The Tenth North American Caribou Workshop,
Girdwood, Alaska, USA,
4-6 May, 2004.

Conservation of Peary caribou based on a recalculation of the 1961 aerial survey on the Queen Elizabeth Islands, Arctic Canada

Frank L. Miller, Samuel J. Barry & Wendy A. Calvert

Canadian Wildlife Service, Environment Canada, Prairie & Northern Region, Room 200, 4999 – 98th Avenue, Edmonton, Alberta T6B 2X3, Canada (corresponding author: frank.miller@ec.gc.ca).

Abstract: The estimate of 25 845 Peary caribou (*Rangifer tarandus pearyi*) on the Queen Elizabeth Islands (QEI) in the Canadian High Arctic in summer 1961 is the only nearly range-wide 'benchmark' for the past number of caribou. No variances or confidence intervals were calculated for this estimate and no estimates were calculated for Peary caribou on the three major islands of Ellesmere, Devon, and Axel Heiberg. We reexamined the 1961 raw data by grouping the QEI into five island-complexes ('eco-units') and calculating, for each unit, the estimated number of caribou and the standard error, and the 95% confidence interval of the estimate, using a 'bootstrap' technique with 100 000 replications. Our goal was to provide an ecological basis for evaluating subsequent changes in numbers rather than relying on single-island evaluations. Our bootstrap reanalysis produced an estimate of 28 288 ± 2205 SE with a 95% CI of 20 436–37 031 Peary caribou on the QEI in summer 1961. Substantial differences in density were apparent among the five eco-units, with about a 50-fold difference from 0.01 caribou • km^{-2} in the Eastern eco-unit to 0.5 caribou • km^{-2} in the Northwestern eco-unit. The 1961 findings, with our subsequent reexamination, are crucial to any evaluation of trends for the number of Peary caribou on the QEI and the relative importance of individual eco-units for these animals. These findings also allow a more accurate evaluation of the magnitude of the subsequent decline of Peary caribou on the QEI during the last four decades and may help predict future potential levels for caribou in each of the five eco-units.

Key words: Canadian High Arctic Islands, conservation, distribution, management, numbers, *Rangifer tarandus pearyi*.

Rangifer, Special Issue No. 16: 65-75

Introduction

Tener (1963) estimated there were 25 845 Peary caribou (*Rangifer tarandus pearyi*) on the Queen Elizabeth Islands (QEI) in summer 1961. This initial, range-wide, systematic aerial survey of Peary caribou has never been repeated. Tener found that the distribution of caribou among the QEI was markedly uneven: based on island sizes he used, 94% (24 363) were on western QEI (WQEI), which makes up 24% of the total island landmass, and the remaining 6% (1482) were on eastern QEI (EQEI), with 76% of the landmass (Fig. 1).

Before 1961, the only information on distribution and numbers of Peary caribou across the QEI came from a few interested geologists in the mid- and late 1950s. After Tener's 1961 survey, only three composite multi-island caribou surveys were conducted in WQEI with adequate temporal separation (Miller *et al.*, 1977a; Miller, 1987a, 1987b, 1988, 1989; Gunn & Dragon, 2002). There have been no range-wide systematic aerial surveys for Peary caribou on the EQEI or on any major portion of that region since 1961. Only parts of Ellesmere Island were subsequently aerially surveyed (Riewe, 1973; Case & Ellsworth, 1991; Gauthier, 1996; Manseau *et al.*, 2004).

The 1961 survey of the three largest islands—Ellesmere, Devon and Axel Heiberg—was hindered by persistent bad weather in some sections (Tener, 1963). Survey coverage was low and fragmented. As a result, Tener (1963) did not quantitatively estimate the total number of caribou on those islands and his

"intuitive guesses" for them were exceedingly small. The mean overall density of 0.003 caribou • km^{-2} was but a tiny fraction of what the usable range on those three islands could support (62% of the total usable range on the QEI occurs on these three islands).

Subsequent development of aerial survey techniques and statistical analyses allow us to reevaluate the 1961 data to determine standard errors and confidence intervals. We emphasize that the application of these statistical methods in no way betters Tener's original 1961 data set. The benefits of our approach are: 1) it refines Tener's (1963) estimate of abundance; 2) it permits more detailed comparisons with subsequent aerial surveys; and 3) it identifies five eco-units to serve as the best standard for evaluating future changes in Peary caribou numbers, distributions, and movements. Our statistical analyses may also satisfy those individuals who place an unfounded degree of reliance on probability testing and statistical significance instead of evaluating results in terms of biological significance (e.g., Yoccoz, 1991; Johnson, 1999; Steidl *et al.*, 2000; Anderson *et al.*, 2001). Our objective is to recalculate caribou numbers and densities using recently available accurate measures of island size, to place confidence intervals on those estimates using raw data in a bootstrap simulation, and to provide an ecological basis for the conservation of Peary caribou on the QEI.

Materials and methods

Animals and study area

The Canadian High Arctic Islands form the northern apex of the North American continent and collectively comprise a landmass of 419 061 km^2 (Fig. 1). The QEI are those islands entirely north of ca. 74°N latitude. Although there are 2126 islands in total, only 34 of them each exceed 136 km^2 in size and are considered 'large' islands. The 22 islands surveyed in 1961 differ in size from 412 km^2 to 196 236 km^2 and total 410 765 km^2 or 98% of the entire QEI. The largest is Ellesmere Island, the tenth largest island in the world. The 12 large islands not surveyed in 1961 had a collective landmass of 5975 km^2.

We divided the QEI into western (WQEI) and eastern (EQEI) zones (Fig. 1). We further subdivided the QEI into five island-complexes, which we termed 'eco-units' (Fig. 1). The two major zones and the five eco-units are based on their relative differences in numbers of caribou estimated in 1961, and caribou numbers, distribution, and movements or migrations, as measured between 1961 and 1997 (e.g., Tener, 1963; Miller *et al.*, 1977a, 1977b; Miller, 1990a, 1990b, 1998, 2002; Gunn & Dragon, 2002), climate differences (Maxwell, 1981, 1997), and vegetation differences (Edlund & Alt, 1989; Bliss, 1990; Edlund, 1990). The collective landmass of the relatively large islands within the five eco-units is 416 740 km^2. The portion of the 1961 survey area that we judge to be usable by Peary caribou is 301 978 km^2 or about 72% of the entire QEI. The 2092 small islands (defined as each having an area <137 km^2) with a total landmass of 2321 km^2 are not included in any calculations for the five eco-units. A few caribou do live on these small islands: usually only seasonally, but sometimes even year-round (Miller, 1995a, 1997, 1998).

1961 Aerial survey

Macpherson's (1961) summary of wildlife observations by geologists in the mid- and late 1950s was available as an internal report in 1960 and provided some factual information about the numbers and distributions of Peary caribou or other animals on the QEI. However, Tener (1963: 8) believed that those surveys were "not detailed enough in their animal sightings to be of real value in selecting the method of survey." Discussions with P. Larkin (University of British Columbia) led Tener to choose systematic sampling as the best design for obtaining both distributions and numbers. Although systematic surveying on the Canadian Arctic Archipelago has become a method used by most biologists for aerial surveys of caribou and muskoxen (*Ovibos moschatus*), Tener (1963) did not apply any statistical analysis to his 1961 survey results because he and P. Larkin concluded that a useful statistical approach was not available at the time.

The survey transect flights in 1961 employed two survey crews, each operating with a Piper Super Cub aircraft. The planes were equipped with large, low-pressure tires ('tundra tires') to allow them to take-off and land on unprepared ground. When possible, the crews flew the surveys at about 152 m (500 ft) above ground level and 137 km • h^{-1} (85 miles • h^{-1}) air speed. The single observer in each plane sat directly behind the pilot and limited his observations to the right side of the aircraft. Transect width was about 402 m (0.25 mi). On each island, the first transect was selected at random and drawn on a survey map; additional transects were then drawn parallel to it at fixed intervals.

Aerial coverage varied by island and was small, averaging 4% (see Tener, 1963: Table 1). The interval between transects was determined by the chosen sampling intensity. Tener (1963) based his survey intensity on the belief that using a large number of small samples was better than using only a few large ones and that a large number of systematically spaced transects probably ensured adequate representation

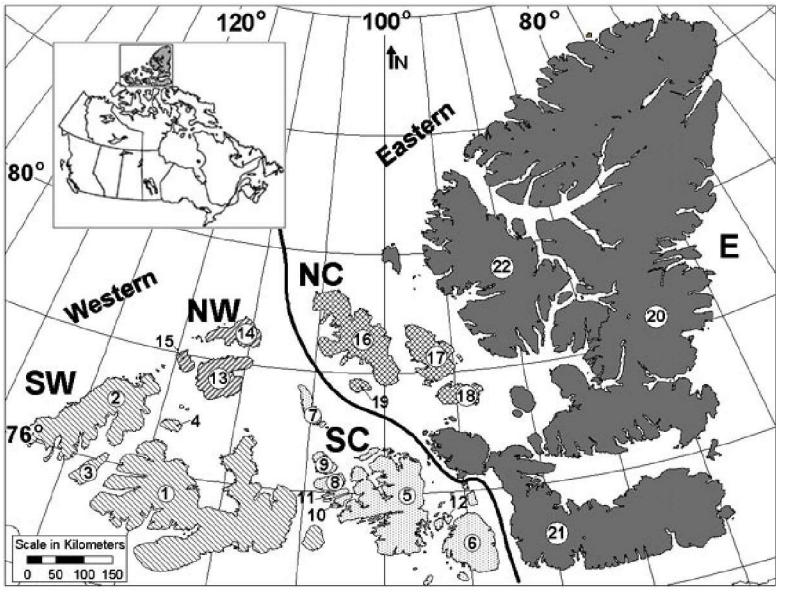

Fig. 1. Queen Elizabeth Islands split into two major zones, western and eastern Queen Elizabeth Islands; and five eco-units, Southwestern (SW), South-central (SC), Northwestern (NW), North-central (NC), and Eastern (E): islands surveyed by Tener in 1961, (1) Melville, (2) Prince Patrick, (3) Eglinton, (4) Emerald, (5) Bathurst, (6) Cornwallis, (7) Lougheed, (8) Vanier, (9) Cameron, (10) Alexander, (11) Massey, (12) Little Cornwallis, (13) Mackenzie King, (14) Borden, (15) Brock, (16) Ellef Ringnes, (17) Amund Ringnes, (18) Cornwall, (19) King Christian, (20) Ellesmere, (21) Devon, and (22) Axel Heiberg.

of range types and the geographical distribution of the animals within them.

Observers used previously prepared forms to record animals within the survey strip as being 'on-transect' and those seen beyond as being 'off-transect.' Tener (1963: 9) believed that the selected transect width and flight altitude facilitated the sighting of all animals on each transect and accurate identification of them by sex and age classes. The exception to this was on parts of Devon Island where, to take advantage of the good weather while the Piper Super Cubs were not ready for service, he used a deHavilland Beaver aircraft. They surveyed two transects each about 805 m (0.5 mi) wide by flying the Beaver aircraft at about 305 m (1000 ft) above ground level.

During the 70-d period between 10 June and 18 August 1961, prevailing weather at the time permitted survey flights on only 34 (49%) days. The Piper Super Cubs flew about 500 h and the Beaver flew about 100 h, but only about 205 h were on survey transects.

Reexamination of 1961 data

Our approach

We relied on the observations plotted and transect lines drawn on the original 14 field survey maps, as the original data forms no longer exist (J. S. Tener, pers. comm., 2001). During his initial analysis, Tener plotted his observations on the maps from the data forms, but after he completed the survey. We compared our raw data tabulations from those maps to the text, tables and figures in Tener (1963). To reconcile minor discrepancies between data on the maps and Tener (1963), Frank L. Miller and Samuel J. Barry each independently tabulated observations of Peary caribou from each data map. They repeated this process four more times over the course of several months, leaving sufficient time between repetitions to decrease 'remembering' their previous interpretation. They then did one joint count to confirm that their reasoning on each observation was the same. Finally, they compared the totals for each island and for each smaller survey land unit (stratum) used by Tener (1963) on those islands.

Calculation of estimated numbers and confidence intervals

We now know that many, perhaps most, caribou on the QEI make seasonal inter-island migrations (e.g., Miller *et al.*, 1977a, 1977b; Miller, 1990a, 1995a, 2002). The objective of this evaluation of the 1961 aerial survey findings (Tener, 1963) was to recalculate the estimates by grouping the 22 individual islands in a more ecologically sound manner into five island-complexes and to attach a measure of variability and confidence to the estimates. At the level of our five eco-units, we used a 'bootstrap' procedure (Krebs, 1999) to estimate the number of caribou, standard errors, and confidence intervals. We then summed the eco-unit statistics to obtain values for WQEI, EQEI, and the entire QEI.

Our bootstrap procedure is as follows. Using only those observations of caribou seen on-transect, we simulated a 'resurvey' of each island 100 000 times. On each resurvey we selected the same number of transects that Tener had flown in 1961 randomly and with replacement from the set of transects for

that island. For each of these 100 000 resurveys we summed the number of caribou 'observed' and the area 'surveyed' from the randomly selected transects. For each of these resurveys, we calculated the number of caribou within each eco-unit by first pooling these island results (caribou observed and area surveyed) among the islands in the eco-unit then multiplying the resulting caribou density (total pooled caribou observed divided by total pooled area surveyed) by the area of usable range within the eco-unit. Our bootstrap estimate of caribou for each eco-unit is the mean of 100 000 of those estimates. We measured bootstrap variability for each eco-unit as the variance of the bootstrap estimates (reported as standard error) and our bootstrap 95% confidence interval as the 2.5th and 97.5th percentiles of the distribution of all bootstrap estimates of caribou numbers. Hereafter, 'caribou' is synonymous with 'estimated caribou' in all cases.

Although Tener (1963) used the best information available at the time for the sizes of the 22 islands he surveyed, the areas of those 22 islands have been recalculated recently (http://atlas.gc.ca/english/facts/islands.html) and the reported sizes for 21 of them have changed. Only Little Cornwallis Island, the smallest island surveyed in 1961, remained at its 1961 measured size of 412 km^2. Therefore, we used sizes for 13 of 21 islands that were smaller than the values used by Tener (1963) by 1% to 44% and for the eight islands that were larger by 1% to 22%. Thus, our estimates of numbers of caribou reflect these changes in island sizes, which cause some deviation from Tener's (1963) original 1961 estimates.

Ellesmere, Devon, and Axel Heiberg islands have large glaciated areas and high elevations that are not suitable caribou range. Additionally, Melville Island has a small west-central permanent ice field. Tener (1963) excluded these areas from his calculation of caribou numbers (but his calculations were based on different island sizes). We recalculated the size of permanently glaciated areas using GIS-based 1:250 000 topographic maps with 150-m elevation contours and the recently revised island sizes (Table 3). As a result, we excluded all land > 750 m above mean sea level (amsl) and the glaciated areas < 750 m amsl from the land area we used for computing estimates for the number of caribou present. This removed all large areas of unsuitable range including all permanent snow and ice fields. We also excluded areas on Axel Heiberg and Ellesmere islands that received no aerial coverage.

Results

We tallied 393 observations of 1583 caribou on-transect on the QEI from Tener's 1961 field maps. Caribou in groups of two or more individuals constituted 78% (306) of the observations and the remaining 87 (22%) were individual caribou. By our calculations, Tener flew 27 872 km of transect lines and surveyed 11 213 km^2 (*ca.* 4%) of the usable range within the 1961 survey area. The 100 000 estimates of caribou numbers formed by randomly resampling transect counts within each eco-unit yielded 28 288 ± 2205 SE and a 95% CI of 20 436–37 031 Peary caribou on the QEI in summer 1961. Our estimate for the QEI is nearly 9% greater than Tener's (1963) original estimate (Table 2). Calves made up 20% of all caribou observed throughout the QEI.

Two major zones

Our recalculation suggests that 90% of Peary caribou on the QEI occurred on the WQEI and only 10% on the EQEI in summer 1961 (Table 2). The number of caribou on WQEI is only 4% greater than the original number estimated there by Tener (Table 2). Tener (1963) did not calculate an estimate for the islands surveyed in the Eastern eco-unit but used only "intuitive guesses"— collectively 650 caribou. When that 650 is combined with the 832 caribou estimated by Tener (1963) on the four islands in the North-central eco-unit there are 1482 caribou on the EQEI in 1961. Therefore, our estimate is 95% greater than the original 1961 collective island estimate plus guesses, although our 95% CI includes Tener's 1961 combined estimate for the EQEI (Table 2). The WQEI and the EQEI represent 24% and 76% of the collective landmass of the 22 islands surveyed in 1961 and 32% and 68% of the potential range for caribou, but the WQEI held nine times as many caribou as the EQEI. Caribou exhibited a strong preference for WQEI with a density 18-fold greater than that on the EQEI in summer 1961.

Five eco-units

Southwestern

There are five islands from 549 to 42 149 km^2 in size that make up this eco-unit (Table 1; Fig. 1). However, Byam Martin Island (1150 km^2) was not surveyed in 1961. Therefore, the eco-unit estimate is based on the other four islands minus 159 km^2 for ice fields on western Melville Island (Table 1). There was a strong preference for Peary caribou in this eco-unit, most (58%) of the caribou on the QEI and 64% of those on WQEI occurred there (Table 2).

South-central

There are 12 islands from 412 to 16 042 km^2 in size that make up this eco-unit (Table 1; Fig. 1). The four smallest islands, Helena (326 km^2), Baillie–Hamilton (290 km^2), Griffith (189 km^2), and Lowther

Table 1. Statistics compiled from 14 observation maps for the 1961 aerial survey of Peary caribou (Tener, 1963) and the most recent values for the 22 islands in the 1961 aerial survey, Queen Elizabeth Islands, Canadian Arctic Archipelago.

Eco-unit	Total length of transects (km)	Area surveyed (km^2)	Caribou observed on-transect	Area used for calculating estimates (km^2)[a]	Overall size of land unit (km^2)[b]
(Western QEI)	(14 410)	(5797)	(1470)	(96 067)	(98 651)
Southwestern	8163	3284	894	59 928	61 237
South-central	5221	2100	363	27 858	28 808
Northwestern	1026	413	213	8281	8606
(Eastern QEI)	(13 462)	(5416)	(113)	(194 535)	(318 089)
North-central	1929	776	30	19 553	19 553
Eastern	11 533	4640	83	174 982[c]	298 536

[a] Includes only potentially usable range for Peary caribou.
[b] Island sizes available from http://atlas.gc.ca/english/facts/islands.html.
[c] Excludes 11 376 km^2 of usable range that did not receive aerial coverage.

Table 2. The 1961 estimates of Peary caribou from Tener (1963) compared to the new estimates, associated standard errors, and confidence intervals calculated from the distribution of 100 000 bootstrap replications for each of five eco-units, Queen Elizabeth Islands, Canadian Arctic Archipelago.

Eco-unit	1961 estimate of Peary caribou	1961 estimated % calves	N[a]	Bootstrap estimates of caribou from this study			Mean density of estimated caribou (caribou • km^{-2})
				Mean	SE	95% CI[b]	
(Western QEI)	(24 363)	(21)	(286)	(25 401)	(2109)	(19 060–32 287)	(0.264)
Southwestern	15 418	20	173	16 315	1779	12 969–19 936	0.272
South-central	4933	21	89	4826	833	3283–6538	0.173
Northwestern	4012	21	24	4260	767	2808–5813	0.514
(Eastern QEI)	(1482)	(15)	(208)	(2887)	(642)	(1376–4744)	(0.015)
North-central	832	21	38	760	293	269–1405	0.039
Eastern	650[c]	12	170	2127	571	1107–3339	0.012

[a] N equals number of aerial survey transects flown.
[b] 95% CI based on the 2.5th and 97.5th percentiles of 100 000 bootstrap estimates of caribou numbers.
[c] Estimates for Ellesmere, Devon, and Axel Heiberg islands were not calculated in 1961 but based only on "intuitive guesses" by Tener (1963).

Table 3. Vertical relief divisions of the three mountainous islands of Ellesmere, Devon, and Axel Heiberg, within the Eastern eco-unit, eastern Queen Elizabeth Islands, Canadian Arctic Archipelago.

Island	Size of island (km^2)	% Area (km^2) in 150-m bands						% Area of ice/ snow	% Usable range
		0–150	151–300	301–450	451–600	601–750	> 750		
Ellesmere	196 236	10	13	15	13	12	37	43	57
Devon	55 247	12	19	15	38	5	11	20	80
Axel Heiberg	43 178	20	19	15	11	9	26	30	70
Totals	294 661	12	15	15	18	10	30	37	63

(145 km²) were not surveyed in 1961. Therefore, the eco-unit estimate is based on the collective landmass of Bathurst, Cornwallis, Lougheed, Vanier, Cameron, Alexander, Massey, and Little Cornwallis islands (Table 1: Tener's (1963) "Bathurst Island" included Bathurst and the islands of Vanier, Cameron, Alexander, and Massey). Caribou within this eco-unit made the second largest contribution to the estimate for the QEI (Table 2: 17%).

Northwestern

There are three islands from 764 to 5048 km² in size that make up this eco-unit (Table 1; Fig. 1). Thus, the eco-unit estimate is based on the collective landmass of Mackenzie King, Borden, and Brock islands, excluding 325 km² from Brock Island due to fog (Table 1). Caribou within this eco-unit made the third largest contribution to the estimate on the QEI (Table 2: 15%). Although the number of caribou contributed from this eco-unit to the QEI estimate was only moderate, the density was exceptionally high (Table 2).

North-central

There are four islands from 645 to 11 295 km² in size that make up this eco-unit (Table 1; Fig. 1). All four islands were surveyed in 1961: Ellef Ringnes (11 295 km²), Amund Ringnes (5255 km²), Cornwall (2358 km²), and King Christian (645 km²). Caribou within this eco-unit contributed the least to the QEI estimate (Table 2: 3%). The density of caribou within this eco-unit was markedly low (Table 2).

Eastern

There are 10 islands from 137 to 196 236 km² in size that make up this eco-unit (Table 1; Fig. 1): Ellesmere (196 236 km²), Devon (55 247 km²), Axel Heiberg (43 178 km²), Graham (1378 km²), Meighen (955 km²), North Kent (590 km²), Coburg (344 km²), Stor (313 km²), Hoved (158 km²), and Buckingham (137 km²). Only the three largest islands of Ellesmere, Devon, and Axel Heiberg were surveyed in 1961. Aerial coverage was low and fragmented due to poor weather. The potential range for caribou on the three islands is 63% of their collective landmass because 108 303 km² are covered by glaciers (Table 3). Only 27% of the land area on the three islands is <300 m amsl; in contrast, about 90% of the entire WQEI lies below the 300-m amsl level (Table 3; Miller *et al.*, 1977a). More importantly, about 60% of the landmass within the Eastern eco-unit is at higher elevations than those found anywhere else on the QEI. Caribou within this huge eco-unit composed only 7% of the total in the QEI, but 74% of the caribou in the EQEI (Table 2). The density of caribou within this eco-unit was exceptionally low, based on usable range for caribou (Table 2). Calves were appreciably lower in this eco-unit than in the other four eco-units (Table 1: $\chi^2 = 21.55$, 4 df; $P < 0.005$).

Discussion

Tener was greatly limited in any interpretation or evaluation of his results, with almost no on-site background information to draw from. In 1961, it appeared that there was a relatively large number of Peary caribou available on the QEI to support the establishment of Inuit settlements there. Unfortunately, that condition has not persisted and Peary caribou on the QEI are now 'Endangered' (Gunn *et al.*, 1981; Miller, 1990b; Miller & Gunn, 2003a, b). Peary caribou populations on the WQEI now occur as mere remnants of their 1961 sizes (Tener, 1963; Miller *et al.*, 1977a; Miller, 1995b, 1998; Gunn *et al.*, 2000; Gunn & Dragon, 2002). With the benefit of 4 decades of fragmentary information, we can extend our assessment of the 1961 findings.

In summer 1961 the relative mean densities and distribution of Peary caribou populations on the QEI indicated strong preferences for the Northwestern, Southwestern and South-central eco-units, low occurrence in the North-central eco-unit, and extremely low occurrence in the Eastern eco-unit. Since then only the Southwestern and South-central eco-units have served as 'heartlands' for Peary caribou.

Two major zones

In summer 1961 there were 18-fold more Peary caribou per unit area of usable range on the WQEI than on the EQEI (Fig. 1). Subsequent aerial surveys suggested that the highest estimates of Peary caribou were still in the Southwestern and the South-central eco-units (e.g., Miller *et al.*, 1977a; Miller, 1990b; Gunn & Dragon, 2002). The high numbers of caribou estimated in summer 1961 within the Northwestern eco-unit and on Lougheed Island in the South-central eco-unit have not been observed again (Miller *et al.*, 1977a; Miller, 1990b; Gunn & Dragon, 2002).

We believe the observed distribution of Peary caribou on the WQEI in 1961 reflected a summertime redistribution of the relatively high density of caribou in the Southwestern eco-unit beyond the eco-unit boundaries to 'out islands' in the Northwestern eco-unit. Thus, the relatively high density of caribou in the Northwestern eco-unit only reflects temporary ingress from elsewhere, not a persistent year-round state. It is also most likely that summer range extended in 1961 to Lougheed Island, with some spillover to the North-central eco-unit islands.

Whether this summertime redistribution involved caribou from both the Southwestern and South-central eco-units is not clear, but Lougheed Island appears to be more closely linked over time with changes in caribou numbers and distributions within the South-central eco-unit than with changes in the Southwestern eco-unit. Lougheed Island could not support caribou at a density of 1.1 • km^{-2} year-round for more than a few years without overutilization of the range. The same applies to Borden Island at 0.6 • km^{-2} and Mackenzie King Island at 0.5 • km^{-2}, where much of the range is on the poorly vegetated Beaufort Formation (Tener, 1963; Edlund & Alt, 1989). However, surveys in winter have shown that sparsely vegetated but wind-blown range on the Beaufort formation can be important to the survival of Peary caribou (Miller *et al.*, 1977a).

Five eco-units

Southwestern

After Tener (1963) completed his analyses, we learned that many, if not most, caribou within this eco-unit make seasonal inter-island migrations, moving from summer ranges on eastern Melville and Byam Martin islands to winter ranges on Prince Patrick and Eglinton islands (Miller *et al.*, 1977a, 1977b). Western Melville Island appears to be important to Peary caribou only during times of high numbers, such as in summer 1961. The small size of Emerald Ile apparently relegates it to transitional range for some few caribou, mainly during spring and autumn.

Inter-island movements within this eco-unit must have persisted over time, as Parry (1821) noted Peary caribou moving off eastern Melville Island in autumn. Therefore, multi-island surveys of at least Melville and Prince Patrick islands are necessary to estimate the number of caribou and any changes in the number of caribou there over time. Ideally, Byam Martin, Eglinton, and Emerald islands should be included in those surveys.

South-central

Caribou within this eco-unit also make seasonal inter-island migrations (Miller, 1995a, 1998, 2002); however, some remain year-round on Bathurst Island (Miller & Barry, 2003) and on other smaller islands (Miller, 1997, 1998). The primary linkage appears to be among Bathurst, Alexander, Marc, Massey, Vanier, and Cameron islands. Ile Marc was not surveyed in 1961: it is small (56 km^2) but important caribou summer range, lying between Alexander and Massey islands. There is some evidence of movement between Bathurst and the other lesser satellite islands as well as Cornwallis and Lougheed islands (Miller, 1997, 1998).

This eco-unit is of particular importance because it is readily accessible by hunters. The Inuit settlement of Resolute Bay on Cornwallis Island was established in the mid-1950s. Bathurst Island became a primary hunting area and remained so until the major die-off of caribou there in winter and spring 1973–74 (Parker *et al.*, 1975; Miller *et al.*, 1977a). Caribou abundance had apparently been adequate to satisfy annual harvest needs from at least the time of settlement until 1973, when they were already decreasing in number. Based on the past, this eco-unit could once again support a harvestable number of caribou, but probably only if the hunters from Resolute Bay give them time to recover. The three most recent annual die-offs between 1994 and 1997 saw the number of caribou reduced from about 3000 to < 100 (Miller, 1998; Gunn & Dragon, 2002; Miller & Gunn, 2003a).

Northwestern

This eco-unit is particularly remote from human settlement and the prevailing weather does not favor systematic aerial surveys. Mackenzie King, Borden, and Brock islands all lie beyond the northern limit of prostrate shrubs, and sedges and vascular plants are sparse, completely herbaceous, and least diverse of the QEI (Edlund & Alt, 1989; Edlund, 1990). This eco-unit has served on occasion as a 'spillover area' for caribou from the Southwestern eco-unit and possibly the South-central eco-unit when the caribou on one or both eco-units uncommonly reached a relatively high density. However, it is the smallest of the five eco-units and there is no reason to believe that it could sustain anything more than a relatively small low density 'reservoir area' for Peary caribou.

North-central

This eco-unit lies mainly in the environmentally stressful northern zone of plant growth (Edlund & Alt, 1989; Edlund, 1990). The ability of this range to support a large number of caribou year-round is highly questionable given its moderate size and meager flora. In all likelihood, this eco-unit serves mainly as a rarely used 'spillover area' for caribou from the Southwestern eco-unit and possibly the South-central eco-unit when caribou on one or both eco-units infrequently reach relatively high densities. This eco-unit should be viewed as a low density reservoir that can help foster the long-term persistence of Peary caribou on the QEI. The islands are not readily accessible to Inuit hunters and could never provide any appreciable level of sustained annual harvest.

Eastern

It is a mystery why there are not many more Peary caribou in this eco-unit. Its vastness makes Tener's

(1963) "intuitive guess" of only 650 Peary caribou there in 1961 appear ultra-conservative. This is especially true as there are at least 186 000 km^2 of potential range within this eco-unit. Our estimate of 2127 ± 571 SE requires only 0.01 caribou • km^{-2} and our estimate minus 1 SE (1556) would require, on average, only 0.008 caribou • km^{-2} of usable range.

Based on the 1961 results and subsequent limited information, we view the Eastern eco-unit as a huge, low-density reservoir for Peary caribou. In the foreseeable future, caribou there can make only a relatively small contribution to annual harvests of Peary caribou on the QEI. However, because of the Eastern eco-unit's large and rugged land base, it has great benefit to the persistence of Peary caribou on the QEI. Also, given the paucity of data for the three major islands in this eco-unit and their large size, there is a chance that this area may have more caribou than anyone is aware of.

Ironically, when the scenarios of 'global warming' are considered, we could speculate that the Eastern eco-unit may become the most important region for Peary caribou on the entire QEI. Because of the ruggedness of its terrain and its elevation relief (Table 3), many micro niches will be available that could foster Peary caribou survival in that region compared to survival in the relatively low-lying WQEI and the North-central eco-unit of the EQEI. If global warming advances as predicted by some, this change could occur within the next century. Even more importantly, it is possible that virtually only the Peary caribou on the Eastern eco-unit may survive the transitional phase of greater snowfall and more frequent icing events during global warming. The probability of this may be tied to the rapidity of warming processes which may cause micro niches to become critically important to the caribou's long-term survival on the QEI.

Management and conservation implications

Future aerial surveys of Peary caribou on the QEI should be at the eco-unit level to maximize both the accuracy of the estimated number of caribou and the probability of detecting real changes in caribou numbers and distribution over time. Surveys should be flown in July, at three-year or shorter intervals as long as the number of caribou remains small and especially if they are being harvested annually. Regardless of when the last survey was carried out, a July survey should be flown in the summer immediately after a winter or spring with exceptionally severe weather to determine the impact, if any, on the overwinter survival of caribou and the production and early survival of calves. Once adequate aerial surveys indicate that the number of caribou has increased to a size where the annual level of harvest would not exceed 5% (cf. Kelsall, 1968), based on the mean estimate minus 1 SE, minus the percentage of calves present, the interval between surveys could be extended to 5 years. In all cases, however, an aerial survey still should be carried out following any winter or spring with exceptionally severe weather to prevent a major decline in number going undetected.

The past and current status of Peary caribou in the EQEI remains debatable. No current information exists for caribou in the North-central eco-unit. In the Eastern eco-unit, recent information from northern Ellesmere Island suggests a stagnant condition with a minimum of only 45 Peary caribou estimated there between 1988–2002 (Manseau *et al.*, 2004). However, recent information from Inuit hunters from Grise Fiord on southern Ellesmere Island suggests that caribou are increasing there, based on sightings of a low number of caribou in places where they have been absent for several decades. Both M. Raillard, Canadian Wildlife Service, and J. England, University of Alberta, believe that while conducting other field activities they have seen numbers of caribou on parts of Ellesmere and Axel Heiberg islands in summers 1999–2001 that suggest increases are probably occurring on some relatively well-vegetated sections. The accuracy of island-wide extrapolations of caribou numbers from such casual observations cannot be measured with confidence. Thus, such extrapolations form a poor basis for making decisions regarding rates of annual harvest, particularly for an 'Endangered Species.' Only prescriptions for annual harvest that are based on actual counts of caribou that yield a total minimum number adequate to sustain desired harvests should be employed. Even then, following exceptionally severe weather years, harvest of Peary caribou may have to be temporarily halted by emergency action through cooperation with Inuit hunters.

The vastness and concomitant prohibitive costs of aerial surveys on the Eastern eco-unit require a different approach. We recommend the establishment of at least five permanent survey plots, 100 km by 100 km on areas of known importance to Peary caribou and where annual harvests are most likely to occur. These plots should be flown in early July when weather is most stable, and should be flown each time as close as possible to the same days of this month to record the percentage of calves, and ideally yearlings, present and the phenological state of plants for comparisons among years. This procedure would provide a relative estimate of the number of caribou, calving success, yearling recruitment, and annual variation in new plant growth within those 'food patches' that would allow the setting of flex-

ible maximum annual harvest levels. Accurate calf and yearling counts should be made, as a measure of performance to eventually provide a measure of their trend over time to better prescribe the maximal allowable level of annual caribou harvest, especially when annual harvest appears high. After the first year of plot surveys, both the previous number of animals counted and the size of the desired future annual harvest would dictate the needed frequency of those aerial searches. In the absence of a better measure, a maximum of a 5% annual harvest should be adhered to, especially as long as Peary caribou remain an 'Endangered Species.'

It is most unlikely that the concepts of 'carrying capacity' and 'sustained yield' have any real application to Peary caribou on the QEI. To date, everything suggests that the caribou on the QEI function in a 'nonequilibrium grazing system' where abiotic factors, mainly snow and ice, control their fate through infrequently occurring, sporadic and unpredictable 'exceptionally hard weather years' (Caughley & Gunn, 1993; Behnke, 2000; Miller & Gunn, 2003a, b). At such times, extremely unfavorable snow and ice conditions prevent the animals from getting to food or cause caribou to use more energy accessing it than they recover in forage intake. In years when such snow and ice conditions are prolonged and widespread, a large number of caribou (and muskoxen) will die from starvation. This happens because the carrying capacity of those caribou ranges will change, both quickly and unpredictably, with the prevailing severity of the snow and ice cover in each year. The more severe the snow and ice conditions and the longer they persist, the greater the loss of animals regardless of their densities or nutritional state at the beginning of the die-off period. Once the snow and ice melts, the carrying capacity of the range instantly experiences a many-fold increase—the absolute forage supply is still there and is once again readily available to the animals.

Therefore, caribou range in early winter that could support several thousand animals under favorable snow and ice conditions can be rapidly reduced to one that will support only several hundred or fewer animals. Then, following snowmelt, it will return immediately to a relatively favorable state. Such capricious range conditions will not allow a predictable fixed sustainable level of annual harvest of any appreciable size for more than a short series of years, if that. The lack of adequate periodic monitoring programs and the uncertainty of 'climate change' leave the fate of Peary caribou on the QEI unpredictable. Intervals of > 5 years between estimates of caribou on the QEI could run the risk of merely documenting serious declines after the fact, especially if continual annual harvests had been at relatively high levels. Although there is no evidence that harvesting has caused Peary caribou declines on the QEI, it could have accelerated and deepened them in some instances.

Conclusions

The Peary caribou on QEI is a unique part of Canada's High Arctic natural heritage and is recognized as an 'Endangered' form of wildlife in Canada. The number of caribou now on the QEI is a vestige of the number estimated there in 1961; yet, Peary caribou continue to be considered a usable renewable resource! Our recalculation of the 1961 aerial survey is the best benchmark for subsequent evaluations of changes in numbers, distributions, and movements of Peary caribou on the QEI. The division of the entire QEI into five eco-units provides a standard for evaluating the above changes over time on an ecologically sound basis for prescribing and assessing conservation measures for Peary caribou on the QEI.

Continued annual harvesting of Peary caribou—an 'Endangered Species'— requires that special safeguards and an adequate monitoring program be established. Cooperation among wildlife agencies and Inuit hunters is essential, because precautionary measures will require the participation of Inuit users in setting the restrictions and complying with them. No more than a few Peary caribou should be taken from any island within any eco-unit without first obtaining actual counts to determine that enough caribou exist there to sustain the desired level of annual harvest. Otherwise, we run the risk of being found negligent in our stewardship responsibility to this unique resource.

Acknowledgments

We thank the 1961 aerial survey crew, J. S. Tener, C. R. Harington, and D. C. Thomas of the Canadian Wildlife Service (CWS), and pilots K. McLennan and W. Kellog, Bradley Air Services, Ltd. for their pioneering work in obtaining the 'benchmark' data set for Peary caribou on the Queen Elizabeth Islands (QEI). Had the first systematic aerial survey of Peary caribou on the QEI been delayed to the mid-1970s, our understanding of Peary caribou numbers, distribution, and changes over time would be highly distorted and dangerously misleading. We are grateful to the CWS, of Environment Canada (EC) and the Polar Continental Shelf Project of Natural Resources Canada for supporting most of the studies of Peary caribou on the QEI. We also thank Parks Canada Agency of EC and the Department of Resources, Wildlife and Economic Development (RWED) of the Government of Northwest Territories for their assistance over the years and, espe-

cially, A. Gunn and J. Dragon, RWED, for carrying out the 1997 aerial survey of the western QEI. We thank J. S. Tener (past Director-General CWS), Ottawa, Ontario; D. C. Thomas, CWS; and two anonymous reviewers for critically reading the manuscript and making helpful comments and suggestions. We also thank G. Weiss, CWS, EC, for providing Digital Elevation Model analysis and map contours.

References

Anderson, D. R., Link, W. A., Johnson, D. H. & Burnham, K. P. 2001. Suggestions for presenting the results of data analyses. – *J. Wildl. Manage.* 65: 373–378.

Behnke, R. H. 2000. Equilibrium and non-equilibrium models of livestock population dynamics in pastoral Africa: Their relevance to Arctic grazing systems. – *Rangifer* 20 (2-3): 141–152.

Bliss, L. C. 1990. High Arctic Ecosystems: how they develop and are maintained. – *In*: Harington, C. R. (ed.). *Canada's missing dimension: science and history in the Canadian Arctic Islands.* Can. Mus. Nature, Ottawa, Ontario, Canada, pp. 350–384.

Case, R. & Ellsworth, T. 1991. Distribution and abundance of muskoxen and Peary caribou on southern Ellesmere Island, NWT, July 1989. – *Northwest Territories Dep. Renew. Resourc., Manuscript Rep.* 41: 1–23.

Caughley, G. & Gunn, A. 1993. Dynamics of large herbivores in deserts: kangaroos and caribou. – *Oikos* 67: 47–55.

Edlund, S. 1990. Bioclimatic zones in the Canadian Arctic Archipelago. – *In*: Harington, C. R. (ed.). *Canada's missing dimension: science and history in the Canadian Arctic Islands.* Can. Mus. Nature, Ottawa, Ontario, Canada, pp. 421–441.

Edlund, S. & Alt, B. 1989. Regional congruence of vegetation and summer climate patterns in the Queen Elizabeth Islands, Northwest Territories, Canada. – *Arctic* 42: 3–23.

Gauthier, L. 1996. Observations of wildlife on Ellesmere and Axel Heiberg islands between June 12–21, 1995. – *Northwest Territories Dep. Renew. Resourc. Manuscript Rep.* 86: 1–28.

Gunn, A. & Dragon, J. 2002. Peary caribou and muskox abundance and distribution on the western Queen Elizabeth Islands Northwest Territories and Nunavut June–July 1997. – *Northwest Territories Dep. Resourc., Wildl. and Economic Develop. File Rep.* 130: 1–93.

Gunn, A., Miller, F. L. & Nishi, J. 2000. Status of endangered and threatened caribou on Canada's Arctic Islands. – *Rangifer* Special Issue No. 12: 39–50.

Gunn, A., Miller, F. L. & Thomas, D. C. 1981. The current status and future of Peary caribou (*Rangifer tarandus pearyi*) on the Arctic Islands of Canada. – *Biol. Conserv.* 19(1980–81): 283–296.

Johnson, D. H. 1999. The insignificance of statistical significance testing. – *J. Wildl. Manage.* 63: 763–772.

Kelsall, J. P. 1968. *The migratory barren-ground caribou of Canada.* – *Can. Wildl. Serv. Monogr.* 3, Queen's Printer, Ottawa, Ontario, Canada, pp. 350–384.

Krebs, C. J. 1999. *Ecological Methodology*, 2nd ed. Addison–Wesley Longman, Inc., New York, NY, USA.

Macpherson, A. H. 1961. On the abundance and distribution of certain mammals in the western Canadian Arctic Islands in 1958-59. – *Arctic Circular* 14: 1–17.

Manseau., M, Dick, L., Lyons, N., St.-Pierre. C. & Wood, J. 2004. Ecological history of Peary caribou and muskox on northern Ellesmere Island, *ca.* 4300 to present. – *Research Links* 12 (1): 1, 4–8.

Maxwell, B. 1981. Climatic regions of the Canadian Arctic Islands. – *Arctic* 34: 225–240.

Maxwell, B. 1997. Responding to global climate change in Canada's Arctic. – *Environment Canada*, Downsview, Ontario, Canada, pp. 1–82.

Miller, F. L. 1987a. Peary caribou and muskoxen on Bathurst, Alexander, Marc, Massey, Vanier, Cameron, Helena, Lougheed, and Edmund Walker islands, Northwest Territories, July 1985. – *Can. Wildl. Serv. Tech. Rep. Ser.* 20: 1–45.

Miller, F. L. 1987b. Peary caribou and muskoxen on Prince Patrick Island, Eglinton Island, and Emerald Ile, Northwest Territories, July 1986. – *Can. Wildl. Serv. Tech. Rep. Ser.* 29: 1–65.

Miller, F. L. 1988. Peary caribou and muskoxen on Melville and Byam Martin islands, Emerald Ile, Northwest Territories, July 1987. – *Can. Wildl. Serv. Tech. Rep. Ser.* 37: 1–58.

Miller, F. L. 1989. Reevaluation of the status of Peary caribou and muskox populations within the Bathurst Island complex, Northwest Territories, July 1988. – *Can. Wildl. Serv. Tech. Rep. Ser.* 78: 1–86.

Miller, F. L. 1990a. Inter-island movements of Peary caribou: a review and appraisement of their ecological importance. – *In*: Harington, C. R. (ed.). *Canada's missing dimension: Science and history in the Canadian Arctic Islands.* Can. Mus. Nature, Ottawa, Ontario, Canada, pp. 608–632.

Miller, F. L. 1990b. *Peary caribou status report.* Environment Canada report prepared for the Committee on the Status of endangered Wildlife in Canada, Edmonton, Alberta, Canada, pp. 1–64.

Miller, F. L. 1995a. Inter-island water crossings by Peary caribou, south-central Queen Elizabeth Islands. – *Arctic* 48: 8–12.

Miller, F. L. 1995b. Peary caribou conservation studies, Bathurst Island complex, Northwest Territories, July–August 1993. – *Can. Wildl. Serv. Tech. Rep. Ser.* 230: 1–76.

Miller, F. L. 1997. Peary caribou conservation studies, Bathurst Island complex, Northwest Territories, April–

August 1994 and June–July 1995. – *Can. Wildl. Serv. Tech. Rep. Ser.* 295: 1–155.

Miller, F. L. 1998. Status of Peary caribou and muskox populations within the Bathurst Island complex, south-central Queen Elizabeth Islands, Northwest Territories, July 1996. – *Can. Wildl. Serv. Tech. Rep. Ser.* 317: 1–147.

Miller, F. L. 2002. Multi-island seasonal home use by two Peary caribou, Canadian High Arctic, Nunavut, 1993–94. – *Arctic* 55: 133–142.

Miller, F. L. & Barry, S. J. 2003. Single-island home use by four female Peary caribou, Canadian High Arctic Islands, Nunavut, 1993–94. – *Rangifer* Special Issue No. 14: 267–281.

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

Miller, F. L. & Gunn, A. 2003b. Status, population fluctuations and ecological relationships of Peary caribou on the Queen Elizabeth Islands: Implications for their survival. – *Rangifer* Special Issue No. 14: 213–226.

Miller, F. L., Russell, R. H. & Gunn, A. 1977a. Distributions, movements and numbers of Peary caribou and muskoxen on western Queen Elizabeth Islands, Northwest Territories, 1972–74. – *Can. Wildl. Serv. Rep. Ser.* 40: 1–55.

Miller, F. L., Russell, R. H. & Gunn, A. 1977b. Interisland movements of Peary caribou (*Rangifer tarandus pearyi*) on western Queen Elizabeth Islands, Arctic Canada. – *Can. J. Zool.* 55: 1029–1037.

Parker, G. R., Thomas, D. C., Broughton, E. & Gray, D. R. 1975. Crashes of muskox and Peary caribou populations in 1973–74 in the Parry Islands, Arctic Canada. – *Can. Wildl. Serv. Prog. Notes* 56: 1–10.

Parry, W. E. 1821. *Journal of a voyage for the discovery of a Northwest passage from the Atlantic to the Pacific; performed in the years 1819–20, in His Majesty's ships Hecla and Griper, under the Orders of William Edward Parry ...with an appendix containing the scientific and other observations.* John Murray, London, UK.

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 behavoiur of these populations.* Univ. Manitoba, Winnipeg, for Dep. Indian and Northern Affairs, Ottawa, Ontario, Canada, pp. 1–59.

Steidl, R. J., DeStefano, S. & Matter, W. J. 2000. On increasing the quality, reliability, and rigor of wildlife science. – *Wildl. Soc. Bull.* 28: 518–521.

Tener, J. S. 1963. Queen Elizabeth Islands game survey, 1961. – *Can. Wildl. Serv. Occas. Pap.* 4: 1–50.

Yoccoz, N. G. 1991. Use, overuse, and misuse of significance tests in evolutionary biology and ecology. – *Bull. Ecological Soc. America* 72: 106–111.