A geostatistical analysis for the patterns of caribou occupancy on the Bathurst calving grounds 1966–2007

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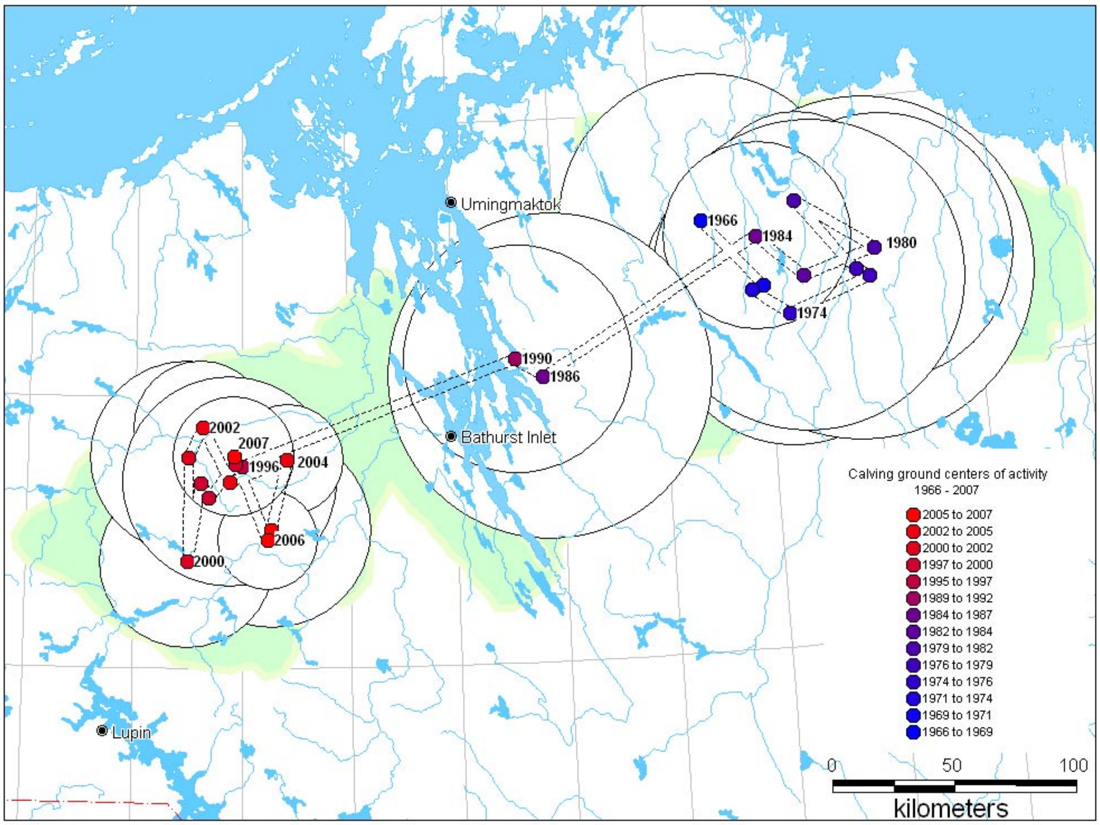

Prepared by

Anne Gunn[1], Kim G. Poole[2], and Jack Wierzchowski[3]

[1] 368 Roland Road, Salt Spring Island, BC V8K 1V1 gunnan@telus.net
[2] Aurora Wildlife Research, 2305 Annable Rd., Nelson, BC V1L 6K4
[3] Geomar Consulting Ltd., Box 856, Terrace, BC V8G 4R1

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SUMMARY

The calving grounds for the Bathurst herd of barren-ground caribou (*Rangifer tarandus groenlandicus*) shifted across Bathurst Inlet in the late 1980s. The shift raised questions about the mobility of calving grounds, especially in the context of managing human activities. We analyzed the spatial and temporal changes in the location and attributes of Bathurst calving grounds using two quite different data sets. We used 15 aerial surveys (1966-1990) and 12 years of satellite telemetry (1996-2007) for the Bathurst herd to delineate the calving grounds and their size, shape and location at the peak of calving. Our analyses of 24 calving grounds over 42 years (1966-2007) revealed that calving ground location at the peak of calving is annually predictable based on overlap between successive calving distribution, which averaged 38% (range 4-78%). A second measure of the predictability of calving ground locations was the shift between the centroids of calving distribution (centres weighted by caribou density), which averaged 17 km. During 1984 to 1996, the shift between centroids was consistently west, and for the other years there was no directional consistency. The net effect of the direction of the shift was two periods when peak calving ground overlap was high and one period when the overlap was low, which was when the calving ground shifted from east to west of Bathurst Inlet (1986-1996). The size and shape of the calving ground at or about the peak of the calving was variable with no consistent trends. Dates of peak calving were annually variable (1996-2007) and appeared to shift about 4 days later during June. The annual dates of arrival on the peak calving ground varied from 20 May to 5 June. On average between 1996 and 2007, the cows spent 20 and 39 days within the peak and annual calving grounds, respectively, with no obvious trend over time. The annual calving ground is the period from birth to the initiation of foraging by calves - at about 3 weeks of age. Based on the collar data, arrival and exit dates into and out of the peak and annual calving grounds were 5 to 10 days later by the end of the 12 years of collaring. Cows used less than half the annual calving ground during any one 5-day period. We identified 2005 as an atypical calving season as the peak of calving in 2005 averaged about 6 days later than other years (1996-2007), which we attribute to the low pregnancy rate in that year. The Bathurst calving grounds have had two periods totalling 30 years when the predictability of the calving ground's location was high. The two periods were separated by an 11-year period when the locations shifted from east to west of Bathurst Inlet. The scale of the shifts will allow the application of area-based and rules-based management for protecting calving grounds. The designation of area-based management will give predictability where rules governing land use activities could be applied (mobile protection measures).

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Acronyms and definitions used in the report

Annual calving ground	The area occupied by parturient caribou from birth through the initiation of foraging by calves - at about 3 weeks after birth (Russell et al. 2002)
CPM	Caribou Protection Measures
DIAND	Department of Indian Affairs and Northern Development
ENR	Environment and Natural Resources, Government of the Northwest Territories
Extent of Calving	The Extent of Calving is the outer perimeter of all known annual calving grounds (Russell et al. 2002)
GNWT	Government of the Northwest Territories
GN	Government of Nunavut
NDVI	Normal Difference Vegetation Index
Peak of calving	The 7-day period when 50% of the cows had calved.
Peak calving ground	The area used by parturient cows during the 7-day period centred on the peak of calving
Peak calving grounds	The outer perimeter of all known peak calving grounds
Traditional Calving Grounds	The total cumulative area used for calving by a particular herd from the 1950s to present (BQCMB 2004).
WKSS	West Kitikmeot Slave Society

INTRODUCTION

Since 1978 the Department of Indian Affairs and Northern Development (DIAND) has taken a lead role in managing human activities on calving grounds of barren-ground caribou *Rangifer tarandus groenlandicus*. The efforts started with the Caribou Protection Measures applied to the Beverly and Qamanirjuaq herds (Darby 1978, Gunn et al. 2007). More recently, DIAND contracted a survey of agencies involved in land and wildlife management in the Northwest Territories and Nunavut to elicit their experience with and views on managing human activities on caribou calving grounds (Weihs and Usher 2001). The interviews revealed questions about what is a calving ground and a perception of the mobility of calving grounds, as well as clear support for 'mobile protections measures'. The perception of 'mobility' raised doubts about the validity of area-based protection. We suspect that in part the impression of mobility is from the Bathurst calving grounds, which between 1986 and 1996 moved westward across Bathurst Inlet returning to areas used in the 1950s (Figure 1). Subsequently the calving grounds have not shifted, yet there is a persistent belief in the mobility of calving grounds (for example, Weihs and Usher 2001). A re-appraisal of the location of the calving grounds will clarify the spatial and temporal scale of the mobility.

To answer those questions for the Bathurst herd requires analyses of the two quite different data sets available to describe the location and attributes of calving grounds: aerial surveys and satellite telemetry. Aerial survey data on the Bathurst herd calving grounds were compiled from 1966 to 1996 but not analysed spatially (Sutherland and Gunn 1996). Subsequent survey information is given in several reports (Gunn et al. 2001, 2005, Gunn and D'Hont 2003, Nishi et al. 2007). The aerial surveys map the size and location of calving at or shortly after the peak of calving. However, the aerial surveys generally were at intervals of 3 to 6 years. The second available method to describe calving grounds is radio- or satellite-collared individuals with the advantage that the data are available annually (Griffith et al. 2001; Gunn et al. 2001, In Press). Satellite telemetry provides a series of locations for individual cows as they enter the calving ground, calve, and leave. This allows us to describe the pattern of how caribou occupy calving grounds and their residency on the calving grounds in successive years.

In the 1990s, the Bathurst herd was the focus of research supported by the West Kitikmeot Slave Society (WKSS) in response to extensive exploration for diamonds. The research included compiling traditional knowledge about the herd (Dogrib Treaty 11 Council 2001, Thorpe et al. 2001) as well as satellite collaring to describe seasonal distribution and calving ground ecology (Griffith et al. 2001, Gunn et al. 2001). The Department of Environment and Natural Resources (Government of the Northwest Territories, ENR GNWT) has maintained the satellite telemetry project. We now have 12 years of satellite telemetry as well as developments in the use of Geographic Information Systems (GIS) to allow geostatistical analyses. We use those analyses to address questions about annual variation in location of calving grounds and patterns of caribou occupancy within annual calving grounds. Those analyses and a retrospective analysis of calving ground locations mapped during aerial surveys since the 1960s can be used to characterise the extent and pattern of mobility of the Bathurst calving grounds. We can then depict variations in the patterns of occupancy for any geographic location on the annual calving grounds as well as the duration of that occupation.

By 2006, the Bathurst herd was about half the size it was in 1986 (Nishi et al. 2007). The decline has heightened concerns about the future of the herd. The decline of the Bathurst herd and other caribou herds led to the GNWT hosting a Caribou Summit in Inuvik in January 2007, where the delegates identified protection of calving grounds as the top priority for action. Although the 2004 draft West Kitikmeot Regional Land Use Plan recommended the application of mobile protection measures, the draft plan noted the need for research to develop the measures (Nunavut Planning Commission 2004). Our intent is to bring together what is known about the predictability of calving distribution as a step toward managing human activities on the Bathurst herd's calving ground. Our approach is to build upon the previous WKSS research to examine attributes of calving distribution over the timescale of decades. The objectives were to (1) describe variations in the location, size and shape of the calving grounds; (2) describe the patterns and predictability of caribou occupation of their calving grounds; and (3) recommend how to use the currently available monitoring data to establish calving ground boundaries that reflect the probability of the location and occupation of their calving grounds.

Given the strength of concerns about caribou calving grounds, we also considered how monitoring calving distribution will contribute to regional monitoring in the context of cumulative effects. We considered conceptual relationships between the calving distribution and the head start that caribou calves need to ensure their resilience to conditions elsewhere on the annual ranges.

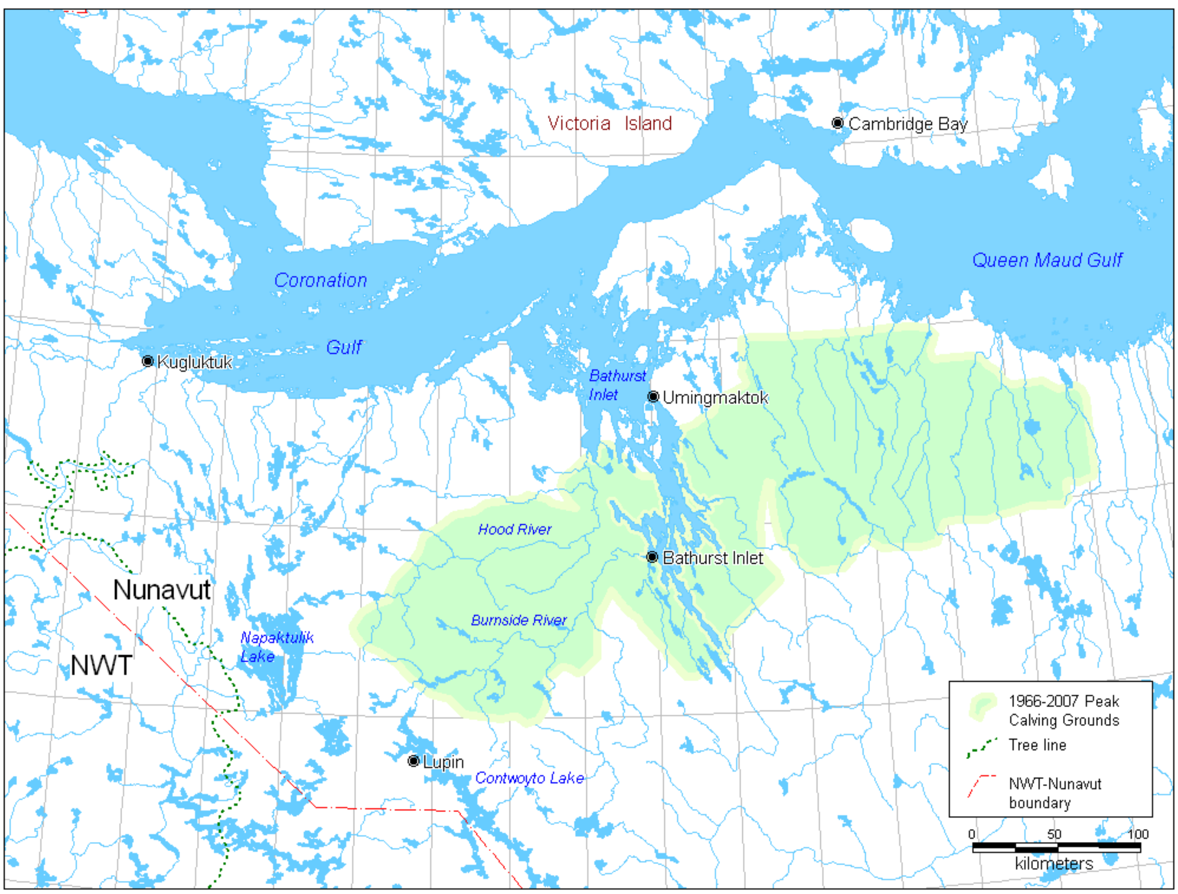


Figure 1. Bathurst caribou peak calving grounds based on aerial surveys and satellite collar telemetry, 1966-2007.

DEFINITIONS

To clarify our terminology related to identification of calving grounds derived from aerial surveys and telemetry data, we applied the following definitions (Table 1), building on those provided in Russell et al. (2002). To take into account the time period when the calves are completely dependent on their cow's milk and the cow is dependent on foraging to produce milk, Russell et al. (2002) defined the *annual calving ground* as the area used from the peak of calving for about 3 weeks. This definition depends on the availability of telemetry data, which for the Bathurst herd only started in 1996. Before 1996, only aerial survey data are available, flown at or close to the peak of calving. Thus we defined the *peak calving ground* as the area used by caribou each year during the 7-day period encompassing the peak of calving (when 50% of cows in the herd have calved). This is determined during aerial calving ground surveys (for example, Nishi et al. 2007), or using telemetry data to define when most parturition has occurred (see Methods). Little movement occurs by neonatal caribou in the first days of life (for example, Kelleyhouse 2001), which indicates that the two methods measure comparable events at the herd (aerial survey) and individual (telemetry) scales. Over a longer time scale, the peak calving grounds overlap to become the cumulative area of annual *peak calving grounds*. The peak calving ground is arguably an important subset of the annual calving ground, as it is where cows drop their calves. This is comparable to the "calving ground" as defined by Wolfe (2000:7), which was determined from locations of calving sites where radio-collared females were first observed with a live calf at heel.

Table 1. Definitions for caribou calving grounds relative to data sources and dates of available data for the Bathurst herd.

	Temporal scale	
Method	**Annual**	**Cumulative**
Aerial surveys	Peak calving ground	1966-1984 peak calving grounds
7 days of concentrated calving around the peak		
Telemetry	Peak calving ground	1996-2007 peak calving grounds
7 days of concentrated calving around the peak		
Peak calving plus 3 weeks	Annual calving ground (Russell et al. 2002)	Extent of calving (Russell et al. 2002)

METHODS

Peak of calving: We had two sets of data available for this analysis. We had paper maps from the reports for aerial surveys of Bathurst caribou herd calving grounds from 1966 to 2006, and we had location data from the satellite-collared cows from 1996 to 2007.

Peak of calving and early post-calving movement rates from satellite telemetry: We analyzed calving and early post-calving movement data from 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 31 December 2007 from 78 caribou from the Bathurst herd. Where multiple locations were obtained for an individual caribou each day, the best location each day was used as classified by on-board collar software (Table 2) (A. D'Hont, ENR, pers. comm.). Duty cycle varied over this time period, from every 7 days to every 1 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). Locations with class code 0 were not used in the analysis.

Table 2. Satellite collar class codes.

Class	Location accuracy
3	<150 m
2	150-350 m
1	350-1,000 m
0	>1,000 m

We used the techniques of Testa et al. (2000) and Vore and Schmidt (2001) to identify calving areas. Vore and Schmidt (2001) observed a significant increase then decrease in daily movements by maternal female elk (*Cervus elaphus*), coupled with fidelity to a small area, as evidence of parturition. A similar pattern was observed with moose (*Alces alces*) in Alaska (Testa et al. 2000) and caribou (for example, Kelleyhouse 2001). Movement rates were used to determine timing of calving from the collar data on an annual basis, as peak of calving may vary among years (for example, Sutherland and Gunn 1996). The movement pattern of each caribou each year was screened to remove outliers, generally caribou that did not reach the calving grounds (mostly non-breeders). The 7-day period that best depicted reduced rates of movement from the animals collared that year (and presumably peak of calving) was identified (for example, Gunn et al. 2001). Each year the pattern of movements between successive locations was examined for both 5 or 7-day fix locations, and for daily fix locations (detailed below). Since the majority of satellite collars provided locations at 5-day intervals, the datasets were further culled to provide a maximum of two locations per caribou per calving period. This was done to allow equal comparison of kernel estimates of the peak calving ground among years (see below).

Movement analysis was based on collar databases containing satellite radiolocations. Distances between consecutive locations were calculated using an in-house developed program (Geomar Consulting Ltd, 2007, unpublished data) that calculates Euclidian distances between radiolocations. The program considered as sequential only these records that were obtained within a user-specified time threshold (1 month, for example). The program was written in MapBasic programming language and used MapInfo's libraries[1]. Microsoft's Excel program[2] was used to further process the data and to generate movement charts.

Mapping of peak calving ground (1966-2007): Digital coverage of peak calving ground distribution based on aerial surveys was not available, thus we relied on published reports. For aerial surveys conducted prior to 1995, we used Sutherland and Gunn (1996). Subsequent to 1995, we used Gunn et al. (1997), Gunn et al. (2005) and Nishi et al. (2007). We did not use two aerial surveys (1995 and 2002) that were conducted only to determine the approximate location of calving relative to whether it was east or west of Bathurst Inlet. The two surveys (1995 and 2002) were conducted as preparation for a subsequent census and did not determine calving ground boundaries (Gunn 1996; Gunn and D'Hont 2003). For years 1966 to 1996, paper copies of selected peak calving grounds polygons were scanned at 150 dpi and registered to the Latitude/Longitude coordinate system using as a reference the 1:250,000 digital hydrology database of Nunavut made available for this project.

We used the reported estimates of the peak of calving from the aerial surveys; those peaks were mostly based on when at least 50% of the cows had calved (Sutherland and Gunn 1996). The selected peak calving ground polygons were the distribution of cows and calves mapped during unsystematic (1970) or systematically spaced transects (1966, 1971 and 1974) during aerial surveys. For the 1977 aerial survey and subsequently, the calving distribution mapped during the reconnaissance flights was stratified into high, medium and low densities. We used the combined outline of all the designated strata (high, medium and low density) for each year. The average registration error did not exceed three pixels or 1 km in any direction. Vector versions of the calving ground outlines were generated through the on-screen digitizing of the scanned and registered maps using MapInfo version 6.0 desktop GIS software.

For years 1996 to 2007, peak calving ground polygons were generated using satellite telemetry locations. The peak calving ground for each year was determined using 90% fixed kernel estimates (Worton 1989, Seaman and Powell 1996) of occurrence from the distribution of satellite-collared caribou using the Home Range Extension (Rodgers and Carr 1998) for ArcView (Environmental Systems Research Institute, Redlands California, U.S.A.). Fixed kernel estimates of range have been found to have lower bias and lower surface fit error than other methods (Seaman et al. 1999). We calculated 90% fixed kernel peak calving ground ranges using unit variance standardization, h-user set to 0.4-0.8 (depending upon the spatial pattern of locations), and raster resolution set to 120. Kernel estimates are influenced by sample size (Seaman et al. 1999). Although the number of collared individuals was low, a comparison of their distribution compared to aerial surveys in 1996, 2003 and 2006 (this report) indicates that the collared individuals represent the overall caribou distribution during calving. Samples sizes during peak of calving in 8 of 12 years were <20 locations (the minimum used by Kelleyhouse 2001), but were retained to show trend over time.

To examine the spatial distribution of peak calving grounds, we plotted the frequency of cumulative distribution of peak calving grounds (in effect, areas were weighted by the number of years they were used for peak of calving; Gunn et al. 2007). We constructed this figure for

[1] MapBasic Version 4.5, MapInfo Version 6.0. This software package was used to develop all programs described in this document.
[2] Microsoft Office Small Business Edition 2003, SP2.

data from 1966 to 1990 (based on aerial survey data), and 1996 to 2007 (based on satellite collar data).

Comparison of the size and location of peak calving grounds as described by aerial surveys and satellite telemetry (1996, 2003 and 2006): We had three aerial surveys during the period when we had telemetry data. We tested our assumption that the satellite collared caribou were representative of the overall calving distribution for any one year by comparing the centroids (see next section) for and sizes of the peak calving grounds determined in 1996, 2003 and 2006 during aerial surveys with the peak calving distribution as mapped by the satellite collars. For these years we plotted the 50%, 90% and 99% kernel polygons on top of the stratification blocks mapped during aerial surveys. We included the medium and high-density strata (except 1996 when we included a low-density stratum as there was no medium-density stratum with caribou). Most (91, 86 and 98% of the breeding females in 1996, 2003 and 2006, respectively) were in the high-density stratum (Gunn et al. 1997, 2005; Nishi et al. 2007).

Peak calving ground size, and arrival, residency and departure from the peak calving ground (1996-2007): Boundaries for the peak calving ground (calculated using kernel analysis) were used to estimate peak calving ground size, and arrival, residency and departure from the peak calving ground. For each animal in each year, the date of arrival into the peak calving ground was assumed to be the mid-point of telemetry dates of the first entry into the peak calving ground and the previous location outside the peak calving ground. A similar analysis was conducted to determine exit date from the mapped calving ground. If a caribou exited the peak calving ground, then re-entered, the exit date was determined to be the final exit from the peak calving ground.

Residency on the peak calving ground for each caribou was the difference in days between the calculated entry and exit dates. The median entry and exit dates from the peak calving ground, and the residency, were plotted to examine temporal changes in use of the calving ground during parturition. We used box plots to show the annual median and variability in dates and days for various parameters. In the box plots, horizontal bars show the location of median values, boxes represent the interquartile range (between 25th and 75th percentile) of the values, and whiskers represent the spread of about 99% of values. Outlier (those values that are between 1.5 to 3 box lengths over or below the interquartile box) or extreme (over 3 boxes under or above the interquartile box) values are shown with circles.

Overlap, shape and relative size of peak calving grounds (1966-2007): We calculated the compactness of each peak calving ground. The compactness (in effect, the complexity of the shape) was calculated as a ratio computed by comparing the area of a polygon to that of a circle having the same perimeter as the polygon. The formula is:

$$C = SQRT(Ap/Ac)$$

where C is the compactness ratio, SQRT is the square root function, Ap is the area of the polygon being calculated, and Ac is the area of a circle having the same perimeter as that of the polygon being calculated. This ratio provides an indication how dispersed the caribou were during the time on each peak caving ground.

The in-house program was used to map the frequency of overlap among 1966 to 2007 peak calving ground polygons (polygons derived from aerial survey and telemetry data). Using these polygons, it also calculated area of overlap and the overlap index of all peak calving ground polygons. The following formula was used:

Overlap Index = 2*area_overlap*100/(area_polygon1+area_polygon2)

Peak calving ground centroids: We also calculated centroids of calving distribution that were weighted by the density of calving caribou (as against estimating a geographic centre). To calculate the centroids weighted by density, we represented peak calving ground polygons by the distributions of random locations (virtual caribou). An in-house developed program was used to generate the stratified random locations for each of the 1966 to 2007 peak calving ground polygons derived from aerial survey maps and telemetry data. Nearly 80,000 points were generated. The locations falling within large water bodies - polygons defined as lakes in the hydrology database of the former NWT and within Bathurst Inlet - were excluded from the set. For aerial surveys, low-density polygons were assumed to have 0.35 caribou/km^2, medium-density had densities equal to 0.7 locations/km^2, and high-density polygons had densities of just over 1 location/km^2 (Figure 2). Polygons derived from telemetry data were assigned a single density of stratified random locations. The selection of the initial density value was arbitrary as it had no bearing on further analyses and processing of the data. The described technique also facilitated further statistical analyses and simplified graphical displays. For example, to visually compare the aerial survey polygons and the telemetry-derived polygons, we created circles, the radii of which was weighted by virtual caribou density so as to be comparing areas on a common basis.

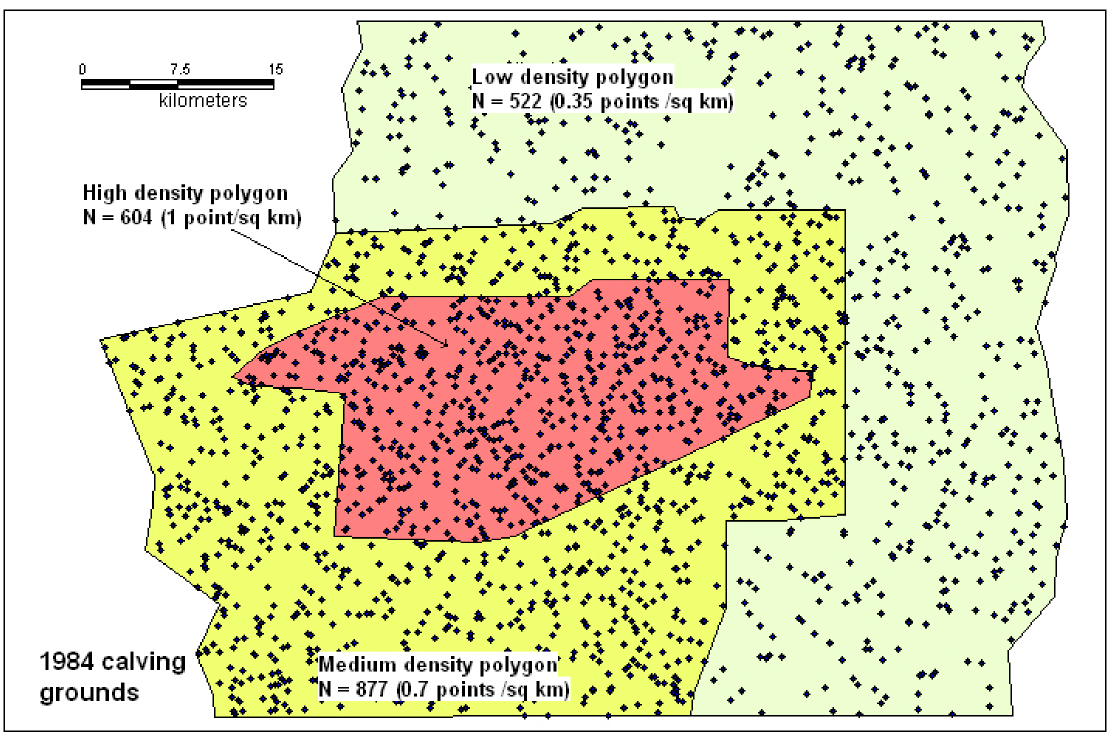


Figure 2. Example of the distribution of stratified random locations generated for the 1984 peak calving ground.

Peak calving ground density: Based on the above set of random locations, an in-house developed program was used to generate peak calving ground density maps. The program employs a moving window technique[3]. To convert the output into a relative density map, the calculated density values were expressed as a fraction of a maximum density value found within the total survey area (42 years of known calving distribution). To facilitate comparisons to the density maps generated from aerial survey data, a kernel of 5 km radius and the step of 1 km were selected (Figure 3). Stratified random location points were also used to determine the location of each polygon's centroids, representing the peak calving ground "centres of activity" during the 1966-2007 period.

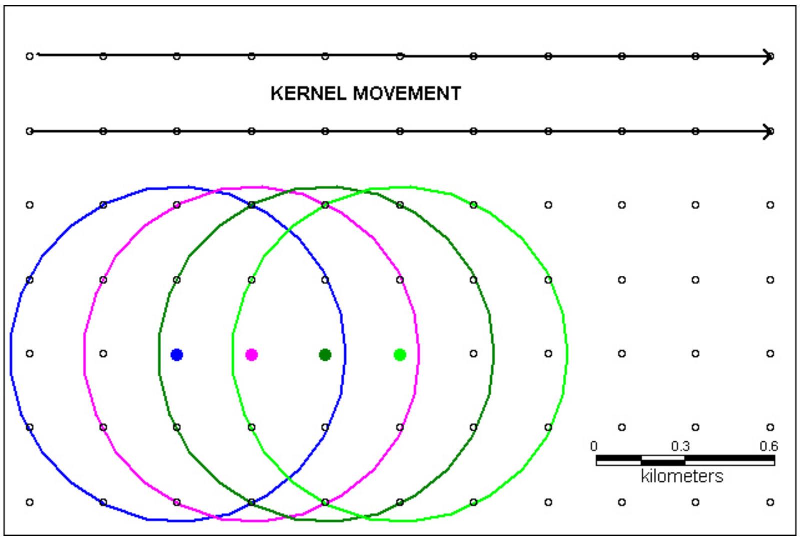


Figure 3. Kernel step and radius concepts in the moving window technique. For each step, equal to the distance between the nodes, within each circle (called a kernel) the density/number of random locations is calculated and assigned to the circle's central node (blue circle – blue node, etc.). To generate peak calving ground density map, step of 1 km and kernel radius of 5 km was used.

We plotted the distance between consecutive centroids of the peak calving grounds against the size of consecutive peak calving grounds to determine whether there was a relationship between the size of the shift between consecutive peak calving ground centroids and the sum of the areas occupied during the consecutive calving season. We were checking whether a decrease or increase in peak calving grounds centres had a bearing on the size of the shift between consecutive calving seasons. We applied a Variance to Mean Ratio test to determine the character of the centroids' spatial distribution.

[3] This technique has two main advantages over the fixed (static) density grids – it is insensitive to the grid's point of origin, and permits the use of variable kernel radii without sacrificing the spatial resolution.

Mapping of annual calving grounds 1996-2007: We mapped the annual calving ground, the area used by collared caribou from the peak of calving to 3 weeks after the peak (Russell et al. 2002). The analysis was restricted to the years with satellite telemetry (1996-2007). To retain comparison and sample size of locations among individuals among years (accounting for differences in collar fix rates), we selected one location per caribou for each 5-day period after the peak of calving (the final period had 7 days). We constructed 90% fixed kernel polygons using the settings noted above. We also produced subsets of caribou use of the calving ground for each year in 5-day periods (7 days for the last period) after the peak of calving to examine temporal trends with increasing time from calving. Annual calving grounds were amalgamated to produce an extent of calving map, which plotted the frequency of cumulative distribution of annual calving grounds. Entry into and exit out of the annual calving grounds were graphed as per peak calving grounds.

We illustrated the amount of time that any given point (such as a camp) within the extent of calving may encounter caribou during the period from peak of calving to 3 weeks after the peak of calving. To demonstrate this, we randomly placed 20 points within the extent of calving polygon and summed the number of 5 to 7 days periods each random point was in 5 to 7-day sub-polygons of the annual calving ground for each year.

RESULTS

Peak of calving

We approximated the peak of calving from the average distance moved by collared Bathurst caribou, which was generally lowest during the second or third 5-day period in June (Figure 4). Based on the assessment of daily movement distances from 5-day and daily collar locations, we established the timing of peak of calving activity for each year (Table 3). Dates of peak calving varied annually and appeared to shift about 4 days later in June from the first few years of the collaring program to the years since 1999. The 2005 calving season was latest and the trajectory of movement rates showed less variability. The movement patterns indicated peak of calving in 2005 averaged about 6 days later than peak of calving during the remainder of the 2000s.

The 8 June 5-day midpoint had the lowest movement overall (summed) in 1996-99 and 2005 (marginally over 13 Jun), 2006, and 2007. However, the 13 June midpoint had the lowest movement rate in 2000-04 (18 June was slightly lower in 2004). In all but 1997 the differences were, however, not significant between 8 and 13 June (based on 95% confidence intervals). The rate of movement of the Bathurst cows dropped to 5.3 km/day as an overall mean for 6-10 June, but this does not factor in the shift in peak of calving among years. Some years the average during the lowest movement period was 2.5-3.5 km/day.

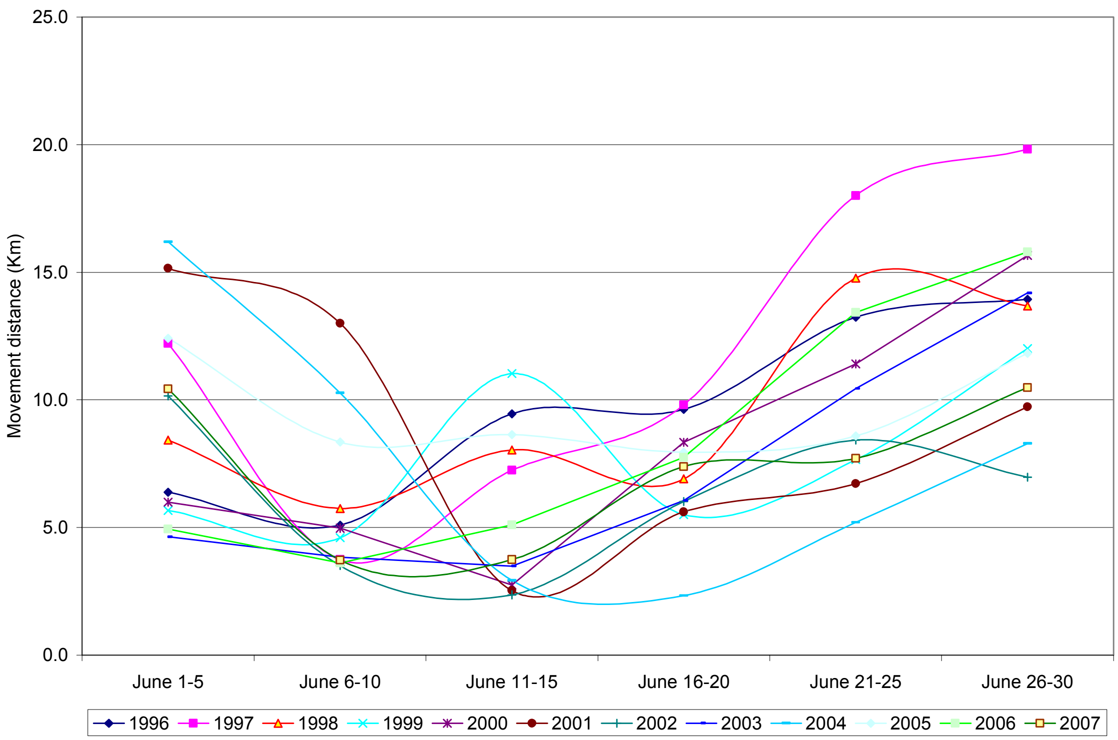


Figure 4. The average (smoothed) daily movement distances (km/day) for the Bathurst caribou, 1996 to 2007, as determined by 5-day collar frequency.

Size of peak and annual calving grounds (1996-2007)

The number of collars available for the analyses was between 2 and 19 individual cows with 10 or more collars for 8 of the 12 years (Table 3). The correlation between sample size and size of the peak calving ground was insignificant and weak ($r = 0.08$, $P = 0.8$), which suggested that the collar locations reflect peak calving grounds regardless of sample size for the study period 1996-2007.

We determined the size of the peak calving ground each year from the 90% fixed kernel analysis of a maximum of two locations from each caribou during the peak calving period (Table 3). We also determined the size of annual calving ground from 90% fixed kernel analysis with 5-day spacing on caribou locations from peak of calving plus 3 weeks (Table 3). Mean Bathurst peak calving ground size from 1996 to 2007 as calculated from the collars was 3,017 km^2 (±473.7 SE), and annual calving ground size was 13,906 km^2 (±1,525), approximately four times larger. There was no indication that peak calving ground size ($r = 0.08$, $P = 0.8$) or annual calving ground size ($r = –0.11$, $P = 0.7$) changed with time during 1996 to 2007.

Table 3. Peak of calving for the Bathurst herd, 1996-2007, as determined from satellite collar data. Size of peak calving ground each year determined from 90% fixed kernel analysis of a maximum of two locations from each caribou during the peak calving period. Size of annual calving ground determined from 90% fixed kernel analysis with 5-day spacing on caribou locations from peak of calving plus 3 weeks.

Year	No. of caribou[1]	Peak of calving	Peak calving grounds (km^2)	Annual calving grounds (km^2)
1996	9	4-10 Jun	614	7937
1997	7	4-10 Jun	3035	9551
1998	2	4-10 Jun	2005	16761
1999	12	8-14 Jun	3974	23372
2000	11	8-14 Jun	3900	20536
2001	10	8-14 Jun	4760	12015
2002	11	8-14 Jun	2345	11155
2003	10	8-14 Jun	5793	20274
2004	5	8-14 Jun	1611	8910
2005	12	14-20 Jun	4962	14014
2006	14	8-14 Jun	1316	14276
2007	19	8-14 Jun	1884	8072

[1] Number of collared caribou used to calculate ranges, after outliers removed (see Appendix A).

We also used aerial survey data to measure the size of the calving grounds close to the peak of calving (Table 4). We digitized the survey areas stratified by caribou density either for visual survey (prior to 1980) or for photography (after 1980), as the photography usually was timed during the surveys to occur as close to the peak as was practical. We also included the peak of calving (Table 4) as described in the reports from when at least 50% of the caribou had calved (Sutherland and Gunn 1997, Gunn et al. 1997).

Table 4. Range of dates and sizes for peak calving grounds for the Bathurst herd, 1966-1996, as determined from aerial survey data. The areas were digitized from the listed Figure numbers from Sutherland and Gunn (1996).

Year	Peak calving grounds (km^2)[1]	Dates of delineation of calving areas	Peak identified from reports Sutherland and Gunn 1996	Digitized Figure numbers
1966	8844	6-Jun	5-9 Jun	Figure 5
1970	6205	8-Jun	11-15 Jun	Figure 7
1971	4308	8-12 Jun	7-10 Jun	Figure 9
1974	6964	6-7 Jun	4-9 Jun	Figure 12
1977	7241	5-8 Jun	4-8 Jun	Figure 15
1978	11298	5-7 Jun	5-9 Jun	Figure 19
1979	3139	14-Jun	10-14 Jun	Figure 24
1980	6832	3-8 Jun	4-8 Jun	Figure 29
1982	9506	10-12 Jun	6-10 Jun	Figure 35
1984	3547	8-9 Jun	3-7 Jun	Figure 41
1986	11890	10-16 Jun	9-18 Jun	Figure 45
1990	5945	11-Jun	9-11 Jun	Figure 52

[1] Area from 1977 on includes low, medium and high strata; see Sutherland and Gunn (1996) for further clarification.

The size of the calving grounds ($\bar{x}$ = 7,143 km^2 (±1,525 SE)) and the dates for the peak of calving varied annually and we did not detect any trends or relationship between aerial survey calving ground size and date of peak calving (r = –0.12, P = 0.7). We suggest that part of the variability in size from 1966 to 1980 (Coefficient of Variation [CV] 21%) was because survey methods were being refined and improved. As the survey methods had not been standardised, especially the criteria when to end a survey transect, this likely contributed variation to describing boundaries and timing of calving.

Comparison of the size and location of peak calving grounds as described by aerial surveys and satellite telemetry (1996, 2003 and 2006)

Our analysis assumed that the peak calving grounds mapped from the satellite-collared cows represent the overall distribution of caribou. To test this assumption, we compared the centroids and areas for 1996, 2003 and 2006 when both aerial survey and satellite telemetry were available. We plotted 50%, 90% and 99% kernel polygons of the peak calving period and compared them to the aerial stratification conducted during calving ground censuses in 1996, 2003, and 2006 (Figure 5). Although the average distance between telemetry and aerial survey-based calving ground centroids was slightly smaller for the 50% kernels compared with the 90% kernels (8.6 and 9.6 km, respectively), the overlap index was considerably lower (36.1 and 53.5%, respectively)(Table 5). Therefore, in general the 90% kernel provided a better fit than the 50% kernel of the distribution of caribou as determined from aerial surveys. However, as the survey flights and the subsequent stratification generally take place at or after the peak of calving, the temporal "snapshot" will not align perfectly between the aerial surveys and the telemetry. The telemetry is based on 5-day periods whose timing depends on the how the collar transmitter was configured. The peak defined from observations during the aerial surveys was

5-9 June 1996, 8-11 June 2003 and 9-11 June 2006 (Gunn et al. 1997, 2005; Nishi et al. 2007), which is within the peak defined by telemetry (Table 3).

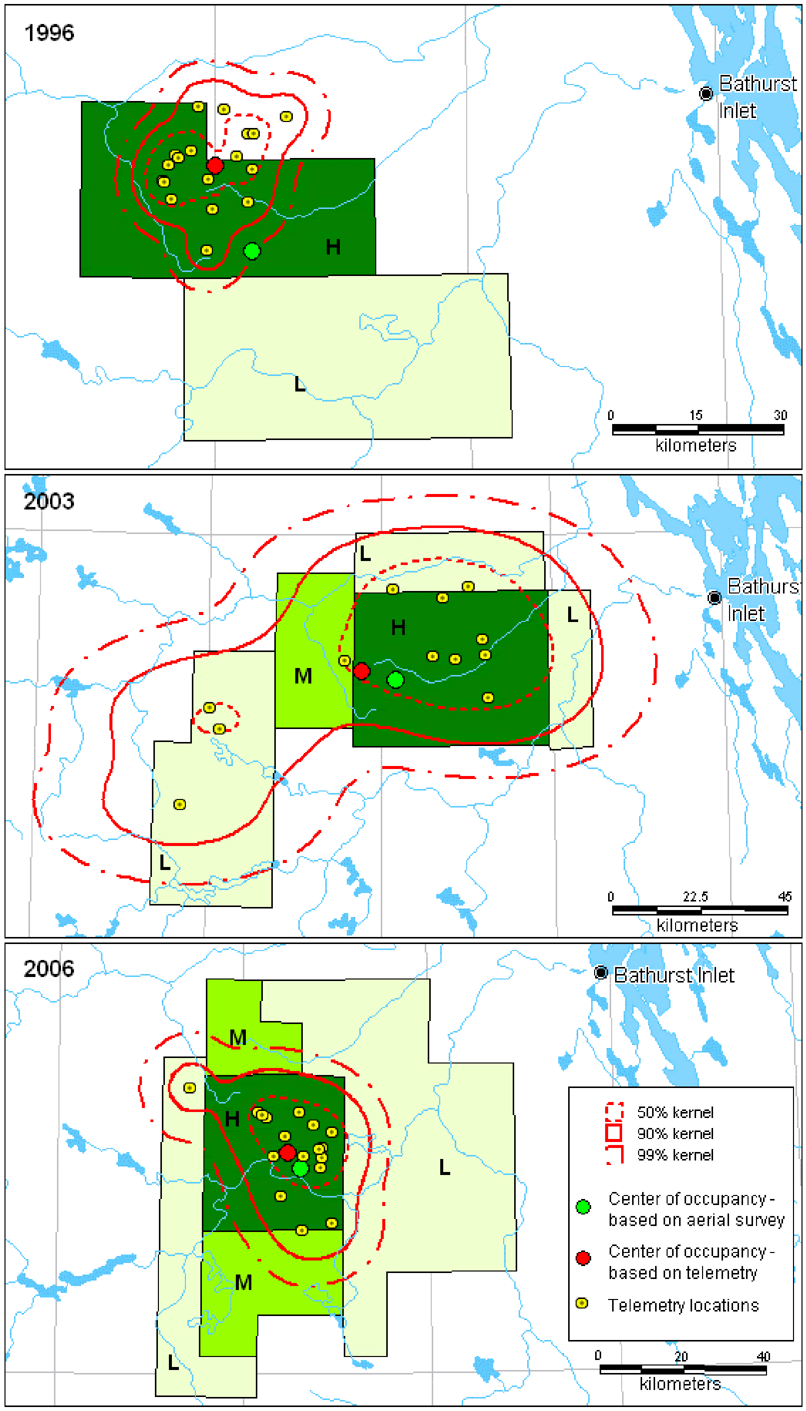


Figure 5. Relationship between peak calving grounds as determined by satellite collars and peak calving grounds as determined from stratification from aerial surveys. Caribou locations used to derive the peak calving grounds (during the peak calving period) are shown.

Table 5. Overlap and distance between centroids for peak calving grounds (CG) as determined by satellite collars and peak calving grounds as determined from stratification from aerial surveys.

Year	Fixed kernel	Aerial survey CG area (km^2) moderate and high density only	Peak CG based on telemetry (km^2)	Overlap as % of CG area (telemetry)	Overlap as % of CG area (aerial survey)	Overlap index (%)	Distance (km) between CG (telemetry- and aerial survey-based) centroids
2006	90%	2477	1308	82.1	43.4	56.7	6.6
2003	90%	2762	5758	44.8	93.4	60.6	15.7
1996	90%	1263	611	66.3	32.1	43.2	6.5
2006	50%	2477	374	98.1	14.8	25.8	10.9
2003	50%	2762	1685	81.0	49.4	61.4	7.8
1996	50%	1263	217	71.9	12.4	21.0	7.1

Overlap in peak calving grounds (1996-2007)

We mapped the peak calving grounds using the polygons based on the aerial surveys and satellite telemetry from 1966 to 2007 (Table 6, Figures 6, 7). The frequency of cumulative distribution of peak calving grounds shows areas weighted by the number of years they were used for peak of calving (Figure 6). The map shows two areas with 9-10 years of use separated by a 'bridge' across the Bathurst Inlet area when the calving grounds were only mapped three times over 11 years (1986, 1990 and 1996).

We compared the overlap between consecutive aerial calving ground surveys, even although the interval (number of years between surveys) varied. As distance between peak calving ground centroids decreased from one year to the next, the amount of overlap increases in some years, but the overlap (Table 6) was also affected by the shape of the two polygons relative to one-another. The mean overlap between peak calving grounds as determined from surveys from 1966 to 1986 (54% ± 4.2%; CV 24.5%) was higher than the mean overlap between peak calving grounds as determined from collared caribou from 1996 to 2007 (32% ± 4.0%; CV 41.5%) (*t*-test on log-transformed data; $t = 2.86$, $P = 0.014$) (Table 6, Figure 8). Overall, the overlap over the 24 calving grounds during the 42 years of monitoring averaged 43% (± 3.8%; CV 40.8%).

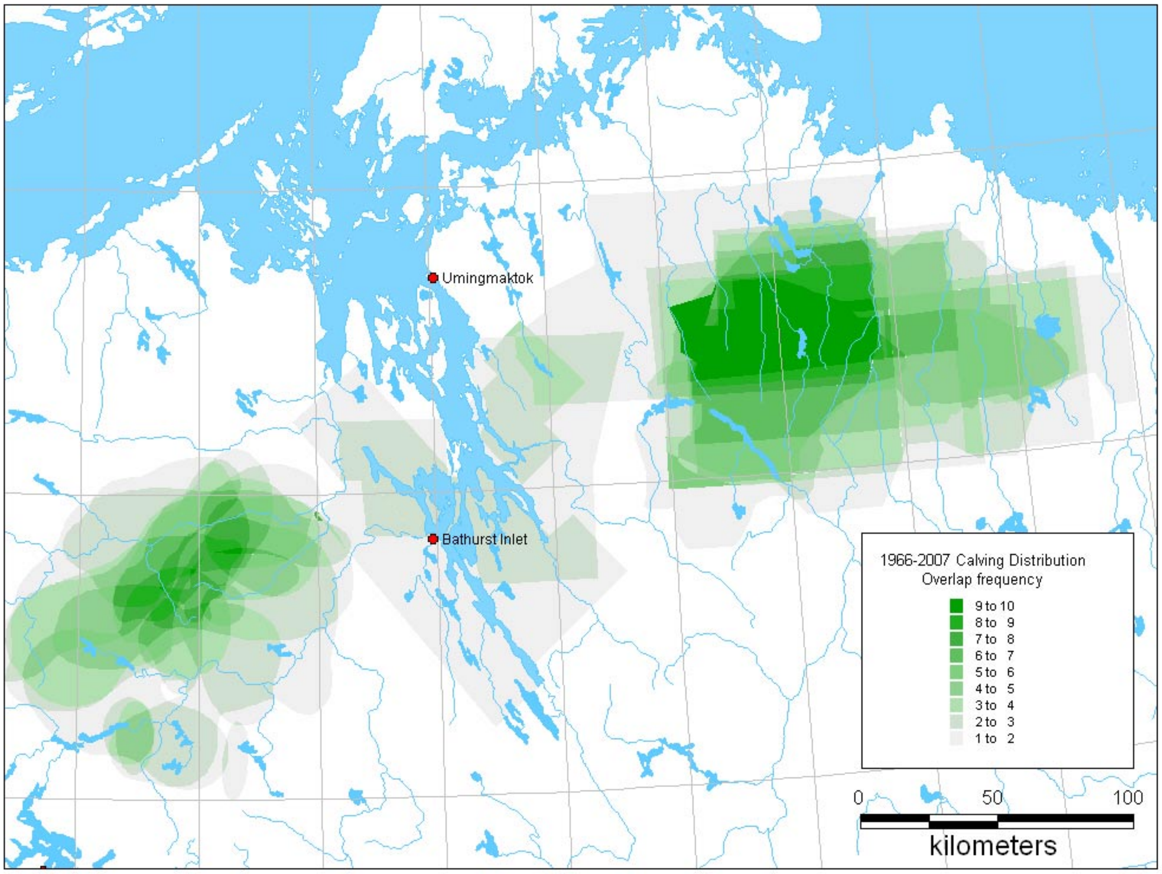


Figure 6. The frequency of cumulative distribution of overlap in peak calving grounds for the Bathurst herd based on aerial surveys (1966-1990) and satellite telemetry (1996-2007).

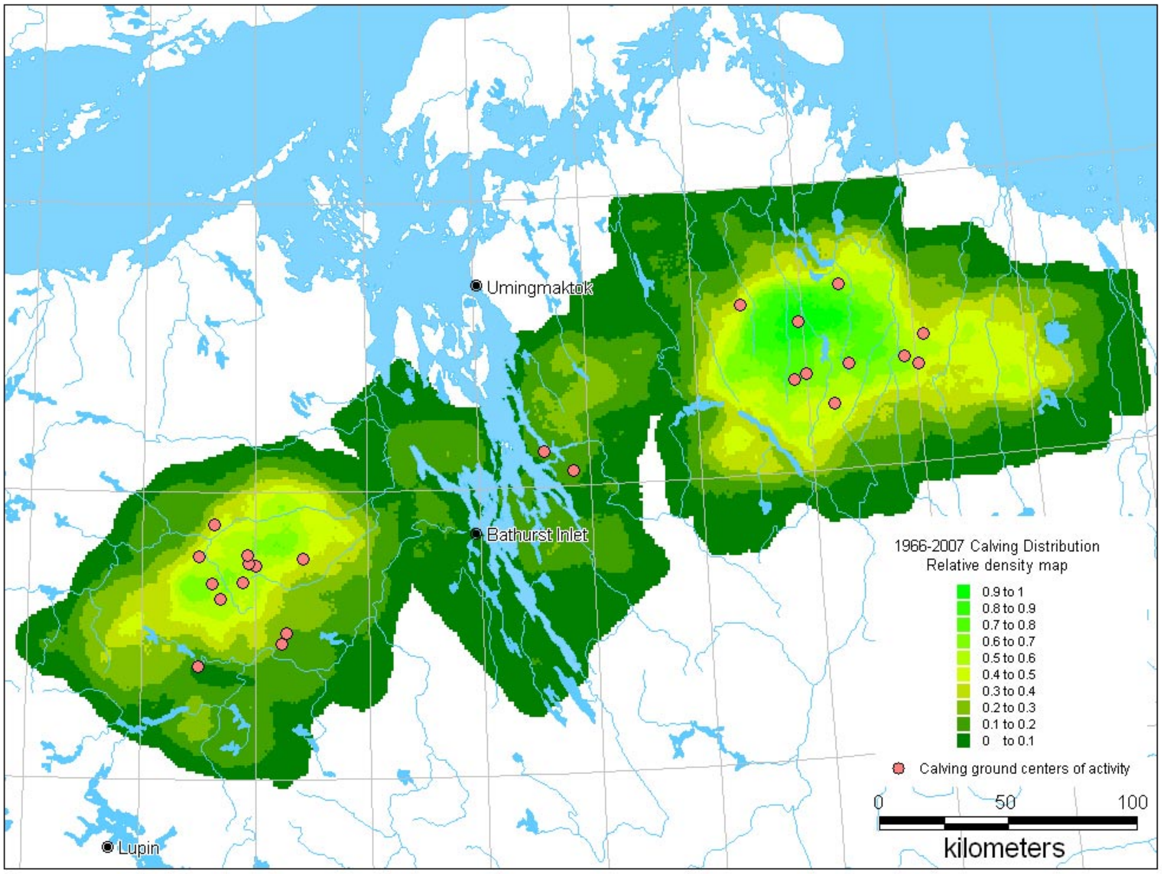
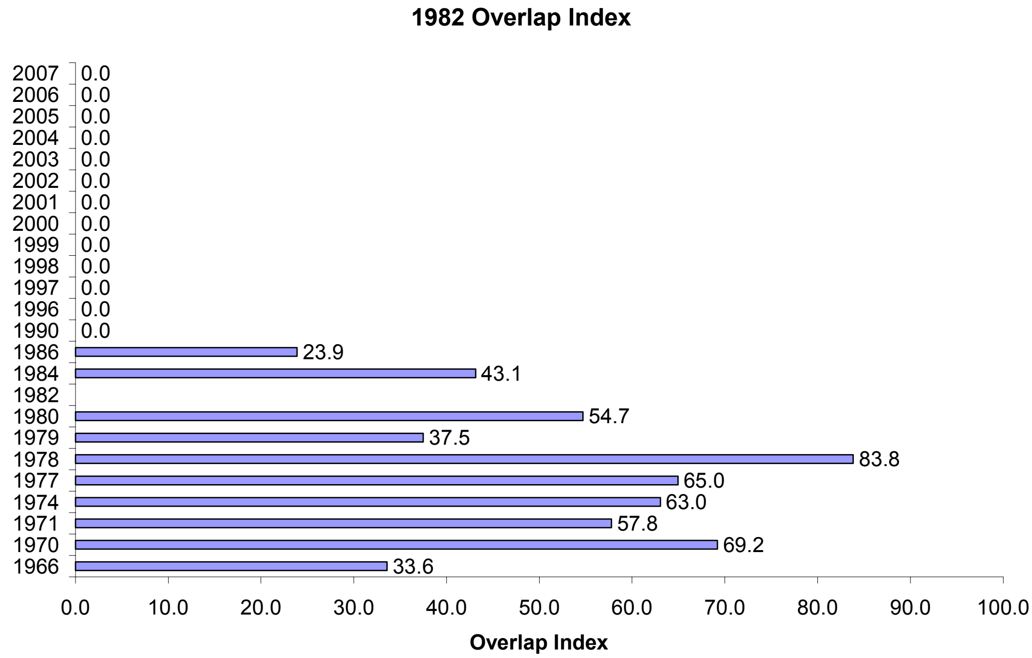


Figure 7. The cumulative density of peak calving grounds based on a moving window analysis of relative densities for the Bathurst herd aerial surveys (1966-1990) and satellite telemetry (1996-2007).

Table 6. Matrix of overlap indices of annual peak calving ground overlap, Bathurst herd, NU 1966-2007

	1966	1970	1971	1974	1977	1978	1979	1980	1982	1984	1986	1990	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1966	100																							
1970	45.1	100																						
1971	38.6	78.0	100																					
1974	23.1	57.5	60.4	100																				
1977	24.4	52.0	51.1	64.3	100																			
1978	35.7	60.6	50.0	58.0	68.5	100																		
1979	32.8	24.1	16.2	8.1	16.3	39.9	100																	
1980	32.9	34.7	30.1	35.8	54.9	67.2	52.3	100																
1982	33.6	69.2	57.8	63.0	65.0	83.8	37.5	54.7	100															
1984	57.2	55.9	53.9	27.5	32.0	42.9	54.2	49.5	43.1	100														
1986	38.4	32.4	25.0	14.4	16.1	23.4	19.0	27.0	23.9	37.8	100													
1990	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.0	100												
1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100											
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	100										
1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.1	38.0	100									
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	13.7	44.9	41.1	100								
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7	36.6	37.7	38.1	100							
2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8	42.5	25.2	62.0	11.3	100						
2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	37.0	11.3	24.4	8.7	49.2	100					
2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	19.2	46.1	48.0	74.7	36.6	57.7	28.3	100				
2004	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.3	33.4	21.2	29.2	12.6	27.0	2.1	33.6	100			
2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.4	36.1	30.6	18.6	41.5	12.5	5.3	42.9	33.7	100		
2006	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	11.4	12.7	3.2	17.8	0.0	5.8	12.7	0.0	38.5	100	
2007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.7	65.3	26.2	38.6	14.4	39.8	44.7	39.8	19.5	15.7	3.9	100



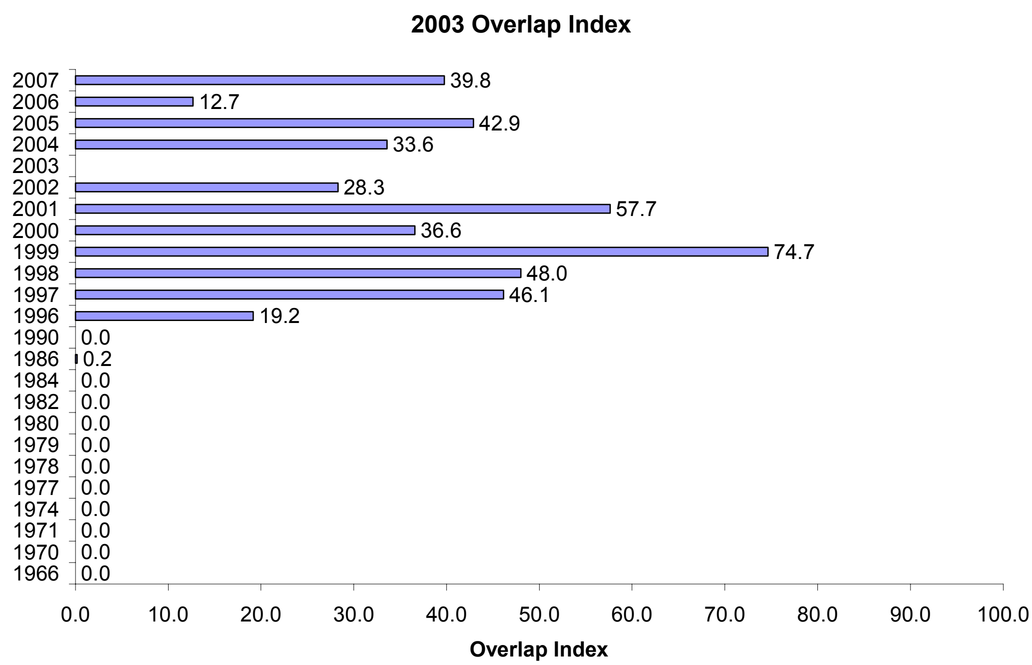


Figure 8. Examples of overlap among peak calving grounds for 1982 and 2003.

Relative size of peak calving grounds

The box plots did not suggest a trend over time in the relative size of the calving grounds (Figure 9). The 1986 peak calving ground stands out as a relatively large area (based on aerial survey) and 1996 as a relatively small area (based on telemetry).

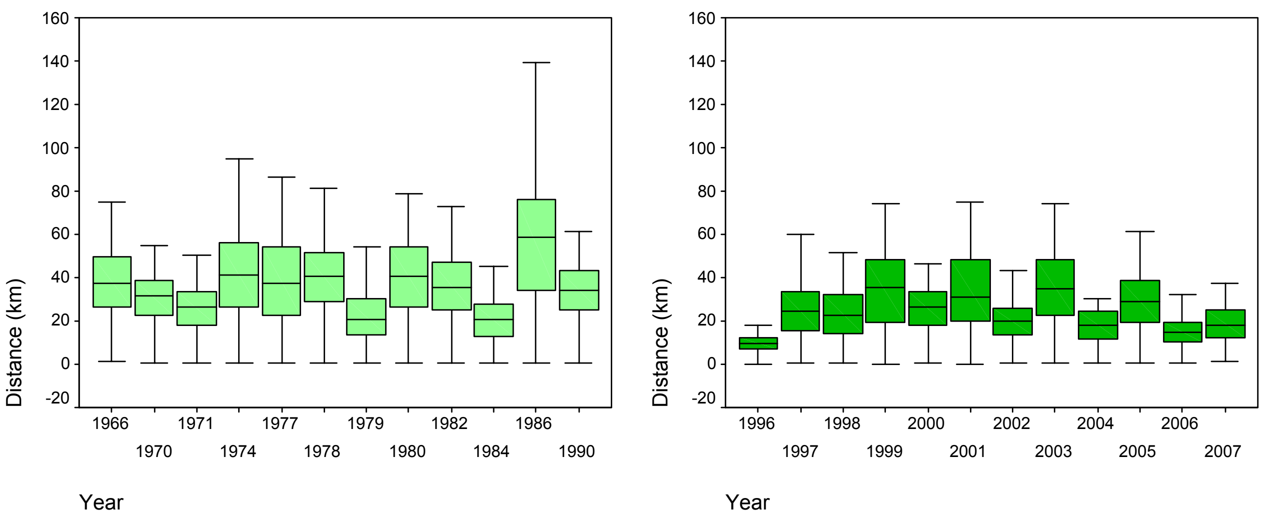


Figure 9. Box plots showing distribution of distances calculated from calving grounds centroids to their constituent random locations (virtual caribou). Boxes depict spread of 50% of values, black bar shows location of median value, and top and bottom whiskers show spread of about 99% of values. Light green – peak calving ground based on aerial surveys and dark green based on telemetry.

Peak calving ground centroids: The Variance to Mean Ratio test confirmed a clustered nature of calving distribution for the 1966-2007 peak calving grounds (Figure 10). The two clusters differed in their nature; a non-significant result for the northeast quadrant (Table 7) suggested a random distribution of calving grounds centroids for the 1966 to 1984 time period. The non-significant result in the northeast quadrant (east of Bathurst Inlet) may be partly a consequence of the low number of centroids tested, as compared to the size of the 1966-2007 calving area[4]. Nevertheless, based on the calculated statistics (Table 7) the southwest quadrant of the study area showed a greater degree of clustering of the calving grounds centroids. This was further confirmed by a lower mean value of the distances calculated from the centroids of the southwest quadrant to their geographic centre ($\bar{x}$ = 17.8 km, area of 998 km^2) as compared to the mean calculated for the northeast quadrant ($\bar{x}$ = 24.1 km, area of 1,827 km^2). This finding was noteworthy when examined in conjunction with the average centroid shift rates for both quadrants: 13.8 km for the northeast quadrant (1966 to 1984 period) and 21.1 km for the southwest quadrant (1996 to 2007 period). At first glance, the higher shift rate in the more "clustered" southwest quadrant and a lower shift rate in the less clustered northeast quadrant

[4] Given the total number of centroids tested (N = 24) the ideal size of the cell for this statistic would be 50 km by 50 km, producing only four cells within the study area, thus rendering this analysis meaningless. The 10X10 and 20X20 km grid was a trade-off between the ideal cell size and the known average separation among the calving grounds' centroids.

seem counterintuitive. However, it points to a greater separation of consecutive yearly centres of activity within considerably tighter (than the northeast quadrant) geographic bounds.

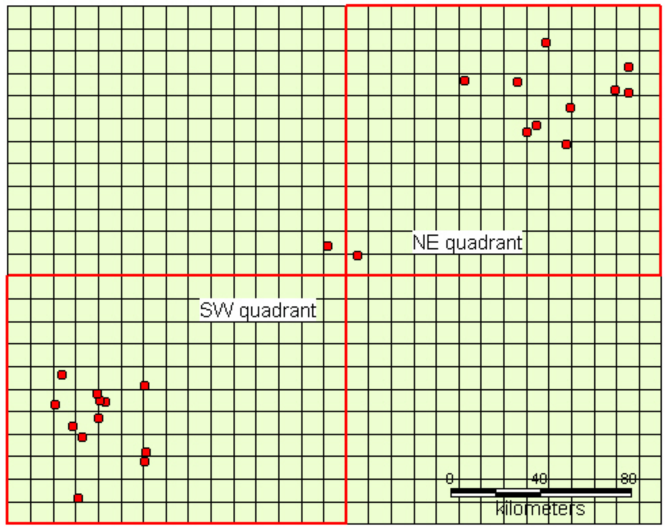


Figure 10. Cell size (10 km – comparable to the grid size used by ENR) and study area extents used to calculate Variance to Mean Ratio. Red points show location of calving grounds centroids.

Table 7. Point pattern statistics for calving grounds centroids. Test statistics compares observed value to 1 – equivalent to fully random distribution. Similar significance results were obtained using 20 km by 20 km cell size (not shown).

	SW quadrant	NE quadrant	Entire study area
N (number cells)	165	168	644
Mean (density)	0.0727	0.0655	0.0373
Variance (of cell totals)	0.1166	0.0735	0.0515
Variance/Mean Ratio	1.6037	1.1230	1.3815
t	5.4664	1.1242	6.8413
df	164	167	643
Significance level	<0.001	>0.05	<0.001

Direction and distance of shift between peak calving grounds: We also mapped the centroids for each of the circles representing the annual peak calving to illustrate the geographical location of the centroids (Figure 11). The map shows the two periods (1966-1984; 1996-2007) when the centroids were relatively clumped (Figure 10) linked by a period of directional shift between 1980 and 1996. The direction of the shift between the centroids (Table 8) was consistently west between 1980 and 2000. Between the two periods (1966-1980; 2000-2007) when the calving grounds were clustered, the shifts between the centroids alternated between northwest and southwest. The effect of the consistency in the directional shift is evident (Figure 11) and covers the period when calving grounds shifted from east to west of Bathurst Inlet.

The shifts between the consecutive 24 peak calving grounds averaged 17 km (Table 8) over 42 years (1966-2007) but were highly variable (3-120 km). The variable time interval (up to 6 years prior to 1996) contributes to the variability. The distances between centroids were highest between 1982 and 1996, but this was based on only four aerial surveys over 15 years (Figure 12). The average yearly shift rate was 21 km (± 4.0 SE) for the 1996-2007 cluster of 11 centroids, which is when we had continuous annual data from the satellite-collared cows. The average yearly shift rate was lower (about 13 km) for the 1966-1980 cluster of 7 centroids based on aerial surveys. Considering only calving grounds delineated on an annual basis, the shift averaged 21 km (± 3.7 SE). The distance between consecutive centroids of the peak calving grounds plotted against the combine size of the consecutive peak calving grounds was insignificant ($r = 0.10$, $P = 0.72$). The distance between the centre for 1966-1984 grouping and 1996-2007 grouping was 250 km.

Index to peak calving ground shape: We also examined the shape (compactness) of the peak calving grounds (Table 8). The compactness ratio averaged 0.77 (±0.19 SE; CV = 12.1%) over the 24 years, with no trend in time ($r = 0.13$, $P = 0.54$).

Table 8. Size, shape ratio (measured by compactness ratio), distance between centroids, and direction of shift for successive peak calving grounds. determined by satellite collars and peak calving grounds for the Bathurst herd, NU (green shading denotes consecutive years).

Shift dates	Peak calving ground area (km^2)	Area annually consecutive calving grounds	Shape ratio	Distance between centroids (km)[1]	Azimuth NE 0-90	Azimuth SE 91-180°	Azimuth SW 181-270°	Azimuth NW 270-359°
1966	8778		0.82					
1966-1970	6157		0.91	37 (9)		136		
1970-1971	4275		0.77	5			245	
1971-1974	6909		0.66	18 (6)		121		
1974-1977	7180		0.71	36 (12)	64			
1977-1978	11205	18385	0.83	6				296
1978-1979	3113	14319	0.72	37				318
1979-1980	6774	9887	0.67	38		120		
1980-1982	9429		0.78	31 (16)			249	
1982-1984	3519		0.84	26 (13)				309
1984-1986	15096		0.63	104 (52)			236	
1986-1990	5905		0.65	14 (4)				301
1990-1996	611		0.88	120 (20)			248	
1996-1997	3472	4083	0.73	3				291
1997-1998	1993	5466	0.70	18			218	
1998-1999	3950	5943	0.66	7				330
1999-2000	3876	7826	0.76	32			189	
2000-2001	4731	8607	0.72	43	1			
2001-2002	3088	7819	0.93	13	25			
2002-2003	5758	8846	0.79	25		153		
2003-2004	1237	6995	0.98	25	69			
2004-2005	4932	6169	0.76	26			193	
2005-2006	1308	6240	0.83	4			202	
2006-2007	3785	5094	0.78	37				338

[1] Distances in brackets denote annual average for periods >1 year.

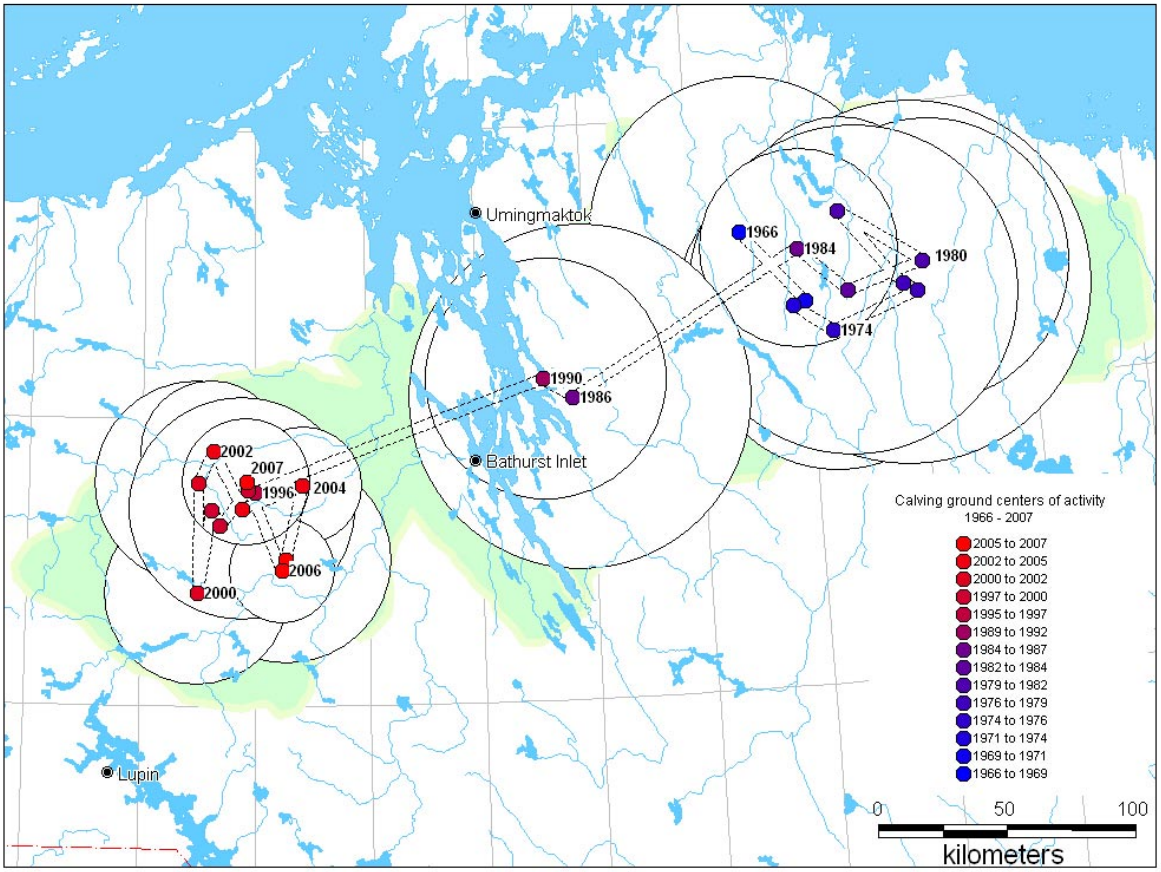


Figure 11. Peak calving ground centroids for the Bathurst herd, 1966 to 2007. The centroids are embedded in circles that have the radii equal to the mean distance from the centroids to their respective distributions of random points (virtual caribou). Larger circles denote larger peak calving grounds.

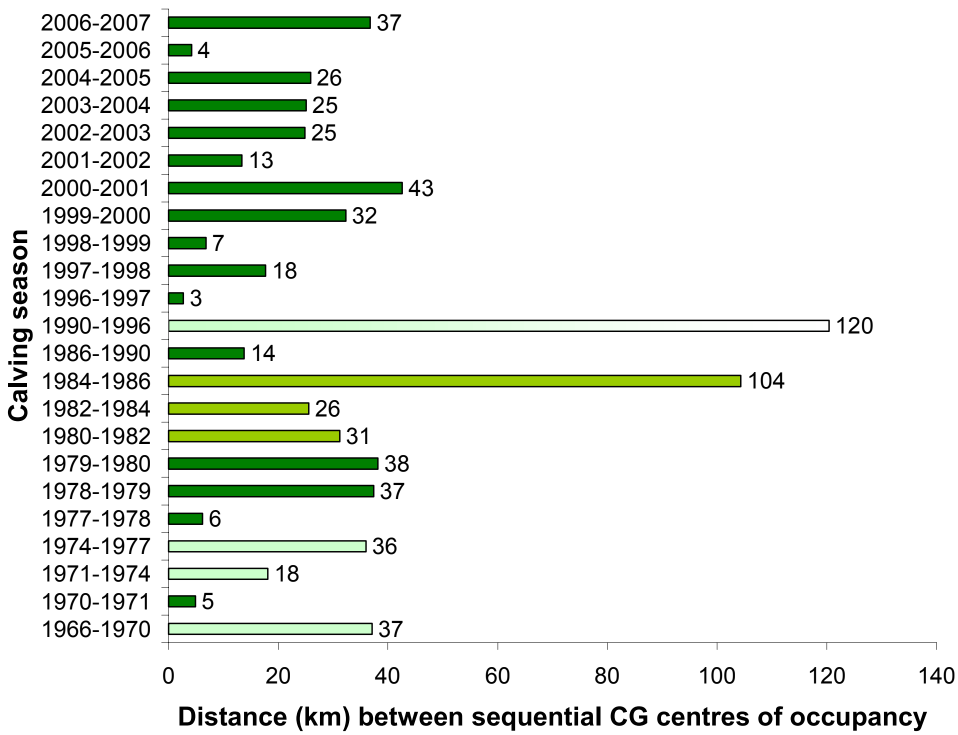


Figure 12. Distance between sequential peak calving ground (CG) centres of occupancy. Dark green bars denote sequential annual CG surveys, medium green denotes 2 years between surveys, and light green bars denote 2-6 years between surveys.

Annual calving grounds

We used the satellite telemetry data from 1996 to 2007 to map the use of the calving grounds from the peak of calving to 3 weeks after the peak, which is the time before the calf can independently forage. This extent of calving covered 37,700 km^2, over three times larger than the cumulative peak calving grounds for the same period (11,800 km^2) (Figure 13).

Box plots show the variation in entry and exit into the peak calving ground (Figure 14) and extent of calving (Figure 15). The dates of entry were latest in 2005, which is when pregnancy rates were lower than average (Gunn In Prep.). Correspondingly, the dates of exit were later.

For ease of comparison we plotted the median dates of entry and exit into and out of the peak calving grounds and the annual calving grounds on the same graph, and plotted simple linear regression lines for each series (Figure 16). The correlation coefficients are relatively low (r^2 0.14-0.38), but all lines trend up (parameter values 0.414-0.878), suggesting entry and exit from the peak and annual calving grounds on average occurred 5 to 10 days later by the end of the 12 years. The average median residency in the peak and annual calving grounds was 20 and 39 days, respectively, with no obvious trend over time (Figure 17). The mean residency (peak calving grounds: 20 ± 1.1 days, CV = 18.6%; annual calving grounds: 40 ± 2.0 days, CV = 17.1%) was similar to median values.

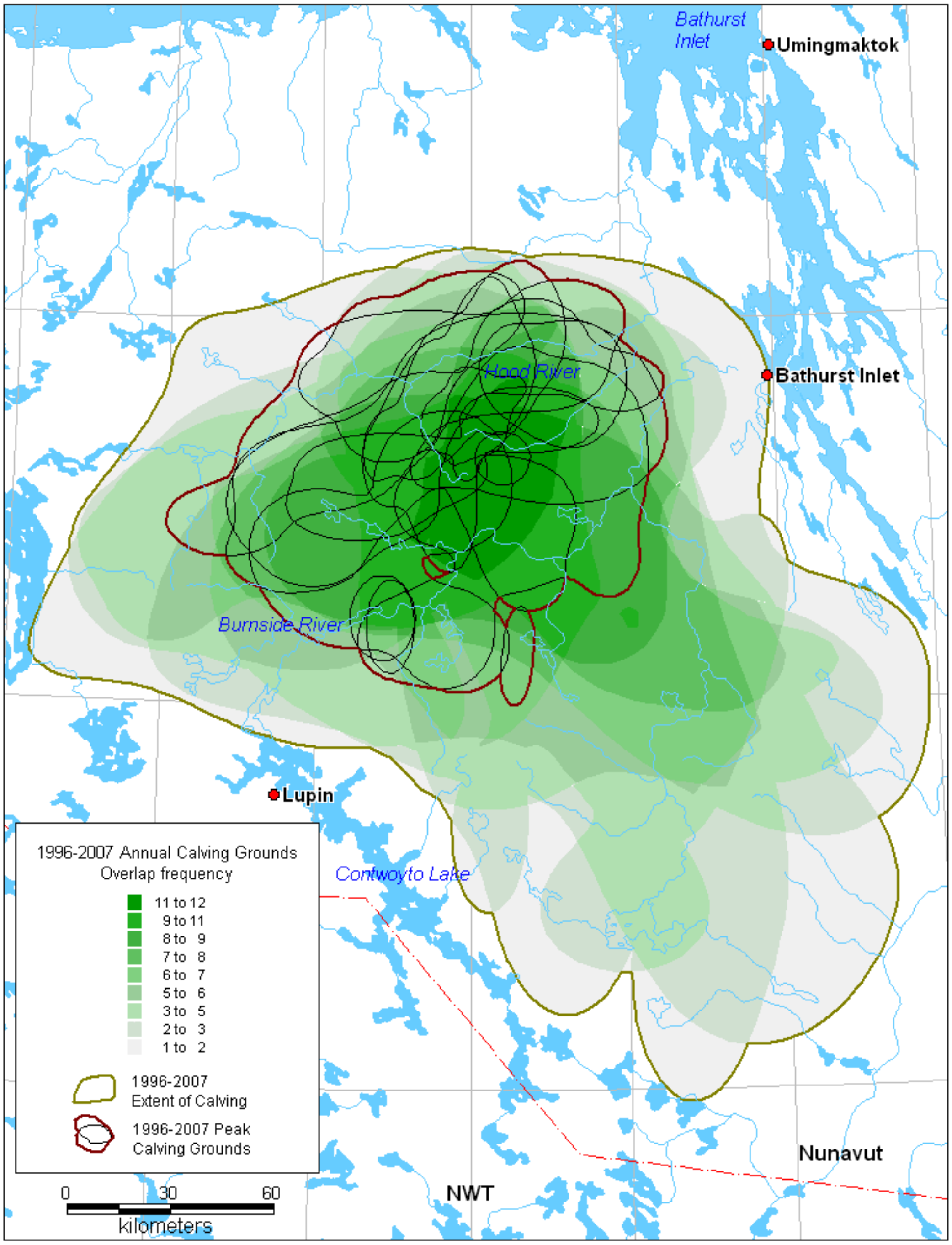


Figure 13. Cumulative overlap of annual calving grounds for the Bathurst herd, 1966 to 2007, as determined from satellite collars. The darker shading depicts areas with greater frequency of use during peak of calving.

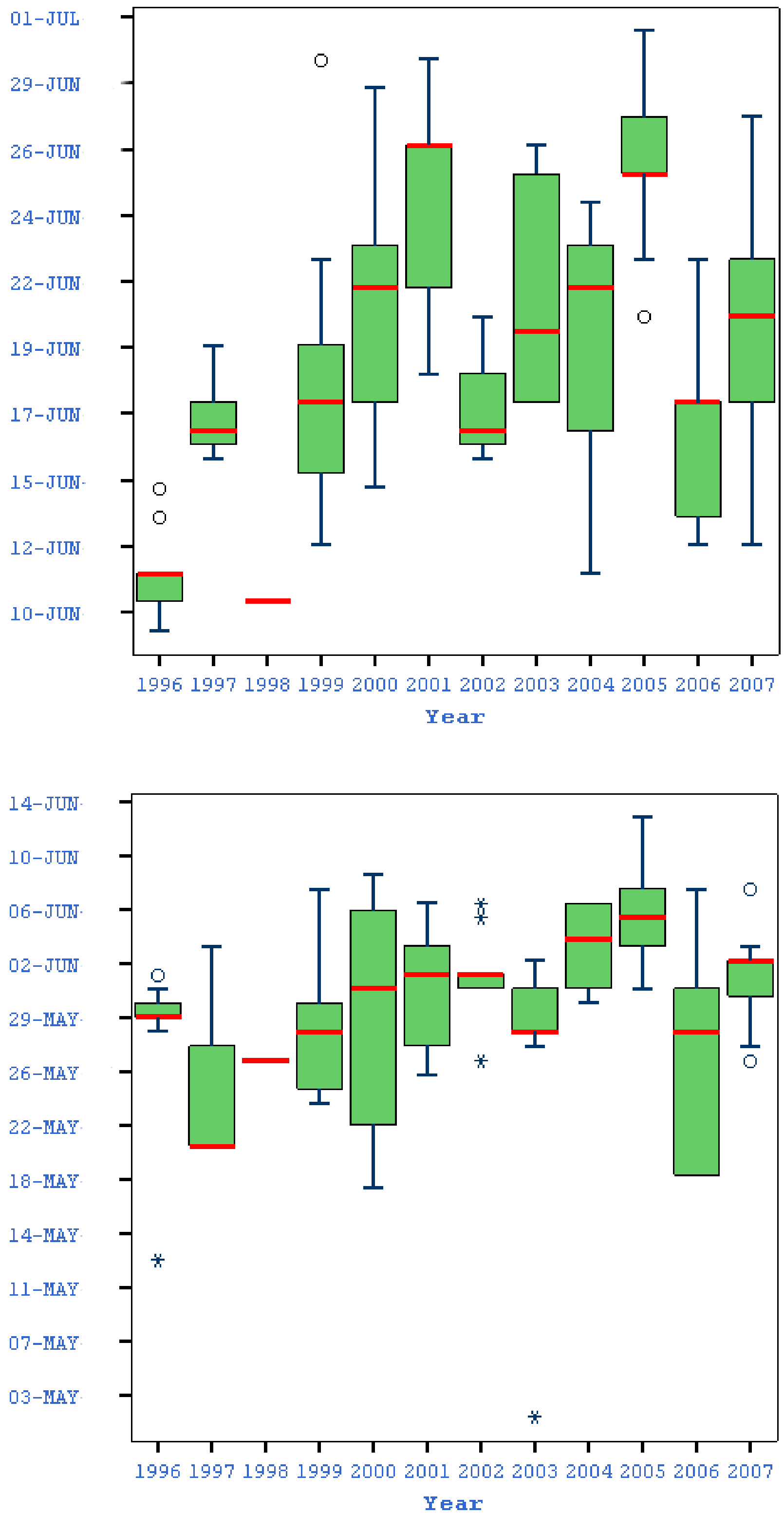


Figure 14. Box plots showing dates of entry (lower figure) and exit (upper figure) into and out of the peak calving ground each year as determined using satellite collar data, Bathurst herd, 1996 to 2007.

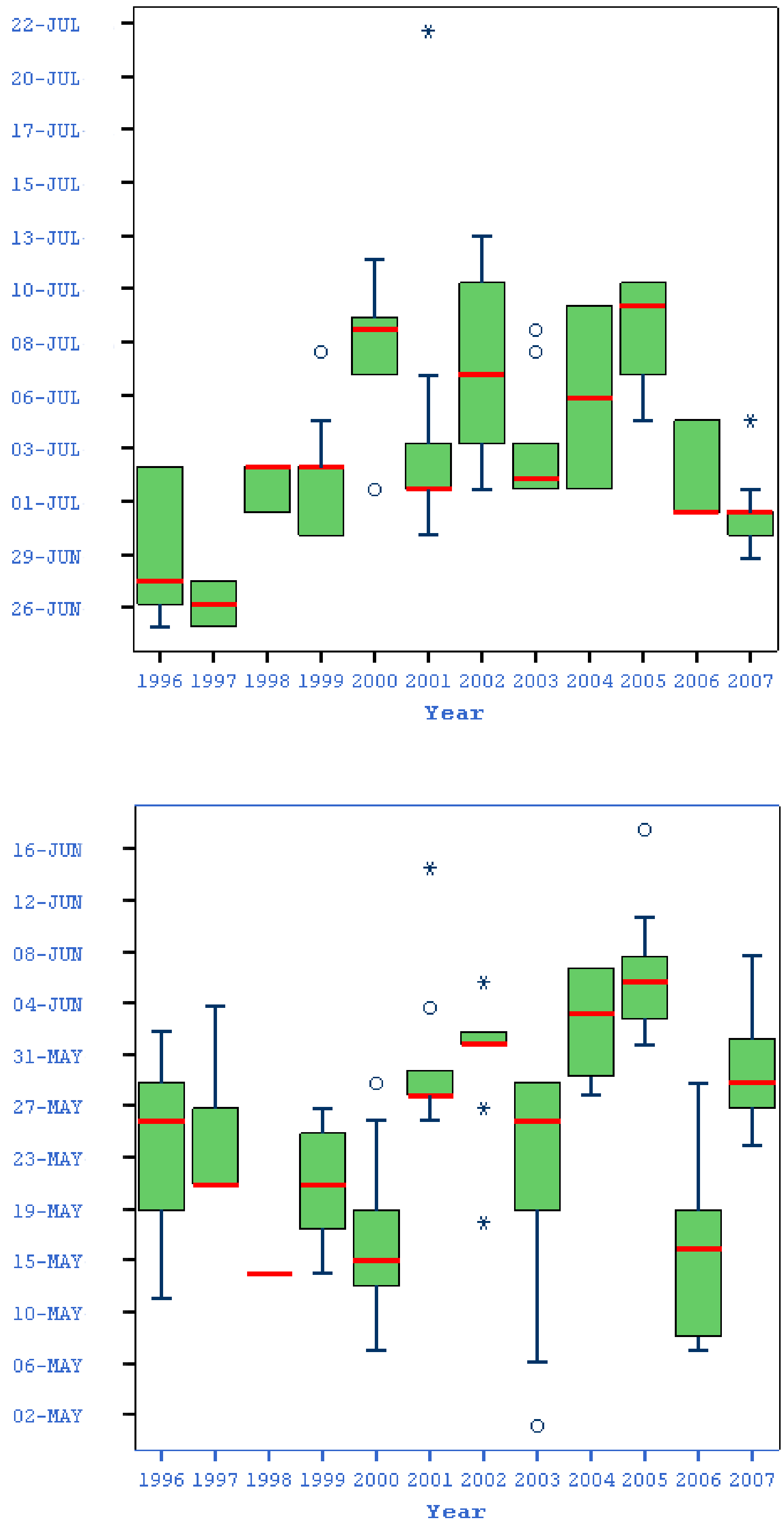


Figure 15. Box plots showing dates of entry (lower figure) and exit (upper figure) into and out of the annual calving ground, as determined using satellite collar data, Bathurst herd, 1996 to 2007.

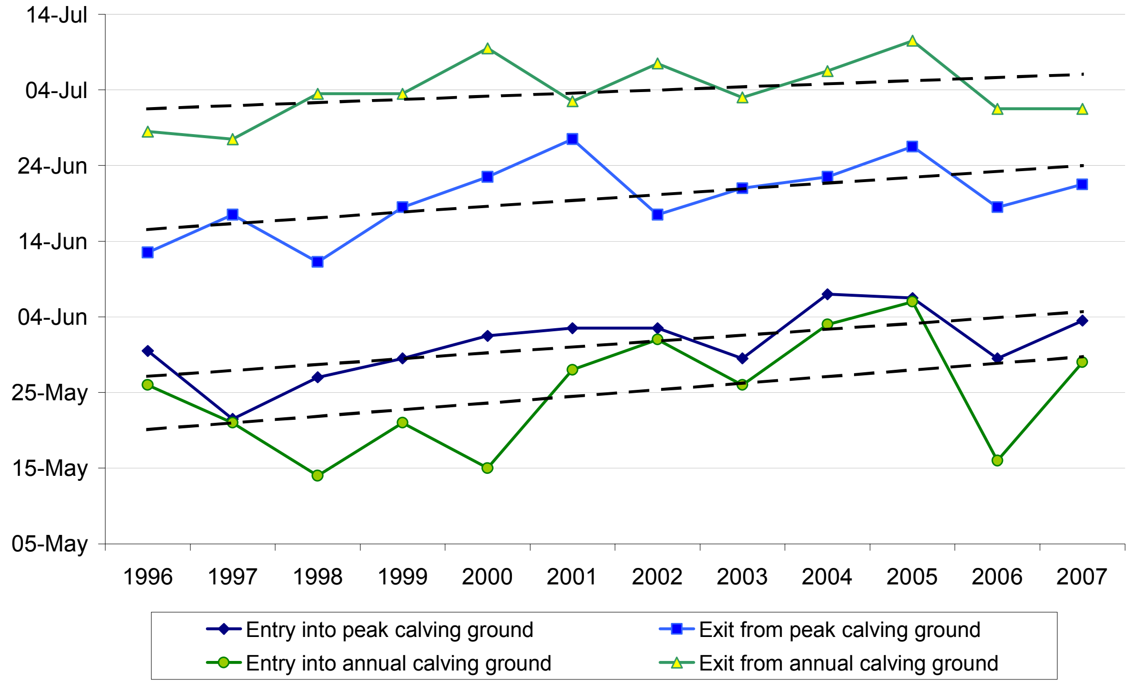


Figure 16. Median dates of entry and exit into and out of the peak calving ground and the annual calving ground, Bathurst caribou herd, 1996 to 2007, as determined from satellite collar data. Linear regressions were produced in Excel.

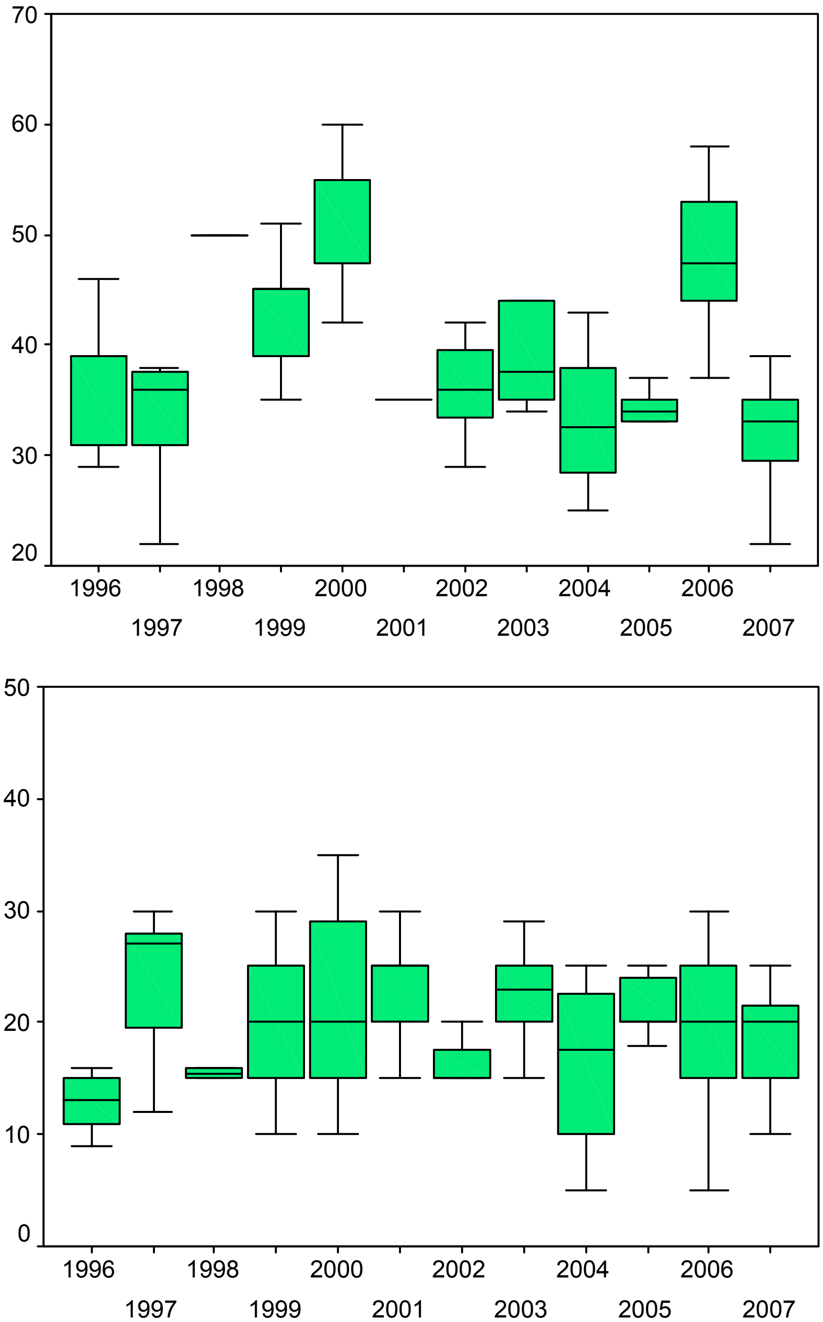
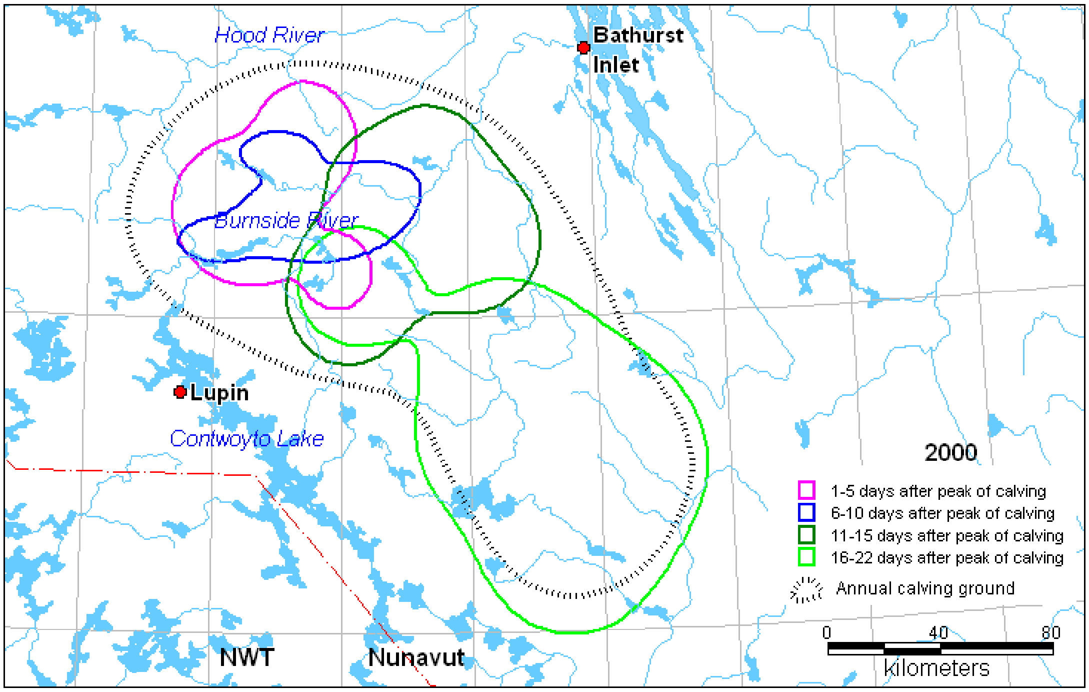


Figure 17. Box plots showing days of residency (y-axis) within the peak calving ground (lower figure) and annual calving grounds (upper figure), as determined using satellite collar data, Bathurst caribou herd, 1996 to 2007.

The annual calving ground was a relatively large area as it is the area occupied for a 3-week period. However at any one time, a relatively small proportion generally was occupied (overall mean of annual calving grounds used during any 5-day session among years 37% (±2.7; CV = 50%) (e.g., Figure 18). On average the proportion of the annual calving ground occupied increased from the first two 5-day periods after peak calving to the end of the annual calving ground period (days 16-22) (Figure 19). Between 1996 and 2007, the cows used a mean of 30% (±5.6; CV = 61%), 30% (±4.1; CV = 47%), 41% (±6.4; CV = 54%), and 45% (±4.2; CV = 33%) of the annual calving ground during days 1-5, 6-10, 11-15, and 16-22 post peak of calving, respectively. Although not significantly different among periods (log-transformed data: $F = 2.47$, 3, 43 df, $P = 0.074$), the proportion of the annual calving ground used during days 16-22 was larger than the proportions used during days 1-5 and 6-10 (Duncan's multiple range test, $P < 0.5$).

We also examined how the caribou's occupancy of the annual calving ground varied over time at a finer scale than the 5-day periods, again using the telemetry data for 1996 to 2007. We randomly placed 20 points within the extent of calving (Figure 20); those random points were used for an average of 3.4 days (±0.45; range 0.6-7.7 days) each year. On average, each random location was used 4.7 of 12 years (±0.49; range 1-9; 40% of the years of monitoring). This means that there is a greater than 50% probability that a given point within the extent of calving will not experience caribou during the period from peak to 3 weeks post peak of calving.



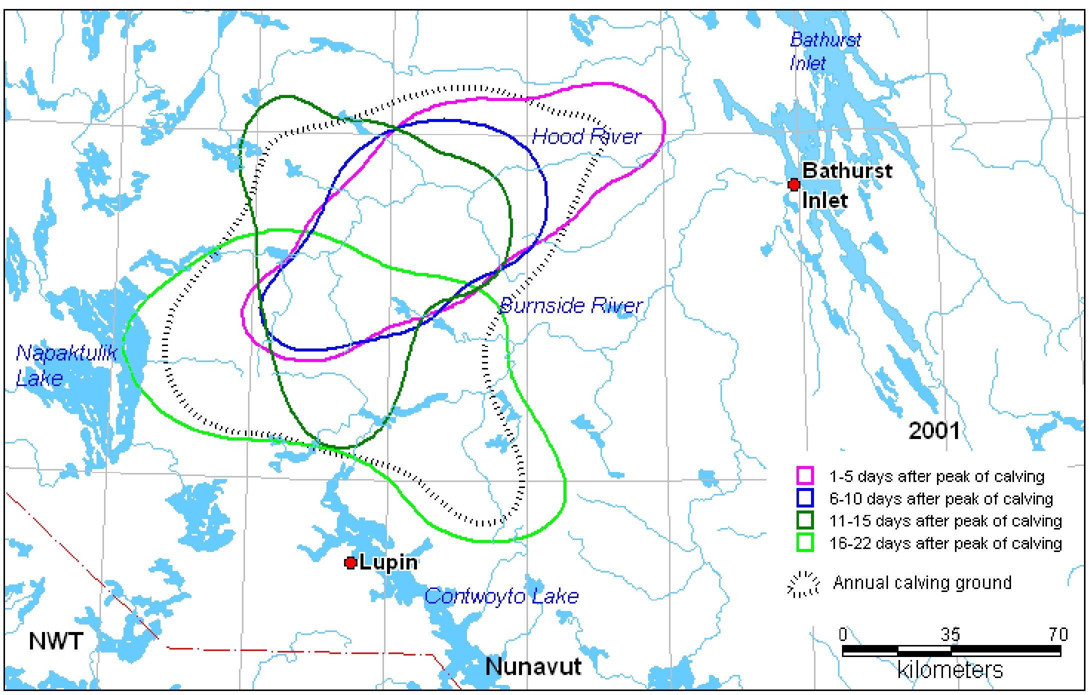


Figure 18. Area use by Bathurst caribou within in the annual calving grounds, as depicted by 5 to 7-day periods after the peak of calving. Annual maps for 1996 to 2007 are provided in Appendix B.

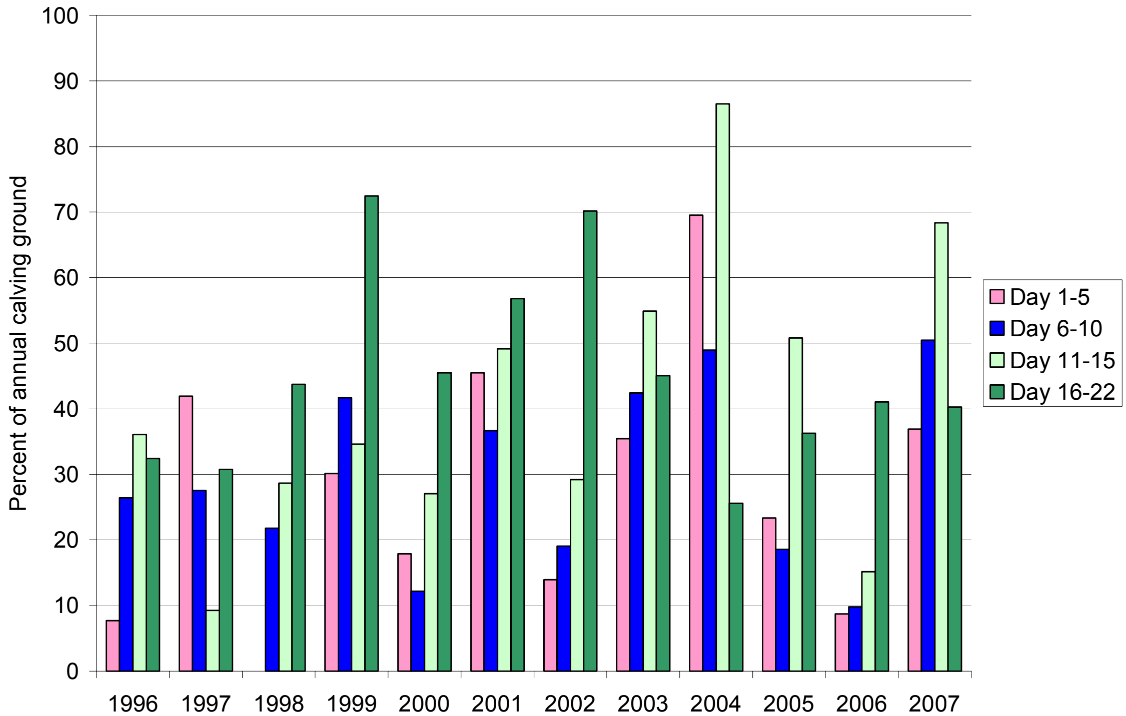


Figure 19. The percentage of each consecutive 5 to 7-day area occupied of the annual calving grounds for the Bathurst herd, based on satellite telemetry 1996-2007.

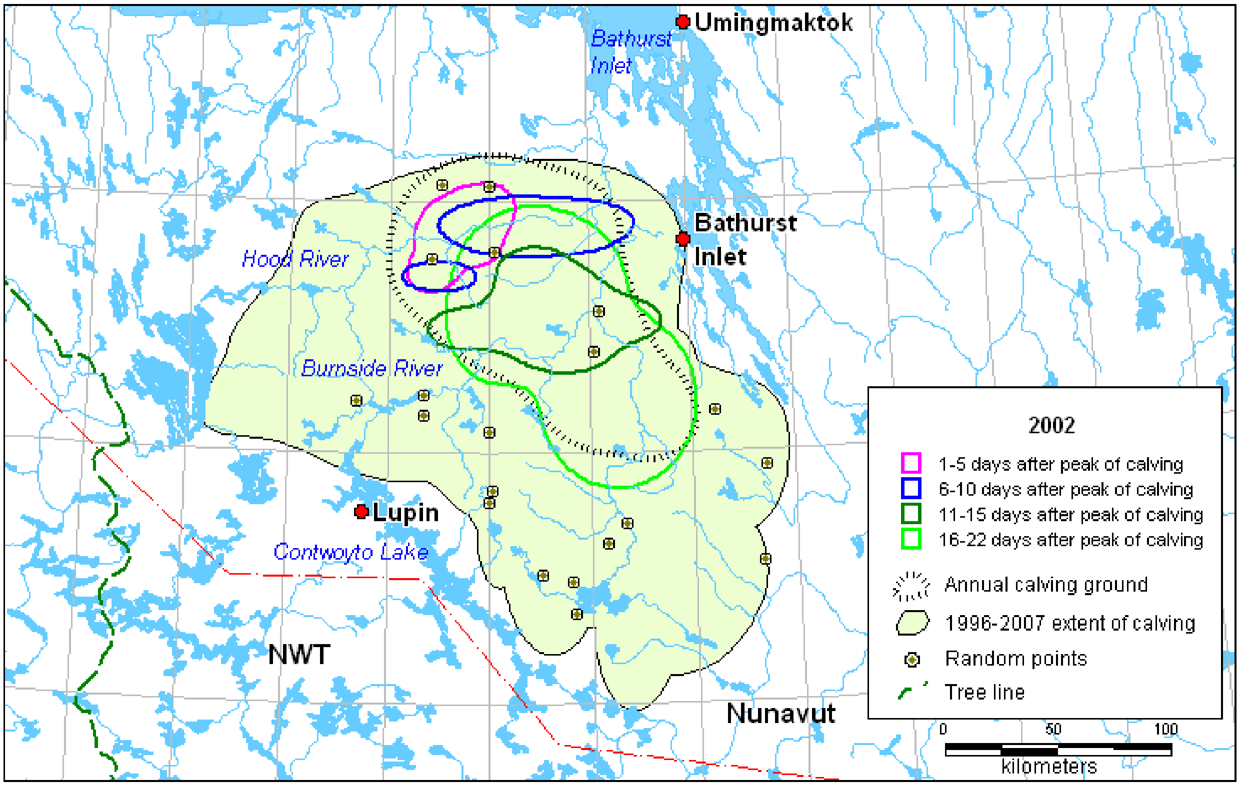


Figure 20. Demonstration of random points within the extent of calving and their relationship with caribou use of areas after peak of calving in 2002.

DISCUSSION

A defining characteristic of barren-ground caribou is the annual return of the cows to a traditional calving ground (Kelsall 1968, Skoog 1968, Thomas 1969, Gunn and Miller 1986). The concentration of cows and their newborn calves at a specific location is vulnerable to disturbance from human activities (e.g., Nellemann and Cameron 1998, Wolfe et al. 2000). From the perspective of managing human activities on calving grounds, the need is to understand firstly, how predictable, and conversely how variable, is the caribou cow's return to a particular geographic location to calve. Geographic fidelity has been questioned: for example, Weihs and Usher (2001) reported a perception that calving grounds are relatively mobile. Secondly, managing human activities requires understanding the attributes of how caribou use their calving grounds, such as where the cows are at any one time and for how long.

We used the 12 years of satellite telemetry and 15 aerial surveys for the Bathurst herd to delineate the annual calving grounds and their size, shape and location at or about the peak of calving. Given the two sets of data have different attributes we devised analyses that could use both data sets. We compared the centres, size and overlap of peak calving grounds based on aerial surveys and telemetry. Our analyses of the 24 calving grounds over 42 years (1966-2007) grounds revealed that the size and shape of the calving ground at or about the peak of the calving was annually variable with no consistent trends. To describe the spatial scale and temporal variation of calving ground locations, we looked at the degree of overlap between successive calving grounds as well as where they were centred. We found that the calving location is annually predictable based on overlap between successive calving distribution at the peak of calving (Figure 6) which averaged 43% although variable. There is an apparent exception between 1990 and 1996, when no overlap occurred. However, the 1990 and 1996 calving distributions overlapped the 1995 calving distribution mapped during an aerial reconnaissance survey (Gunn 1996, Sutherland and Gunn 1996).

As well as measuring overlap between successive calving grounds, we also calculated centroids, which were the geographic centre of each calving ground. During the 42 years, the overall shift between centroids averaged 17 km/year and the total distance shifted over the 42 years was 250 km. The degree of predictability decreased over decades as the pattern in the overlap of calving grounds varied. The annual calving grounds overlapped as two clusters during 1966-1984 and 1996-2007, linked by 1986 and 1990 calving distributions when there was directional shift to the west. The clusters occurred as the shift between the centroids of the calving distribution showed no consistency in direction. From 1996 to 2007, the grouping of annual calving grounds west of Bathurst Inlet was more clustered, although with a slightly higher shift rate between centroids. Possibly this reflects a more repetitive occupation of the same area which may be associated with vegetation characteristics or changes in density as the herd was declining during that period. There are differences in the vegetation between clusters, as the vegetation east of Bathurst Inlet has more wetland grasses and sedges and shrubs than in the west, which has more lichen heath (Griffith et al. 2001).

The locations of the calving grounds were predictable for at least 18 and 12 years (before and after the jump across Bathurst Inlet) and less predictable between 1986 and 1996. During the 11-year period (1996-96), when the shift in the overlap between consecutive calving grounds was consistently directional to the west and the distance between the centroids increased to an annual average 22 km. Although the shift to west of Bathurst Inlet was not documented until

1986 based on the aerial surveys, it likely started a year earlier as Page Burt (pers. comm. to Doug Heard *in* Gunn et al. 1997) had observed calving on both sides of Bathurst Inlet starting in 1985. The shift to west of Bathurst Inlet was a return to calving in areas used during the 1950s (Kelsall 1968, Ruttan in Sutherland and Gunn 1996, Thorpe et al. 2001).

The greater rate of movement and directional shifting of the Bathurst calving grounds from 1986-1996 coincided with three factors that could have influenced calving distribution. Firstly, snow melt in 1986 was exceptionally late and Heard (1991 *in* Gunn et al. 1997) suggested that the cows calved along the east coast of Bathurst Inlet as there was snow-free ground compared to complete snow cover further east. Given a choice, cows will select snow free patches to calve as an anti-predator strategy (Bergerud et al. 1984, 2008).

Secondly, a possible explanation for the 1985-1996 higher rate and directional shift may be a consequence of the increase in herd size in the early 1980s. This is based on a parallel with the George River herd as argued by Bergerud et al. (2008). Bergerud et al. (2008) argued that George River and Leaf herds shifted their calving ground progressively toward the treeline when the herds were increasing in caribou numbers (1978-92). Bergerud et al. (2008) attributed the shift to over-grazing as the cows expanded into areas not recently used for calving. Although the shift toward the treeline bought the cows closer to wolves denning along the treeline, Bergerud et al. (2008) suggested that the increase in calf mortality was the consequence of the decline in cow condition on over-grazed calving and summer ranges rather than predation.

Thirdly, a trend in environmental variation could have influenced the shift in calving for the Bathurst herd. Coincident with the timing of the directional shift of the calving ground to west of Bathurst Inlet was a warming trend. We detected the trend based on satellite imagery (NDVI621), which indicates an earlier start to plant green-up (Griffith et al. 2001). An earlier start to green-up is favourable for cows as it is a likely increase in forage for cows at the peak of lactation demand (Griffith et al. 2002). On the calving grounds east of Bathurst Inlet, there was no warming trend and Griffith et al. (2001) commented that calving on the east side would probably need to be about a week later to match green-up conditions on the west side of the Inlet. The basis of choice at least for 1997-99 was that the cows were calving where the green plant biomass (based on satellite imagery, Normal Difference Vegetation Index [NDVI]) would be high at peak lactation (Griffith et al. 2001).

The first explanation for the directional shift in causing the directional shift of calving to the west side of Bathurst Inlet, the late snow melt in 1986, is least likely of the three proposed explanations. In other instances where caribou cows have been delayed by snow conditions, they have continued moving after calving in the direction of previously used calving grounds. And in the subsequent years, the cows continue to return to the calving grounds used previously rather than calving where they had been delayed the previous year. One example is the Beverly herd in June 1979 (Gunn and Sutherland 1997). A second example is the Western Arctic Herd; in 2000 when break up was exceptionally late cows calved en route to the calving ground, but the following year they calved on the calving grounds used previous to 2000 (Kelleyhouse 2001, Dau 2003).

The directional shift in the Bathurst calving ground (1985-96) was likely a consequence of environmental trends and the cows trading off gaining maximum nutrition relative to predation risks, which in turn reflects the trade-off between calving in familiar and unfamiliar areas.

Complexity is added because calving is gregarious and cows are likely responding to each other and the suites of conditions rather than geographical locations.

On a smaller geographic scale within the cumulative calving grounds, Wolfe (2000) described relatively detailed accounts of changes in patterns of use within a calving ground with an oilfield and roads. Within the Central Arctic herd calving ground, Wolfe (2000) reported a directional shift of calving distribution for calving (averaged for 3-year periods for 1980-95) that was away from oilfield activity and a directional shift in calving distribution away from the activity in the vicinity of oilfield activity.

Analyses of annual calving distribution of herds other than the Bathurst herd reveal that consecutive calving distributions overlap and the extent of overlap varies (non-directional shifts). Overlap in the annual calving distribution for the Western Arctic, Teshekpuk, Central Arctic and Porcupine herds varied annually, and a directional shift was not evident for the duration of monitoring, which varied from 10 to 20 years (Wolfe 2000, Kelleyhouse 2001, Griffith et al. 2002). A similar pattern of non-directional shifts was apparent for the Qamanirjuaq herds based on an analysis of centroids estimated from 1993-2005 satellite telemetry (Gunn et al. 2007). The time period during which the Qamanirjuaq calving distribution showed non-directional shifts in overlap was extended when the 25 aerial surveys between 1963 and 1990 were included (Beverly Qamanirjuaq Caribou Management Board www.arctic-caribou.com/parttwo/pdf/qcy.pdf). However, neither the aerially mapped Qamanirjuaq calving distributions nor the 1957-1994 Beverly calving distribution have been digitized and analyzed in detail. The calving grounds north of Beverly Lake have been used consistently during 1978-1994 with a high degree of overlap (Gunn and Sutherland 1997). Between 1958 and 1974, areas south and north of Beverly Lake were used with variable overlap and further analyses would be required to determine the extent and consistency of any directional shift (Gunn and Sutherland 1997).

For the George River and Leaf River herds in northern Quebec and Labrador, the shifts are pronounced over decades (Bergerud et al. 2008). Both herds shifted from calving at or near treeline to calving further north. In the case of the Leaf River herd, the directional shift was 400 km north during 1974 to 1991 – a rate comparable with the Bathurst herd although over a longer time period. The Leaf River herd's northward shift brought the calving close to where it was reported in the 1870s. The George River herd shifted about 250 km between two apparent clusters between during 1973 to 1985. Bergerud et al. (2008) interpreted the shift north as a response to reduce the risk of predation as the herds increased in size.

In the context of managing human activities, the analyses of the Bathurst calving distribution and knowledge of the other migratory tundra herds reveals the likelihood of both directional and non-directional shifts. At this stage, we cannot tell if the apparent absence of directional shifts for most herds is simply that the duration of sampling has not long been or whether it is a herd characteristic. Over decades, the directional shifts appear to be a rotation to areas used previously. Consistency in directional shifts for the Bathurst herd occurred over a longer time period (20 years) but that was also a time when there were few observation points (aerial surveys). Between 1990 and 1996, the centroids were separated by 120 km – on an annual basis, that distance was within the average seen between consecutive years. This means that either annual aerial surveys or satellite telemetry will detect shifts in calving distribution. Longer survey intervals (>10 years) increase the risk of not detecting directional shifts.

Managing human activities requires understanding characteristics of the caribou's use of the calving grounds, such as how much area the cows occupy at any one time and for how long. We used the satellite telemetry to describe the date of arrival and exit from the peak of calving ground. The median dates of entry and exit into and out of the peak calving grounds and the annual calving grounds suggest a trend toward entry and exit from the peak calving grounds on average occurred 5-10 days later during the 12 years (1996-2007). This likely relates to the possible trend toward later peak of calving although the nature of the data (1-5 day periods) does not allow resolution at a fine (daily) scale. The late calving in 2005 may have skewed the trend toward later calving. The late calving in 2005 followed a summer when calf survival was exceptionally poor and pregnancy rates were low (63%), which suggests the cows were in poor condition (Gunn In Prep.).

The cows spent an average of 20 days within the peak of calving area with no apparent trend over time except for later entry and exit. The average median residency in annual calving grounds was 39 days, again with no obvious trend over time with the exception of later entry and exit. Using random locations (potential surrogates for land use sites), we depicted variation in the pattern of occupancy for any geographic location on the calving grounds, and showed at most an average of 37% of the annual calving ground was used during any one 5-day period.

The return to gregariously calve is one of the defining characteristics of tundra migratory caribou. The fidelity to a traditional calving ground must offer considerable evolutionary advantages to caribou. Through their success in raising a calf on the calving grounds, caribou cows are 'tracking' the suite of environmental conditions, such as the rate of plant green up and risk of predation. The ecological advantages of returning to a suite of ecological conditions to successfully raise a calf suggests that fidelity has an ecological and behavioural basis as much as a geographic one (meaning the cow's migrate to a known geographic destination). Fidelity has been variously defined and is sensitive to the scale of measurement For example, Schaeffer et al. (2000) defined fidelity "as the propensity for consecutive-year locations of an individual to be closer together than random pairs of locations from the radio-tracked population, bounded by its distribution over a specified time". Using this definition and radio-collared cows, Schaeffer et al. (2000) documented fidelity to calving (and post-calving to fall ranges) at the scale of annual ranges. Our results also suggest that time and spatial scales are linked. On an annual basis using the satellite collar data, geographical fidelity to the calving grounds for the Bathurst herd averaged 21 km between centroids.

The context for our analysis was management of human activities on calving grounds and therefore we examined how data availability affects describing the characteristics of the calving grounds. We used two sets of data to assess the predictability and characteristics of the Bathurst calving grounds. Firstly, we had the maps from aerial surveys at or close to the peak of calving during some years from 1966 to 2006 (Sutherland Gunn 1996, Gunn et al. 1997, 2005, Nishi et al. 2007). Secondly we had locations from between 2 and 19 satellite-collared caribou from 1996 to 2007. The two data sets measure different attributes of the calving distribution.

The aerial surveys describe the overall distribution of calving and the relative densities for a 1-2 day period usually close to or just after the peak of calving. The size of the calving ground reflects how the boundaries are determined and timing relative to the peak of calving. The criteria for the boundaries were not always described in the earlier reports. By 1996, the reports included details of the criteria, such as ending the flight lines a set distance (few kilometres past the last sighting of breeding cow) so the boundaries are based on known criteria (Gunn et al. 2005, Nishi et al. 2007). The surveys use regularly spaced transects and thus the survey areas tend to be rectangular which is an obvious artefact relative to actual distribution.

The locations of the satellite-collared cows allow estimation of the rates of movements and hence the peak of calving (based on the cows reducing their daily rates of travel). The change in the rate of travel may be a herd-specific characteristic: the daily rates of movements by parturient cows was 8.5 km/day for the Western Arctic herd compared to 4.5 km/day for the Teshekpuk herd and 2.5 km/day for the Porcupine herd (Kelleyhouse 2001). The rate of movement of the Bathurst cows was as low as 2.5-3.5 km/day in most years. However, there are difficulties in comparing the rates of movement as Kelleyhouse (2001) used 10-day periods from 1-20 June and we used a 5-day period at the peak of calving.

The centroid of the collared cow locations at the peak of calving was similar to the centroids calculated from the aerial surveys during 1996, 2003, and 2006. The similarity indicates that using the locations of the satellite-collared cows to position the peak calving ground is valid despite the relatively low number of collared cows. The relationship between the area occupied by the satellite-cows as calculated using 50%, 90% and 99% fixed kernel polygons and the area of the high and medium density survey blocks varied between the 3 years available for comparison. We suggest that the 90% kernel derived from the satellite-collared cows is predictive for the high-density strata. That the satellite-collared cows' locations would be representative of the location of the calving ground is not surprising as the calving ground is very much a concentration of cows – for example, between 86 and 98% of the estimated numbers of breeding females occurred within the high density survey blocks in 1996, 2003 and 2006. The satellite collar kernels are less representative of the low-density strata, which is to be expected as they are mostly non-breeding cows and juveniles. In summary, the satellite telemetry is predictive of the location of the calving ground and the area of high density (90% kernel) and less predictive of the overall calving ground boundary.

In Alaska, delineation of calving grounds is based on caribou cows fitted either with VHF radio-collars or satellite collars. During calving, a radio-collared cow is visually checked from an aircraft to determine her breeding status. Dau (2003) commented that mapping boundaries based on a cow with neonate at heel is more conservative than using cows with hard antler (pregnant but not calved) as cows can move 10-20 km/day up to the time of birth. Wolfe (2000), Kelleyhouse (2001), and Griffith et al. (2002) used similar approaches to map the calving grounds for the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds. The annual calving grounds were the 99% utilization fixed kernel analysis using VHF radio-collared cow locations. Having available VHF radio-collars increased sample size as typically more VHF collars are deployed than satellite collars. Kelleyhouse (2001:31) used 37 ± 3.9 and 24.5 ± 2.4 locations to map calving ground size for the Western Arctic and Teshekpuk herds, respectively.

While we have presented the fixed kernels to illustrate the areas occupied by the satellite-collared cows, we acknowledge that our sample sizes were small. Sample size was the limitation as to why we did not apply spatial modelling to investigate how to apply boundaries to calving grounds that reflect the predictability of caribou distribution over specified time periods.

In the context of managing human activities on the calving grounds, the previous approach used in DIAND's Caribou Protection Measures was to define a cumulative boundary to map calving distribution based on as many years of aerial surveys as were available. This was relatively robust, and if the boundaries were updated at intervals, it is a practical approach for the herds whose calving grounds are mapped during aerial surveys (Gunn et al. 2007). However, using cumulative boundaries may be insensitive to environmentally-forced variation. For example, if snow conditions delayed migration, the cows may not reach the calving ground (cumulative boundaries). The late arrival of the migrating cows may be associated with a large calving ground extended in direction of migration – for example the Beverly herd in 1979 (Gunn and Sutherland 1997). In the Alaskan Western Arctic Herd, the calving ground was larger than usual in 2000 (32,278 km^2), which was a year when break up was exceptionally late (Dau 2001) and cows calved en route.

For the Western Arctic Herd in 1994, the calving ground was again larger than average even although there was no evidence that spring travelling conditions delayed the migrating cows. Instead the timing of the survey to locate the calving cows may have been late and the cows were already moving to their insect relief habitat (Jim Dau, pers. comm. February 2008). This does make the point that the boundaries and therefore the size of the calving ground is sensitive to the methods used to delineate the calving distribution.

Delineating calving grounds is a necessary step for effective management of human activities on calving and post-calving ranges. Our results are that satellite telemetry, especially if the number of collared individuals is increased, can be used to monitor both the location of areas used (peak calving and annual calving grounds) and their boundaries (90% kernel) for the high density calving (>85% of breeding females). The low and some medium density of caribou (mostly non-breeders) would likely be under-represented by the 90% kernel boundaries. The advantage of the satellite telemetry also is that the times of entrance and exit and residency time in peak calving and annual calving grounds can be monitored. Monitoring calving distribution will contribute to regional monitoring in the context of cumulative effects and managing human activities on calving and post-calving ranges.

Monitoring location, boundaries and timing of occupancy of calving and post-calving ranges is essential information to feed into decisions about managing caribou calving areas. The previous management of land use activities on calving grounds was DIAND's Caribou Protection Measures. Gunn et al. (2007) reviewed the effectiveness of those Caribou Protection Measures, which were applied to land use activities on the Qamanirjuaq and Beverly herds' calving grounds. Their analyses for the Qamanirjuaq and Beverly herd suggested that geographic fidelity was conspicuous and that area-based protection was feasible. Gunn et al. (2007) suggested that satellite telemetry and contemporary GIS techniques could be easily adapted as a set of consistent rules to objectively determine boundaries for calving grounds (which could be termed Caribou Calving Management Areas) and which would be included as part of Mobile Protection Measures. The value of the area-based management is that it gives land users a degree of predictability of where the rules would be applied. The rules have to be developed through consultation but could, for example, include boundaries determined from the distribution of the annual calving grounds for the 5 previous years based on 95% probabilities. Our analyses for the Bathurst herd suggest that similar rules could be developed for the Bathurst herd calving grounds.

Given the strength of concerns about caribou calving grounds as expressed for example in GNWT's Caribou Summit in 2007, we also considered how monitoring calving distribution will contribute to regional monitoring in the context of cumulative effects. In the Porcupine herd, the extent of calving cows varies with the timing of plant green-up, which in turn affects calf survival (Griffith et al. 2002). The mechanism for the effect on calf survival is through the cows and their forage intake and its effect on milk production. Calving distribution also affects the risk of predation on the calves – in years when the Porcupine herd responds to late snow melt by calving in the foothills, predation on calves is increased. Calving distribution then affects the head start that caribou calves need to ensure their resilience to conditions elsewhere on the annual ranges as there is no evidence that calves can 'catch-up' their growth rate later in the summer. This suggests that monitoring calving distribution and environmental conditions has explanatory power for the results of monitoring calf survival elsewhere on the annual ranges.

We found that the Bathurst calving grounds have had two periods totalling 30 years when the predictability of the calving ground's location was high. The two periods were separated by an 11-year period when the locations shifted from east to west of Bathurst Inlet. Our results have also shown that the cows' timing of arrival and departure from calving grounds varies annually, although the time spent on the calving grounds is less annually variable. We suggest that the scale of the shifts will allow the application of area-based and rules-based management for protecting calving grounds. The designation of area-based management is to give predictability where rules governing land use activities could be applied. At a finer geographical scale within the annual calving grounds, the satellite-collared caribou can be used to monitor calving distribution.

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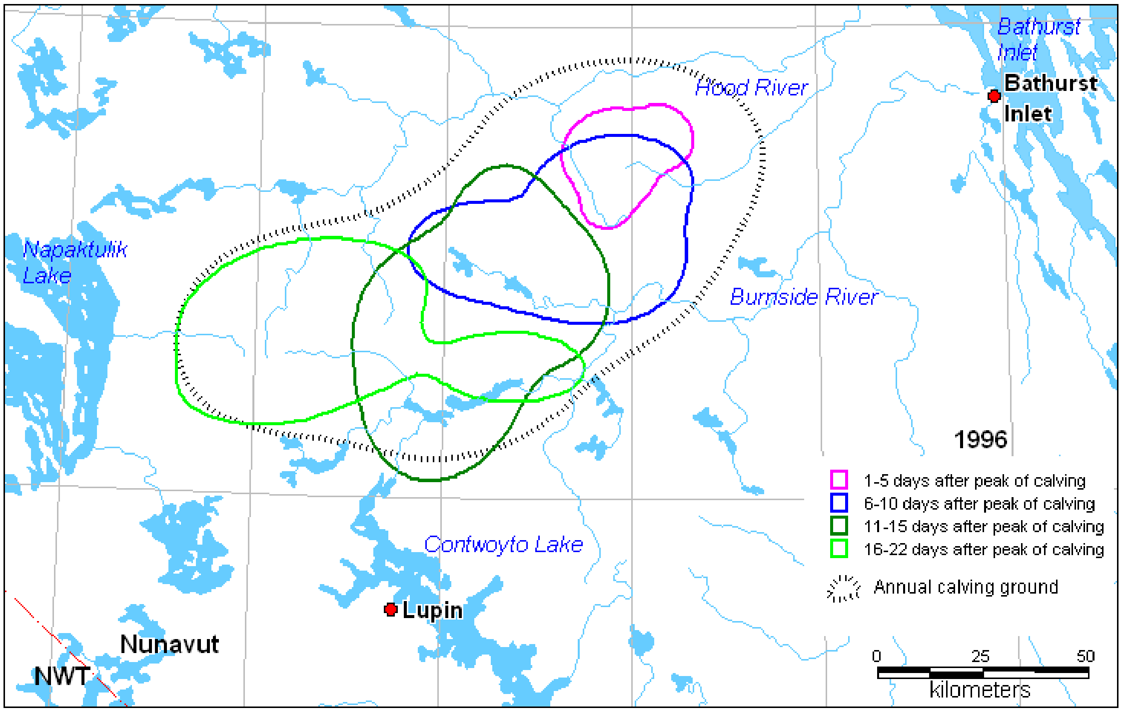
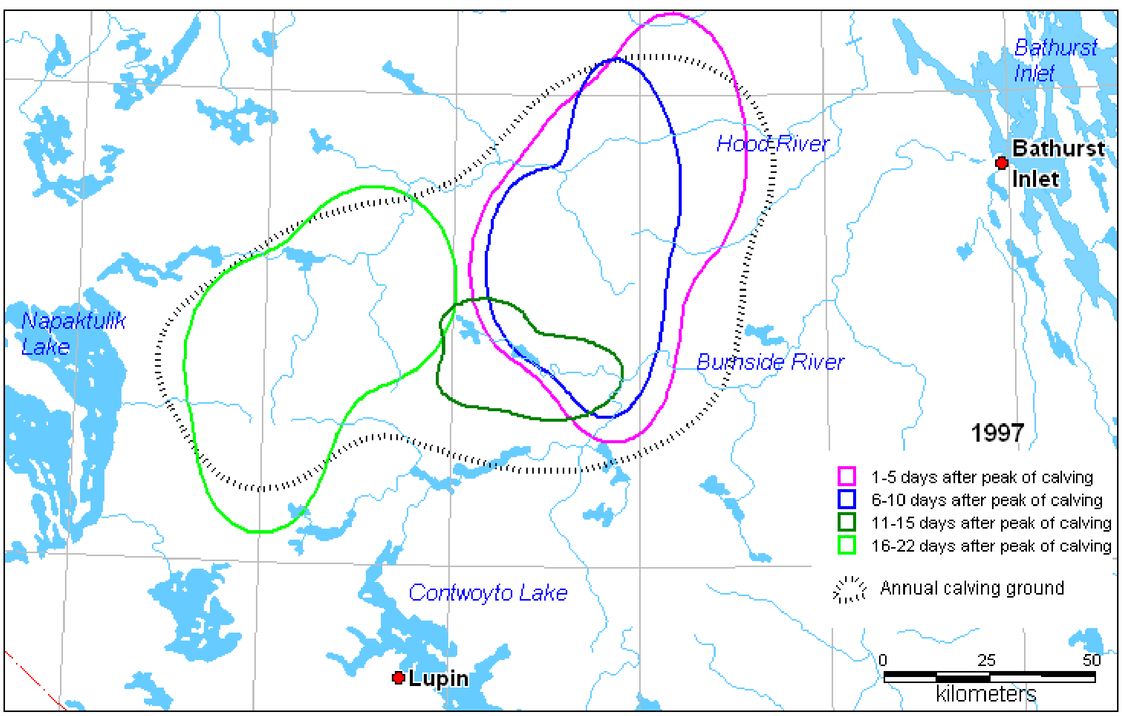
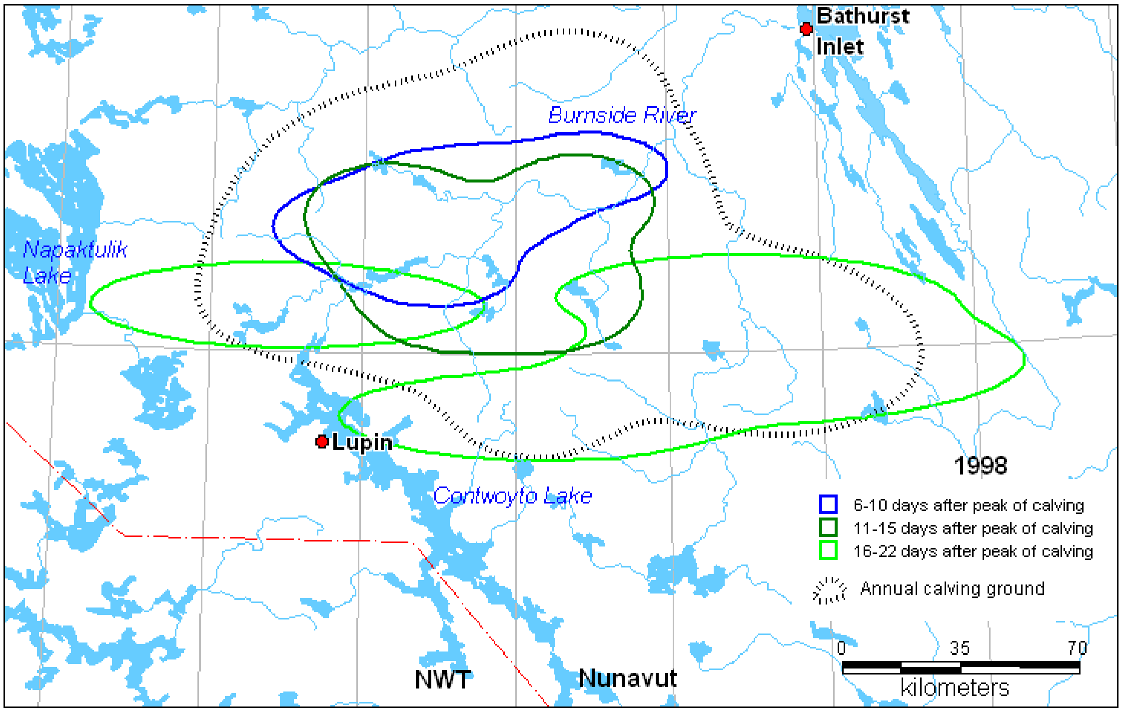
APPENDIX A. BATHURST CARIBOU OUTLIERS REMOVED.

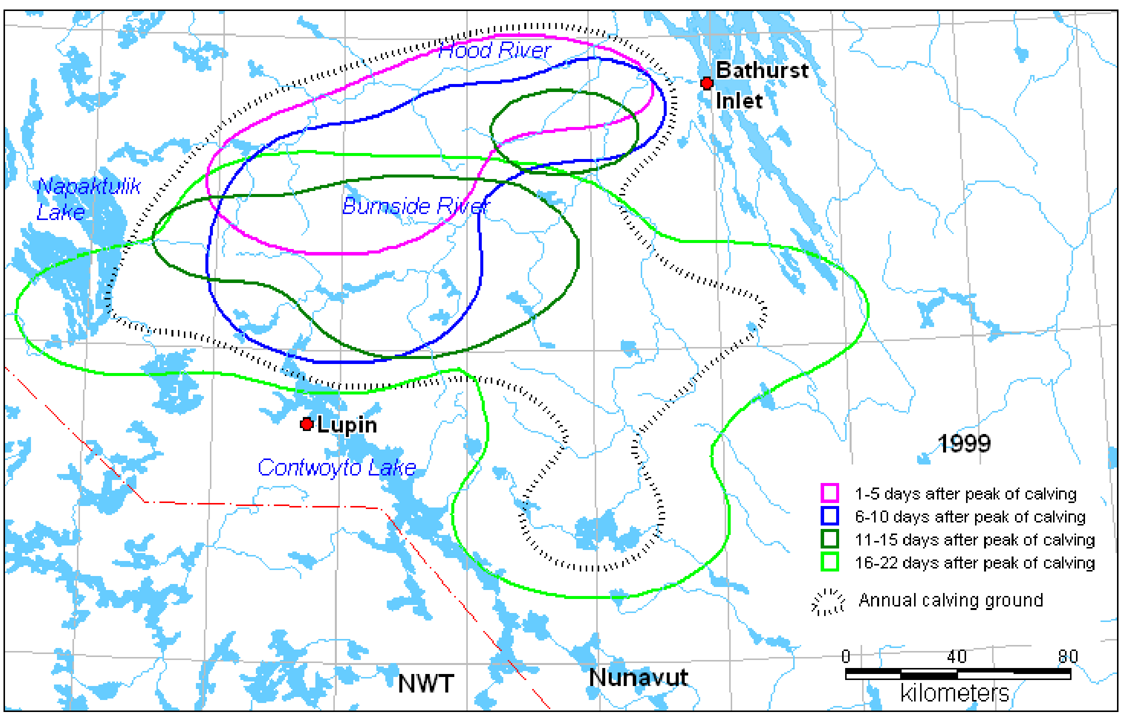
Year	Comments
1996	
1997	
1998	
1999	1 outlier removed (127 never got to Cont L)
2000	1 outlier removed (128)
2001	3 outliers removed (105, 126, 124)
2002	
2003	1 outlier removed (137)
2004	1 outlier removed (156)
2005	5 suspected non-breeders removed (185 (200 km S and W), 192 (Kugluktuk), 184 (by 26 Jun still at N tip Contw.), 191 (got to CG 19 Jun but never slowed), 171 (never slowed <7-8 km/d)
2006	
2007	Kept 197 in (8, 12 Jun); likely calved to south

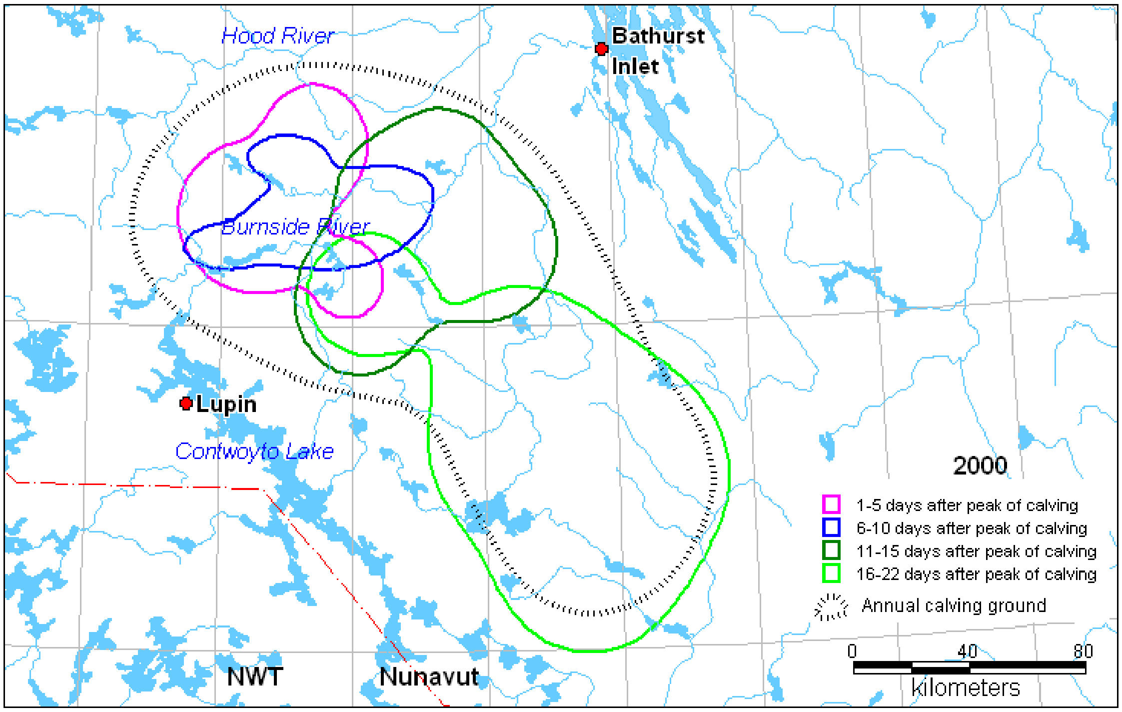
APPENDIX B. CARIBOU DISTRIBUTION AFTER PEAK OF CALVING

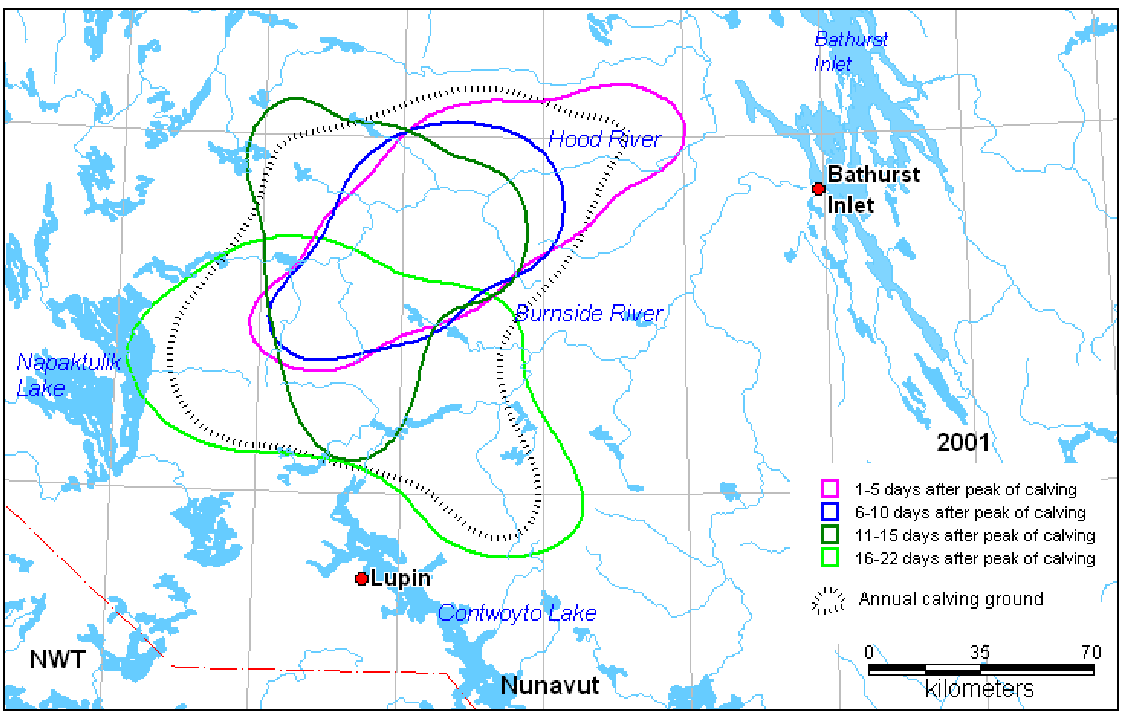


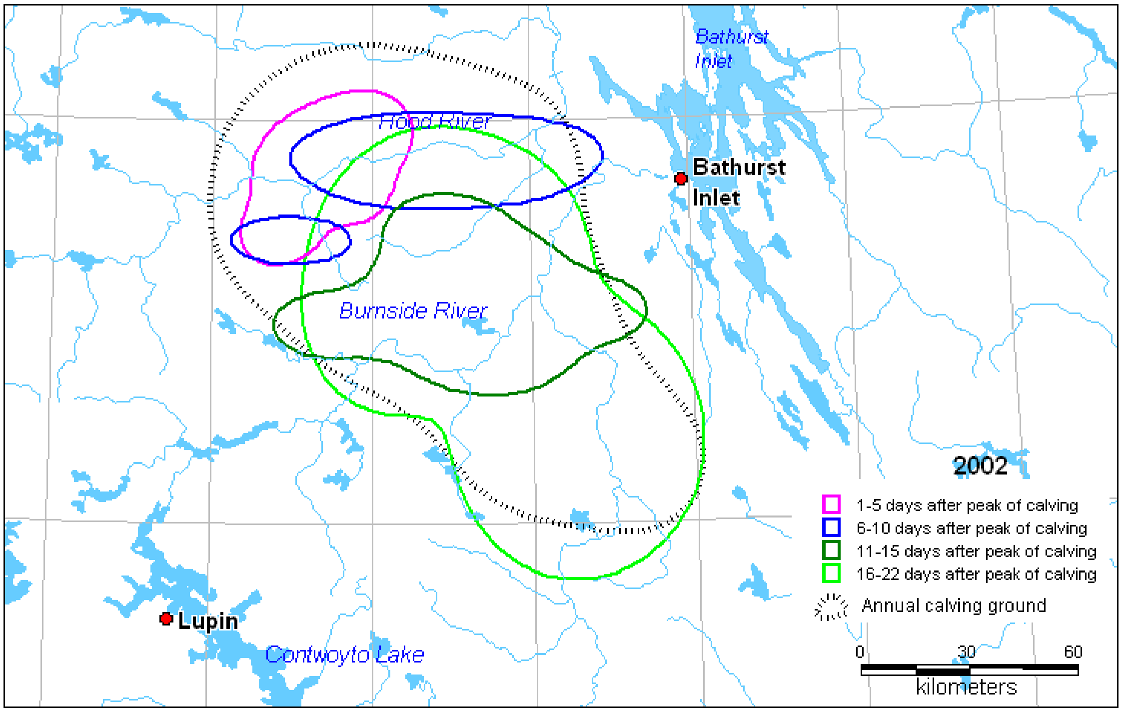


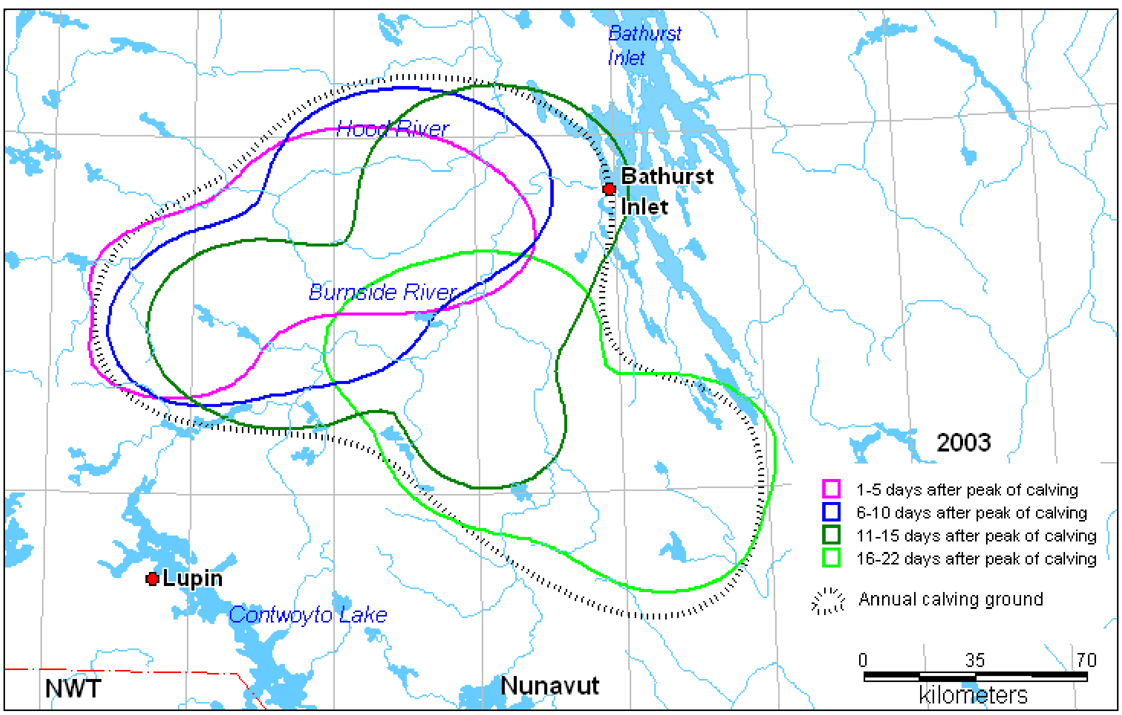

Bathurst
Inlet
Burnside River
Napaktulik
Lake
Lupin
Contwoyto Lake
1998
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
0
35
70
kilometers
NWT
Nunavut

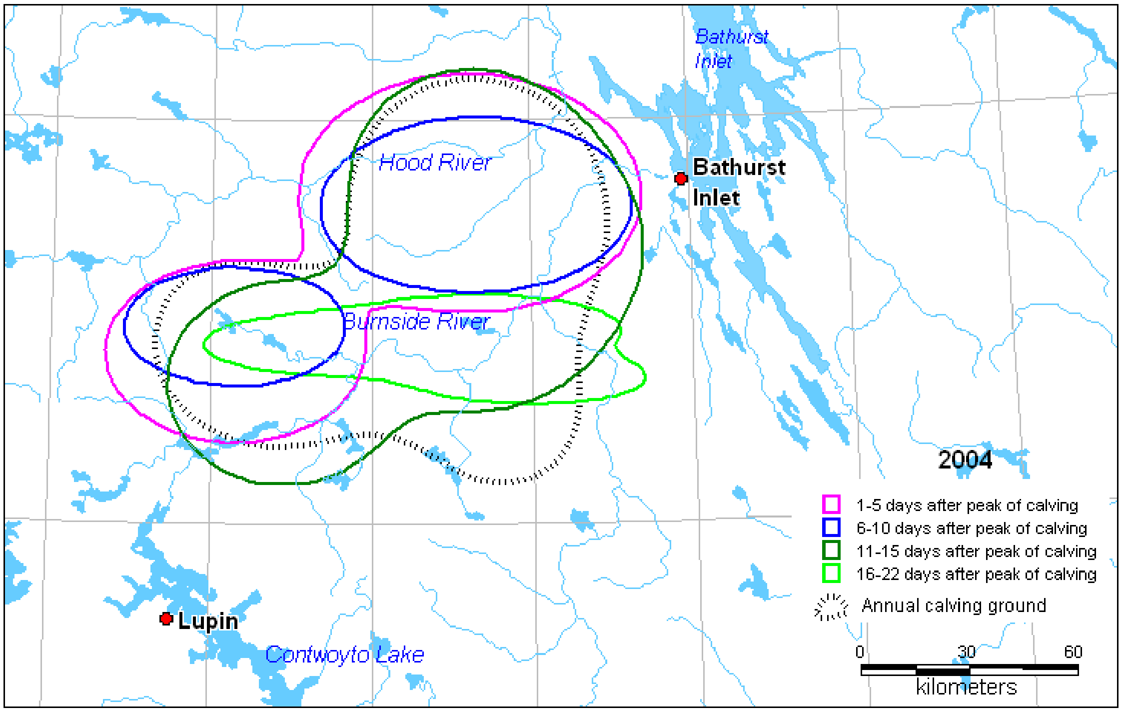

Hood River
Bathurst
Inlet
Napaktulik
Lake
Burnside River
Lupin
Contwoyto Lake
1999
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
0
40
80
kilometers
NWT
Nunavut

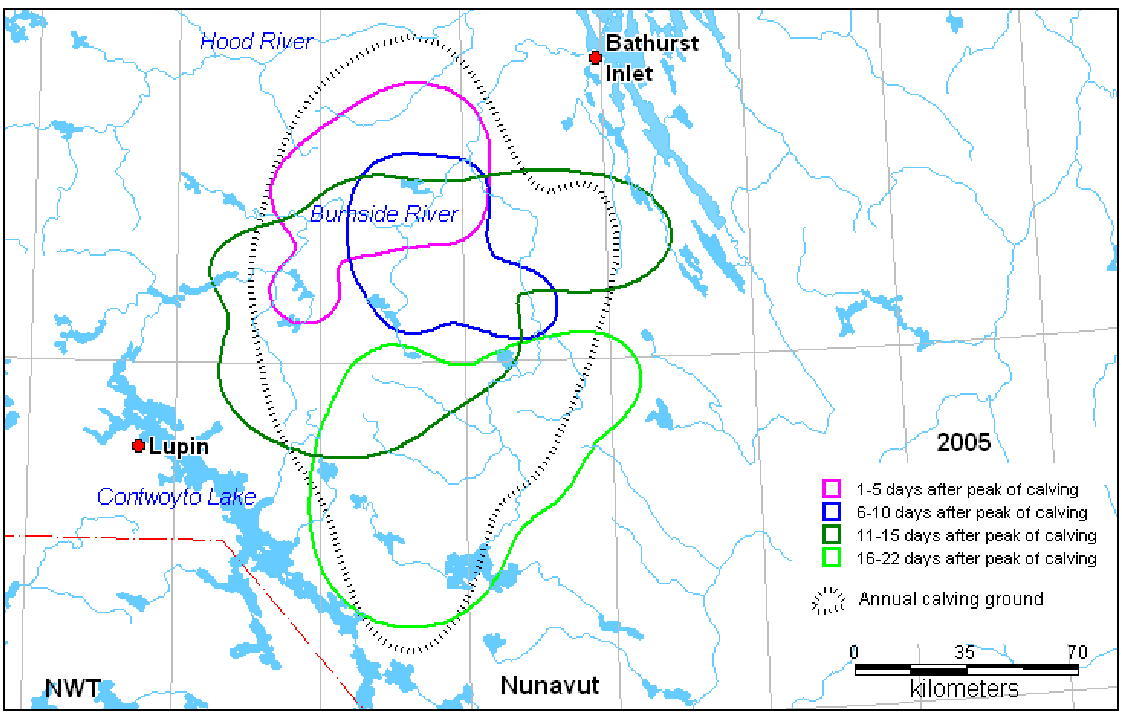

Hood River
Bathurst
Inlet
Burnside River
Lupin
Contwoyto Lake
2000
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
0
40
80
kilometers
NWT
Nunavut

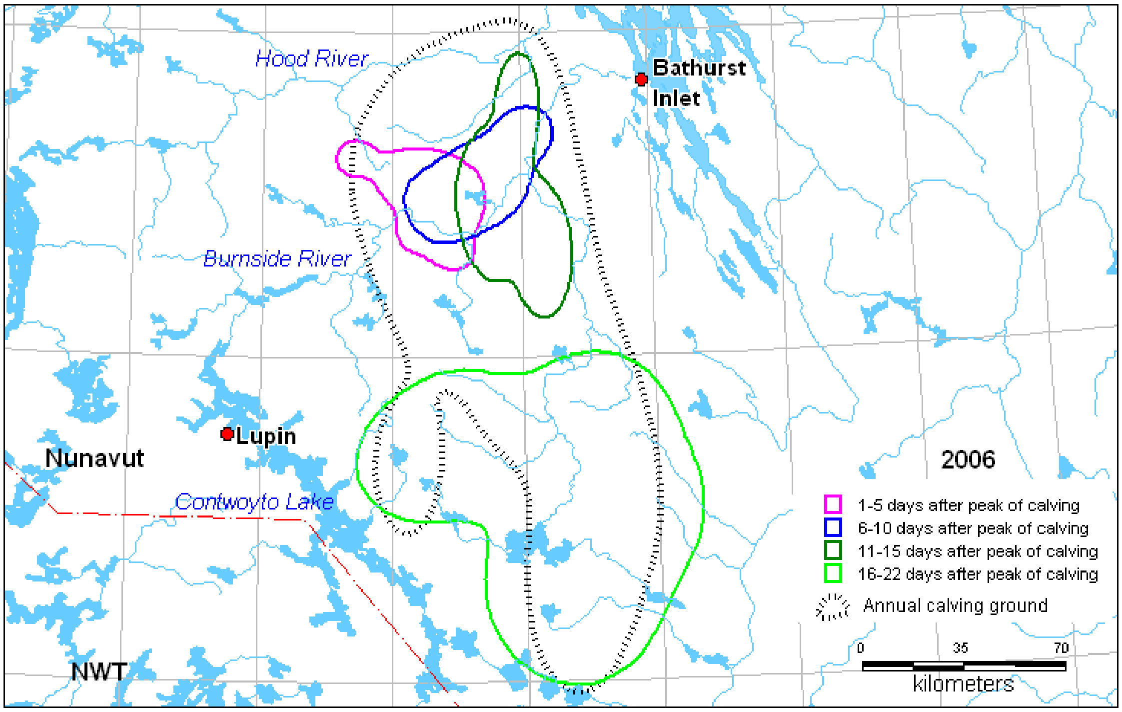

Bathurst
Inlet
Hood River
Bathurst
Inlet
Burnside River
Napaktulik
Lake
2001
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
0
35
70
kilometers
Lupin
Contwoyto Lake
NWT
Nunavut

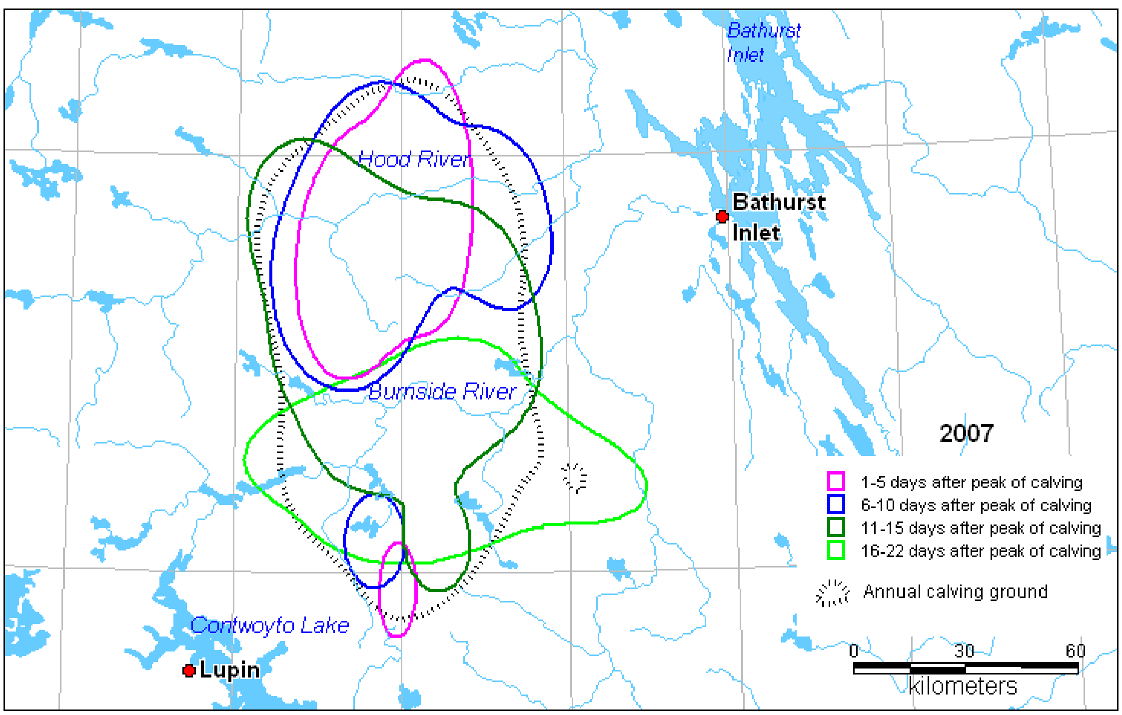

Bathurst Inlet
Hood River
Bathurst Inlet
Burnside River
2002
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
Lupin
Contwoyto Lake
0 30 60
kilometers


Bathurst Inlet
Hood River
Bathurst Inlet
Burnside River
2003
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
Lupin
Contwoyto Lake
NWT
Nunavut
0 35 70
kilometers


Bathurst Inlet
Hood River
Bathurst Inlet
Burnside River
2004
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
Lupin
Contwoyto Lake
0 30 60
kilometers


Hood River
Bathurst Inlet
Burnside River
Lupin
Contwoyto Lake
2005
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
0 35 70
kilometers
NWT
Nunavut


Hood River
Bathurst
Inlet
Burnside River
Lupin
Nunavut
Contwoyto Lake
NWT
2006
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
0
35
70
kilometers


Bathurst
Inlet
Hood River
Bathurst
Inlet
Burnside River
2007
1-5 days after peak of calving
6-10 days after peak of calving
11-15 days after peak of calving
16-22 days after peak of calving
Annual calving ground
Contwoyto Lake
Lupin
0
30
60
kilometers