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MOVEMENT PATTERNS OF THE PORCUPINE CARIBOU HERD IN RELATION TO OIL DEVELOPMENT

by
Kenneth R. Whitten
and
Wayne L. Regelin

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SUMMARY

Since March 1985, 8 to 18 and 2 to 10 caribou (*Rangifer tarandus*) in the Porcupine Caribou Herd (PCH) and Central Arctic Herd (CAH), respectively, have been successfully relocated several times per day by a satellite-tracking system. Movement patterns in relation to topographic features and broad habitat types will be determined and compared between the 2 herds. Movements in relation to petroleum production facilities and activities will be determined for CAH caribou, and these data will be used to predict effects of potential development on the PCH. Data are currently being collected and analyzed.

Key words: caribou, migration, satellite radio-tracking.

CONTENTS

BACKGROUND

The Porcupine Caribou (Rangifer tarandus) Herd (PCH), is composed of approximately 165,000 animals that migrate seasonally between wintering areas in the boreal forests of northwestern Canada and northeastern Alaska and the calving grounds on the arctic coastal plain within both the Yukon Territory and Alaska. Large-scale development of nonrenewable resources is planned throughout this resource-rich area. Concerns about the impact of development on the PCH have been expressed by numerous governmental agencies, environmental groups, and subsistence users. International concern is exemplified by efforts to develop an international agreement between the U.S. and Canadian governments to protect the PCH and its habitat.

Exploration for oil and gas is currently underway on the traditional calving grounds of the PCH and on the arctic coastal plain. It is highly likely that development will occur in the near future. The PCH wintering areas in the Ogilvie and Richardson Mountains in Canada and on Venetie tribal lands in Alaska are also subject to intensive oil and mineral exploration. A road has already been built between Dawson and the MacKenzie River Delta (Dempster Highway). Protection of habitats on calving grounds and key winter ranges and mitigation of the impacts of development require detailed knowledge of habitat use, movement patterns, and travel corridors.

The large size, remote location, and international movements of the PCH make it difficult and costly to study. Monitoring movements and habitat use through direct observation or by relocating caribou equipped with conventional radio collars has proven difficult. The feasibility of using satellite radio collars to monitor daily movements of caribou in the PCH was tested in 1984. The prototype satellite radio collars (i.e., PTT's for "platform terminal transmitters") provided accurate and reliable data at a reasonable cost. A 2nd-generation satellite transmitter was developed and deployed in 1985; in April 1985, 8 and 2 PTT's were placed on PCH and Central Arctic Herd (CAH) females, respectively. Preliminary results have demonstrated a capability for describing migration routes and movement patterns in greater detail than had been previously possible. In particular, we noted extensive mid- and late-summer movements that had not been previously reported. Also, activity recorders in the PTT's have the potential to provide data on daily activity patterns of caribou. Additional collars were deployed in October 1987 and April 1988 to increase sample sizes to 18 PCH females. Mortality and battery exhaustion have reduced the current sample size (May 1988) in the CAH to 6 PTT's. In June 1988 additional PTT's will be deployed to raise the sample sizes to 20 PTT's in the PCH and 10 in the CAH. Collars on CAH females allow comparisons of relatively sedentary caribou with the highly migratory PCH and also provide an opportunity to describe caribou reactions to existing oil field development.

This study is 1 component of a cooperative program between the Alaska Office of Research, U.S. Fish and Wildlife Service, and the Alaska Department of Fish and Game. The overall goals of this cooperative study are 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 identify migration routes between summer and winter ranges and to determine movement patterns on the arctic coastal plain in relation to topographic features, broad habitat types, and existing or potential petroleum production and transportation facilities.

The U.S. Fish and Wildlife Service is the lead agency in determining habitat utilization and preferences as well as daily activity budgets. Objectives that are the primary responsibility of the U.S. Fish and Wildlife Service are not addressed in this report.

METHODS

Eighteen adult female caribou from the PCH and six from the CAH are currently equipped with collars bearing both PTT and standard transmitters. Each PTT transmits 6 hr/day, provides 2-5 locations daily, and functions for approximately 1 year. Each collared caribou is monitored as long as possible; that is, until it dies or can no longer be located because of failure of both the PTT and standard transmitters. When a PTT expires or is near the end of its projected battery life, that caribou is located using the standard transmitter and recaptured; the old collar is reclaimed, and a new collar is attached. When a collared caribou dies, the collar is retrieved, refurbished as necessary, and placed on a different caribou.

Migration Routes

All PTT locations are plotted on digitized terrain maps so that migration routes and distances traveled each day can be correlated with slope, aspect, and major geographical features. Satellite locations are supplemented by fixed-wing tracking of standard radio-collared caribou. Trail systems are noted during tracking flights as well as during general reconnaissance surveys of the migrations. Trails are clearly visible in snow, and fresh trails can also be distinguished along river bars and in tundra vegetation during summer and fall. In this way, data from satellite relocations can be compared with routes used by other members of the herd. Thus various migration paths can be compared for distances traveled, elevation changes, and rates of movement. Estimates of numbers, composition, and group sizes of caribou using various routes are then possible; these estimates could not have resulted from sole use of the PTT's.

Calving Areas

During calving, PTT locations are plotted on digitized terrain and habitat maps. Location of calving is correlated with habitat types and terrain features to determine if preferences occur. Time of calving for PTT-collared caribou is determined by observation from fixed-wing aircraft. Again, tracking of standard radio collars and general reconnaissance flights provide comparative data on numbers and composition of caribou using the calving grounds.

Insect Relief Habitat

Periods of severe insect harassment of caribou are identified from (1) local weather records of wind and temperature conditions favorable to insect activity, (2) concurrent studies by U.S. Fish and Wildlife Service on insect activity and abundance in the Arctic National Wildlife Refuge, and/or (3) direct field observations.

PTT locations are plotted on digitized terrain maps and again compared with supplemental data from standard radio collars and general aerial surveys. Specific areas or types of habitats consistently used during insect harassment periods can then be compared, and any distinguishing characteristics such as vegetation type, elevation, temperature, and wind conditions noted.

RESULTS AND DISCUSSION

Tables 1 and 2 show capture dates, recaptures for collar replacement, and current status of satellite radio-collared caribou. PTT's in the CAH have been deployed so that some collared caribou are likely to frequently encounter oil field facilities (i.e., captured in or near the Prudhoe Bay and Kuparuk Oil Fields), while others are likely to encounter development only infrequently (i.e., captured in the Canning River/Sadlerochit Mountains area far east of the oil field).

Each location fix for each caribou is entered into a computerized mapping system. An attribute file for that fix is then automatically created that includes location, date, slope, aspect, vegetation type, ambient temperature, and activity of the caribou. Slope, aspect, and vegetation data are obtained from LANDSAT imagery, while temperature and animal activity are provided by sensors in the PTT. The data are in the process of being analyzed.

A paper comparing seasonal movements of the PCH and CAH has been prepared in conjunction with our Fish and Wildlife Service cooperators. A draft has been submitted to the Canadian Journal of Zoology and is included as an Appendix.

ACKNOWLEDGMENTS

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PREPARED BY:

Kenneth R. Whitten
Game Biologist II

SUBMITTED BY:

Wayne L. Regelin
Regional Research Coordinator

APPROVED BY:

W. Lewis Pamplin, Jr., Director
Division of Game

Donald E. McKnight, Planning Chief
Division of Game

Table 1. Deployment data and current status of satellite radio collars (PTT's) on female caribou from the Porcupine Caribou Herd.

I.D. No.	Capture date	Recapture for collar replacement	Comments and current status (April 1988)
S8	4/85	3/86, 10/86, 10/87	Still alive; PTT transmitting
S9	4/85	3/86, 5/86	PTT failed 5/86; recollared with conventional transmitter 6/86; died of unknown causes 12/86
S10	4/85	3/86, 3/87, 4/88	Still alive; PTT transmitting
S11	4/85	3/86, 3/87, 7/87, 4/88	Still alive; PTT failed 5/87
S12	4/85	3/86	Died of unknown causes 12/86; PTT retrieved
S13	4/85	3/86, 10/86, 10/87	Still alive; PTT transmitting
S14	4/85	3/86, 10/86, 3/87, 4/88	Still alive; PTT transmitting
S15	4/85		Killed by bear (along with calf) 6/85; PTT retrieved
S16	6/85		Killed by wolves 11/85; PTT retrieved
S17	3/86		Died of unknown causes 5/86; PTT retrieved
S18	10/86		Killed by wolves 2/87; PTT retrieved
S19	10/86	10/87	Still alive; PTT transmitting
S20	10/86	10/87	Still alive; PTT transmitting
S29	10/86		Died of unknown causes 3/88; PTT retrieved
S30	3/87		Died 4/87, apparent capture mortality; PTT retrieved
S31	3/87	4/88	Still alive; PTT transmitting
S32	3/87		Still alive; PTT failed 9/87

Table 1. Continued.

I.D. No.	Capture date	Recapture for collar replacement	Comments and current status (April 1988)
S35	10/87		Still alive; PTT transmitting
S36	10/87		Still alive; PTT transmitting
S37	10/87		Still alive; PTT transmitting
S40	10/87		Still alive; PTT transmitting
S42	4/88		Still alive; PTT transmitting
S43	4/88		Still alive; PTT transmitting
S44	4/88		Died of unknown causes 4/88; PTT not retrieved
S45	4/88		Died 4/88, apparent capture mortality; PTT retrieved
S46	4/88		PTT failed 4/88
S47	4/88		Still alive; PTT transmitting
S48	4/88		Killed by wolves 4/88; PTT retrieved
S49	4/88		Died of unknown causes 4/88; PTT not retrieved
S50	4/88		Died of unknown causes 4/88; PTT not retrieved

Table 2. Deployment data and current status of satellite radio collars (PTT's) on female caribou from the Central Arctic Caribou Herd.

I.D. No.	Capture date	Recapture for collar replacement	Comments and current status (April 1988)
S5	4/85	3/86	Presumed alive; PTT batteries exhausted 3/87 and standard transmitter failed. No longer trackable. Collar not retrieved.
S6	4/85	3/86, 3/87	Died of unknown causes 6/87; PTT retrieved
S21	10/86	10/87	Still alive; PTT failed 4/88
S22	10/86	10/87	Still alive; PTT transmitting
S23	10/86	11/86, 3/87, 10/87	Still alive; PTT transmitting
S24	10/86	10/87	Still alive; PTT transmitting
S25	10/86	10/87	Still alive; PTT transmitting
S26	10/86		Still alive; PTT batteries exhausted; PTT not retrieved
S27	10/86	8/87	Died of unknown causes 10/87; PTT retrieved
S28	10/86	10/87	Still alive; PTT transmitting
S33	5/87	4/88	Killed by wolves at capture site 4/88; PTT retrieved
S34	7/87		Still alive; PTT batteries exhausted
S38	10/87		Still alive; PTT failed 1/88
S39	10/87		Still alive; PTT transmitting
S41	10/87		Still alive; PTT transmitting

APPENDIX. D R A F T

Seasonal Movements of Caribou in Arctic Alaska As Determined by Satellite

S.G. Fancy
U.S. Fish and Wildlife Service, 101 12th Ave., Box 20
Fairbanks, Alaska 99701

L.F. Pank
U.S. Fish and Wildlife Service, 1011 E. Tudor Rd.
Anchorage, Alaska 99503

K.R. Whitten
Alaska Department of Fish and Game, 1300 College Road
Fairbanks, Alaska 99701

W.L. Regelin
Alaska Department of Fish and GAme, 1300 College Road
Fairbanks, Alaska 99701

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Between 1985 and 1987, 49,283 locations and 79,101 sets of activity data were obtained for 34 adult female caribou (*Rangifer tarandus granti*) of the Porcupine and Central Arctic herds using satellite telemetry. Daily movement rates of female caribou from the two herds, which differ greatly in size and separation of seasonal ranges, were similar except during the spring and fall migration periods. Movement rates in July exceeded those during migration in both herds. The minimum annual distances travelled by caribou cows, ranging to 5055 km, were the longest movements documented for any terrestrial mammal.

INTRODUCTION

The extensive movements and migrations of barren-ground caribou (Rangifer tarandus granti and R. t. groenlandicus) are among the most notable characteristics of the species. Each year, most caribou herds in the arctic migrate between winter ranges south of treeline, and tundra-dominated calving grounds on the Arctic slope (Kelsall 1968, Skoog 1968, Hemming 1971, Parker 1972, Miller 1982). The spring migration in April and May is led by pregnant females which commonly travel 7-24 km/d (Thompson 1978, Parker 1972, Fancy 1986, Duquette and Klein 1987). If the onset of migration is delayed by deep snow, rates of movement may exceed 40 km/d (Thompson 1978). After calving, cows and calves form into increasingly larger groups that include some bulls and yearlings. During July and early August, caribou are periodically harassed by mosquitos (Aedes and Culicidae), bot and warble flies (Oestridae), and black flies (Simuliidae). Large, mixed groups of caribou may form and travel extensively to habitats providing relief from insects. By August, caribou disperse in small groups, but continue to travel long distances before beginning the return migration in September and October to winter ranges in the taiga (Kelsall 1968, Skoog 1968, Hemming 1971, Parker 1972).

The seasonal movement pattern summarized above is based primarily on observations of herd distribution made by aerial surveys at several times of the year. Several recent studies using radio-collared individuals have confirmed this general seasonal movement pattern (e.g., Valkenburg et al. 1983, Whitten et al. 1985, Cameron et al. 1986). However, because of the high cost of relocating radio-collared caribou in remote areas of the arctic, prolonged darkness in winter, and unpredictable weather, most of our knowledge about seasonal movements of marked individuals is based on small and sometimes incomplete data sets.

Since 1984, the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game have been developing and evaluating satellite telemetry as an alternative means of monitoring caribou movements. We have found satellite telemetry to be a cost-effective, accurate and reliable means of systematically obtaining locational and activity data for caribou in an arctic environment. We present here some of our findings, based on this technology, from studies on the Porcupine Caribou Herd (PCH), which migrates between separate winter and summer ranges in Canada and Alaska, and the much smaller Central Arctic Herd (CAH), with less distinctive migration patterns between overlapping seasonal ranges.

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C.H. Curby, D.C. Douglas and J.C. Greslin with data analysis and presentation. Use of trade names of commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation by the U.S. Government.

STUDY AREA

The range of the PCH, estimated at ca. 170,000 caribou in 1987 (unpubl. data), 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 varies considerably among years, but the 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. 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 (Roseneau and Stern 1974, Thompson 1978, Whitten and Cameron 1983, Garner and Reynolds 1986).

The CAH, estimated at 16,000 caribou in 1986 (R. Cameron, pers. comm.), ranges north of the crest of the Brooks Range primarily between the Colville and Canning rivers (Fig. 1). The distribution of the CAH in winter is generally south of that in summer (Cameron and Whitten 1979), but considerable overlap of summer and winter distributions occurs, and caribou use of areas within 40 km of the coast during winter is not uncommon. Walker (1985) provided a detailed description of the vegetation and climate of the Central Arctic region.

METHODS

Between April 1985 and December 1987, we obtained daily movement and activity data on 34 adult female caribou of the PCH and CAH using the Argos Data Collection and Location System (Argos 1984, Fancy et al. 1988). The Argos system is a cooperative project of the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Centre National d' Etudes Spatiales (CNES) of France. The system consists of two polar-orbiting weather satellites (currently NOAA-9 and NOAA-10), three ground tracking stations, and processing centers in France and Maryland. Fancy et al. (1988) provided a detailed description of the Argos system and potential applications for wildlife research and management.

Caribou were captured on winter range and fitted with a neck collar equipped with an Argos-compatible transmitter and a conventional VHF transmitter. The VHF transmitter was used to relocate the caribou by aircraft, and served as a backup in the event of satellite transmitter failure. The canister housing the satellite transmitter measured approximately 7 cm x 11 cm x 6 cm and weighed 1.5 - 1.6 kg. The complete package was built by Telonics, Inc. (Mesa, AZ). To prolong battery life, Generation 2 satellite transmitters (i.e., transmitters manufactured prior to September 1986) were programmed to transmit for 6 h each day, giving a theoretical battery life of 1 year. More advanced units (n = 13) deployed after September 1986 were programmed to transmit for 12 h each day between 1 May and 30 September, and for 6 h on alternate days between 1 October and 30 April. Each signal included a unique identification number, synchronization and error-checking information, and 32 bits of sensor data, and was transmitted at ca. 60 sec intervals on a frequency of 401.650 MHz. Location was calculated from the Doppler shift in the carrier frequency of the transmitted signal as the satellite approached and then moved away from the transmitter (Argos 1984, Fancy et al. 1988).

Transmitters also contained sensors for monitoring the internal temperature of the canister (an approximation of ambient temperature; Pank et al. 1985, unpubl. data) and the caribou's activity. For activity monitoring, a microprocessor determined the number of seconds each minute during which a mercury tip-switch calibrated for caribou (Pank et al. 1987) was activated. This short-term activity index, having a maximum value of 60, was a reflection of activity 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 travelled by each caribou between two successive locations was calculated by connecting locations with straight lines. For each month, we calculated the mean daily movement rate for each caribou by summing the lengths of each line segment and dividing by the corresponding 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). Statistical comparisons were evaluated at the 95% confidence level.

RESULTS

System Reliability and Location Accuracy

During 1985-1987, we received 79,101 sets of sensor data and 49,283 locations for satellite-collared caribou of the PCH and CAH. Only 5 of the 42 transmitters deployed on caribou before October 1986 failed within 6 mo of deployment. A mean of 3.5 locations/d was obtained for caribou with Generation 2 transmitters. Caribou with transmitters that operated 12 h/d in summer were located a mean of 8.0 times daily. The mean location error for Generation 2 transmitters placed at known locations was

763 m (n = 2711). Newer Generation 3 transmitters had a mean error of 483 m (n = 403), and 90% of the calculated locations were within 900 m of the true transmitter location. The high frequency and accuracy of locations allowed us to determine very detailed movement patterns for each caribou (Fig. 2).

Seasonal Movement Patterns

The PCH and CAH exhibited similar annual patterns in their daily rates of movement, with highest values in July and lowest values in February or March (Fig. 3). Differences in mean movement rates between herds and among years were compared for mid-winter (February), spring migration (May), mid-summer (July), and fall migration (September). Movement rates in February and July were not significantly different (two-way Anova; February $F = 0.08$; $p > 0.75$; July $F = 0.14$; $p > 0.70$). In contrast, differences in movement rate between herds were highly significant during both migration periods (May $F = 16.27$; $p < 0.001$; September $F = 49.20$; $p < 0.0001$), and differences in between-year movement rates were significant for May ($F = 5.69$; $p < 0.01$) and July ($F = 6.67$; $p < 0.005$). Although movement rates during May and July in 1985 and 1986 were similar, they were significantly lower than those in 1987 (Duncan's Multiple Range Test; SAS 1985; Fig. 3).

A potential seasonal bias in movement rates exists because we assumed that each caribou moved in a straight line between successive locations. This assumption is probably reasonable when movements tend to be rapid and directional, such as during spring migration or insect-induced movements (Skoog 1968, Thompson 1978). However, when movements are relatively localized, during calving and mid-winter, a substantial underestimate is possible. We do not believe that the bias is serious, however, because the annual pattern in the long-term activity index, an independent measure of mobility (Pank et al. 1985, 1987; Fancy et al. 1988), follows a pattern similar to that of the movement rates (Fig. 4). In work with captive caribou, we have found that high activity counts are associated with walking and running, and we have found a highly significant linear relationship between the mean monthly long-term activity index and caribou movement rates for the PCH and CAH (regression; $r^2 = 0.21$; 388 df; $p < 0.0001$).

Annual Distance Travelled

For each caribou, we summed the distances between successive locations to obtain an estimate of the minimum distance travelled per year. We included only those caribou that were tracked over a period of 10 mo or longer. The mean annual distance travelled for 10 PCH cows (4355 ± 150 SE km) was significantly greater than that for 10 CAH cows (3031 ± 97 km; Anova; $F = 55.01$; $p < 0.0001$). To our knowledge, the movements made by these caribou, ranging to 5055 km/yr, are the longest documented movements by any terrestrial animal.

Comparative Costs of Satellite- vs. Radio-Telemetry

In our study area, satellite telemetry is the only means of systematically acquiring location or sensor data for free-ranging large animals. Fixed observation sites or radio-tracking stations cannot be used because of terrain and the mobility of the animals, and radio-tracking flights frequently cannot be conducted because of darkness or poor weather. Even if it were possible to systematically locate radio-collared caribou from aircraft, the cost per location would be much higher than that for locations determined by satellite (Table 1). For example, in a 5-year study using 10 caribou, the cost to obtain 1 location/d using radio-telemetry would have been 43 times that using satellite telemetry. If only 1 location/wk were required to meet study objectives, the cost per location using radio-telemetry would be 10 times higher. In this example, satellite-telemetry would be cost effective if 3 or more locations/yr were needed for each caribou. In a study involving 50 caribou, the cost to relocate each animal from an aircraft would be reduced, yet satellite-telemetry would still be cost-effective if more than 13 locations/yr were needed to address study objectives.

DISCUSSION

Gregarious behavior and seasonal migrations are common to many ungulate species living in open environments. Examples include the wildebeest (Connochaetes taurinus), Thomson's gazelle (Gazella thomsonii) and several species of antelopes in Africa (Bell 1971, Estes 1974), alpine sheep and goats (Lawson and Johnson 1982, Wigal and Coggins 1982), and caribou and reindeer in North America, Scandinavia and northern Asia (Kelsall 1968, Gaare and Skogland 1975, Geller and Borzhanov 1984). In each case, migrations are related to seasonal changes in weather patterns that affect forage availability and quality.

The search for adequate food in a seasonal and often harsh environment is a primary factor influencing caribou movements (Murie 1935, Banfield 1954, Skoog 1968, Bergerud 1974). Bergerud (1974) hypothesized that gregarious behavior by caribou was incompatible with "a sedentary life in an environment dominated by slow growing plants whose availability in space and time varied with snow conditions. Thus, mobility had selective value and caribou developed their characteristically restless mode of life". We believe that the characteristic migrations of barren-ground caribou between winter ranges and calving grounds are consistent with an optimal range use strategy governed by energy and nutrient availability, and risk of predation on calves. Caribou winter ranges are characterized by a relatively high biomass of highly-digestible lichens, and relatively soft or shallow snow. However, lichens are deficient in protein and minerals, and caribou cannot sustain rapid growth and milk production on a predominantly lichen diet (Jacobsen and Skjenneberg 1975, Holleman et al. 1979, Rognmo et al. 1983). The optimal range use strategy during the summer period of lactation and rapid growth therefore involves movements to areas where highly-digestible forages in the early stages of growth and containing high amounts of nitrogen and minerals can be obtained (Klein 1970, Whitten and Cameron 1980). In addition to their high latitude and often varied topography, factors that prolong the availability of vegetation in the early stages of growth (Fleck and Gunn 1982), the calving grounds of the barren-ground herds are usually characterized by reduced predation risk on calves, delayed insect emergence, and frequent periods of cool, windy weather when insect activity is reduced (Kelsall 1968, Skoog 1968, Bergerud 1974).

Towards the end of the plant growing season in August and September, following the period of intense insect activity, the gross latitudinal trends in plant phenology found in early summer become less pronounced, and caribou disperse throughout a large portion of their annual range to take advantage of localized foraging opportunities (Klein 1970, Whitten and Cameron 1980). When the digestibility and nutrient content of summer forage species declines at the end of the growing season, lichens again become the most digestible forage and most available source of energy, and movements to areas of high lichen biomass and suitable snow conditions are adaptive.

Caribou have evolved the highest efficiency of walking of any terrestrial mammal (Fancy and White 1987). Because of the multiplier effect (White 1983) of factors associated with energy intake, and the relatively low cost of locomotion, caribou can compensate for the energy cost of extensive movements and can take advantage of foraging opportunities limited in space and time. Thus, from an energetic standpoint, extensive movements between and within seasonal ranges are adaptive if they result in even small increases in daily eating time, eating rates, or forage digestibility (Fancy 1986).

Differences in the extent of area covered by cows of the PCH and CAH may be largely a function of herd size. As herds decrease in size, the size of their range also decreases (Banfield 1951, Skoog 1968). Conversely, as herd size increases, caribou expand their range, and movements become more unpredictable. Skoog (1968) believed that there are social limits on population density that can be sustained by free-ranging caribou herds. Apparently, caribou of the CAH are able to obtain adequate forage throughout the year within a relatively small area, whereas at a higher density, the caribou would presumably consume and trample the forage in an area, making it necessary to abandon it. Nevertheless, CAH cows exhibit the same "restlessness" as PCH cows and move almost as far during a year, but the factors selecting for a highly migratory pattern are absent.

We cannot fully explain the significantly greater movements by satellite-collared caribou in May and July of 1987 compared to 1985 and 1986. Almost the entire PCH wintered in Alaska in the vicinity of Arctic Village in 1986-1987, and the length of the spring migration route in 1987 was similar to those used in 1985 and 1986. April snow depths in 1987, and the timing of migration, were also similar to the previous two years. Approximately two-thirds of the PCH cows calved in Canada in 1987, further east than usual, and movements by post-calving aggregations in July tended to be further west than in preceeding years, accounting for increased movements in July 1987. The number of days in 1987 when weather conditions were conducive to moderate or severe insect activity (calculated from Barter Island weather records using the methods of White et al. 1975) was twice that in 1985, but only slightly higher (11 vs. 9 days) than in 1986. The distribution of CAH caribou and insect activity in July 1987 was not noticably different from preceeding years, yet CAH cows moved as far as those in the PCH.

Satellite telemetry has proven to be an accurate, reliable and cost-effective approach for monitoring caribou movements and activity in an arctic environment. Improved equipment and software are continually being developed, and smaller, lighter and more durable transmitters with the capability of monitoring animal behavior, physiology and physical environment are becoming available. The very detailed data sets we have obtained for caribou using this technology will further our ability to conduct in-depth analyses on the many puzzling questions on caribou ecology and physiology.

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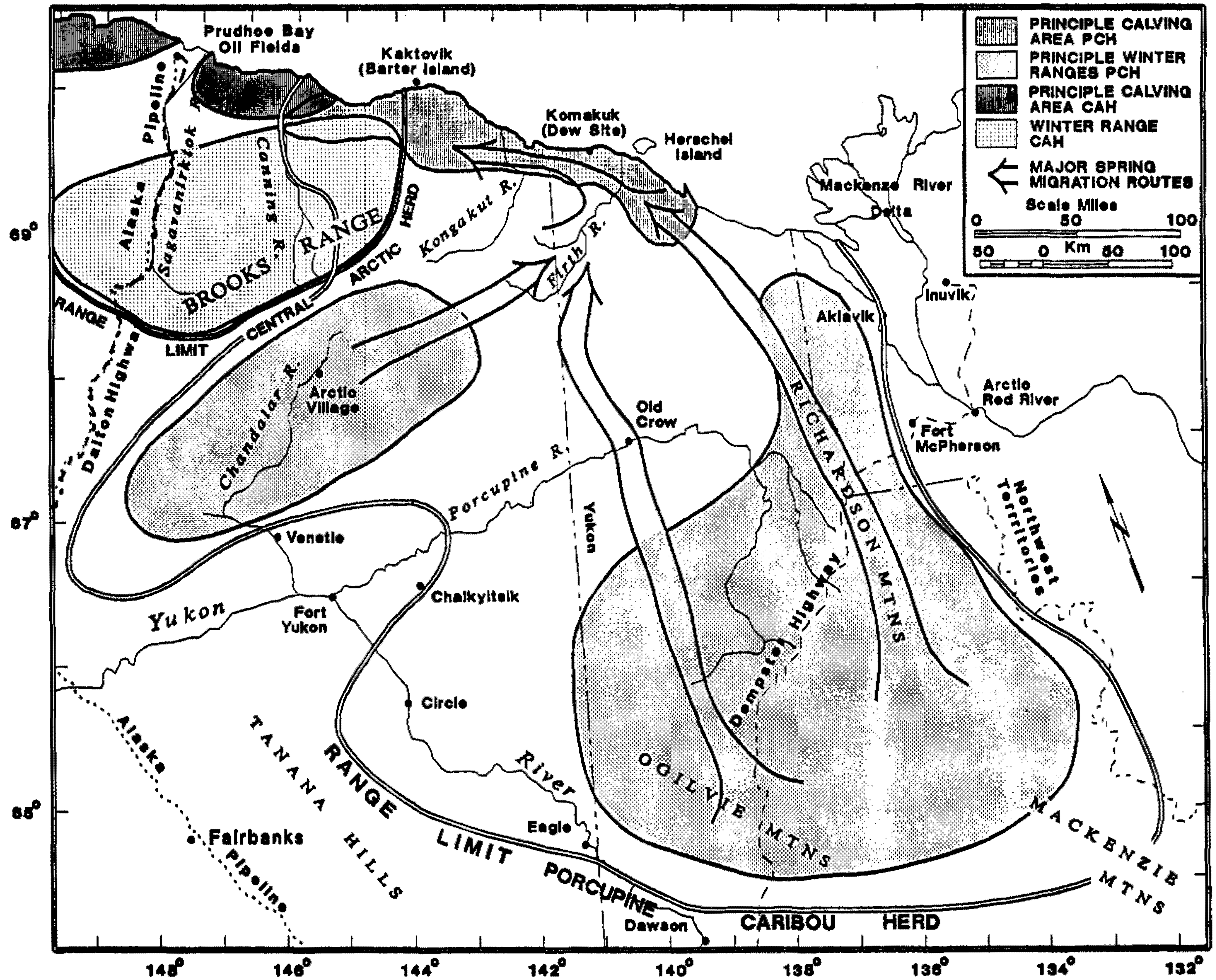
FIGURE CAPTIONS

Fig. 1. Annual range of the Porcupine and Central Arctic caribou herds in northeastern Alaska and northwestern Canada.

Fig. 2. Movements by adult female caribou S10 between 1985 and 1987 as determined by the Argos Data Collection and Location System.

Fig. 3. Movement rates (means ± 1 SE) of the Porcupine and Central Arctic caribou herds between 1985 and 1987.

Fig. 4. Mean long-term activity index (± 1 SE) for adult female caribou of the Porcupine and Central Arctic caribou herds between 1985 and 1987. The index represents the number of seconds each day during which a mercury switch calibrated for caribou was activated.



PRINCIPLE CALVING AREA PCH
PRINCIPLE WINTER RANGES PCH
PRINCIPLE CALVING AREA CAH
WINTER RANGE CAH
MAJOR SPRING MIGRATION ROUTES
Scale Miles
0 50 100
50 0 Km 50 100
Prudhoe Bay Oil Fields
Kaktovik (Barter Island)
Komakuk (Dew Site)
Herschel Island
Mackenzie River Delta
Inuvik
Aklavik
Arctic Red River
Fort McPherson
Northwest Territories
Yukon
Old Crow
Porcupine R.
Kongakut R.
Firth R.
Pipeline
Alaska
Sagavanirktok R.
Canning R.
BROOKS RANGE
CENTRAL ARCTIC HERD
RANGE LIMIT
Dalton Highway
Chandalar R.
Arctic Village
Venetie
Chalkyitsik
Fort Yukon
Yukon River
Circle
Eagle
Dawson
Fairbanks
Alaska Pipeline
TANANA HILLS
RANGE LIMIT PORCUPINE CARIBOU HERD
RICHARDSON MTNS
Dempster Highway
OGILVIE MTNS
MACKENZIE MTNS
69°
67°
65°
148°
146°
144°
142°
140°
138°
136°
134°
132°

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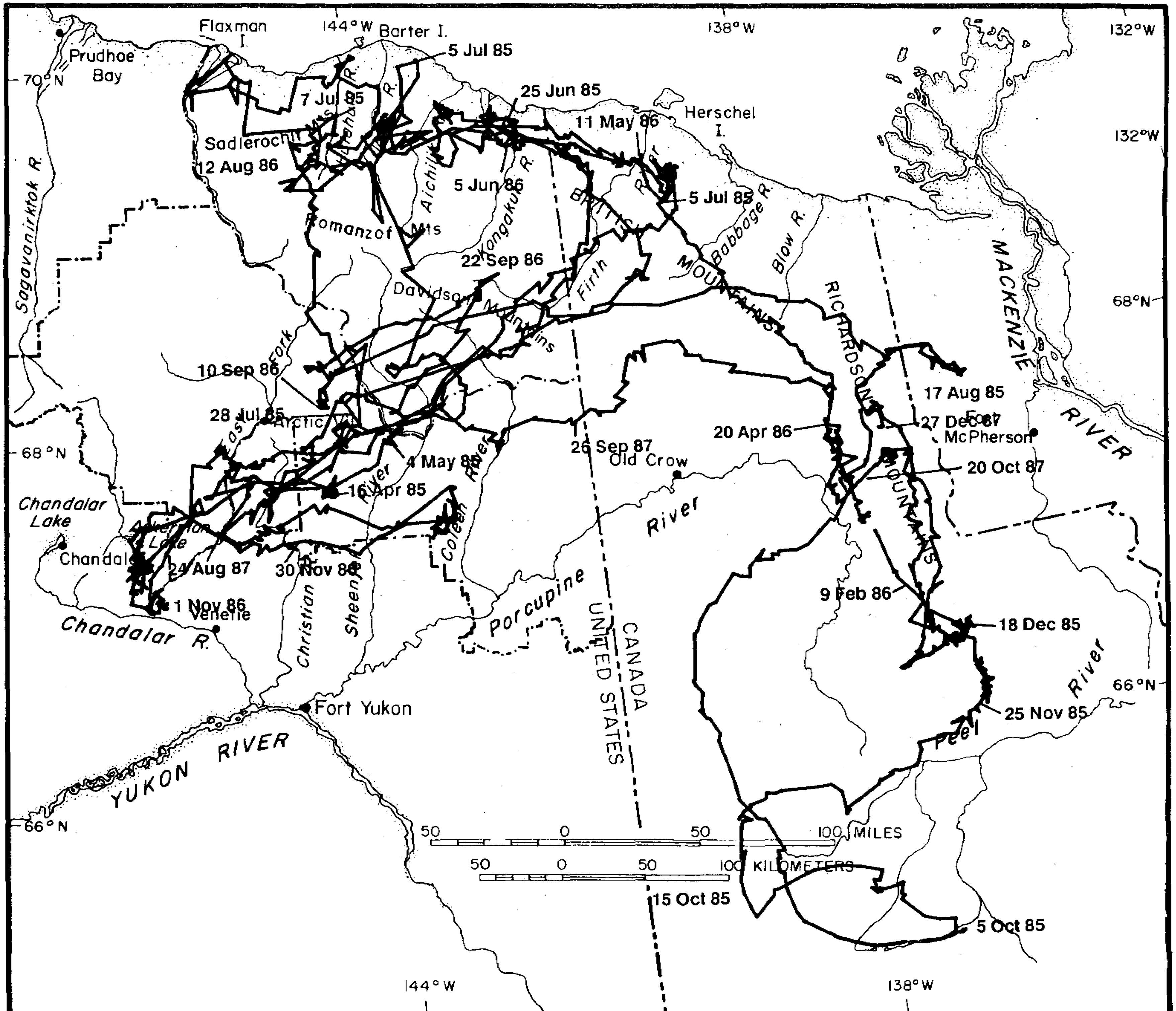
Flaxman I.
144°W
Barter I.
Prudhoe Bay
70°N
5 Jul 85
7 Jul 85
25 Jun 85
11 May 86
Herschel I.
132°W
132°W
Sadlerochit Mts.
12 Aug 86
Sagavanirktok R.
5 Jun 86
Aichilik R.
Kongakut R.
5 Jul 85
Babbage R.
Blow R.
Romanzof Mts
22 Sep 86
Firth
BRITISH
MOUNTAINS
RICHARDSON
MACKENZIE
Davidson Mountains
East Fork
68°N
10 Sep 86
17 Aug 85
28 Jul 85
Arctic
27 Dec 87
Fort McPherson
20 Apr 86
RIVER
68°N
26 Sep 87
Old Crow
4 May 85
Coleen River
20 Oct 87
16 Apr 85
MOUNTAINS
Chandalar Lake
Ackerman Lake
River
Chandalar
24 Aug 87
30 Nov 86
Porcupine
9 Feb 86
1 Nov 86
Venetie
18 Dec 85
Chandalar R.
Christian
Sheenjek
UNITED STATES
CANADA
River
66°N
25 Nov 85
Fort Yukon
Peel
YUKON RIVER
66°N
50
0
50
100 MILES
50
0
50
100 KILOMETERS
15 Oct 85
5 Oct 85
144°W
138°W
138°W

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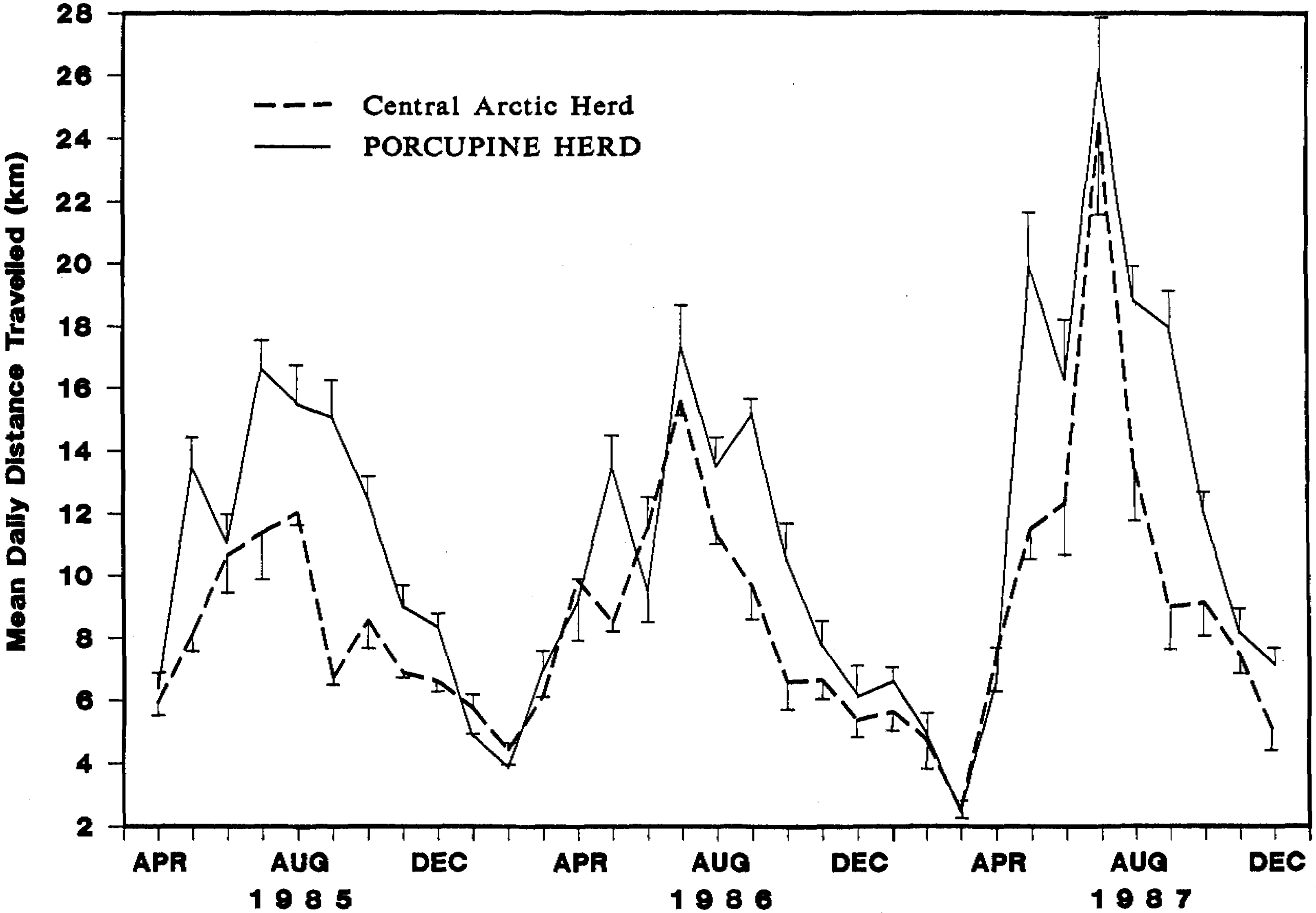

Central Arctic Herd
PORCUPINE HERD
Mean Daily Distance Travelled (km)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
APR
AUG
DEC
APR
AUG
DEC
APR
AUG
DEC
1 9 8 5
1 9 8 6
1 9 8 7

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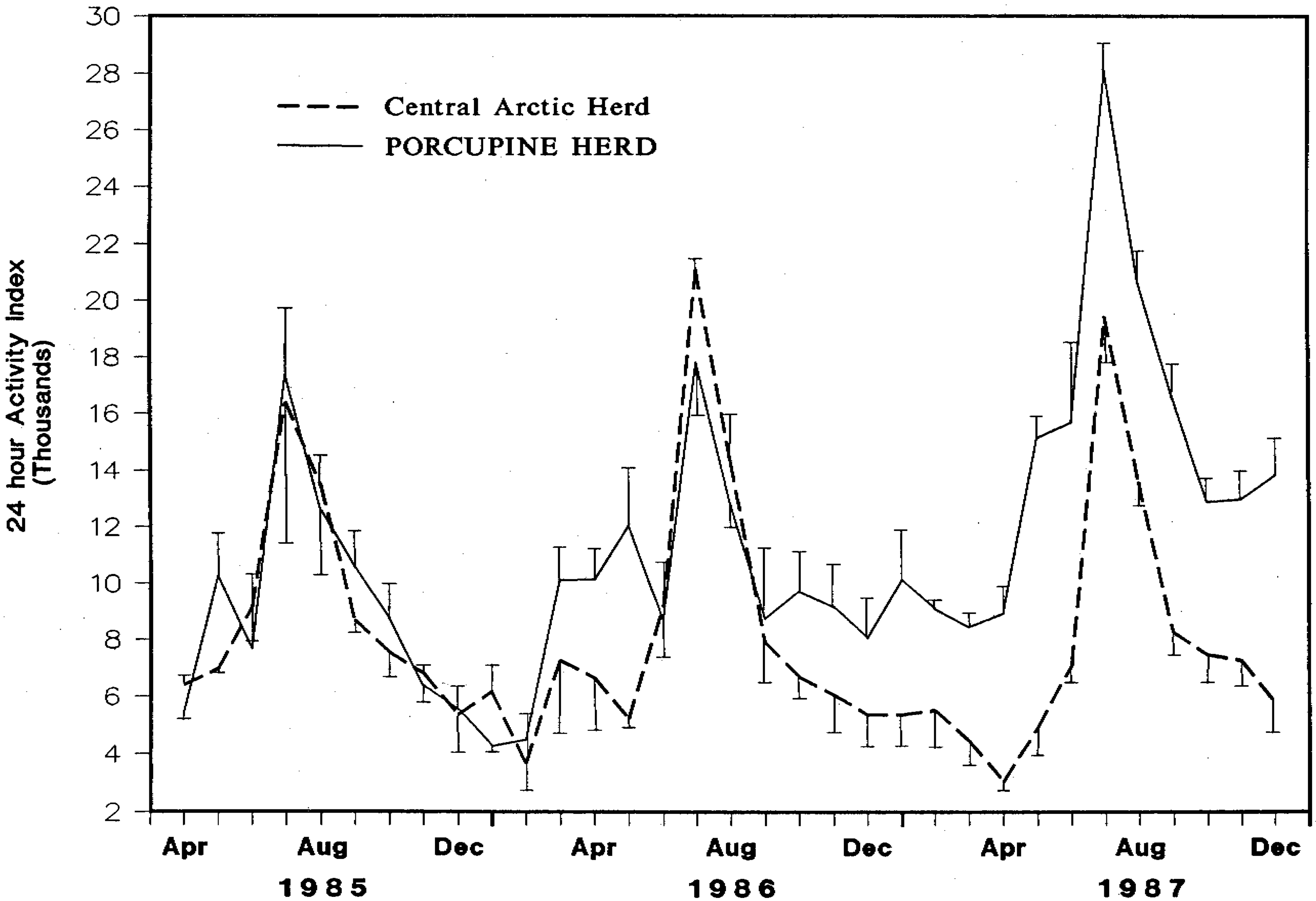

Central Arctic Herd
PORCUPINE HERD
24 hour Activity Index (Thousands)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Apr
Aug
Dec
Apr
Aug
Dec
Apr
Aug
Dec
1985
1986
1987

Table 1. Comparative cost per animal to locate 10 caribou using satellite- vs. radio-telemetry techniques in northern Alaska. Calculations are based on a 5-year study using satellite transmitters with a 1-year battery life or radio-transmitters with a 3-4 year battery life. An additional set of collars is included to replace used collars when the caribou is recaptured. Radio-telemetry study costs includes $3500 for radio-tracking equipment. Labor costs are not included.

Satellite-Telemetry	Per Collar Cost	Cost per Location (Locations per Year)		
Initial cost per collar (includes backup VHF transmitter)	$3300.00	n=10	n=52	n=365
Additional collar	3300.00			
Refurbishment costs ($750 x 4)	3000.00	$350	$ 74	$ 18
Capture costs ($1500 x 5)	7500.00			
Argos processing ($8.22/d)				
Radio-Telemetry				
Initial cost per collar	$ 330.00	$893	$778	$754
Additional collar	330.00			
Capture costs ($1500 x 2)	3000.00			
Radio-tracking flight	750.00[1]			

[1] Assumes that each caribou is located visually to get an accurate location. Full coverage of study area requires 30 h @ $250 /h air charter cost.