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Sea-ice crossings by caribou in the south-central Canadian Arctic Archipelago and their ecological importance

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Abstract: The islands of the Canadian Arctic Archipelago lie immediately north of mainland North America in the Arctic Ocean. They are surrounded by ice for most of each year. Caribou (*Rangifer tarandus*) cross the sea ice in seasonal migrations among the islands and between the mainland and Arctic Islands. We compiled observations of 1272 discrete caribou crossings on the sea ice of northeastern Franklin Strait, Bellot Strait, Peel Sound and Baring Channel in the south-central Canadian Arctic Archipelago during four May–June search periods from 1977 to 1980. We clustered the 850 caribou trails found on the sea ice of northeastern Franklin Strait and on outer Peel Sound as 73 sea-ice crossing sites. We investigated whether caribou at the origin of a sea-ice crossing site could see land on the opposite side at the potential terminus. We measured the straight-line distance from where the caribou first came onto the ice (origin) to the first possible landfall (potential terminus). Potential termini were geodetically visible to caribou from elevated terrain near 96% of the origins of the 73 sea-ice crossing sites and still visible at sea-level at the origins on 68%. Caribou are able to take advantage of seasonal use of all of the islands and the peninsula by making sea-ice crossings, thereby helping to increase the magnitudes and durations of population highs and reduce their lows. Knowledge of these alternative patterns of use made possible by sea-ice crossings is necessary to fully understand the population dynamics of these caribou and the importance of possible future changes in ice cover.

Key words: Canadian Arctic Islands, inter-island and mainland-island seasonal migrations, *Rangifer tarandus*.

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Introduction

The Canadian Arctic Archipelago is the northernmost extension of the North American continent (Fig. 1). It lies in the Arctic Ocean, spanning 22° of latitude (61–83°N) and nearly 65° of longitude (61–126°W), with a maximum north–south extent of *ca.* 2400 km and a maximum east–west breadth of *ca.* 2700 km. The archipelago has a collective island-landmass of >1.3 million km^2 (one-seventh of the land area of Canada), with >18 000 islands north of the Arctic Circle. However, only 70 of those islands each have a landmass ≥137 km^2 (http://atlas.gc.ca/english/facts/islands.html). The weather is highly variable and often extreme, especially on the High Arctic Islands (Maxwell, 1981, 1997). Throughout the entire archipelago, only tundra vegetation occurs: bryophytes, cushion plants, graminoids, herbs, lichens, and prostrate shrubs, with dwarfed or low erect shrubs occurring on some areas of southern islands (Edlund & Alt, 1989; Bliss, 1990; Edlund, 1990; Thomas *et al.*, 1999).

The islands of the Canadian Arctic Archipelago are surrounded by ice for ≥9 months each year, and the northern fringe of the Queen Elizabeth Islands remains virtually ice-bound all year. This condition allows caribou (*Rangifer tarandus*) to make seasonal migrations and sporadic movements across the sea ice virtually throughout the Canadian Arctic Archipelago and between the southern islands and the mainland. At various times in the past, caribou have reached every or almost every island.

We consider all caribou sea-ice crossings reported herein to have been a component of their habitual

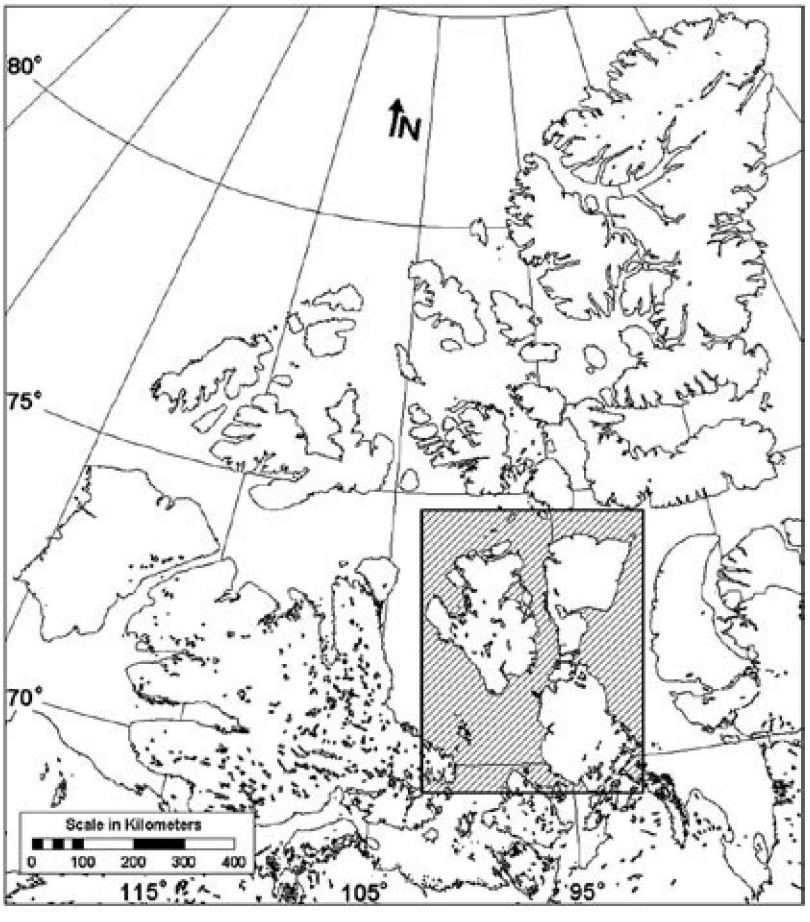

Fig. 1. Canadian Arctic Archipelago and the most northerly extension of mainland North America. Shaded area indicates Prince of Wales Island–Somerset Island–Boothia Peninsula Complex study area.

pattern of movement (seasonal migration) made during the late winter and spring within the Prince of Wales Island–Somerset Island–Boothia Peninsula Complex (PSBC) by the majority of caribou in this "geographic population." The actual trails on the sea ice or on land are not necessarily fixed migration routes used every year—but they are indicative of a broad migration path or zone that the caribou use to get from winter ranges to calving areas and summer ranges. The caribou return to winter ranges to the east and south in an early winter migration sometime after freeze-up and repeat the round-trip each year. Although the early winter migration after freeze-up has not been systematically documented, it is well-known among Inuit hunters from Resolute Bay, Cornwallis Island (G. Eckalook, pers. comm., 1980). It is also known that caribou from Prince of Wales Island together with caribou from Somerset Island occur regularly in winter on Boothia Peninsula. For example, caribou that summered on southern Somerset Island in the 1920s and 1930s moved annually to winter ranges on Boothia Peninsula, returning in spring to Somerset Island (A. Ooyukuluk via M. A. D. Ferguson, pers. comm., 2000). Inuit hunters see caribou from "Kingailak" (Prince of Wales Island) on Boothia Peninsula in winter, and select them because their meat is preferred to meat from mainland caribou (A. Buchan, pers. comm., 2000). The temporal pattern of these migrations within the PSBC (e.g., Miller & Gunn, 1978, 1980; Miller *et al.*, 1982; Miller, 1990a) is similar to seasonal migrations by caribou in other parts of the Canadian Arctic Archipelago and between the archipelago and the mainland: Queen Elizabeth Islands (Miller *et al.*, 1977a, 1977b; Miller, 1990a, b); and Dolphin and Union herd (Manning, 1960; Gunn *et al.*, 1997; Gunn & Fournier, 2000a, b). These late winter–spring migrations from winter range to calving areas and summer range and return to winter range in early winter are on a smaller scale but similar in purpose to those performed by caribou on the mainland (e.g., Kelsall, 1968; Skoog, 1968).

Our objectives were (1) to describe the seasonal migrations of caribou between and among the islands and peninsula within the PSBC, (2) to document the north–south extent of sea-ice crossings in northeastern Franklin Strait and Peel Sound, (3) to document that caribou move directly from Boothia Peninsula to Prince of Wales Island, (4) to evaluate whether caribou could see the opposite side of the sea-ice crossing sites, and (5) to assess whether caribou need visual reference points before making sea-ice crossings. We also discuss possible mechanisms that allow *R. tarandus* to make long-distance sea-ice crossings. In doing so, we hope to provide a better understanding of the various patterns of island and peninsula use of seasonal and annual ranges available to caribou within this region. We believe these movements

also have general application to virtually all of the archipelago, and understanding these movements is important to the development of needed conservation and management efforts.

Methods

We selected the PSBC in the south-central Canadian Arctic Archipelago (Fig. 1) where caribou exhibit several intricate patterns of annual and seasonal use of islands and a mainland peninsula. Caribou sea-ice crossings on northeastern Franklin Strait, Bellot Strait, Peel Sound, and Baring Channel were included. We emphasized northeastern Franklin Strait and Peel Sound because they are wide and bisect the PSBC, with Prince of Wales Island (33 339 km^2) to the west and Boothia Peninsula (32 331 km^2) and Somerset Island (24 786 km^2) to the east. The entire study area encompasses about 212 000 km^2, including *ca.* 93 000 km^2 of land.

We used information from Inuit hunters, aerial and ground searches, and satellite telemetry reported in published articles, internal project reports, and unpublished data to summarize the seasonal dynamics of the annual distribution of caribou within the PSBC. We reviewed the evidence for inter-island and mainland-island movements and migrations of caribou over the sea ice within the PSBC, and other island complexes in the archipelago and between islands and adjacent mainland areas (e.g., Manning, 1960; Banfield, 1961; Manning & Macpherson, 1961; Fischer & Duncan, 1976; Miller *et al.*, 1977a, 1977b, 1982; Miller & Gunn, 1978, 1980; Miller & Kiliaan, 1980a, b, 1981; Thomas & Everson, 1982; Gunn & Miller, 1983; Gunn & Ashevak, 1990; Miller, 1990a, b, 1995, 1998, 2002; Gunn & Dragon, 1998; Gunn *et al.*, 1997, 2000a; Gunn & Fournier, 2000a, b).

We place our emphasis on observations made within the PSBC between 1977 and 1980 by Miller & Gunn (1978, 1980) and Miller & Kiliaan (1980a, 1981). A Bell 206B helicopter was used in all 4 years of those studies as the main search aircraft. It was flown at 10–25 m above mean sea level (amsl) and 96 km • h^{-1} in 1977 with three observers plus pilot, then at 20–60 m amsl (usually <40 m amsl) and at an airspeed of 130 km • h^{-1} in 1978–80 with two observers plus pilot. When a trail was encountered, it was circled, hovered over, or the helicopter landed by the trail so that the observers could determine the direction the caribou were traveling.

In 1978, a deHavilland Twin Otter also was used in the searches. It was flown at 25–60 m amsl and at 220 km • h^{-1}, with an observer in the copilot seat and the pilot also acting as an observer. In 1979, snowmobile-mounted observers reported trails to the helicopter crew, who subsequently overflew any trails that had not already been recorded. The entire course of 40% of the 1272 trails recorded was flown, but each of the other 60% was either directly flown or crisscrossed only as far as necessary to determine its course, usually about halfway across the frozen water body. The direction of travel by caribou was determined for all trails seen in 1977, 1979, and 1980. In 1978, the direction of travel along 111 trails seen from the Twin Otter could not be verified with confidence. These included 5% of trails on outer Peel Sound, 16% of those on inner Peel Sound, and 29% of those on Baring Channel.

We produced a schematic illustration of sea-ice crossing sites representing multiple trails used by caribou while in migration, as springtime inter-island or mainland-island routes within the PSBC. The schema shows approximate locations of caribou crossing sites across the frozen water bodies. We clustered the 850 trails found on northeastern Franklin Strait between Boothia Peninsula and Prince of Wales Island and on Peel Sound between Somerset Island and Prince of Wales Island as 73 sea-ice crossing sites. To determine crossing distances, we measured the straight-line distance at sea-level where the caribou first came onto the ice (origin) to the nearest possible landfall (potential terminus), rather than to the point at which caribou actually left the ice. We investigated whether caribou at the origin could possibly see land at the potential terminus. We then determined the highest ground ≤10 km from each origin and potential terminus. Caribou crossing sites on inner Peel Sound between and among the satellite islands and Prince of Wales Island, on Baring Channel, and on Bellot Strait are not considered in detail because of the relative narrowness of those water bodies.

All locations were approximations and are reported to the nearest 0.1° (6 min) of latitude and longitude for reference purposes only. All elevations were in meters amsl. Elevations were taken either from values indicated on maps (verified Geodetic Survey of Canada benchmarks or less exact (±) unverified elevations) or from contour lines. All distances were recorded as kilometers in a straight-line along a horizontal plane. We used both 1:250 000–scale topographical maps and Geographical Information System computer-generated maps for this task.

We investigated whether land at the terminus was visible to caribou on the sea ice at the origin of each crossing site by calculating whether the geodetic horizon impedes visibility of the potential terminus from the origin. We did this by computing the distance to the "visible horizon" from an elevated origin by the following standard formula (The American Practical

Table 1. Sea-ice crossings by caribou within the Prince of Wales Island–Somerset Island–Boothia Peninsula Complex, south-central Canadian Arctic Archipelago, May–June 1977–1980.

Year	Search days (dates)[a]	Caribou trails	Caribou[b]	Search vehicle	Data source
1977	4 (12–18 June)	158	0	helicopter	Miller & Gunn (1978)
1978	20 (16 May–30 June)	422	53	helicopter, Twin Otter	Miller & Gunn (1980)
1979	10 (21 May–22 June)	107	25	helicopter, snowmobiles	Miller & Kiliaan (1980a)
1980	4 (14–22 June)	588	15	helicopter	Miller & Kiliaan (1981)

[a] For example: "4 (12–18 June)" equals 4 days of searching took place within the 7-day interval between 12 and 18 June 1977.
[b] Number of live caribou seen walking in trails on the sea ice during that search period.

Navigator, 2002), adjusted for refraction (http://www.sailingissues.com/vier/mathproof2.html):

$$d = \sqrt{\frac{h(1+2r)}{\rho}}, \text{ where}$$

h = height (m)
r = radius of earth – 6378137 m
ρ = 0.8279 is the coefficient of atmospheric refraction
d = distance to visible horizon (m).

Using this formula, we calculated the maximum distance that two points could be separated and still be visible to each other over the curvature of the earth.

Results

Search effort during May–June 1977 through May–June 1980 varied markedly in terms of timing, duration, and areas searched (Table 1). The greatest search efforts were made where the greatest numbers of trails were found. Therefore, these data do not accurately indicate the proportional occurrence of caribou trails on the sea ice among the various search areas, but instead provide a qualitative guide to where most sea-ice crossings took place (Table 2; Fig. 2).

Those 4 years of limited aerial searches documented 1272 caribou trails on the sea ice within the PSBC (Tables 1–3; Fig. 2). Ninety-four percent (142) of the 151 trails found on northeastern Franklin Strait between Boothia Peninsula and Prince of Wales Island were from east to west. The remaining 6% (9), all in 1979, were made by caribou traveling west to east. Ninety-two percent (645) of the 699 caribou trails seen on Peel Sound between Somerset Island and Prince of Wales Island or the satellite islands in Peel Sound were also from east to west. The direction of travel of caribou on 5% (35) of the 699 trails could not be verified from the Twin Otter. The other 3% (19) of the trails on Peel Sound went from west to east: 18 in 1979 and one in 1980.

Elevations on the high ground ≤10 km from the origins and termini of the 73 crossing sites varied by 188 and 282 m, respectively (Table 3). The length of 26 crossing sites between Boothia Peninsula and Prince of Wales Island ranged from 39–84 km between the elevated points. The 47 caribou crossing sites between Somerset Island and Prince of Wales Island ranged from 30–57 km. The longest distance we recorded for caribou traveling on the sea ice without making a landfall was 109 km. The last 25 km were, however, on sea ice in a bay where land was ≤5 km to the side of them. Thus, the animals could have left the ice at any point after reaching the 84-km potential terminus.

In good weather, caribou on an elevated position ≤10 km from the origin of a trail could have seen the terminus on the far side at 96% (70) of the 73 crossing sites on northeastern Franklin Strait and Peel Sound (Table 2; Fig. 2). If the visibility was adequate, the termini of the sea-ice crossing sites could still be seen for 68% of the 73 sites even when the caribou were standing on the sea ice (from 1 m amsl) at the origins (Tables 2–4). Caribou could see potential termini on Prince of Wales Island from most (88%) elevated positions near origins on Boothia Peninsula and from 100% of the origins on Somerset Island (Table 2). However, once on the sea ice, caribou could see Prince of Wales Island from origins of only 38% of crossing sites on northeastern Franklin Strait and from origins of 85% of crossing sites on outer Peel Sound (Table 2). Prince of Wales Island could be seen from sea level (1 m amsl) at all of the origins for the crossing trails on inner Peel Sound and on Baring Channel.

Seventy-nine percent (550) of the 699 trails found on Peel Sound went directly between Somerset Island and Prince of Wales Island (Fig. 2). The remaining 21% (149) went between Somerset Island and one of the four satellite islands off the east coast of Prince of

Table 2. Numbers of caribou crossing sites on northeastern Franklin Strait and Peel Sound presented in relation to whether the terminus could be seen from the high ground ≤10 km before the origin of the crossing site, south-central Canadian Arctic Archipelago, May–June 1977–80.

Water body crossed (latitudinal zone)	Crossing sites[a]	Trails seen	Length of crossing sites (km)		Elevation of terminus visible from ≤10 km of origin (m amsl)				Terminus not visible at origin
			Minimum	Maximum	1	5–20	25–40	110–115	
Franklin Strait (71–72° N)	26	151	39	84	10	7	4	2	3
South Peel Sound (72–73° N)	19	450(106)[b]	30	51	17	2			
North Peel Sound (73–74° N)	28	249(214)[b]	31	57	23	5			

[a] Caribou crossing sites representative of distribution of 1170 caribou crossing trails on northeastern Franklin Strait and throughout Peel Sound; the sites on Bellot Strait and Baring Channel are not included in this analysis.

[b] Values in parentheses are for trails on inner Peel Sound among the east-central satellite islands of Pandora, Prescott, Vivian, and Lock and between those islands and Prince of Wales Island.

Wales Island. The 88 crossing sites between the satellite islands and Prince of Wales Island were 15–29 km long. The 232 crossing sites between and among the 4 satellite islands were only 1–7 km long. The crossing sites on Baring Channel also were only ≤ 7 km long. Bellot Strait, only 1–4 km wide, had the narrowest crossing sites. It was searched only once, in 1979, because it was common knowledge that caribou crossed it. Although only four complete caribou trails were found on that occasion, the numerous broken trails on both the south and north shores indicated that many caribou had crossed recently from Boothia Peninsula to Somerset Island, then continued northward along the west coast of Somerset Island.

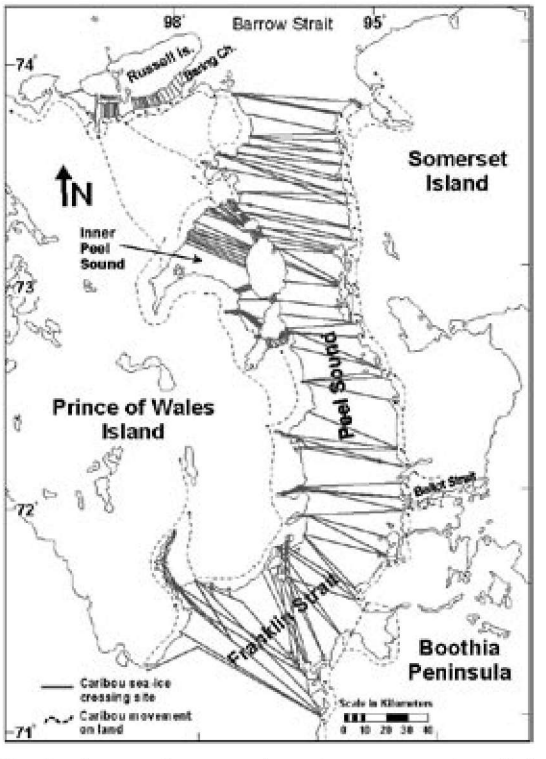

Fig. 2. Seventy-three crossing sites representing 850 caribou trails on northeastern Franklin Strait and Peel Sound, south-central Canadian Arctic Archipelago, May–June 1977–1980.

Discussion

Importance of seasonal use of islands

Caribou trails across the sea ice effectively joined all neighboring land areas for most of each year (Fig. 3), making it possible for caribou to range throughout the complex. Thus, the potential annual home range expanded from a single major land unit of roughly 25 000–33 000 km^2 to >90 000 km^2 among all three major land units, while the satellite islands would add another 3000 km^2 to the maximum overall range. This greatly increased the collective landmass available seasonally compared to what was available if caribou within the PSBC remained on a single island or Boothia Peninsula.

No evidence was obtained during this study for caribou crossing from Prince of Wales, Russell, or Somerset islands to islands north of 74.5°N latitude or vice versa. Also, no additional evidence for such caribou crossings between the PSBC and those more northerly islands was obtained during aerial searches as part of studies in the Bathurst Island complex from 1989 to 1996 (Miller, 1998).

In summer and early autumn, the food supply was adequate and readily accessible throughout the PSBC (e.g., Fischer & Duncan, 1976; Russell *et al.*, 1978; Miller *et al.*, 1982). Calving occurred annually on Prince of Wales Island, Russell Island, Somerset Island, and on lesser satellite islands (e.g., Fischer & Duncan,

Table 3. Elevation of high ground ≤10 km of origins and termini of 73 caribou crossing sites, south-central Canadian Arctic Archipelago, May and June 1977–1980. (see Table 2).

Water body	*n*	Elevations (m amsl) Minimum	Maximum
Origins			
Franklin Strait	26	61	238
South Peel Sound	19	90	210
North Peel Sound	28	50	110
Termini			
Franklin Strait	26	46	234
South Peel Sound	19	110	328
North Peel Sound	28	61	349

Table 4. Distance to visible horizon (km) from various land elevations (m amsl).

Elevation of origin	Elevation of terminus or potential terminus 1	30	60	100	150	200	250	300	350
1	8								
30	25	42							
60	34	51	59						
100	42	59	68	77					
150	51	68	77	85	94				
200	58	75	84	93	101	109			
250	65	82	90	99	108	115	121		
300	70	87	96	105	113	121	127	133	
350	76	93	102	110	119	126	132	138	144

1976; Miller & Gunn, 1978, 1980; Miller *et al.*, 1982; Gunn & Fournier, 2000b). The Prince of Wales Island and Somerset Island seasonal resident caribou returned to calve and summer on those islands along with the year-round residents (Miller & Gunn, 1980; Miller *et al.*, 1982). As soon as freeze-up occurred in early winter, the annual cycle of migrations over the sea ice was renewed and the PSBC caribou returned to their winter haunts. Caribou found on Boothia Peninsula in summer were not part of the PSBC geographic population, but were either year-round residents or migrants from the mainland further south (Gunn & Ashevak, 1990; Gunn & Dragon, 1998; Gunn & Fournier, 2000b; Gunn *et al.*, 1997, 2000a).

Winters on Boothia Peninsula are slightly shorter and, in general, less harsh than on the Arctic Islands. Most importantly, more of the forage on Boothia Peninsula should be accessible in winter because plant growth is more erect and taller there than on the Arctic Islands. We speculate that caribou moving from Prince of Wales and Somerset islands to winter on Boothia Peninsula would reduce overwinter grazing pressure on forage plants on their island summer ranges. Range rotation would allow faster recovery and better growth of forage plants on summer range during the following growing season and this would lessen grazing pressure. This could allow the caribou population to increase more than if it was restricted to a single island (Fig. 3). Of course, this is all conditional on the absence of exceptionally severe weather years, heavy predation, or unsustainable levels of annual harvesting.

Do caribou need visual aids for sea-ice crossings?

Caribou could see the potential terminus from elevated positions at the trail origin of all but the three longest sites, 84 km from the trail origin, which were the most southerly trails on Franklin Strait. Potential termini for these three crossing sites were slightly beyond what was geodetically visible, but distant land forms were visible in other directions, and may have been used for guidance.

The influence of the curvature of the earth on the distance to the horizon from an elevated point of land determines the visibility under a given set of conditions (Table 4). In the Arctic, however, this relationship can be markedly altered by the common occurrence of mirages. Mirages can effectively elevate the coast lines of low-lying islands many times above their true height, making it possible to see low-lying landmasses at much greater distances than the values in Table 4 indicate. Conversely, persistent fog is common and together with occasional blizzards would hinder or prevent the use of visual guidance by caribou migrating between or among the islands or the mainland and an island.

There is no indication that higher origins or termini were used preferentially by caribou in migration; seemingly, elevations at crossing sites just reflect the variation in heights of high ground found along the coasts. The lack of preference for high origins or termini is supported by the fact that crossing sites were distributed rather evenly from 71–74°N (Fig. 2), regardless of the length of the sea-ice crossing site or the elevation at its origin or terminus.

Other authors have reported that reindeer and caribou are capable of making sea-ice crossings over great distances well beyond the sight of land. The longest reported distance traveled over the sea ice without any possible landfall and well out of sight of any land was recorded for a reindeer marked by natives on Novaya Zemlya that then crossed 380 km of sea ice to Kong Karls Land, then 340 km to Franz–Josef Land, plus a further 90 km to Edgeøya

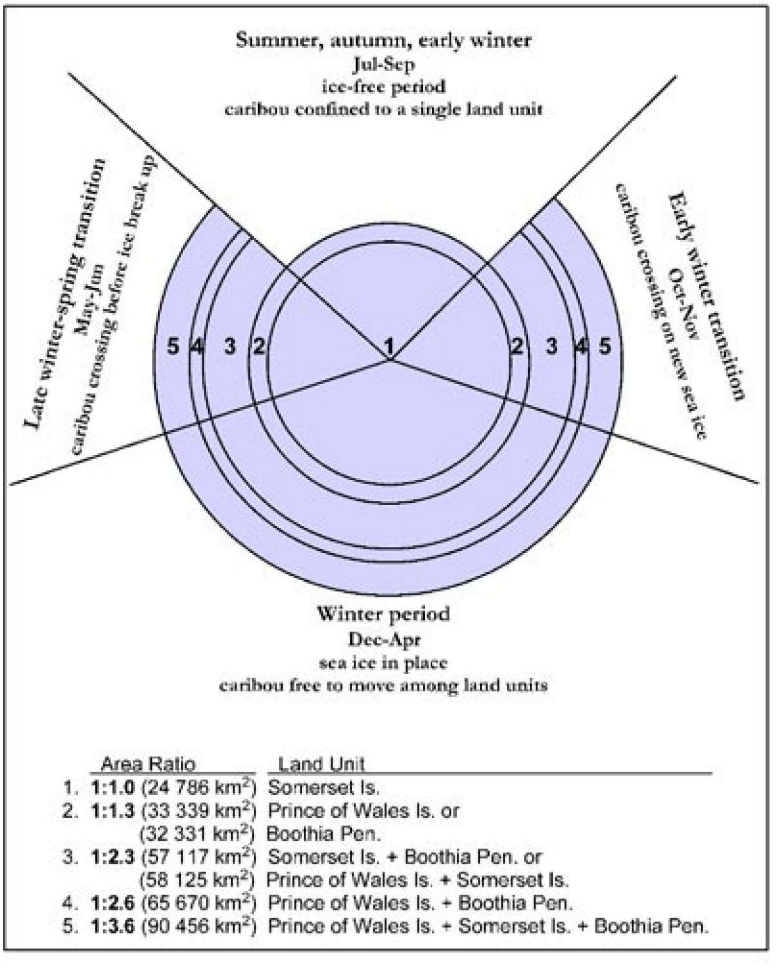

Fig. 3. Schematic ratio representation of annual expansion (nearly quadrupling) of annual caribou home ranges made possible by seasonal inter-island, mainland-island, and island-mainland late winter–spring and early winter migrations across the sea ice within the Prince of Wales Island–Somerset Island–Boothia Peninsula Complex, south-central Canadian Arctic Archipelago.

in Svalbard before being killed there (Banfield, 1961; Hakala *et al.*, 1985). Banfield (1961) also notes records of reindeer crossing from the New Siberian Islands to Bennet Island, a distance of 125 km. Manning & Macpherson (1958) report that caribou are known to cross from Banks Island to Cape Bathurst on the mainland, a distance of about 185 km. Other examples of long-distance movements by *R. tarandus* over the sea ice are reported in Miller (1990a). Thus, it appears that while caribou might often cross frozen water bodies at sites where a visual terminus exists on the far side, such visual cues are not necessary.

Mechanisms for sea-ice crossings

Although we know little about their methods, the navigational prowess of *R. tarandus* is well known. For caribou and wild reindeer, seasonal migrations are accomplished through "learned traditions" incorporating innate behavior (Ortstreue: Wynne Edwards, 1962). It is most likely that the odoriferous materials produced by their interdigital scent-glands and secondarily by tarsal and caudal scent glands and in urine and feces (e.g., Quay, 1955; Lewin & Stelfox, 1967; Andersson *et al.*, 1975; Muller-Schwarze *et al.*, 1978) facilitate long-distance migrations by reinforcing the coherence of the different groups in migration and directionality during daily travels (e.g., Miller, 2003).

The caribou's habit of walking single-file when moving or migrating and often stepping in exactly the same spot is well known. This behavior would concentrate scent deposits from the interdigital glands and greatly intensify the scent markings that guide visually separated trailing animals. Lapp herders have long believed that the interdigital glands serve in layering an odor track on the ground (Muller-Schwarze *et al.*, 1978). It is quite possible that odorous material such as a long-lasting pheromone in the tracks of the first caribou to make a sea-ice crossing would be detectable by following caribou for some time afterwards. This could be true even after the tracks have been obliterated by snow and even after no visual or tactile stimulus could be transmitted from footprints in the snow pack.

If the caribou choose to retreat back along their trail, they have a strong scent trail (including a "trail pheromone": Muller-Schwarze *et al.*, 1978) to guide them, even if the trail has been obliterated by new snowfall or wind action. No other form of guidance would be necessary to allow them to return to land. Most importantly, once a few or possibly just one caribou crosses successfully, all other caribou can follow the scent trail without additional guidance. On two occasions, F. L. Miller observed caribou on previously established trails on Peel Sound coming

onto northeastern Prince of Wales Island in fog and low overcast that at times allowed only about 1 km forward visibility.

Caribou would also add to their scent trail with urine and feces. When caribou urinate on snow in subzero weather, the urine freezes into a "urine cone." On the High Arctic Islands, these urine cones are often 15–20 cm high with a base 6–10 cm wide that tapers upward to only 2–4 cm in width where the hot urine first penetrated the snow pack. Foraging caribou often deliberately sniff and are seen to lick such frozen urine deposits; it seems reasonable that urine cones in the snow cover, or frozen pooled urine on a hard surface would serve as "sign posts" for migrating caribou. If they needed any further guidance, scent from feces obviously could aid caribou in migration and general body odors and the smell of the land may provide additional aids. Visual, tactile, and auditory aids may be useful on occasion but are not necessary for caribou to travel over long distances along a particular course.

Potential impacts of climate change

If climate change advances as predicted, the caribou will experience radical changes in their environment and the ultimate result might be restriction to a single island or to the mainland. Changes due to climate warming are predicted to occur first and most severely in the Arctic (Maxwell, 1997; Weller, 2000). Climate change at its most drastic may test thousands of years of caribou evolution in this region and throughout the Arctic.

Recent trends suggest that the seasonality and characteristics of sea ice cover surrounding the Arctic Islands and particularly the sea ice linking the islands to the mainland may greatly change in the near future (Comiso, 2002). Increases of 1–3 months in the duration of the ice-free season are predicted, suggesting that freeze-up could be delayed well into November, that the melt could begin in May, and that sea-ice break-up could occur in early June. If such changes occur, they would seriously alter the timing and, perhaps, the opportunity for seasonal migrations across the sea ice. The timing of these migrations is linked to annual life history phases of caribou. Thus, many of the benefits to caribou derived from migration between land areas could be severely reduced or virtually lost due to later freezing or earlier melting of sea ice. A series of years with extremely short periods of ice cover could cause caribou to alter or lose their tradition of inter-island or mainland-island seasonal migrations. Loss of these migrations could seriously reduce the ability of the region to support viable populations of caribou.

Delayed freeze-up would lead to increased mortality of caribou attempting to migrate over sea ice that was still too weak to support them (e.g., Miller & Gunn, 1986). Already in recent years, there have been reports of the drowning of a large number, perhaps several hundred, of the Dolphin and Union caribou herd during their autumn migration from Victoria Island to the mainland (Gunn *et al.*, 1997, 2000b; A. Gunn, pers. comm., 2005).

Ship traffic through the ice-covered channels among the Arctic Islands and especially between those islands and the mainland would be another impediment to caribou seasonal migrations (Miller, 1990a, b). Five shipping lanes through Arctic waters have been proposed in initial scenarios and as many as 20 ships a day have been forecast to pass through the Northwest Passage (*ca.* 74–75°N latitude): an average rate of one ship every 1.2 hours. At that rate, it is most unlikely that the shipping track could refreeze sufficiently to support caribou crossings between ship passages. Although caribou can easily swim open-water ship tracks, the ice shelf and the ice-block rubble pushed-up along the edges of the track could be a death-trap, especially for the small-bodied calves, yearlings, and 2-yr olds, but in some instances for any caribou that enters the water.

The economic enticement for heavy use of shipping lanes in Arctic waters is great. Nationally, this shipping is focused on the extraction of nonrenewable resources (oil, liquefied natural gas, and mineral ores) from the Canadian Arctic islands and the coastal mainland. All-season shipping will bring greatly increased exploration and development activities for nonrenewable resources and the associated human-induced novel stimuli could be detrimental to the long-term well-being of caribou populations in the Canadian Arctic Archipelago and on the coastal mainland (e.g., Miller & Gunn, 1979). Internationally, the greatest benefit from shipping through Arctic waters arises from the 11 000 km that would be cut off the Europe–Asia route through the Panama Canal and the 19 000-km reduction for the trip around Cape Horn for supertankers unable to use the canal (Kerr, 2002). Thus, the continued feasibility of caribou making seasonal inter-island migrations, and especially migrations between the mainland and the Arctic Islands, is questionable. When and if climate warming and heavy shipping traffic come to pass, those caribou now prospering from seasonal migration over the sea ice would be forced to face the rigors of life imposed on a "single-island dweller." For at least some and possibly many islands, extirpation of caribou would be the result.

Conservation and management implications

Although the search efforts from 1977 through 1980 were limited, a large number of caribou sea-ice crossing trails were documented (Tables 1 and 2; Figs. 2 and 3). These migrations over the sea ice allow marked expansions of caribou use of different land units on a seasonal basis for about nine months of each year (Fig. 3). The importance of these intricate seasonal movements over the sea ice cannot be ignored when planning conservation efforts or making management prescriptions for these caribou.

We demonstrate that while caribou could see 96% of the termini from elevated positions, once on the sea ice they could see only 68% of the termini (Table 2). Prince of Wales Island can be seen from sea level (1-m amsl) at all of the origins for the crossing trails on inner Peel Sound and Baring Channel (Table 2). Information from the literature shows that caribou and reindeer travel great distances on the sea ice well beyond any possible sight of land. This, in itself, rules out the supposed necessity that caribou or reindeer be able to see land on the opposite side before beginning a migration or movement over the sea ice.

The majority of caribou on Prince of Wales and Somerset islands (and their satellite islands), apparently functioned as an intricate geographic population with several calving areas and rutting areas, with different segments exhibiting different seasonal and annual patterns of island and peninsula use. However, some caribou stayed year-round on either of the two major islands and could be considered as at least two separate local populations with different annual patterns of single-island use. If they were, in fact, functioning as discrete ecologically meaningful local populations, then they may be a "metapopulation" or part of one. The extensive movements among the islands and the peninsula suggest that, for purposes of conservation and management, it would be best to treat the entire PSBC as one unit.

The caribou's ability to move freely over the sea ice for most of each year makes it ecologically invalid to view caribou on the Canadian Arctic Archipelago as compulsory single-island dwellers. This is particularly true in terms of the greater environmental limitations that could be imposed on caribou restricted to a single Arctic island for their entire lifetime. Important exceptions, when no great benefits are derived from inter-island movements, are the years with exceptionally severe widespread snow and ice conditions that lead to major winter die-offs. These occur infrequently and sporadically and thus unpredictably on a widespread and sometimes range-wide basis (Miller *et al.*, 1977a; Miller, 1998; Gunn *et al.*, 2000b; Gunn & Dragon, 2002; Miller & Gunn, 2003a, b).

In all likelihood, annual inter-island and island-mainland migrations represent the most important behavioral tradition held by caribou on most of the Canadian Arctic Archipelago, as they greatly expand the available land base. This includes the caribou in the PSBC, and the Dolphin and Union herds that calve and summer on Victoria Island and winter on the mainland. Migrations allow all caribou to greatly expand their annual home range through seasonal movements to different islands or onto the adjacent mainland. Inter-island, island-mainland, or mainland-island movements can take the form of seasonal migrations, sporadic environmentally-forced responses, and chance events. More specifically, migration across the sea ice can reduce caribou grazing pressure on the forage through expansion of annual range by using different seasonal ranges. This should reduce grazing pressure per unit area and markedly increase the magnitudes and durations of population highs and reduce the depths and lengths of their lows (e.g., Miller, 1990a).

In the Canadian Arctic Archipelago, possibly only Baffin Island (the fifth largest island in the world at 507 451 km^2) is an exception to the restrictions imposed on a single-island dweller. Although caribou on Baffin Island experience population highs and lows along with range shifts (Ferguson & Messier, 2000), the island's huge size and varied terrain negate the need for caribou to use more than one island for seasonal ranges. Nevertheless, even the Baffin Island caribou might benefit, at times, from using summer ranges on nearby islands to reduce the year-round grazing pressure on some ranges on Baffin Island. It is possible that caribou on Victoria Island (the 9th largest island in the world at 217 291 km^2) and Ellesmere Island (the 10th largest island in the world at 196 236 km^2) would also not need to move to other islands. Infrequent major die-offs could occur, however, on large sections of those two islands if the caribou do not shift their range or emigrate when they are subjected to exceptionally severe and prolonged snow and ice conditions.

It is critical for both ecologically sound conservation and biologically sound management of these caribou to document the full repertoire of seasonal migrations among the islands and the peninsula within the PSBC. Most importantly, this information should be used in conservation and management efforts for these caribou. Knowledge of these alternative patterns of use made possible by sea-ice crossings is necessary to truly understand the population dynamics of these caribou and the importance of possible future changes in ice cover.

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