USE OF A DISTANCE-BASED TEST OF INDEPENDENCE TO MEASURE GRIZZLY BEAR-CARIBOU ASSOCIATION IN NORTHEASTERN ALASKA

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Abstract: We used a distance-based test of independence to measure the association between concurrent distributions of radio-collared grizzly bears (*Ursus arctos*) and calving caribou (*Rangifer tarandus*) of the Porcupine caribou herd (PCH) on the Arctic National Wildlife Refuge (ANWR), Alaska. The analysis utilized 552 grizzly bear and 585 caribou radio relocations recorded during 5 consecutive time intervals between 29 May and 22 June, 1988-90. Correlation coefficients of bear and caribou distributions tended to be positive in 1988 and negative in 1990. Those trends corresponded with annual variations in snowmelt in the Alaska portion of the PCH calving grounds and mortality for calves of radio-collared PCH cows. Concurrent distributions of bears and caribou were positively correlated ($P < 0.05$) during time intervals 29 May-2 June and 8-12 June 1989. We hypothesize that positive correlations were the result of extensive overlap and a high degree of interspersion between bear and caribou distributions. The majority (13/15) of concurrent distributions of bears and calving caribou were not significantly correlated. We hypothesize this occurred because the ANWR bear population did not respond to the availability of calving caribou in a homogeneous manner. The distance-based test of independence appeared to be an acceptable technique for quantifying associations between discrete, but interacting, populations of wildlife.

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In 1988, the U.S. Fish and Wildlife Service initiated a study to investigate relationships between predators and calving caribou on Arctic National Wildlife Refuge (ANWR) in northeastern Alaska. This study was in response to the Final Legislative Environmental Impact Statement for ANWR that reported that petroleum exploration and development in ANWR would have major effects on caribou (Clough et al. 1987). A primary concern was that calf survival might decline if the Porcupine caribou herd (PCH) was displaced from traditional high-density calving areas to peripheral areas where predators (grizzly bears, wolves [*Canis lupus*], and golden eagles [*Aquila chrysaetos*]) were believed more abundant.

An objective of our research was to determine whether distributions and movements of grizzly bears were associated with distributions of a contiguous population of calving caribou. One approach we used to measure this association between discrete populations involved a nearest-neighbor analysis technique. Nearest-neighbor analyses were first introduced in forestry (Diggle and Cox 1983) either to estimate the number of plants in a study area region or to test the "randomness" of plant patterns (Bythe and Ripley 1980). Pielou (1961) developed an 'absolute' nearest-neighbor technique to measure the association, or segregation, between bivariate populations. Diggle and Cox (1983) presented a "distance-based" nearest-neighbor technique for measuring the association among sparsely-sampled multivariate populations. This paper only presents the more current "distance-based" nearest-neighbor technique used in measuring bear-caribou associations in ANWR; analyses using other techniques (e.g., Multi-response Permutation Procedures, utilization distribution overlap using adaptive kernel methods) are in progress and will be reported later.

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STUDY AREA

The study area was located in northeastern Alaska between the Canning River and the Canadian border north of the Brooks Range Divide (Fig. 1). During late spring and early summer, the migratory PCH (ca. 160,000 in 1992) uses the coastal plain and foothills of the study area as calving grounds, although intensity of use of specific localities varies from year to

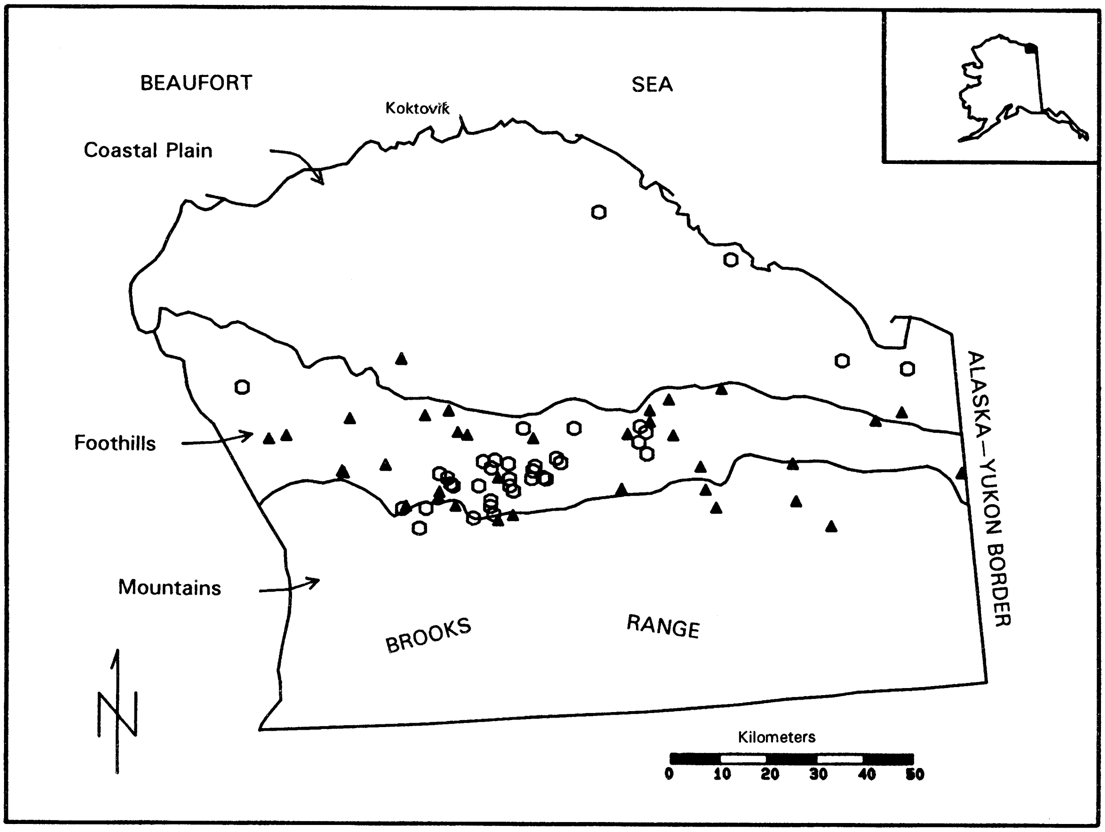

Fig. 1. Concurrent distributions of radio-collared grizzly bear groups (▲) and radio-collared female caribou accompanied by calves (O) during peak calving (3-7 June 1988) on the Arctic National Wildlife Refuge, Alaska. This time interval was representative of concurrent bear and caribou distributions during the 1988 calving period.

year (Garner and Reynolds 1986, Whitten et al. 1992). Grizzly bears use the mountains and foothills throughout the year, but use the coastal plain only seasonally (Garner and Reynolds 1986, Young et al. 1992).

The study area was divided into 3 physiographic zones: the coastal plain was generally flat with elevations <300 m; the foothills were characterized by buttes and ridges, with elevations between 300 and 900 m; the mountains with elevations >900 m and river valleys at elevations of 500-1,000 m (Reynolds and Garner 1987) (Fig. 1). These zones comprised 38%, 19%, and 43% of the 16,000 km^2 study area, respectively.

A detailed description of the physiography, vegetation, and climate of the study area is provided in Garner and Reynolds (1982).

METHODS

Bears were captured from a helicopter using the immobilizing drug Telazol (*tiletamine hydrochloride* and *zolazepam hydrochloride*; A.H. Robins Co., Richmond, Va.) administered via a dart gun (Taylor et al. 1989). Once immobilized, the bears were weighed, measured, and had a premolar extracted; bears then were fitted with standard VHF radio collars (Telonics, Inc., Mesa, Ariz.) (Garner et al. 1985). Ages were determined by examining cementum annuli of premolar teeth (Stoneberg and Jonkel 1966). The age composition of radio-collared bears (83% adult) was similar to that described for other North Slope grizzly bear populations (Reynolds 1980, Garner et al. 1985). Composition of the radio-collared cohort of bears was biased toward females (annual mean = 67%, range = 63-70%) due to capture selectivity. We assumed that spatial distributions of the radio-collared cohort of bears (annual mean = 49 bears) was representative of the population considering that approximately 45% of the bear population was radiocollared. This figure was based on a 1983 estimate of 108 bears on and near the study area (Garner et al. 1984:350). Preliminary analyses indicated that the ANWR bear population was stable between 1982 and 1990 (H.V. Reynolds, Alaska Dep. Fish and Game, unpubl. data).

Caribou were captured from a helicopter using a mixture of Carfentanil citrate (Wildlife Laboratories, Fort Collins, Colo.) and Acepromazine maleate, with Naloxone (Wildlife Laboratories) administered as the antagonist (Fancy and Whitten 1991, Fancy et al. 1992). Caribou were fitted with standard VHF radio collars (Telonics, Inc.). Radio-collared caribou were assumed to be a geographically representative sample of the PCH (Harris et al. 1989, Fancy et al. 1992).

Radio-collared grizzly bears and caribou were located from fixed-wing aircraft from late May through June at approximately 3-5 day and 1-3 day intervals, respectively. Grizzly bear and caribou radio relocations (relocations) were plotted on U.S. Geological Survey 1:63,360- and 1:125,000-scale topographic maps, respectively, then computer digitized in Universal Transverse Mercator (UTM) coordinates.

The sampling unit for grizzly bears was a bear group (i.e., a single bear, a family group, or a breeding pair). The sampling unit for caribou was a female caribou accompanied by a calf. Because we were primarily interested in the impact of predation by bears on caribou calves, in the event a caribou lost her calf, then that individual was excluded from all further analyses for that year. Since several investigations of grizzly bear and caribou ecology (e.g., movements, reproduction, survival) were being conducted concurrently using the same sample of radio-collared animals, it was necessary to censor multiple relocations of individuals to maintain equal representation among individuals. Thus, only 1 relocation/animal/5-day time interval was used in the analyses. In instances where multiple relocations were obtained for an individual animal within a single time interval, a single relocation was selected randomly. The sampling period was 29 May-22 June (hereafter referred to as the calving period), 1988-90, and was divided into 5, 5-day time intervals as follows: 29 May-2 June (early calving); 3-7 June (peak calving); 8-12 June (late calving); 13-17 June (post calving); 18-22 June (preaggregation). These intervals were based on observations of Garner and Reynolds (1986). They reported that the first calves of the season were usually observed in the last week of May; the peak of calving was in early June (3-8 June); and that calving was essentially completed by 15 June.

We tested hypotheses regarding the association of concurrent (i.e., within 5 consecutive days) distributions of radio-collared bears (n = 47, 53, 46, 1988-90, respectively) and caribou (n = 55, 47, 53, 1988-90, respectively) using a distance-based test of independence (paired point-to-animal distances analysis) (Diggle and Cox 1983). These analyses compared distances from systematically distributed sample points to the nearest bear and caribou relocations (events) using Kendall's coefficient of rank correlation (Sokal and Rohlf 1969). Distances were measured digitally by computer. The number of sample points was approximately 25% of the total number of bear and caribou relocations per time interval. This procedure was based on the suggested sampling intensity for a systematic grid arrangement according to the sparse-sampling null distribution theory (Diggle and Cox 1983). To minimize edge effect (Diggle and Cox 1983), sample points were excluded from the sample grid when they were closer to the study area boundary than that of the nearest event, either bear or caribou. As a result, the density and distribution of sample points (i.e., the systematic grid) varied by sample period based on the spatial distribution of events.

RESULTS

Grizzly Bear and Caribou Distributions

Six-hundred eighty-nine grizzly bear relocations and 1,158 caribou relocations were obtained during the sampling periods, 1988-90. Of these, 552 grizzly bear and 585 caribou relocations were used in paired point-to-animal distances analyses after multiple relocations were censored.

There was considerable annual variation in the distributions of calving Porcupine herd caribou, 1988-90 (Figs. 1-4). In 1988, caribou calved primarily in the southern foothills and calving tended to be concentrated in the upper Okerokovik River drainages. In 1989, caribou calved primarily in the northern foothills-southern coastal plain interface and calving tended to be more dispersed in an east-west direction across the calving grounds than in 1988. In 1990, caribou calved almost exclusively on the coastal plain. During the calving period, grizzly bears were relocated mostly in the foothills, 1988-90 (Figs. 1-4); bear use of the coastal plain was lowest in 1988 (12.7%; n = 55) and highest in 1990 (38.9%; n = 95) (Young et al. 1992).

Paired Point-to-Animal Distances Analyses

We observed annual trends in direction (i.e., positive or negative values) of correlation coefficients of

Table 1. Sample sizes, Kendall's coefficients of rank correlation (KCRC) and probability values by time interval for paired point-to-animal distances analyses of concurrent radio relocations of grizzly bear groups and female caribou accompanied by calves, 29 May-22 June 1988-90, on the Arctic National Wildlife Refuge, Alaska.

Time interval[a]		Number bear relocations	Number caribou relocation	Number sample points	KCRC	P^b
1988	1	36	48	22	0.3333	>0.10
	2	35	38	21	0.2762	>0.20
	3	43	39	20	0.2842	>0.20
	4	21	40	15	0.2571	>0.20
	5	35	32	16	0.0167	>0.50
1989	1	34	44	18	0.6078	<0.01
	2	40	43	21	-0.0286	>0.50
	3	40	40	22	0.4286	<0.05
	4	40	39	24	-0.0362	>0.50
	5	41	40	22	0.1175	>0.20
1990	1	36	41	16	-0.3500	>0.10
	2	33	45	22	-0.0823	>0.50
	3	41	38	20	0.0316	>0.50
	4	40	24	16	-0.1167	>0.50
	5	37	34	18	-0.2288	>0.20

[a] Time interval: 1 = 29 May-2 June; 2 = 3-7 June; 3 = 8-12 June; 4 = 13-17 June; 5 = 18-22 June.
[b] Two-tailed test.

concurrent distributions of radio-collared bears and calving caribou (Table 1). In 1988, 5 of 5 correlation coefficients were positive. In 1990, 4 of 5 correlation coefficients were negative. Although no trend was apparent in 1989, significant positive correlations ($P < 0.05$) were observed during time intervals 29 May-2 June and 8-12 June of that year (Table 1).

DISCUSSION

Annual trends in direction of correlation coefficients of concurrent distributions of radio-collared grizzly bears and calving caribou in ANWR corresponded with annual variation in snowmelt. This relationship was most apparent during 1988 and 1990. In 1988, snowmelt on the Alaska portion of the PCH calving grounds was the latest on record (Fancy and Whitten 1991). That year, calving was concentrated in the southern foothills in the upper Okerokovik River drainages, and bears were found almost exclusively in the foothills (Fig. 1). All correlation coefficients of concurrent bear and caribou distributions were positive that year.

In contrast, snowmelt in the Alaska portion of the calving grounds was the earliest ever recorded in 1990 (Fancy and Whitten 1991). Caribou were dispersed across the entire coastal plain during the early to mid-calving periods (Fig. 2) and gradually moved to the western portion of the study area where, by the late calving period, their distributions became more concentrated. Although, use of the coastal plain by bears was greater in 1990 than 1988 (Young et al. 1992), most bears remained in the foothills (Fig. 2) even though the coastal plain was snow free and most calving occurred there. Four of 5 correlation coefficients of concurrent bear and caribou distributions were negative in 1989.

Annual trends in direction of correlation coefficients of bear and caribou distributions also corresponded with annual variation in calf mortality. Fancy and Whitten (1991) reported high calf mortality for calves of radio-collared cows through the month of June in 1988 (31%), a year in which correlation coefficients were positive during all time intervals in our study. In 1989, when 3 of 5 time intervals had positive correlation coefficients, 2 of which were significantly correlated, they reported mortality for calves of 26%. In 1990, when 4 of 5 correlation coefficients were negative, they

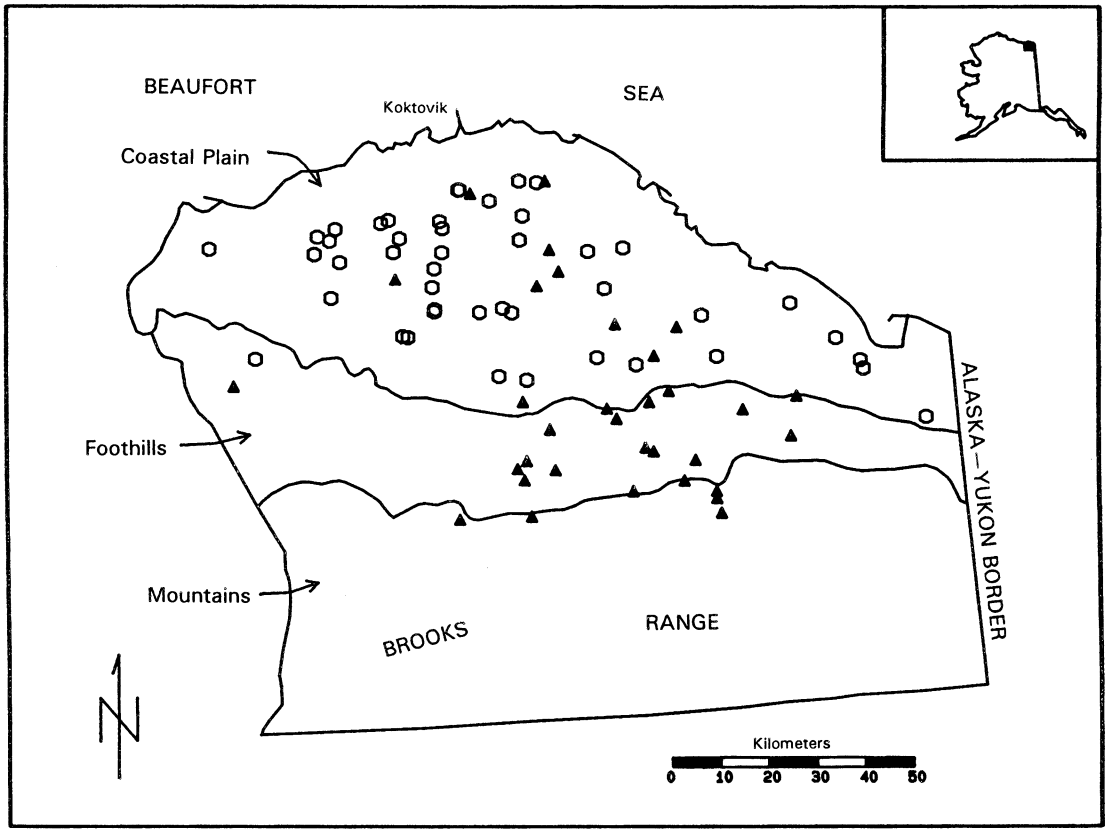

Fig. 2. Concurrent distributions of radio-collared grizzly bear groups (▲) and radio-collared female caribou accompanied by calves (O) during peak calving (3-7 June 1990) on the Arctic National Wildlife Refuge, Alaska. This time interval was representative of concurrent bear and caribou distributions during the 1990 calving period.

reported only 9% mortality for calves. Fancy and Whitten (1991) did not report the cause of the observed mortality, however. Mortality of calves may have been the result of predation by other predators (i.e., wolves and golden eagles) or related to other factors, such as nutritional stress. Reynolds and Garner 1987 (citing K. Whitten et al. 1984, 1985; Whitten, Alaska Dep. of Fish and Game, pers. commun.) reported 15.9%, 6.7%, and 14.5% mortality of neonatal calves of radio-collared cows in ANWR during June 1983, 1984, and 1985, respectively. Grizzly bear predation accounted for 10.0% of this mortality in 1983, none in 1984, and 22.2% in 1985.

Positive correlations ($P < 0.05$) between concurrent bear and caribou distributions were observed during time intervals 29 May-2 June and 8-12 June 1989. During the early calving period that year, caribou were found primarily in the northern foothills and on the southern coastal plain, although calving distributions expanded northward to approximately the mid-coastal plain by the late calving period (Figs. 3 and 4). In addition to the northward expansion, caribou distributions appeared to oscillate north and south between the foothills and southern coastal plain during the calving period (D.D. Young, pers. observation). Bear distributions did not appear to oscillate, however, but did expand northward to include much of the coastal plain by the late calving period (Young et al. 1992). We hypothesize that positive correlations during time intervals 29 May-2 June and 8-12 June were the result of extensive overlap and a high degree of interspersion between concurrent bear and caribou distributions (Figs. 3 and 4). This differed from distributions in 1988 when bears and caribou were restricted to the foothills, but calving tended to be concentrated in a localized area (i.e., the Okerokovik River drainages).

Even though we observed annual trends in direction of correlation coefficients, the majority of concurrent bear and caribou distributions were not significantly correlated. We hypothesize that the paucity of

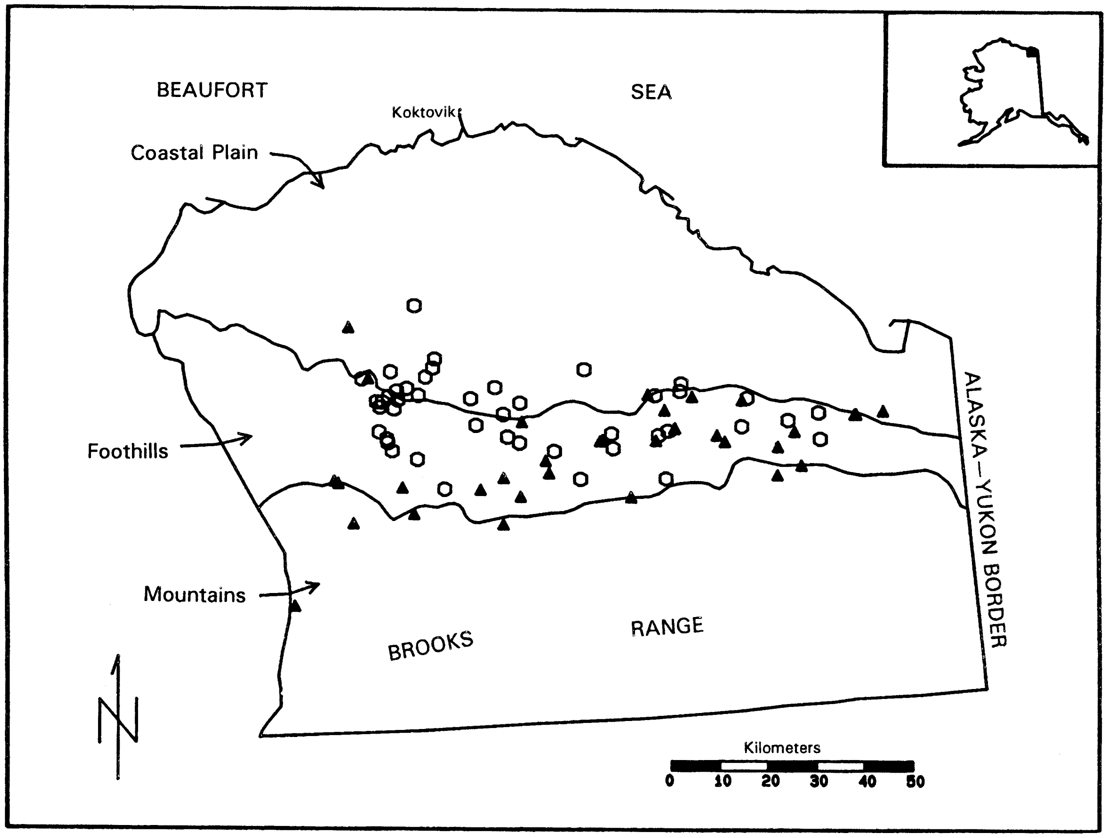

Fig. 3. Concurrent distributions of radio-collared grizzly bear groups (▲) and radio-collared female caribou accompanied by calves (O), 29 May-2 June, 1989 on the Arctic National Wildlife Refuge, Alaska.

significant associations between distributions was because the ANWR bear population did not respond homogeneously to the availability of calving caribou. For example, in 1988, when calving was concentrated in the southern foothills of the upper Okerokovik River drainages, some radio-collared bears appeared to be associated with the calving concentration; however, most bears remained dispersed throughout the foothills region (Fig. 1). Also, in 1990, when caribou calved primarily on the coastal plain, 61% (n = 95) of the relocations of radio-collared bears were in the foothills and mountains (Young et al. 1992; Fig. 2). Reynolds and Garner (1987) observed for the PCH, 1982-85, that when caribou were on the coastal calving grounds of ANWR, most bears moved there. In contrast, they found that bears in the western Brooks Range did not extend their home ranges to reach caribou concentrations. Pearson (1976) did not detect a shift in home ranges of bears to take advantage of migrating caribou in the Barn Mountains of the Yukon Territory. During our study, the ANWR bear population did not respond to the availability of calving caribou in a homogeneous manner, and apparently, as a result, concurrent distributions of bears and caribou were seldom correlated.

CONCLUSIONS

The distance-based test of independence was able to quantify grizzly bear-caribou associations in our study. Results of paired point-to-animal distances analyses tended to be consistent within years (i.e., annual trends in direction of correlation coefficients were apparent); and results could be explained biologically (e.g., annual trends appeared to be related to annual snowmelt patterns and rates of calf mortality). One limitation of this technique is the need for large samples (i.e., point locations), due to constraints imposed by the sparse-sampling null distribution theory. We feel the results may have been more conclusive if the sample of radio-collared caribou had been larger. Although assumed to be geographically representative, the relatively small

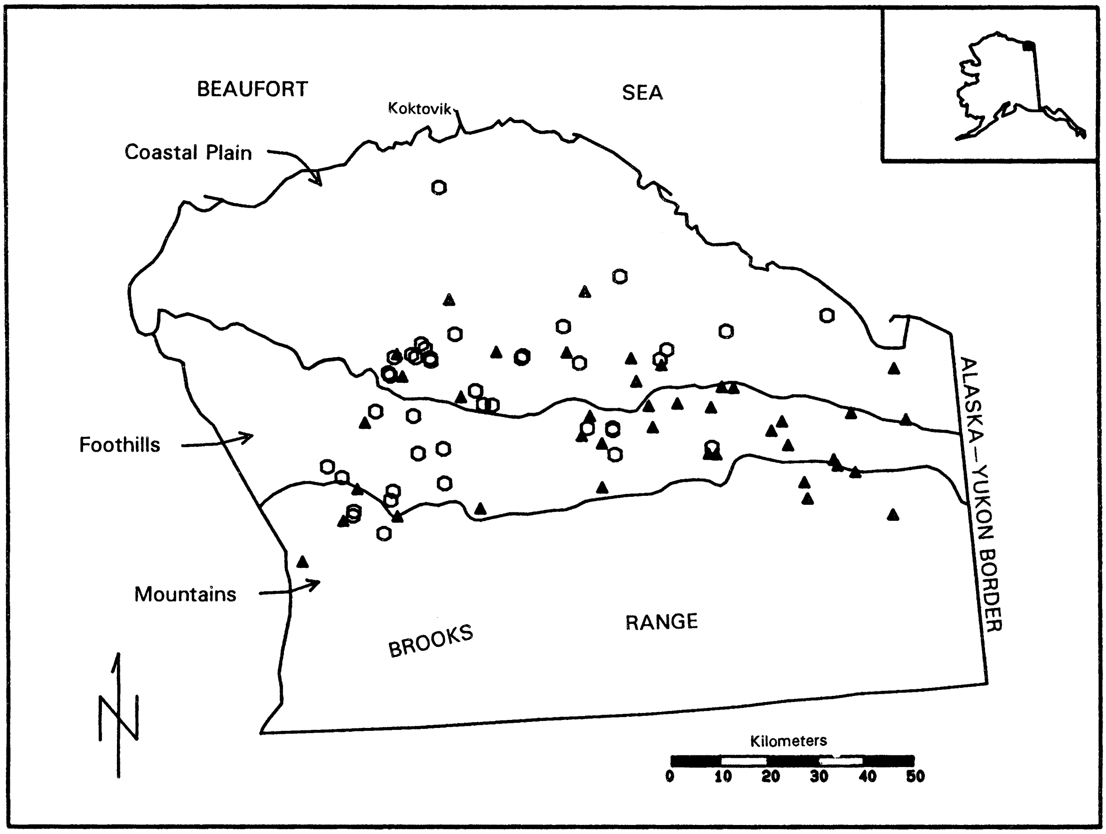

Fig. 4. Concurrent distributions of radio-collared grizzly bear groups (▲) and radio-collared female caribou accompanied by calves (O), 8-12 June, 1989 on the Arctic National Wildlife Refuge, Alaska.

sample (<0.1% of adult female caribou were radiocollared) meant that many caribou may have been available for the bears throughout the calving area. The fact that the specific radio-collared caribou were not more statistically correlated with radio-collared bears does not rule out the possibility that bears are moving, in some respect, to take advantage of the calving caribou. However, the distance-based test of independence appeared to be an acceptable technique for quantifying associations between discrete, but interacting, populations of wildlife.

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