Fall Population Estimate of the Dolphin and Union Caribou herd (*Rangifer tarandus groenlandicus* x *pearyi*) Victoria Island, October 2015

And

Demographic Population Indicators 2015-2017

Lisa-Marie Leclerc[1]
John Boulanger[2]

[1]Wildlife Biologist Kitikmeot Region, Department of Environment
Wildlife Research Section, Government of Nunavut, P.O. Box 377 Kugluktuk, NU X0B 0E0
[2]Integrated Ecological Research, Nelson, BC

STATUS REPORT 2018-10
NUNAVUT DEPARTMENT OF ENVIRONMENT
WILDLIFE RESEARCH SECTION
KUGLUKTUK, NU

Executive Summary

Dolphin and Union Caribou (*Rangifer tarandus groenlandicus* x *pearyi*) have a large distribution covering Victoria Island and the northern region of the Canadian mainland. This paler and smaller caribou, similar to Peary Caribou in appearance, are genetically distinct from other Barren-ground caribou herds in addition to displaying unique behaviors. The main objective of this study is to provide an extrapolated population estimate, as well as highlight the demographics of the Dolphin and Union Caribou (DUC) herd. In fall of 2015, the total estimate of the final visual strata was 14,730 (SE=1,507, CV=10.2%, CI=11,475-17,986) caribou (1 year and older), resulting in an extrapolated population estimate of 18,413 ± 6,795 (95% CI=11,664-25,182) by using real time collar location. This estimate shows gross change of 66% from the 2007 survey estimate (z-test, Z=-2.19, p=0.036). This translates to a statistically significant annual rate of decline of 4% (CI=1-7%) since the 1997 survey. The yearly collared female survival estimate from the Program MARK was 0.70 (SE=0.071, CI=0.55-0.82). In the fall 2016, the Dolphin and Union calf to cow ratio, measured as calves/100 cows, was 0.25 while calf survival dropped by 0.11 in the following spring of 2017. Laboratory analysis of female feces, collected from collared caribou, were analysed to determine the pregnancy rate. The pregnancy rates were consistent between years (2015 and 2016) with 88%. Though pregnancy rates appear normal, calf to cow ratio and survival rate show little indication of recovery for the DUC population since the last population surveys and low calf survival suggest that further decline is likely to occur. Since there is low survival and low calf productivity this hers would not be able to tolerate a substantial harvest levels. With the current available information, it is recommended to inform users about the current decline and increase the research and monitoring effort on this herd.

Contents

List of Figures

List of Tables

Introduction

Dolphin and Union Caribou (*Rangifer tarandus groenlandicus* x *pearyi*) are of great importance for Inuit subsistence and cultural needs for the communities of Kugluktuk, Cambridge Bay, Bay Chimo, and Bathurst Inlet. At the beginning of the century, although Dolphin and Union Caribou (DUC) were recognized as a distinct species, there was little information about this population. The only available information pertinent to their abundance was registered in explorers' log books, records from trading posts, and observations from geologists during short exploration trips (Manning, 1960; Hewitt, 1921). Based on these historical transcripts, it was estimated that there was an abundance of caribou in the Arctic that may have reached up to millions in 1907 according to Ernest Seton estimate (Godsell, 1950). After the early 1900s, hunters reported almost no caribou sightings; and by the early 1920s, the caribou had essentially disappeared of the barren land. It was also observed that a small portion of caribou remained on Victoria Island year round, and the remaining portion migrated across the Dolphin and Union Strait (Manning, 1960). In the early first half of the century, the caribou herd had declined to levels where the caribou's behavior halted its migration to the Canadian mainland (Godsell, 1950). In the 1970s and into the early 1980s, hunters reported increased sightings of caribou on southern and central Victoria Island that suggested an increase in abundance (Gunn, 1990). By 1993, the DUC migrated by the thousand from the mainland back to Victoria Island; 2,500 animals were seen to cross north, while an additional 4,700 caribou were staged to cross (Gunn *et al*., 1997).

As the herd started to increase, the first attempt to systematically survey the DUC herd took place in 1987 and 1988, following the calving ground survey methodology for Barren-ground caribou (Heard, 1985). In June 1987, 1,601 km were flown and 652 adult caribou and 94 newborn calves were counted on the west-central Victoria Island transect (Gunn and Fournier, 2000). Low cloud cover prevented the determination of the northern and the eastern edge of the calving ground, in addition cow-calf pairs were sparse on the eastern transects. In June 1988, the survey area was increased to the south and to the northeast to 2,155 km of transect lines and 805 caribou and 203 calves were counted on transect (Gunn and Fournier, 2000). The boundaries for the calving grounds were diffuse, and the sparse density of calving cows made it difficult. Defining the boundary of the calving ground is essential when applying the calving ground survey method, as the abundance estimate depend on the extrapolating from the area surveyed.

In 1994, Nishi and Buckland (2000), aiming to define the core calving area, flew transects in the western part of Victoria Island and estimated 14,529 ± S.E. 1,015 caribou on 63% of the island. This assessment underestimated the total number of the DUC herd, since an unsystematic aerial search in the eastern portion of Victoria Island confirmed additional female caribou sightings. Therefore, the amount of area covered was still insufficient to delimit the DUC calving ground. Newborn calves were also observed on eastern Victoria Island from the Collinson Peninsula up to Storkerson Peninsula (Nishi and Buckland, 2000). Satellite collar data confirmed that DUC have an individualistic calving strategy that extends over most of Victoria Island, despite some higher density aggregations. June 1988 and 1994 systematic aerial surveys of west-central and western Victoria Island respectively failed to effectively delineate the DUC calving ground. The determination of caribou population estimate based on traditional calving ground is not applicable to caribou herd that seems to have an individualistic and dispersed calving strategy (Bergerud, 1996).

Because of the inability to effectively delineate the calving ground, a new survey technique was developed by Nishi and Gunn (2004). Based on hunter observations, biologists designed the survey with the premise that the large majority of DUC gather during the rut on the southern coast of Victoria Island waiting for the sea-ice to form. There, they wait to begin their migration across the mainland as soon as the grey ice form to a thickness allowing it. Using this method, the first population census of the DUC resulted in an estimate of 27,948 ± SE 3,367 caribou in 1997 (Nishi and Gunn, 2004).

In 2007, following the same survey technique, Dumond and Lee (2013) estimated 21,753 ± SE 2,343 caribou in the survey area on the south of Victoria Island. Based on satellite collar data from previous years, Dumond later extrapolated this estimate to 27,787 ± CI 3,613, by taking into consideration the proportion of latent caribou that had not yet reached the coast at the time of the aerial survey (Dumond and Lee, 2013). The same analysis was applied to the 1997 estimates resulting in a revised extrapolated estimate of 34,558 ± CI 4,283 caribou (Dumond and Lee, 2013). Statistically, the difference between the 1997 and 2007 population estimates were not significant. Although the survey area remained reasonably consistent between 1997 and 2007, it was slightly extended based on local observations. No trend in the population between these two surveys was statistically confirmed. Based on the 1997 and 2007 surveys, the only conclusion made was that the population remained at best stable over that decade (Dumond and Lee, 2013). Nonetheless, potential annual fluctuations could have taken place during the interval between surveys.

Local knowledge including interviews conducted in Cambridge Bay in 2014-2015, indicated that there was a period when the caribou population was increasing (1960-1990), followed by a peak reaching a high in abundance between (1990-2005), followed by a period of population decline (mid-2000s to present), more evident since 2010 (Tomaselli, 2018). Interviewees indicated that they were seeing about 80% less caribou around Cambridge Bay compared to what they observed in the 1990s. Trends in age class, body condition and health of DUC were also observed between the peak period and the declining period. Since the decline, hunters have observed a decrease in the yearlings and calves, observations of poorer caribou body condition, and increased observations of caribou with abnormalities or diseases (Tomaselli, 2018).

Due to the minimal information on the population size in relation to the increase of harvest level of this herd, the DUC was assessed by the Committee on the Status of Endangered Wildlife (COSEWIC) in Canada and is listed under Schedule 1, Part 4 of the Species at Risk Act in Canada in 2004 (COSEWIC 2004; Miller 1990b; Gunn *et a*l., 2000; Harding 2004). In 2011, it was listed as a species of "Special Concern" by the Canadian Wildlife Service under the *Species at Risk Act (SARA)*. Over the last three to four years, hunters have noticed a decrease in the number of DUC around the community of Cambridge Bay.

This project aims to address concerns of Inuit, as well as to provide new scientific information, by establishing a new population estimate on the DUC for fall 2015. In addition, demographic indicators will be monitored from 2015-2017. By increasing the monitoring of this herd, this ongoing effort would have four additional objectives: 1) Determine the cow survival rate 2015-2017, 2) Determine the pregnancy rate among female in spring 2015 and 2016, 3) Determine the sex ratio of the herd during rut in the fall 2016, 4) Determine the calf: cow ratio in the fall 2016, 5) Determine recruitment, calf: cow ratio in spring 2017.

Methodology

Study area

The range of the DUC encompasses Victoria Island and the Canadian mainland, more specifically the land on both sides of Bathurst Inlet. Victoria Island is mainly characterized with undulating lowlands formed on flat-lying Palaeozoic and late Proterozoic carbonate rock that slope gently and where the maximum elevation is 200 meters (Environment Canada, 1995). The land is covered with low rocky promontories, scattered eskers, and numerous ponds and small lakes. Victoria Island is part of the Northern Arctic Ecozone characterized with three ecoregions, the Wager Bay Plateau, Victoria Island Lowlands, and the Shaler Mountains (Environment Canada, 1995). The willows in southeastern Victoria Island are also found to be greater than further north on the island (Eldun, 1990). The southern coast of Victoria Island is part of the Wager Bay Plateau ecoregion. Some sites are characterized by taller dwarf birch and alder, but the vegetation is mostly characterized with a discontinuous cover consisting of willow, northern Labrador tea, *Dryas* ssp., and *Vaccinium* spp. In the Wellington Bay region (southeastern), eight vegetation classes were distinguished and the presence of *Dryas* and *Salix* in many habitat classes suggests a wide capacity for environment tolerance (Schaefer and Messier, 1993). The Victoria Island Lowlands ecoregion, which constitute two-thirds of Victoria Island, is mainly dominated by arctic willow, alpine foxtail, wood rush, and other saxifrage species, such as the purple saxifrage. The lakes are surrounded with sedge, cotton grass, saxifrage and moss (Environment Canada, 1995).

Bathurst Inlet, within the Canadian Shield, is part of the mainland between Thee River and The Queen Maud Gulf Bird Sanctuary. Its northern location, above the tree line, place it within the southern border of the Arctic tundra region. There are Uplands on either side of the inlet; to the east the Buchan and Bathurst Drift Uplands; and to the west, the Contwoyto Plateau, Wilberforce Hills and the Tree River Uplands (Bird and Bird, 1961). The vegetation in the river valley is lush where shrubs, birch, and the willow can reach up to 2 -3 meters (Cody *et al.,* 1984). The Uplands are characterized by a rock desert cover with a patchy distribution of cushion plants, prostrates shrubs, lichens, and bryophytes. The winter conditions are among the most severe in the Arctic and the summer is relatively mild at the head of the inlet (Maxwell, 1981).

Collar deployment 2015 and 2016

The DUC winter on the tundra on the Canadian mainland. As the spring approaches, the caribou move to the coast of the mainland, concentrate to feed and rest, and start to cross back to Victoria Island in the thousands (Gunn *et al.* 1997; Bates, 2006). At this time, they are found in high densities near the coastlines. Collars were deployed at this time, from Tree River to Hope Bay, to take advantage of these aggregations before they disperse on Victoria Island for the summer. Adjacent herds are believed not to be t in the coastal area. The Beverly herd, are believed to be in taiga habitat, south of the treeline, and the Ahiak herd on the tundra further south and east than the DUC spring distributions (Campbell *et al*., 2013).

At the end of March and early April, between Kugluktuk and the western fringe of the Queen Maud Migratory Bird Sanctuary, 25 caribou were collared in 2015 and 19 in 2016. The caribou were collared with Lotek GPS Globalstar Lifecycle satellite collars following the capture methods involving tangle net and net gunning team from a helicopter (TAEM, 1996). The caribou capture work was performed by an experienced capture crew: net gunner and two handlers, under a fixed time. The time between the beginning of the pursuit (which was kept under 1 minute) to the animal being released did not exceed 10 minutes. This was done in order to keep stress levels to a minimum and thereby increase the survival rate post-collaring. To decrease post-collaring mortality, collars were deployed at outside temperature above -25° C to avoid freezing the lung tissue of the caribou. Once the caribou was immobilized, hair samples from two different body locations (rump and neck), feces, blood samples, and photographs (teeth, body and eye) were taken. By palpitation of the shoulder, ribs, and hips/spine, a body condition score (based on fat) was given according to CARMA’s protocol level 2 for live animals (CARMA, 2008) to determine overall fatness. All noticeable injuries were recorded. The scat samples were sent for laboratory analysis under the standard set of 19 microsatellite markers to confirm the specific genetics signature of the DUC similarly to what has been employed in past caribou projects from across Canada (Serrouya *et al.,* 2012).

Population Estimate

Aircraft configuration

During the rut, at the end of October, DUC congregate along the southern coast of Victoria Island waiting for the sea-ice freeze-up. Once the highest proportion of the collared caribou would have reached the shore, the study area, from Read Island to Parker Bay, would be surveyed. The reconnaissance survey and the systematic transects line survey were both flown with a fixed-wing single engine turbine aircraft, a Single Otter. The transect lines were surveyed at a speed of 160 km/hr and at an altitude of about 150 meters, which was easily maintained with an radar altimeter and due the flat relief of the study area. Pre-determined transect width of 400 meters was set on each wings based on calculation using the formula of Norton-Griffiths (1978) and others (Gunn and Patterson, 2000; Howard, 2011; Nishi and Gunn, 2004; Dumond and Lee, 2013).

$$w = W\left(\frac{h}{H}\right)$$

Where, *W*= the required strip width; *h* = the height of the observer's eye from the tarmac; and H= the required flying height (Figure1).

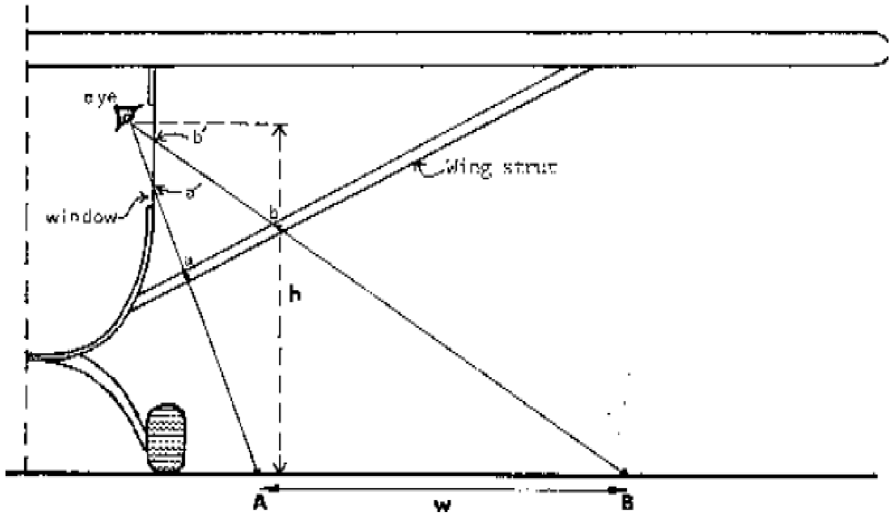


Figure 1: Schematic diagram of aircraft configuration for strip width sampling North-Griffiths (19878). W is marked out on the tarmac, and the two lines of sight a'-a-A and b'-b-B establish, whereas a'- and b' are the window marks.

The survey crew consisted of the pilot, the front right navigator/recorder, a front and rear observers on both sides of the plane and a second recorder on the left side in the back of the plane as backup. Sighting and caribou count, all sexes, were recorded on a touch screen tablet computer commonly used in other barren-ground caribou surveys. As each caribou group waypoints (observations) were instantaneously entered with the number of caribou composing the group and a real-time GPS waypoint was generated allowing geo-referencing of the survey data. The use of this tablet did not only increase the data entry speed, accuracy, but it reduced the time require to perform preliminary analysis of the reconnaissance data for stratification needed in the visual survey.

The survey was structured into two main components 1) a systematic reconnaissance survey that was used to delineate the extent of caribou on the coastal study area and 2) the systematic visual survey that was used for estimates. Effort for survey strata was allocated using a proportional allocation methodology similar to calving ground surveys of other herds (Boulanger et al., 2014b). Two potential strategies for allocation were considered. First, optimal allocation of survey effort was considered based on sampling theory (Heard 1987, Thompson 1992, Krebs 1998). Optimal allocation basically assigned more effort to strata with higher densities given that the amount of variation in counts is proportional to the relative density and size of caribou within the stratum. If strata were reasonably small, then optimal allocation was further adjusted to ensure an adequate number of transect lines for each stratum. In particular, previous surveys suggested that there should be a minimum of 10 transects per stratum with closer to 20 transects being optimal for high density areas. In general, coverage should be at least 15% with higher levels of coverage for high density strata. In the context of sampling, increasing the number of lines in a stratum is insurance that it minimizes the influence of any one line on estimate precision. As populations become more clustered, a higher number of transect lines is required to achieve adequate precision (Thompson 1992, Krebs 1998). Caribou abundance in each strata was estimated using standard formulas for aerial surveys (Jolly, 1969; Krebs, 1998). The population estimates for fixed-width strip sampling using Jolly's Method 2 for uneven sample sizes are derived from the following equation:

$$\hat{Y} = RZ = Z\frac{\sum_i y_i}{\sum_i z_i}$$

Where $\hat{Y}$ is the estimated number of animals in the stratum, R is the observed density of animals (sum of animals seen on all transects $\sum_i y_i$ divided by the total strta area$\sum_i z_i$), and Z is the total strata. The variance for each strata is given by:

$$Var(\hat{Y}) = \frac{N(N-n)}{n}\left(s_y^2 - 2Rs_{zy} + R^2 s_z^2\right)$$

Where N is the total number of transects required to completely cover stratum Z, and n is the number of transects sampled in the stratum. s_y^2 is the variance in counts, s_z^2 is the variance in areas surveyed on transects, and s_{zy} is the covariance. The estimate $\hat{Y}$ and variance $Var(\hat{Y})$ are calculated for each stratum and summed. The Coefficient of Variation (CV = σ/$\hat{Y}$) was calculated as a measure of precision.

Analysis of collared caribou data

Sixteen radio collared DUC on Victoria Island were tracked daily to index the distribution of the caribou herd relative to the coastal study area. The daily fixes were not always returned for individual caribou. In these cases, the location of the caribou was interpolated under the assumption that movement rate and trajectory was constant between successive daily locations. An example of this would be that an interpolated location for day 2 would be midway between a straight line connecting GPS fixes on day 1 and 3. The systematic reconnaissance survey was triggered when the greatest portion of the collars had reached the southern coast of Victoria Island, but still had yet to start their migration across the newly formed sea-ice.

For the collars that did not reach the study area during the reconnaissance survey, we flew to the collar locations to determine the groups sizes of animals associate to specific collars, as well as to determine the presence or absence of other groups in the area. The collar locations relative to when the strata areas were surveyed were also summarized to determine the proportion of collared caribou that were within the survey area when the aerial transect sampling occurred. This percentage was later used to extrapolate the final herd estimate as detailed in the Extrapolated Population Estimate section.

Extrapolated Population Analyses

The Lincoln Peterson estimate of herd size was calculated based on the proportion of collared caribou being within the survey area when the survey occurred. The estimate of herd size was calculated as:

$$N_{LP}= (((M+1)*(C+1))/(R+1))-1$$

with M equal to the number of collared caribou, R equal to the number of collared caribou detected, and C equal to the estimate of herd size from the strata surveys (N_{strata};) (Seber, 1982; Krebs, 1998).

The estimate of variance from just the Lincoln Petersen estimator was not correct given that there was error in both the strata estimate and in the proportion of caribou estimated in the study area. Using the Lincoln Petersen estimate of variance accounted for variance in the estimate of detection probabilities based on collared caribou. Therefore, we used a modification of the variance estimator proposed by Innes *et al*., (2002) that considers both sources of variance. In this case the variance estimate was:

$$var(\, N_{LP}) = N_{LP}^2(\, CV^2(p_{LP}) + CV^2(N_{strata}))$$

where CV^2=(var(x)/x^2). The variance of the Lincoln Petersen estimate of capture probability (p_{LP}) was estimated based on the hypergeometric probability distribution which is assumed with the Lincoln Petersen estimator (Thompson 1992). Confidence limits were calculated using the t-statistic from strata surveys.

The estimate from the availability estimator of Innes *et al*., (2002) was similar to the Lincoln Petersen estimator given that it uses the same general method to estimate detection probabilities of caribou in the study area. The main difference was that the Lincoln-Petersen formula adjusts the herd estimate for small sample sizes of marked animals. The Lincoln-Petersen estimator also assumes a representative distribution of collared caribou relative to caribou within the herd, so that the ratio of caribou within the study area indicates the detection probability of caribou within the herd (Rivest *et al.,* 1998).

Overall Trend

The 2015 estimates was initially compared to the 2007 estimate using a t-test to determine if the two estimates were significantly different (Gasaway *et al.*, 1986). This comparison did not allow an actual estimate of trend given that 8 years separated the two surveys. The low number of points (3) also challenged the use of traditional regression methods. A Monte Carlo sampling-regression approach (Manly, 1997) was therefore applied to estimate trend from the 1997, 2007, and 2015 surveys. The basic procedure employed was to generate simulated estimates for each year surveyed (1997, 2007, and 2015) based on the point estimate and confidence limit of each survey under the assumption of a normal distribution of survey estimates. The normal distribution was generated using a t-distribution with degrees of freedom used to calculate the confidence interval for the estimates. Trend was then estimated as the slope of the log of population estimates and year using regression analysis (Thompson *et al*., 1998). Estimates of slope of the regression were an estimate of r (per capita growth rate). The per capita growth rate can be related to the population rate of change (λ) using the equation $\lambda=e^r=N_{t+1}/N_t$. The simulations were repeated 1,000 times which resulted in 1,000 estimates of λ. The point estimate of λ and the percentile based confidence limits were then estimated, therefore providing an estimate of annual rate of change.

Population demography, 2015 -2017

Demographic indicators for the population of DUC, survival rate, the sex ratio, fall calf:cow ratio, spring calf:cow ratio, and the pregnancy rate were investigated between 2015 and 2017. The interaction between these various indicators can be difficult to interpret, but they nonetheless increase the overall understanding of the herd population demography and can be used in a population modelling (Boulanger *et al.*, 2011) to help determining the future trajectory of the herd and inform future management recommendations.

Cow survival rate

From the time the collared caribou was released until a mortality notification was received, the data generated from the DUC collared female caribou were monitored. The fates of the DUC collared caribou were determined by receiving the mortality notification once the collar stopped moving for 720 minutes, which was then recorded as mortality. Due to the logistical challenge to access the site after the notification was received to perform a necropsy, a determination of the cause of death was not possible. Additionally, it was impossible to rule out the possibility of collar failure or device drop-off. This estimate of survival from collared caribou may be negatively biased if a substantial proportion of collars that were reported as mortalities were actually collar drop off or collar failure. Program MARK known fate models (White and Burnham, 1999) were used to estimate DUC year estimates of survival from April 2015 to April 2017.

Pregnancy rate

Fertility in caribou is usually influenced by body condition, of which two possible indicators could be body weight and body fat (Ouellet *et al.,* 1991). The pregnancy rate of female caribou is determined at the peak of calving by counting the number of females that have a calf at their heel. However, the Dolphin and Union calving ground is undefined and spread over Victoria Island making the identification of DUC cow/calf pairs problematic to determine (Nishi and Buckland, 2000). To keep the caribou capture time under 10 minutes in the field, we did not include determination of the pregnancy with an ultrasound. Therefore, we used progesterone levels in sampled feces to determine the pregnancy rate.

From the Dolphin and Union females collared in 2015 and 2016, fresh scat samples were collected. The samples were kept frozen until they were sent to the Toronto Zoo, Reproductive Physiology Laboratory for analyses. Immediately upon thawing, fecal pellets were mixed together, 0.5 g of feces was weighed into a glass vial, and 5 ml of 80% methanol in distilled water (v:v) was added to each vial. Samples were briefly vortexed and extracted overnight in a sample rotator. Samples were then centrifuged for 10 minutes and the supernatants were transferred to a clean glass vial for storage at -20C until analysis. Progesterone concentrations in the extracts were quantified using a progesterone enzyme immunoassay (CL425 from C. Munro, UCDavis). 96-well microtiter plates were coated with progesterone antibody (CL425) and incubated overnight. Progesterone standards, fecal extracts and HRP-labelled progesterone were diluted in assay buffer and loaded onto the microtitre plates in duplicate. Binding of the HRO was detected using ABTS and the color reaction measured using a spectrophotometer. Female caribou with > 600 ng/g progesterone were categorized as pregnant and caribou with 0.20-200 ng/ g of progesterone were categorized as non-pregnant.

Fall and spring composition survey

The fall and spring composition surveys were undertaken based on the location of the DUC during their fall and spring migration. The proportion of calf per cow is based on two assumptions: 1) female and male recruitment and mortality are comparable and stable and 2) female mortality is small relative to offspring mortality (McCullough, 1994). Prior to the start of the composition survey, the location of caribou was determined with the collar information and community-based observations.

At the end of October 25th to 29th, 2016, the fall composition survey took place during the rut along the shore of Victoria Island, from Cape Peel to Richardson Bay, to determine the sex ratio of the herd and the calf: cow ratio. A fixed-wing, Twin Otter, was used to reach the remote caribou locations and classify the caribou due to the challenging weather conditions and assure crew safety. The survey altitude was set to 160 meters above the ground level with the slowest possible speed. The crew consisted of the pilot and the co-pilot, as well as one caller and two community members as recorders for each side of the aircraft. The external characteristics was limited to the presence of big antler and long hair below the neck for the male, small size of the calf, intermediate-size and straight face profile fort the yearling, and medium size with small hard antler for the female.

At the end of March 23rd to 28th, 2017, the spring composition survey took place to identify the recruitment of the calves by re-assessing the calf:cow ratio. Classification was done from a helicopter, where the majority of caribou seen from Tree River to Hope Bay were classified. Due to the space limitation in the aircraft, the crew consisted of the pilot, the caller, and the recorder. For these composition surveys, when possible using a helicopter the caribou was classified based on their appearance and external characteristics under predetermined groups: calves, yearlings, bulls, and cows. Sex determination was possible when the caribou was seen from the rear and was based on the presence or absence of the vulva patch; females have a darker coloration at this body location. Yearlings were characterized by their intermediate-size and straight face profile and calves by their small-bodied and short faces.

The variances of the fall and spring for the composition data was calculated using the Tukey's Jacknife method (Cochan, 1977; Krebs 1989; and Sokal & Rohlf, 198).

Results

Collar Deployment 2015 and 2016

Target locations for caribou capture were based on past information on winter distribution, local observations and Inuit Traditional Knowledge. Collar deployment began on April 6th, 2015 from Hope Bay (TMAC mine site) located on the east side of Bathurst Inlet. The first day, seven collars were deployed on the west side and one on the east side of Bathurst Inlet. On April 7th, a total of nine collars were set out, two on the east side of the Bathurst Inlet south of Hope Bay and seven on the west side of the inlet. The remaining collars were deployed on April 8th, all of which were on the east side of Bathurst Inlet and mostly south-east of the mine site towards the Queen Maud Bird Sanctuary (Figure2, dots). A total of 1,214 km of non-systematic lines were travelled to collar 25 female caribou (DU-01-15 to DU-25-15).

In 2016, 19 additional collars were deployed (DU-51-16 to DU-69-16) (Figure 2, triangles). As in previous years, the collar deployment was from Hope Bay. On April 11th, 2016, 11 groups of caribou were seen, but only two collars were deployed. On April 15th, three additional collars were deployed and on April 16th seven animals were collars at the northwest part of Kent Peninsula. Further attempts to collar the DUC on the west side of Bathurst Inlet were undertaken, however, no caribou were found. Tracking evidence in the area suggested most of the caribou had initiated their crossing and were unavailable for capture. On April 17th, the seven remaining collars were deployed east of Hope Bay. A total of 1,594 km of non-systematic lines were covered during the deployment period. No mortalities were observed after 1 month of collaring, with all collars transmitting. Pre-programming of data transmission coincided with a three-year battery lifespan. Data transmission from these 2015 and 2016 collars will continue until the collar release mechanism is activated in fall 2017 and 2018 respectively.

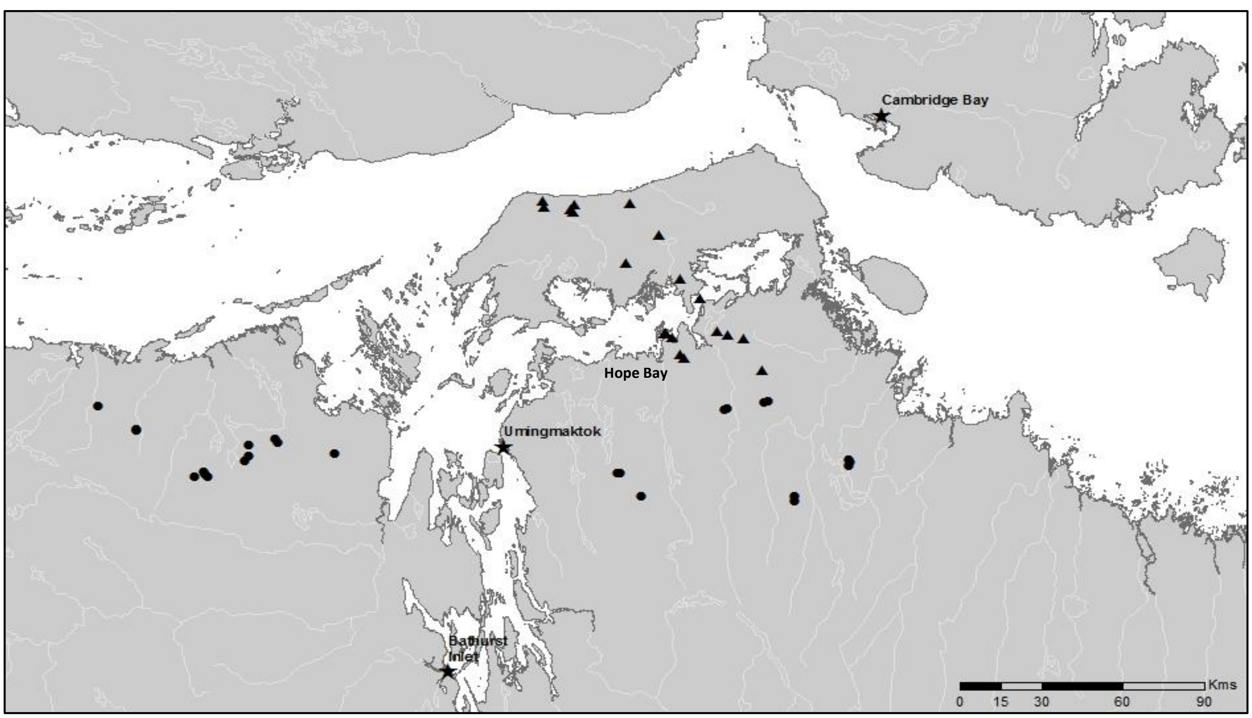
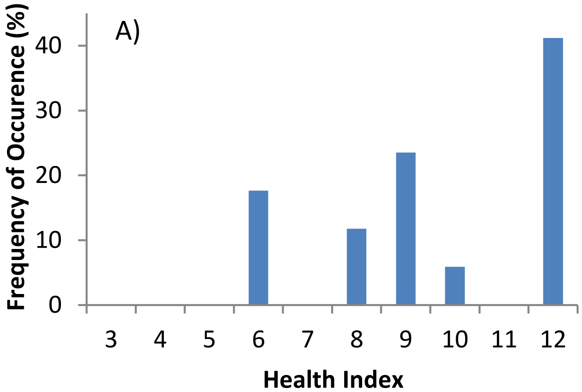


Figure 2: Map of Bathurst Inlet representing the 44 collar locations in April 2015 (dots) and 2016 (triangles) on the east and west side of the Inlet.

In 2015 and 2016, collars were unintentionally deployed on Ahiak caribou. Barren-Ground caribou had mixed amongst Dolphin Union caribou on the east side of Bathurst Inlet. From the caribou captured, eight caribou (DU-01-15, DU-10-15, DU-17-15, DU-18-15, DU-20-15, DU-22-15, DU-62-16, and DU-64-16) were genetically confirmed as Barren-Ground caribou. For the caribou that failed to be genetically identified, DU-19 and DU-24, the herd identity was confirmed based on two other criteria: their calving location on the mainland and their physical characteristics. For these two animals, slight phenotypic differences were noticed such as darker back with brown legs, elongated snout, and longer legs than DUC. Three of the collared animals (DU-52-2016, DU-63-2016, and DU-68-2016) were harvested within two weeks of collaring, so the identification based on calving location was impossible. Nevertheless, these three caribou were taken into consideration as DUC due to their physical appearance: cream back and legs, short snout and legs. Thus, a total of 34 DUC were collared, 17 in 2015 and 17 in 2016, and the remaining 10 caribou were not taken into consideration during the fall population survey nor in the body condition, cow survival, pregnancy rate indicators. From all the Dolphin and Union collared caribou, five mortality events were recorded during the 2015 and 2016 fall migration (October 26 to December 7) with only one during the crossing. DU-05-2015 died on the ocean a few kilometers from the mainland on November 24th 2016. This mortality site was investigated in March 2017, but neither the caribou carcasses nor the collar were seen.

Body condition of captured caribou in 2015 and 2016

For each DUC captured (n = 34), we assessed its body condition by palpitation of the shoulder, ribs, and hip-spine to attribute a score from 1 to 4 (CARMA, 2008). The total score ranged on a scale from 6 to 12, where 12 is the healthiest caribou. For both years, no caribou scored below 4; with a mean of 9 for both years (Figure 3, A and B). The majority of DUC scored 12 where it was hard to feel the edges of the bones of the shoulders, the ribs were nearly flush with fat tissues between them, and the hips were well padded.



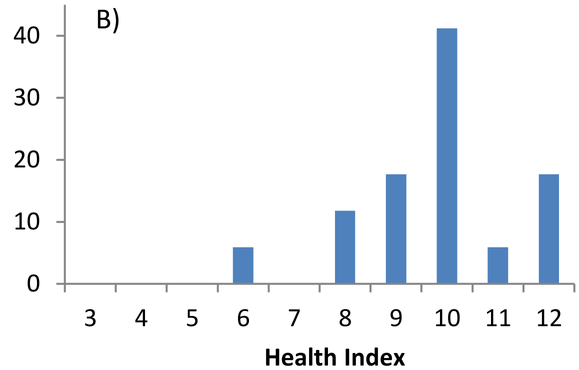


Figure 3: Average body score condition displayed as frequency of occurrence (%) of captured Dolphin and Union caribou in A) 2015 (n = 17) and B) 2016 (n = 17). The index score scale range from 6 to 12, where low number represent unhealthy to high number represent healthy caribou.

Population estimate:

DUC 2015 fall distribution

From October 10th to November 11th, the collar locations of 15 DUC on Victoria Island were closely monitored. In mid-October, most of the collars were moving south, but did not reach the study area, a distance within 10 kilometers of the shoreline (Figure 4). Assuming that these collars characterize the distribution of the herd, the reconnaissance and the visual survey need to be timed with the distribution of the collared caribou relative to the study area, without having initiated their migration over the forming sea-ice. In the circumstance that the sea-ice formation allows for 30% of the collar to cross, the survey would be cancelled and postponed to the following year. One mortality event on Victoria Island, DU-04-2015, happened during the survey. On November 11th, five collars left the study area and were completing the crossing of the Coronation Gulf and Dease Straight (Figure 4).

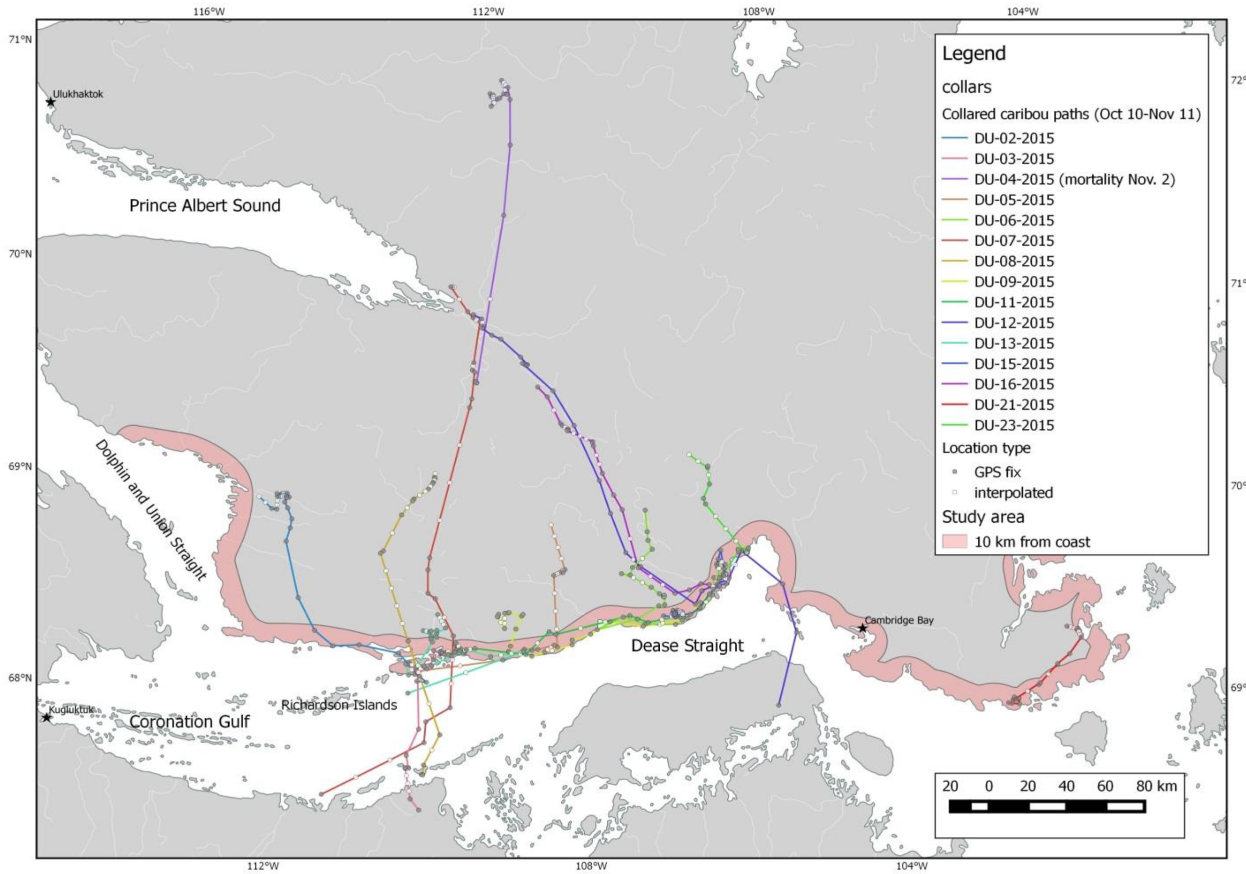


Figure 4: The movement pattern of 15 Dolphin and Union caribou from October 10 to November 11, 2015 in relation with the costal study area extending from the shoreline to 10 km in land (pink).

Collared caribou that were far away from the shoreline or outside the study area were considered in the design of the visual strata. When possible, we flew to the specific collar location (DU-02-15, DU-04-15, DU-16-15, and DU-21-15,) to determine the number of caribou associated with the specific collar. Only small isolated groups of caribou, varying from 2 to 21 individuals, were seen. None of the group found associated with the collar or in its proximity, were large enough to justify a stratified transect sampling at these locations outside the study area (Table 1). However, the occurrence caribou outside the final visual strata was still included in the final extrapolated population estimate.

Table 1: Minimal occurrence of small group of DUC outside the final visual strata

Area	Number of caribou	Likely impact on overall population estimate
East Victoria Island	9 caribou (all off transect) on October 29. 12 caribou with DU-21-15 on October 27.	Minimal given that surveys close to Ross point in the same time period observed large aggregations of caribou.
West Victoria Island	13 caribou were associated with DU-02-15 on October 31.	Minimal given that surveys close to Ross point in the same time period observed large aggregations of caribou.
Western strata	21 caribou observed on Richardson Islands (off transect and out of strata) on November 2 survey.	Minimal given ice condition and lower densities of caribou observed in the same area on October 31.
Coronation Gulf	Single collared caribou crossed the ice on November 1st prior to survey.	Minimal given poor ice condition during this time and low numbers of caribou observed in the MD_W stratum on October 31
Inland survey, Northwest Territory	4 groups of 14, 6, 2 and 13 caribou were observed in the proximity of DU-04-15 on October 30, which one died on November 2.	Minimal given that there caribou could have been Peary Caribou that are known to winter in these areas.
Inland survey	13 caribou were observed with collar DU-16-15 on October 30 and crosses into strata on November 9.	Minimal as no other caribou were observed in the proximity.

Systematic reconnaissance survey

Two reconnaissance surveys were flown. The first initial reconnaissance effort done over three days (October, 25th, 26th, and 27th) was to survey parallel to the shoreline to determine aggregation of caribou on the coast from Read Island to Collinson Peninsula (Figure 5). The 1997 and 2007 survey area was extended eastward to account for the possibility of caribou east of the Island based on hunter observations. Transects were oriented perpendicular to the coastline to reduce potential bias and to detect possible concentration of caribou that has not reach the coast yet. Ten transects were flown perpendicular to the coast line 30 kilometers inland to assess the possibility of large concentration of caribou further away from the coast. We observe 0 to 5 caribou per 10 km segments (Figure5). To the east of Cambridge Bay on October 27th, only 12 caribou were observed in association with the only collar in the area, DU-21-15. To the west, larger aggregations of caribou were observed from Wellington Bay to west of Ross Point. No caribou were observed past Lady Franklin point to Read Island.

Given the distribution of collar caribou inland from the shoreline, further flying was postponed until October 29th and 31st when most collared caribou were closer to the study area (Figure4, pink area). A systematic reconnaissance survey with 10 to 30 kilometer transects spaced 10 to 12 kilometers apart was conducted to the east of Cambridge Bay on October 29th as well as within lower density abundance survey areas in the extreme west of Victoria Island on October 31st (Figure6, dotted lines). Even though few caribou where observed, effort was still concentrated in this very low density area to rule out the possibility of having missed significant aggregations of caribou during the first reconnaissance survey and to confirm that there were few to no caribou on shoreline areas or inland. To the East, only nine caribou were observed, of which were off transect. These areas were not surveyed further given extremely low density and lack of caribou occupancy.

On October 31st, a second reconnaissance survey from west of Ross Point to Wellington Bay, in the higher density area, was carried out to capture any potential shift of caribou along the coastline and/or a higher number of caribou reaching the coastline. The largest aggregations of caribou were observed from the west side of Wellington Bay to west of Ross Point. This data was also used to stratify and allocate effort between the west visual strata.

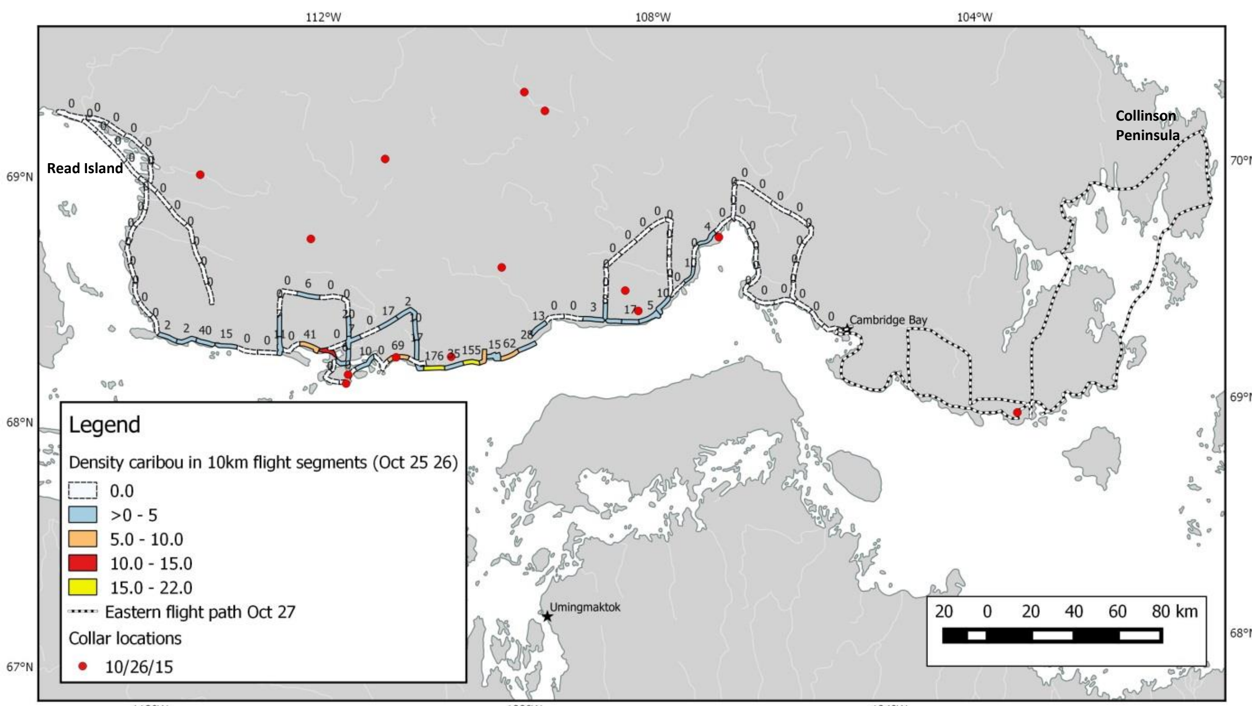


Figure 5: Transect of the initial reconnaissance fight on October 25th, 26th West of Cambridge Bay, dotted line) and October 27th (East of Cambridge Bay, color coded segments). The density of caribou observed per 10 km was attributed a color code where white is = 0, blue = 0 to 5, orange = 5 to 10, red = 10 to 15, and yellow = 15 to 22. The collar locations, as on October 26th, are indicated by red dots.

Systematic visual surveys

The observations from the shoreline reconnaissance survey of October 26th and October 31st and the latest GPS collars were used to stratify the highest density area into visual strata (Figure6). The average segment densities were then used to allocate sampling effort. The final visual strata had to be flown in 1.5 days, which assumed full flying days of 600 km with ferry time from Cambridge Bay and daylight restriction. Using the location and number of caribou per group, density strata were delineated to increase the survey effort where the density of caribou is found to be the highest. Five visual strata were defined: low density west (LD_W), medium density west (MD_M), a high density (HD) and medium density east (MD_E), and a low density east (LD_E). Note that the coverage for the LD_E stratum was kept similar to the MD_E strata given uncertainty in the density of the strata (Figure6). The final coverage for each stratum varied from 27.9% for the high density (HD) stratum to 13.6% for the low density stratum (LD_W) (Table 2) based on optimal allocation from the reconnaissance survey data. The total kilometers flown on transect was 900 km.

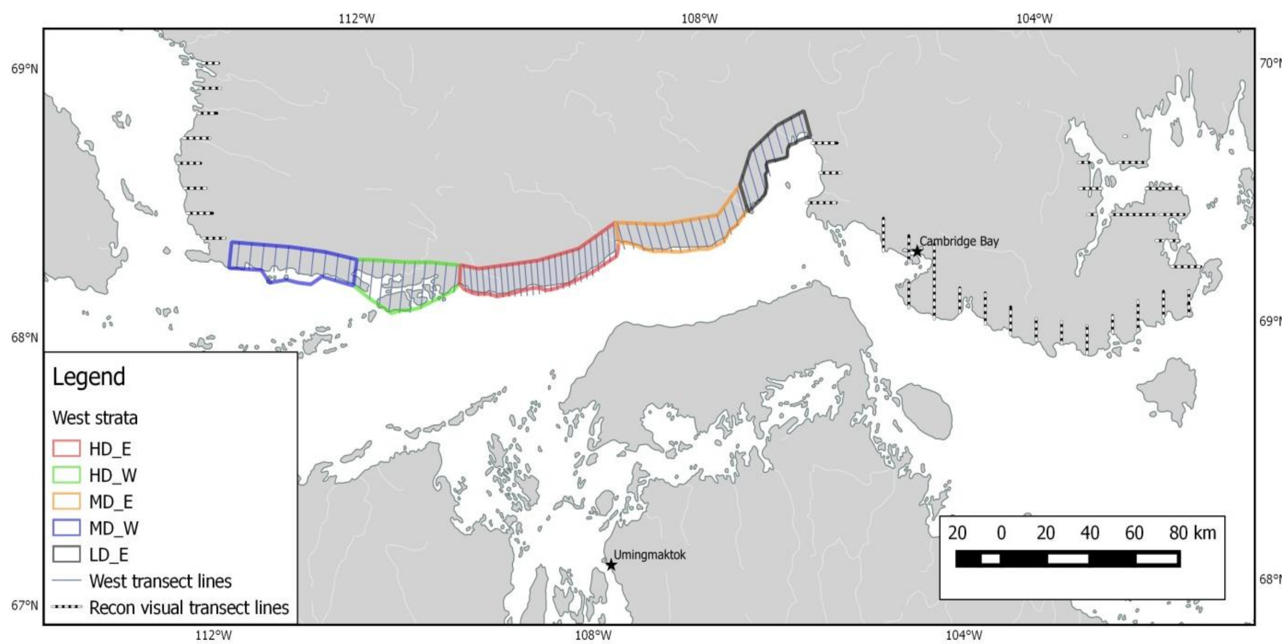


Figure 6: Final systematic reconnaissance transects for east of Cambridge Bay and west of Cambridge Bay (dotted lines) with the final visual stratification layout in blue (MD_W), green (HD_W), red (HD_E), orange (MD_E) and black (LD_E).

Table 2: Strata dimensions for the Dolphin and Union population survey based allocation.

Strata	Area of strata (km^2)	Baseline (E-W) distance (km)	Total transects possible	Number of transects sampled	Transect area sampled (Km^2)	Coverage
LD_W	740.87	56.9	71.1	10	100.5	13.6%
MD_W	841.33	47.5	59.4	10	138.4	16.5%
HD	944.98	72.4	90.5	26	263.2	27.9%
MD_E	672.57	55.4	69.3	14	115.8	17.2%
LD_E	548.79	40.2	50.3	10	102.5	18.7%

The visual surveys were conducted on November 2nd and 3rd when the highest proportion of collars were in the survey area and a minority started their migration on the sea-ice and was out of reach (MD_W, HD, MD_E and LD_E), which coincided with peak numbers of collared caribou in the survey strata (Figure5). Only one collar, DU-03-15, had left to MD_W and HD strata and started crossing when it was surveyed. The low density stratum was surveyed on November 5th (LD_W), when one collared caribou, DU-02-15, was within the stratum. The timing of the survey of the higher density area (November 2nd) occurred with the most collared caribou near the shore, but before they started crossing the Coronation Gulf (Figure5). The locations of collars indicated minimal movement between November 1st and 2nd when the remainder of the areas to the east were sampled. Only one collar, DU-16-15, remained in land during the visual survey.

The Figure 7 summary the timing in which the reconnaissance and visual surveys took place in function of the caribou movement. The reconnaissance and visual surveys were scheduled for the time period when caribou were at the highest concentration in the study area. Locations of caribou were categorized by whether they were inland, in the study area, or crossing the sea-ice (Figure5). Using this information, the initial reconnaissance surveys were conducted on October 25th, 26th, and 27th to determine relative densities and locate aggregations of caribou. Systematic surveys were conducted in low density areas (east and west of Victoria Island) on October 29th and 31st. A second reconnaissance of the study area of highest caribou density was conducted on October 31st. This result was used to stratify and allocate effort between strata since it captured latest possible lateral caribou movement along the shoreline. The visual abundance surveys were conducted on November 2nd and 3rd when the highest proportion of radio collared caribou was in the visual strata and the lower density stratum was delayed to be survey until November 5th due to weather.

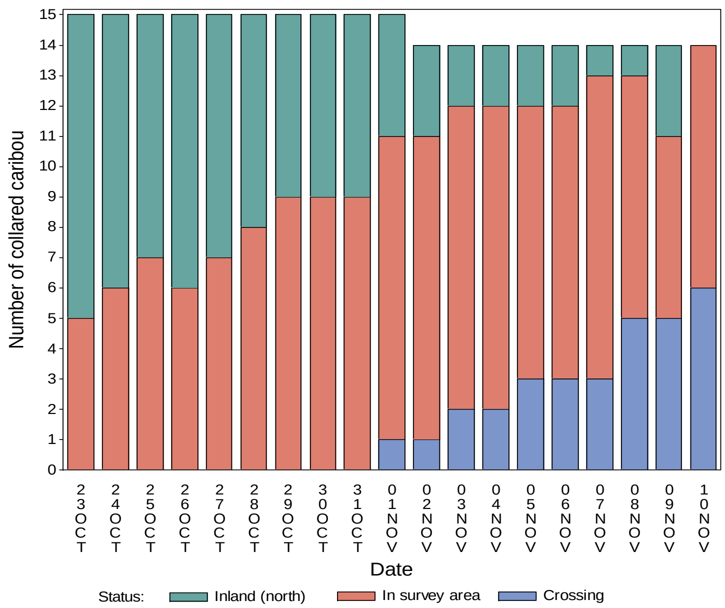


Figure 7: Status of collared caribou by date of survey based on their location, inland (green), survey area (pink) and crossing (blue) between October 23rd and November 1st.

During the visual survey 3,083 caribou were counted in 210 groups (Table3). Approximately half (47%) of group sizes were 10 or less caribou with 23% being great than 20 caribou with a mean group size of 15.2 (median=10, std. dev=16.7, min=1, max=135) (Figure8). Observations were assigned to strata and transect lines within strata for estimation of caribou within each stratum.

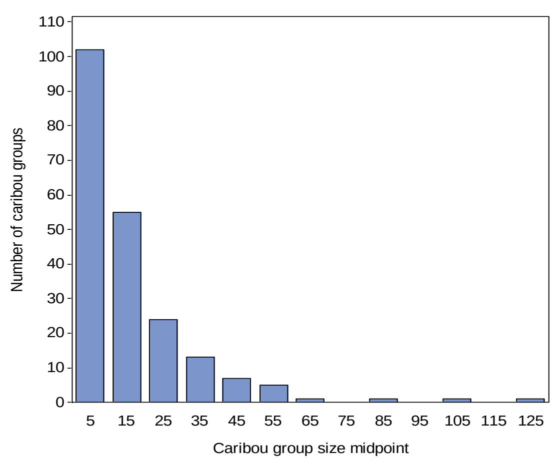


Figure 8: Distribution of group sizes observed during the final visual surveys on November 2nd, 3rd, and 5th.

The final estimates from the five visual stratum are given in Table 3. Highest densities of caribou were found in the HD and MD_E stratum with five caribou per km^2 and the lowest density was found in LD_W strata with one caribou per km^2. One third of the population was estimated from the HD strata. The resulting estimate of 14,730 (SE= 1,507, CV= 10.2%, CI= 11,475-17,986) caribou was precise with a coefficient of variation of 10.2%. No caribou were seen on transects east from Cape Enterprise, and the majority of caribou were continuously distributed between Ross Point and Cape Peel (Figure9).

Table 3: Estimate of caribou on visual survey strata based on aerial survey conducted on November, 2nd, 3rd, and 5th 2015.

Strata	Caribou counted on transect	Density (Caribou per km²)	Estimated caribou ($\hat{N}$)	Standard Error ($\hat{N}$)	Coefficient of variation
LD_W	140	1.39	1,032	377.3	36.6%
MD_W	533	3.85	3,240	769.8	23.8%
HD	1,537	5.84	5,518	814.2	14.6%
MD_E	584	5.04	3,393	754.9	22.2%
LD_E	289	2.82	1,548	550.6	35.6%
Total	3,083		14,730	1,507.0	10.2%

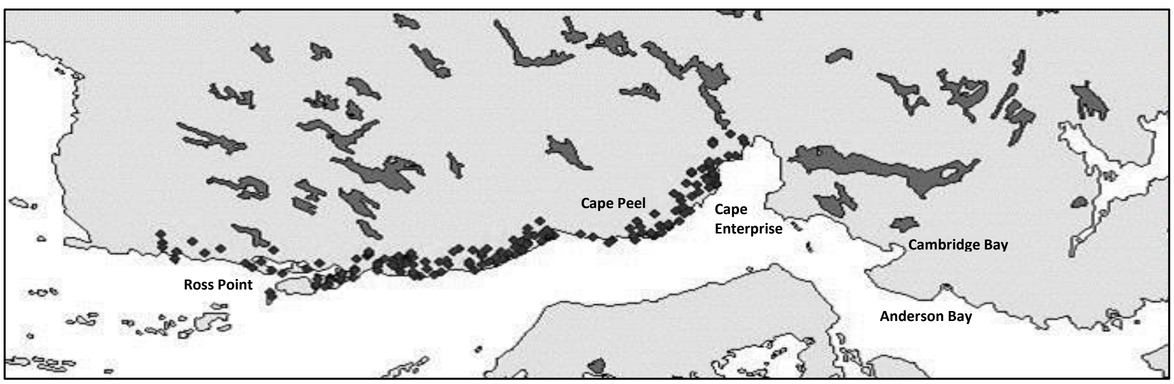


Figure 9: Distribution of Dolphin and Union caribou based on the location of the groups observed during the Final systematic reconnaissance transect line and the final visual stratification.

Extrapolated population analysis

Overall, 11 of 14 collared caribou were within the final strata as the visual survey was progressing. The three collars outside the survey area were: DU-03-15 that crossed the ice, DU-16-15 that was north of the strata for the entire survey, and DU-21-15 that was in areas east of Cambridge Bay. This eastern area was surveyed twice during the reconnaissance flight and the sample sizes of caribou were too low (12 caribou observed on transect) to derive an estimate of caribou at this location. Therefore, DU-21-15 was considered to have not been surveyed, so that the estimate would pertain also to the eastern area. The resulting percentage of collars within the visual survey strata was 79%.

Table 4: Summary of collar locations relative to surveyed areas used for estimation of proportion of collar available. The shaded boxes indicate when a collared caribou was in a stratum that was surveyed.

Id	Location (Date)				
	Nov 2	Nov 3	Nov 5	Available	Comments
DU-02	north	north	1	1	In strata when surveyed
DU-03	cross	cross	cross	0	Across ice before survey conducted
DU-05	1	1	1	1	
DU-06	1	1	1	1	
DU-07	1	1	cross	1	Crossed ice after being surveyed
DU-08	1	cross	cross	1	Crossed ice after being surveyed
DU-09	1	1	1	1	
DU-11	1	1	1	1	
DU-12	1	1	1	1	
DU-13	1	1	1	1	
DU-15	1	1	1	1	
DU-16	north	north	north	0	North of strata for all of survey
DU-23	1	1	1	1	
DU-21	east	east	east	0	In area east of Cambridge Bay
			Average	0.79	

Assuming that the East side of Cambridge Bay contained minimal caribou, as suggested by the surveys (Table 3), then DU-21-15 should not be included in the extrapolated herd estimate, which would reduce the number of total collars within the survey area to 13 and a resulting proportion of collars in the visual survey strata of 85%. The resulting extrapolated herd estimate, in this case, is 17,185 caribou (SE=2,640.8 CV=15.3%, CI=11,481-22,890) which is 2,455 caribou higher than the strata estimate.

However, the extrapolated herd estimate was also calculated with the 11 of 14 collared caribou being within the survey area. The resulting extrapolated herd estimate, using 14 collared caribou, is 18,413 (SE=3,133.8, CV=17.0%, CI = 11,664 to 25,182), which is higher than the strata-based estimate by 3,683 caribou. Confidence limits were calculated using the t-statistic from strata surveys (Table 2; 2.16) with a resulting confidence limit of 11,664 to 25,182 caribou. The estimate of 18,413 DUC assumes that the survey area to the east of Cambridge Bay contained a sizeable number of caribou as indicated by the collared caribou in this area.

Overall trend

A t-test was initially used to compare the 2015 extrapolated estimate 18,413 (SE=3,133.8, CI=11,664-25,182, df=13) and the 2007 extrapolated population estimate 27,787 (SE=3,613, CI=20,250-35,324, df=20). The difference between estimates was significant ($t=1.91$, $df=32$, $p=0.065$) at $\alpha=0.1$. The ratio of the 2007 to 2015 extrapolated population estimates suggests a gross change in herd size of 66.3% (SE=0.15, CI=19.9-96.2%) during the eight-year interval between surveys. Using a z-test, the 2007 extrapolated estimate is also significantly different from the 2015 extrapolated estimate ($Z= -2.19$, $p= 0.036$)

For the trend analysis, the 1997 extrapolated population estimate 34,558 (SE=4,283,CI=27,757-41,359) (Dumond and Lee 2013) was also considered (Figure9). The simulation-based estimate of annual rate of change was 0.96 (SE=0.015, CI=0.93-0.99) suggesting that a significant decline has occurred (the confidence limit for λ does not overlap 1). This translates to an annual rate of decline of 4% (CI=1-7%) since the 1997 survey. This estimate of trend assumes a constant exponential change in herd size. The small number of data points, three surveys, precluded the use of more complex trend models.

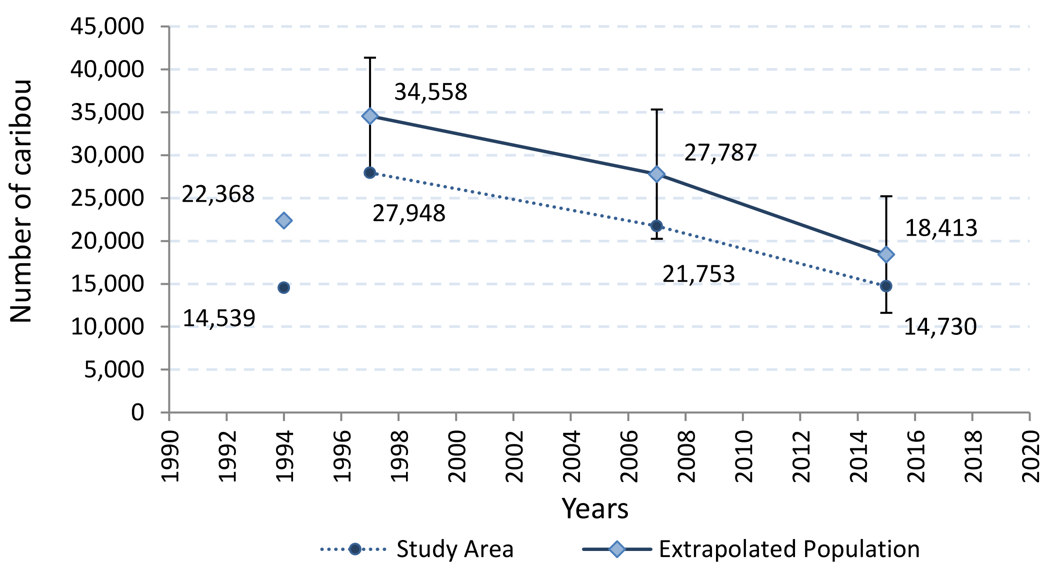


Figure 10: Estimates of herd size for the Dolphin-Union caribou herd from the 1997 survey (Nishi and Gunn 2003), 2007 survey (Dumond and Lee 2013), and the 2015 survey. Estimates based on the surveyed visual strata (dotted line) as well as the extrapolated estimate (solid line) are given.

Population demography, 2015- 2017

Cow survival rate

Dolphin and Union collared caribou were monitored from April 2015 to December 2016 for survival rate analysis. Sample sizes of Dolphin and Union collared caribou ranged from 14 to 30 with an average of 19.7 collars monitored each month (SD = 5.0, n = 21 months) which added up to 414 collar months monitored. During this time there were 18 mortalities with 0.86 deaths per month (SD=1.15, min=0, max=4, n=21 months). Of the mortalities, six (DU-52-2016, DU-57-2016, DU-63-2016, DU-65-2016, DU-67-2016, DU-68-2016) could be attributed to harvest, and one (DU-05-2015) to drowning during the fall migration. Given the relatively low sample sizes, a survival model with equal monthly survival was used. The yearly female survival estimate from this model was 0.70 (SE=0.071, CI=0.55-0.82).

Pregnancy rate

Fecal samples of 34 DUC were collected and 33 were successfully analysed for progesterone level to indicate the pregnancy rate. Individual caribou were confirmed as pregnant if the level was more than 600 ng/g wet feces of progesterone and non-pregnant if this level was below 200 ng/g wet feces (Figure10). From the 33 samples successfully analysed, only four females were barren. This represents a yearly pregnancy rate of 88% in spring 2015 (15/17 caribou pregnant) and 88% in spring 2016 (14/16 caribou pregnant).

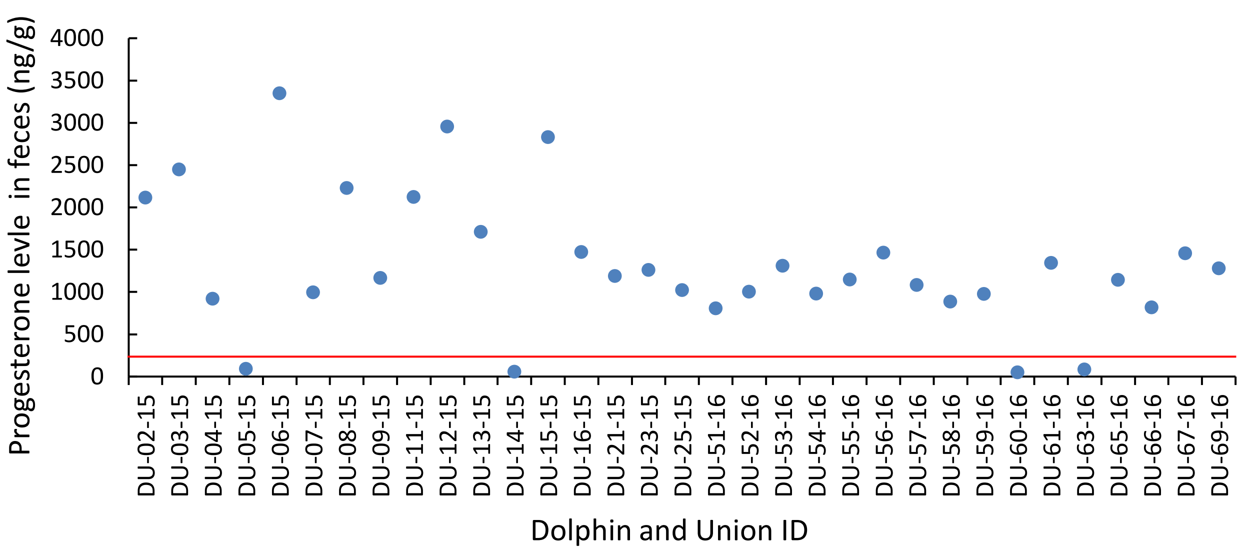


Figure 11: Progesterone level in feces (ng/g) for each Dolphin and Union caribou collared. Level below 200 ng/g were considered as non-pregnant.

Fall and Spring composition survey

The fall composition survey took place from October 26th to 29th, 2016. The survey consisted of transect lines oriented perpendicularly to the shoreline from west of Ross Point all the way to Cape Peel. As the biggest concentration of caribou was found at Ross point and at Cape Peel (Figure11), survey intensity was focus at these two locations with two kilometer transect lines to increase the number of caribou classified.

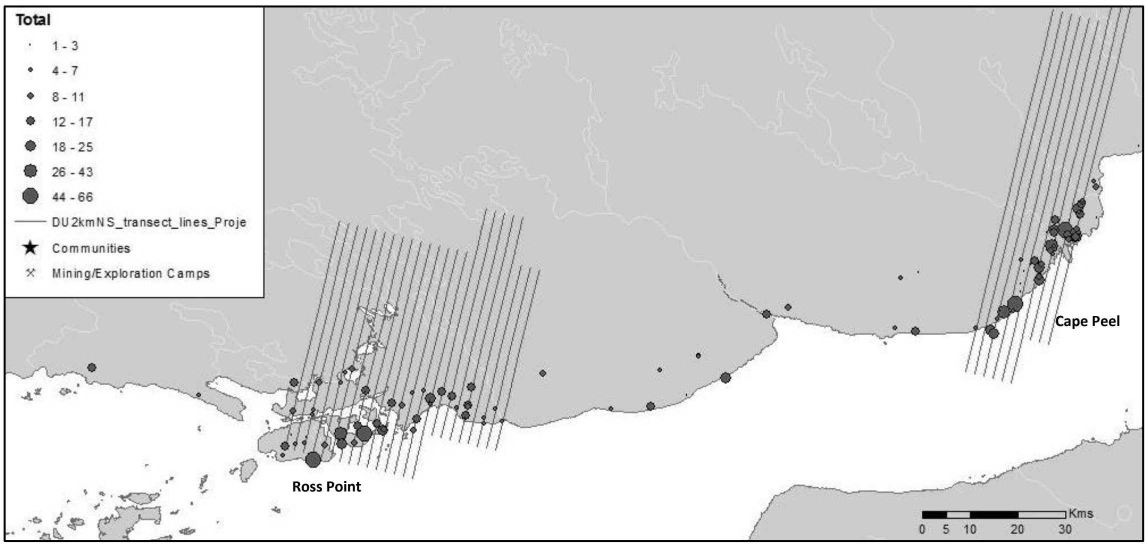


Figure 12: Location and caribou classified in the group during the fall composition survey from October 26 to 29, 2016 along the shore line of Victoria Island mainly at Ross Point and Cape Peel.

During this survey, 136 groups were seen and 1,225 caribou were classified, from which there were 873 cows, 218, calves, 129 yearlings, and 134 bulls. Figure 11 represents the number of caribou classified in each group and not the total caribou within the group. Some caribou were not adequately positioned to assure proper distinction from a male to a female. The calf:cow ratio was of 25:100 (SE= 0.034, CV= 11%). The bull:cow ratio was 15:100. Both Ross Point and Cape Peel has a low bull: cow ratio, which suggests a uniform distribution of sex along the shore line.

The spring composition survey was performed from March 24th to 28th, 2017 on the Canadian mainland from Tree River to Hope Bay. Collar locations (red dots, Figure 12) were used to find caribou. From the 17 collar locations in the study area, 15 were visited and only 2 collars were seen. 24 groups and 229 caribou were classified. The calf:cow ratio was 11:100 (SE= 0.025, CV= 22%).

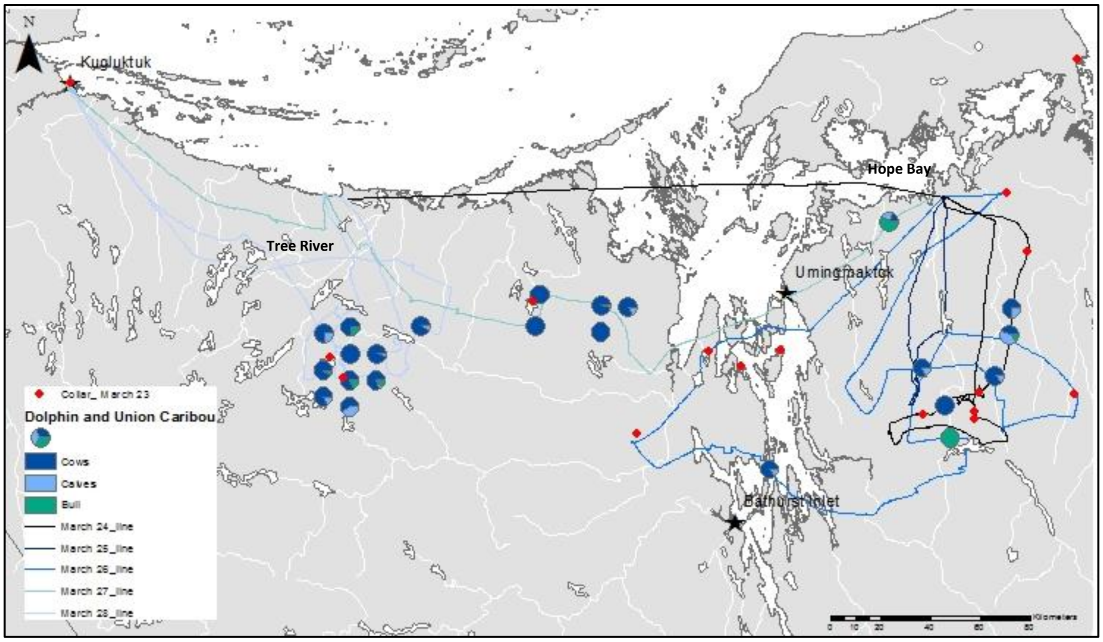


Figure 13: Location and group composition of caribou classified during the spring composition survey from March 24 to 28, 2018 on the Canadian Mainland from Tree River to Hope Bay. Active collar locations are represented by red dots.

Discussion

Collar deployment, 2015 and 2016

The DUC herd winter on both side of Bathurst Inlet and are known to start their spring migration in early April (Gunn *et al*., 1997). In 1993, a mainland coastline survey to monitor the number of caribou crossing back to Victoria Island was carried out between April 30th to May 13th (Gunn *et al.,* 1997) and where the median date for the spring crossing was May 24th in the late part of this decade(Pool *et al.*, 2010). From 2015 and 2016, the best time to find the caribou on the coast line was around April 7th to 11th. The occurrence of caribou along the coast in early April suggests a shift in the timing of the spring migration that might have occurred in the recent years. On April 15th 2016, caribou tracks were already seen off the coast onto the sea-ice, prohibiting us from collaring any further at this location and limiting us to concentrating our effort to the east side of Bathurst Inlet. DUC wintering to the west of Bathurst Inlet are known to cross earlier than the animals to the east side of Bathurst Inlet (Pool *et al.,* 2010).

In addition to a timing difference in the spring migration, it seems that the wintering strategy between the animal wintering on the east and the west side of Bathurst Inlet is also different. Contrary to the west side, the DUC wintering range overlaps spatially and temporally with a

Barren-ground caribou herd on the east side of Bathurst Inlet. Individuals of the DUC herd and Barren ground caribou herd were found together in mixed groups. There are slight physical differences between the two types of caribou such as, the color of their backs and legs, the shape of their snouts, and the longer length of legs, which were confirmed by genetic analysis and/or by their respective calving location determined with collars. Although more intensive study is needed, the DUC herd appears to winter with the Ahiak caribou herd, tundra wintering Barren-ground caribou. Future collaring, harvest management, and the mining companies' mitigation and monitoring programs on the east side of Bathurst Inlet should take into consideration the overlap of these two herds.

During the collaring, DUC were pre-selected based on their general fatness appearance (well-padded ribs and hips) as healthy caribou have a better chance to survive during the collar life. This intentional bias explains the skewed health index toward caribou in good condition (Figure 3). Even though the collared caribou did not show any signs of disease, they can still be seropositive for pathogens. Blood samples from the collared caribou and harvest sample kits in 2015 and 2016 show that the DUC herd has a seroprevalance to *Toxoplasma gondii* (7%), *Brucella suis* (15%), and *Neospora canium* (22%). These two first pathogens are known to cause abortion and weak calves in *Rangifer* or at least in domestic animals in the case of *N. canium* (Carlsson *et al*., in prep). As these pathogens are known to impact survival and fecundity, they can play an important role in ungulate population dynamic (Irvine, 2006).

Population estimates

The DUC were found staging on the southern coast of Victoria Island waiting for the sea-ice to form on Coronation Gulf and Dease Strait to resume their migration toward the Canadian Mainland. The DUC fall aggregation on the south coast of Victoria Island makes a population survey logistically feasible and biologically meaningful.

Nonetheless, conducting aerial surveys in October along the coast of Victoria Island is a challenging task. The weather characterized by freezing drizzle, ice crystals, low ceiling, patchy fog, and the difficulty of flying at survey altitude over thin grey ice makes it challenging. However, the survey took place in relatively good weather, when visibility was maximal or reduced visibility did not persist over the total length of a transect line. As the survey advanced into November, the daylight hours shortened, which meant the survey had to be completed over a short working day. Coupled with these challenges, is the short time frame in which most of the caribou have reached the coast, but not yet moved onto the newly formed sea-ice (Figure 7).

The reconnaissance survey, flown at the same time as the 2007 survey (Dumond and Lee, 2013), allowed us to determine the distribution of caribou, the higher density areas, and the extent of caribou inland. Most caribou group, of both sexes and all age groups, were within a narrow band along the shoreline with no caribou beyond 10 km inland (Figure 6). Transects were short, which kept the observers alert. In the two previous surveys, only a right and left observers were used (Nishi and Gunn, 2004; Dumond and Lee, 2013). In 2015, two observers were used per side on the final visual survey, but their observations were confirmed together and were reported as one observation. Previous research has suggested that if four observers are used fewer caribou will be missed and those that are can be estimated (Campbell *et al.*, 2012, Boulanger *et al.*, 2014a). For future Dolphin and Union surveys, we recommend the use of a double observer platform were the front and rear observers sightings can be recorded independently.

DUC are generally found in small groups along the coastline. In 1997, 322 groups varying from 1 to 477caribou were observed on transect, with a median of 8 and a mean of 15.8 (Nishi and Gunn, 2004). In 2015, the majority of group sizes observed on transect were 10 caribou or less, which is consistent of what has been reported by local knowledge a year prior to the survey (Tomaselli *et al.,* 2018). Some larger group sizes (up to 135 caribou) were also observed in 2015, which could have caused counting bias. The usual direction of counting bias of large caribou group is an underestimation (Elphick, 2008). It is hard to determine the exact magnitude of bias given few empirical comparisons of counted caribou in relation to true group size. A comparison of counts from a photo plane and visual counts on the Bluenose East 2013 survey (Boulanger *et al*., 2014) suggested that counts were up to 15% lower than photos, however, the difference in this study was due to both counting bias and detection of groups. The general assumption, in the context of the DUC studies, is that the magnitude of counting bias has been similar for all years of the study.

In 2015, the extent of the reconnaissance survey was greater than in 1997 and 2007. However, unlike with 1997 and 2007 surveys, no caribou were seen east of Cambridge Bay along the coast from Cape Enterprise to Anderson Bay (Figure 9). There was only a continuous density of caribou along the coastline from the Richardson Island to Cape Peel. Local knowledge gathered in 2014 revealed a decrease of 80% (75-90; range 50-95; n = 7) of DUC, where very few scattered caribou were seen around Cambridge Bay from October to mid-November (Tomaselli *et al.,* 2018). In 1997, 55.5% of the population estimate was determined by the number of caribou east of Cambridge Bay with density reaching 9.79 caribou / km^2 (Nishi and Gunn, 2004). With similar density to the west in 1997 (6.19 and 4, 35 caribou/ km^2) (Nishi and Gunn, 2004) and 2015 (3.85, 5.84 caribou/ km^2), the lack of caribou from Cape Enterprise to Anderson Bay has might have accounted for a decrease in the overall DUC population number. The reason behind the decrease of caribou to the east of their range is currently unknown, but the causes have had an impact at the population level.

All the final visual strata for the three Dolphin and Union population surveys were stratified based on relative caribou density. Therefore, the transect lines flown, the number of visual strata, and the percentage of coverage are expected to vary from survey to survey. In 1997, the survey consisted of 1,047 km of transects with strata variating in coverage from 9 to 20.4%. This resulted in 5,087 caribou counted on transect (Nishi and Gunn, 2004). The 2007 survey had less overall coverage, 651 km total, though survey coverage varied from 11% to 20% and 2,669 caribou were counted on transect and 4,362 counted on a small island (Dumond and Lee, 2013). In 2017, the final visual strata had a total of 900 km of transect line with coverage varying from 13 to 28% and 3,083 caribou were counted on transect. Coefficient of Variation varied between survey (1997= 12% 2007 = 13%, 2015 = 10%) with all falling within the targeted 15% of the mean estimate (95%) confirming the precision of the total number of caribou estimated in all the final visual strata.

Dumond and Lee (2013) used two methods to adjust the resulting estimates and generate an extrapolated population number, the Lincoln-Petersen Index method and Innes *et al*., (2002). All of the collar methods assume that the distribution of collars is representative of the overall distribution of the herd. The Innes *et al*., (2002) considered the availability of caribou on the study area based on collar locations in previous years. In this case, the availability was estimated by the proportion of locations of caribou in the study area for the entire duration of the study (Innes et al 2002). The availability estimator basically equates availability to detection probability to allow a corrected estimate of herd size. The 1997 and 2007 extrapolated population estimate was based on Innes *et al.,* (2002) resulting in 34,558 (SE =4,283, Cl= 27,272-41,359) and 27,787 (SE =3,613, Cl= 20,250-35,324) caribou respectively.

Similarly, we used the Lincoln Petersen Index method, which classified caribou as being within or outside the study area during the survey and used this ratio to estimate detection probability and adjusted herd size. Unlike previous surveys, we had direct locations of caribou during the survey and were therefore able to directly estimate availability relative to where areas were surveyed. The Lincoln Petersen method was then most applicable, since we had current locations of collared caribou during transect sampling. It was possible to accurately determine whether caribou were within or outside the survey strata when they were surveyed. We were also able to provide evidence confirming the assumption behind the fall survey that the large majority of this herd stage along the southern coastline prior to migration, as 79% of the collars had reached the survey area during the final visual survey.

An assumption of the Lincoln Peterson estimator is that the collars are exhibited randomly, so that each collared caribou represents the relative availability of caribou in the herd to be surveyed. Observations of caribou during the survey, and flights around single collared caribou that were not in the survey area indicate that this assumption was likely violated. Namely, the single collared caribou outside of strata were outlier with low numbers of caribou in their vicinity compared to the majority of caribou (and collared caribou), which were aggregated into larger groups. If this is the case, then the actual availability of caribou to be surveyed was higher than that indicated by the collared caribou. Therefore, the adjusted estimate is positively biased. Regardless, the relatively small sample size of collars resulted in a relatively imprecise estimate of availability, which in turn reduced the adjusted herd size estimate. A higher number of collars available during the survey would help timing the final visual survey, increase the precision of the final extrapolated population estimate, and provide additional evidence validating the critical assumption behind a fall survey for this herd.

The 2015 survey resulted in an extrapolated population estimate of 18,413 (SE=3,133.8, CI = 11,664 to 25,182). Cambridge Bay hunters indicated that some caribou were seen in land on the east side of Cambridge Bay a few days after the survey was completed (G. Angohiatok pers. comm). Even though only one collar was at this location and no caribou were seen on transect east of this location, this ground observation justified the inclusion of the collar DU-21-05 in the extrapolated herd estimate, bringing the extrapolated population estimate from 17,185 to 18,413 caribou.

Overall trend

The 2007 and 2015 extrapolated population estimates are significantly different, suggesting that a decline has occurred between these periods. Trend estimates from the 2015 survey suggest the population is declining at a rate of 4% per year (CI= 1-7%). Trend analyses suggest that this decline cannot be attributed to variance in survey estimates. Since the DUC resumed their migration in the 1900s, the herd became accessible to harvest from the community of Kugluktuk, Cambridge Bay, Bay Chimo, and Bathurst Inlet (Department of Resource, Wildlife, and Economic Development, 1998). It was estimated with uncertainty that the harvest on this herd could have reached 2,000 to 3,000 caribou a year (5%-8% harvest rates) (Gunn *et al.,* 1986), which was a contributing factor for the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the DUC has a species of special concern in 2004 (COSEWIC, 2004).

Harvest levels and overall harvest rates for the DUC herd were unknown after the Kitikmeot Harvest study due to an unsuccessful voluntary harvest reporting system in Nunavut. With the decline in population, the DUC became less accessible, which likely had the net effect or reducing harvest pressure on the herd (Environment and Climate Change Canada, 2018). Based on voluntary kill reports and an increase in Conservation Officers' monitoring effort, the total harvest estimate reported 350 caribou in 2015-2016 and 250 caribou in 2016-2017 harvest season, though these figures are likely underestimates. To determine if the current harvest pose a risk to accelerate the decline in the herd size, harvest model simulations with demographic indicators (cow survival, calf productivity) should be carried out to obtain an accurate risk assessment (Boulanger *et al*., 2011; Boulanger *et al*., 2016).

Population demography, 2015- 2017

Cow survival rate

Estimates of survival from collars (0.70, CI=0.57-0.81) suggest a low survival rate, which is lower than the 0.76 survival rate from the collars monitored from 1999 to 2004 for this herd (Poole et al, 2010). The low survival rate is similar to the Bathurst herd in 2009, where survival was estimated at 0.67 (Boulanger *et al.*, 2011). This collar survival rate should be interpreted cautiously given low sample sizes of collars and a minimal amount of knowledge about fates of collared caribou. In this study, six collared females were harvested by Cambridge Bay hunters; one during the fall migration; and the remaining ones to the east side of the Kent Peninsula during the spring migration. Causes of known mortality suggest higher harvest rates then evident though voluntary reporting. With the rarity of DUC and the lack of availability of alternative caribou herds from Cambridge Bay, the Cambridge Bay hunters might not have avoided harvesting collared caribou. Of the non-hunting deaths, only one could have been attributed to a drowning incident. Previously, 50% of the mortality occurred between October 20th and December 8th (Pool *et al*., 2010), and these were mostly related to drowning incidents while the caribou attempted to cross freshly formed grey ice. This fall-early winter sea-ice crossing mortality was observed a few years after the migration to the mainland resumed. Thus, it is possible that the DUC have adapted to their environment and learned to cross the sea-ice more successfully (G. Angohiatok pers. Comm.). However, the delay in sea-ice formation and ice breaking activities can still generate unknown implications for the caribou, such as physiological cost or reduce period of access to winter forage due to a longer staging period (Poole *et al*., 2010).

Pregnancy rate

The reproduction rate is one of the most important parameter used to monitor the growth potential of a population (Bergerud *et al.,* 2008). Pregnancy rate is usually established by the udder counts in June or calve at heel during the peak of calving. However, this would be an expensive method to determine pregnancy rate for the DUC herd due to their independent calving strategy spread over Victoria Island. Nonetheless, pregnancy rate was determined by the level of fecal progesterone of collared cows. Pregnancy rates of the DUC, were considered relatively high at 88% for both years. These finding suggest that the cows are in sufficient body condition to ovulate in the fall (Bergerud *et al.,* 2008). For the George River Caribou Herd, a pregnancy rate of 89% to 100% was needed for the herd to increase in the 1970s, while pregnancy rates from 59% to 78% was recorded when the herd decreased in the early 1990s (Bergerud *et al.,* 2008). The 2015 and 2016 pregnancy rate is consistent with the reproduction rate supporting a population growth.

Additionally, these rates fell within the range of previous recorded pregnancy rates for this herd. Pregnancy rates of DUC, prior to resuming their migration, were available from a late-winter collection (April) on Victoria Island from 1987 to 1992. During this time, pregnancy rates ranged from 65% to 100%, with an average of 79.2%. The pregnancy rates were generally high, but the yearly variation suggested continued monitoring is required to track potential changes and investigate complementary mechanisms (Department of Resource, Wildlife, and Economic Development, 1998).

Fall and Spring composition survey

During the fall, the bull to cow ratio was investigated. The adult ratio is usually 1 male to 2 females, as the males are known to have a higher mortality rate than female (Bergerud *et al*., 2008). The low bull to cow ratio of the DUC herd (15%) might indicate a higher mortality rate for males. Even when the population was at its historic high in the late 1990s, harvesters have mentioned fewer bulls available to hunt during the fall (Department of Resource, Wildlife, and Economic Development, 1998). In the fall, the community of Cambridge Bay usually allows sport harvests to take place on the DUC, which target males only. This practice might explain the lower ratio of males encountered. The differential vulnerability of young caribou is most pronounced in fall and early winter due to exposure to more severe climatic conditions and potential winter food shortages. Results from the fall 2016 composition survey show a high summer mortality rate with 25 calves per 100 cows. However, the results of the fall 2016 composition survey should be interpreted with caution, as classification by fixed-wing is difficult and can be subject to significant error when classifying the sex of yearling. A composition done on the ground might be more suitable method.

The 2017 spring composition survey showed an indicator of the winter mortality. In 2017, the calf to cow ratio was low, 11 calves to 100 cows. Normally, a spring recruitment of 25 calves to 100 cows is necessary to maintain a stable caribou population number and 9-19 calves to 100 cows is characteristic of a declining herd (Bergerud *et al*., 2008). Bias in the spring composition survey was not likely attributed to missing early cows and calves (Gunn *et al.,* 1997), as the survey took place before the migration. However, the 2017 ratio could have been influence by the difficulty to differentiate Barren-ground caribou from Dolphin and Union in the group composition on the east side of Bathurst Inlet. A more accurate spring composition survey should only be carried out on the west side of Bathurst Inlet to avoid this source of bias.

These demographic indicators suggest recruitment rate consistent with decline, since the last population survey. There is a need to monitor these vital rates on a yearly basis to allow for a better estimate of trend in the population in-between survey years (Todd and Rothermel, 2006).

Conclusion

The DUC are a migratory herd that is vulnerable to threats to their habitat and survival along their range. Numerous reported anthropogenic and environmental factors are potentially having a negative impact on the herd. From 1997 to 2007, the DUC population abundance was, at best, stable, but many factors indicate that the population could be declining. The likely: higher harvest level, the increase in predation by predator species colonizing on Victoria Island, increase in fall mortality due to delay of ice formation, and reports of poor body condition (Species at Risk Committee, 2013), were all signs of a potentially declining population. A declining trend was confirmed in 2015 by the population assessment suggesting a 66% reduction in herd size. Since the system of co-management in Nunavut requires an extensive amount of consultation and cooperation between public officials and indigenous users, the development of management recommendations might be lengthy and there is a risk that management actions could be implemented too late. To avoid this from occurring, an early detection system, based on a fixed set of criteria should be developed to trigger population surveys that capture significant change in herd size.

No DUC were observed to be using the coast of Victoria Island from Wellington Bay and East of Cambridge Bay along the coast from Cape Colburne to Anderson Bay. The low number of caribou contributed to the difficulty to accessing the herd during the rut and consequently finding them on the land. Additional health and demographic parameters were investigated to gain a better understanding of the potential causes of the declining trend. Factors such as the low female survival rate and the presence of pathogens in the Dolphin and Union herd, which contribute additionally to the low calf survival and recruitment rate, have been found to be negatively affecting the population number and recovery. For the pregnancies that reached term, the weak calves affected by *Toxoplasma gondii, Brucella suis*, and/or *Neospora canium* could be more at risk of predation (Krumm *et al*., 2010; Murray *et al*., 1997) and their low natural survival rate may result in increased predation by wolves and bears. The harvesters of Kugluktuk and Cambridge Bay have reported an increase in number of predators, Wolf and Grizzly bears, on the seasonal range of the DUC (HTO pers. Comm., 2015, 2016, 2017).

The current research program did not gather information between the potential relationship between the trend towards late sea-ice formation and the increased risk of deaths due to drowning (Pool *et al.* 2010). In addition, development occurring on the eastern wintering range of the Dolphin and Union, may have an unknown degree of impact on the caribou population that could become cumulative over time and become more important as the herd's vulnerability increases. Although the population impact of these two factors remain currently uncertain, the changes to sea-ice affecting migration and human development (mining, roads) are still acknowledged as threats to the Dolphin and Union population (Environment and Climate Change Canada, 2018).

Acknowledgements

I wish to give a very special thanks to Mike Bergmann, for his dedication, support, and enthusiasm. All the pilots involved in the population, fall and spring composition surveys as well as the capture crews. Justin McPherson (Caslys consulting) and John Boulanger assisted with GIS tasks throughout the survey stratification and complementary analysis. Wildlife Technicians, Myles Lamont and Thomas Bolt, for logistic and field work help. I am grateful to the Cambridge Bay Hunters and Trappers Organization for their assistance in providing observers and guides. Special thanks goes to Junior Tikhok, Jimmy Haniliak, David, Gary, Aaron Pedersen, Joseph Tikhok, Brent Nakashook, Kevin Taylor, Ivor Maksagak, Jeff Sather, Howard Greenley, and Richard Epakohak. This project was funded by the Department of Environment (Government of Nunavut), Nunavut Wildlife Research Trust, Habitat Stewardship Program, and TMAC. This program was completed under Research Permits 2015-006, 2016-011, and 2017-015.

References

Bates, P. 2006. Knowing caribou: Inuit, ecological science and traditional ecological knowledge in the Canadian North. Ph.D. dissertation, Aberdeen University, Aberdeen, Scotland. 270 pp.

Bergerud, A.T. 1996. Evolving perspectives on caribou population dynamics. Rangifer Special Issue No.9: 95-118.

Bergerud, A.T., S.N. Luttich, L. Camps. 2008. The Return of Caribou to Ungava. MQUP. 656 pp.

Bird, J.B., and Bird, M.B. 1961. Bathurst Inlet, Northwest Territories. Geographical Branch, Department of Mine and Technical Surveys Memoir 7.

Boulanger, J., A. Gunn, J. Adamczewski, and B. Croft. 2011. A data-driven demographic model to explore the decline of the Bathurst caribou herd. Journal of Wildlife Management 75:883-896.

Boulanger, J., B. Croft, and J. Adamczewski. 2014. An estimate of breeding females and analysis of demographics from the 2012 Bathurst barren ground caribou calving ground survey. Department of Environment and Natural Resources, Government of Northwest Territories File Report No. 142.

Boulanger, J., B. Croft, and J. Adamczewski. 2014. An estimate of breeding females and analyses of demographics for the Bluenose East herd of barren ground caribou: 2013 calving ground photographic survey. Department of Environment and Natural Resources, Government of Northwest Territories, File Report No. 143.

Boulanger, J., and J. Adamczewski. 2016. A General Approach to Harvest Modeling for Barren-Ground Caribou Herds in the NWT and Recommendations on Harvest Based on Herd Risk Status, ENR Manuscript report No 262. Integrated Ecological Research and Environment and Natural Resources, Govt. of NWT.

Boulanger, J., B. Croft, J. Adamczewski, D. Cluff, M. Campbell, D. Lee, Nic Larter. 2017. An estimate of breeding females and analyses of demographics for the Bathurst herd of Barren-ground caribou: 2015 calving ground photographic survey. Department of Environment and Natural Resources, Government of Northwest Territories Manuscript Report No. 267.

Boulanger, J., B. Croft, J. Adamczewski, D. Lee, N. Larter, L-M. Leclerc. 2016. An estimate of breeding females and analyses of demographics for the Bluenose-East herd of Barren-ground caribou: 2015 calving ground photographic survey. Department of Environment and Natural Resources, Government of Northwest Territories Manuscript Report No. 260.

Boulanger, J., M. Campbell, D. Lee, M. Dumond, and J. Nishi. 2014a. A double observer method to model variation in sightability of caribou in calving ground surveys. Rangifer In. prep.

Boulanger, J., B. Croft, and J. Adamczewski. 2014b. An estimate of breeding females and analysis of demographics from the 2012 Bathurst barren ground caribou calving ground survey. Department of Environment and Natural Resources, Government of Northwest Territories File Report No. 142.

Boulanger, J., A. Gunn, J. Adamczewski, and B. Croft. 2011. A data-driven demographic model to explore the decline of the Bathurst caribou herd. Journal of Wildlife Management 75:883-896.

Campbell, M, D. Lee, J. Boulanger, A. Kelly, M. Dumond and J. McPherson. 2013. Calving ground abundance estimates of the Beverly and Ahiak subpopulations of Barren-Ground Caribou (Rangifer tarandus groenlandicus)- June 2013. Government of Nunavut, Department of Environment, Tech. Rep. Ser. No: 01-2013.

Campbell, M., J. Boulanger, D. S. Lee, M. Dumond, and J. McPherson. 2012. Calving ground abundance estimates of the Beverly and Ahiak subpopulations of barren-ground caribou (*Rangifer tarandus groenlandicus*) – June 2011. Nunavut Department of Environment, Technical Summary, Arviat NU. 111 pp.

Campbell, M., J. Boulanger, D. Lee, M. Dumond, and J. McPhearson. 2012. Calving Ground Abundance Estimates of the Beverly and Ahiak Subpopulations of Barren-Ground Caribou (Rangifer tarandus groenlandicus) – June 2011, Technical Summary. Department of Environment, Government of Nunavut.

Carlsson, A.M., P. Curry, B. Elkin, D. Russell, A. Veitch, M. Branigan, M. Campbell, B. Croft, C. Cuyler, S.D. Côté, D. Cooley, L-M. Leclerc, M. Tryland, IH Nymo, S. Kutz. Multi-pathogen serological survey in migratory caribou herds: a snapshot in time. In preparation.

CARMA. 2008. Rangifer Health and Body Condition Monitoring: Monitoring Protocols Level 2. CircumArctic Rangifer Monitoring and Assessment Network. 54 p.

Cochran, W.G. 1997. Sampling Techniques. 3rd ed. Wiley, New York.

Cody, W. J., Scotter, G.W., and Zoltai, S.C. 1984. Addition to the vascular plan flora of the Bathurst Inlet region, Northwest Territories. Canadian field-naturalist, Vol 98 (2): 171-177.

COSEWIC. 2004. COSEWIC assessment and update status report on the Peary caribou *Rangifer tarandus pearyi* and the barren-ground caribou *Rangifer tarandus groenlandicus* (Dolphin and Union population) in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa.

Crete, M. S., S. Couturier, J. Hearn, and T. E. Chubbs. 1996. Relative contribution of decreased productivity and survival to recent changes in the demographic trend of the George River herd. Rangifer 9:27-36.

Department of Resources, Wildlife, and Economic Development. Southern Victoria Island (Dolphin and Union) caribou Management Planning; Summary of User Community Converns and Action Items. October 1998, Kitikmeot Region. Unpublished.

Dumond, M., and D. Lee. 2013. Dolphin and Union caribou herd status and trend. Arctic 66:329-337.

Elphick, C. S. 2008. How you count counts: the importance of methods research in applied ecology. Journal of Applied Ecology 45:1313-1320.

Edlund, S.A. 1990. Bioclimatic zones in the Canadian arctic archipelago. In Canada's missing dimension: science and history in the Canadian Arctic Islands. Vol.1. Edited by C.R. Harington. Canadian Environment Canada. 1982. Canadian climatic normal, 1951-1980. Vols. 2 and 3. Atmospheric Environmental Service, Environment Canada, Ottawa.

Environment Canada 1995. Ecological Framework of Canada. http://ecozones.ca/english/. Accessed September 1 2014.

Environment and Climate Change Canada. 2018. Management Plan for the Barren-ground Caribou (*Rangifer tarandus groenlandicus*), Dolphin and Union Caribou (*Rangifer tarandus groenlandicus* x *pearyi*) in the Northwest Territories and Nunavut. Species at Risk Act Management Plan Series. Environment and Climate Change Canada. Ottawa. 2 parts, 3pp.+ 102pp.

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

Godsell, P. 1950. Arctic Trader. The Travel Book Club. 320 pp.

Gunn A., K. Jingfors, and P. Evalik. 1986. The Kitikmeot harvest study as a successful example for the collection of harvest statistics in the Northwest Territories. Pages 249-259 in Native people and renewable resource management. Proc. Of the 1986 symposium of the Alberta Society of Professional biologists, Edmonton, AB.

Gunn A., A. Buchan, B. Fournier, and J. Nishi. 1997. Victoria Island caribou migrations across Dolphin and Union Strait and Coronation Gulf from the mainland coast, 1976-1994. Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, Yellowknife, Manuscript Report No. 94. 74 pp.

Gunn, A., D. Russell, and J. Eamer. 2011. Northern caribou population trends in Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No 10 Canadian Councils of Resource Ministers. Ottawa, ON. iv+71p.

Gunn, A. and B. Fournier. 2000. Caribou herd delimitation and seasonal movements based on satellite telemetry on Victoria Island 1987-89. Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, File Report No. 125. 104 pp.

Heard, D. C. 1985. Caribou census methods used in the Northwest Territories. McGill Subarctic Research Papers 40:229-238.

Hewitt, C. Gordon. 1921. The conservation of the wildlife of Canada. 344p.

Innes, S., M. P. Heidi-Jorgensen, J. L. Laake, K. L. Laidre, H. J. Cleator, P. Richard, and R. E. A. Stewart. 2002. Surveys of belugas and narwhals in the Canadian High ArcticNAMMMCO Scientific Publications No. 3.

Irvine, R. 2006. "Parasites and the dynamics of wild mammal populations." *Animal Science* 82 (06):775-781.

Jolly, G. M. 1969. Sampling methods for aerial censuses of wildlife populations. East African Agricultural and Forestry Journal 34:46-49.

Joly, K., Wasser, S.K., Booth, R. 2015. Non-invasive assessment of the interrelationships of diet, pregnancy rate, group composition, and physiological and nutritional stress of barren-ground caribou in late winter. PLoS ONE 10(6):e0127586

Krebs, C.J. 1989. Ecological Methodology. Harper and Row, New York.

Krebs, C. J. 1998. Ecological Methodology (Second edition). 2 Edition. Benjamin Cummins, Menlo Park, CA.

Krumm, C.E., M.M. Conner, N.T. Hobbs, D.O. Hunter, and M.W. Miller. 2010. Mountain lions prey selectively on prion-infected mule deer. *Biol. Lett.* 6 (2):209-211.

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

Maxwell, J.B. 1981. Climitic regions of the Canadian Arctic Island. Arctic 34: 225-240.

McCullough, D.E. 1994. What do herd composition counts tell us? Wildl. Soc. Bull. 22: 295-300.

Murray, D.L., J.R. Cary, and L.B. Keith. 1997. Interactive effects of sublethal nematodes and nutritional status on snowshoe hare vulnerability to predation. *J. Anim. Ecol.*:250-264.

Nishi, J., and A. Gunn. 2003. An estimate of herd size for the migratory Dolphin and Union caribou herd during the rut (17-22 October 1997). Department of Resources, Wildlife, and Economic Development, Government of NWT.

Pachkowski, M., Cote, S.D. and Festa-Bianchet, M. 2013. Spring-loaded reproduction: effects of body condition and population size on fertility in migratory caribou (*Rangifer tarandus*). Can. J. Zool. 91: 473-479.

Pool, K., A. Gunn, B. Patterson and M. Dumond. 2010. Sea ice and migration of the Dolphin and Union caribou herd in the Canadian Arctic: An uncertain future. Arctic 63: 414-428.

Ouellet, J.-P., Heard, D.C., Boutin, S., Mulders, R. 1991. Body condition and pregnancy rates of the expanding Southampton Island caribou herd. Rangier, Special Issue No 7: 158

Rivest, L. P., S. Couturier, and H. Crepeau. 1998. Statistical methods for estimating caribou abundance using postcalving aggregations detected by radio telemetry. Biometrics 54:865-876.

Schaefer, J.A., and Messier, F. 1994. Composition and spatial structure of plan communities on southeastern Victoria Island, arctic Canada. Can. J. Bot. 72: 1264-1272.

Seber, G. A. F. 1982. The Estimation of Animal Abundance. 2nd edition. Charles Griffin and Company, London.

Serrouya, R., D., Paetkau, B. N., McLellan, S., Boutin, M., Campbell and D. A. Jenkins. 2012. Population size and major valleys explain microsatellite variation better than taxonomic units for caribou in western Canada. *Molecular Ecology*, *21*(11), 2588-2601.

Species at Risk Committee. 2013. Species Status Report for Dolphin and Union Caribou (*Rangifer tarandus groenlandicus x pearyi*) in the Northwest Territories. Species at Risk Committee, Yellowknife, NT.

Sokal, R.R. and F.J. Rohlf. 1981. Biostatistics, 2nd Ed. Freeman, San Francisco.

TAEM, 1996. 1995/1996 Year One Progress Report. Development and Application of Animal Borne GPS Technology on Woodland Caribou. A report of the Research and Development Committee of Manitoba Hydro.

Thorpe, N.L., S. Eyegetok, N. Hakongak, and Qitirmiut Elders. 2001. The Tuktu and Nogak Project: a caribou chronicle. Final Report to the West Kitikmeot Slave/Study Society. West Kitikmeot Slave/Study Society. Ikaluktuuttiak, Northwest Territories. 198 pp plus maps.

Thompson, S. K. 1992. Sampling. John Wiley and Sons, New York.

Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring Vertebrate Populations. Academic Press, San Diego, California, USA.

Todd, B.D. and B.B. Rothermel. 2006. Assessing quality of clearcut habitats for amphibians: effects on abundances versus vital rates in the soutern toad (*Bufo terrestri*). Biological Conservation 133: 178-185.

Tomaselli, M., S. Kutz, S. Gerlach, C., Checkley, S. 2018. Local knowledge to enhance wildlife population health surveillance: Conserving muskoxen and caribou in the Canadian Arctic. Biological Conservation. 217: 337-348.

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