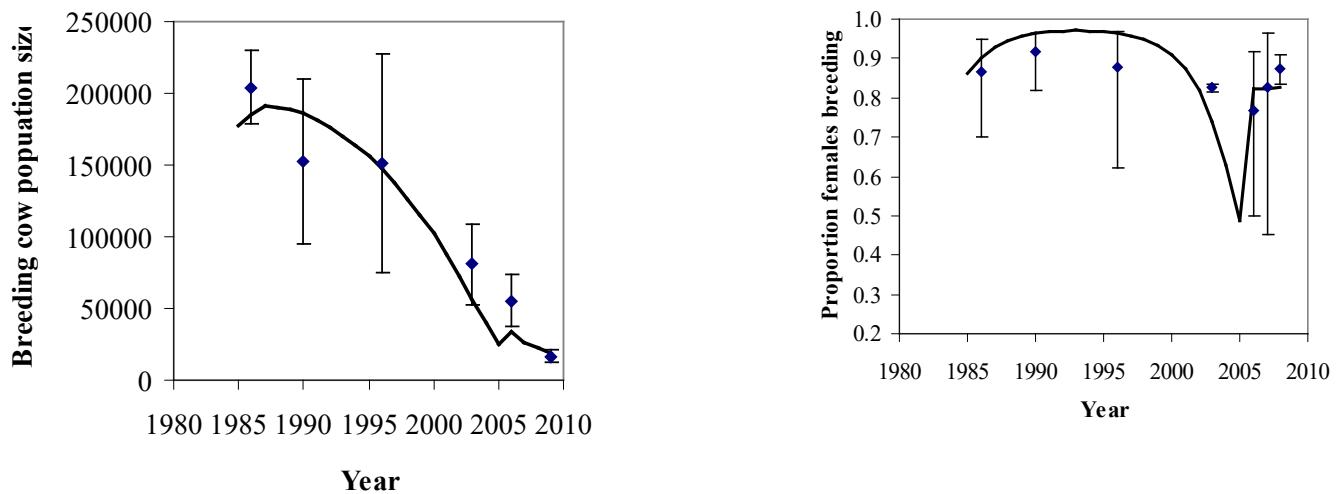
Figure 61. Model averaged OLS demographic model estimates compared to field estimates for late winter calf survival data and adult survival data. Field estimates have associated 95% confidence intervals.

The model fit all field data reasonably well with model-averaged predictions overlapping confidence intervals from field measurements in most cases (Figures 61 and 62). Calf:cow ratios that were adjusted for declining adult survival suggested that field calf:cow ratios overestimated productivity between 2007 and 2009. Model predictions were extrapolations of actual field trends for some relationships such as bull/cow ratio and adult survival, as those parameters were not measured in the 1980s or early 1990s. The adult female survival estimate was within the confidence intervals of point estimates of adult female survival from satellite collar-based estimates. However, the precision of these estimates was low (as indexed by large confidence intervals) and estimates are only available after 1996. Therefore, the model-based estimate is still within the realm of possible field measurements. Model averaged population estimates suggest declines in all cohorts (Figure 63).
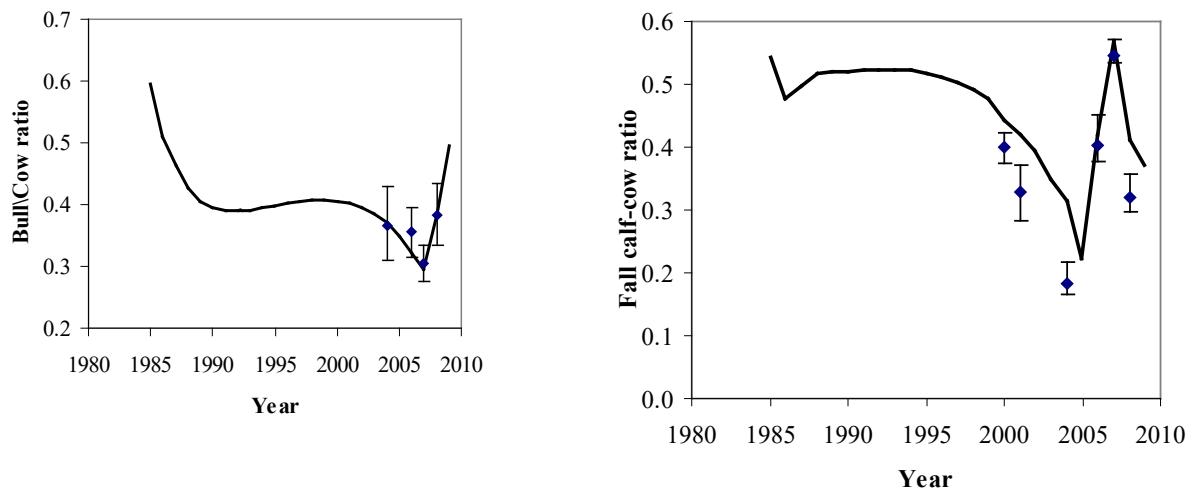
Figure 62. Model-averaged OLS demographic model estimates compared to field estimates for fall survey data. Field estimates have associated confidence intervals.
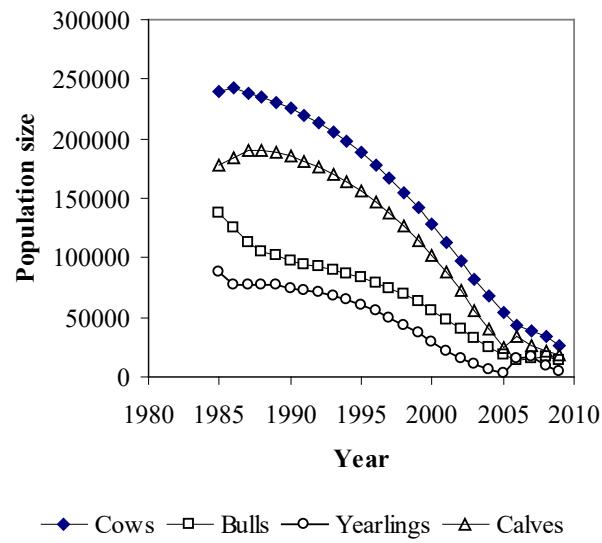
Figure 63. Model-averaged population estimates from OLS deterministic models.

It was also possible to reconstruct the current age structure of the Bathurst herd by expanding the base demographic model to track the fates of successive age cohorts. These results suggested that the current age structure of caribou is dominated by younger caribou and older caribou (See Figure 40, Bathurst herd decline: field data) due to low recruitment up to 2005 followed by a brief surge in recruitment in 2006-2007.

Assessment of the Impact of Harvest on Trends in Adult Survival

OLS model estimates suggested that adult cow survival declined from 0.86 in 1985 to 0.76 in 2006 followed by an accelerated decline down to 0.67 in 2009 for a net change of 19% (Figure 64). One potential factor for this decline could be a relatively constant harvest on the population as it declined. Accurate estimates of recent caribou harvest are unavailable, although a minimum annual estimate based on interviews and check stations is in the likely range of 3,000-5,000 adult cows/year. The Dogrib harvest study (1988-1993; Boulanger and Gunn 2008) for the Bathurst caribou herd provided estimates of the mean annual harvest at 8,380 cows (range 3,318-13,107) and 7,484 bulls (range: 3,855-10,073) per year. Table 17 shows this harvest as the proportion of bulls and cows in the population. We noted earlier that some observers have suggested that the harvest numbers from the Dogrib study may have over-estimated the true harvest.
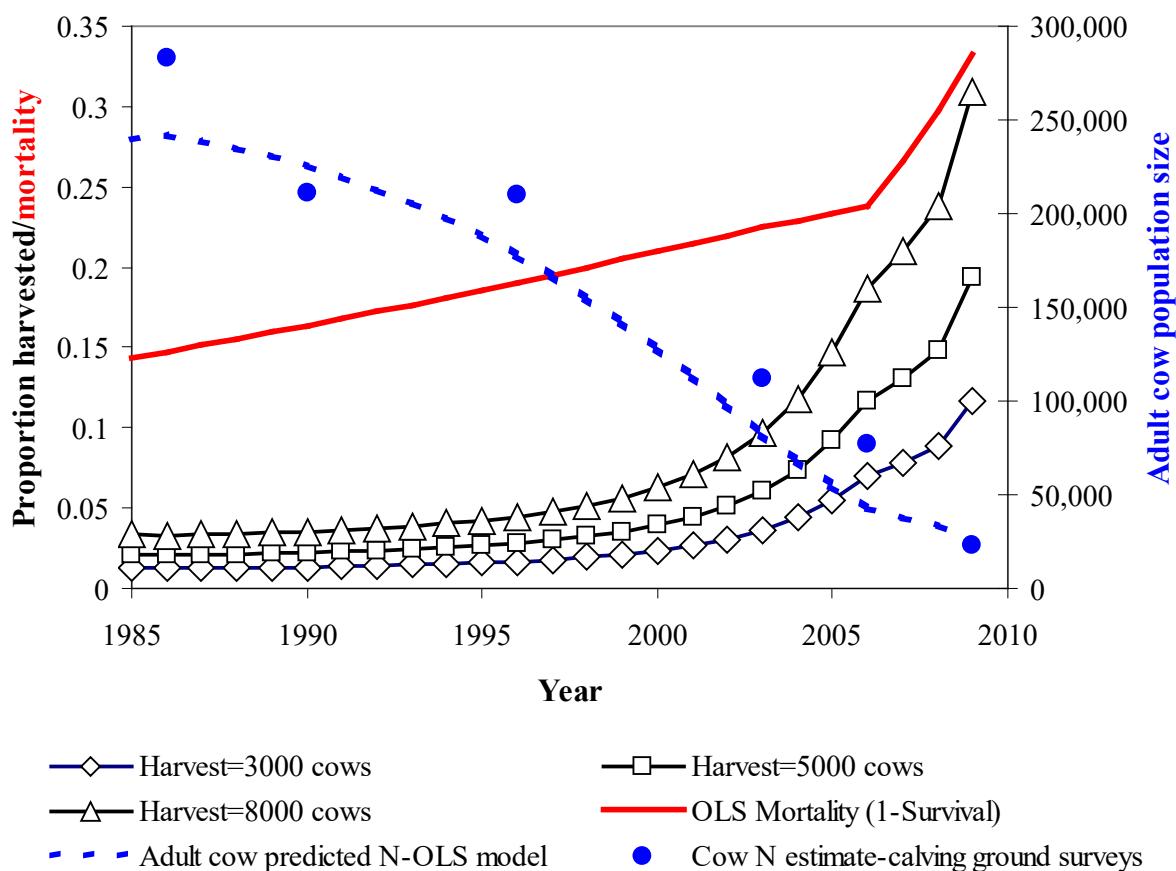
Figure 64. Trends in proportion of adult cows harvested annually as a function of model averaged OLS estimates of adult cow population size, corresponding calving ground survey adult cow estimates, and hypothetical harvest levels of 3,000, 5,000 and 8,000 cows. Model-averaged estimates of mortality rate (the inverse of survival rate or 1-survival rate) for adult cows are also shown for reference.

Table 17. Proportion of Bathurst bulls and cows harvested by Tłı̨chǫ hunters from 1988 to 1993. Estimates of harvest from Dogrib harvest study. Population estimates are based upon model averaged OLS estimates. The percentage harvest is simply the number harvested divided by the population estimate for bulls and cows respectively. Percentages are based upon population levels from 1988-1993 and are most likely higher with current population levels.

Year	OLS model estimate[1]		Caribou harvested		Proportion of $\hat{N}$	
	$\hat{N}$ bulls	$\hat{N}$ cows	bulls	cows	bulls	cows
1988	105,866	234,567	4,606	3,318	4.35%	1.41%
1989	101,303	230,563	3,855	4,730	3.81%	2.05%
1990	97,736	225,611	8,970	8,450	9.18%	3.75%
1991	94,728	219,798	10,073	11,626	10.63%	5.29%
1992	92,023	213,238	9,685	9,046	10.52%	4.24%
1993	89,301	205,878	7,712	13,107	8.64%	6.37%
Average			7,484	8,380	8.56%	4.34%

[1]Model-averaged estimates from models in Table 16.

We contrasted the change in mortality that was estimated as the OLS model averaged survival rate (Figure 61) with proportional harvest mortality for adult cows as estimated by harvest levels divided by OLS population size estimates. From this it can be seen that harvest had relatively little impact on the population until 2000 after which the proportional mortality increased. Harvest rates of 3,000, 5,000, and 8,000 resulted in proportional mortality of 11.6%, 19.3% and 30.9% of the population at 2009 population size. The slope of the proportional harvest curves was roughly parallel to the accelerated mortality curve after 2007, suggesting similar rates of change in mortality could be induced by a constant harvest rate at lower population sizes. The shapes of the curves at harvest rates of 3,000, 5,000, and 8,000 cows are similar; actual harvest year to year most likely varies, but a non-declining harvest would in all cases mean that an increasingly large proportion of cow mortality was due to the harvest.

Under the assumption of minimal harvest pressure on the herd in 1985, the cow mortality estimates for this period (14%) could be conceptualized as natural cow mortality (i.e. mortality from predation and other natural causes). By 2009 cow mortality increased to 0.33, a net change of 19% (Figure 64). Comparing this net change to harvest proportion suggests that an average harvest level near 5,000 cows could cause the same net change in mortality as estimated by the OLS model. Because harvest levels are uncertain and the effects of predation are unknown, conclusions about the role of harvest in the accelerated Bathurst decline 2006 to 2009 must be made with caution.

Multi-strata models (see Likelihood of large-scale emigration from the Bathurst herd) suggest a slight but not statistically significant increase in emigration rates from the

Bathurst which would also cause survival to decrease given that emigration would appear similar to mortality. However, the low and statistically insignificant levels of net movement, and observed decline in the Ahiak herd from 2006 to 2009 suggests that that it is extremely unlikely that movement to other herds could cause the observed trends in mortality.

Looking Ahead: Prospects for the Bathurst Herd (CN and JB)

We used a simple deterministic model, the Caribou Calculator devised for the Porcupine herd and adapted by C. Nicolson to the Bathurst herd, to look ahead for a period of five years under various sets of conditions. These model projections are shown in Figures 65 and 66.

Scenarios modeled in Figure 65 include a continuation of recent trends and harvest (Business as Usual) at 4,000 cows and 1,600 bulls/year. Under these conditions, the herd is likely to disappear in four to five years. Under the best-case scenario (no harvest, cows in good condition and very good calf survival), the herd might stabilize and begin to increase after five years. An increase would require several years of good calf recruitment and maturation of these young caribou (particularly the females) to the point (usually 2 and ½ years) when they begin to bear young. In two additional scenarios with either no harvest or a limited bull harvest, likely outcomes in five years are a slowed decline and possible stabilizing trend.
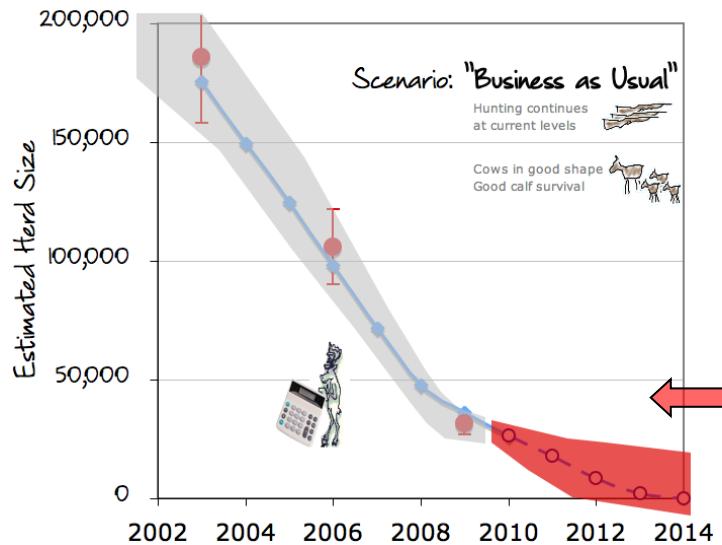
Business as Usual

If the hunter harvest stays the same, cows stay in good shape, and recent good calf survival continues, the herd will most likely disappear in the next 4-5 years. There is no level of calf production or survival that can compensate for current high cow death rates. Harvest assumed as 4,000 cows and 1,600 bulls.
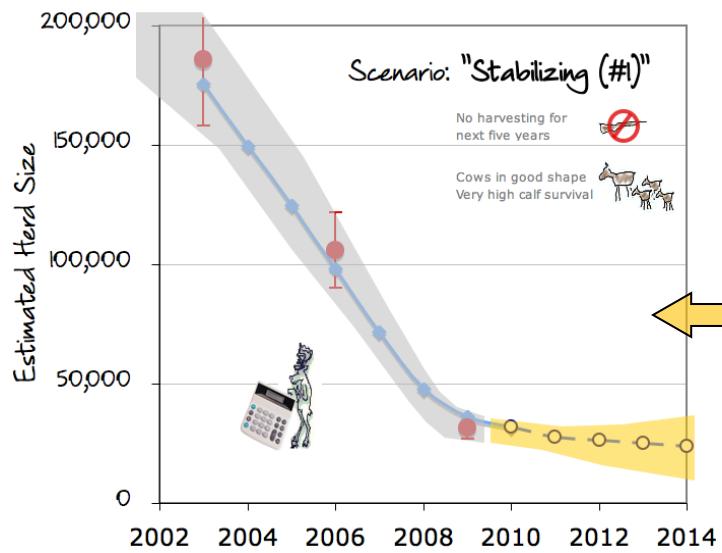
Stabilizing Scenario #1

If there is no harvest for the next 5 years, cows are in good shape, and calf survival is very good, the decline should slow down and the herd might begin to stabilize.

Figure 65a. Two potential 5-year scenarios for the Bathurst herd 2009-2014 from Caribou Calculator model.

Scenario: "Stabilizing (#2)"

Small bull harvest
NO cow harvest

Cows in good shape
Very high calf survival
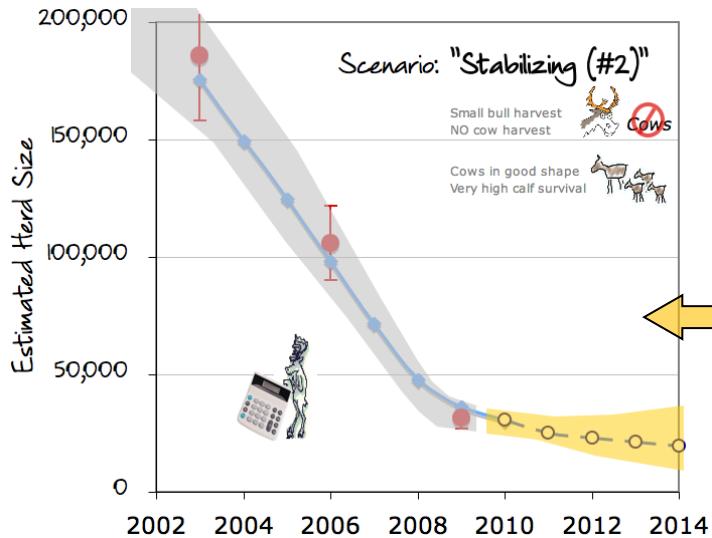
Stabilizing Scenario #2

If there is no cow harvest for the next 5 years and a limited harvest of small bulls (1600), cows are in good shape, and calf survival is very good, the decline should slow down and the herd might begin to stabilize.

Scenario: "Best conditions"

No harvesting for next five years

Cows fat & healthy
Very high calf survival
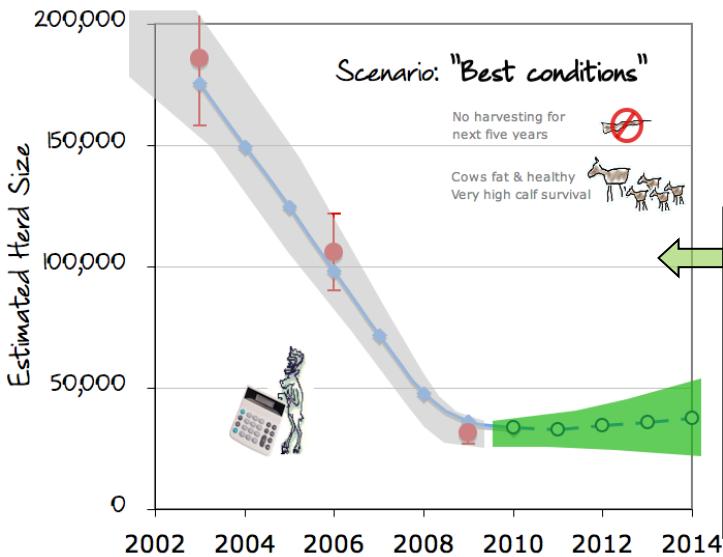
Best Conditions

If there is no harvest for 5 years, cows stay in very good shape, and calf survival is very good, the herd might stabilize and start to increase. Currently the herd has a large proportion of young caribou that are not yet breeding. This is one reason why an increase in the herd can at best be slow under best conditions.

Figure 65b. Two further potential 5-year scenarios for the Bathurst herd 2009-2014 from Caribou Calculator model.

An additional three scenarios were modeled in Figure 66, each with a total annual harvest of 2,800 caribou, but with varying proportions of cows and bulls in the harvest. All three of these scenarios are likely to mean continued decline and stability is unlikely. However, the size of the cow harvest (2,000 cows in (a), 1,400 cows in (b), and 800 cows in (c)) affects the outcome and the slowest continuing decline would be for the lowest cow harvest and the most rapid for the highest cow harvest.
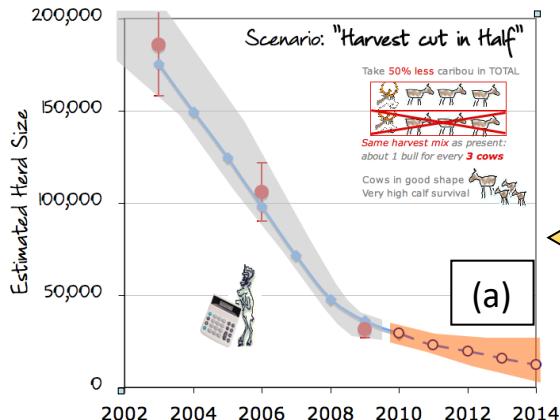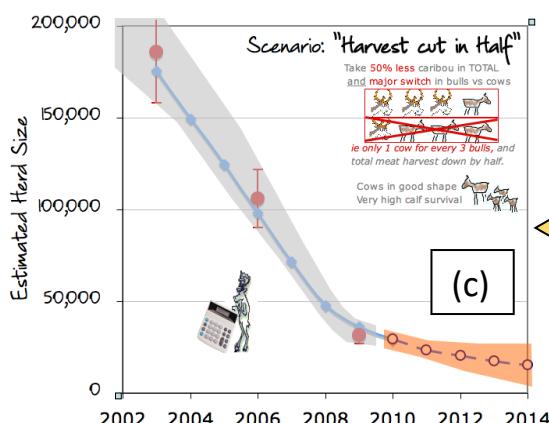
Figure 66. Three further potential 5-year scenarios for the Bathurst herd 2009-2014 from Caribou Calculator model, with varying levels of cow and bull harvest.

The graphs in Figures 65 and 66 are not predictions, but they give some idea of likely trends under various sets of conditions.

Stochastic Simulations for the Bathurst Herd (JB)

We also used stochastic simulations based on OLS model values to consider the Bathurst herd's likely future depending on cow and calf survival rates. We incorporated variance in model parameters as survival rates, weather and other variables in the real world are never fixed. Given the herd's current rapid decline rate and the prospect of changes to harvest, projections for more than five years would have little value[22].

We used a stochastic demographic model to estimate demographic parameter values that were needed for the Bathurst herd to recover. The stochastic model was similar to the OLS model and the Caribou Calculator used for model fitting as described in previous sections except that it also simulated variance in demographic parameters. Parameters such as adult survival and calf survival vary by individual caribou and vary temporally. It is essential that this variation, which can affect overall herd growth, is considered when evaluating scenarios for herd recovery. Estimates of variance from field-based measurement contain both sampling and biological or process variance. For demographic modeling, process or biological variation in parameters is most useful (White 2000). We first used a variety of statistical methods to separate process from the sampling variance in estimates.

We then ran sets of simulations in which the model was run many times with variation simulated in all demographic parameters. This generated unique yearly population sizes for each run as illustrated in Figure 67.

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[22] Harvest modeling for the Bathurst herd was continued in 2010 after this report was written and reported by Boulanger and Adamczewski (2015). Further harvest modeling for a wide range of harvest levels and harvest sex ratio and caribou herd with varying trend, cow survival and calf productivity was described by Boulanger and Adamczewski (2016).
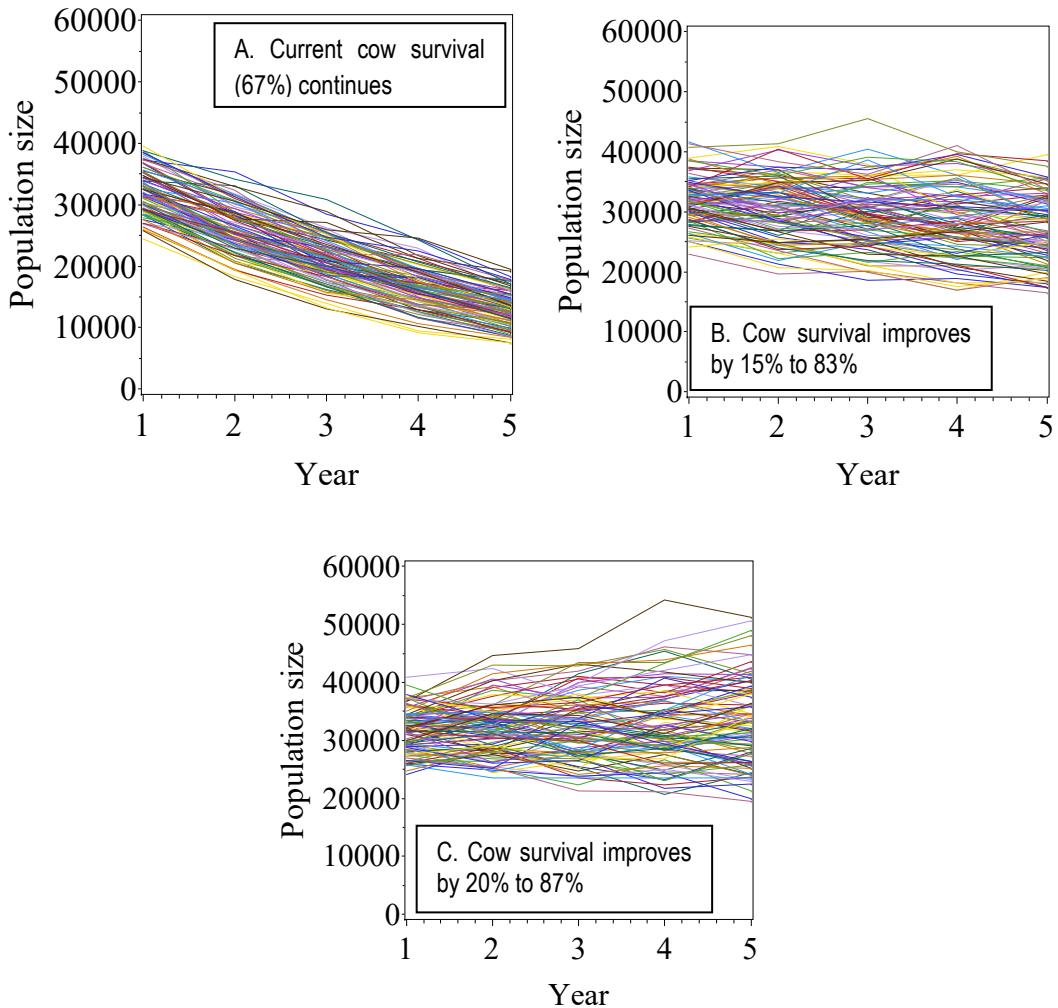
Figure 67. Stochastic simulations of possible futures for the Bathurst herd at varying cow survival rates. A. At current low cow survival rates, the herd cannot stabilize. B. If cow survival increases by 15%, a continued slow decline or a stable herd is likely. C. If cow survival increases by 20%, the herd is likely to be stable or increasing slightly.

We simulated a range of values for adult female survival rate, calf survival rate, and fecundity as suggested by the OLS model exercise, and then ran simulations of population growth with variance in each parameter simulated. The geometric mean of successive change in population size, termed λ, was then estimated to determine what range of parameters was needed for the population to recover. A λ of 1 would mean that the population in a given year was similar to the population in the previous year, implying stability. A λ value <1 would imply the population is decreasing whereas a λ >1 would imply the population is increasing. The female segment was simulated for this exercise.

It should be noted that the simulations shown vary some parameters but leave cow survival as unchanged. A cow survival rate of 67% would assume that the harvest of cows

would decrease as the number of cows got smaller. If the cow harvest remains at a constant level (as in the Caribou Calculator projections), cow survival would continue to decline, and these projections would then produce similar results to the Caribou Calculator projections.

Results from simulations suggested that the herd would continue to decline unless calf survival was >0.30 regardless of increases in adult female survival (Figure 68). An increase in adult female survival to 0.86 (which is the estimated 1985 level) would allow the herd to stabilize with calf survival levels of 0.53 (low F_a) to 0.50 (high F_a). An increase in adult female survival to 0.91 would allow the herd to stabilize with calf survival values of 0.32 (high F_a) to 0.35 (low F_a). The parameter levels required for recovery are similar to those associated with stability in the Western Arctic herd (Haskell and Ballard 2007) and the Porcupine herd (Fancy et al. 1994, Walsh et al. 1995).
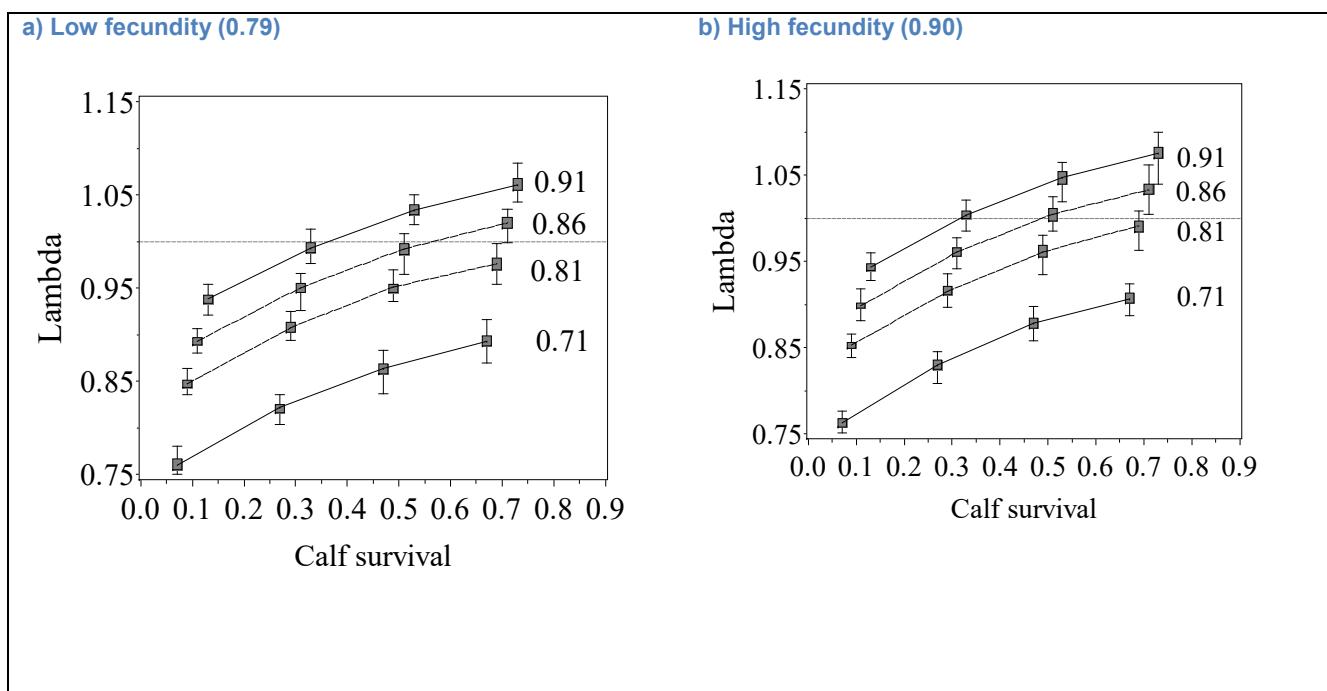
Figure 68. Projected Bathurst population trend (lambda) with various combinations of calf survival and cow survival, at low or high fecundity.

Risks Associated with a Strongly Skewed Sex Ratio (Few Males) (JB and JA)

The sensitivity of population trend to small changes in barren-ground caribou cow survival rates (Porcupine herd: Fancy et al. 1994, George River herd: Crête et al. 1996, Bathurst herd: this report) is well established. Management of the Bathurst herd will need to result in substantially higher cow survival rates if the herd is to have any chance of recovering. However, a heavy harvest of males may lead to a highly skewed sex ratio (low bull:cow ratio) and this strategy, if taken to extremes, may also have negative

implications for the Bathurst herd. As reviewed earlier, bull:cow ratios in the Bathurst herd have been the lowest (2006-2008) of the herds ENR monitors. We review some studies on the effects of a male-biased hunter harvest in this section.

Caribou and reindeer are gregarious and during the breeding season, prime bulls often have harems of a dozen or more females, and the prime bulls will attempt to breed as many of these females as possible (Bergerud 1974). Present-day (2009) reindeer herders in Alaska maintain one bull for every 15-20 females (5-7 bulls:100 cows), as their experience has been that this is sufficient to breed all the females (G. Finstad, University of Alaska, pers. comm. 2009). In moose, which are much less gregarious and where cows might conceivably not find a bull if bulls are very scarce, a change from 16 bulls:100 cows to 29 bulls:100 cows in a heavily hunted population had no effect on calf:cow ratios, (normal) pregnancy rates, or sex ratio of calves in Alaska (Schwartz et al. 1992). In an experimental study with reindeer, a strongly skewed sex ratio of 8-14 bulls:100 cows did not affect calving rate (Holand et al. 2003). Bergerud (1974) felt that at a sex ratio of 1 bull:12 cows (8 bulls:100 cows), there might not be enough bulls to breed all the cows in Newfoundland caribou. It is clearly possible for one caribou or reindeer bull to breed several females, and a sex ratio somewhat skewed toward low bull:cow ratios is not likely to affect pregnancy rate. However, there are reasons to be cautious about skewing a caribou herd's sex ratio heavily toward females, particularly if it persists for an extended period.

Recent experience with other polygamous large herbivores suggests the need for caution when the sex ratio becomes skewed strongly to females (Langvatn and Loison 1999, Mysterud et al. 2002, Hard et al. 2006). The mechanisms for population decline in other species with a sex ratio strongly biased toward females include breeding by young bulls, which may cause delayed conception, later calving, lower birth weights and lower calf survival (Mysterud et al. 2002). Holand et al. (2003) used an experimental approach to investigate the consequences of a very skewed sex ratio (8-14 bulls:100 cows) in reindeer. Calving was later with the skewed ratio, but the age of the bulls did not affect the date of calving, and the calving rate (productivity) was not affected. Synchrony of births and calf birth weight increased with the higher sex ratio. Although the reindeer were in a large enclosure, the number of animals was low which suggests caution in extrapolating these results to free-ranging caribou. Coltman et al (2003) showed that over a 30-year period, harvest of about 40% of a bighorn population's large rams affected the herd's genetics and there was a tendency toward smaller horns in males. Hard et al. (2006) suggested a minimum sex ratio of 18 males:100 females in red deer to avoid negative genetic effects of a very skewed sex ratio and to ensure that a sufficient number of large older males survived the breeding season. This echoes concerns that have been raised in NWT communities about heavy harvest of prime bulls and the potential impacts

to the herd's health and genetics, as well as the role of prime bulls in the southward migration to wintering grounds.

Although this is not an exhaustive review of the subject, caution should be used in considering harvest management for the Bathurst and other caribou herds. The Bathurst herd's sex ratio in recent years has been lower than in other NWT herds, which may in part reflect harvest pressure on this herd. Leaving a healthy number of prime bulls to breed the cows should be an objective of management, even if the highest priority should be to increase Bathurst cow survival, without which the herd cannot recover.

CONCLUSION

The data and modeling presented in this report are incomplete and the strength of the data sets varies, but there is little doubt among the authors that the decline of the Bathurst herd from 2006-2009 is real and that the herd cannot recover unless cow survival rates increase substantially in the near future, along with continued good calf survival and high pregnancy rates. Barren-ground caribou herds have most likely varied widely in numbers for hundreds and perhaps thousands of years, and a large part of the Bathurst decline since 1986 is likely due to weather-related effects such as years with a late spring or poor summer vegetation growth. The Bathurst herd would most likely have declined between 2000 and 2006 due to these kinds of environmental factors. The high pregnancy rates, good condition in cows, and increased calf:cow ratios from 2007-2009 suggest that the herd is experiencing better environmental conditions and might stabilize or begin to increase if cow survival rates improve. However, many factors outside human control will continue to affect the herd, and the best harvest management (closure) can only provide the herd with an opportunity to recover.

We would also underscore the importance of not allowing the Bathurst herd to fall to very low numbers, as has happened to the Beverly herd recently and to the Fortymile herd in the past. At very low numbers, barren-ground caribou may have a fundamentally different relationship with predators, and several barren-ground caribou herds (George River, Fortymile, Mulchatna) that fell to very low numbers spent extended periods at low numbers, in some cases decades, before increasing again. At very low numbers, Beverly caribou cows have had very low adult survival and very low calf survival, and some of the cows have moved to the Ahiak herd's calving grounds. They no longer have the advantage of swamping predators by calving in large numbers in an area with few predators, the strategy that allows barren-ground caribou to reach numbers beyond the capacity of predators to limit. The likelihood of unpredictable and perhaps uncontrollable changes in barren-ground caribou behaviour and predator-prey ecology increases as a caribou herd reaches very low numbers.

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LITERATURE CITED

Adamczewski, J., A. Gunn, K. G. Poole, A. Hall, J. Nishi, and J. Boulanger. 2015. What Happened to the Beverly Caribou Herd after 1994? Arctic 68: 407-421.

Adamczewski, J., J. Boulanger, Croft, B., T. Davison, H. Sayine-Crawford, and B. Tracz. 2017. A comparison of calving and post-calving photo-surveys for the Bluenose-East herd of barren-ground caribou in northern Canada in 2010. Canadian Wildlife Biology and Management 6: 4-30.

Adamczewski, J. Boulanger, H. Sayine-Crawford, J. Nishi, D. Cluff, J. Williams, and L.-M. LeClerc. 2019. Estimates of breeding females & adult herd size and analyses of demographics for the Bathurst herd of barren-ground caribou: 2018 calving ground photographic survey. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 279.

Alaska Board of Game. 2006. Fortymile Caribou Herd Harvest Plan 2006-2012. Alaska Department of Fish and Game, Juneau, Alaska. 13pp.

Beaulieu, D. 2012. Dene traditional knowledge about caribou cycles in the Northwest Territories. Rangifer Special Issue 20: 59–67.

Bergerud, A.T. 1974. Rutting behavior of Newfoundland caribou. In: V. Geist and F. Walther (editors): The behavior of ungulates and its relation to management. Papers of an international symposium in Calgary, Nov. 2-5, 1971. International Union for the Conservation of Nature, Morges, Switzerland. pp. 395-435.

Bergerud, A.T. 2000. Caribou (Chapter 31) in: Demarais, S. and Krausman, P. R. (editors). Ecology and management of large mammals in North America. Prentiss-Hall, New Jersey.

Bergerud, A.T., S.N. Luttich, and L. Camps. 2008. The return of caribou to Ungava. McGill-Queen's University Press, Montreal and Kingston, Ontario.

Bolger, D.T., W.D. Newmark, T.A. Morrison and D.F. Doak 2007. The need for integrative approaches to understand and conserve migratory ungulates. Ecology Letters 11: 63-77.

Boulanger, J. and A. Gunn. 2008. Exploring possible mechanisms for the decline of the Bathurst of barren-ground caribou using demographic modeling. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 175.

Boulanger, J., and J. Adamczewski. 2015. Simulations of Harvest and Recovery for the Bathurst Caribou Herd, with Annual Variation. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. File Report 145.

Boulanger, J., and J. Adamczewski. 2016. A general approach to harvest modeling for caribou herds in the NWT and recommendations on harvest based on herd risk status. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 262.

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., K. G. Poole, A. Gunn and J. Wierzchowski. 2012. Estimating the zone of influence of industrial developments on wildlife: a migratory caribou Rangifer tarandus groenlandicus and diamond mine case study. Wildlife Biology 18: 164-179.

Boulanger, J., M.Campbell and D. Lee. 2018a. Estimating abundance and trend of the Qamanirjuaq mainland migratory barren-ground caribou subpopulation - June 2017. Government of Nunavut, Department of Environment, Technical Summary - No: 01-2018.

Boulanger, J., J. Adamczewski, and T. Davison. 2018b. Estimates of caribou herd size using post-calving surveys in the Northwest Territories and Nunavut, Canada: A meta-analysis. Rangifer 38: 39-78.

Boulanger, J., J. Adamczewski, J. Nishi, D. Cluff, J. Williams, H. Sayine-Crawford, and L. M. LeClerc. 2019. Estimates of breeding females & adult herd size and analyses of demographics for the Bluenose-East herd of barren-ground caribou: 2018 calving ground photographic survey. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 278.

Boulet, M., S. Couturier, S. D. Côté, R. Otto and L. Bernatchez. 2007. Integrative use of spatial, genetic, and demographic analyses for investigating genetic connectivity between migratory, montane and sedentary caribou herds. Molecular Ecology 16: 4223-4240.

Brown, D., and P. Rothery. 1993. Models in biology: Mathematics, statistics, and computing. John Wiley and Sons, New York.

Brownie, C., J.E. Hines, J.D. Nichols, K.H. Pollock, and J.B. Hestbeck. 1993. Capture-recapture studies for multiple strata including non-markovian transitions. Biometrics 49:1173-1187.

Burnham, K.P., and D.R. Anderson. 1998. Model selection and inference: A practical information theoretic approach. Springer, New York.

Cameron, R.D., W.T. Smith, S.G. Fancy, K.L. Gerhart, and R.G. White. 1993. Calving success of female caribou in relation to body weight. Canadian Journal of Zoology 71: 480-486.

Cameron, R.D., W.T. Smith, R.G. White, and B. Griffith. 2005. Central Arctic Caribou and petroleum development: distributional, nutritional and reproductive implications. Arctic 58: 1-9.

Campbell, M., Boulanger, J., Lee, D.S., Dumond, M., and McPherson, J. 2012. Calving ground abundance estimates of the Beverly and Ahiak subpopulations of barren-ground caribou (Rangifer tarandus groenlandicus) – June 2011. Technical Summary. Department of Environment, Government of Nunavut.

Carroll, G. 2005. Unit 26A caribou management report. Pages 246–268 In C. Brown, editor. Caribou management report of survey and inventory activities 1 July 2002–30 June 2004. Alaska Department of Fish and Game. Juneau, Alaska.

Caughley, G. 1977. Analysis of Vertebrate Populations. John Wiley and Sons, London.

Chen, W., D.E. Russell, A. Gunn, B. Croft, W.R. Chen, R. Fernandes, H. Zhao, J. Li, Y. Zhang, K. Koehler, I. Olthof, R.H. Fraser, S.G. Leblanc, G.R. Henry, R.G. White and G.L. Finstad. 2013. Monitoring habitat condition changes during winter and pre-calving migration for Bathurst Caribou in northern Canada. Biodiversity 14(1): 36-44.

Chen, W., L. White, J. Z. Adamczewski, B. Croft, K. Garner, J. S. Pellissey, K. Clark, I. Olthof, R. Latifovic, and G. L. Finstad. 2014. Assessing the impacts of summer range on Bathurst Caribou's productivity and abundance since 1985. Natural Resources 5: 130-145.

Chen, W., J. Z. Adamczewski, L. White, B. Croft, A. Gunn, A. Football, S. G. Leblanc, D. E. Russell, and B. Tracz. 2018. Impacts of climate-driven habitat change on the peak calving date of the Bathurst caribou in Arctic Canada. Polar Biology https://doi.org/10.1007/s00300-018-2259-8.

Cluff, H.D., L.R. Walton, and P.C. Paquet. 2002. Movements and habitat use of wolves denning in the central Arctic, Northwest Territories and Nunavut, Canada. Final report to the West Kitikmeot/Slave Study Society, Yellowknife, Northwest Territories, Canada. Available at: www.wkss.nt.ca.

Cluff, H.D., M. Musiani, P.C. Paquet, L.R. Walton. 2010. Wolf ecology and management in the Northwest Territories, Canada. Perspectives from the Rennie Lake wolf hunt. Chapter In M. Musiani, P.C. Paquet, and L. Boitani, editors. The world of wolves: new perspectives on ecology, behaviour and policy. University of Calgary Press, Alberta, Canada.

Coltman, D.W., P. O'Donoghue, J.T. Jorgenson, J.T. Hogg, C. Strobeck, and M. Festa-Bianchet. 2003. Undesirable evolutionary consequences of trophy hunting. Nature 426: 655-658.

Cornelissen, J.H.C., T.V. Callaghan, J.M. Alatalo, A. Michelsen, E. Graglia, A.E. Hartley, D.S.Hik, S.E. Hobbie, M.C. Press, C.H. Robinson, G.H.R. Henry, G.R. Shaver, G.K. Phoenix, D. Gwynn Jones, S. Jonasson, F.S. Chapin III, U. Molau, C. Neill, J. Lee, J.M. Melillo, B. Sveinbjörnsson, and R. Aerts. 2001. Global change and Arctic ecosystems: is lichen decline a function of increases in vascular plant biomass? Journal of Ecology 89: 984–994.

Coulson, T., P. Rohani and M. Pascual. 2004. Skeletons, noise and population growth: the end of an old debate? Trends in Ecology and Evolution 19:359-364.

Couturier, S., R. Courtois, H. Crepeau, 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.

Crête, M., S. Couturier, B.J. Hearn, and T.E. Chubbs. 1996. Relative contribution of decreased productivity and survival to recent changes in the demographic trend of the Rivière George Caribou Herd. Rangifer Special Issue 9: 27-36.

Daniel, C., D. Russell, and M. Carlson. 2009. Modeling the effects of development on the Bathurst Caribou herd: Demonstration Project. Draft Contract Report, ENR GNWT, Yellowknife.

Dau, J. 2003. Western Arctic herd caribou management. In C. Healy, editor. Caribou Management Report of Surveys and Inventories Activities 1 July 2000-30 June 2002. Alaska Department of Fish and Game, Juneau, Alaska. Pages 204-251.

Dauphiné, T.C., Jr. 1976. Biology of the Kaminuriak population of barren-ground caribou. Part 4. Growth, reproduction, and energy reserves (Report Series 38). Canadian Wildlife Service, Ottawa.

Davis, J.L., R. Shideler, and R.E. LeResche. 1978. Fortymile caribou herd studies. Alaska Department of Fish and Game. Final Report Federal Aid in Wildlife Restoration Projects W-17-6, W-17-7. 69pp.

Davis, J.L., P. Valkenburg and R.D. Beortje. 1986. Empirical and theoretical considerations toward a model for caribou socio-ecology. Rangifer 1:151–159.

Eberhardt, L.L. 1985. Assessing the dynamics of wild populations. Journal of Wildlife Management 49: 997-1012.

Eberhardt, L.L. and K.W. Pitcher. 1992. A further analysis of the Nelchina caribou and wolf data. Wildlife Society Bulletin 20: 385-395.

Epstein, H.A., M.P. Calef, M.D. Walker, F.S. Chapin III, and A.M. Starfield. 2004. Detecting changes in Arctic tundra plant communities in response to warming over decadal time scales. Global Change Biology 10: 1325–1334.

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.

Festa-Bianchet, M., J.-M. Gaillardt and S.D. Cote.2003. Variable age structure and apparent density dependence in survival of adult ungulates. Journal of Animal Ecology 72: 640-649.

Frame, P.F.,and H.D.Cluff. 2011. How many wolves? Can we use observations from caribou surveys as an index? Department of Environment and Natural Resources, Government of the Northwest Territories. Poster presented at International Arctic Ungulate Conference in Yellowknife, Northwest Territories, August 2011.

Frame, P.F., H.D. Cluff, and D.S. Hik. 2007. Response of wolves to experimental disturbance at homesites. Journal of Wildlife Management 71: 316-320.

Fuller, T.K., L.D. Mech, and J.F. Cochrane. 2003. Wolf population dynamics. In L.D. Mech and L. Boitani, Editors. Wolves. Behavior, ecology, and conservation. University of Chicago Press, Illinois, USA. Pages 161-191.

Gasaway, W.C., S.D. Dubois, D.J. Reed, and S.J. Harbo. 1986. Estimating moose population parameters from aerial surveys. Biological Papers of the University of Alaska No 22: 1-108.

Golder Associates Ltd. 2008a. Analysis of environmental effects from the Diavik diamond mine on wildlife in the Lac de Gras region. Submitted to Diavik Diamond Mines, Yellowknife, NT.

Golder Associates Ltd. 2008b. Snap Lake mine: analysis of environmental effects on wildlife 1999 to 2007. Submitted to De Beers Canada Inc., Yellowknife, NT.

Griffith, B., D.C. Douglas, N.E. Walsh, D.D. Young, T.R. McCabe, D.E. Russell, R.G. White, R.D. Cameron, and K.R. Whitten. 2002. Section 3: the Porcupine Caribou Herd. USGS/BRD 2002-0001 Biological Science Report.

Gunn, A. 2003. Voles, lemmings and caribou – population cycles revisited? Rangifer Special Issue 14: 105-111.

Gunn, A. 2013. Satellite collaring and calf survival in the Bathurst herd of barren-ground caribou 2003-2005. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 228.

Gunn, A., and F.L. Miller. 1986. Traditional behaviour and fidelity to calving grounds by barren-ground caribou. Rangifer Special Issue 1: 151-158.

Gunn, A., Fournier, B., and Nishi, J. 2000. Abundance and distribution of the Queen Maud Gulf Caribou Herd, 1986-1998. Yellowknife: Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. File Report 126.

Gunn, A., J. Lee and B. Elkin. 2005a. Catalogue of data files for caribou collections (morphologic measurements, parasitology, contaminants). Northwest Territories Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 160.

Gunn, A., J. Nishi, J. Boulanger and J. Williams. 2005b. An estimate of breeding females in the Bathurst herd of barren-ground caribou, June 2003. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 164.

Gunn, A., K.G. Poole, J. Wierzchowski and M. Campbell. 2007. Assessment of Caribou Protection Measures. Unpublished report Submitted to Indian and Northern Affairs Canada, Gatineau, Québec, 45pp.

Gunn, A., J. Adamczewski, and J. Nishi. 2008a. 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, Yellowknife, Northwest Territories, Canada. Manuscript Report 178.

Gunn, A., K.G. Poole, and J. Wierzchowski. 2008b. A geostatistical analysis for the patterns of caribou occupancy on the Bathurst calving grounds 1966-2007. Unpublished report Submitted to Indian and Northern Affairs Canada, Yellowknife, NWT. 51pp.

Gunn, A., C.J. Johnson, J.S. Nishi, C.J. Daniel, M. Carlson, D.E. Russell and J.Z. Adamczewski. 2011. Addressing Cumulative Effects in the Canadian Central Arctic – Understanding the Impacts of Human Activities on Barren-ground Caribou. Pp.113-133 in Krausman, P.R. and L.K. Harris (Eds.) Cumulative Effects in Wildlife Management: A Critical Aspect of Impact Mitigation. CRC Press, Boca Raton, FL.

Gunn, A., A. D'Hont, J. Williams and J. Boulanger. 2013. Satellite collaring in the Bathurst herd of barren-ground caribou 1996-2005. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 225.

Hard, J.H., L.S. Mills, and J.M. Peek. 2006. Genetic implications of reduced survival of red deer Cervus elaphus under harvest. Wildlife Biology 12: 427-441.

Haskell, S.P., and W.B. Ballard. 2007. Modeling the Western Arctic caribou herd during a positive growth phase: Potential effects of wolves and radio collars. Journal of Wildlife Management 71: 619-627.

Heard, D.C. 1985. Caribou census techniques used in the Northwest Territories. In Proceedings of the 2nd North American Caribou Workshop. McGill Subarctic Research Paper No. 40. Pages 229-238.

Heard, D.C. and T.M. Williams. 1992. Distribution of wolf dens on migratory caribou ranges in the Northwest Territories, Canada. Canadian Journal of Zoology 70: 1504-1510.

Heard, D. C., T. M. Williams, and D. A. Melton. 1996. The relationship between food intake and predation risk in migratory caribou and implications to caribou and wolf population dynamics. Rangifer Special Issue 2: 37-44.

Helle, T. and L. Tarvainen. 1984. Effects of insect harassment on weight gain and survival in reindeer calves. Rangifer 4(1): 24-27.

Hestbeck, J.B., J.D. Nichols, and R.A. Malecki. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada geese. Ecology 72: 523-533.

Hinkes M.T., G.H. Collins, L.J. Van Daele, S.D. Kovach, A.R. Aderman, J.D. Woolington, and R.J. Seavoy. 2005. Influence of population growth on caribou herd identity, calving ground fidelity, and behaviour. Journal of Wildlife Management 69: 1147-1162.

Holand, Ø., Røed, K.H., Mysterud, A., Kumpula, J.M., Nieminen, M. and M.E. Smith. 2003. The effect of sex ratio and male age structure on reindeer calving. Journal of Wildlife Management 67:25-33.

Holmes, E.E., York, A.E. 2003. Using age structure to detect impacts on threatened populations: a case study with Steller sea lions. Conservation Biology 17: 1794-1806.

Johnson, C.J., M.S. Boyce, R.L. Case, H.D. Cluff, R. Gau, A. Gunn, and R. Mulders. 2005. Cumulative effects of human developments on arctic wildlife. Wildlife Monograph 160: 1-36.

Kennedy, P.K., M.L. Kennedy, P.L. Clarkson, and I.S. Liepins. 1991. Genetic variability in natural populations of the gray wolf, Canis lupus. Canadian Journal of Zoology 69: 1183-1188.

Klaczek, M. R., C. J. Johnson, and H. D. Cluff. 2015. Den site selection of wolves (Canis lupus) in response to declining caribou (Rangifer tarandus groenlandicus) density in the central Canadian Arctic. Polar Biology 38:2007–2019.

Klaczek, M. R., C. J. Johnson and H. D. Cluff. 2016. Wolf-caribou dynamics within the central Canadian Arctic. Journal of Wildlife Management 80: 837-849.

Kofinas, G., D.E. Russell, and R.G. White. 2002. Monitoring caribou body condition: workshop proceedings. Canadian Wildlife Service Technical Report Series No. 396. Ottawa, ON. 31pp.

Lancia, R.A., W.L. Kendall, K.H. Pollock, and J.D. Nichols. 2005. Estimating the number of animals in wildlife populations. In TC. E. Braun, Editor. Techniques for wildlife investigations and management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA. Pages 106-153.

Langvatn, R., and A. Loison. 1999. Consequences of harvesting on age structure, sex ratio and population dynamics of red deer Cervus elaphus in central Norway. Wildlife Biology 5: 213-223.

Lieb, J.W., W.B. Cella, and R.W. Tobey. 1994. Population dynamics of the Mentasta caribou herd. Research final report. Alaska Department of Fish and Game, Division of Wildlife, Juneau, Alaska. 72pp.

Manly, B.F.J. 1997. Randomization, bootstrap and Monte Carlo Methods in Biology. 2nd edition. Chapman and Hall, New York.

Mattson, I.J.K., C.J. Johnson, and H.D. Cluff. 2009. Winter survey of Bathurst caribou and associated wolf distribution and abundance. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 185.

McLoughlin, P.D. L.R . Walton, H.D. Cluff, P.C. Paquet, and M.A. Ramsey. 2004. Hierarchical habitat selection by tundra wolves. Journal of Mammalogy 85: 576-580.

Mech, L.D., and L. Boitani. 2003. Wolf social ecology. In L.D. Mech and L. Boitani, Editors. Wolves. Behavior, ecology, and conservation. University of Chicago Press, Illinois, USA. Pages 1-34.

Morneau, C., and Payette, S., 1998: A dendroecological method to evaluate past caribou (Rangifer tarandus L.) activity. Ecoscience, 5: 64–76.

Morneau, C., and Payette, S., 2000: Long-term fluctuations of a caribou population revealed by tree-ring data. Canadian Journal of Zoology, 78: 1784–1790.

Mueller, F.P. 1995. Tundra esker systems and denning by grizzly bears, wolves, foxes, and ground squirrels in the central arctic, Northwest Territories. Department of Renewable Resources. File Report 115.

Musiani, M., J.A. Leonard, H.D. Cluff, C.C. Gates, S. Mariani, P.C. Paquet, C. Vila, and R.K. Wayne. 2007. Differentiation of tundra/taiga and boreal coniferous forest wolves: genetics, coat colour and association with migratory caribou. Molecular Ecology 16: 4149-4170.

Mysterud, A., T. Coulson and N.C. Stenseth. 2002. The role of males in the population dynamics of ungulates. Journal of Animal Ecology 71: 907–915.

Nagy, J.A. 2009. Population Estimates for the Cape Bathurst and Bluenose-West Barren-ground Caribou Herds Using Post-Calving Photography. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report (in prep.).

Nagy J.A., and B. Tracz. 2005. Estimates of the Number of Barren-ground Caribou in the Bluenose-East Herd Derived Using Post Calving Photography, July 2005. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report (in prep.).

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, Yellowknife, Northwest Territories, Canada. Manuscript Report 171.

Nagy, J.A., and B. Tracz. 2006. Estimates of the number of barren-ground caribou in the Bluenose-East herd derived using post calving photography, July 2006. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report (in prep.).

Nagy, J.A., Johnson, D.L., Larter, N.C., Campbell, M.W., Derocher, A.E., Kelly, A., Dumond, M., Allaire, D., and Croft, B. 2011. Subpopulation structure of caribou (Rangifer tarandus L.) in Arctic and Subarctic Canada. Ecological Applications 21(6): 2334 – 2348.

Nellemann, C., I. Vistnes, P. Jordhoy, O. Strand, and A. Newton. 2003. Progressive impact of piecemeal infrastructure development on wild reindeer. Biological Conservation 113: 307-317.

Nesbitt, L. and J. Adamczewski. 2013. Decline and recovery of the Bathurst caribou herd: workshops held October 1 and 2 and 5 and 6, 2009 in Yellowknife. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 238.

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, Yellowknife, Northwest Territories, Canada. File Report 137.

Nishi, J., B. Croft, J. Boulanger and J. Adamczewski. 2014. An estimate of breeding females in the Bathurst herd of barren ground caribou, June 2009. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. File Report 144.

Nishi, J., and A. Gunn (editors). 2016. Contributing Authors: Jan Z. Adamczewski, Matt J. Carlson, Colin J. Daniel, Anne Gunn, Chris J. Johnson, John S. Nishi, Don E. Russell, J. Brad Stelfox, and David Taylor. Development of modeling tools to address cumulative effects on the summer range of the Bathurst caribou herd – a demonstration project. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. File Report 148.

Person, B.T., A.K. Pritchard, G.M. Carroll, D.A. Yokel, R.S. Suydam, and J.C. George. 2007. Distribution and movements of the Teshekpuk Caribou herd 1990-2005: prior to oil and gas development. Arctic 60: 238-25

Phillips, G.E., and G.C. White. 2003. Pronghorn population response to coyote control: modeling and management. Wildlife Society Bulletin 31: 1162-1175.

Poole, K.G., Gunn, A., and Wierzchowski, J. 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 the Northwest Territories, Yellowknife, Northwest Territories, Canada. File Report 141.

Rescan. 2006. Ekati diamond mine CALPUFF air dispersion modeling assessment report. Prepared for BHP Billiton Diamonds Inc., Rescan Environmental Services Ltd., October 2006.

Rettie, J. 2017. Determining optimal satellite collar sample sizes for monitoring barren-ground caribou populations. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada. Manuscript Report 264.

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, D.E., K.L. Gerhart, R.G. White, and D. van de Wetering. 1998. Detection of early pregnancy in caribou: evidence for embryonic mortality. Journal of Wildlife Management 62: 1066-1075.

Russell, D.E., R.G. White and C.J. Daniel. 2005. Energetics of the Porcupine Caribou Herd: A computer simulation model. Technical Report series No. 431. Canadian Wildlife Service. Ottawa, Ontario, 64pp.

SAS Institute. 2000. The SAS System for Windows. The SAS Institute, Cary, NC.

Schwartz, C.C., K.J. Hundertmark, and T.H. Spraker. 1992. An evaluation of selective bull moose harvest on the Kenai Peninsula. Alces 28: 1-13.

Seip, D.R. 1991. Predation and caribou populations. Rangifer Special Issue 7: 46-52.

Stephens, P.A. and W.J. Sutherland. 1999. Consequences of the Allee effect for behaviour, ecology and conservation. Trends in Ecology and Evolution 14: 401–405.

Thomas, D.C. 1998. Needed: less counting of caribou and more ecology. Rangifer Special Issue 10: 15-23.

Valkenberg, 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 2nd North American Caribou Workshop. McGill Subarctic Research Paper No. 40.

Valkenburg, P., R.A. Sellers, R.C. Squibb, J.D. Woolington, A.R. Aderman, and B.W. Dale. 2003. Population dynamics of caribou herds in southwestern Alaska. Rangifer Special Issue 14: 131–142.

Vors, L.S., and M.S. Boyce. 2009. Global declines of caribou and reindeer. Global Change Biology 15: 2626-2633).

Walsh, N.E., B. Griffith, and T.R. McCabe. 1995. Evaluating growth of the Porcupine caribou herd using a stochastic model. Journal of Wildlife Management 59: 262-272.

Walton, L.R., H.D. Cluff, P.C. Paquet, and M.A. Ramsay. 2001. Movement patterns of barren-ground wolves in the central Canadian Arctic. Journal of Mammalogy 82: 867-876.

White, G.C. 2000. Population viability analysis: Data requirements and essential analyses. In L. Boitani, andT. K. Fuller, editors. Research techniques in animal ecology: Controversies and consequences. Columbia University Press, New York. Pages 289-331.

White, G.C., and K.P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study Supplement 46:120-138.

White, G.C., and B. Lubow. 2002. Fitting population models to multiple sources of observed data. Journal of Wildlife Management 66: 300-309.

Williams, T.M. 1990. Summer diet and behaviour of wolves denning on barren-ground caribou range in the Northwest Territories, Canada. MSc. thesis, University of Alberta, Edmonton, Canada.

Wolfe, S.A., B. Griffith, C.A.G. Wolfe. 2000. Responses of reindeer and caribou to human activities. Polar Research 19: 63-73.

Zalatan, R., A. Gunn, and G.H.R. Henry. 2006. Long-term abundance patterns of barren-ground caribou using trampling scars on roots of Picea mariana in the Northwest Territories, Canada. Arctic, Antarctic and Alpine Research 38(4): 624-630.

APPENDIX A. Detailed Information for June 2009 Bathurst Calving-ground Photo Survey.

Field team involved in June 2009 Bathurst Calving Ground Survey

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 and 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 and Community Representative	Yellowknife Dene First Nation
Doug Evans (DE)	Photographer (Challenger C-GEOS)	Geographic Air Survey Ltd.
Ron Fatt (RF)	Observer and Community Representative	Lutsel K'e Wildlife Lands and 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 and Community Representative	North Slave Metis Alliance
John Nishi (JN)	Biologist	EcoBorealis Consulting Inc.

APPENDIX B. Number of 1+ Year-old Caribou Observed During a Photographic Transect Survey of a High-density Stratum, Bathurst Calving Ground, 8 June 2009.

High-density Photographic Stratum			
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	1,039
19	54.49	49.82	279
20	54.49	49.82	266
21	54.49	49.82	426
22	54.49	49.82	189
Total	1,154.87	1,055.91	7,140

APPENDIX C. Number of 1+ Year-old Caribou Observed During a Photographic Transect Survey of Medium-density Strata, Bathurst Calving Ground, 9 June 2009.

Medium-density Photographic Stratum			
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	441.80	404.00	1,007

APPENDIX D. Number of 1+ year-old Caribou observed during an Aerial Transect Survey of Three Low-density Visual Strata (Low N, Low SW, and L SE), Bathurst Calving Ground, 8-9 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	234.22	5

Low Density Visual Stratum - Low SW

Transect No.	Transect Length (km)	Transect Area (km^2)	1+ yr-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	235.40	188.32	15

APPENDIX E. 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	16	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
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

	n=	65		
Sum Breeding Females	1248	Sum Calves	892	Sum all caribou	2732
Sum 1+ Yr Old Caribou	1847	Ratio Calf:cow	0.7147		
Overall proportion Breeding Females	0.6757			

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

mean	0.678
variance	0.118
SD	0.343
SE	0.043
CV	0.063

$\text{Ø}i = nS - (n-1) St$

Where:

$\text{Ø}i$ = 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)

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APPENDIX F. Composition of 1+ year-old Caribou Classified in the Medium-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
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				

$$Øi = nS - (n-1) St$$

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)

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

mean	0.879
variance	0.005
SD	0.070
SE	0.017
CV	0.019

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)

mean	0.113
variance	0.021
SD	0.143
SE	0.048
CV	0.423

$\emptyset i = nS - (n-1) St$

Where:

$\emptyset i$ = 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)