Distribution and abundance of muskoxen (*Ovibos moschatus*) and Peary caribou (*Rangifer tarandus pearyi*) on Graham, Buckingham, and Southern Ellesmere Islands, March 2015

Morgan Anderson[1] & Michael C. S. Kingsley[†]

[1] Wildlife Biologist High Arctic, Department of Environment, Wildlife Research Section, Government of Nunavut Box 209 Igloolik, NU X0A 0L0. Current address: BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development, 2000 South Ospika Blvd Prince George BC V2N 4W5, (Corresponding author: Morgan.Anderson@gov.bc.ca).

Abstract: We flew a survey of southern Ellesmere Island, Graham Island, and Buckingham Island in March 2015 to obtain estimates of abundance for muskoxen and Peary caribou. Generally, muskoxen were abundant north of the Sydkap Ice Cap along Baumann Fiord, north of Goose Fiord, west and north of Muskox Fiord, and on the coastal plains and river valleys east of Vendom Fiord. Although few, they were also present on Bjorne Peninsula and the south coast between the Sydkap Ice Cap and Jakeman Glacier. We observed a total of 1146 muskoxen. Calves (approximately 10-months old) made up 22% of the observed animals. The population estimate was 3200 ± 602 SE (standard error) muskoxen, the highest muskox population size ever estimated for southern Ellesmere, Graham and Buckingham islands. This could be because previous efforts typically surveyed only a portion of our area or focused elsewhere, or the results were provided only as minimum counts rather than estimates of abundance. Regardless, our results indicate that the muskox population has recovered from low levels in 2005 of 312-670 (95% confidence interval [CI]) individuals. Peary caribou abundance appears to be low. We only saw 38 Peary caribou during our 2015 survey. This confounds appraisal of possible abundance change since 2005, when 109-442 caribou (95% CI) were estimated to inhabit the same surveyed area. We estimated 183 ± 128 SE Peary caribou, and suggest that their numbers are likely stable at low density on southern Ellesmere Island.

Key words: Peary caribou; *Rangifer tarandus peary*; muskox; *Ovibos moschatus*; Ellesmere Island; aerial survey; abundance.

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Introduction

Peary caribou (*Rangifer tarandus pearyi*) are found only in the Canadian Arctic Archipelago in the Northwest Territories and Nunavut, from the Boothia Peninsula in the south to Ellesmere Island in the north. Peary caribou are currently listed as Endangered under Canada's Species at Risk Act, although recently reassessed by the Committee on the Status of Endangered Wildlife in Canada as threatened (COSEWIC, 2015). Monitoring of Peary caribou, including both local knowledge and scientific investigation, is a challenge across their range due to logistic and funding constraints, severe weather, limited observation seasons, and long distances from a few small communities. Surveys of Peary caribou, and muskoxen (*Ovibos moschatus*), with which they are sympatric over most of their range, have been infrequent and irregular since 1961, especially in the northern and eastern arctic (COSEWIC, 2015). Local knowledge of population trends and abundance is available for areas visited by hunters, typically near communities, but this knowledge is limited or unavailable in areas of rugged topography and unstable sea ice. The most recent surveys on Ellesmere Island for population estimates and distribution of muskoxen and Peary caribou were in 2005 and 2006 (Jenkins *et al.,* 2011), although a partial survey was flown in 2014 and not completed, due to weather. The 2005 survey estimated 456 muskoxen (95% CI=312-670) and 219 Peary caribou (95% CI=109-244), and noted poor body condition of many muskoxen (Campbell, 2006; Jenkins *et al.,* 2011). Residents of Grise Fiord recall that in the fall and winter 2005 there was freezing rain and ground-fast ice, which may have resulted in many muskoxen starving (Iviq Hunters and Trappers Association, pers. comm.).

The muskoxen and Peary caribou of northern Devon Island, southern Ellesmere Island, and Graham Island are essential natural resources for the Grise Fiord community. Muskoxen have been an important food source since the government hunting ban was lifted in 1969. Muskox tags are currently set aside for domestic/commercial and sport harvest, administered by

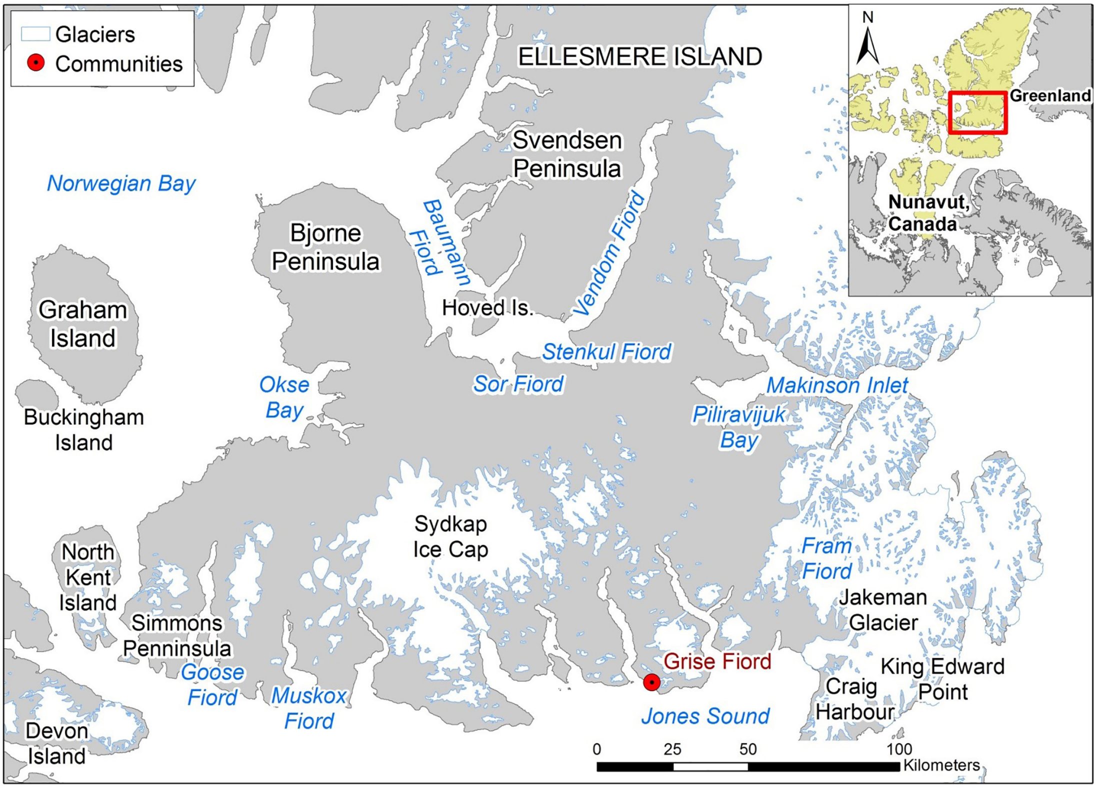

Figure 1. Study area on southern Ellesmere Island (approx.. 76°N to 78°N, 81°W to 90°W), Graham Island, and Buckingham Island, with major topographic features labelled. Peary caribou range is shown in yellow on the inset map for context.

the Hunters and Trappers Association (HTA). Peary caribou have been continuously hunted since Grise Fiord was established in 1953, although the community did impose voluntary restrictions on harvest areas when caribou populations were low. Primary areas frequented by hunters since at least 1964 include the Bjorne Peninsula, south shore of Baumann Fiord, and Graham Island (Riewe 1973, Inuit Qaujimajatuqangit [IQ] in Taylor 2005, Iviq HTA pers. comm.). Local knowledge suggests that petroleum exploration in the 1970s had a negative impact on the Peary caribou by altering their range use and movements, and there is concern that future industrial activity would also be detrimental (Iviq HTA, pers. comm.).

In March 2015, using the 2005 survey area, we conducted an aerial fixed-wing survey to update population estimates, distributions and demographics of the muskoxen and Peary caribou on southern Ellesmere Island, Graham Island, and Buckingham Island. Our results suggest abundance trends for these species and introduce a method to determine variance for strip transect surveys of low density species.

Material and methods

From March 19-26, 2015, we completed an aerial systematic strip transect survey for muskoxen and Peary caribou over a study area including Graham Island, Buckingham Island, and Ellesmere Island approximately 76°N to 78°N and 81°W to 90°W (Figure 1). The survey season was selected to allow us to assess recruitment as well as determine abundance, to avoid disturbing wildlife immediately pre-calving or when newborn calves are present, to minimize chances of animals moving among transects during migration or high movement seasons, and to have adequate snow cover and daylight to maximize detection. The total area, which included lakes and rivers but excluded ice-caps, was approximately 22,791 km^2. We used 77 systematic survey lines along parallels of latitude spaced 5 km apart. Survey strips were 500 m wide to each side of the aircraft for a total strip width of 1 km. Distance sampling was not used, because we did not expect sufficient caribou observations to calculate the effective strip width required for that sampling technique.

The area south of Jakeman Glacier to King Edward Point was originally included in the survey area but could not be flown due to weather; it was not flown in 2005 either. Ice caps were excluded from our survey, and we did not detect any caribou, muskoxen, or their tracks during ferry flights over ice caps. Although North Kent Island was not surveyed in 2005 and no muskoxen or caribou were observed during a 2008 survey (Jenkins *et al.*, 2011), hunters reported caribou at the north end of the island in the recent past, so we gave this island a reconnaissance (albeit no systematic transects) in 2015.

To define the transect width for observers, we marked survey aircraft wing struts following Norton-Griffiths (1978). We did not stratify the study area, because stratification relevant for muskoxen could be irrelevant for Peary caribou, as they may have dissimilar distribution densities. Stratifications from the 2005 survey did not align well with reconnaissance and current local knowledge of distribution, and the 2005 survey only stratified based on Peary caribou density. It was uncertain whether older surveys reflected current distribution, or how well the stratification they employed captured the distribution of muskox and caribou density. Furthermore, funding and logistic constraints make pre-survey stratification flights impractical for the study area.

Transects were flown at 150 km/hr (81 kts) with a DeHavilland Twin Otter fixed-wing aircraft. We flew only on days with good visibility and high contrast to facilitate detection of animals, tracks, and feeding craters, as well as for operational reasons to ensure crew safety. Flight

Table 1. Survey strata for southern Ellesmere Island, March 2015. Although 73 transects were flown, transects flown on the same latitude were combined as lines for further analysis.

Stratification	Block ID	Location	Strata Area, Z (km^2)	Transect Spacing (km)	Transects Surveyed	Lines Surveyed	Survey Area, z (km^2)	Sampling Fraction, f (%)
All	A	South Ellesmere	21260	5	62	39	4896.0	0.199
	C	Graham, Buckingham	1531	5	11	11	296.5	0.201
Elevation	A	South Ellesmere Low Elevation (<400 m)	13921	5	62	39	3322.5	0.195
	B	South Ellesmere High Elevation (>400 m)	7339	5	54	38	1573.6	0.199
	C	Graham, Buckingham	1531	5	11	11	296.5	0.198
Bjorne	A	South Ellesmere	18988	5	52	39	4439.1	0.201
	B	Bjorne Peninsula	2272	5	10	10	456.9	0.199
	C	Graham, Buckingham	1531	5	11	11	296.5	0.265
Case and Ellsworth	I	South Ellesmere	10029	5	31	31	2657.9	0.201
	III	East Vendom Fiord	2865	5	17	17	576.0	0.202
	IV	Bjorne Peninsula	3397	5	16	16	685.2	0.197
	V	Southwest Ellesmere	4969	5	18	18	977.0	0.230
	C	Graham, Buckingham	1531	5	11	11	296.5	0.201

height was set at 152 m (500'), using a radar altimeter, and adhered to as closely as possible given the rugged terrain.

Several local hunters experienced in caribou and muskox surveys were trained and employed as observers. For each survey flight, there were four observers (two front and two rear on each side of the aircraft) and additionally a data recorder/navigator. The observers followed a co-operative double-observer platform protocol, which has been successful elsewhere in Nunavut (Campbell *et al.,* 2012; Anderson, 2014). Paired front and rear observers communicated via intercom and consolidated their observations into one pool. On those occasions when a fourth observer was unavailable, the data recorder/navigator also served as an observer. Animal observations and lines flown were recorded using handheld Garmin 62STC GPS (Global Positioning System) units. Since we limited disturbance to one flight pass, sex and age classification were normally not possible, however, classification as adult or calf (approximate age 10-months) was often feasible owing to size differences. Given the March timing of this survey, newborn muskoxen and caribou were not present – animals classified as calves during this survey refer to approximately 10-month old calves.

Analysis

Post-survey stratification

Although the survey was completed without stratification for probable high and low animal densities, we did apply several post-survey stratifications to investigate the impact of different stratification regimes on the final estimate, which may aid in future survey planning. Post-survey stratifications were generally based on separating or clumping some or all of the three surveyed islands. Elevations and treating the Bjorne Peninsula separately were also considered (Figure 2, Table 1). Finally, to permit comparison with a July 1989 survey, post-survey stratification followed Case & Ellsworth (1991). The 2005 survey was flown with a flexible stratification regime, tightening transects to 2.5 km apart when Peary caribou were encountered, which did not address muskox distribution, so we did not attempt to replicate the 2005 stratification.

Owing to this study's systematic transect lines, and the distribution of animals in distinct patches of suitable habitat between mountains, ice sheets, and coastlines, we expected our muskox and caribou observations to be patchily distributed and serially correlated. Although Jolly's (1969) Method II is widely used for population estimates from surveys, it is intended for a simple random design, rather than our systematic survey of a patchy population. For systematic samples from serially correlated populations, estimates of uncertainty based on deviations from the sample mean are expected to be upwardly biased and influenced by the degree of serial correlation; high serial correlation implies that there is less random variation in the unsurveyed sections between systematically spaced transects than if serial correlation were low (Cochran, 1977). Calculating uncertainty based on nearest-neighbor differences incorporates serial correlation, and the upward bias in the uncertainty is expected to be less than if it were calculated based on deviations from the sample mean. Nearest-neighbor-difference methods have been used previously to calculate variance around survey estimates on the unweighted ratio estimate (Kingsley & Smith, 1981; Stirling *et al.,* 1982; Kingsley *et al.,* 1985).

The model for observations on a transect survey following Cochran (1977) is:

$$y_i = Rz_i + \varepsilon_i\sqrt{z_i}$$

Where y_i is the number of observations on transect i of area z_i, R is the mean density and error terms ε_i are independently and identically

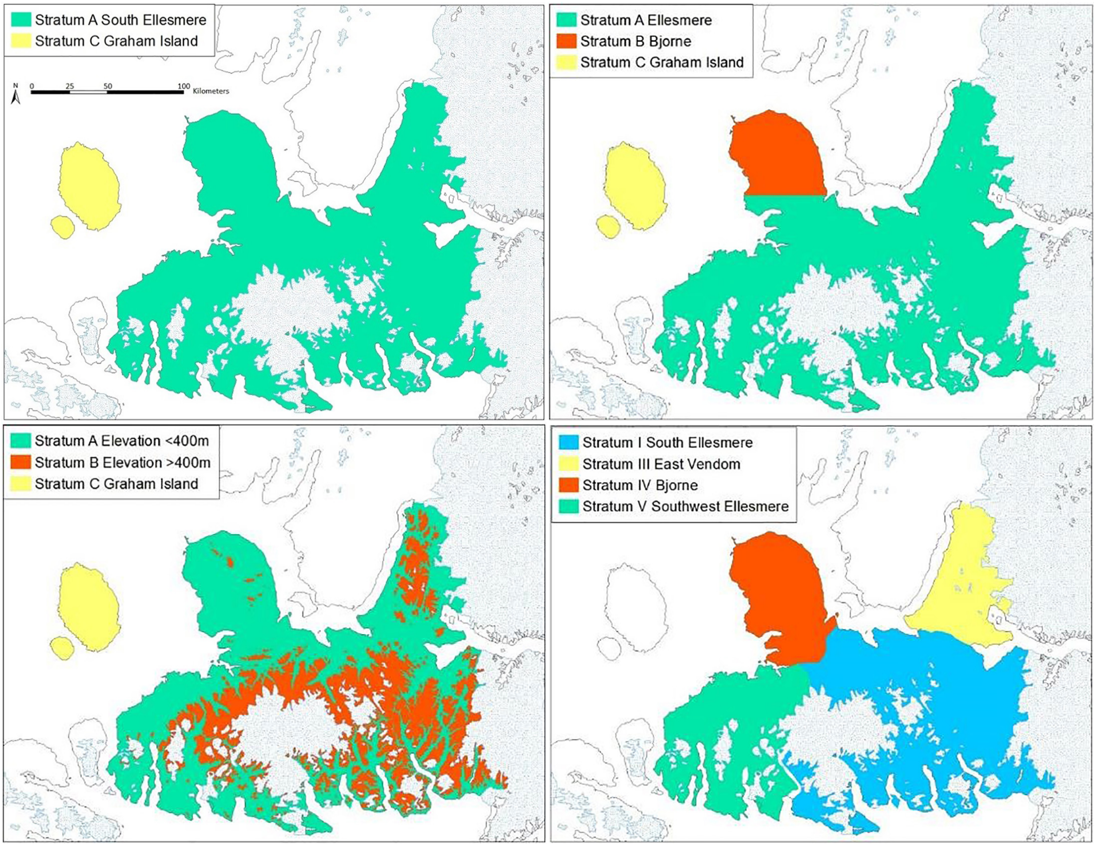

Figure 2. Several stratification regimes for the study area based on geography, elevation, and Case & Ellsworth's (1991) strata.

distributed. In this model, the variance of the error term is proportional to the area surveyed. The best estimate of the mean density $\hat{R}$ is:

$$\hat{R} = \frac{\sum_i y_i}{\sum_i z_i}$$

The error sum of squares, based on deviations from the sample mean, is given by:

$$\left(\sum_i \frac{{y_i}^2}{z_i}\right) - \frac{(\sum_i y_i)^2}{\sum_i z_i}$$

The finite-population-corrected error variance of $\hat{R}$ is:

$$Var(\hat{R}) = \frac{(1-f)}{(n-1)\sum_i z_i}\left(\left(\sum_i \frac{{y_i}^2}{z_i}\right) - \frac{(\sum_i y_i)^2}{\sum_i z_i}\right)$$

Where f is the sampling fraction and n is the number of transects. Lines flown on the same latitude were combined as a transect for analysis, a total of 39 transects on Ellesmere Island and 10 transects on Graham and Buckingham islands. This reduced *n*, the total number of transects, but also meant that short segments between icefields and across peninsulas were not considered separately as a complete transect. The sampling fraction also provides the scaling factor for moving from a ratio (population density) to a population estimate. It is calculated as $((\sum z_i))/Z$, where Z is the study area. The irregular study area boundaries mean that f varies from the 20% sampling fraction indicated by the 1-km survey strip and 5-km transect spacing.

To incorporate serial correlation in the variance, we used a nearest-neighbor-difference calculation, with the error sum of squares given by:

$$\sum_{i=1}^{n-1}\left(\frac{y_i^2}{z_i}+\frac{y_{i+1}^2}{z_{i+1}}-\frac{(y_i+y_{i+1})^2}{z_i+z_{i+1}}\right)$$

i.e. the sum of squared deviations from pairwise weighted mean densities. The nearest-neighbor-difference error variance of $\hat{R}$ is:

$$Var(\hat{R})=\frac{(1-f)}{(n-1)\sum_i z_i}\sum_{i=1}^{n-1}\left(\frac{y_i^2}{z_i}+\frac{y_{i+1}^2}{z_{i+1}}-\frac{(y_i+y_{i+1})^2}{z_i+z_{i+1}}\right)$$

Both variance calculations were applied to several stratification regimes for the southern Ellesmere Island survey data. For the final estimate, we used the unstratified (Ellesmere plus Graham and Buckingham islands) estimate and the nearest-neighbor-difference variance. All distance measurements used North Pole Azimuthal Equidistant projection and area-dependent work used North Pole Lambert Azimuthal Equal Area, with central meridian at 85°W and latitude of origin at 76°N (centered over the study area for high precision) in ArcGIS 10.1 (ESRI, Redlands, CA).

Population growth rates were calculated following the exponential growth function, which approximates growth when populations are not limited by resources or competition (Johnson 1996): $N_t=N_0e^{rt}$ and $\lambda= e^r$ where N_t is the population size at time t and N_0 is the initial population size (taken here as the previous survey in 2005). The instantaneous rate of change is r, which is also represented as a constant ratio of population sizes, λ. When $r>0$ or $\lambda>1$, the population is increasing; when $r<0$ or $\lambda<1$ the population is decreasing. Values of $r\sim0$ or $\lambda\sim1$ suggest a stable population.

Results

The survey took 49.5 flight hours (35.6 hours on transect) and we completed 73 of the intended 77 systematic transect lines, for a total combined survey line distance of 4,521 km (Figure 3). Given strip width was 1 km and total study area 22,791 km^2, our survey coverage was 19.8% of the total area. We were unable to fly on March 22 due to low cloud, but otherwise conditions were good with <10% cloud cover, no blowing snow, and complete snow cover, except where it was blown clear from ridges or did not accumulate in cliffy terrain.

We saw 636 muskoxen and 36 Peary caribou on the systematic transect lines (Figure 2). The spatial data presented are waypoints along the flight path, so groups that were observed on transect were within 500 m of the waypoint and groups off transect were >500 m from the waypoint. A further 510 muskoxen and 2 caribou were observed off transect (> 500 m from the aircraft) for a total of 1146 muskoxen and 38 Peary caribou. Some off-transect muskox observations were more than 2 km away. Average group size was 8.9-12.1 (95% CI) for muskoxen, and 2.6-6.9 (95% CI) for Peary caribou. No muskoxen, Peary caribou or their tracks were observed during the reconnaissance of North Kent Island.

Abundance estimates

For southern Ellesmere Island, Graham Island, and Buckingham Island, our non-stratified survey resulted in a muskox abundance estimate of 3200 ± 602 SE, with a Coefficient of Variation (CV) of 19% (Table 2). The Peary caribou estimate was 183 ± 128 SE (CV=70%; Table 3). The use of nearest-neighbour-difference analysis had a positive effect, lowering the variance and CV of the final population estimates (Tables 1, 2). Caution should be exercised when interpreting the Peary caribou population size estimate, because few caribou (n=36) were actually seen.

Late winter calf percentage

In March 2015 it was possible to age classify 101 groups of muskoxen, which included 289 adults and 64 calves (approximate age 10-months). This was a late-winter calf percentage of 22.1% for muskoxen. Only four caribou groups were

Table 2. Calculations following Cochran (1977) for a systematic survey and ratio estimator for muskoxen on southern Ellesmere Island. Variance was calculated based on sample mean and based on nearest-neighbor to account for serial correlation in the data.

Stratum	Stratum area Z (km^2)	Surveyed area z (km^2)	Count, y	Esti-mate, $\hat{Y}$	Density,	Nearest-neighbor-difference				Deviations from sample mean			
						Error Sum of Squares	Var ($\hat{Y}$)	SE	CV	Error Sum of Squares	Var ($\hat{Y}$)	SE	CV
All	21260	4225	636	**3200**	0.151	164.804	362230	602	0.188	194.057	426528	653	0.204
Low Elev	13921	2792	571	2847	0.205	180.633	257061	507	0.178	202.559	288263	537	0.189
High Elev	7339	1433	65	333	0.045	14.438	11488	107	0.322	15.726	12513	112	0.336
Total	21260	4225	636	**3180**	0.150		268549	518	0.163		300776	548	0.172
Main	18988	3768	623	3140	0.165	247.205	486171	697	0.222	340.405	669465	818	0.291
Bjorne	2272	457	13	65	0.028	3.069	3076	55	0.858	2.768	2775	53	0.815
Total	21260	4225	636	**3204**	0.151		489248	699	0.218		672240	820	0.256
I Southeast	10029	2658	222	838	0.084	48.545	43637	209	0.249	91.216	81994	286	0.342
III Vendom	2865	576	212	1054	0.368	209.096	140033	374	0.355	255.597	171175	414	0.392
IV Bjorne	3397	685	30	149	0.044	8.269	6949	83	0.560	7.128	5990	77	0.520
V Southwest	4969	977	172	875	0.176	36.869	41588	204	0.233	34.958	39433	199	0.227
Total	21260	4896	636	**2916**	0.137		232207	482	0.165		298592	546	0.187

classified, and included eight adults and one calf (approximate age 10-months), which is not sufficient to determine a late winter Peary caribou calf percentage.

Group size

Muskox group size averaged 8.9-12.1 muskoxen (95% CI, *n*=106, median=8). Caribou groups were smaller, 2.6-6.9 caribou (95% CI), but only eight groups were seen.

Discussion

Muskox abundance trends

Previous surveys of southern Ellesmere Island have used different survey aircraft, methodologies, and survey areas. The disparate methodologies and survey areas complicate any comparison of the estimates obtained, especially to determine long-term population trends for muskoxen and Peary caribou in the southern Ellesmere Island area. However, a review of past survey results is still warranted and large changes in density are still be apparent (Table 4). Although some previous surveys also used strip transects, our nearest neighbor difference variance reduced CV and SE, particularly useful when variance is expected to be high, as in surveys with relatively few observations for low density populations, or where reducing variance through effective stratification may not be possible due to logistics or lack of information.

In 2005, southern Ellesmere Island from Vendom Fiord south, the same area in this survey, was flown with an adaptive sampling technique, with east-west transects spaced 5 km apart, tightened to 2.5 km where caribou or caribou sign was detected (Jenkins *et al.,* 2011). In addition to the very low proportion of 10-month old muskox calves in the population (2%), observers reported 40 muskox carcasses and 2 adult muskoxen near death (Campbell, 2006; Jenkins *et al.,* 2011). Residents of Grise Fiord recall ground-fast ice in winter 2005 and suggested rain in winter 2002 (Taylor, 2005) may have reduced muskox condition, survival and reproduction that year as well (Iviq HTA, pers. comm.). The final population estimate in 2005 was only 456 muskoxen (Jenkins *et al.,* 2011).

Our survey estimated 3200 ± 602 SE muskoxen in 2015. Our use of nearest-neighbour-difference analysis appears to have added precision to the estimate. Comparing the 2005 and 2015 estimates results in an instantaneous growth rate (*r*) of 0.202 annually, and a finite rate of increase lambda (λ) of 1.224, i.e., a 22% change per individual per year. We suggest that by 2015, muskox abundance had recovered from the weather events of 2002 and 2005. Population growth would be supported by the 2015 calf percentage (22%). Interestingly, a 2014 helicopter survey (incomplete due to weather) of the same area observed 33 groups and included 311 adults and 42 calves, which suggests the proportion of late-winter calves may have been about 16% (Government of Nunavut, unpublished data). Alternately, the increased population size in 2015 may have resulted if muskoxen moved into the survey area from adjacent populations on central Ellesmere Island or Devon Island.

Peary caribou abundance trends

Peary caribou have apparently not been abundant on southern Ellesmere Island in recent times, although there are places where caribou can be reliably found, including at Sor Fiord and the Bjorne Peninsula (Iviq HTA pers. comm.). Previous surveys have mostly relied on extrapolation and minimum counts (Table 5).

The few caribou sightings resulted in a large variance for our 2015 estimate of 183 ± 128 SE Peary caribou. The error is too broad to make a determination of population trend since the 2005 estimate of 109-442 caribou (95% CI). It remains unknown whether Peary caribou in the region have increased, decreased or remained stable. More sophisticated analyses incorporat-

Table 3. Calculations following Cochran (1977) for a systematic survey and ratio estimator for Peary caribou on southern Ellesmere Island. Variance was calculated based on sample mean and based on nearest-neighbor to account for serial correlation in the data.

Stratum	Stratum area Z (km^2)	Surveyed area z (km^2)	Count, y	Estimate, $\hat{Y}$	Density, $\hat{R}$	Nearest-neighbor-difference				Deviations from sample mean			
						Error Sum of Squares	Var ($\hat{Y}$)	SE	CV	Error Sum of Squares	Var ($\hat{Y}$)	SE	CV
All	21260	4225	26	131	0.006	5.606	14405	120	0.618	7.247	18622	136	0.702
Graham	1531	296	10	52	0.034	3.513	2036	45	0.874	3.172	1838	43	0.830
Total	22791	4521	36	**183**	0.008		16441	128	0.702		20460	143	0.784
Low Elev	13921	2792	26	130	0.009	9.150	16458	128	1.103	9.193	16537	129	1.106
Graham	1531	296	10	52	0.034	3.513	2035	45	0.874	3.172	1838	43	0.830
Total	15452	3088	36	**181**	0.012		18493	136	0.750		18375	136	0.747
Main	18988	3768	3	15	0.001	0.072	168	13	0.793	0.067	156	12	0.845
Bjorne	2272	457	23	114	0.050	7.699	7717	88	0.768	14.800	14836	122	1.065
Graham	1531	296	10	52	0.034	3.513	2036	45	0.874	3.172	1838	42	0.830
Total	22791	4521	36	**181**	0.008		9921	100	0.550		16830	129	0.716
IV Bjorne	3397	685	26	129	0.038	8.027	6745	82	0.637	15.240	12806	113	0.878
Graham	1531	296	10	52	0.034	3.513	2036	45	0.874	3.172	1838	42	0.830
Total	4928	981	36	**181**	0.037		8781	94	0.519		14644	121	0.670

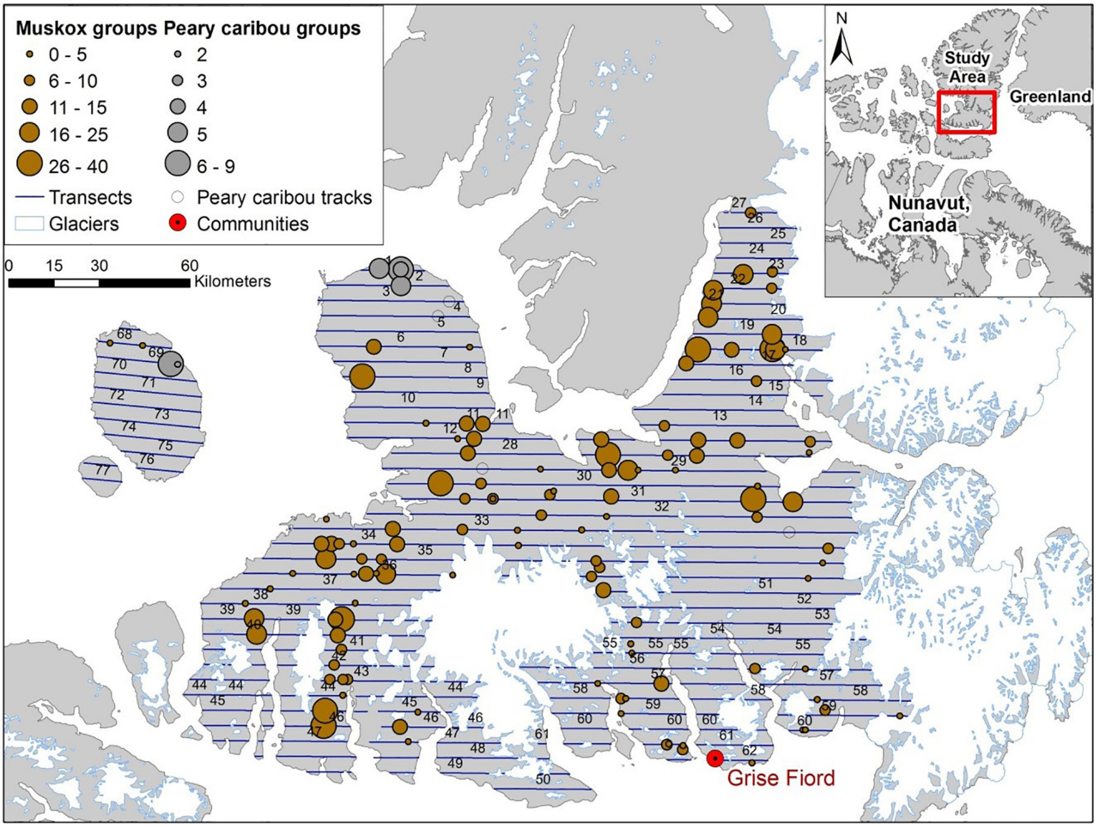

Figure 3. Observations of Peary caribou and muskoxen on southern Ellesmere, Graham, and Buckingham islands during the March 2015 aerial survey. Flight transects are labelled by number.

ing uncertainty in the estimates have not been undertaken, but the large uncertainty in both estimates would likely still make trend determination tenuous. However, the pattern observed by hunters in Grise Fiord over several decades seems to suggest a persistent, relatively stable, low abundance of Peary caribou in the study area.

The abundance estimate from this survey suggests that the south Ellesmere, Graham, and Buckingham island area currently supports approximately 1.3% of the estimated global Peary caribou population of 13,200 adults (COSEWIC, 2015). The study area is part of the Eastern Queen Elizabeth Islands group of Peary caribou, an island group which accounts for about a quarter of the global Peary caribou population (COSEWIC, 2015).

Distribution - muskox

In the past, concentrations of muskoxen have occurred along Baumann Fiord, Sor and Stenkul Fiords, the flat plain along Vendom Fiord, north of Muskox Fiord and along Norwegian Bay, and at Fram Fiord (Iviq HTA, pers. comm.; Tener, 1963; Riewe, 1973; Case & Ellsworth, 1991; Jenkins *et al.,* 2011). During the 2015 survey, muskoxen were also observed in these areas. The situation was similar on previous survey attempts in April and August 2014 for the areas covered by those surveys (Government of Nunavut, unpubl. data). The most notable change in distribution was the relative lack of muskoxen on Graham and Buckingham islands in 2015 as compared to the most recent 2005 survey by Jenkins *et al.* (2011). In contrast to 2005, when three groups totaling 12 muskoxen were observed, in 2015 we saw only two groups

Table 4. Summary of previous surveys for muskoxen in the southern Ellesmere Island area.

Area	Year	Dates	Total Observed	Abundance Estimate	SE	Percent calves	Aircraft	Method	Reference
Ellesmere Island south of Baumann Fiord and Vendom Fiord, Graham Island	1967	Mar 1966-Aug 1967	520	520		12.5	Snowmobile	Minimum count/ extrapolation ground survey	Freeman, 1971
Bjorne Peninsula, Sor Fiord to Stenkul Fiord, Vendom Fiord	1973	May 8-28	365				Snowmobile	Minimum count ground survey	Riewe, 1973
Bjorne Peninsula and shores of Vendom Fiord	1973	May 8, May 15	447				Fixed wing (DeHavilland Twin Otter; flown at 1500-2500')	Reconnaissance/ minimum count	Riewe, 1973
Bjorne Peninsula, Sor Fiord to Stenkul Fiord, and Buckingham, Graham, and Hoved islands	1973	Jul 4-7	606	655		16	Fixed wing (DeHavilland Twin Otter)	Reconnaissance/ minimum count	Riewe, 1973
Ellesmere Island south of Baumann Fiord and Vendom Fiord	1989	Jul 17-23	839	2020	285	17.3	Helicopter (Bell 206B)	Fixed-width strip transect	Case & Ellsworth, 1991
Bjorne Peninsula, Sor Fiord to Stenkul Fiord	2005	May 8-16	56				Snowmobile	Minimum count ground survey	Jenkins *et al.*, 2011; Government of Nunavut, unpubl. data
Ellesmere Island south of Baumann Fiord and Vendom Fiord, Graham Island	2005	May 4-30	273	456 (1+ yr olds)	312-670 (95% CI)		Helicopter (Bell 206LR)	Line transect distance sampling	Jenkins *et al.*, 2011
Ellesmere south coast and south of Sor and Stenkul fiords	2014	Apr 12-24	311			15.6	Helicopter (Bell 206LR)	Incomplete survey (distance sampling)	Government of Nunavut, unpubl. data
Ellesmere south coast and south of Sor and Stenkul fiords	2014	Aug 13, Aug 15	88			23.9	Fixed wing (DeHavilland Twin Otter)	Incomplete survey (fixed-width strip transect)	Government of Nunavut, unpubl. data
Ellesmere Island south of Baumann Fiord and Vendom Fiord, Graham Island	2015	Mar 19-26	1146	3200	602	22.1	Fixed wing (DeHavilland Twin Otter)	Fixed-width strip transect	This survey

totaling three muskoxen. Part of this discrepancy is explained by the adaptive sampling protocol used in 2005; transects were flown 2.5 km apart on Graham and Buckingham islands in 2005 and 5 km apart in 2015.

Distribution – Peary caribou

Riewe (1973) noted some caribou on Graham Island, between Sor and Stenkul fiords, and on the Bjorne Peninsula. Case & Ellsworth (1991) described caribou observations as scattered across the study area, but in 2005 there were some obvious areas of higher density on Graham and Buckingham islands, northern Bjorne Peninsula, and southeast of Okse Bay (Jenkins *et al.,* 2011). In 2014 and 2015, we saw caribou in the same areas, as well as a group on northern Vendom Fiord. We did not detect any caribou along the south coast of Ellesmere Island, although in the 1950s and 1960s they were found in the area of Craig Harbour, Fram Fiord, and King Edward Point, and occasionally seen there into the 1990s (IQ in Taylor, 2005). We only saw one set of tracks south of Piliravijuk Bay, although caribou have been found there previously (IQ in Taylor, 2005; Iviq HTA pers. comm.). Grise Fiord residents were also surprised that we did not see caribou at the head of Goose Fiord or Muskox Fiord, since they usually occur there. Similar to the muskoxen, there was a scarcity of caribou on Graham and Buckingham islands in 2015 when only two groups totaling ten caribou were seen, versus the 18 groups totaling 50 animals in 2005. Again the difference may be partially explained by the adaptive sampling protocol used in 2005. Further, it is well known that caribou move between islands in regular seasonal movements or when conditions force them (Miller, 2002; Miller *et al.,* 2005; IQ in Taylor, 2005), and they do move between Graham Island and the Bjorne Peninsula (IQ in Taylor, 2005; Iviq HTA, pers. comm.).

Percentage calves: muskoxen

Freeman (1970) developed a preliminary population model that suggested 10.5% late-winter calves would be required to balance natural mortality in the muskox populations in this region. Only two newborn calves were seen on the May 2005 survey (Campbell, 2006; Jenkins *et al.,* 2011), but calf percentage was indicative of a stable or increasing population by 2014 and 2015, based on Freeman's (1970) late-winter muskox calf percentages. The April 2014 (16% calves; Government of Nunavut, unpubl. data) and March 2015 (22% calves) survey results suggest good to high recruitment respectively, and are similar to previously observed percentages for the area (Table 4).

Observations were too few for conclusions about Peary caribou calf percentages.

Group sizes: muskoxen & Peary caribou

Muskox groups are largest early in the spring and smaller as summer progresses (Freeman, 1971; Gray, 1973), with winter groups (including April and May) about 1.7 times larger than summer groups (range 1.2-2.3 times larger, based on typical group size where G_i is size of the i^{th} group; Heard, 1992). Heard (1992) noted that muskox group size is not generally related to their density. However, the muskox group size in May 2005, which averaged 2.7 muskoxen (2.4-3.0, 95% CI), was much smaller than group sizes encountered in April 2014 and March 2015, or previously in 1966-67 (10 muskoxen per group; Freeman, 1971). One possible explanation may be that the severe 2005 ground-fast ice event and subsequent die-off fragmented the groups and normal group structure was not observed during the 2005 survey.

Ferguson (1991) suggested that caribou groups are largest in August and smaller in late winter. Fischer & Duncan (1976) noted that groups across the Arctic islands averaged 4.0 caribou in late winter, 2.8 caribou in early

Table 5. Summary of previous surveys for Peary caribou in the southern Ellesmere Island area.

Area	Year	Dates	Total Observed	Abundance Estimate	SE	Percent calves	Aircraft	Method	Reference
Ellesmere Island, excluding parts of the south, east and northwestern coasts (due to weather)	1961	Jul 30-Aug 11		200		11	Fixed wing (Piper Super Cub)	Extrapolation/ expert opinion (most were north of our study area; only 11 were seen at the head of Baumann Fiord)	Tener, 1963
Bjorne Peninsula, Sor Fiord to Stenkul Fiord, Vendom Fiord	1973	May 8-28	67				Snowmobile	Minimum count	Riewe, 1973
Bjorne Peninsula and shores of Vendom Fiord	1973	May 8, May 15	17				Fixed wing (De-Havilland Twin Otter; flown at 1500-2500')	Reconnaissance/ minimum count	Riewe, 1973
Bjorne Peninsula, Sor Fiord to Stenkul Fiord, and Buckingham, Graham, and Hoved islands	1973	July 4-7	67	100		5.5	Fixed wing (De-Havilland Twin Otter)	Minimum count/ expert opinion	Riewe, 1973
Ellesmere Island south of Baumann Fiord and Vendom Fiord	1989	Jul 17-23	45	89	31	22.2	Helicopter (Bell 206B)	Fixed-width strip transect	Case & Ellsworth, 1991
Bjorne Peninsula, Sor Fiord to Stenkul Fiord	2005	May 8-16	17				Snowmobile	Minimum count ground survey	Jenkins *et al.*, 2011; Government of Nunavut, unpubl. data
Ellesmere Island south of Baumann Fiord and Vendom Fiord, Graham Island	2005	May 4-30	57	219 (1+ yr olds)	109-442 (95% CI)		Helicopter (Bell 206LR)	Line transect distance sampling	Jenkins *et al.*, 2011
Ellesmere south coast and south of Sor and Stenkul fiords	2014	Aug 13, Aug 15	8				Fixed wing (De-Havilland Twin Otter)	Incomplete survey (fixed-width strip transect)	Government of Nunavut, unpubl. data
Ellesmere Island south of Baumann Fiord and Vendom Fiord, Graham Island	2015	Mar 19-26	38	183	128		Fixed wing (De-Havilland Twin Otter)	Fixed-width strip transect	This survey

summer, and 8.8 caribou in mid-summer. The scarcity of observations during any of the survey attempts makes it difficult to evaluate any seasonal effect of group size for Peary caribou. Still, our average group size of 2.6-6.9 caribou (95% CI) is similar to the late winter group sizes encountered by Fischer & Duncan (1976).

Management implications

The survey conducted by Case & Ellsworth (1991) in July 1989 was in response to observations by Grise Fiord residents of declining caribou populations and increasing muskox populations, and a similar dynamic may be manifesting in the south Ellesmere Island area today. Although there was a crash in muskox abundance in the early 2000s, the muskox population has increased over the last decade. The Peary caribou population has not followed the same trajectory. An inverse relationship between caribou and muskox abundance is widely accepted by many communities where Peary caribou and muskoxen are sympatric (Iviq HTA and Resolute Bay HTA, per. comm.; IQ in Taylor, 2005). However, a mechanism explaining this pattern remains elusive and elsewhere both species coexist at relatively high densities, e.g., on Bathurst and Melville islands (Davison & Williams, 2012; Anderson, 2014).

In September 2015, the Government of Nunavut updated wildlife regulations and, working with co-management partners, removed the quota on muskoxen in Muskox Management Unit MX-01, Ellesmere Island, increasing harvest opportunities. Whether lifting harvest restrictions will reduce muskox abundance remains to be seen, since to date harvest has been light and limited to areas accessible from Grise Fiord (Anderson, 2017).

Peary caribou are currently listed as Endangered under the Canadian Species at Risk Act, and a Recovery Strategy is in development. Population monitoring is difficult and infrequent across much of Peary caribou range. Surveys like this one fill important knowledge gaps, but more information on ecological relationships, population drivers, and response to disturbance will be needed to ensure the continued persistence and sustainable use of Peary caribou as part of the arctic landscape.

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References

Anderson, M. 2017. Trends in high arctic muskox (*Ovibos moschatus*) harvest, 1990-2015. – *Rangifer* 37(1): 47-58. https://doi.org/10.7557/2.37.1.4182

Anderson, M. 2014. Distribution and abundance of Peary caribou (*Rangifer tarandus pearyi*) and muskoxen (*Ovibos moschatus*) on the Bathurst Island Group, May 2013. – Status Report, Nunavut Department of Environment, Wildlife Research Section, Igloolik, Nunavut. 39pp.

Campbell, M. 2006. Estimating Peary caribou (*Rangifer tarandus pearyi*) and muskox (*Ovibos moschatus*) numbers, composition and distributions on the high arctic islands of Nunavut. – Status report 19, Nunavut Department of Environment, Wildlife Research Section, Arviat, Nunavut. 12 pp.

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

Case, R. & Ellsworth, T. 1991. Distribution and abundance of muskoxen and Peary caribou on southern Ellesmere Island, NWT, July 1989. – Manuscript Report 41, Northwest Territories Department of Renewable Resources, Yellowknife, Northwest Territories. 23pp.

Cochran, W.G. 1977. Sampling techniques. 3rd ed. Wiley, New York, NY. 428pp.

Department of Environment, in collaboration with Nunavut Tunngavik Inc. (NTI) Wildlife, Resolute Bay Hunters and Trappers Association, Ikajutit Hunters and Trappers Organization (Arctic Bay), Iviq Hunters and Trappers Association (Grise Fiord) & the Qikiqtaaluk Wildlife Board. 2013. Management Plan for the High Arctic Muskoxen of the Qikiqtaaluk Region, 2013-2018. – Nunavut Department of Environment, Iqaluit, Nunavut. 20pp.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2015. COSEWIC Assessment and Status report on the Peary Caribou *Rangifer tarandus pearyi* in Canada. – COSEWIC, Ottawa, Ontario. 92pp.

Ferguson, M.A.D. 1991. Peary caribou and muskoxen on Bathurst Island, Northwest Territories, from 1961-1981. – File Report 88, Northwest Territories Department of Renewable Resources, Yellowknife, Northwest Territories. 54pp.

Fischer, C.A. & Duncan, E.A. 1976. Ecological studies of caribou and muskoxen in the Arctic Archipelago and northern Keewatin. – Report prepared for Polar Gas Project by Renewable Resources Consulting Services. 194pp.

Freeman, M.M.R. 1970. Productivity studies of high arctic muskoxen. – *Arctic Circular* 20: 58-65.

Freeman, M.M.R. 1971. Population characteristics of musk-oxen in the Jones Sound region of the Northwest Territories. – *Journal of Wildlife Management* 35 (1): 103-108. https://doi.org/10.2307/3799877

Gray, D.R. 1973. Social organization and behavior of muskoxen (*Ovibos moschatus*) on Bathurst Island, NWT. – PhD Thesis. University of Alberta, Edmonton, Alberta. **212pp.**

Heard, D. 1992. The effects of wolf predation and snow cover on muskox group size. – *The American Naturalist* 139 (1): 190-204. https://doi.org/10.1086/285320

Jenkins, D., Campbell, M., Hope, G., Goorts, J. & McLoughlin, P. 2011. Recent trends in abundance of Peary Caribou (*Rangifer tarandus pearyi*) and muskoxen (*Ovibos moschatus*) in the Canadian Arctic Archipelago, Nunavut. – Wildlife Report No. 1, Nunavut

Department of Environment, Pond Inlet, Nunavut. 184pp.

Johnson, D.H. 1996. Population analysis. – *In*: T. A. Bookhout, ed. *Research and management techniques for wildlife and habitats.* The Wildlife Society, Bethesday, Maryland, pp. 419-444.

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

Kingsley, M.C.S. & Smith, G.E.J. 1981. Analysis of data arising from systematic transect surveys. – *In*: Miller, F.L., and Gunn, A., eds. *Proceedings, Symposium on Census and Inventory Methods for Populations and Habitats*. Banff, Alberta, April 1980, pp. 40-48.

Kingsley, M.C.S., Stirling, I. & Calvert, W. 1985. The distribution and abundance of seals in the Canadian high arctic, 1980-82. – *Canadian Journal of Fisheries and Aquatic Sciences* 42 (6): 1189-1210. https://doi.org/10.1139/f85-147

Miller, F.L. 2002. Multi-island seasonal home range use by two Peary caribou, Canadian High Arctic, 1993-94. – *Arctic* 55: 133-142. https://doi.org/10.14430/arctic697

Miller, F.L, Barry, S.J. & Calvert, W.A. 2005. Sea-ice crossings by caribou in the south-central Canadian Arctic Archipelago and their ecological importance. – *Rangifer* Special Issue 16: 77-88. https://doi.org/10.7557/2.25.4.1773

Miller, F.L. & Gunn, A. 2003. Catastrophic die-off of Peary caribou on the western Queen Elizabeth Islands Canadian High Arctic. – *Arctic* 56: 381-390. https://doi.org/10.14430/arctic635

Miller, F.L., Russell, R.H. & Gunn, A. 1975. The decline of caribou on the western Queen Elizabeth Islands. – *Polarforschung* 45: 17-22.

Norton-Griffiths, M. 1978. Counting animals. – *In*: Grimsdell, J.J.R., ed. *Handbooks on techniques currently used in African wildlife ecology.* No 1. African Wildlife Leadership Foundation, Nairobi, Kenya.

Riewe, R.R. 1973. Final report on a survey of ungulate populations on the Bjorne Peninsula, Ellesmere Island: determination of numbers and distribution and assessment of the effects of seismic activities on the behaviour of these populations. – Report fulfilling contract YK-73/74-020, University of Manitoba, Winnipeg, Manitoba. 58pp.

Stirling, I., Kingsley, M.C.S. & Calvert, W. 1982. The distribution and abundance of seals in the Beaufort Sea, 1974-1979. – Occasional Paper 47, Canadian Wildlife Service.

Taylor, A.D.M. 2005. Inuit Qaujimajatuqangit about population changes and ecology of Peary caribou and muskoxen on the High Arctic Islands of Nunavut. – MA Thesis. Queen's University, Kingston, Ontario. 123pp.

Tener, J.S. 1963. Queen Elizabeth Islands game survey, 1961. – Occasional Paper No. 4, Canadian Wildlife Service. 50pp.

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