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Movement Patterns of the Porcupine Caribou Herd in Relation to Oil Development

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SUMMARY

The Porcupine Caribou (*Rangifer tarandus*) Herd has consistently calved at high densities on the coastal plain of the Arctic National Wildlife Refuge. Calf survival is lower when calving is displaced from this area. Since 1979, the Porcupine herd has grown steadily at a rate of about 5% per year and was estimated at 178,000 in 1989. During this report period, a journal publication on factors involved in calving site selection was accepted for publication and an article on calf mortality was submitted for publication.

Key Words: caribou, migration, *Rangifer tarandus*, satellite radio-tracking.

CONTENTS

BACKGROUND

In 1980 the U.S. Congress set aside a portion of the coastal plain in the Arctic National Wildlife Refuge for oil and gas exploration. Results of the geological exploration indicate that the coastal plain (now commonly referred to as the 1002, or "ten-oh-two," area) is the best remaining onshore prospect for a major new oil discovery in North America.

Congress also mandated baseline ecological research of the 1002 area, and the Porcupine Caribou (*Rangifer tarandus*) Herd (PCH) ($\underline{n}$ = 178,000 in 1989) has thus been the subject of cooperative studies conducted by the Alaska Department of Fish and Game (ADF&G), the U.S. Fish and Wildlife Service, the Canadian Wildlife Service, and the governments of the Yukon and Northwest Territories. These studies have focused on seasonal movements of the PCH within both the U.S. and Canada. Satellite transmitter collars were found to be an effective addition to standard telemetry for following seasonal movements. Intensive tracking of both radio-collared cows and radio-collared calves yielded valuable information on timing and distribution of calving and spatial variation in calf survival. In most years, about 50-75% of the calves in the PCH are born in an area which comprises 25% of the overall calving grounds. Calf survival tends to be particularly high when calving occurs in the low-lying coastal plain portions of this traditional high-density calving area rather than in nearby foothills and mountains where predators are more abundant.

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The 1002 area overlaps most of the coastal plain portion of the traditional calving area. All of the 1002 area is used as postcalving habitat by the PCH, and much of the western part of the 1002 area is used by the Central Arctic Caribou Herd (CACH) (n = 19,000 in 1991) as late summer and winter range. Studies of the CACH in the Prudhoe Bay and Kuparuk Oilfield areas have indicated a potential for displacement of caribou from traditional ranges and disruption of traditional movement patterns. The overall goals of the current study are to continue to identify potential conflicts between caribou and oil development and to recommend measures for minimizing the impact of oil development on caribou and their habitat.

OBJECTIVES

To synthesize existing knowledge on migration routes between seasonal ranges, selection of calving areas on the arctic coastal plain, selection of winter ranges, and long-term natality and mortality rates of radio-collared caribou.

STUDY AREA

The study area encompassed the entire range of the PCH in northern Alaska and in the Yukon and Northwest Territories in Canada.

METHODS

Migration Routes

Migration routes between summer and winter ranges are determined primarily from the cumulative location data from satellite-collared caribou. Details of the satellite telemetry system have been reported previously (Fancy et al. 1989a,b; Whitten and Fancy 1991). For the purposes of analyses conducted so far, fall migration occurs during September and October and spring migration occurs in April and May (Whitten and Fancy 1991). Extensive movements between distant ranges also occur during other times of the year, however, and future analyses may consider these other movements as well. Computer printouts of migration routes will be compared with geographical features on topographic maps and with available data on vegetation, habitat type, and snow cover.

Selection of Calving Sites

Movement toward calving areas is monitored using satellite-collared cows. Movement toward specific calving sites within the overall calving area is monitored by intensive (i.e., daily) tracking flights to visually locate both satellite and conventional radio-collared cows. General calving areas and specific calving sites are compared with topographic features, forage quality and availability, predator distribution, and annual variation in snow cover. Appendix A provides a more detailed description of methods used.

Selection of Winter Ranges

Selection of winter ranges will be investigated by plotting distributions of both satellite and conventional collared caribou. Particular emphasis will be placed on winter distribution in relation to topographic and vegetative features and to variation in snowfall. The hypothesis that individual caribou maintain long-term fidelity to specific winter ranges will also be tested using multi-year data from individual radio-collared caribou and by comparing the relative numbers of radio-collared caribou using various areas each year.

Long-term Natality Rates of Radio-collared Caribou

Natality of radio-collared cows is determined annually by extensive monitoring on the calving grounds. Parturient status is determined using a combination of observations, including presence or absence of a calf, antler condition, and udder distension. Individual radio-collared cows are relocated frequently from about 28 May to 10 June because past experience has indicated that point-in-time observations may not positively identify all parturient females. More detailed methods appear in Appendix B. Radio-collar batteries usually last 3-5 years, and many cows have been recaptured and fitted with new radio collars so that a sizable sample of females with >2 years of natality data is now available for analysis.

Long-term Mortality Rates of Radio-collared Caribou

Long-term mortality has been studied using data from radio-collared calves, yearlings, 2-year-olds, and adults. Detailed methods are presented in Appendix B.

RESULTS AND DISCUSSION

Existing data on calving ground use and calving site selection are synthesized in Appendix A, which confirms traditional use of a high-density calving area overlapping the 1002 area. Survival of calves is higher when parturient cows are able to use this area and lower when they are displaced (by adverse snow conditions) to areas with more predators. In the future, ADF&G will continue to monitor the general correlation between a more coastal calving distribution and higher calf survival. More specific attention will be given to the role of nutrition and forage quality and quantity in calving site selection.

It is anticipated that this nutrition work will be conducted primarily by the U.S. Fish and Wildlife Service, however.
Long-term data on population dynamics, including changes in population size, natality, and mortality, are summarized in Appendix B. A technical journal article is being prepared which will incorporate the long-term natality and mortality findings of Appendix B into a computer model of the dynamics of the PCH, with discussion of its potential application to other caribou populations.

Data on migration routes and selection of winter ranges are still being accumulated and will be analyzed in future reports.

During this report period the following article was accepted for publication:

Fancy, S. G., and K. R. Whitten. 1991. Selection of calving sites by Porcupine Herd Caribou. Can. J. Zool. 69:000-000.

Another article is undergoing final editing and should be published during the next report period:

Whitten, K. R., G. W. Garner, F. J. Mauer, and R. B. Harris. Calf survival in the Porcupine Caribou Herd. J. Wildl. Manage. 00:000-000.

Additional papers on field techniques for determining natality in free-ranging caribou and on long-term reproductive histories of individual females will be prepared during the next report period and submitted for publication in professional journals.

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Whitten, K. R., and S. G. Fancy. 1991. Movement patterns of the Porcupine Caribou Herd in relation to oil development. Alaska Dep. Fish and Game. Fed. Aid in Wildl. Restor. Prog. Rep. Proj. W-23-3. Juneau. 43pp.

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APPENDIX A.

WORK UNIT I Potential impacts of petroleum exploration and development on the numbers, distribution, and status of caribou on the arctic coastal plain

Work Subunit Ib Effect of potential displacement of caribou from the 1002 area on mortality rates of calves

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INTRODUCTION

In 1980 the U.S. Congress set aside 600,000 hectares (1.5 million acres) of the coastal plain in the Arctic National Wildlife Refuge (ANWR) for limited oil and gas exploration. Results of that exploration program indicated a potential for significant petroleum resources, and Congress is now considering additional legislation to open those lands (commonly referred to as the 1002 area) to leasing and development (Clough et al. 1987).

The Porcupine Caribou (*Rangifer tarandus granti*) Herd (PCH) has consistently calved at high densities in the eastern portion of the 1002 area (Garner and Reynolds 1986). Studies of the adjacent Central Arctic Herd (CAH) have found that disturbance associated with petroleum development can displace calving caribou (Cameron et al. 1991). The Prudhoe Bay oilfield has the lowest calving densities of any portion of the CAH calving grounds (Whitten and Cameron 1985), and in the Kuparuk oilfield, density of calving caribou was inversely correlated with distance from development (Dau and Cameron 1986). If the 1002 area is leased, biologists, conservationists, and sport and subsistence hunters are concerned that subsequent development could displace parturient PCH caribou from the traditional calving grounds (Elison et al. 1986, Clough et al. 1987).

The objectives of this Work Subunit were to re-evaluate use of the 1002 area for calving by the PCH, determine causes of early calf mortality, and examine whether calf survival differed between the 1002 area and areas to which calving might be displaced. This report combines data collected from 1988 to 1990 with data collected during earlier baseline studies (Whitten et al. 1984, 1985, 1987).

METHODS

The study area included all north flowing drainages between the Canning River in Alaska and the Blow River in the Yukon Territory. Essentially all calving by radio-collared females of the PCH occurs in this area every year. Mountains rise sharply at the southern edge of this area, about 60-80 km inland from the coast in the west, but only about 25 km inland in the east. Moderate to gentle relief foothills dominated by cottongrass (*Eriophorum vaginatum*) tussocks lie just north of the mountains, while nearly flat, marshy tundra extends along the coast. Numerous large rivers traverse the area from south to north, characterized by open gravel bars, mat tundra vegetation on old floodplain terraces, and discontinuous stands of low riparian willows (*Salix* spp.). More detailed descriptions of the study area are given by Garner and Reynolds (1986), Felix et al. (1989), and Christiansen et al. (1990).

Calving Surveys

Radio-collared cows were observed from fixed-wing aircraft at 1- to 3-day intervals between approximately 28 May and 30 June each year to determine date and location of calving and the fate of calves. Calving dates and neonatal survival for calves of collared cows were determined from a combination of criteria, including presence of a live calf at heel, presence or absence of hard antlers, udder distention, or observations of cows standing over a dead calf (Whitten 1990). Cows not showing any overt signs of pregnancy, but not obviously barren (e.g., already possessing velvet antlers), were relocated at least weekly until 30 June to ensure that no pregnancies were missed. Cows that apparently lost calves were observed at least once more during the calving period to confirm that no calf was present.

Calving sites of radio-collared cows between 1983 and 1990 were digitized and entered into the ARC/INFO geographic information system (GIS) for analysis of calving distribution and calving site selection. Most calving occurred on the coastal plain and foothills. We tested whether the distribution of calving sites on the coastal plain and foothills was random by partitioning the area into 6 blocks of similar size (Fig. 1) and determining the number of calving sites expected within each block if the 267 sites were evenly distributed. Blocks were delineated on the east and west by major rivers or the Alaska-Yukon border, and on the north by the coastline. The southern boundaries of the blocks were drawn where the coastal plain and foothills give rise to the mountains of the Brooks and British Ranges. The area within each block was determined using the ARC/INFO geographic information system.

Calving Site Selection

Movements of parturient females toward calving sites were monitored by following individuals collared with satellite transmitters. Physical and habitat factors influencing calving site selection were determined by comparing attributes of calving sites for all radio-collared cows from 1983 to 1990 with those of randomly selected sites within the area bounded by the outermost calving sites (including those in the mountains, but excluding 2 cows that calved with the CAH, west of the Canning River; Fig. 1). We excluded sites where 16 cows were first observed with a calf because the calf was estimated to be >5 days old and may have been born several kilometers away. These 16 cows were used in the calving distribution analysis above because they were located within the same block before and after calving.

We determined the elevation, slope, and landcover type for each calving site and random site using digital maps with a resolution (i.e., pixel size) of 50 m x 50 m in Alaska (USGS Eros Data Center, Anchorage, AK; Garner and Reynolds 1987:60) or 100 m x 100 m in Canada (Nixon et al. 1989). Landcover maps in both Alaska and Canada were based on LANDSAT multispectral scanner data; however, the use of different classification algorithms for each map precluded direct comparisons. Snow cover at each site on 1 June each year (i.e., <25%, 25-75%, >75% snow cover) was determined from TIROS-N AVHRR imagery (Eastland et al. 1989). For each site, we converted latitude and longitude to UTM coordinates and calculated shortest distance to the coast, shortest distance to a major river, shortest distance to the foothills (i.e., the southern border of the blocks in Fig. 1; locations south of this line were assigned negative distances), proportion of area within a 1 km radius that was dominated by tussock tundra, and proportion of area within a 1 km radius that contained landcover types dominated by *Dryas* vegetation types. *Dryas* vegetation types included dry prostrate dwarf scrub and moist prostrate dwarf scrub types in Alaska, and the *Dryas* sedge type in Canada. Logistic regression analyses (Hosmer and Lemeshow 1989, McDonald 1991) were conducted to determine which attributes best discriminated between 305 calving sites of radio-collared cows and 305 random sites on the calving grounds. Attributes of calving sites were included in a logistic regression model if their regression coefficient was significantly different from zero at the 95% confidence level (X2 test with 1 degree of freedom; BMDP 1988).

Calving Site Fidelity

We determined whether individual cows showed fidelity to calving sites in different years by comparing distances between all calving sites for each radio-collared cow between 1983 and 1990 with a distribution of distances between random points obtained through computer simulation. The number of calving sites for each cow varied from 2 to 7; separate analyses were required depending on the number of calving sites included. For each cow, we calculated the shortest distance between any 2 calving sites and the shortest distance connecting all calving sites. For each simulation, we generated 8,000 sets (i.e., 2-7 locations) of random sites from the calving grounds (Fig. 1), and calculated the same distance parameters. Differences between cumulative frequency distributions of observed and simulated distances were compared using the Kolmogorov-Smirnov test for goodness of fit (Sokal and Rohlf 1969:573).

Effect of Habitat and Geographic Location on Calf Survival

Relationships between habitat and calf mortality were estimated by comparing attributes of sites where radio-collared cows were observed with live calves and sites where cows were first observed without a calf. The site where a cow was first observed without a calf was assumed to be the site where she lost her calf. We excluded all locations in Canada from this analysis because (1) if displacement occurred, it would most likely be to areas immediately south and east of the 1002 boundary; (2) different landcover classification schemes were used in Alaska and Canada, precluding direct comparisons of landcover data; (3) no landcover data were available in Canada for the area north and west of the Malcolm River; and (4) digital elevation and slope data were not available for the northern Yukon, and obtaining these data directly from maps for all locations in Canada would be a very time-consuming process. Because serial observations of individual cows with calves may not be independent, we randomly selected only one location each year during late May through June 1983-90 for each cow observed with a live calf.

Geographic variability in calf survival was also investigated by deploying mortality-sensing transmitters on 118 calves on 2-3 June 1988, using methods described by Garner et al. (1985). Previous experience with calf capture (Whitten et al. 1984, 1985, 1987; Garner et al. 1985) indicated that calves abandoned after capture died within 48 hours. Because inclement weather precluded observations of collared calves for 2 days following capture in 1988, and we could not distinguish between natural and capture-induced abandonment, we excluded from further analysis 14 calves that died within 48 hours of capture. Sample size was reduced to 55 collared calves in the 1002 area and 49 in adjacent areas to the south and east. Findings in 1988 were compared with results from similar studies conducted during 1983-85.

Earlier studies (Whitten et al. 1984, 1985, 1987, 1991) indicated that calf mortality in the PCH may be divided into 2 phases. We referred to death within 48 hours of birth as perinatal mortality, and death during days 3-30 after birth as post-perinatal mortality. We investigated the correlation between post-perinatal mortality rates of calves born to radio-collared cows and the percentage of parturient radio-collared cows which calved inside the 1002 boundary during 1983-89 with Spearman's rank correlation procedures. We also tested the null hypothesis that post-perinatal calf mortality rates in years of early snowmelt (1983-85, 1989, 1990), when cows had easy access to the coastal plain, were the same as mortality rates in years of late snowmelt (1987-88) using the Mann-Whitney U test.

Causes of Calf Mortality

Causes of early, or perinatal, mortality were investigated in 1989 by conducting low-level aerial searches for dead or abandoned calves on the calving grounds between the Hulahula and Aichilik Rivers. Sixty-one calves were necropsied, and primary cause of death could be determined in 56 cases (Roffe 1990).

Causes of non-perinatal calf mortality were determined from collared calves in 1983-85 and 1988. Supplemental data were also collected from 44 carcasses of unmarked calves and 4 carcasses of calves of collared cows which were necropsied in 1983-85 (Whitten et al. 1984, 1985, 1987).

RESULTS

Calving Distribution

The majority of calving sites (267/321) and concentrated calving activity occurred on the coastal plain and in the foothills (Fig. 1) between the Katakturuk and Babbage Rivers. The remaining sites were widely scattered through the Brooks Range, British Mountains, and/or west of the Katakturuk River. Distribution of calving sites in 1983-90 was nonrandom (Table 1; X2 = 77.0; 5 df; $\underline{P} < 0.0001$). The area between the Hulahula River and the Alaska-Canada border (blocks B, C, and D, Fig. 1) contained 1.5 times as many calving sites/km^2 as expected, whereas the area east of the border (blocks E and F, Fig. 1) contained only 0.7 times as many sites as expected. Within Alaska, the coastal plain between the Aichilik River and the Canadian border is often snow-free or has mottled snow during the early calving period. In contrast, much of the area west of the Aichilik River is at higher latitude, and complete snow cover remains near the coast in most years (Eastland et al. 1989). Thus, the areas actually available in most years west of the Aichilik River are smaller than those shown in Fig. 1, and are probably even more strongly selected than the data in Table 1 suggest.

The east-west distribution of calving sites was related to the herd's winter distribution (Fancy et al. 1991). Cows that wintered in the Richardson Mountains calved farther west than those that wintered in Alaska or the Ogilvie Mountains (Fig. 2). We found a significant correlation between date of arrival on the calving grounds and longitude of calving sites (early-arriving cows calved farther west) for cows tracked by satellite (Spearman's rank correlation; $\underline{n} = 38$; $r = 0.646$; $\underline{P} < 0.001$). However, we found no relationship between arrival date on the calving grounds and date of calving (Spearman's rank correlation; $\underline{n} = 39$; $r = 0.25$; $\underline{P} > 0.20$).

Calving Site Selection

The movements of parturient cows tracked by satellite between 1985 and 1989 averaged >10 km/d in a northwest direction during the 12-day period before calving (Table 2). During the 6-day period beginning at calving, cows moved <5 km/d and movement direction was random. Daily relocations of radio-collared cows indicated that most cows selected a calving site <3 days before their calving date, and remained in that general area for 1-2 weeks. The 24-hour activity index, an independent measure of caribou movement (Fancy et al. 1989), followed a pattern similar to rates of movement (Table 2).

Selection for landcover types characterized by E. vaginatum tussock tundra occurred in both Alaska and Canada (Table 3). In Alaska, 55% of calving sites were located in Moist Graminoid Tundra or Mesic Erect Dwarf Shrub types characterized by E. vaginatum (Garner and Reynolds 1987:60), whereas only 40% of the randomly selected sites were located in these types (Table 3). In Canada, 54% of calving sites were located in tussock tundra types, compared with 30% for randomly selected sites. When landcover types in both Alaska and Canada were classified as tussock or nontussock types, we found that a highly significant proportion of cows had their calves in tussock type vegetation. (Fisher's exact test, $\underline{P} < 0.0001$).

Univariate analyses indicated that calving sites were significantly farther west, farther north, at lower elevations, on gentler slopes, closer to major rivers, farther from the foothills, and had more snow and tussock tundra than did randomly selected sites ($\underline{t}$-tests, $\underline{P} \leq 0.002$) (Table 4). Because calving site selection is likely a multivariate process, and we measured several variables simultaneously at each site, multivariate analyses were most appropriate for detecting differences between calving sites and random sites. Multivariate logistic regression analysis yielded the selection function ($X2 = 53.84$; 3 df; $\underline{P} < 0.0001$): $w(x1, x2, x3) = \exp(1.571x1 + 0.015x2 - 2.830x3)$ where $w(x1, x2, x3)$ was the estimated relative probability of selection function, and x1 was the proportion of area within 1 km of a site dominated by Eriophorum tussocks, x2 was the distance between a site and the foothills, and x3 was the percent slope. This selection function was solved for different sites to determine the relative probability of that site being selected for calving (Hosmer and Lemeshow 1989, McDonald 1991). For example, a site 20 km north of the foothills characterized by 100% tussock tundra within 1 km and a slope of 2% was 29 times more likely to be selected for calving than a site 20 km south of the foothills line which has no tussocks and a slope of 45%. Remaining variables did not contribute significantly to the prediction equation.

Calving Site Fidelity

Although PCH cows consistently used the calving grounds between the Katakturuk and Babbage Rivers, they did not return to the same sites on the calving grounds each year to calve (Table 5). None of the cumulative frequency distributions of distances between calving sites were different from the distributions for randomly selected sites (Kolmogorov-Smirnov test; $\underline{P} > 0.10$).

Thus, although cows selected areas with certain characteristics (e.g., away from the foothills, containing tussock tundra) for calving they did not calve at the same location each year.

Calf Survival

Mean calf survival for 312 cows monitored through June in 1983-90 was 73.4% (Table 6; some cows were monitored several times across years). In 1988 we were able to compare mortality of calves born to collared cows with the mortality of a separate sample of collared calves; June mortality for calves of radio-collared cows was 31% (22/71), compared with 13% (14/104) for radio-collared calves. However, many calves may be stillborn or die before collaring commences, and elimination of questionable deaths occurring shortly after capture further biases collared calf data against early mortality. Thus, the data from collared calves analyzed here pertains only to the post-perinatal period. Similar mortality rates were obtained for collared calves and calves of collared cows once the collared cow data were adjusted to exclude perinatal mortalities (Table 7).

Geographic Variability in Calf Survival

Locations where parturient radio-collared cows were first observed without calves in 1983-90 were significantly farther south and closer to the foothills/mountain boundary (Fig. 1) than locations where cows were observed with live calves (Table 8). In 1988, no significant difference (X2 = 0.84; $\underline{P} > 0.10$) was found between mortality of calves originally collared within the 1002 area (9/55) and those collared south and east of the 1002 area (5/49). Previous calf collaring studies (Whitten et al. 1991) also noted no difference in mortality based on where calves were captured, but did indicate that sites where cows were first observed without a calf were significantly correlated with higher elevations peripheral to the coastal plain. Location data were not obtained for surviving collared calves in 1988, precluding a detailed analysis of mortality sites versus areas used by surviving calves. During 1983-90 the percentage of radio-collared cows that calved within the 1002 area ranged from 1.6% to 69.2% (Table 9). Post-perinatal mortality of calves during the same period ranged from 0.0% to 18.0% and was inversely correlated ($r = -0.793$; $\underline{P} < 0.05$) with the proportion of cows calving in the 1002 area. In particular, post-perinatal calf mortality was higher in years when late snowmelt prevented many cows from calving in the 1002 area ($\underline{P} = 0.04$; 1987-88 median = 13%; data not available for 1986). During 1983-85 and 1989-90, when snowmelt was early and many cows calved within the 1002 area, median post-perinatal calf mortality was 9%.

Causes of Calf Mortality

Primary cause of death was diagnosed for 56 of the 61 calf carcasses found during low-level aerial searches and necropsied in 1989. These carcasses were all collected during the peak calving period when calves were very young and were assumed representative of perinatal mortality. Emaciation and malnutrition accounted for 52% of the deaths for which cause could be determined, stillbirth accounted for another 23%, 18% died of trauma, and 7% died of various other causes (Roffe 1990). Most of the trauma deaths (8/10) were attributed to predators. The sample may have been biased against predation deaths because heavily scavenged carcasses were not retrieved. Calves that were killed by predators were generally in good body condition. Earlier necropsy work conducted in 1983-85 (Whitten et al. 1984, 1985, 1987, 1991), although less rigorous in that examinations were not performed by a trained veterinary pathologist, gave results consistent with Roffe (1990). Neither of 2 carcasses of calves of collared cows which died during the perinatal period showed signs of predation, nor did 15/28 (54%) carcasses of unmarked calves aged less than 2 days.

During the post-perinatal period, predation was the predominant cause of calf deaths, although nonpredation deaths still occurred. Thirteen of eighteen (68%) post-perinatal deaths among collared calves, 2/2 among calves of collared cows, and 13/16 (81%) among unmarked calves were caused by predators.

CONCLUSIONS

Distribution of PCH calving sites during 1983-90 was nonrandom. The area between the Hulahula River and the Canadian border was used by calving caribou 1.5 times more than expected. We hypothesize that variation in snow cover, both along migration routes and on the calving grounds, accounts for much of the annual variation in location of areas having the highest concentration of calving caribou. Snow along migration routes influences the initiation and progress of spring migration (Thompson and Roseneau 1978; Garner and Reynolds 1986; Russell et al., unpubl. data). The Chandalar and Ogilvie wintering areas are separated from the calving grounds by areas that, in many years, are covered by relatively deep, persistent snow. In contrast, the windswept ridges of the Richardson Mountains are contiguous with the coastal plain in Canada, often allowing caribou to begin spring migration and arrive on the calving grounds earlier than cows wintering elsewhere (Thompson 1978). Thus, cows wintering in the Richardson Mountains tend to calve farther west than cows wintering in Alaska or the Ogilvie Mountains, but in low snow or early snow-melt years such as 1990, all cows may arrive early and calve farther to the west than in late snow-melt years.

PCH females did not show fidelity to specific geographic sites for calving. However, analysis of calving sites indicated that there is selection by parturient PCH females for certain habitat attributes. Sites dominated by *Eriophorum vaginatum* tussocks and on gentle slopes were most likely to be selected as calving sites. Thus, although cows select areas with the above attributes, we hypothesize that the selection of a specific geographic site is modified by yearly variation in wintering sites, migration routes, and amount of snow remaining on the coastal plain and foothills.

Our analyses show that post-perinatal survival of PCH calves is associated with calving site. Studies in 1983 and 1984 were able to show no significant difference between survival of calves collared in each year's concentrated calving area and those collared in peripheral areas, but did indicate that mortalities were associated with higher elevation areas. Analysis of the fates of all calves born to radio-collared cows during 1983-90 indicates that post-perinatal mortality rates are significantly higher when greater proportions of radio-collared cows calve outside the 1002 area. In years when deep snow persisted into June (1987-88), and large numbers of cows were apparently inhibited from calving in the 1002 area, median post-perinatal mortality of calves was 13%. In years of early snowmelt (1983-85, 89-90), median post-perinatal mortality was 9%. Sites where radio-collared cows were first observed without their calf were found to be farther south and closer to the foothills/mountain boundary of the study area blocks (Fig. 1) than sites where cows were observed with live calves. These findings combine to suggest that displacement from the traditional coastal plain calving area to areas south and east could cause parturient females to spend more time at higher elevations, which could result in a greater mortality risk to their calves.

Necropsies of calves dying within 48 hours of birth (perinatal mortality) suggested inadequate nutrition of the dam and/or calf was a factor. Seventy-five percent of unmarked calf carcasses were stillborn or died of emaciation or malnutrition, and only 14% were killed by predators. Earlier studies (Whitten et al. 1984, 1985, 1987, 1991) were consistent with these results. Complete consumption of calf carcasses by predators could have biased our estimates of predator-caused perinatal calf mortality downward.

Our analysis of causes of post-perinatal mortality indicated that predation was involved in a majority of deaths. Although exact predator densities on the coastal plain and in foothills areas are currently unknown, extensive radio-tracking of grizzly bears (*Ursus arctos*) during the calving period has shown that the majority of bears remain in the foothills or mountains (Young 1990). Thus, the proximate mechanism for increased post-perinatal mortality rates when cows are displaced from the traditional calving area may be an increase in predation risk. Because nutritionally stressed calves may be behaviorally or otherwise predisposed to predation, nutritional attributes of the traditional calving area may ultimately influence post-perinatal mortality. At this point, we do not have sufficient data to evaluate the relative contribution of predation and nutrition to post-perinatal mortality.

MANAGEMENT IMPLICATIONS AND POTENTIAL RESEARCH DIRECTIONS

The 1002 area east of the Hulahula River is consistently used by calving PCH females and their offspring throughout June and July. When a greater proportion of PCH females use areas within the 1002 boundaries during calving, post-perinatal calf survival is higher than when cows calve elsewhere. The increased calf mortality which occurs when calving is closer to the foothills and mountains boundary may be due to increased predation risk. Predator densities and rates of predation by individual bears and wolves (*Canis lupus*) on caribou are necessary to estimate the potential amount of change in calf survival rates and the effect on the population as a whole.

In addition, more information is needed on forage quantity and quality in the traditional calving area versus peripheral areas. Preliminary studies indicate that the historical concentrated calving area has higher quality and quantity of caribou forage than adjacent areas. In 1990, the concentrated area had significantly higher biomass of 2 important forage species (*Eriophorum vaginatum* and *Salix planifolia*). *E. vaginatum* flowers in the concentrated area also had significantly higher concentrations of nitrogen and phosphorus and lower concentrations of fiber (Jorgenson et al. 1991).

The relative importance of maternal nutrition and predation, and their interaction, on the survival rates of calves is unknown. In the CAH, females that are heavier in the fall are more likely to conceive, calve earlier, and produce a viable calf (Cameron et al. 1991). Thus, quantity and quality of forage obtained by PCH females during the entire calving and postcalving period is likely to have a significant effect on their ability to gain weight during the summer, and to produce a viable calf the following year. In addition, calves born in poorer condition may be predisposed to predation, thus exacerbating the effects of poor maternal nutrition on calf survival.

Monitoring of calving distribution and calf mortality relative to geographic location should continue. Plans for petroleum production in the 1002 area should acknowledge the value of the traditional calving area between the Hulahula and the Aichilik Rivers. Because studies of the adjacent CAH have shown that maternal females and calves tend to avoid areas of high human activity, including road and pipeline corridors (Dau and Cameron 1986), any petroleum development in the 1002 area should proceed cautiously. Use of the traditional calving areas within the 1002 boundaries may enhance population stability by offsetting years of naturally low calf production or survival. These types of questions are currently being addressed through simulation modeling of PCH dynamics.

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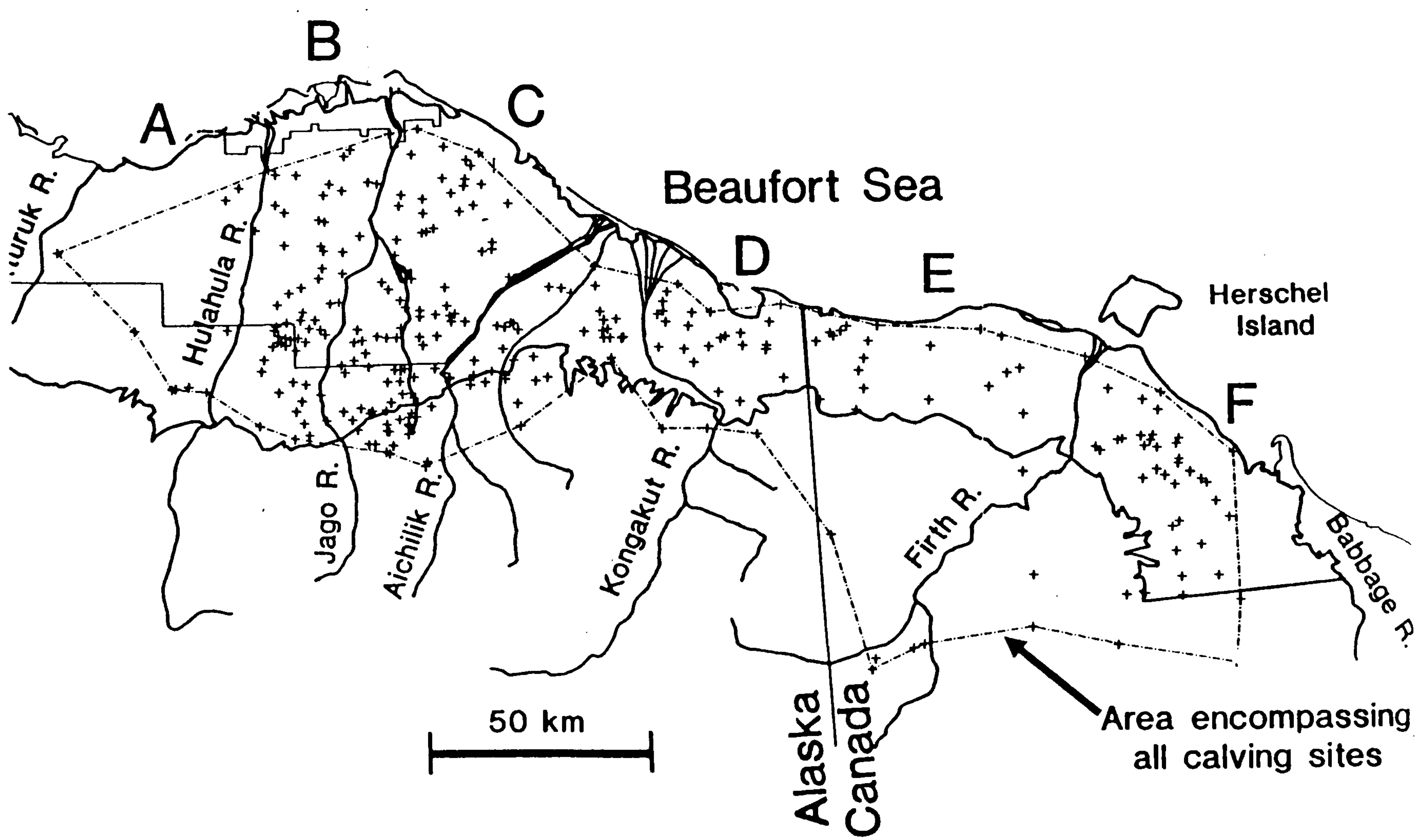

Figure 1. Calving grounds of the Porcupine Herd, showing areas used in analyses of calving distribution, calving site selection, and fidelity. Blocks A-F were used to test for random distribution of calving sites on the coastal plain. The area encompassing all sites where radio-collared cows were first observed with a calf in 1983-90 (sites marked by crosses; area delineated by a dashed line) was used in analyses of calving site selection and fidelity.

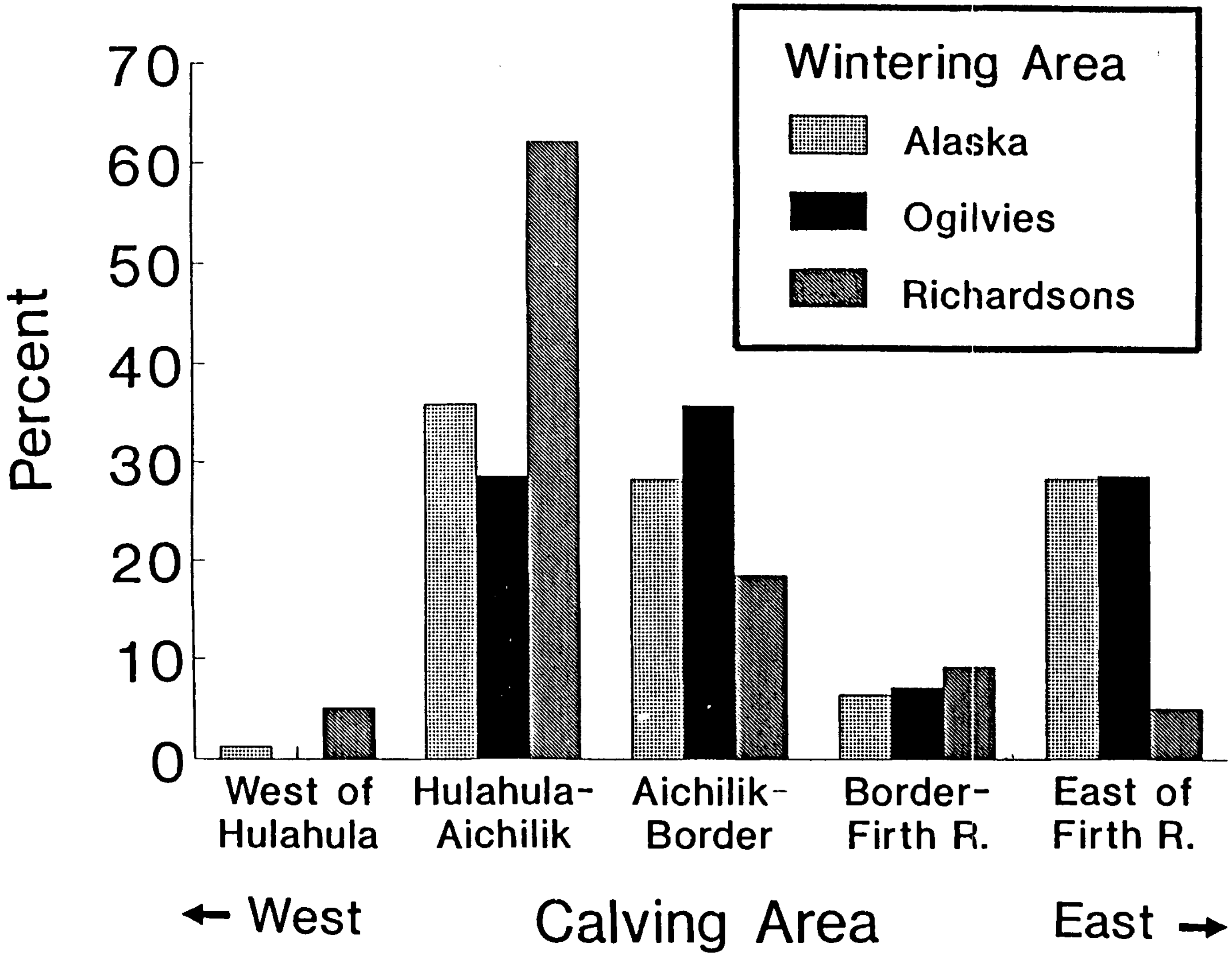

Figure 2. Relationship between locations of calving sites for individual cows and their previous wintering area.

Table 1. Distribution of 267 calving sites in 1983-90 on the coastal plain of northeastern Alaska and northern Yukon. Blocks A-F refer to areas shown in Fig. 1.

Block	% of Area	Sites observed	Sites expected	Ratio obs:exp	Selection[a] probability
A	21.37	11	57.1	0.19	0.032
B	15.61	66	41.7	1.58	0.259
C	19.26	70	51.4	1.36	0.223
D	16.03	65	42.8	1.52	0.249
E	12.49	18	33.3	0.54	0.088
F	15.24	37	40.7	0.91	0.149

[a] Relative probability that block will be selected as a calving site.

Table 2. Movement and activity of parturient cows during 3-day intervals relative to their date of calving. Data collected between 1985 and 1989 using the Argos Data Collection and Location System (Fancy et al. 1989).

Days relative to calving date	*n*	Distance traveled (km/d) Mean ± SE	24-h activity index Mean ± SE	Mean direction Azimuth	*P*
-12 to -10	42	12.8 ± 1.7	13713 ± 1270	339	-[a]
-9 to -7	42	13.0 ± 1.5	13508 ± 1338	326	-[a]
-6 to -4	42	11.9 ± 1.1	13469 ± 1298	303	-[a]
-3 to -1	42	10.3 ± 1.0	11917 ± 1098	289	-[a]
0 to ±2	40	4.7 ± 0.5	8316 ± 882	290	-[b]
±3 to ±5	41	4.2 ± 0.6	7524 ± 839	111	-[b]
±6 to ±8	41	6.9 ± 2.3	10037 ± 1179	244	-[b]
±9 to ±11	39	5.4 ± 0.5	11382 ± 1223	212	-[b]
±12 to ±14	38	7.0 ± 0.7	12700 ± 1347	233	-[b]
±15 to ±17	35	9.0 ± 1.2	14443 ± 1533	261	-[b]
±18 to ±20	34	9.3 ± 0.9	15634 ± 1552	270	-[b]
±21 to ±23	33	10.9 ± 1.0	16994 ± 1924	308	-[c]
±24 to ±26	30	13.9 ± 1.2	19624 ± 1999	317	-[b]

[a] $P < 0.001$.
[b] ns = direction not significant; Rayleigh test (Batschelet 1981:54).
[c] $P < 0.005$.

Table 3. Percent occurrence of landcover types at calving sites ($\underline{n}$ = 284) and randomly selected sites ($\underline{n}$ = 277) in Alaska and Canada. No landcover data were available for the area in Canada west of the Malcolm River.

	Randomly selected sites	Calving sites
Alaska		
Barren floodplain	1.7	0.4
Barren scree	1.7	0.4
Dry prostrate dwarf scrub	6.9	3.0
Moist prostrate dwarf scrub	22.4	20.4
Mesic erect dwarf scrub[a]	18.4	24.3
Moist graminoid tundra[a]	21.3	30.9
Moist/wet tundra complex	13.8	10.9
Wet graminoid	10.3	8.3
Very wet graminoid	0.0	0.9
Scarcely vegetated	3.5	0.5
Canada		
Dryas/sedge	5.8	3.7
Dense shrub slope	2.9	1.9
Open shrub heath	12.6	20.4
Low shrub tundra	1.0	0.0
Lichen/barren	30.1	9.3
Tussock tundra with 0-15% shrubs[a]	10.7	22.2
Tussock tundra with 16-25% shrubs[a]	12.6	24.1
Tussock tundra with 26-35% shrubs[a]	6.8	7.4
Unvegetated	16.5	7.4
Alluvial	1.0	3.6

[a] Landcover types dominated by tussock tundra.

Table 4. Characteristics of 305 calving sites and 305 randomly selected sites within the calving grounds, 1983-90. No vegetation data were available for 21 calving sites and 28 randomly selected sites.

Variable	Random sites		Calving sites		P[a]
	Mean	SE	Mean	SE	
Longitude (UTM)	706393	4065	682689	3805	0.0001
Latitude (UTM)	7717719	1505	7725461	1252	0.0001
Elevation (m)	365	18	260	14	0.0001
Slope (%)	9.0	0.7	4.9	0.4	0.0001
Snow cover (class)	2.3	0.1	2.1	0.1	0.0017
Distance to coast (km)	30.2	1.0	30.5	1.1	0.817
Distance to river (km)	4.1	0.3	2.9	0.2	0.002
Distance to foothills	7.4	1.2	14.7	1.0	0.0001
Tussocks <1 km (%)	35.0	1.9	48.6	2.0	0.0001
Dryas <1 km (%)	20.5	1.2	20.7	1.1	0.899

[a] t-test for difference between means.

Table 5. Comparisons of distances (Mean ± SE, km) between calving sites of radio-collared cows located in 2-7 different years with distances between randomly selected sites. Cumulative frequency distributions of distances between calving sites and 8,000 sets of randomly selected sites were compared using the Kolmogorov-Smirnov test (Sokal and Rohlf 1969:573).

No.		Shortest distance between 2 sites			Shortest distance connecting all sites		
Years	*n*	Observed	Random	Dmax[a]	Observed	Random	Dmax
2	43	67.1 ± 49.1	93.6 ± 59.7	0.097			
3	19	27.9 ± 12.0	38.9 ± 21.7	0.266	125.0 ± 58.7	145.3 ± 55.1	0.111
4	7	26.2 ± 10.0	26.2 ± 14.3	0.202	192.8 ± 27.4	179.2 ± 48.5	0.184
5	6	17.6 ± 8.6	19.8 ± 10.7	0.145	179.6 ± 47.9	206.7 ± 43.8	0.201
6	5	7.2 ± 2.7	15.7 ± 8.4	0.297	176.3 ± 28.5	229.7 ± 41.6	0.373
7	2	5.9 ± 1.4	13.2 ± 7.1	0.424	229.1 ± 105.3	250.6 ± 42.2	0.498

[a] Kolmogorov-Smirnov test statistic; all values nonsignificant ($P > 0.10$).

Table 6. Parturition rates and June calf survival for adult (≥3-year-old) cows of the Porcupine Herd, 1982-90. No data are available for parturition rate of collared cows in 1981 or June calf survival in 1981, 1982, and 1986.

Year	n	No. pregnant	Parturition rate	No. monitored through June	Survival rate
1982	9	8	0.89	--	--
1983	22	17	0.86	20	0.65
1984	31	25	0.81	25	0.84
1985	56	43	0.77	43	0.65
1986	42	31	0.74	--	--
1987	51	40	0.78	41	0.66
1988	89	73	0.82	71	0.69
1989	72	57	0.79	58	0.74
1990	65	54	0.83	54	0.91
Mean			0.81 ± 0.02		0.73 ± 0.04

Table 7. Percent mortality of collared calves and/or calves of collared cows during late May and June, 1983-90. Data for 1983-85 obtained from Whitten et al. (unpubl. manuscript). Relocations in 1986 were too infrequent to calculate mortality rates. Numbers in parentheses are sample sizes.

Year	Calves of collared cows		Collared calves
	Overall	Adjusted[a]	Adjusted[a]
1983	35 (20)	7 (14)	9 (59)
1984	16 (25)	10 (21)	7 (60)
1985	35 (43)	10 (30)	15 (60)
1986	--	--	--
1987	34 (41)	18 (33)	--
1988	31 (71)	12 (51)	13 (104)
1989	26 (58)	9 (47)	--
1990	9 (54)	0 (52)	--

[a] Adjusted mortality includes only those calves known to be >48 hours old when last observed alive. Perinatal and possible perinatal mortalities are excluded.

Table 8. Characteristics of sites within Alaska where calves of radio-collared cows were observed alive (n = 263) and sites where cows that lost calves (including perinatal mortalities) were first observed without their calf (n = 42) during late May and June 1983-90.

Variable	Cows with calves		Lost calves		P[a]
	Mean	SE	Mean	SE	
Longitude (UTM)	648849	2442	655658	4800	0.211
Latitude (UTM)	7732351	1160	7725792	2513	0.034
Elevation (m)	272	15	316	35	0.292
Slope (%)	6.6	0.8	4.8	1.2	0.194
Dist. to coast (km)	31.9	1.2	38.0	3.0	0.065
Dist. to river (km)	2.5	0.1	2.0	0.3	0.129
Dist. to foothills (km)	18.4	1.1	10.4	2.1	0.001
Tussocks <1 km (%)	45.0	2.2	45.9	5.3	0.881
Dryas <1 km (%)	26.1	1.2	19.7	2.5	0.041
Wet/very wet graminoid <1 km (%)	23.8	1.8	26.2	4.2	0.618
Barrens <1 km (%)	5.0	0.6	8.2	1.7	0.068

[a] t-test for difference between means.

APPENDIX B.

WORK UNIT I Potential impacts of petroleum exploration and development on the numbers, distribution, and status of caribou on the arctic coastal plain

Work Subunit Ia Population dynamics and demographics of caribou in developed and undeveloped areas of the arctic coastal plain

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INTRODUCTION

In 1980, Congress directed the Department of the Interior under section 1002 of the Alaska National Interest Lands Conservation Act to conduct biological and geological studies on the coastal plain of the Arctic National Wildlife Refuge (ANWR). As a result of those studies, the 1002 area is considered the most promising onshore petroleum exploration area in the United States (Clough et al. 1987). However, the area contains important fish and wildlife habitats, including the most frequently used calving and postcalving areas for the Porcupine Caribou Herd (PCH; *Rangifer tarandus granti*; $\underline{n}$ = 178,000 in 1989). The Department of the Interior concluded that major impacts to the PCH could occur if a major oil discovery is located and developed (Clough et al. 1987).

The association of the nearby Central Arctic Herd (CAH; $\underline{n}$ = 12,900 in 1983) with petroleum development in the Prudhoe Bay region provides a useful comparison with the PCH for assessing the potential effects of petroleum exploration and development in ANWR. For example, studies of the CAH (e.g., Whitten and Cameron 1983, 1985; Dau and Cameron 1986) have demonstrated that development can disrupt caribou movements and displace parturient cows from traditional calving areas, raising concerns that similar effects in the 1002 area could increase mortality of PCH calves by exposing them to higher predation risk or reducing foraging opportunities for cows. This report presents results from continued investigations of PCH and CAH population dynamics and seasonal range use patterns conducted from 1988 to 1990 by the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game. Pertinent findings from previous studies of the PCH and CAH are incorporated so that conclusions and management recommendations are properly synthesized from all available information.

METHODS

The range of the PCH includes tundra habitats on the arctic coastal plain and mountainous and forested habitats in northeastern Alaska, northern Yukon Territory, and northwestern Northwest Territories (Fig. 1). The vegetation, geomorphology, and climate of the study area have been described by Spetzman (1959), Wiken et al. (1981), and Garner and Reynolds (1986). Winter distribution of caribou varies considerably among years, but primary wintering areas include the Ogilvie and Richardson Mountains in the Yukon, and the Chandalar, Sheenjek, and Coleen drainages of northeastern Alaska. Spring migration occurs within three broad corridors referred to as the Old Crow, Richardson, and Chandalar migration routes (Fancy et al. 1989). Calving occurs primarily during the first week of June on the coastal plain between the Canning River in Alaska and the Blow River in the Yukon (Thompson 1978, Whitten and Cameron 1983, Garner and Reynolds 1986).

The range of the CAH is between the Colville/Itkillik Rivers and the Katakturuk River on the arctic slope in Alaska. Primary wintering areas are in the Brooks Range and northern foothills, although some animals occasionally winter near the coast. Calving and summer ranges are along the arctic coast. Compared with the PCH, seasonal migration distances are relatively short (Cameron and Whitten 1979).

Caribou Capture and Handling

Most caribou were captured on winter range in snow, resulting in shorter chases. Caribou were located from a Piper Super Cub aircraft acting as a spotter plane for the capture helicopter. A specific animal was then chased a short distance with the helicopter and darted with a mixture of M99 (6.25 mg Etorphine hydrochloride) and 7.5 mg Acepromazine maleate fired from a Cap-Chur rifle (Palmer Chemical and Equipment Co., Douglasville, GA) into the rump or shoulder of the caribou. The antagonist M50-50 (14 mg Diprenorphine hydrochloride) was administered to effect recovery. Beginning in April 1988, all adult caribou were immobilized using a mixture of 3 mg Carfentanil citrate (Wildlife Labs, Fort Collins, CO) and 7.5 mg Acepromazine maleate, with Naloxone (450 mg; Wildlife Laboratories) administered as antagonist. Thicker, winter pelage and a subdermal fat layer cushioned the impact of the dart, and cold temperatures alleviated problems with hyperthermia. We attempted to weigh each captured caribou, take a blood sample from the jugular vein, record body and antler measurements, and attach a standard VHF or satellite radiocollar (Telonics, Inc., Mesa, AZ.). We attempted to recapture collared caribou as needed every 3-5 years to replace transmitters before batteries were exhausted.

Tracking Caribou via Satellite

Satellite transmitters compatible with the Argos Data Collection and Location System (Fancy et al. 1988, 1989) were deployed on 41 PCH cows and 24 CAH cows between April 1985 and August 1990. Data were received monthly from Service Argos (Landover, MD) and processed as described by Fancy et al. (1988, 1989). The satellite transmitter package weighed 1.6 kg (including a VHF radio transmitter to locate the caribou from an aircraft) and had a battery life of 1 year. Individual caribou were monitored for $\leq$5 years by replacing their transmitters annually. Transmitters were programmed to operate 6 hours/day, or 6 hours/2 days, and provided 3-4 locations per day of operation. Mean location errors were 760 m for Generation 2 transmitters (68% of locations used in this study) and 480 m for newer, Generation 3 transmitters (32% of locations; Fancy et al. 1989).

Transmitters also contained sensors for monitoring the internal temperature of the canister (an approximation of ambient temperature; Pank et al. 1985) and the caribou's activity. For activity monitoring, a microprocessor in the canister determined the number of seconds each minute during which a mercury tip-switch calibrated especially for caribou was activated (Pank et al. 1987). The resulting short-term activity index, having a maximum value of 60, was a reflection of activity (i.e., lying, feeding, walking, running) during the minute prior to transmission. In addition, a long-term activity index was computed as the sum of 60-sec counts for a 24-h period (Pank et al. 1987, Fancy et al. 1988).

Location and sensor data were obtained monthly from the Argos processing center on 9-track computer tapes and processed through a series of programs for entry into the ARC/INFO and MOSS/MAPS Geographic Information Systems as described by Fancy et al. (1988). The minimum distance traveled by each caribou between two successive locations was calculated by connecting locations with straight lines. We calculated the mean daily movement rates for each caribou by summing the lengths of line segments and dividing by monthly time interval. Differences in monthly movement rates between herds and years were tested by two-way analysis of variance using the General Linear Model (GLM) procedure (SAS 1985). For each caribou, we summed the distances between successive locations to obtain an estimate of the minimum distance traveled per year. We included only those caribou that were tracked over a period of 10 months or longer. Statistical comparisons were evaluated at the 95% confidence level.

Seasonal Distribution

Calving distribution was determined for the PCH (Whitten et al. 1991) and the CAH (Cameron et al. 1991). PCH and CAH summer distributions were recorded during census attempts and from satellite transmitter data.

Approximately 2-5 times each winter, between October and early May, we conducted radio-tracking flights covering the entire range of the PCH using fixed-wing aircraft to relocate collared caribou. Locations during the period between early January and early April, when cows were most sedentary (Fancy et al. 1989), were classified into 1 of 3 categories (Alaska, Richardson Mountains, or Ogilvie Mountains) to determine relationships between wintering areas and calving sites. For the purpose of this analysis, all wintering locations in the Yukon that were south and west of the Porcupine and Eagle Rivers were included in the Ogilvie Mountains category, whereas locations east of the Eagle River and along the axis of the Richardson Mountains were included in the Richardson Mountains category. CAH winter distribution was estimated from radiocollar surveys in October/November and March/April each year.

Population Size

A photographic census (Davis et al. 1979, Valkenberg et al. 1985) of the PCH was conducted in July 1989. Formation and distribution of large postcalving aggregations was monitored by intensive aerial reconnaissance, radio-tracking, and satellite telemetry to determine when the caribou were optimally aggregated for photographing. Three aircraft searched the summer range of the PCH until all radio-collared caribou were located, and the areas around the radio-collared animals were searched for groups of caribou. One tracking/spotter plane then worked in conjunction with the photo plane to photograph large aggregations. The other aircraft continued to search for any caribou not associated with radio-collared animals.

Aggregations were photographed with a Fairchild T-11 aerial camera mounted in the belly of a DeHavilland Beaver aircraft, using black and white film. Several overlapping transects were required to photograph some large groups. Transects were oriented along the long axis of each group (usually the direction of movement). We attempted to overlap photographs by approximately 30% both within and between contiguous transects to ensure complete coverage. Photo scale varied from 1:1000 to 1:3000 depending on the size and configuration of each aggregation.

Caribou were counted from black and white prints (ca. 23 cm x 23 cm) using magnifying lenses and hand-held tally registers. After determining overlap, lines delineating the portion of each photo to be counted were drawn directly on each print to prevent caribou appearing on adjacent photos from being counted twice. A transparent acetate grid was taped to each photo, and its position marked on the photo so that the grid could be replaced in the same position for replicate counts. Ten observers cooperated in counting the caribou on photos. Accuracy and consistency among different observers was assessed by comparing counts of a series of reference photos which were distributed blind through each observer's stack of photographs. A mean total count was determined for the reference photos, and a correction factor was calculated for each observer so that the final, overall total for all photos could be adjusted as if a single "average" observer had done the entire count. Numbers of calf and adult caribou were tallied separately.

Attempted censuses of the CAH in 1988 and 1989 could not be completed because the distribution of CAH caribou east of the Sagavanirktok River overlapped the PCH distribution. In late June 1990, an estimate of the number of CAH caribou located east of the Sagavanirktok River was attempted using a stratified random sampling procedure. However, distributions of herds once again overlapped before the sampling could be completed. The last successful photocensus of the CAH was completed in 1983.

Population Composition

PCH sex and age structure was estimated from composition counts conducted during the postcalving aggregation period in 1988 and during the census in 1989. Observers were flown to large aggregations by helicopter and counts were made using spotting scopes and binoculars. Standard criteria such as external genitalia, relative body size, and antler development were used for classification. In both years, composition counts were done on coastal plain groups only. Past experience has indicated that mountain groups are likely to be predominantly bulls. For this reason, the 1988 and 1989 midsummer composition counts were considered to be indicative of calf:cow ratios, but not of overall herd structure.

Composition of the PCH was also determined in April 1990. Caribou in three large aggregations located south of Arctic Village, east of Arctic Village, and in the Ogilvie Mountains were classified directly from a helicopter. Each aggregation was sampled by flying random transects, but intensity of sampling in each area was unknown. These three aggregations accounted for most of the herd, based on radiocollar distribution. Composition was considered to be representative of overall herd structure.

Low level aerial surveys were flown on the calving grounds of the CAH June 1987-90 to estimate herd composition (Whitten and Cameron 1985). Because all bulls are not usually present on the calving grounds, these composition estimates are also not indicative of overall herd structure.

Productivity and Calf Survival

Annual parturition rates and survival of calves through the first month of life (i.e., through June) was determined for the PCH (Whitten et al. 1991), and early survival of calves was also determined for the CAH (Cameron et al. 1991).

Survival estimates (Kaplan and Meier 1958) of PCH calves during the 11-month period between 1 July and 31 May were calculated for radio-collared calves born in 1983, 1984, 1985, and 1988 using monthly time intervals. Differences in survival functions for male and female calves in each of the 4 years were tested using the log-rank test (Pollock et al. 1989).

No calves were collared in the CAH, but overwinter survival was roughly estimated in some years from yearling:cow counts.

Yearling and 2-year-old Survival

Yearling survival in the PCH was determined from the fates of 39 radio-collared calves which were recaptured and recollared when they were 10-12 months old and from 57 caribou first captured on winter range when they were 5-10 months old. Data from all years were pooled, and sex-specific survival estimates for the 75 female and 21 male yearlings were calculated by dividing the number of caribou that survived to their second birthday by the number alive at the beginning of the period (Pollock et al. 1989). Survival rates for 62 female and 16 male 2-year-olds were similarly calculated. The log-rank test was used to compare male and female survival functions.

Very small samples of known-age radio-collared yearlings and 2-year-olds in the CAH preclude any survival analyses.

Adult Survival Analyses

Survival rates of adult ($\geq$3-year-old) PCH animals were determined using the staggered entry design (Pollock et al. 1989) with 9 annual intervals beginning on 1 June 1981. Adult caribou that were captured in March or April were not considered at risk in survival analyses until the next annual interval began on June 1.

No survival analyses have yet been done on radio-collared CAH adults. Less effort was put into investigating suspected mortalities or into searching for missing animals. Therefore, survival analysis may be impossible given the current CAH data.

Harvest Information

Annual hunter harvest figures for the PCH and CAH in Alaska were compiled from records kept by the Alaska Department of Fish and Game. Harvest of the PCH in Canada was obtained from the Yukon Department of Renewable Resources. Harvest of the PCH was also calculated from radiocollar mortality data, using methods described for the adult survival analysis above.

RESULTS

Seasonal Movement Patterns

The PCH and CAH exhibited similar annual patterns in their daily rates of movement. Highest rates occurred in July and lowest rates in February or March. Differences in mean movement rates between herds and among years were compared for February, May, July, and September. We found no significant differences in movement rates between the 2 herds in February or July (two-way ANOVA; February $F = 0.08$; $\underline{P} > 0.75$; July $F = 0.14$; $\underline{P} > 0.70$). In contrast, differences in movement rates between herds were highly significant during spring and fall migration periods (May $F = 16.27$; $\underline{P} < 0.001$; September $F = 49.20$; $\underline{P} < 0.0001$). Between-year differences in movement rates were found for May (two-way ANOVA; $F = 5.69$; $\underline{P} < 0.01$) and July ($F = 6.67$; $\underline{P} < 0.005$). Movement rates during May and July in 1985 and 1986 were similar, but were significantly lower than those in 1987 (Duncan's Multiple Range Test; SAS 1985; Fig. 2).

Annual Distance Traveled

The mean annual distance traveled for 10 PCH cows (4355 $\pm$ 150 SE km) was significantly greater than that for 10 CAH cows (3031 $\pm$ 97 SE km; Anova; $F = 55.01$; $\underline{P} < 0.0001$). Nevertheless, some CAH females moved greater total distances than some PCH cows. Greatest recorded yearly distance traveled in this study was 5,055 km by a PCH cow.

Herd Status and Trend

Postcalving aggregations of the PCH were photographed during July 1989. Ten groups consisting mainly of males were photographed in the upper Sheenjek valley on the south slope of the Brooks Range on 4 July. The remainder of the herd was located on the coastal plain between the Canning and Sadlerochit Rivers, where 9 more groups were photographed on 6 July. An estimate of 187,944 caribou (with a SD = 463, attributable to among observer variability in counting caribou on photos), was determined from the resulting photos. Some caribou may not have been discernible on the photographs, and the count is therefore considered a minimum of the animals actually present. However, a large portion of the CAH was mixed with PCH aggregations near the Canning River. Therefore, the final estimate of PCH population size was adjusted downward to 178,000. This estimate indicates that the PCH has increased at an annual rate of 4.8% ($r = 0.048$) from 1979 to 1989 (Fig. 3). The CAH grew rapidly in the late 1970's and early 1980's; the most recent population count was 12,900 in 1983.

Population Composition

Composition counts of the PCH during July (Table 1) indicated calf:100 cow ratios of 62, 54, and 45.5 for 1987, 1988, and 1989, respectively. The 1989 ratio of 45.5 was lower than the 1971-89 mean of 54.3 (SE = 2.7), although the difference was not significant ($\underline{P}$ = 0.2). Nine months later, in April 1990, composition of the herd was estimated again. Currently, only the total counts are available from the Yukon Game Board: 9,215 PCH caribou were classified, including 4,460 cows, 1,928 calves, and 2,827 bulls. The April bull:cow ratio was 63:100 and the calf:cow ratio was 43:100.

Surveys of the calving grounds of the CAH during June 1987-90 provide the only current estimates of sex/age composition (Table 2).

Productivity and Early Calf Survival

The mean parturition rate for radio-collared cows aged 3 years or older between 1982 and 1990 was 81% (Table 3; *n* = 437 potential calving events; some cows were sampled >1 year) (Whitten et al. 1991). However, parturition among 3- and 4-year-olds (43/66 = 65%) was lower than for older cows (305/371 = 82%). Only 2 of 62 (3.2%) 2-year-olds gave birth. Mean calf survival for 312 cows monitored through the month of June was 73% (Table 3).

Productivity data for the CAH were not collected as rigorously as were data for the PCH. Individual CAH radio-collared cows often were not located until after calving, and surveys of the calving grounds were usually confined to higher density calving areas and may have overlooked areas with predominantly barren cows. Also, surveys occurred a week or more after the peak of calving and may thus have been biased by early mortality which had already occurred. Thus, direct comparisons of CAH and PCH data are difficult.

Productivity in the CAH was estimated by calves:100 cows ratios on the calving grounds in June. Differences between areas east and west of the Sagavanirktok River were small until 1989 at which time calf:100 cow ratios west and east of the Sagavanirktok River were 29 and 63, respectively (Table 4).

Survival of Calves from 1 to 12 Months

We found no significant differences in the PCH between male and female calves in survival from 1 to 12 months. Data for both sexes were therefore pooled to test for differences in calf survival among years. We were not able to detect a difference in survival functions in the 4 years tested (1983-85, 1988; K-sample test; 3 df; $\underline{P}$ = 0.56; Lee 1980:144). The probability of a calf surviving the 11-month period between 1 July and 31 May was 0.738 (Table 5). Estimated annual survival of calves, calculated as the product of June survival and 1- to 12-month survival, was 54.2%.

Recent estimates of yearling:cow ratios in the CAH have all been low (Table 4). These low ratios may result in part from smaller initial cohort size (i.e., poor productivity; see Cameron et al. 1991). In addition, all recent counts are from calving grounds only and may exclude some yearlings.

Yearling and 2-year-old Survival

Female yearlings in the PCH had significantly higher survival than male yearlings (Table 6; log-rank test; X^2 = 5.44; P = 0.02). Two-year-old females tended to have higher survival than 2-year-old males, but the difference was not significant (X^2 = 2.22; P = 0.14).

Adult Survival

Annual mortality of adult PCH females based upon radiocollars ranged from 4% to 27%. Annual mortality of adult PCH males based upon radiocollars ranged from 0% to 31%. Mean annual mortality rates for females and males were 15.3% and 13.7%, respectively (Table 7). The probabilities of an adult female and adult male caribou surviving from the beginning of the study to the end (1981-89) were 0.22 and 0.25, respectively (Table 7).

Harvest

Between 1987 and 1990 the total estimated harvest of the PCH ranged from about 2,500 to 4,500 animals (Table 8), or about 1-3% of estimated population size. An independent harvest estimate based on return of radiocollars is similar (2.6% for 1983-89).

Estimates of harvest of the CAH between 1987 and 1990 ranged from 240 to 381 animals (Table 9).

CONCLUSIONS

The PCH and the CAH differ greatly in population size, annual range use, and migratory patterns. The mean annual distance traveled by adult females of the CAH was significantly less than the migratory PCH, although some CAH animals are known to move as much as PCH animals during a yearly cycle. Annual patterns in daily activity patterns and rates of movement are similar between the 2 herds; differences are found mainly in distance traveled during migration periods. Thus, the 2 herds differ in many ways, and the PCH cannot be considered directly comparable with the CAH.

Several factors combine to indicate that the PCH has been experiencing a relatively stable rate of increase. Percentage of calves in the herd varied little during 1986-89 (22-27%; Table 1). Recent July calf:cow ratios do not differ from the 1971-89 mean calf:cow ratio. Estimates of parturition rate based on radio-collared individuals varied only between 78% and 83% during 1987-90. Survival of collared calves through the first year of life was not significantly different among the 4 years studied (1983-85, 1988). However, our sample sizes of collared calves were inadequate to detect statistical significance in the small differences we observed. No trends in mortality rates of adult females were evident from the past 9 years' data. Survival of adult females has been identified as the most important parameter affecting the rate of increase of long-lived species (Nelson and Peek 1982, Fowler and Smith 1973), and should continue to be monitored closely in the PCH. The population has been growing at an annual rate of 4.8% since 1979.

Our estimate of PCH adult male mortality was calculated from a relatively small sample of collared animals. In general, males of ungulate species have different life history strategies than females, leading to shorter life spans. However, our estimate indicates survival of males to be greater than or equal to females. We believe there is reason to suspect that our estimate of male mortality is biased low. The small sample ($\underline{n}$ ≤13 in all years), and the fact that most of the bulls collared were young, may combine to give an underestimate of bull mortality rates.

The available data from the CAH are largely inadequate to detect if rate of growth of this herd is slowing. The CAH has been associated with petroleum development for approximately 20 years, and appeared to grow rapidly during the 1970's and early 1980's (Whitten and Cameron 1983). The last census of the CAH was in 1983, and at that time the herd was estimated at 12,900. June ratios of calves:100 cows are used as an estimate of productivity in the CAH. June calf:cow ratios for that segment of the CAH associated with development west of the Sagavanirktok River have been slightly lower than ratios east of the area since 1989 (Table 4). June calf:cow ratios for the entire herd decreased from 67:100 in 1988 to 51:100 in 1989 but returned to 75:100 in 1990 (Table 4). These ratios may underestimate true parturition rate because calves dying shortly after birth are missed. In the PCH, productivity is estimated by parturition rate of radio-collared females and ranged from 78% to 83% during the same time period. Spring ratios of short yearlings:100 cows are the only information available regarding first year survival of calves in the CAH. There is concern that rate of growth in the CAH is declining, but the available data are not sufficient to detect such a change.

MANAGEMENT IMPLICATIONS AND POTENTIAL RESEARCH DIRECTIONS

The process of modeling the dynamics of the Porcupine caribou population is currently underway. Accurately predicting the growth or decline of a population is always an uncertain and complex procedure, and reasonable predictions can only be obtained with unbiased estimates of the input parameters. Thus, priorities for future research are to continue to estimate survival and productivity parameters through the use of radio-collared individuals.

Because survival of adult females is an important parameter driving the dynamics of long-lived species, it is desirable to maintain a sufficient sample of radio-collared PCH females to allow detection of any changes in mortality rates. The number of collared females should remain at current levels or increase to achieve mortality rate estimates with acceptable levels of precision. A more precise estimate of PCH male mortality is desired. To accomplish this, the sample size of radio-collared males must be increased; preliminary analyses indicate that precision is poor unless the number of animals tagged at a particular time is >20 (Pollock et al. 1989). Frequent tracking flights will allow a more precise determination of rates and causes of male and female mortality. An additional priority for future research is to obtain information regarding diet composition and nutritional quality of forage during the calving and postcalving seasons, when energy demands on caribou are high. Also, information on the relationship between caribou distribution and the potential numerical and functional response of predator populations is needed. These types of information are necessary inputs to simulation models of PCH population dynamics for purposes of estimating the potential effects of an oil and gas leasing program in ANWR on the PCH.

Although parturition rates and age-specific survival information are available for the PCH, comparative estimates for some parameters are lacking for the CAH due to the smaller sample sizes of marked and known-age animals in this herd. Our current estimates of parturition rates and age-specific survival in the CAH are based on a small sample of marked animals or the use of calf:cow ratios and have varied greatly among the last few years. With the available data, a change in the growth rate of the CAH is very hard to detect. Further research should concentrate on obtaining better estimates of CAH population parameters. The small sample sizes currently available have restricted our ability to use some statistical analyses and limited our conclusions to the identification of trends.

Sample size of radio-collared CAH adult females should be increased to obtain better estimates of age-specific parturition rates and perinatal calf mortality in developed and undeveloped areas. By increasing frequency of relocations of collared adult females we can obtain estimates of June calf survival, comparable with those available for the PCH. Causes of perinatal as well as later calf mortality should be determined using calves of collared adult females as well as collared calves. Sex and age composition data for the CAH has been limited for some time to estimates obtained during June; reliable estimates of bull:cow ratios are also needed and necessitate sampling at a time when the bulls and cows are mixed. An estimate of population size of the CAH will be necessary for validation of any population model. A photocensus will be attempted again in 1991.

If productivity and survival of the CAH are both changing, we need to determine if changes are related to petroleum development in the region. It is possible that stresses associated with interaction with development could decrease chance of successful conception. A decrease in calf production and/or early calf survival might be related to factors such as contaminants, or changes in female body condition brought about by increased energy expenditure. If a cause and effect relationship exists, the exact mechanisms that determine changes in population productivity need to be determined.

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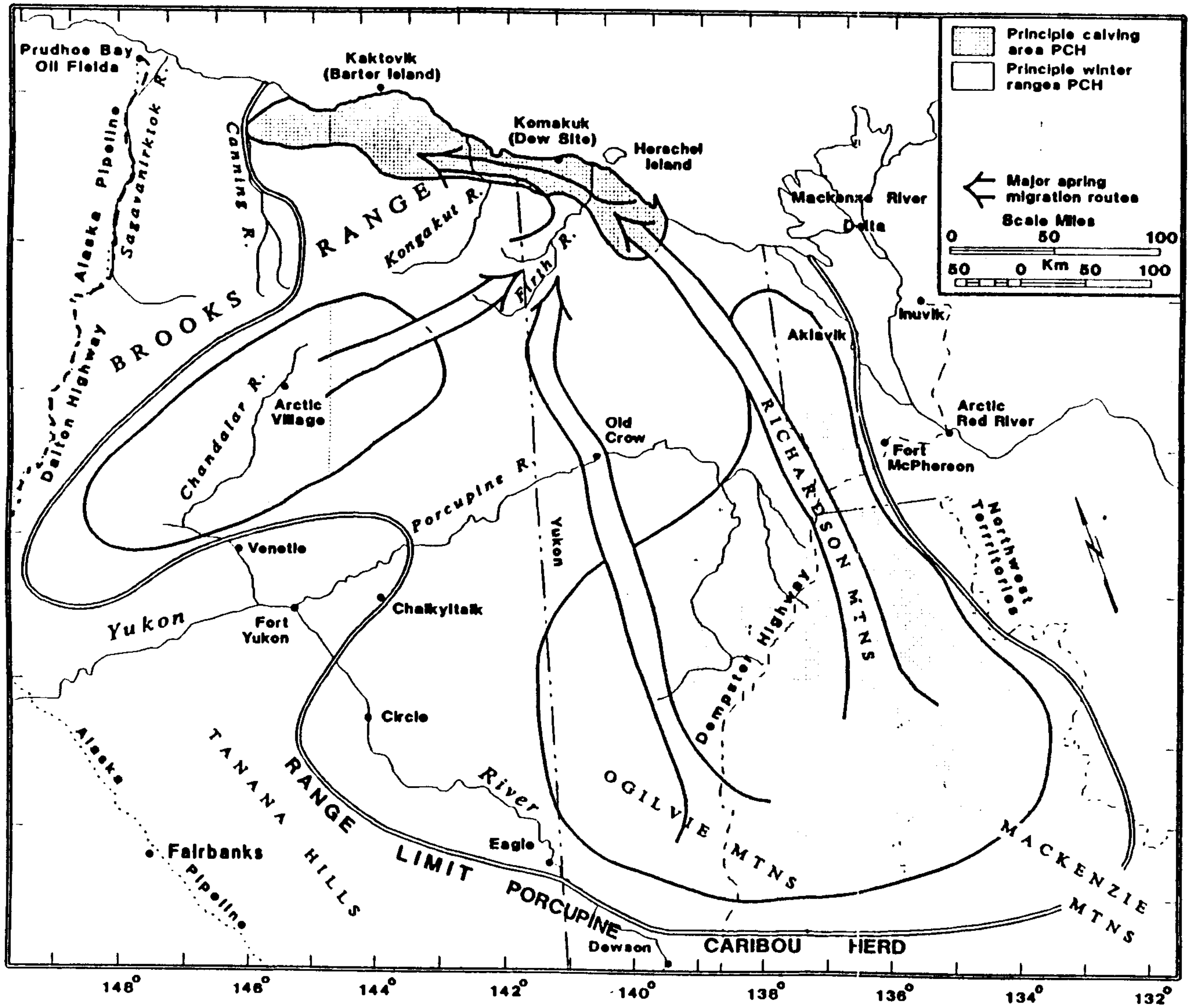

Figure 1. Range of the Porcupine Caribou Herd, in northeastern Alaska and northwestern Canada, including primary wintering areas and primary calving area.

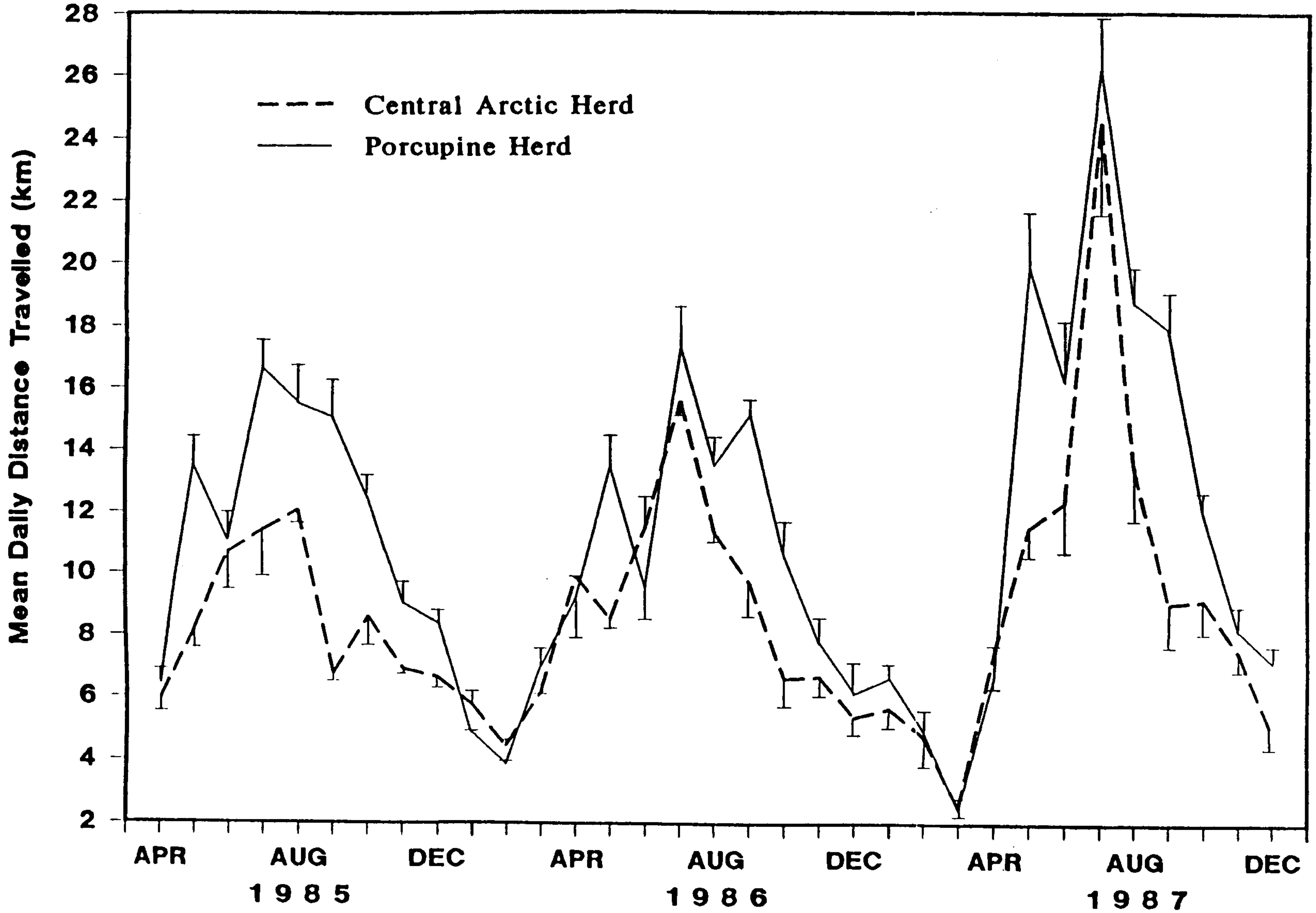

Figure 2. Movement rates of (means ± 1 SE) of Porcupine and Central Arctic herd cows between 1985 and 1987.

Table 1. Composition counts of the PCH (% of total) in postcalving aggregations during early July 1972-89 (numbers for bulls include immatures and adults.)

Year	Percent				
	Cows	Calves	Yearlings	Bulls	No. classified
1971	56	21	10	13	29,197
1972	53	26	9	12	11,721
1973	58	27	6	10	19,101
1974	55	37	3	5	14,127
1975	52	27	9	12	18,814
1976	55	32	10	2	13,762
1977	61	24	11	4	25,520
1978	46	31	7	14	18,668
1979	30	17	5	15	34,730
1980	39	26	11	23	9,046
1981		No data			
1982	36	17	15	34	19,718
1983	52	38	5	5	2,584
1984		No data			
1985		No data			
1986	42	22	12	25	19,483
1987	38	24	10	28	33,044
1988	50	27	10	14	6,420
1989	55	25	11	9	23,251
1990		No data			

Table 2. Composition counts of the CAH (% of total) during calving surveys in early June 1978-89 (numbers for bulls include immatures and adults.)

Year	Percent			
	Cows	Calves	Bulls	No. classified
1978	53	36	10	950
1979	47	38	3	1,865
1980	45	31	2	787
1981	46	40	4	3,337
1982	55	34	11	1,101
1983	50	42	8	1,879
1984	45	40	4	2,692
1985	42	37	7	2,357
1986	51	29	4	891
1987	51	37	2	4,839
1988	49	32	3	4,892
1989	59	28	4	2,520
1990	46	35	14	6,543

Table 3. Parturition rates and June calf survival for adult (≥3-year-old) cows of the PCH, 1982-90. No data are available for June calf survival in 1982 and 1986.

Year	n[a]	No. pregnant	Parturition rate	No. monitored through June	Survival rate
1982	9	8	0.89	--	--
1983	22	17	0.86	20	0.65
1984	31	25	0.81	25	0.84
1985	56	43	0.77	43	0.65
1986	42	31	0.74	--	--
1987	51	40	0.78	41	0.66
1988	89	73	0.82	71	0.69
1989	72	57	0.79	58	0.74
1990	65	54	0.83	54	0.91
Mean			0.81 ± 0.02		0.73 ± 0.04

[a] $\underline{n}$ = 437 potential calving events; some cows were sampled >1 year.

Table 4. Sex and age composition of CAH caribou observed during helicopter[a] surveys of the calving grounds, June 1987-90.

	No./100 cows								
	W. of Sagavanirktok R.			E. of Sagavanirktok R.			Total		
Year	Calves	Yrlg	Bulls	Calves	Yrlg	Bulls	Calves	Yrlg	Bulls
1987	77	16	3	71	23	4	74	21	4
1988	68	33	6	66	34	7	67	34	7
1989	29	29	12	63	12	3	51	18	4
1990	72	13	40	81	7	18	75	11	31

[a] Based on transects at 9.6 km-intervals.

Table 5. Eleven-month Kaplan-Meier survival estimates for radio-collared calves of the PCH alive on July 1 in 1983, 1984, 1985 and 1988. Data for 1983-85 obtained from Whitten et al. (unpubl. manuscript).

	Females			Males			Both sexes			
Year	n	Survival	95% CI	n	Survival	95% CI	n	Survival	95% CI	X^2[a]
1983	30	0.7414	0.5566-0.9261	24	0.7895	0.5385-1.0405	54	0.7596	0.6106-0.9086	0.08
1984	23	0.7802	0.6112-0.9492	31	0.6083	0.4371-0.7795	54	0.6814	0.5575-0.8053	1.55
1985	26	0.7379	0.5400-0.9358	25	0.7350	0.5368-0.9332	51	0.7379	0.5980-0.8779	0.00
1988	47	0.7862	0.5957-0.9766	42	0.7349	0.5293-0.9406	89	0.7633	0.6232-0.9033	0.06
Combined	248	0.7380	0.6693-0.8068							

[a] Log-rank test comparing survival functions for male and female calves each year. None of the values were significant ($P > 0.20$).

Table 6. Kaplan-Meier survival estimates for yearling and 2-year-old radio-collared PCH caribou.

Sex	Age	At risk	Died	Censored	Survival	95% CI
Female	1	75	3	3	0.9600	0.9165-1.0035
Female	2	62	2	6	0.9677	0.9245-1.0110
Male	1	21	4	0	0.8095	0.6584-0.9606
Male	2	16	2	11	0.8750	0.7234-1.0266

Table 7. Kaplan-Meier survival estimates for adult radio-collared PCH caribou for annual intervals beginning 1 June 1981. Survival in year *t* is the probability of a caribou surviving from the beginning of the study to the end of year *t*. Caribou that were first captured in March or April were included in analyses when the next annual interval began on June 1.

	Adult females					
Year	At risk	Died	Censored	Survival	95% CI	Annual mortality
81	11	3	0	0.7273	0.5028-0.9517	0.2727
82	12	1	0	0.6667	0.4489-0.8844	0.0833
83	25	1	2	0.6400	0.4895-0.7905	0.0400
84	28	4	3	0.5486	0.4120-0.6851	0.1429
85	31	3	2	0.4955	0.3716-0.6194	0.0968
86	51	11	10	0.3886	0.3052-0.4720	0.2157
87	61	6	5	0.3504	0.2795-0.4213	0.0984
88	89	22	5	0.2638	0.2168-0.3108	0.2472
89	74	13	4	0.2174	0.1736-0.2613	0.1757

1981-90 Mean annual female mortality = 0.1525

	Adult males					
Year	At risk	Died	Censored	Survival	95% CI	Annual mortality
81	5	0	0	1.0000	0.0000-0.0000	0.0000
82	7	0	0	1.0000	0.0000-0.0000	0.0000
83	11	1	2	0.9091	0.7471-1.0711	0.0909
84	8	2	3	0.6818	0.4153-0.9483	0.2500
85	9	1	0	0.6061	0.3575-0.8546	0.1111
86	7	1	1	0.5195	0.2527-0.7862	0.1429
87	12	1	1	0.4762	0.2812-0.6712	0.0833
88	13	4	1	0.3297	0.1829-0.4764	0.3077
89	8	2	1	0.2473	0.0986-0.3959	0.2500

1981-90 Mean annual male mortality = 0.1373

Table 8. Annual harvest of the PCH, 1984-89. Canadian harvest from Yukon Department of Renewable Resources. Harvest in Alaska obtained from Alaska Department of Fish and Game (Whitten 1991).

Season	Reported				Estimated unreported			Total
	Male	Female	Unk	Total	Alaska	Canada	Total	
1984-85	49	4	0	53	500-700	4,000	4,500-4,700	4,554-4,754
1985-86	52	12	1	65	500-700	4,000	4,500-4,700	4,564-4,764
1986-87	70	14	0	84	1,000-2,000	500-1,000	1,500-3,000	1,584-3,084
1987-88	106	22	1	129	<500	2,000-4,000	2,500-4,500	2,629-4,629
1988-89	82	7	0	89	<500	2,000-4,000	2,500-4,500	2,589-4,589
1989-90	104	8	0	112	500-700	2,000	2,500-2,700	2,612-2,812

Table 9. Annual harvest of the CAH, 1984-89.

Season	Reported harvest				Estimated unreported harvest[a]	Total harvest
	Male	Female	Unk	Total		
1984	313	55	0	368	100-200	468-568
1985	482	177	3	662	100-200	762-862
1986	311	34	0	345	100-200	445-545
1987	176	2	3	181	100-200	281-381
1988	179	7	0	255	100-200	286-386
1989	132	8	0	140	100-200	240-340

[a] Estimate by H. Golden, pers. commun.

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