11 September 2009 **DRAFT**

ENVIRONMENTAL TRENDS ACROSS THE RANGE OF THE BATHURST CARIBOU HERD AND TIMING OF THE ARRIVAL OF COWS ON THEIR CALVING GROUND 1996–2009

Submitted in fulfillment of SC 417469
Environment and Natural Resources, Yellowknife, NWT

Prepared by
Anne Gunn[1] and Kim G. Poole[2]

* * * * * * *

"Everything is changing. It is not the same as before. Sometimes it does not snow as much as it used to. It never gets as cold as it used to." (May Algona 1999 in Thorpe et al. 2001)

Climate change in polar regions is expected to be among the largest and most rapid of any region on the Earth (IPCC 2001)

[1] 368 Roland Road, Salt Spring Island, BC V8K 1V1 gunnan@telus.net

[2] Aurora Wildlife Research, 2305 Annable Rd., Nelson, BC V1L 6K4 kpoole@aurorawildlife.com

ABSTRACT

We compiled and summarized environmental trends across the range of the Bathurst caribou (*Rangifer tarandus groenlandicus*) herd to help examine whether changes now being observed on the caribou's range had a role in the decline and whether they will affect the caribou herd's recovery. We also addressed whether environmental conditions during 2009 may have affected the arrival of caribou on the calving grounds. We compared rates of pre-calving migration and timing of arrival onto the calving grounds from 1996 to 2009.

The environmental trends at the circumpolar, regional (ecozone) and Bathurst range are consistent at those three spatial scales. The trends are for warming temperatures and increases in precipitation (although less precipitation is falling as snow), and changes in the length of seasons; the key trend is the warmer temperatures. The plant growing season is longer, although the increase in plant biomass has not increased forage quality. Snowmelt on the calving ground was annually variable; 1998 and 2008 were two early snowmelt years, and 2001 and 2005 were two late years.

Based on movement data as calculated from satellite collars on cows, dates of peak calving shifted about four days between the mid to late 1990s to the years after 1999. Overall mean date for crossing into the annual peak calving grounds was 26 May. The trend in timing of arrival in the calving area was later between 1996 and 2005, but this trend does not appear to have continued since 2005. With the exception of 2005, in all years only 1–2 collared caribou either did not enter the peak calving grounds or entered after 10 June. Year 2005 was particularly unusual, as seven caribou (39%) entered the peak calving grounds between 13–30 June. On average, Bathurst caribou begin to increase their movement to the calving grounds in mid-April, with peak distances moved in mid to late May, and the least movement during 10–14 June corresponding with calving. There was a positive relationship between distance from winter range to calving grounds and both mean daily movement rates during May and date of entry into the peak calving area. In terms of the numbers of satellite-collared cows, the dates of arrival on the calving ground and the rate of travel, 2009 was not an unusual year compared to other years since 1996.

TABLE OF CONTENTS

Abstract ii
Introduction 1
Methods 1
  Environmental trends 1
  Movement data 2
  Peak of calving 3
  Timing of entry into the calving area 3
  Distance from winter range to calving ground 5
  Movement rates 5
Results 6
  Environmental trends 6
  Peak of calving 19
  Timing of entry into the calving area 19
  Distance from winter range to calving ground 20
  Movement rates 22
Discussion 26
Acknowledgements 28
Literature cited 28
Appendix 1 32

LIST OF FIGURES

Figure 1. Location of inner (61 km radius) and outer (122 km radius) distance circles for quantifying movement approaching and into the Bathurst caribou herd calving ground. The green polygon represents the 1996–2009 peak calving grounds. 4
Figure 2. Trends in surface air temperature anomaly (1900–2008) and the Arctic Oscillation trend for 1950–2008 (from AMAP 2009). 6
Figure 3. Annual anomalies of land-surface air temperature in the Arctic (60º to 90º N) for the period 1900 to 2003 using the GHCN dataset (updated from Peterson and Vose 1997). Anomalies were calculated relative to the 1961–1990 average. The smoothed curve was created using a 21-point binomial filter, which approximates a 10-year running mean (figure from ACIA 2005).. 7
Figure 4. Colour-coded trend map for the entire Arctic derived through linear regression of monthly anomalies in each data element from 1981–2001. The anomalies were calculated by subtracting monthly climatology from each of the monthly values (Fig. 5 from Comiso 2003). 8
Figure 5. Time series of variations in the frequency of days with thaw, averaged over the Arctic land area for winter, spring, and autumn (from Groisman et al. 2003 in ACIA 2005). 9
Figure 6. Mean temperature anomalies by season for 1950–2007 relative to the base period (1961–1990) mean, based on data from 3 stations in the western portion of the Taiga Shield Ecozone (Zhang et al. 2008). 12
Figure 7. 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 (Chen et al. In prep. a). 13
Figure 8. 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 $n = 22$ (from Chen et al. In prep. a). 14
Figure 9. Trend line and annual scores 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 In prep.). 15
Figure 10. Mean ice content in snow (ICIS) for the winter range of the Bathurst caribou herd from 1963 to 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 $n = 44$ (From Chen et al. In prep. b)..16
Figure 11. Percent snow cover averaged over the Bathurst caribou habitat during 16 April–15 June from 1982–2006, derived from AVHRR Polar Pathfinder data. The straight line represents the temporal trend: $R^2 = 0.05$, $F = 1.1$, $P = 0.3$, $n = 25$ (from Chen et al. In prep. b). 17
Figure 12. 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 to 2009 (calculated from Table 1)..19
Figure 13. 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. See Fig. 1 for a map of the distance circles...21

Figure 14. Mean (SE) distance from winter range and the centre of the Bathurst calving grounds, 1996–2009. The heavy black horizontal line represents the mean distance among years (grey lines represent the 95% confidence interval around the overall mean)...........21
Figure 15. Mean daily movement distance by 5-day period by Bathurst caribou during pre-calving migration, April to mid-June, for years when surveys occurred (1996, 2003, 2006, 2009). The heavier black line shows the overall mean movements.................................22
Figure 16. Mean daily movement distance by 5-day period by Bathurst caribou during pre-calving migration, April to mid-June, for two representative early snowmelt years (1998, 2008) and two late years (2001, 2005). The heavier black line shows the overall mean movements. 23
Figure 17. Mean daily movement during May by Bathurst caribou, 1996–2009. The heavy black horizontal line represents the mean May movement among years (grey lines represent the 95% confidence interval around the overall mean). 23
Figure 18. Regression of distance between winter range and the centre of the calving ground and A) mean daily movement distance during May, and B) date of entry in to the peak calving ground, Bathurst caribou, 1996–2009. 25
Figure 19. Mean daily movement distance by 5-day period by Bathurst caribou en route to the calving grounds, April to mid-June, 1996–2009. The heavier black line shows the overall mean movements. 32

LIST OF TABLES

Table 1. Timing of spring snowmelt in the Ekati study area, 1997 to 2009 (BHP Billiton 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) 18
Table 2. 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. 2008, and updated to 2009). Primarily GPS collar data were used in 2009. Determination of calving based on changes in movement rates. 20
Table 3. Mean daily movement during May by Bathurst caribou, 1996–2009. 24

INTRODUCTION

The caribou's world is changing. This is a comment frequently made during meetings about the Bathurst herd of migratory tundra caribou *Rangifer tarandus groenlandicus* (B. Croft, Environment and Natural Resources [ENR], pers. comm. 2009). When observations about the land and weather have been compiled, they tell the same story of changing conditions (for example, Thorpe et al. 2001, Lutsel K'e Dené First Nation 2005, Dené Nation and Ecology North 2007, Ford et al. 2008). A similar story of change is being reported elsewhere around the Arctic and led, for example, to the Arctic Council to call for an assessment of the changing arctic climate (ACIA 2005).

The Bathurst caribou herd declined from an estimated 470,000 caribou in 1986 to <50,000 in 2009 (will be updated by late Sept.) (B. Croft, pers. comm. August 2009). Increases and decreases in abundance have happened before and may be part of a natural cycle (Zalatan et al. 2006). The question is, however, whether the changes now being observed on the caribou's range had a role in the decline and whether they will affect the caribou herd's recovery. To address this, the first step is to compile and summarize environmental trends across the range of the Bathurst herd. In this report, we summarize existing analyses using remotely sensed indicators and Environment Canada's weather data to identify the environmental tends for caribou of the Bathurst herd.

The trend in numbers of caribou in the Bathurst herd is measured from photographic surveys over the calving grounds. The technique depends on all the breeding females returning to their calving ground. Occasionally environmental conditions such as late snowmelt can delay the cows during pre-calving migration. Questions have been raised as to whether pre-calving migration was late in 2009 and not all cows reached the calving ground (B. Croft, pers. comm. 2009). To answer that question, we determined if there was evidence that the return of the Bathurst cows to their calving ground was later than average and whether all collared cows reached the calving ground before the dates of the photographic census. We analyzed the mean annual rates of travel for the satellite-collared cows 1996–2009 (1 April to 20 June each year) to identify years when the rates of pre-calving migration were slower than average and arrival on the calving ground was later than average. We also identified years when not all collared cows reached the calving grounds within the timeframe identified as peak of calving.

METHODS

Environmental trends

The trends described in this summary are either for climate or driven by climate (such as freeze-up of lakes and rivers or changes in vegetation). Changes in land use activities such as tourism, outfitter camps and industrial exploration are not included in this summary, although their trends over time are part of the caribou's environment. Other trends such as number of people in the communities and trends in contaminants are also not included.

The information on the environmental trends in this report is provided at three geographic scales. Some information is large-scale – circumpolar or North American Arctic. Secondly, trends are more regional, being at the scale of the ecozone (regions with similar climate, ecology and landform). The Bathurst herd mostly summers within part of the Arctic Ecozone and mostly winters within the Taiga Shield Ecozone. And thirdly, some trends have been specifically compiled for the Bathurst herd's seasonal ranges.

Trends across the circumpolar Arctic are difficult to measure for three reasons. Firstly, the arctic climate is highly variable over time and space. Secondly, climate data are relatively few given the lack of weather stations, their coastal locations and that the duration of the records is often relatively brief. This general point is amplified when the geographical scale is smaller – for example there is only one weather station within the Bathurst herd's summer range. The alternative to weather station data is to use remote sensing. However, indicators based on remote sensing also have a relatively short duration of records, which hinders detecting trends when annual variation is high (Chen et al. In prep. a). The amount of information for the three scales varies widely with most information available for the circumpolar/North American scale. There is a large amount of information in, for example, the Arctic Climate Impact Assessment (ACIA 2005), which has been updated for some indicators in the Arctic Monitoring and Assessment Programme's (AMAP 2009) recent report.

At the ecozone scale, Environment Canada is undertaking a Canada-wide review of status and trends, which includes not just climate but the status and changes in biodiversity. The review is only recently being compiled and so reports are "in press". Other examinations of environmental trends for the Bathurst herd include remote sensing indicators and weather data (Chen et al. In prep. a, b). As a additional indicator for the timing of snowmelt during pre-calving migration, we obtained timing of snowmelt data from BHP Billiton's Ekati diamond mine (BHP Billiton 2009, D. Abernathy, BHP Billiton, pers. comm.). The last dates when 100%, 50%, and 0% snow cover were present at Ekati have been recorded since 1997.[3]

The Arctic's indigenous people, of course, are knowledgeable about their climate. Most of the information is oral but there are compilations for the range of the Bathurst herds. For example, Inuit on the range of the Bathurst herd have recorded their observations about climate and how it is changing, especially during the 1990s (Thorpe et al. 2001:137). Observations are not just about weather but how caribou behaviour and vegetation are changing. Elsewhere on the southeastern ranges of the Bathurst herd, Dené from Lutsel K'e have commented on environmental trends including warming temperatures and unusual weather (Lutsel K'e Dené First Nation 2005). Note: in the final draft we will refer to a draft report by Petter Jacobsen that discusses Whati Elders and Knowledge-holders' comments on climate change.

Movement data

We analyzed movement data from locations of satellite-collared cows as obtained from the ENR Bathurst caribou collar database. This database included satellite locations from collars deployed on female caribou by the ENR Yellowknife office, covering 11 April 1996 to 30 June 2009 from 81 caribou from the Bathurst herd (182 caribou-years covering our period of interest). Duty cycle varied over this time period, from every seven days to every one day, with most collars on a 5-day cycle, and most daily cycles during earlier and later years of the program (Gunn et al. 2001; A. Gunn, unpublished data). Beginning in November 2008, satellite-linked GPS collars were deployed. Within these datasets were a number of animals that were not Bathurst caribou (as defined as calving on the traditional Bathurst calving grounds; Gunn et al. 2008), and there were a very few animals that switched calving grounds between years. Animals that did not end up on or near the Bathurst calving grounds in a particular year were

[3] We are awaiting plant phenology data from the ITEX site at Daring Lake

removed from analyses. To bolster samples sizes for 2009, we obtained satellite location data for two Bathurst caribou from animals collared by the South Slave region.

Peak of calving

We used Gunn et al.'s (2008) estimated timing for the annual peak of calving 1996-2007 and updated the analysis of the movement data for 2008 and 2009. *Peak of calving* is the seven days of concentrated calving around the peak (when 50% of cows in the herd have calved). As detailed in Gunn et al. (2008), we used the techniques of Testa et al. (2000) and Vore and Schmidt (2001) to identify timing of calving from telemetry data using changes in rates of movement. Little movement occurs by neonatal caribou in the first days of life (for example, Kelleyhouse 2001). The 7-day period that best depicted reduced rates of movement from collared animals (and presumably peak of calving) was identified.

Timing of entry into the calving area

We used the timing of caribou crossing two concentric circles to measure the timing of arrival of collared caribou through the late part of their pre-calving migration and into the peak calving ground area (Figure 1). We used calculations for the peak calving ground available in Gunn et al. (2008) and updated data to include 2008 and 2009. The area of the cumulative peak calving grounds was determined (11,812 km^2) and a circle was constructed of similar area (61 km radius; "inner"). This circle was overlaid on the annual peak calving grounds to represent entry into the peak calving area. As a second metric into the periphery of the calving grounds, the circle was doubled to 122 km radius ("outer"), to represent a more distant feature to enumerate caribou earlier in their pre-calving migration. These two circles were used to reduce the influence of caribou that entered the calving area early, overshot, and returned, as well as to enumerate animals that did not reach the peak calving grounds at the end of migration.

The date of crossing these two circles was calculated as the midpoint of telemetry dates of the first entry within each circle and the previous location outside that circle.

We also calculated the number of collared Bathurst caribou available that either did not enter the inner distance circle representing the peak calving area, or entered late. Our cut-off for late arrivals was 10 June, since aerial photographic censuses of the Bathurst herd since 1996 have occurred between 9 and 15 June (Gunn et al. 1997, 2005; Nishi et al. 2007; J. Nishi, pers. comm.).

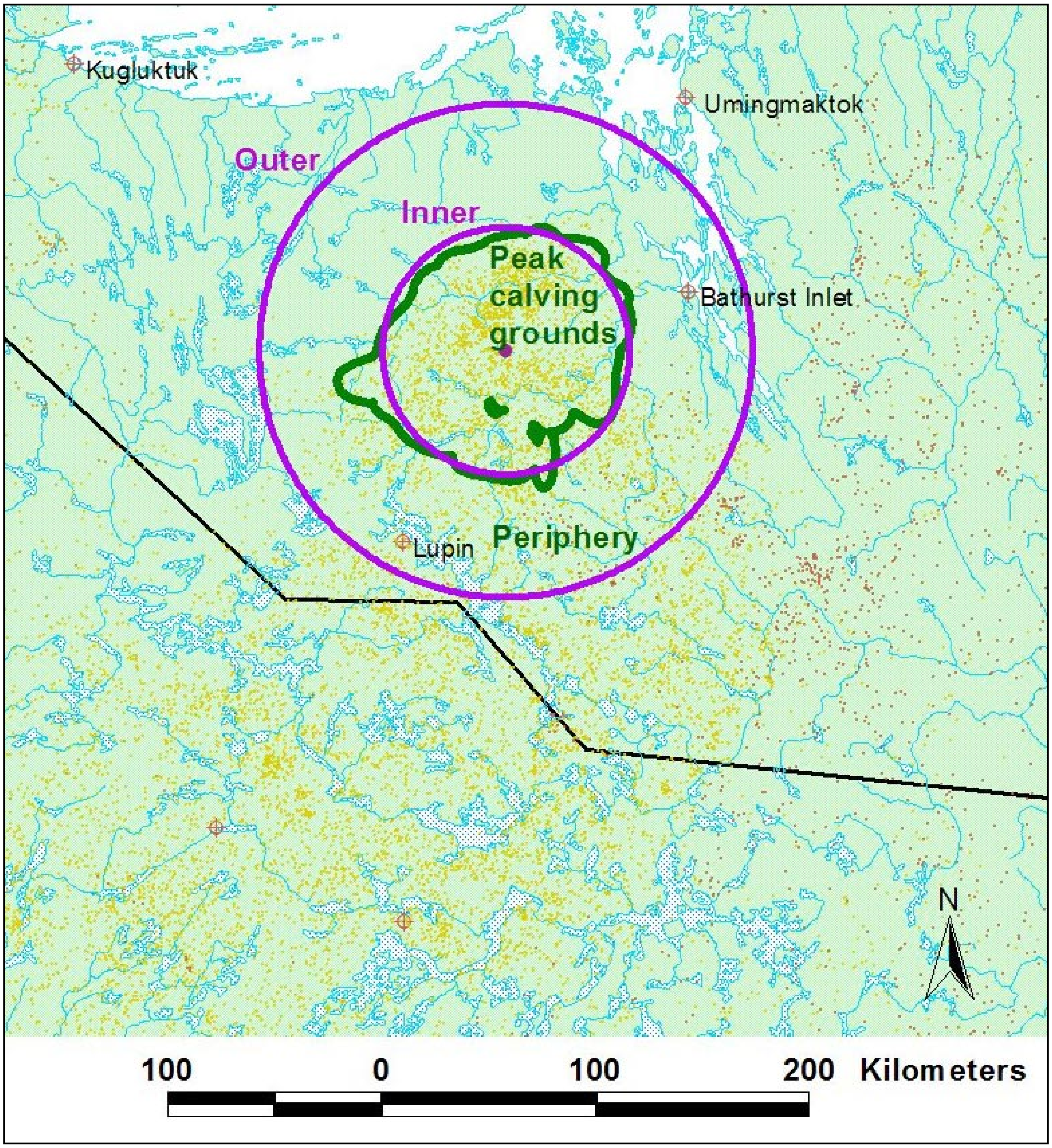

Figure 1. Location of inner (61 km radius) and outer (122 km radius) distance circles for quantifying movement approaching and into the Bathurst caribou herd calving ground. The green polygon represents the 1996–2009 peak calving grounds.

Distance from winter range to calving ground

The location of the winter ranges varies between years and thus the distance animals wintered from the calving grounds may affect rates of pre-calving movement. To calculate the distance each caribou was from the calving grounds during winter, we chose a satellite location as close to 1 February as possible, when caribou would be expected to be relatively stationary on their winter range. When locations were not available for this mid-winter period, we used the earliest location available (16 March – 27 May). We then calculated the distance from the winter range location to the centroid of the circles representing the middle of peak calving grounds (Gunn et al. 2008, updated to 2009).

Movement rates

We calculated movement rates of caribou from approximately 1 April to 20 June. Since most collars had a 5-day duty cycle, we subset all locations with <5 day duty cycle to a 5-day fix rate to standardize the metric, and calculated the mean daily movement for each 5-day period. As noted by Miller and Barry (2001), daily movements calculated from daily locations will provide similar movement rates to daily movements calculated from 5-day locations only if the movements are constantly directional. Here we use the terms "movement" and "travel" to be synonymous with "displacement" (the difference between the initial position and any later position, measured as a horizontal plane vector) as proposed by Miller and Barry (2001). If movements are not directional, the daily movement rates calculated from daily locations will be greater than the daily movement rates calculated from locations spaced five days apart, but correcting for these differences is problematic. We assigned the date for each 5-day period as the mid-point of that period, and calculated mean daily movement rates for each year for each 5-day period starting 1 April. Because of the 7-day duty cycle for collars deployed in 1996, not every 5-day period was represented in first two years of collaring.

Bathurst caribou moved at the greatest daily rate during May (see Results). To facilitate comparison among years, we averaged daily movement rates from all 5-day periods in May for each animal, and calculated annual summaries. We compared mean daily movement rates for May among years using an ANOVA (PROC GLM; SAS Institute, Cary, NC), and examined differences among years with Duncan's multiple range tests. We used a regression (PROC REG) to examine the influence of distance between winter range and calving ground and mean daily movement rates for each animal.

For simplicity and because of tight time lines for this analysis, we calculated all distances and movement rate using the UTM zone 12 grid. Euclidean distance, which takes into account curvature of the earth and can better address longer distances beyond normal UTM zones, would have been a more accurate measure. We acknowledge we have introduced a minor but likely unbiased error into the calculations.

RESULTS

Environmental trends

Circumpolar climate trends

Decadal-scale variability: Sea-level atmospheric pressure is strongly linked to atmospheric circulation and thus is a strong influence on arctic weather. The Arctic Oscillation (AO) is an indicator for sea-level pressure associated with phases of strengthening and weakening of the polar vortex on roughly a decadal scale. The AO index was at its most negative in the 1960s (Figure 2). From about 1970 to the early 1990s, there was a general increasing trend with strongly positive values during 1989–1994. For the next 10 years the AO varied between weakly positive and weakly negative but in 2007 and 2008, returned to stronger positive values, although not as strong as in the early 1990s (AMAP 2009).

When the AO has negative values, winds tend to be weaker and winter temperatures cooler. Positive values of the AO are opposite, with stronger winds and warmer winters. Cyclone activity in the Arctic is complex but Zhang et al. (2004) noted that during the unusually strong AO index value 1988-92, cyclone activity was strengthened in the Arctic.

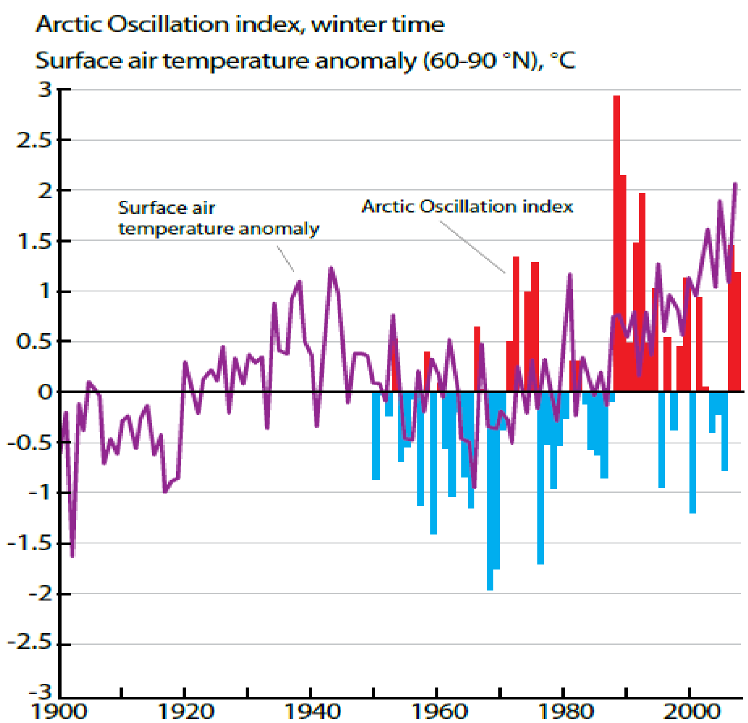

Figure 2. Trends in surface air temperature anomaly (1900–2008) and the Arctic Oscillation trend for 1950–2008 (from AMAP 2009).

The strong positive AO indices from the mid-1980s–90s were accompanied by warmer winters (surface air temperature anomaly), but then the trends in the AO index and temperatures departed from this pattern. Although the AO index recently has been weakly negative or positive, the trend for warmer winter temperatures has continued (Figure 2). This suggests that atmospheric circulation patterns may be changing (AMAP 2009).

In the first half of the 20th century, indices to caribou abundance (frequency of the hoof scars and Tlicho elder's information) suggested a relationship with the AO phase changes. The relationship between the caribou abundance cycle and the AO was that from about 1900 until mid-1970, when the AO was in a negative phase, caribou numbers increased, and when the AO was in a positive phase, caribou numbers decreased. Subsequent to the mid-1970s the relationship between caribou abundance and the AO changed. Although the current decline in caribou abundance occurred when the AO was strongly positive, the decline has continued despite weakly positive and negative AO indices (Zalatan 2006). However, the AO itself only explains 20–30% of the total variability in sea-level pressure and its signal is strongest in winter. Also the relationship between weather and the AO is incompletely known, although it is complex involving freshwater fluxes, sea-ice dynamics and feedback loops (Serreze and Barry 2005).

Circumpolar temperature trends

Annual trends are for increasing temperatures (Figure 3) with 2007 being the warmest year on record since the beginning of the 20th century (AMAP 2009). The Arctic's warming trend of 0.09°C/decade for 1900-2003 was greater than the overall Northern Hemisphere trend of 0.06°C/decade (IPCC 2001). Within the overall trend, there have been periods of cooler and warmer temperatures. The warmer temperatures during the 1920s to 1940s were followed by cooler temperatures until the warming trend beginning in the 1970s. However, scarcity of data before 1945 restricts any conclusion about whether the Arctic was as warm in the 1930s and 1940s as it was during the 1990s and 2000s. One effect of this is that the uncertainties in the historic data means that trends are sensitive to the duration of the time period.

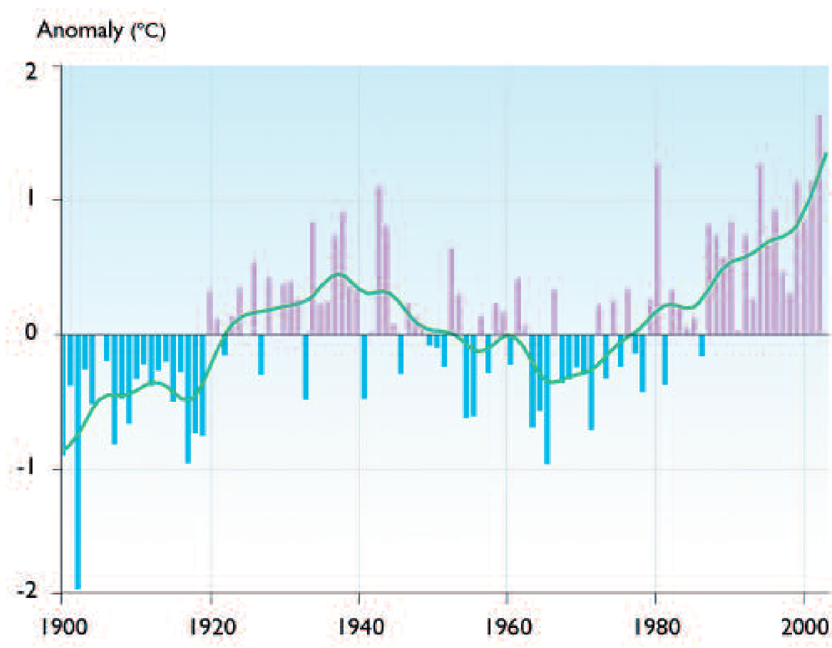

Figure 3. Annual anomalies of land-surface air temperature in the Arctic (60º to 90º N) for the period 1900 to 2003 using the GHCN dataset (updated from Peterson and Vose 1997). Anomalies were calculated relative to the 1961–1990 average. The smoothed curve was created using a 21-point binomial filter, which approximates a 10-year running mean (figure from ACIA 2005).

Other measures of surface temperatures such as from satellite thermal infrared measurements (Figure 4) reveal significant warming except in Greenland and Russia (Comiso 2003). The shorter sampling period of the satellite imagery was not a problem as the trends were consistent with weather station data (Comiso 2003). The average trend was highest in North America with 1.09 ± 0.22^{o} C per decade (95% confidence level 0.65–1.53^{o}C per decade). Annually the anomalies were generally negative in the 1980s to 1989 then positive, which fits with the phase change to positive of the AO in 1989.

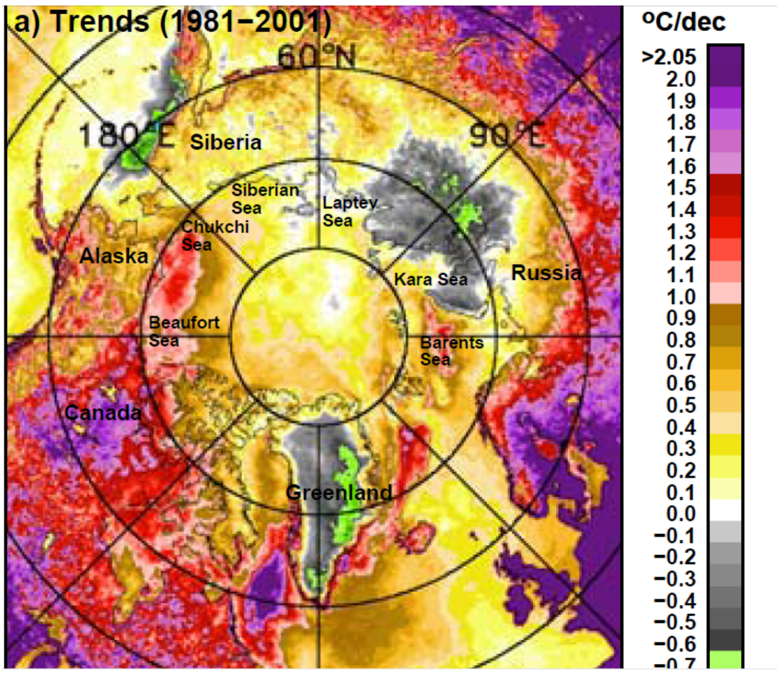

Figure 4. Colour-coded trend map for the entire Arctic derived through linear regression of monthly anomalies in each data element from 1981–2001. The anomalies were calculated by subtracting monthly climatology from each of the monthly values (Fig. 5 from Comiso 2003).

Other trends related to warming temperatures were an increase in thaw days (a day with snow on the ground when the daily mean temperature is above -2°C; Figure 5). The increasing trends for fall and winter at the rate of 1.5 to 2 days/50 years were significant (from Groisman et al. 2003 in ACIA 2005).

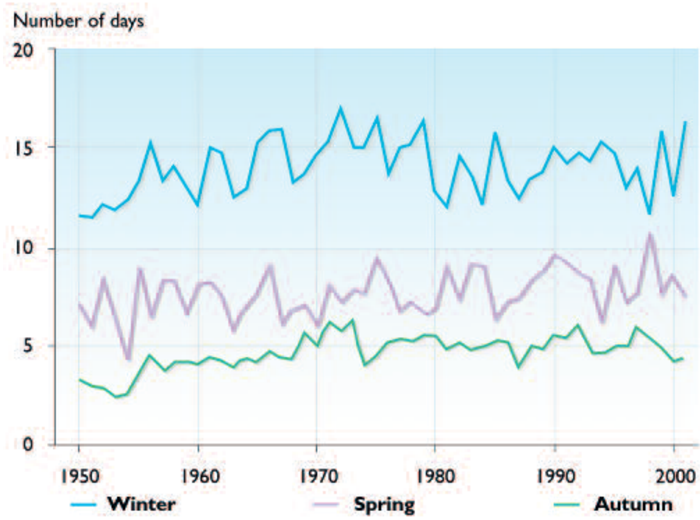

Figure 5. Time series of variations in the frequency of days with thaw, averaged over the Arctic land area for winter, spring, and autumn (from Groisman et al. 2003 in ACIA 2005).

The trend in the duration of snow-free period was an increase of five to six days per decade based on satellite imagery between 1972 and 2000. The week of the last observed snow cover in spring was three to five days earlier per decade, which is an overall shift of about 9–15 days (Dye 2002). Trends in rain-on-snow events have decreased in western Canada mostly due to reduced snow cover, but increased in western Russia (ACIA 2005). However, because rain-on-snow events can be small-scale spatially – 50 x 50 km – they can likely be under-reported in the Arctic (Putkonen et al. 2009).

Circumpolar precipitation trends

Overall, the circumpolar trend for precipitation was an increase of 1.4% per decade with the greatest increases in the fall and winter (ACIA 2005). The amount of precipitation falling as snow has decreased. The amount of heavy and extreme precipitation events has increased, although the trends vary among regions.

Trends in circumpolar biodiversity indicators

Three of the 21 indicators of trends in Arctic biodiversity developed by the Circumpolar Biodiversity Monitoring Programme (www.cbmp.is) relate to caribou ecology. The indicators are trends in vegetation ('Greening' of the Arctic), trends in the timing of plant growth and reproduction (Reproductive Phenology) and trends in ice cover on lakes and rivers. A preliminary assessment of the status and trends of key Arctic biodiversity indicators is currently underway in preparation for a report in 2010.

The arctic vegetation is changing. Firstly, the area of 'tundra climate', the cold temperature and low precipitation that support the polar tundra, barrens and ice and snow biomes, has declined by about 20% over the last 25 years (Wang and Overland 2004). With the warming climate, vegetation is shifting to shrub-dominated communities, while grasses, sedges, mosses and lichens are decreasing (Henry In prep.). The increasing productivity from the increase in shrubs is detectable using satellite imagery at a circumpolar scale and the increase corresponds with areas where temperatures have warmed the most – Alaska and the western Canadian Arctic as well as parts of Russia (Henry In prep.).

Consistent with the trends in warming spring temperatures and earlier snow loss, the plant growing season is as much as 18 days longer in boreal and Arctic latitudes based on remote sensing data from 1981–99 (Zhou et al. 2001). While there is a body of evidence from ground-based and remote sensing studies for trends toward earlier plant growth and flowering in spring (Menzel and Fabian 1999), there is less information on the timing of autumn senescence (Sparks and Menzel 2002). However, warmer temperatures of 2.5^{o}c experimentally delayed plant senescence by 15 days in High Arctic tundra (Marchand et al. 2004). Although the general trends toward lengthening of the plant growth season relative to warming temperatures are now well-established, understanding the complexities is still developing. Different species add to variability in responses, as does geographic area. Most attention has focused on flowering plants with little information on, for example, trends in mushroom fruiting, which in fall is important to caribou foraging. However, mushroom fruiting has been delayed about 13 days in northern and alpine Norway (Kauserud et al. 2008).

The timing of plant growth and flowering coincides with the peak nutritional demands of lactating caribou (Griffith et al. 2002) and thus changes in the timing of plant growth have implications for caribou foraging. However distinguishing between the effect of trends in weather on caribou and plant growth is complicated and simple answers are unlikely (Post and Stenseth 1999).

The warmer temperatures and increases in precipitation affect river discharge, soil moisture, permafrost depth and lake or river ice freeze-up and break-up. The duration of ice-cover for lakes and rivers in the northern hemisphere over the last 150 years has declined by almost two weeks as freeze-up dates are later at an average rate of 5.8 days per century and break-up dates are earlier at a rate of 6.5 days per century (Magnuson et al. 2000). In North America, trends over 1951–2000 are for later freeze-up dates but variation among regions was strong, probably because of local site variations (Duguay et al. 2006). Earlier spring break-ups are noted across Canada, especially in the NWT.

Ecozone trends

In the Arctic Ecozone (which includes the Bathurst caribou summer range as well as the Arctic Islands), the trends are for warming temperatures with significant temperature increases since 1950 of 0.9°C in the summer and 1.7°C in the fall based on the records from the 22 weather stations across the Arctic Ecozone (Zhang et al. 2008). Total precipitation has increased significantly in all seasons, especially in winter. Maximum snow depths have decreased although regional variation is high (Zhang et al. 2008). The duration of snow cover was reduced in spring by five days with no change in fall dates. Based on the first date when the daily temperature has been >5°C for five consecutive days, the potential growing season was 16 days earlier (1950–2007). Although the end of the season has not changed, the growing season is now significantly 20 days longer (Zhang et al. 2008).

The Bathurst herd's winter range is mostly within the Western Taiga Shield ecozone. Between 1950–2007, the warming trend in the Western Taiga Shield was most pronounced in winter (December, January and February). The degree of warming was a significant increase of 4.7°C based on three weather stations (Figure 6). Between 1995 and 2007, the mean December to

January temperatures were consecutive positive anomalies. Temperature trends for the spring, summer and fall were not statistically significant. Precipitation trends for spring and winter were significant increases (Zhang et al. 2008).

SPRING

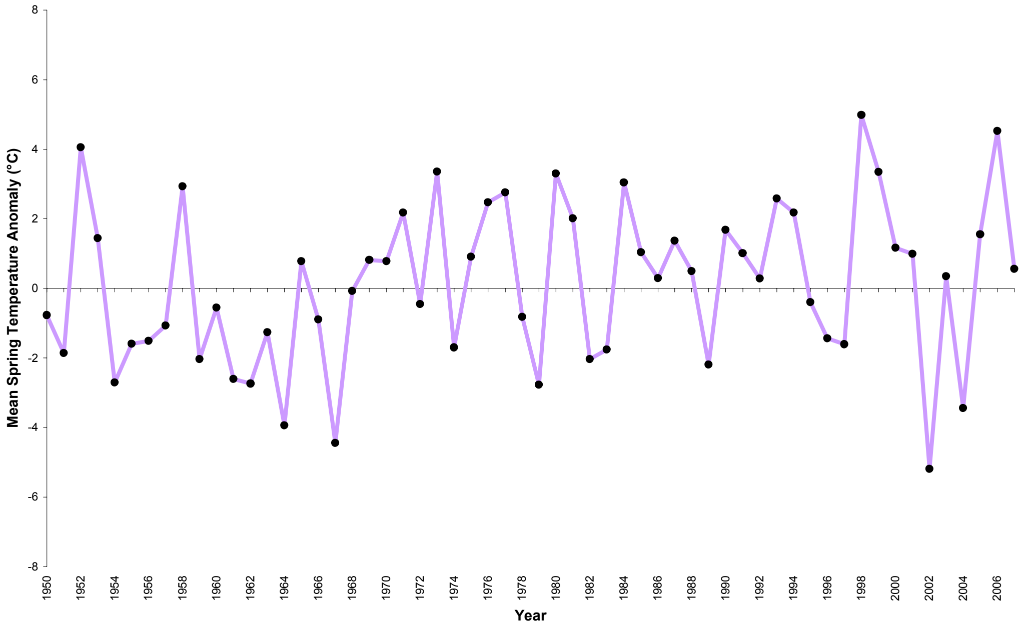

Figure F.Cl.TSw 1: Spring (March, April, May) mean temperature anomaly for 1950-2007 in the western portion of the Taiga Shield Ecozone^{plus} relative to the base period (1961-1990) mean. There is no significant ($p > 0.05$) change in mean Spring temperature from 1950-2007 {70000}. This analysis is based on data from 3 stations in the western portion of the Taiga Shield Ecozone^{plus}.

SUMMER

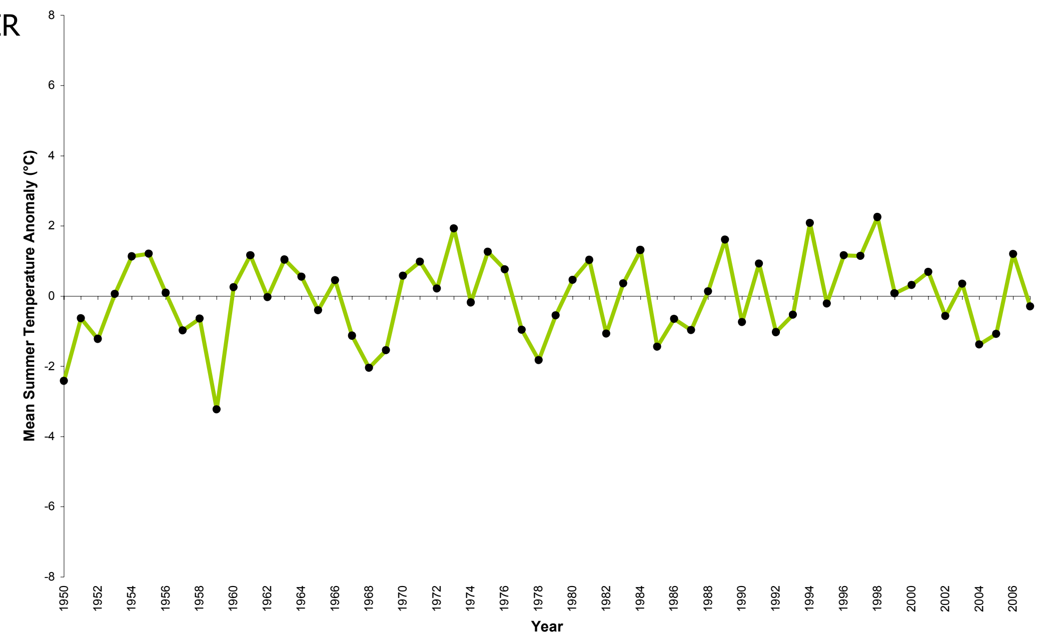

Figure F.Cl.TSw 2: Summer (June, July, August) mean temperature anomaly for 1950-2007 in the western portion of the Taiga Shield Ecozone^{plus}. There is no significant ($p > 0.05$) change in mean Summer temperature from 1950-2007 {70000}.This analysis is based on data from 3 stations in the western portion of the Taiga Shield Ecozone^{plus}.

Figure 6. See caption next page.

FALL

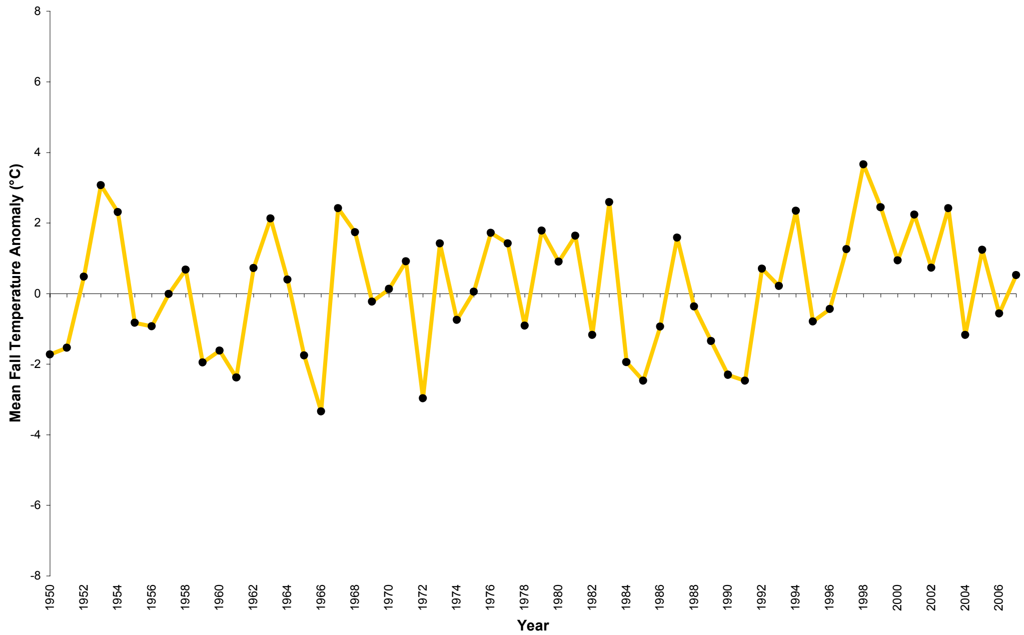

Figure F.CI.TSw 3: Fall (September, October, November) mean temperature anomaly for 1950-2007 in the western portion of theTaiga Shield Ecozone plus . There is no significant ($p > 0.05$) change in mean Fall temperature from 1950-2007 {70000}.This analysis is based on data from 3 stations in the western portion of the Taiga Shield Ecozone plus .

WINTER

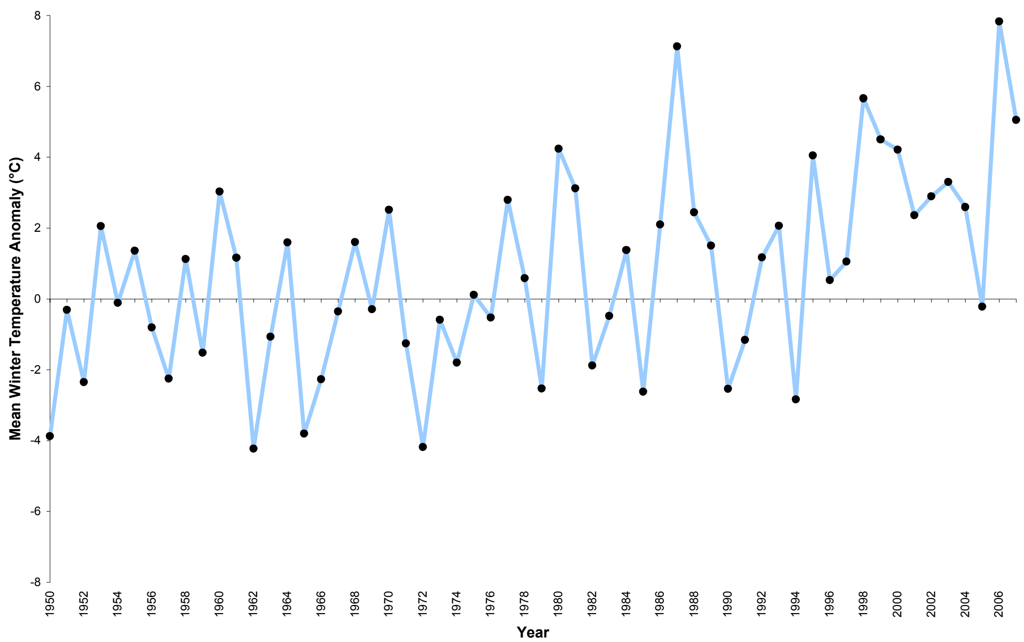

Figure F.CI.TSw 4: Winter (December, January, February) mean temperature anomaly for 1950-2007 in the western portion of the Taiga Shield Ecozone plus . The data indicate a significant ($p < 0.05$) increase of 4.7 °C from 1950-2007 {70000}.This analysis is based on data from 3 stations in the western portion of the Taiga Shield Ecozone plus .

Figure 6. Mean temperature anomalies by season for 1950–2007 relative to the base period (1961–1990) mean, based on data from 3 stations in the western portion of the Taiga Shield Ecozone (Zhang et al. 2008).

Trends for the Bathurst herd's range

At the scale of the Bathurst caribou's seasonal ranges, Chen et al. (In prep. a and b) measured trends using mostly remote sensing approaches.

a) Trends for the calving grounds and summer range

Based on satellite imagery for 1985–2006, there was essentially no green foliage biomass during pre-calving (21–31 May; Figure 7). During 1–10 June, only 3 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) annually varied and appeared to increase 55% from 1985 to 2006, but the high annual variation meant that the trend was insignificant. 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 encroachment that has reduced 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).

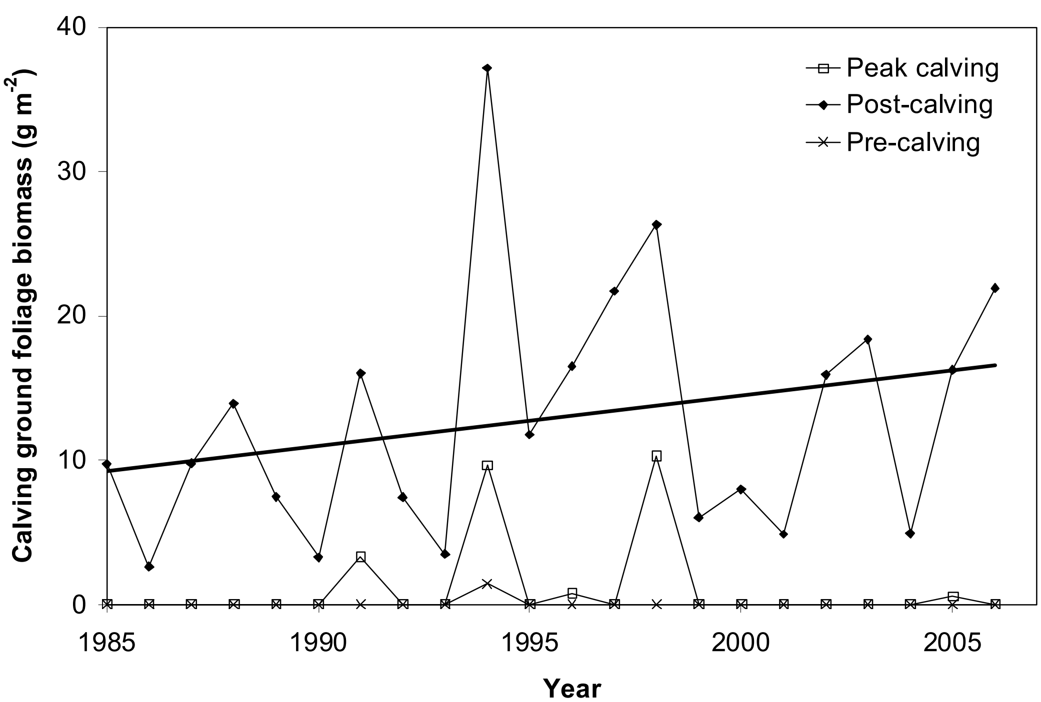

Figure 7. Green foliage biomass during pre-calving (21–31 May), peak calving (1–10 June), and post-calving (11–30 June) on the calving ground of the Bathurst caribou herd, 1985–2006 (Chen et al. In prep. a).

On the summer range (11 Jun–20 Sep), mean foliage biomass showed a significant increasing trend despite high levels of annual variability (Figure 8). 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.

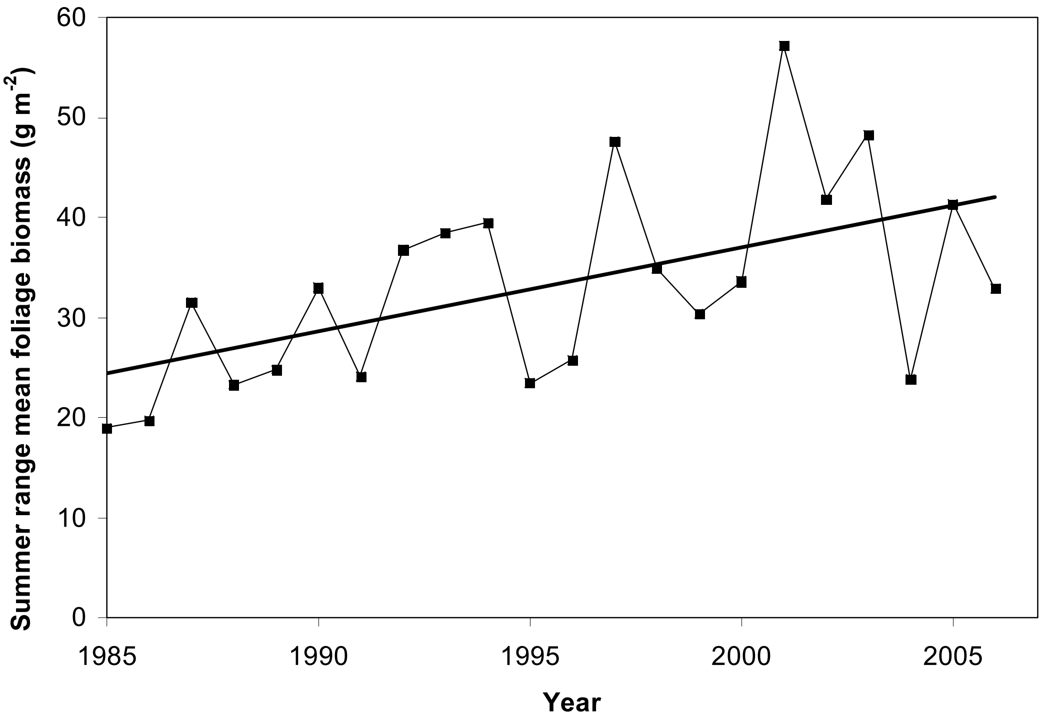

Figure 8. Summer forage availability indicator (foliage biomass), defined as the average foliage biomass from 11 June to 30 September in the summer range, for the Bathurst caribou herd, 1985–2006. The straight line represents temporal trend with $R^2 = 0.29$, $F = 8.3$, $P = 0.009$, and $n = 22$ (from Chen et al. In prep. a).

Insects can also affect caribou energy balance. The late 1970s and early 1980s marked the beginning of a global temperature increase (Jones and Moberg 2003). Based on this, the period of 1957–2005 was divided into 2 groups: 1957–1981, and 1982–2005. The number of "High" osterid ratings was significantly greater in the 1982–2005 grouping than during the earlier time period ($\chi^2 = 18.68$, df = 1, $P < 0.01$; Figure 9).

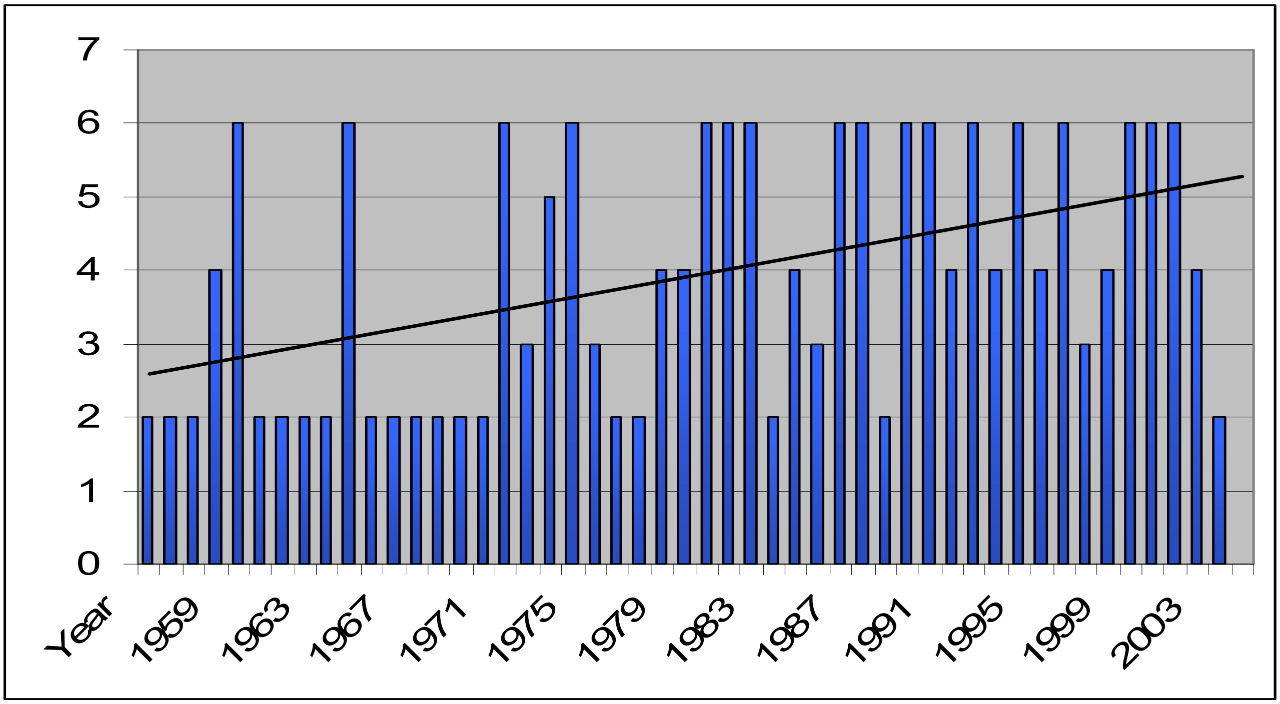

Figure 9. Trend line and annual scores oestrid fly harassment (scored as 1 for low, 2 for moderate and 3 for high) based on 1957–2005 weather records for Contwoyto Lake, NU (from Gunn In prep.).

b) Trends for the winter ranges

The area of lichen ranges as indexed by mature forests has declined between 1959 and 2006 and the decline was caused by periodic forest fires. The area of forest burnt was significantly related to mean 1 June–30 September temperatures over the winter range of the Bathurst herd during 1959–2006, and those temperatures have increased (Chen et al. In prep. b).

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. In prep. b). 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 10). The percent of years in which ice in snow was >10 mm water equivalent increased from 14 to 43%, during 1960s to 2000–06, respectively. Overall, 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. In prep. b).

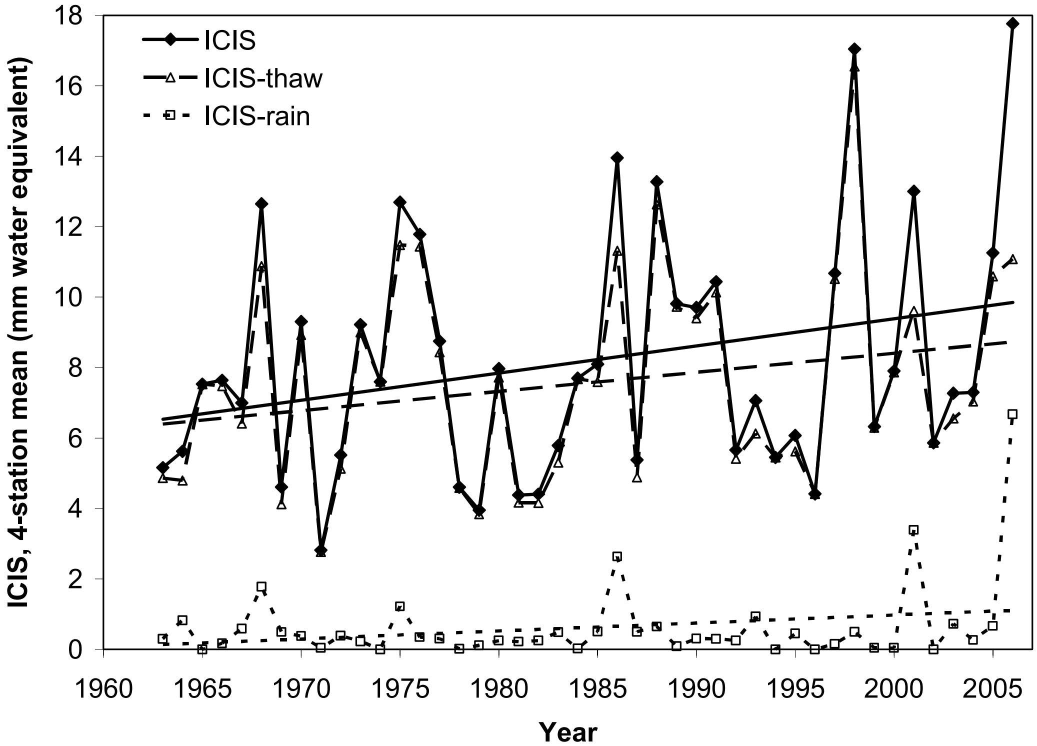

Figure 10. Mean ice content in snow (ICIS) for the winter range of the Bathurst caribou herd from 1963 to 2006, for Yellowknife, Reliance, Rae Lakes, and Uranium City climate stations. The straight lines represent temporal trends: for $ICIS_{rain}$ $y = 0.0225x - 44.065$, $R^2 = 0.06$, $F = 2.86$, $P = 0.1$, 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 $n = 44$ (From Chen et al. In prep. b).

The average of snow presence/absence during pre-calving migration (16 April–15 June) based on AVHRR imagery was annually variable, which prevents determining if there was a trend between 1982–2006 (Figure 11). Snow presence or absence during pre-calving migration was negatively correlated with 16 April–15 June mean air temperature during 1982–2006.

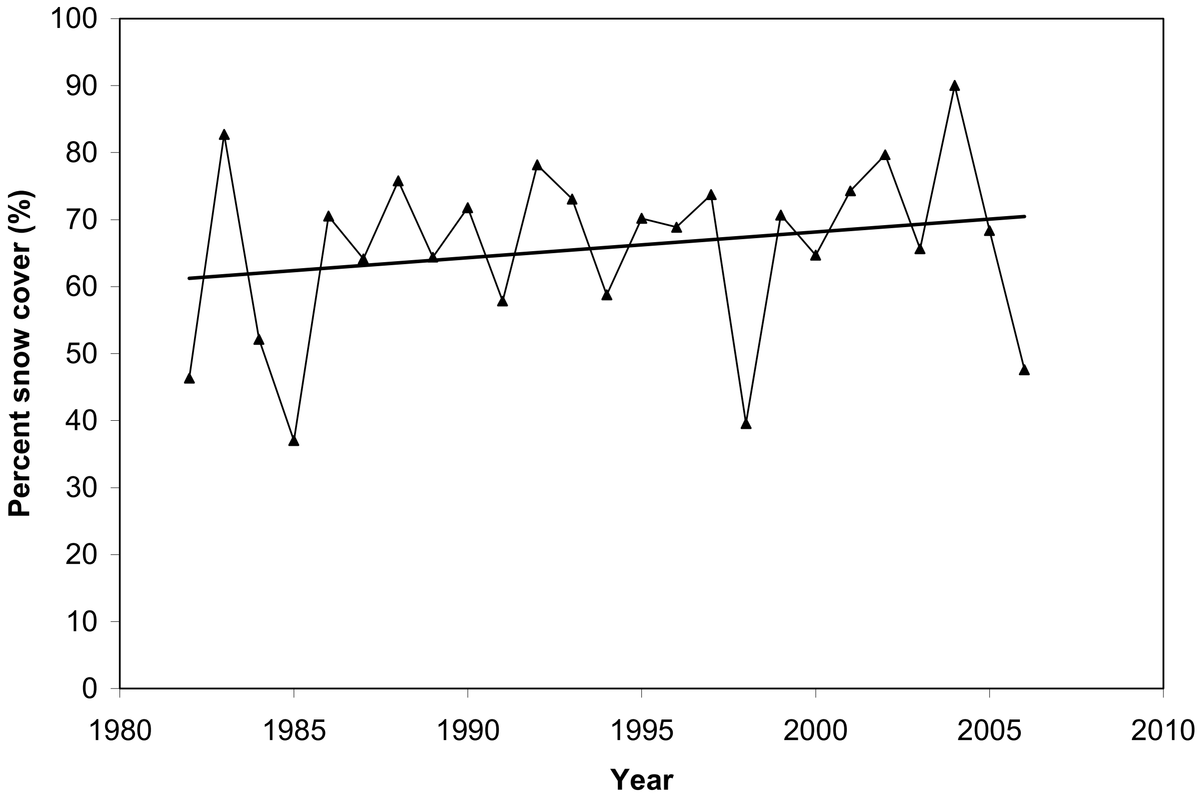

Figure 11. Percent snow cover averaged over the Bathurst caribou habitat during 16 April–15 June from 1982–2006, derived from AVHRR Polar Pathfinder data. The straight line represents the temporal trend: $R^2 = 0.05$, $F = 1.1$, $P = 0.3$, $n = 25$ (from Chen et al. In prep. b).

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 1, Figure 12). Year 2009 was noteworthy in that early snowmelt was late as the 100–50% 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. In prep. b) during the duration of pre-calving migration (Table 1). Years with lesser or greater snow cover had early 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%. Years 2007 and 2008 were actually a bit later even 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 2 years.

Table 1. Timing of spring snowmelt in the Ekati study area, 1997 to 2009 (BHP Billiton 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 was that overall snowmelt was average
[2] Snow cover was 60%.
[3] Snow cover was 40%.
[4] Snow cover was 95%.

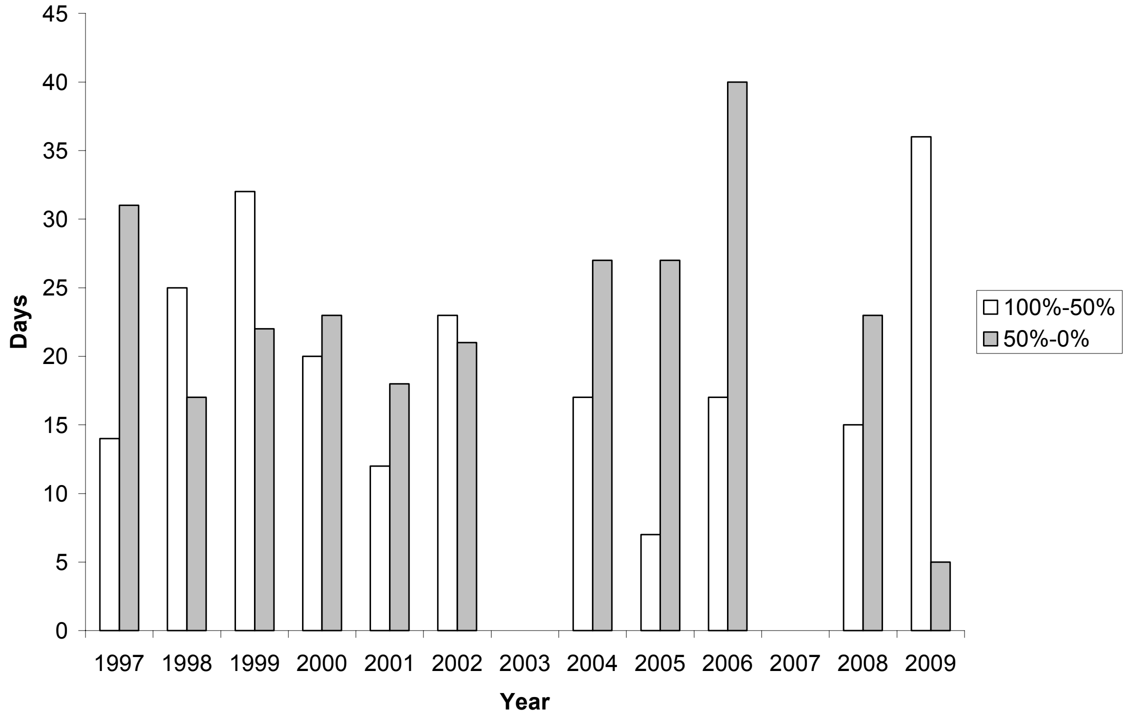

Figure 12. Number of days elapsed between the last day of 100% snow cover and the first day of 50% snow cover, and between 50% snow cover and 0% snow cover in the Ekati study area, 1997 to 2009 (calculated from Table 1).

Peak of calving

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 2). 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.

Timing of entry into the calving area

Overall mean dates for 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 lowest years being 1996 and 1998), but this trend does not appear to have continued over the past four years (Figure 13). 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 from an alternate year switch.

With the exception of 2005, in all years only 1–2 collared caribou either did not enter the peak calving grounds or entered after the 10 June cut-off (Table 2). In all but four years this represents <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 between 13–30 June. 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.).

Table 2. 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. 2008, and updated to 2009). Primarily GPS collar data were used in 2009. Determination of calving 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 Jun	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	8-14 Jun	12	10 (83)	2 late arrivals; did not calve
2009	8-14 Jun	13	12 (93)	1 never entered CG

Distance from winter range to calving ground

The overall mean distance between Bathurst caribou wintering areas and the centre of the calving grounds was 409 km (Figure 14). Distance from calving grounds varied among years. The greatest distance occurred in 2001, when all collared caribou wintered from just south of the East Arm of Great Slave Lake to the Saskatchewan border. During 2009, caribou that calved on the Bathurst calving ground wintered south and southeast of Great Bear Lake.

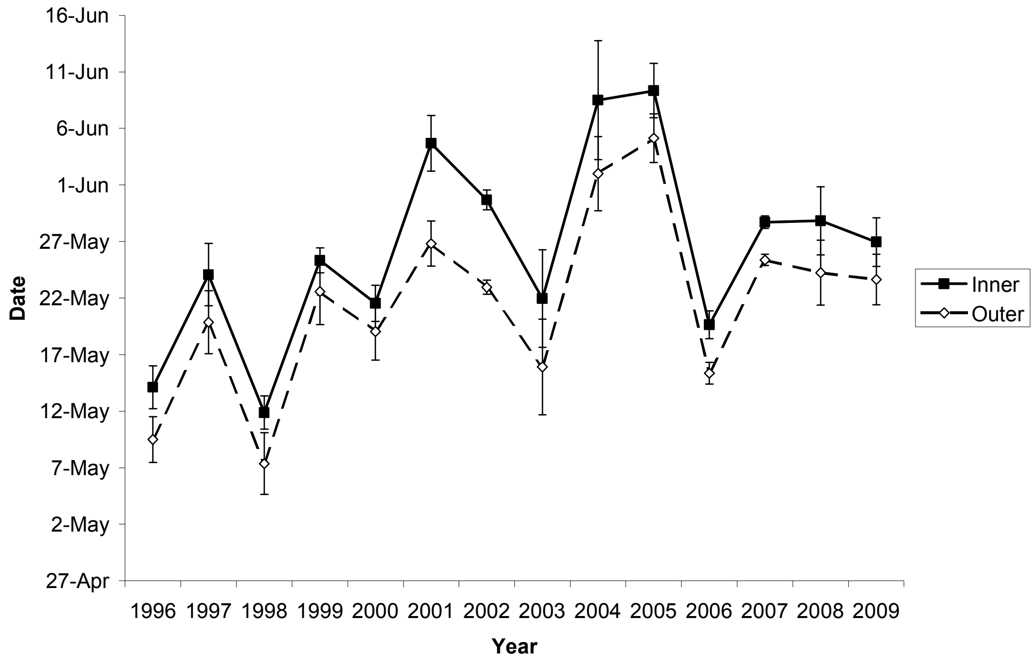

Figure 13. Mean (SE) dates of crossing of the outer (122 km radius) and inner (61 km radius) distance circles surrounding the centre of the Bathurst caribou herd calving grounds, 1996–2009. See Fig. 1 for a map of the distance circles.

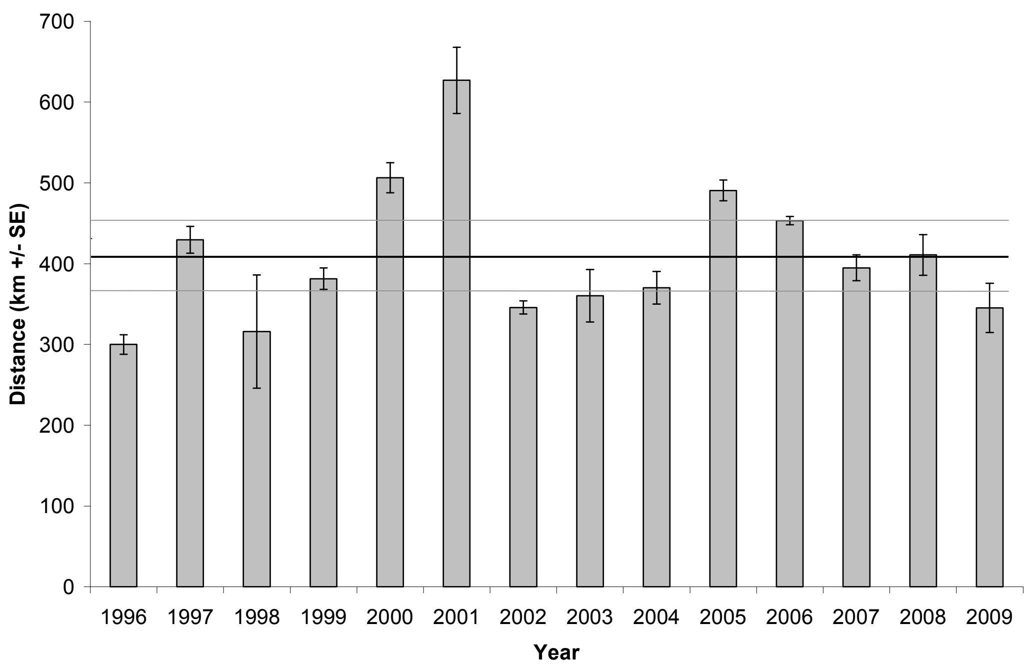

Figure 14. Mean (SE) distance from winter range and the centre of the Bathurst calving grounds, 1996–2009. The heavy black horizontal line represents the mean distance among years (grey lines represent the 95% confidence interval around the overall mean).

Movement rates

On average, Bathurst caribou begin to increase their movement to the calving grounds in mid-April, with peak distances moved in mid to late May (~14 km/day), and the least movement during 10–14 June corresponding with calving (<3–4 km/day; Figures 15, 16; Appendix 1). Bathurst caribou pre-calving movements during 2009 were characterized by a slightly delayed initiation of longer movements, some slowing of movement rates in mid-May, and uniformly reduced movement on the calving grounds during the 10–14 June period (Figure 15).

Caribou movement rates were greatest during May (Figure 15). The broad pattern of movements was consistent among years that calving ground surveys occurred (Figure 15). During early snowmelt years caribou generally slowed their movements in late May, while during years of late snowmelt, increased movement rates continued into early June (Figure 16). Average May movement rates overall averaged 12.5 km/day, and differed among years ($F_{13,75}$ = 6.19, $P < 0.0001$; Figure 17, Table 3). The years with significantly greater rates of movement during May were 2000, 2001, and 2006, and with significantly less rates were 1996, 1998, 2003, and 2004 (Table 3). There was a positive relationship between distance from winter range to calving grounds and both mean daily movement rates during May ($y = 0.014x + 7.10$, $r^2 = 0.24$, $P < 0.0001$) and date of entry into the peak calving area ($y = 0.035x$ + 13 May, r^2 = 0.13, $P < 0.0001$; Figure 18).

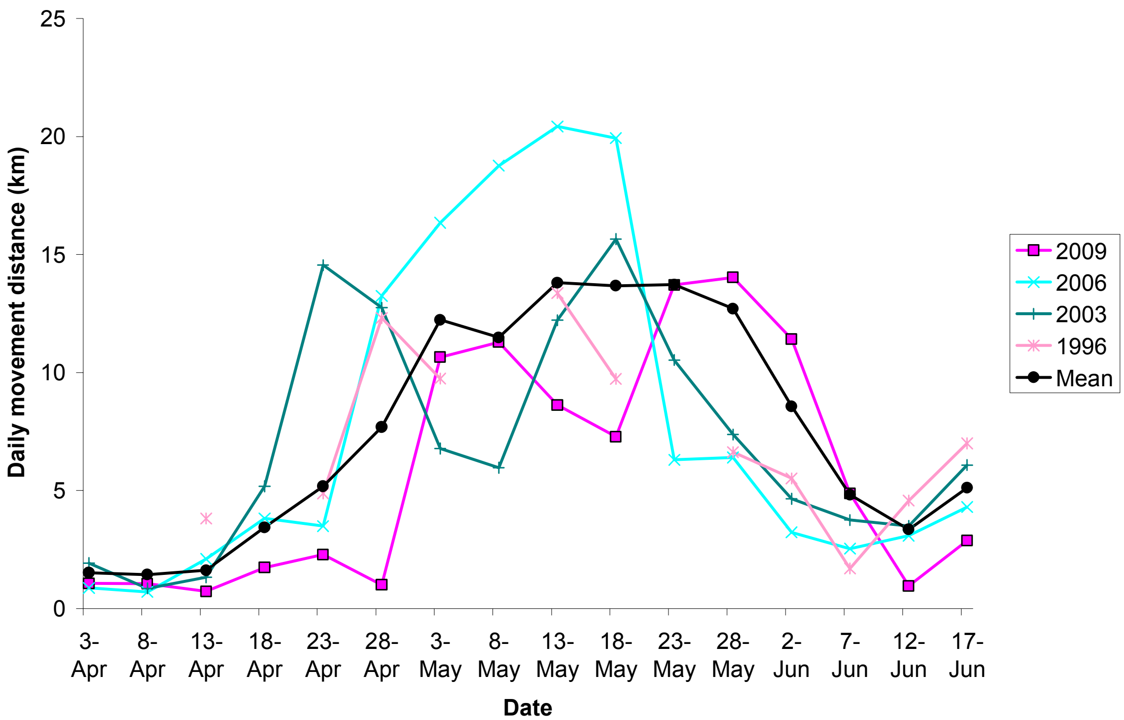

Figure 15. Mean daily movement distance by 5-day period by Bathurst caribou during pre-calving migration, April to mid-June, for years when surveys occurred (1996, 2003, 2006, 2009). The heavier black line shows the overall mean movements.

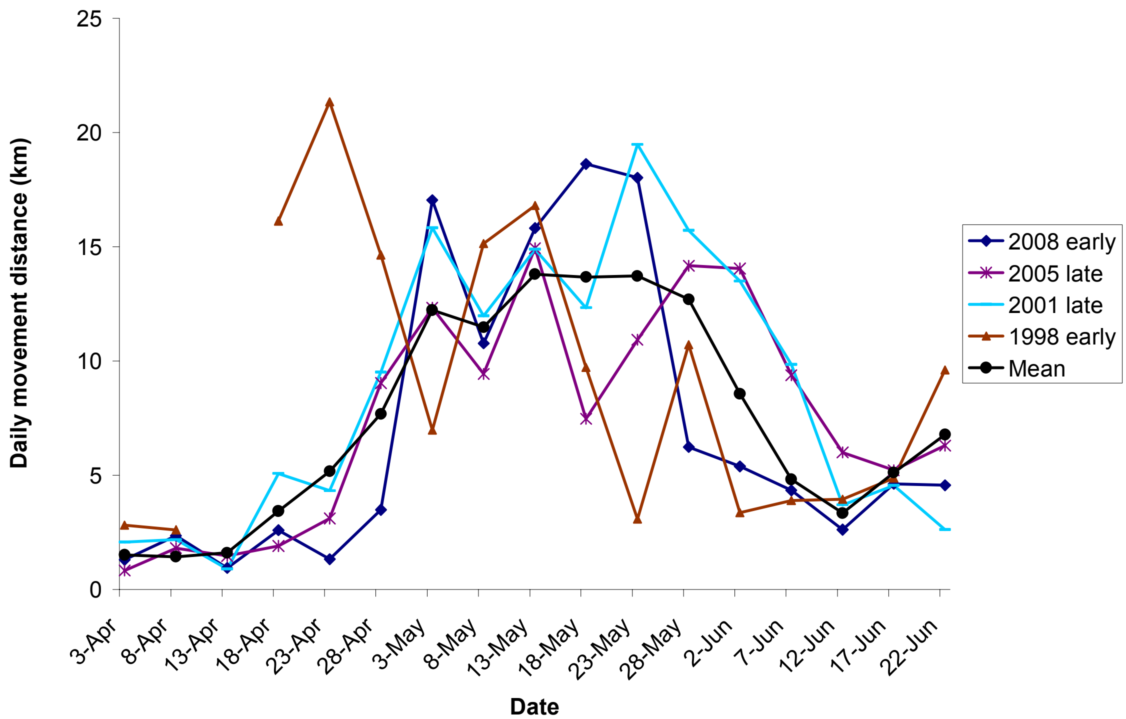

Figure 16. Mean daily movement distance by 5-day period by Bathurst caribou during pre-calving migration, April to mid-June, for two representative early snowmelt years (1998, 2008) and two late years (2001, 2005). The heavier black line shows the overall mean movements.

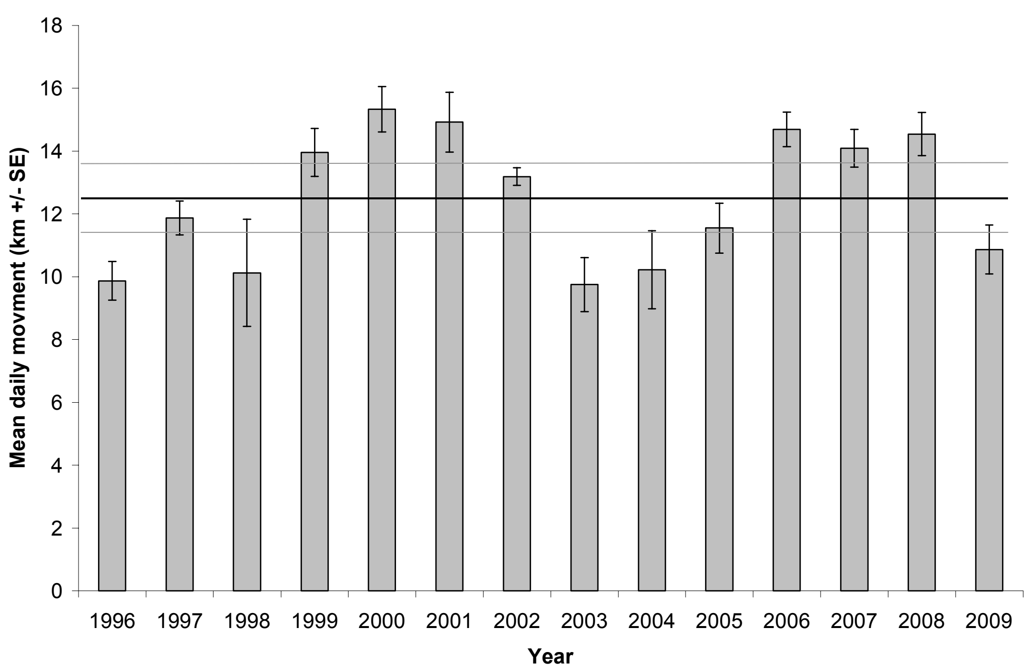

Figure 17. Mean daily movement during May by Bathurst caribou, 1996–2009. The heavy black horizontal line represents the mean May movement among years (grey lines represent the 95% confidence interval around the overall mean).

Table 3. Mean daily movement during May by Bathurst caribou, 1996–2009.

Year	Km/day[1]	SE
2000	15.3 a	0.72
2001	14.9 a	0.95
2006	14.7 a	0.55
2008	14.5 a,b	0.69
2007	14.1 a,b,c	0.60
1999	14.0 a,b,c	0.76
2002	13.2 a,b,c,d	0.28
1997	11.9 b,c,d,e	0.54
2005	11.5 c,d,e	0.80
2009	10.9 d,e	0.78
2004	10.2 e	1.24
1998	10.1 e	1.71
1996	9.9 e	0.62
2003	9.8 e	0.86

[1] Means with the same letter not significantly different (Duncan's multiple range tests).

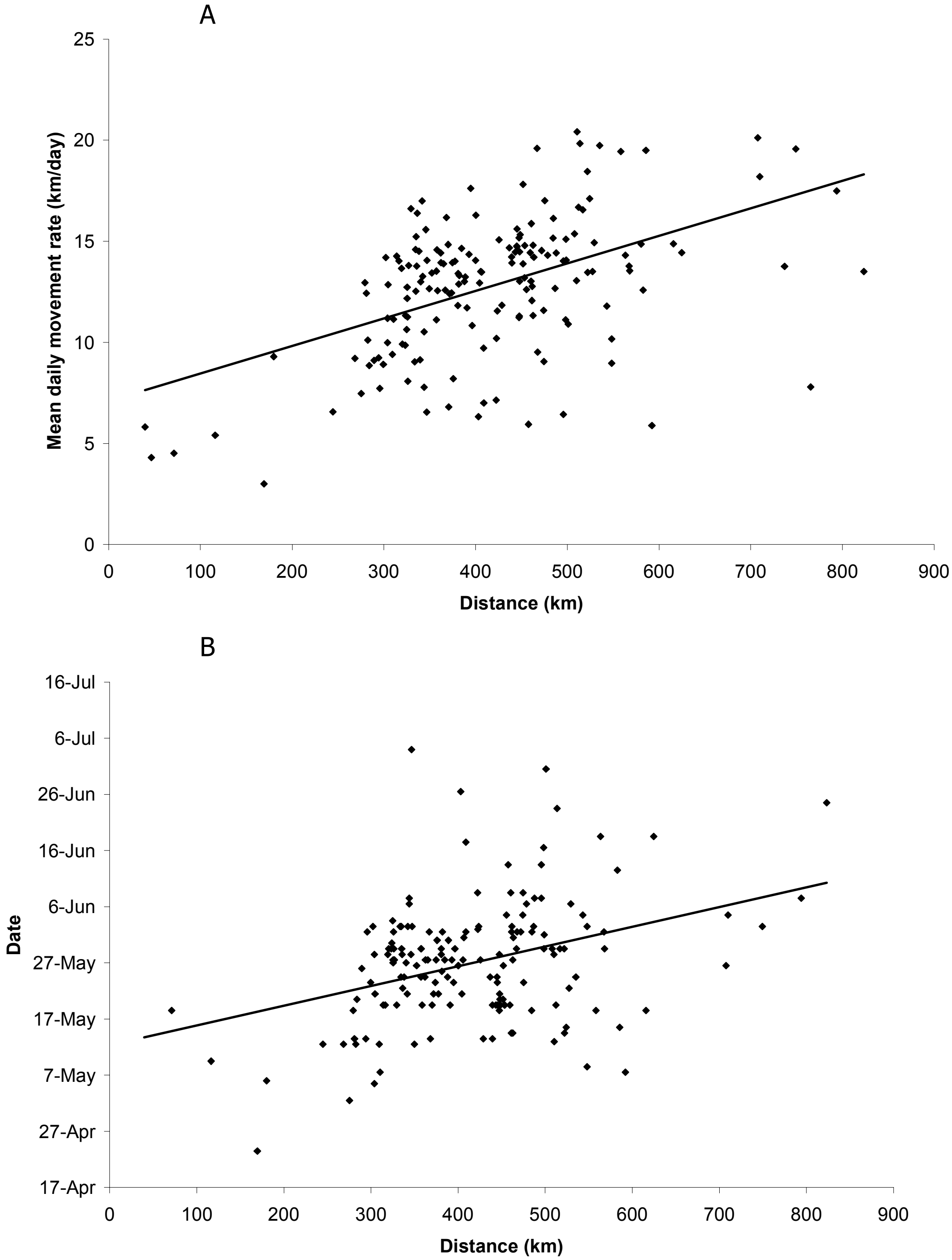

Figure 18. Regression of distance between winter range and the centre of the calving ground and A) mean daily movement distance during May, and B) date of entry in to the peak calving ground, Bathurst caribou, 1996–2009.

DISCUSSION

In terms of the numbers of satellite-collared cows, the dates of arrival on the calving ground and the rate of travel, 2009 was not an unusual year compared to other years since 1996. In 2009, the start of snowmelt at Ekati mine was late and initially slow and then rapid. Despite this late start to the melt, all except one of the 13 satellite-collared cows reached the calving ground prior to 10 June, which is almost identical to the average percentage (92% ± 2.9% SE) for the return of collared cows to the calving ground by 10 June for other years since 1996. The mean timing of arrival in 2009 for the periphery and peak calving ground (outer and inner circle) was 23 May and 26 May, respectively. This is similar to the overall average dates for crossing the outer and inner circles, which were 21 May and 26 May, respectively, between 1996 and 2009. Although the cows reached the calving ground within or close to the average dates, the start of pre-calving migration was later (28 April) which is similar to 2007 and 2008, although not as late 2004 and 2002 (3 May and 8 May, respectively). In 2009, the collared cows slowed down their rate of travel in mid-May, which is similar to 2003, another year with late melt. Judging by representative early and late snowmelt years, caribou in late snowmelt years generally moved at a greater rate in late May and early June relative to years of early snowmelt, and 2009 movements fitted this pattern.

The distance the caribou have to migrate from the wintering range as well as the snow conditions also affects the rate of pre-calving migration. The longer the distance to the winter range, the greater the average rate of travel. In 2009, the mean distance from the winter range to the centre of the calving ground was similar to the average for 1996–2009.

Although the timing and extent of pre-calving migration for the satellite-collared cows for 2009 appears typical, two years, 1998 and 2005, were atypically early and late, respectively. In 1998, an early snowmelt, low snow coverage, and shorter average distance between winter range and calving ground may have resulted in early entry into the peak calving grounds and lower overall movement rates during May (possibly a result of shorter distance and higher movement rates during mid to late April). In 1998 all 10 collared caribou returned to the calving grounds.

An atypically late year was 2005, when the number of satellite-collared cows returning to the calving ground was lower than average by 10 June (61%). Seven cows were late (2 calved, and 5 possibly did not). The late arrival in 2005 may have reflected conditions during pre-calving migration in 2004 as the cows in 2004 were also late arriving, and may have been in poor condition as the percentage of snow cover during 2004 pre-calving migration was high, melt was late and plant biomass after the peak of calving was also lower than average. During the summer 2004, plant biomass was also lower than average, although leaf nitrogen was high. By fall 2004 calf survival was low and pregnancy rates measured in late winter 2004–05 north of Yellowknife were lower than average at 63% (Gunn In prep.). Hunters from Lutsel K'e commented on an early and cold fall 2004 with Bathurst caribou being in poor shape (Lutsel K'e Dené First Nation 2005).

The indicators for environmental trends for conditions during pre-calving migrations were based on observations of snow melt at Ekati mine site (150 km from the calving ground) and from the percentage snow cover for the area used by satellite-collared cows 16 April–15 June, 1982-2006 derived from 5 km AVHRR Polar Pathfinder data (from Chen et al. In prep. b). Those indicators likely only reveal relative trends for the calving grounds and do not account for storms during calving such as in 2003, when a 3-day blizzard temporally reverted conditions back to full snow cover.

The environmental trends at the circumpolar, regional (ecozone) and Bathurst range are consistent at those three spatial scales: the trends are for warming temperatures and increases in precipitation (although less precipitation is falling as snow), and changes in the length of seasons. The key trend is the warmer temperatures, which is driving a cascade of changes throughout the ecosystem and which are occurring at different timescales. Some responses such as plant growth are rapid, but other changes such as in plant communities are occurring more on the scale of decades. The snow seasons are shorter and the plant growing season longer, although the increase in plant biomass has not increased forage quality (as indexed by leaf nitrogen). At the scale of the caribou seasonal ranges, high annual variability impedes describing the statistical significance of trends (Chen et al. In prep. a and b) and mostly, the trends have been measured since the mid-1980s when remote sensing indicators became available.

We have not, for this report, compared the environmental trends to the demography of the Bathurst caribou herd. Any correlations between environmental trends and changes in abundance through effects on, for example, pregnancy rates, calf and adult survival are complex, as there are autocorrelation between environmental factors, lag effects and interactions among factors.

We have described how environmental indicators such late winter snow conditions affect the timing and rate of pre-calving migration, but we also note that other factors, such as the distance from the winter range and the condition of the caribou, will affect the pre-calving migration. Published evidence for the effect of distance between winter and calving ranges is from the George River herd. Declines in fat indices correlated with an increase in pre-calving migration distance from about 300 to 600 km during 1978–93 (Bergerud et al. 2008). The date of the beginning of migration and rate of movements also correlated with distance from the calving ground (1987–92) based on conventional (VHF) radio-collars (Bergerud et al. 2008). However, Bergerud et al. (2008) did not describe annual variations in timing of the cows reaching the calving grounds relative to environmental trends such as snow melt. They did note that calving in the George River herd shifted from 4 to 12 June (based on calf cow ratios and antler shedding) during the time when the herd was increasing (1975–80) to when it was declining (1984–93). Bergerud et al. (2008) related the later calving mostly to the poor fall condition of the cows the previous year and later conception, as summer range was over-grazed and growth of birch was reduced.

Our criteria of whether the cows were late arriving to the calving ground (10 June) was chosen so as to examine the possibility that late return of the cows could affect a census that depends on reconnaissance flights before the peak of calving and then the photographic census during the peak of calving. Although late arrival of cows is occasionally mentioned in reports, systematic descriptions of the timing of arrival of the cows is mostly lacking despite the ease of using data from satellite-collared cows. We have comparable information to the Bathurst herd for the Qamanirjuaq herd dates of entering the calving grounds (Gunn et al. 2007). Similar to the Bathurst herd during 1996–2003, the Qamanirjuaq dates have a generally alternate year pattern of early and later dates (saw tooth). However, dates of arrival for the Porcupine Herd (1985–93) varied over a 15 day period but not as a regular pattern (Griffith et al. 2002). For comparison, the arrival of the Bathurst herd varied over a 25-day period (1996–2009) and the Qamanurjuaq herd over 39 days (1993–2006). Again, this reinforces the point made above, that the condition of the cows as well as environmental conditions influence the timing of arrival on the calving ground.

ACKNOWLEDGEMENTS

We thank Bruno Croft for the opportunity to conduct this analysis and review. We appreciate the assistance of Adrian D'Hont and Bonnie Fournier (Environment and Natural Resources, Government of the Northwest Territories) for their help in accessing the satellite and GPS telemetry databases. Jack Wierzchowski conducted database projections.

LITERATURE CITED

ACIA (Arctic Climate Impact Assessment). 2005. Arctic Climate Impact Assessment, Cambridge Univ. Press, New York, 1042pp.

AMAP (Arctic Monitoring and Assessment Programme). 2009. Update on selected climate issues of concern. Arctic Monitoring and Assessment Programme, Oslo, Norway.

Bergerud, A.T., S.N. Luttich, and L. Camps. 2008. The return of the caribou to Ungava. McGill-Queen's University Press, Montreal, Quebec. 586pp.

BHP Billiton. 2009. EKATI Diamond Mine 2008 Wildlife Effects Monitoring Program. Prepared for BHP Billiton Diamonds Inc. by Rescan Environmental Services Ltd. March 2009.

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. Phoneix, 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.

Chen, W., D.E. Russell, A. Gunn, B. Croft, J.Z. Adamczewski, W. 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. In prep. a. Habitat indicators for migratory tundra caribou under a changing climate.

Chen, W., D.E. Russell, A. Gunn, B. Croft, J. Z. Adamczewski, W. 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. In prep. b. Habitat indicators for migratory tundra caribou under a changing climate: winter and pre-calving migration ranges.

Comiso, J. 2003. Warming trends in the Arctic from clear sky satellite observations. Journal of Climate 16:3498–3510.

Dené Nation and Ecology North. 2007. NWT Climate Change Leadership Summit: A Call to Action. Proceedings Report (accessed 7 August 2009 at http://www.c-ciarn.ca/pdf/nwt_climate_change_summit_report_final.pdf).

Duguay, C.R., T.D. Prowse, B.R. Bonsal, R.D. Brown, M.P. Lacroix, and P. Ménard. 2006. Recent trends in Canadian lake ice cover. Hydrological Processes 20:781–801.

Dye, D.G. 2002. Variability and trends in the annual snow-cover cycle in Northern Hemisphere land areas, 1972–2000. Hydrological Processes 16:3065–3077.

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.

Ford, J.D., T. Pearce, J. Gilligan, B. Smit, and J. Oakes. 2008. Climate change and hazards associated with ice use in Northern Canada. Arctic, Antarctic, and Alpine Research 40:647–659.

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. The Porcupine caribou herd. Pages 8-37 in D.C. Douglas, P.E. Reynolds, and E.B. Rhode, editors. Arctic Refuge coastal plain terrestrial wildlife research summaries, USGS Biological Science Report, USGS/BRD/BSR-2002-0001.

Groisman, P.Y and coauthors. 2003. Contemporary climate changes in high latitudes of the Northern Hemisphere: Daily time resolution. Preprints, 14th Symp. on Global Change and Climate Variations, Long Beach, CA, Amer. Meteor. Soc., CD-ROM, 4.8.

Gunn, A. In prep. Satellite collaring and calf survival in the Bathurst Herd of barren-ground caribou 2003 – 2005. Department of Environment and Natural Resources, Manuscript Report .

Gunn, A., J. Dragon and J. Boulanger. 2001. Seasonal movements of satellite-collared caribou from the Bathurst herd. Final Report to the West Kitikmeot Slave Study Society, Yellowknife, NWT. 80pp.

Gunn, A., Nishi, J.S., J. Boulanger, and J. Williams. 2005. An estimate of breeding females in the Bathurst herd of barren-ground caribou, June 2003. Manuscript report no. 164, Environment and Natural Resources, Yellowknife, NWT.

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., K.G. Poole, and J. Wierzchowski. 2008. A geostatistical analysis for the patterns of caribou occupancy on the Bathurst calving grounds 1966–2007. Unpublished report prepared for Indian and Northern Affairs Canada, Yellowknife, NWT.

Henry, G.R. In prep. Greening of the arctic. Arctic 2010 Biodiversity Highlights Report.

IPCC. 2001. Climate Change 2001:The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. J.T. Houghton,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson (eds.). Cambridge University Press, 881pp.

Jones, P.D., and A. Moberg. 2003. Hemispheric and large scale surface air temperature variations: an extensive revision and update to 2001. Journal of Climate 16:206–223.

Kauserud, H., L.C. Stige, J.O. Vik, R.H. Økland, K. Høiland, and N. Chr. Stenseth. 2008. Mushroom fruiting and climate change. Proceedings National Academy Science 105:3811–3814.

Kelleyhouse, R.A. 2001. Calving ground habitat selection: Teskekpuk Lake and Western Arctic caribou herds. MS thesis, University of Alaska, Fairbanks, Alaska. 140pp.

Lutsel K'e Dené First Nation. 2005. Ni hat'ni – Watching the Land: Results of 2003-2005 Monitoring Activities in the Traditional Territory of the Åutsÿl K'e Denesôåine. Report to the West Kitikmeot Slave/Study Society. Yellowknife, NT.

Menzel, A, and P. Fabian P. 1999. Growing season extended in Europe. Nature 397:659.

Magnuson, J.J., D.M. Robertson, B.J. Benson, R.H. Wynne, D.M. Livingstone, T. Arai, R.A. Assel, R.G. Barry, V. Card, E. Kuusisto, N.G. Granin, T.D. Prowse, K.M. Stewart, and V.S. Vuglinski. 2000. Historical trends in lake and river ice cover in the Northern Hemisphere. Science 289:1743–1746.

Marchand, F.L., I. Nijs, M. Heuer, S. Mertens, F. Kockelbergh, J-Y. Pontailler, I. Impens and L. Beyens. 2004. Climate warming postpones senescence in High Arctic tundra. Arctic, Antarctic, and Alpine Research 36:390–394.

Miller, F.L., and S.J. Barry. 2001. Single-island home range use by four female Peary caribou, Bathurst Island, Canadian High arctic, 1990-94. Rangifer, Special Issue No. 14:267–281.

Monk, W.A., D.J. Baird, D.L. Peters, R.A. Curry, and N. Glozier. 2009. Trends in biodiversity in lakes and rivers. Technical Background Reports: Ecosystem Status and Trends Report for Canada (in preparation). 1-83 pp.

Nishi, J.S., B. Croft, J. Williams, J. Boulanger, and D. Johnson. 2007. An estimate of breeding females in the Bathurst herd of barren-ground caribou, June 2006. File report no. 137, Environment and Natural Resources, Yellowknife, NWT.

Peterson, T.C., and R.S. Vose. 1997. An overview of the Global Historical Climatology Network temperature data base. Bulletin of the American Meteorological Society 78:2837–2849.

Post, E., and N.C. Stenseth. 1999. Climatic variability, plant phenology, and northern ungulates. Ecology 80:1322–1339.

Putkonen,J., T.C. Grenfell, K. Rennert, C. Bitz, P. Jacobson and D. Russell. 2009. Rain on snow: little understood killer in the North. EOS 90:221–222.

Serreze, M.C., and R.G. Barry. 2005. The Arctic climate system. Cambridge University Press, 402 pp.

Sparks, T.H. and A. Menzel. 2002. Observed changes in seasons: an overview. International Journal of Climatology 22:1715–1725.

Testa, J. W., E.F. Becker, and G.R. Lee. 2000. Movements of female moose in relation to birth and death of calves. Alces 36:155–162.

Thorpe, N.L., Eyegetok, S., Hakongak, N., and Qitirmiut Elders. 2001. The Tuktu and Nogak Project: A Caribou Chronicle. Final Report to the West Kitikmeot Slave/Study Society. Ikaluktuuttiak, NT. 2001.

Vore, J.M., and E.M. Schmidt. 2001. Movements of female elk during calving season in northwest Montana. Wildlife Society Bulletin 29:720–725.

Wang, M., and J.E. Overland. 2004. Detecting Arctic Climate change using Koppen climate classification. Climatic Change 67:43–62.

Zalatan, R. 2006. The relation between climate and abundance cycles in barren-ground caribou herds of the Northwest Territories, Canada. Ph.D. thesis, University of Britsh Columbia, BC. 111 pp.

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 38:624–630.

Zhang, X., J.E. Walsh, J. Zhang, U.S. Bhatt, and M. Ikeda. 2004. Climatology and interannual variability of Arctic cyclone activity: 1948–2002. Journal of Climate 17:2300–2317.

Zhang, X., R. Brown, W. Skinner, Y. Feng, E. Mekis, and L. Vincent. 2008. Canadian Climate Trends. Technical Background Reports: Ecosystem Status and Trends Report for Canada. Environment Canada.

Zhou, L., C.J. Tucker, R.K. Kaufmann, D. Slayback, N.V. Shabanov, and R.B. Myneni. 2001. Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. Journal of Geophysical Research 106:20,069–20,083.

APPENDIX 1

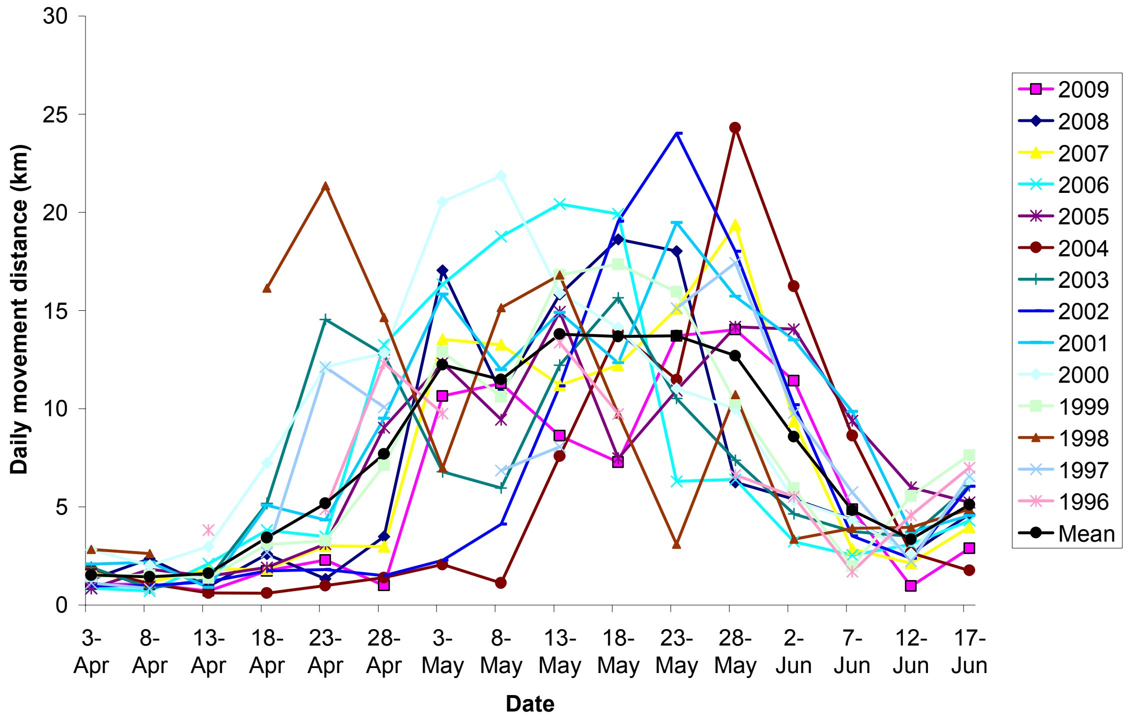

Figure 19. Mean daily movement distance by 5-day period by Bathurst caribou en route to the calving grounds, April to mid-June, 1996–2009. The heavier black line shows the overall mean movements.