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QUALITATIVE AND QUANTITATIVE ASPECTS OF NATURAL MORTALITY OF THE WESTERN ARCTIC CARIBOU HERD

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SUMMARY

Using radiotelemetry, 46 adult female and 28 adult male caribou (Rangifer tarandus granti) were monitored from 1979 through 1984. Mean annual mortality rates were calculated for these Western Arctic caribou using Gasaway et al.'s (1983) method. Mean annual natural mortality rates for 1979-84 were 16% for adult males and 8% for adult females. Mean man-caused mortality rates for the period were 13% for adult males and 4% for adult females. Mean total mortality was 29% for adult males and 12% for adult females. Comparable total mortality rates calculated by the Trent and Rongstad (1974) method were 26% for adult males and 10% for adult females. Total adult mortality rates calculated from an arithmetic model of the Western Arctic Caribou Herd's (WACH) population dynamics produced estimates ranging from 0.6% in 1978 to 17.6% in 1982. The apparent linear population growth from 1976 through 1984 in the WACH, and data inadequacies in the model are discussed. We believe that mortality rates calculated both from our radio-collared caribou data and from our arithmetic modeling are biased and do not represent actual mortality to the caribou population. However, we believe the calculated rates are useful indices to actual mortality rates and are more realistic than previously used values extrapolated from the literature.

Predation was the greatest proximate cause of natural mortality (all mortality not caused by humans). Sixteen radio-collared caribou died from natural causes vs. 10 from hunting. In general, wolves (Canis lupus) did not appear to select for caribou in poor condition or for caribou of a particular age group. However, they killed more males than expected, based on the proportion of males in the population. Predation rates have been low to moderate in most areas because the wolf population was low throughout the study.

We found no evidence that winter weather or disease contributed directly to the decline of the WACH during the early 1970's, although the decline occurred during a period of comparatively severe weather.

Correlations and depletion patterns of marrow fat among bones of caribou appear in a manuscript (Appendix A) to be submitted to the Journal of Wildlife Management.

Key words: caribou, modeling, mortality rate, natural mortality, population dynamics, predation, radiotelemetry, *Rangifer*, Western Arctic Caribou Herd, wolves.

CONTENTS

BACKGROUND

The Western Arctic Caribou Herd (WACH) was one of several Alaskan caribou (*Rangifer tarandus granti*) herds that declined during the early 1970's (Davis and Valkenburg 1978, Davis et al. 1980). The WACH was the largest herd in North America, and its decline was numerically most dramatic, so its population dynamics and management became a focus of public and scientific attention for several years.

Major controversy centered around the cause and mechanism of the WACH decline (Davis et al. 1980). Although many hypotheses were advanced to explain the WACH's decline, the herd grew from approximately 75,000 in 1976 to 175,000 in 1982 under a management program focused on reduced harvest by humans coincident with a major reduction in wolf (*Canis lupus*) abundance and relatively mild winters.

Population modeling of the WACH (Doerr 1979, 1980; Davis et al. 1980) and intensified management demonstrated the need for better biological data. Several studies addressing aspects of the biology of the WACH were initiated from 1975 through 1979 and provided some required data. However, the causes and rates of natural mortality were not determined. Davis et al. (1980) concluded that natural mortality, particularly predation, contributed greatly to the recent decline of the WACH.

Most caribou biologists who study population dynamics agree that knowledge of the rates and sources of natural mortality is central to understanding population change and hence successful management (Klein and White 1978). Until the late 1970's, few data were available regarding natural mortality rates. Skoog (1968) and Kelsall (1968) suggested annual natural mortality rates of 5-6% for caribou older than yearlings when relatively few wolves and grizzly bears (*Ursus arctos*) were present. Bergerud (1971) found that male Newfoundland caribou had a higher mortality rate (9%) than females (4%). In each of these studies the authors had spent many years in the field with the respective caribou herds, but much of the basis for their mortality estimates was "professional judgment."

Bergerud (1971, 1978, 1980, 1983) has repeatedly emphasized that ascertaining mortality rates is crucial to management and is requisite to understanding caribou population dynamics. Bergerud (1980) pointed out that conventional life table analysis (Banfield 1955, Bos 1973, Miller 1974) has limited usefulness for caribou populations because caribou populations normally have an unstable age structure, resulting from natural variation in calf survival.

Bergerud (1980) suggested using census, recruitment, and hunting parameters to determine the natural mortality rate of caribou populations.

Martell and Russell (1983) concluded that Bergerud's alternative is limited in usefulness because it depends on accurate estimates of caribou numbers, recruitment, and harvest, which are difficult to obtain. Martell and Russell (1983) believed that a new approach was needed to produce accurate estimates of mortality rates and suggested following radio-collared calves to breeding age. This technique would resolve the inconsistencies in estimates of early mortality rates, and cohort analysis may produce a better estimate of adult mortality rates by avoiding the problem of an unstable age structure. Whitten et al. (1984) discussed the difficulties of using radio-collared calves to obtain calf survival data that are representative of the herd. For example, it is difficult to overcome biases contributed by stillbirths and early neonatal mortality. The selection of calves for collaring may contribute bias also.

We agree with Martell and Russell (1983) that the use of radio collars to facilitate cohort analysis can aid in avoiding the problem of an unstable age structure. However, when one considers there may be at least 10-12 male cohorts and 15 or more female cohorts, it becomes obvious that large samples of radio-collared individuals are required. For these and other reasons, it is difficult to obtain adequate mortality data from radio-collared caribou to permit cohort analysis. Nevertheless, there appeared to be merit in monitoring radio-collared caribou to estimate adult mortality rates. By 1979, technology and miniaturization of reliable radio-transmitter packages had improved greatly. It appeared feasible to determine the natural mortality rate of a cohort of radio-collared individuals over a period of years without the bias of having significant numbers of marked individuals whose fate was unknown (White 1983).

Although the primary emphasis of this study was on the quantitative aspects of mortality (i.e., mortality rates and their influence on population biology), we also recognized the importance of documenting the qualitative aspects of mortality as well. A major portion of evaluating the qualitative aspects of natural mortality was in the context of considering if mortality might be additive or compensatory. In that context, we ascertained the sex, age, and condition of caribou dying from natural causes, particularly wolf predation, and compared those data to the characteristics of hunter-killed animals and those collected for scientific purposes. Thirty-five years ago Adolf Murie (1944) wrote, "It is well known that wolves kill adult caribou but it is difficult to learn what proportion of the caribou killed are below standard in strength." Murie's observation was generally accurate when we initiated this study and answering the question he posed was 1 goal of this study.

OBJECTIVE

To monitor 50 or more radio-collared caribou to help quantify mortality factors, and to determine the age, sex, condition, and cause of death of adult caribou dying from natural causes (all factors other than human-induced mortality).

PROCEDURES

Quantifying Natural Mortality

We estimated adult mortality rates primarily from radio-collared caribou data using procedures described by Trent and Rongstad (1974) and Gasaway et al. (1983). We also estimated adult natural mortality using simple iterative mathematical modeling based on estimates of changes in herd size, recruitment, and harvest by humans (Bergerud 1978, Martell and Russell 1983). Calf mortality was estimated from serial herd composition counts and productivity (e.g., distended udder counts) surveys conducted during 2 or more of the following times: calving, postcalving migration, fall, and April.

Estimating Natural Mortality Rates With Radiotelemetry:

Caribou were captured and radio-collared using 3 methods: (1) capture from riverboat as caribou were swimming the Kobuk River during fall migration (Davis and Valkenburg 1979), (2) chemical immobilization (Valkenburg et al. 1983a, Davis and Valkenburg 1984), and (3) a hand-held net gun (Valkenburg et al. 1983a). We were unsuccessful at driving caribou into tangle nets (Miller et al. 1971, Miller 1982) due to shallow snow and lack of cover.

From all caribou captured (Table 1), except those caught by riverboat, we obtained standard body measurements (Alaska Department of Fish and Game (ADF&G), unpubl. data), a tooth for aging (Tables 2 and 3), and a blood sample for chemical analysis and determining the disease exposure profile (ADF&G, unpubl. data).

Radio collars were constructed of triple-layered, rubberized (butyl) machine belting to which a hermetically sealed metal box containing the transmitter and batteries was attached. A highly visible, yellow, vinyl-covered canvas collar (15.2 cm wide and 71 cm long for females, or 86 cm long for males, with 10 cm high black numerals) was pop-riveted to each radio collar. The entire unit weighed less than 850 g. All radios contained movement-sensitive mortality switches (Telonics Inc., Mesa, Ariz.). Normal transmitter pulse rate was approximately 60 beats/min. When transmitter movement ceased for approximately 4 hours, the pulse rate doubled or tripled.

Three types of aircraft were used for radio-tracking: Cessna 185, Bellanca Scout, and Piper Super Cub. Each plane was equipped with paired 2-, 3-, or 4-element antennas and a scanning receiver (Telonics Inc., Mesa, Ariz.). Range of signal reception varied from 16 km to 240 km and seemed to depend on aircraft type, antenna type, terrain, elevation of the tracking aircraft, and perhaps weather/atmospheric conditions. The Bellanca Scout was our preferred radio-tracking aircraft because of its relative speed, maneuverability, rate of climb, comfort, and short takeoff and landing performance.

Estimating Natural Mortality Rates Through Modeling:

The arithmetic model used to estimate natural mortality rates required annual estimates of the number of caribou harvested, the caribou recruitment rate, and the population size. Harvest estimates were subjective assessments made by ADF&G Area Biologists. Their estimates were extrapolated, in part, from permit and harvest report returns. Recruitment was estimated from March or April counts of short yearlings (10-11 months old). Population size of the WACH was estimated using an aerial photo-direct count-extrapolation (APDCE) technique (Hemming and Glenn 1968) in 1976 and 1977. A modified APDCE technique (Davis et al. 1979) was used in 1978, 1980, and 1982. A count of females on the calving area was the basis for the 1979 population estimate. Estimates for 1981, 1983, and 1984 were merely projected estimates because no census was conducted.

Qualitative Assessment of Natural Mortality

Qualitative data about natural mortality (other than human-induced mortality) of the WACH were obtained from monitoring the cohort of radio-collared individuals and from the herd at large.

We flew periodic reconnaissance flights near known concentrations of caribou to locate and collect specimens from dead caribou. Contacts with pilots, guides, and local residents helped locate carcasses. Surveys for species such as wolves, caribou, and moose (*Alces alces*), as well as radio-tracking surveys for the WACH conducted for other research objectives, provided additional means of locating carcasses. Aerial surveys were often multi-purpose, such as simultaneously radio-tracking caribou, searching for wolves and caribou carcasses, and conducting composition counts. Aircraft used included helicopters, Piper Super Cubs, Cessna 185's, and a Bellanca Scout. We flew about 1,020 hours on this project from October 1979 through October 1983, flying roughly 250 hours in each of the 4 years.

Specimen Collection and Handling:

Specimens were collected from carcasses whenever possible. Field necropsy was conducted on all carcasses not brought into the lab for examination. ADF&G lab personnel and research veterinarians at the University of Alaska were available to examine specimens. Relative body condition was evaluated via standard fat reserve measurements (Dauphiné 1976), including quantitative bone marrow fat determinations (Neiland 1970).

We collected femurs and 1 or more long leg bones or a mandible from caribou of both sexes and from calf, yearling, and adult age classes. A few samples from earlier dates were included in our analysis (ADF&G, unpubl. data).

All specimen collections were opportunistic and were made while working on projects with varied principal objectives. Many of the bones were collected from dead caribou, located primarily by aerial search in winter. Temperatures were normally colder than 0 C in the study area when bones were collected.

Marrow Fat Analysis:

We analyzed only intact bones with no cracks. All bones were frozen or were allowed to freeze when they were collected and stored intact in sealed plastic bags in a freezer until analyzed, usually a few weeks later. These steps minimized the problems associated with dehydration prior to fat analysis.

Samples of marrow for analysis were taken from the central portion of the femur and usually amounted to 10-30 g fresh weight. The other long bones were treated similarly and consequently the fresh weight was considerably less from some bones because of smaller marrow cavities.

We used a band saw to cut the midsection from long bones and then placed the bone on a concrete floor and struck it with a hammer to fracture the bone without damage to the marrow. Cracked bones were carefully separated from the marrow. For mandibles, we used the same procedure, but most were not precut before splitting. We scraped off bone dust and fragments from the frozen marrow samples and were careful to keep all bones well frozen while extracting the marrow. Otherwise, in marrows with little fat, fluid could be lost from the marrow cavity prior to weighing.

Once the marrow samples were extracted from the bone, the procedure used was identical to that described by Neiland (1970). The percentage of bone marrow fat was determined by immediately weighing the extracted marrow and then oven drying it at 55 C to 65 C until no water remained, as determined by repeated weighing until weight of the sample stabilized. Drying time averaged 3 to 6 days. Percent fat was calculated as dry weight divided by fresh weight times 100. The small amount of residue that Neiland (1970) reported was ignored similarly to Franzmann and Arneson (1976) and Snider (1980).

Mean femur marrow fat percentages within sex and age categories were compared between wolf-killed caribou and those killed by: hunters, accidents/scientific collection, malnutrition, grizzly bears, and lynx (*Lynx canadensis*). The paired Student *t* test at probability level of $\alpha = 0.05$ was used to test for significant differences.

Sex and Age Determination:

Sex of caribou was determined by genitalia or other diagnostic anatomical features, if present, when genitals were lacking. Age was determined by tooth eruption and wear for calves and yearlings and by cementum annuli for older animals (Miller 1974).

Determining Cause of Death:

We were frequently faced with the problem of trying to determine the cause of death of caribou when only skeletal parts remained. Our procedure for judging the cause of death of caribou was similar to that in the literature summarized by Haynes (1982). Predator species use or dispose of their prey in a methodical, orderly manner (Schaller 1967, 1972; Mech 1970; Kruuk 1972, 1975; Carbyn 1974; Haber 1977; Peterson 1977), so conscientious examination of kill sites, carcasses, and bones can often allow determination of the predator involved and whether the incident was predation or scavenging. The remains of a scavenged carcass can usually be distinguished from those of a predator kill (Mech 1970, Haber 1977, Peterson 1977, Allen 1979).

It is common in predator/prey investigations to examine the type and location of wound, occurrence of hemorrhage, and tissue trauma induced before death to differentiate predation (wound inflicted on living animal) from scavenging (i.e., postmortem tissue damage). Tracks, hair, and droppings of predators; wounds in soft tissue; and behavioral clues, such as bears covering carcasses, also may indicate the predator/scavenger species (Buskirk and Gipson 1978). Some subjective judgment is always involved in diagnosing the cause of unwitnessed deaths of prey, but investigation of carcasses with known cause of death is valuable help in recognizing common patterns among predator species.

Carcasses are commonly utilized by more than 1 predator/scavenger species. Fortunately, it is often possible to distinguish the end effects of feeding by various species, even without the presence of tracks, by examination of gnaw damage to bone elements (Haynes 1982).

Influence of Weather and Disease:

We calculated a winter severity index (WSI) by multiplying the number of heating degree days from 1 October through 30 April by the inches of snow on the ground at the end of April for the years 1960 through 1983 (U.S. Dep. Commerce, Environmental Science Services Administration). We then compared the WSI and various measures of calf survival using linear regression. There is currently no consensus among caribou researchers regarding the most useful WSI. Individuals argue the relative roles of temperature, snow depth, and snow characteristics. Our WSI was consistent with a WSI based on accumulated snow depth only, so we saw no reason not to combine temperature and snow depth to incorporate any role temperature might contribute.

A summer weather index (SWI) calculated by multiplying the number of heating degree days by average windspeed (mph) for July and August, was compared to the reported incidence of necrobacillosis to see if warm, still weather influenced the outbreak of the disease. Validity of the winter and summer indices are questionable because weather reporting points were scarce and were usually not located near caribou.

We reviewed the literature to determine trends in the incidence of disease in the WACH and to compare the past presence of disease to our observations. Reported observations of extreme weather conditions and diseased caribou were also investigated, especially reports by local residents of icing conditions on the arctic coastal plain and southwestern wintering areas.

Predator Abundance:

As an index to relative abundance, we recorded sightings of predators and evidence of their presence, examined sealing records for harvested wolves, and recorded the observations of residents of areas in which caribou wintered.

RESULTS AND DISCUSSION

Quantifying Natural Mortality

Estimating Natural Mortality Rates With Radiotelemetry:

Females: Sixty-one female caribou were handled and 46 were successfully radio-collared and survived long enough to provide data on natural mortality rates. Nine caribou died during the collaring procedure (Valkenburg et al. 1983a), 4 died within a few days after collaring, 1 lost its collar, and 1 was never relocated. One additional caribou (included in the 46) was monitored for several months and then its signal apparently failed. We excluded this caribou when calculating natural mortality rates. During 1983, we were unable to hear radio signals from some caribou that we had monitored for several years. Any radio collar not heard after 36 months of operation was assumed to have expired batteries. Some collars operated longer than 48 months, and 1 lasted at least 60 months.

The fate of all but 2 radio-collared female caribou was known prior to the period when battery exhaustion was presumed to have occurred. Therefore, the potential bias in calculating mortality rates when the fate of some animals is unknown was small (Trent and Rongstad 1974, White 1983).

Causes of mortality were not always ascertained. If major hemorrhaging was evident on a carcass, we assumed that the caribou had been killed traumatically. Hunters usually left some tell-tale signs on the carcass (e.g., knife cuts or bullet holes) or in the vicinity of kills (snow machine tracks). In most cases, we felt confident in distinguishing between natural mortalities and hunter-caused mortalities, but less confident in determining the specific source of the natural mortality (Tables 2 and 3). Any incorrect determination of the cause of death would bias our calculated mortality rates.

Total mortality (includes natural and hunting mortality) rates for female WACH caribou, based on the method of Trent and Rongstad (1974), ranged from 0 to 24% for each 6-month period from summer 1979 through winter 1983-84 (Table 4). The mean rate during this period was 10%. Chi-square frequency analysis indicated that summer total mortality averaged 1.5% and was not significantly different between 1979-81 and 1982-83

(χ^2 = 3.09, 0.05 < P < 0.10, df = 1). Winter total mortality averaged 8.7% and increased significantly in 1982-84 from 1979-81 (χ^2 = 3.90, 0.02 < P < 0.05, df = 1).

The increased total mortality rate in the later winter period resulted from both increased hunting mortality and increased natural mortality. There was no significant difference (P < 0.05) between either winter or summer rates between periods for natural mortality alone or hunting mortality alone.

In summary, the mean total annual mortality rate for females was 12% (8% natural, 4% man-caused) using Gasaway et al.'s (1983) method and 10% (7% natural, 3% man-caused) using the Trent and Rongstad (1974) method.

Males: Twenty-eight of 31 males handled were successfully radio-collared, 2 died, and 1 was collared with a visual collar only. However, signals from 3 of the radio-collared males were never heard after collaring, and 1 was heard for only a few months; all 4 were excluded in calculating mortality rates. Eight of the remaining 24 radio-collared males shed their collars during the 1st winter after being collared and provided little data for calculation of mortality rates. One radio lasted at least 54 months, but those that were not heard after 36 months (expected battery life) were assumed to have expired batteries.

As with females, we calculated winter and summer mortality rates for males from summer 1979 through winter 1983-84 using Trent and Rongstad's (1974) method (Table 5). There was no significant difference between total mortality rates for summers 1979-81 (9.6%) vs. 1982-83 (8.0%) (χ^2 = 0.02, 0.8 < P < 0.9, df = 1). There was no significant difference between total mortality rates for winters 1979-80 and 1980-81 (8.9%) vs. 1981-82 through 1983-84 (20.8%) (χ^2 = 2.11, 0.1 < P < 0.2, df = 1,). The mean annual mortality rate for males was 29% (16% natural, 13% man-caused) using Gasaway et al.'s (1983) method and 26% (13% natural, 13% man-caused) using the Trent and Rongstad (1974) method.

Estimating Natural Mortality Rates Through Modeling:

We used an arithmetic model (Table 6) based on total population size (older than calves), recruitment, and harvest to calculate annual natural mortality rates from 1976 through 1982. There are obvious limitations, which have been discussed previously (Bergerud 1978, Martell and Russell 1983), inherent in our modeling procedure.

Adult natural mortality rates, calculated from the model, appeared to increase from 0.6% in 1978 to 17.6% in 1982

(Table 6). In addition, the population growth curve for the WACH, from 1976 through 1982, implies an increasing trend in total mortality (Fig. 1). A linear, rather than exponential, increase in a population with relatively stable recruitment (Table 7) is most easily explained by an increasing mortality rate and/or an increasing dispersal rate. Cursory analysis of radio-collared caribou movement data suggests no increasing dispersal rate from the WACH.

Increasing natural mortality, harvest, or both, could cause increased total mortality. Although the estimated number of caribou harvested annually from 1977 through 1982 apparently increased, there was no apparent change in harvest rate as a percentage of the population (Table 6). Available harvest data amount to little more than educated guesses. Although harvest reporting has been legally required since 1976 for the WACH, reported harvest in most years has accounted for no more than about 30% of the subjectively estimated total harvest.

Mortality rates, calculated from the model (Table 6), are very sensitive to changes in recruitment and harvest, and we have discussed the poor quality of our harvest data. If recruitment was not constant from 1976 through 1982 as implied until now, a decreasing recruitment rate could also explain the linear population growth. Recruitment is very difficult to accurately measure, especially in large migratory herds such as the WACH. Caribou are frequently socially segregated by April when recruitment surveys are conducted, with the bulls and many short-yearlings trailing cows in migration.

Until now, this discussion has implied that a linear model is the best fit model of census data. Considering the precision, probable accuracy, and frequency of our population estimates, it is possible to fit a series of 2 or more exponential curves to the data points which may more credibly reflect the herd's population dynamics than a single linear model. The linear model presented in Fig. 1 predicts a 1985 population of 224,000 vs. a predicted population of 246,000 by an $\underline{r} = 0.11$ model for post-1980 growth.

Sources of Natural Mortality:

During this study, predation-implicated deaths were the greatest proximate cause of natural mortality of radio-collared adult caribou. Ten adult female and 6 adult male radio-collared caribou died of natural causes. Of the 16 natural mortalities, predation was implicated in 10 cases, unknown natural mortality was implicated in 3 cases (unable to rule out predation), and nonpredation natural mortality accounted for 3 cases (Tables 2 and 3). The 10 mortalities attributable to predation equaled the 10 mortalities attributable to hunting.

For the 10 female mortalities, specific causes of death were: breech delivery in parturition, 1; malnutrition (hoofrot probably a factor), 1; unknown natural causes (meaning no immediate sign of human involvement), 2; unknown predators, 2; wolf kill, 1; wolf or wolverine (*Gulo gulo*) kill, 1; and wolves or grizzly bears, 2.

Causes of death for the 6 male caribou were: malnutrition, 1; natural causes, 1; grizzly bear kill, 1; and wolf kill, 3.

Qualitative Assessment of Natural Mortality

Qualitative aspects of natural mortality in the WACH were examined by pooling data into categories determined by the apparent cause of death. Condition based on marrow fat values, sex, and age of the caribou in each category were compared (Table 8). In the case of predation, the degree of carcass consumption was recorded.

Condition of Wolf-killed Caribou:

Most caribou killed by predators had less femur fat than caribou that were harvested by hunters but not less than caribou that died from other causes (Table 8). There was no significant difference in the percentage of femur fat of caribou killed by wolves vs. caribou killed by grizzly bears and wolverines. The mean percentages of femur marrow fat from adult females, adult males, and adults of unknown sex were significantly lower than from caribou killed by hunters but not from caribou killed by accidents or for scientific collection. (Caribou collected for science were often visibly debilitated which explains in part why they were in poorer condition than hunter-killed caribou.) The mean percentage of marrow fat in yearling femurs did not differ significantly regardless of cause of death. Calves killed by hunters and accidents and for scientific collection had significantly more femur fat than calves killed by wolves. Adult and calf caribou that died from malnutrition had the lowest mean femur fat percentage of any category and the percentage of fat was significantly lower than in the predator kills.

Condition of Terminally Malnourished Caribou:

The term "terminally malnourished" is used in lieu of "winter-killed" because several caribou in this category died during summer, and "starved" seemed less appropriate because most caribou in this category died with food in their rumens and food was generally available at the death site (particularly in summer).

The mean percentage of femur fat for adults and calves (of both sexes) that died from malnutrition was <10%, similar to what Franzmann and Arneson (1976) found in Alaskan moose that died from malnutrition. The lowest individual percentage of femur marrow fat we recorded from caribou that died of malnutrition was 1% in adults and 4% in calves.

Age and Sex of Caribou Killed by Wolves:

Only 6 of 53 (11%) wolf-killed caribou were calves, whereas calves composed 20-27% of the population during the late 1970's and early 1980's. Although certain biases could contribute to locating fewer wolf-killed calves than older animals (e.g., calves are smaller and proportionately more is eaten so it may be harder to see them during aerial searches), the data certainly suggest that calves and yearlings were not selected by wolves during winter. Other studies reviewed by Davis et al. (1978) indicated that wolves may or may not select calves, depending on the circumstances. In general, where caribou are easier to kill (i.e., deep snow), wolves tend not to be selective (Burkholder 1959). If, on the other hand, wolves have to work harder for their prey, they tend to kill more vulnerable animals (Skoog 1968, Davis and Valkenburg 1979).

Our data show that wolves killed significantly more adult males and fewer adult females than their proportions in the population ($\chi = 4.37$, $0.02 < P < 0.05$, df = 1). Of 35 wolf-killed adult caribou whose sex was known, 16 were females and 19 were males. In the population at large, adult females composed about 50% and adult males about 25% (Table 7).

Infirmities and Abnormalities in Caribou Killed by Wolves:

Excluding the evidence of lower mean percentage of marrow fat in wolf-killed caribou than in human-killed caribou, we found no evidence of predisposing factors (such as muscle or bone abnormalities) for any of the prime age caribou preyed upon by wolves in this study. It is apparent to critical investigators that prime age animals without greatly depleted marrow fat can otherwise still be highly vulnerable to predators. Any acutely debilitating factor, such as an accident, can render the prey animal highly vulnerable to predation before marrow fat would be depleted. Similarly, chronic locomotive weakening, such as arthritis, could make prey animals more vulnerable to predators without making them nutritionally disadvantaged to a point of lower marrow fat values, as Peterson (1977) argued about moose on Isle Royale. Given these considerations, we critically examined all prey remains for signs of bone deformities (Doerr and Dieterich 1979, Peterson et al. 1984) and found none.

Weather as a Mortality Factor:

Severe weather in late winter, especially icing conditions, has been reported to cause drastic reductions of caribou populations on the arctic islands (Parker et al. 1975), and blizzards during calving were thought by Kelsall (1968) to be an important mortality factor of young calves in some years. Skoog (1968:581) reviewed the historical literature in Alaska and reported that icing conditions had at times caused die-offs of caribou and reindeer in coastal areas such as the Pribilof Islands, Nunivak Island, St. Matthew Island, Unimak Island, and the Alaska Peninsula. He concluded that weather conditions other than icing were unlikely to influence mainland caribou populations.

We analyzed weather records for Barrow, Bettles, Kotzebue, Kobuk, and Umiat between 1960 and 1983 (Table 9, Fig. 2) and found no relationship between our WSI and calf survival to 1 month, 4 months, 9 months, or 16 months (Table 10). We also analyzed weather data from Barrow for June (Table 11) and found poor correlation between our SWI and calves/100 cows in July (r^2 = 0.12, n = 9). These analyses are admittedly crude because the weather at Barrow may not be generally representative of weather on the calving area, local weather conditions can vary considerably over an area as large as the range of the WACH (Appendix B), and our calculated WSI does not reflect icing conditions. However, calf production and survival in the WACH have been consistently high with little variation (Table 7), and in years when calf numbers were comparatively low, the decreases could not be attributed to winter severity.

Nevertheless, it is tempting to speculate that the severe winters of 1971-72, 1972-73, and 1975-76 (Fig. 2) contributed to the precipitous decline of the WACH during the early 1970's. Doerr (1979) believed that weather-related factors contributed to 2-year-old (cementum age) caribou being underrepresented in a sample of jaws collected from the WACH during winter 1975-76 compared with the abundance of 2 year olds in a sample of jaws collected in 1960-61. The 2 year olds collected in 1975-76 would have been born in 1973 following the relatively severe winter of 1972-73. However, winter 1971-72 was even more severe than 1972-73, and there is no evidence of a weak 1972 cohort.

It could also be argued that the severe weather in the 1960's and early 1970's (Fig. 2) coupled with a continually large hunter kill initiated a decline in the WACH in the 1960's which continued until the mid-1970's. Others argue that the primary decline was between 1970 and 1976.

Severe weather during the decline of the WACH may have contributed indirectly to higher mortality through increased predation (Skoog 1968:581) and a higher incidence of morbidity due to disease and parasitism (Neiland 1972), although substantiating data are lacking. In 1977 Shepherd (pers. commun.) observed wolves killing at least 50 out of a few hundred caribou wintering in deep snow at Norutak Lake, and Davis et al. (1979) documented surplus killing by wolves in this same area. Further, Davis and Valkenburg (1979) documented the deaths of 6 caribou with high parasite (Oedemagena and Cephenemyia) infestations in 1978 on the arctic coastal plain. The deaths apparently were from a combination of the heavy parasite load and the normally harsh weather encountered there (albeit winter 1977-78 was comparatively mild for the area). During that winter (1977-78) there was a marked difference in calf/cow ratios among caribou wintering on the arctic coastal plain (19 calves/100 cows) compared to those wintering south of the Brooks Range (35 calves/100 cows). Unfortunately, a fall calf/100 cow ratio was not available for caribou wintering on the arctic coastal plain.

It is difficult to determine the historic influence of deep, lingering snow cover or icing conditions on the WACH. Lent (1966) mentioned that the northward migration of WACH caribou was delayed in 1961-62 and many females failed to reach the Utukok calving area. Skoog (1968) reported similar conditions in spring 1964 resulting in many caribou in poor condition. N. Walker (pers. commun.) and R. Pegau (1973) reported a delayed migration due to deep snow south of the Noatak River in spring 1972 with many caribou calving south of the Utukok calving area.

Local residents of the North Slope reported icing conditions almost every year between 1975 and 1983, as did residents of GMU 23, and they were often concerned for the welfare of the caribou. We flew aerial surveys of the arctic coastal plain several times every winter between 1976 and 1983 and failed to find evidence of significant mortality except, ironically, in 1977-78 which was a comparatively mild winter with little icing. In November 1979 and January 1983, following rain and warm weather on the arctic coast, caribou were seen moving inland toward the Brooks Range. The 1983 movement was confirmed by relocations of radio-collared caribou, and we thought it possible that these movements were in response to the unfavorable icing conditions along the coast. Some icing conditions seem to occur almost every year on the arctic coastal plain but they are locally variable and seldom widespread. Even within these areas caribou can usually find places to break through the ice layer, and the great mobility of the caribou also makes it possible for them to avoid severe conditions.

A relationship between the incidence of necrobacillosis (hoofrot) and particularly warm weather in July and August has been suggested by Neiland (1972). Since 1960, 3 epizootics of necrobacillosis have been reported in the WACH; others may have gone unnoticed. We examined the July and August weather records for Barrow (Table 11) to see if there was a connection between warm weather and these epizootics. The epizootic of 1962 reported by Neiland (1972) occurred during a particularly warm July and August at Barrow, and the outbreak in 1977 was accompanied by a warm August, but the 1980 outbreak occurred during a cool July and August at Barrow. Here again, however, weather at Barrow is not necessarily representative of weather farther inland where the caribou are likely to be. Valkenburg lived at Driftwood during summers 1979 and 1980 and spent considerable time there in 1981. In the Driftwood area, 1980 was a relatively warm summer compared to either 1979 or 1981, so there may be some relationship between warm weather and necrobacillosis.

In conclusion, there is little evidence that weather has directly influenced the population dynamics of the WACH since 1960, although the precipitous decline of the herd in the early 1970's was preceded by and occurred during a period of what might be considered unfavorable weather conditions. Winters 1971-72, 1972-73, and 1975-76 were cold with relatively deep snow, and summers 1972, 1973, and 1974 were warm. Since the population recovery began in 1977, winters (except 1982-83) have been mild.

Disease as a Mortality Factor:

Disease can be an important mortality factor among *Rangifer* populations, especially in domestic reindeer (Skoog 1968), but it apparently plays a relatively minor role in the population dynamics of Alaskan caribou (Neiland 1972, 1978; Neiland et al. 1968; Skoog 1968). Necrobacillosis, and perhaps brucellosis, have been responsible for some mortality of Western Arctic caribou since they were first reported in 1960 (Neiland 1972). In addition, a syndrome of unknown origin leading to abnormally long retention of the placenta following parturition apparently causes higher mortality of affected calves and perhaps their mothers as well (Neiland 1978). We discuss these diseases separately although there may be some, as yet unknown, relationship between them.

Studies of the prevalence of various disease-causing organisms in Alaskan wildlife are continuing. Since 1979, caribou serum samples have been collected and tested for a multitude of microbial pathogens (Zarnke 1983), and there is no indication so far that disease is a significant factor in the dynamics of Alaska caribou populations.

Brucellosis: Brucellosis is a bacterial disease (Brucella suis type 4) which was first found to exist in the WACH in 1961 (Neiland et al. 1968, Neiland 1972). Neiland (1972) reported that the disease was endemic to caribou and reindeer thoughout their circumpolar distribution. The disease is apparently generally chronic and in this form it most often causes swollen joints and sterility in males (Neiland 1978). In its acute form it causes abortion, and it sometimes causes placental retention (Neiland 1978). Although the prevalence of serologic reactors among WACH caribou ranged from 5% to 30% of samples taken between 1961 and 1981 (Table 12), there was no apparent trend in the occurrence of Brucellosis reactors (Table 13). Neiland (1969) suspected that Brucella was involved in the retained placenta syndrome, but later investigations involving collecting and sampling serum of affected caribou failed to demonstrate a significant relationship (Neiland 1972, 1978).

Necrobacillosis (hoofrot): Unlike brucellosis, necrobacillosis, or hoofrot, has been directly responsible for the deaths of many caribou in the WACH. The disease is caused by a bacterium (Fusobacterium necrophorum) which is thought to occur naturally in soil and in the digestive tract of the caribou (Neiland 1972). In Eurasia, outbreaks of the disease seem to occur with greater intensity during warm, dry summers, perhaps due to increased insect harassment (Neiland 1972), although we found no obvious connection between warm summers (Jul and Aug) and reported outbreaks of the disease in this study (Table 11). Recognizable outbreaks were noticed in the WACH in 1962, 1977, and 1980, but there were no accurate estimates of the number of caribou that succumbed.

The 1962 outbreak was reported by seismic crews in the Umiat area in August and about 10 caribou were found dead (Neiland 1963). Neiland (1963) flew to the area and collected and necropsied a sick caribou from which the hoofrot bacterium was isolated. Skoog (1963) also sampled 117 caribou in October 1962 and hoofrot bacteria were isolated from one of these. However, Skoog (1968) reported 3 infected caribou out of 337 checked between 1957 and 1964 in the WACH, so the occurrence was not limited to 1962. The 1977 and 1980 outbreaks were reported by guides and D. Johnson, ADF&G Area Biologist, Kotzebue. In total, about 30 dead caribou were reported during those years. We located 5 of these during a 4-hour survey in the upper Utukok and Kugurok drainages in late August 1980. A similar survey in 1977 in the upper Alatna and Killik Rivers in early September failed to reveal any carcasses despite reports of at least 5 dead caribou in the area in August. The only other significant report of an epizootic in Alaska occurred on the Alaska Peninsula in 1968 (Neiland

1972). Various people reported lame and dying animals and surveys revealed about 1% limping caribou. One limping bull was collected and the hoofrot bacterium was isolated.

It is likely that deaths from hoofrot occur regularly in caribou in Alaska, at least in the WACH, but Neiland (1972) estimated that even in severe outbreaks less than 1% of the caribou are affected, and some of these recover.

In 1981, a year in which no incidental reports of the disease were received, we found 1 radio-collared female dead on the Colville River with a healthy calf standing nearby. Although hoofrot was not positively diagnosed, the dead caribou's emaciated condition and lesions between the digits implicated the disease.

Placental Retention: Abnormal placental retention in some WACH caribou was noticed during the 1st intensive study of caribou on the calving grounds from 1959-62 (Lent 1964). Subsequently, Neiland (1978) began studies of the condition in 1963 in conjunction with other ongoing work on diseases of Alaskan wildlife. Prevalence of the condition was apparently relatively high in 1963 and 1965 but apparently lower from 1966 through 1982 (Tables 14 and 15). Even if real, the decline in the prevalence of a retained placenta syndrome occurred well before the decline of the population. It is therefore unlikely that the 2 events were related.

Initially, retention of the placenta was thought to be associated with brucellosis (Skoog 1963, Lent 1964, Neiland et al. 1968). However, collection and sampling of 52 affected caribou in 1969, 1970, 1971, and 1977 failed to provide a direct link because only 3 had serologic reactions to brucellosis (Neiland 1978, Zarnke and Neiland 1979).

Neiland (1978) reported that placental retention may cause higher than normal mortality of calves of affected mothers and some mortality of the mothers as well. Retention of the placenta for several days is not always fatal, as evidenced by 1 radio-collared female we were able to monitor. This female (accession number 102,276) calved on or before 7 June 1982, and on 9 June the placenta had still not been expelled although both she and her calf appeared healthy. She was relocated again on 14 June and by then the placenta had been expelled. Mother and calf were both healthy when rechecked in early July.

Another condition, referred to as hemorrhagic perineum (bloody posterior), has also been noted during surveys for retained placentas. Neiland (1972) and Lent (1964) both initially related this condition to brucellosis and sometimes lumped afflicted animals with those having retained placentas during surveys for the latter condition (Table 14). No mention was made of this condition by Neiland (1978) when he discussed placental retention. One observation of a radio-collared caribou with hemorrhagic perineum is of interest. In April 1980, we collared a female with very worn teeth and a minimum of 8 cementum lines on her canine tooth. She calved successfully in 1980 and 1981, although in the latter year she lost her calf by August. In 1983 she appeared on the calving ground, but when first seen on 4 June, she had no antlers, a very small udder, and a bloody posterior; no calf was present. It does not appear unusual for some caribou to have trouble birthing, and one might expect some hemorrhaging that could result from any number of complications. Notably, 1 other radio-collared caribou died in 1981, as a result of an abnormally-positioned calf. The calf was positioned front-feet-first, but its neck was turned, making delivery impossible.

Neiland (1978) suggested that poor nutrition, or a combination of poor nutrition and disease, could also be involved in the retained placenta condition. As yet, however, the causative agent remains an enigma.

Predator Abundance:

Although we made no systematic effort to document the abundance of predators during the course of our study, we did record incidental observations of predators, especially wolves, grizzly bears, and golden eagles (*Aquila chrysaetos*). We also gathered information on the reported number of wolves taken within the range of the WACH (Table 16). In addition, Reynolds (1979, in press) documented grizzly bear densities, and Stephenson (1979) studied the movements and abundance of wolves in the western Brooks Range. Wolf surveys were conducted in some portions of the WACH range irregularly (ADF&G, unpubl. data and S&I Reports), depending on snow conditions and available personnel, between 1976 and the present. The following discussion is a synthesis of these studies and our observations.

Wolves: Wolf densities throughout the entire 362,600 km^2 range of the WACH have been and continue to be extremely variable. There is evidence (Stephenson 1979, James 1983a) that some wolves in northwest Alaska move seasonally in response to movements of large prey, especially where stable prey bases such as sheep and moose are rare or absent. From the mid-1970's to the present, wolves have been uncommon in large areas north of the Brooks Range, especially on the arctic coastal plain. For this reason, landing and shooting of wolves was stopped by regulation in Unit 26 beginning with winter 1982-83. This method of aircraft hunting usually accounted for 50% or more of the reported harvest, although there has undoubtedly been a substantial unreported harvest by local residents. James (1983b) estimated the wolf density in the northern three-quarters of Subunit 26A at 1 wolf/1,691-3,947 km^2, and in the remainder (northern Brooks Range) at 1 wolf/140-295 km^2. The abundance of wolves in Subunit 26A has probably been most influenced by their vulnerability to hunting (aircraft and snowmachines) and the distribution of caribou. Caribou wintering in Subunit 26A have been relatively free from wolf predation, especially along the arctic coastal plain, and wolves are uncommon on the Utukok River calving area.

Wolves are more numerous in the central Brooks Range (GMU 24) where Shepherd and Quimby (1979) estimated densities at 1 wolf/148 km^2. Since then, the wolf population has probably remained stable. In GMU 24, wolves are generally not heavily trapped nor are they particularly vulnerable to hunting, although favorable snow conditions can result in an increased harvest (e.g., 1978-79). The mountainous portions of the northern part of GMU 24 are heavily used by caribou; up to one-third of the herd wintered in this area during 2 out of the 5 winters included in this study. Of the 3 winter ranges consistently used by the WACH (Valkenburg et al. 1983b), the central Brooks Range had the highest density of wolves, but it also received the least use by caribou.

Unlike the situation in GMU 24 and Subunit 26A, where wolf populations were probably stable during the late 1970's and early 1980's, we believe that the GMU 23 wolf population declined substantially after 1976-77. We base this on the relatively high number of incidental observations of wolves and wolf kills found during caribou surveys in spring 1977 and the paucity of similar observations from 1978 through 1983, in addition to major reductions in the annual harvests by proficient wolf hunters. In addition, Johnson (1978) reported estimated densities of wolves in GMU 23 of 1/176 km^2 and Quimby (1982), who surveyed mostly areas where caribou were wintering, reported estimated minimum densities of only 1/233 km^2. The decline of wolf populations in GMU 23 is further substantiated by the decline in reported harvest (Table 16) and by James (1984) who found only 1 pack during a 2-day search, in an effort to locate wolves for radio-collaring. He concluded, as do we, that the wolf population in GMU 23 has been stabilized at a low to moderate level by hunting. The decline of the wolf population on this major winter range (GMU 23) after 1977 was fortuitous because the decreased predation undoubtedly helped to reverse the decline of the WACH.

Grizzly Bears: Grizzly bears are generally common in the mountainous portions of the WACH range. In the only study of bear density and population dynamics in northwest Alaska, Reynolds (in press) reported a density of 1/41 km^2 in the Utukok drainage on the southern fringe of the WACH calving ground. Bears were observed to take caribou calves on several occasions during summer, but the overall influence of bear predation on caribou is not large. This conclusion is based on the mortality data from our radiotelemetry study and from serial calf/cow ratio surveys conducted on the calving ground and postcalving areas. Unlike wolves, bears apparently do not follow migrating caribou (Reynolds 1980), and they hibernate during winter, so their potential influence on caribou is reduced.

Other Predators: Golden eagles, lynx, and wolverines are also known to prey on caribou occasionally, but there is no evidence that they are significant sources of mortality to WACH caribou. We observed a wolverine unsuccessfully chasing a caribou calf on 1 occasion. We also found where a wolverine had killed a caribou that had previously been wounded by hunters, and we found 2 caribou carcasses where wolverines could have contributed to the kill. Relatively few golden eagle/caribou encounters were observed in the WACH, and their overall density is probably low compared to the Porcupine Herd calving area and other areas in the Alaska Range and Tanana Hills where we regularly observed golden eagles killing calves. We made only 1 observation where a lynx apparently killed a WACH caribou, but lynx have been observed to kill caribou in the Fortymile Herd (Table 8) (Stephenson, pers. commun.).

CONCLUSIONS

Currently, the best method of ascertaining a caribou population's natural mortality rate is to monitor a sample of radio-collared caribou containing the same sex and age structure as the study population. We used this method from 1979 through 1983 to ascertain mean annual mortality rates for the WACH. Our sample was probably biased and overestimated natural mortality rates for males because we avoided collaring young males to minimize collar retention problems. We determined mean annual mortality rates for males and females of 29% (16% natural, 13% man-caused) and 12% (8% natural, 4% man-caused), respectively, using Gasaway et al.'s (1983) formula for calculating mortality rates. Comparable mortality rates using the Trent and Rongstad method were 26% for males (13% natural, 13% man-caused) and 10% for females (7% natural, 3% man-caused). Bergerud (1971) also found higher mortality rates in males (9%) than females (4%) in Newfoundland where there were no wolves.

For modeling the WACH's population dynamics, the mean natural mortality rates we measured can be applied for the 1978-84 period when wolf abundance was generally low in most of the herd's range and moderate in local areas. It is imperative to redetermine natural mortality rates if wolves become abundant in the range of the WACH.

The natural mortality rates we determined during low wolf abundance suggest that past modeling (Davis et al. 1980) underestimated the role of predation during the 1970-76 decline of the WACH. Davis et al. (1980) had assumed a 7-9% natural mortality rate to generate a scenario for the 1970-76 population decline. This 7-9% natural mortality rate was assumed during a period of relatively high wolf abundance. By combining mean mortality rates for each sex and the mean population sex ratio for 1978-83 (Table 7), the mean annual natural mortality rate and the total mortality rate were 10% and 17%, respectively, for the adult portion of the WACH. This 10% mean for both sexes was found during low wolf abundance, so the 7-9% natural mortality rate assumed by Davis et al. (1980) underestimated pre-1977 natural mortality rates for the WACH.

The simple arithmetic model (Table 6) used in this report as an alternative technique for calculating mortality rates was inadequate for the purpose. Imprecision and inaccuracy in herd size estimates, recruitment, and harvest by humans all additively biased the calculated mortality rates.

Also, as was necessary for simplicity, the model generated mean herd mortality rates for both sexes combined. The limitations imposed by this constraint and implications to population dynamics should be stressed. For example, in our above discussion, we calculated a mean total mortality rate of 17% for the herd from an 11.0% rate for females and a 27.5% rate for males. The apparent rate of herd growth with these rates is depicted in Fig. 1. Herd growth would have been much slower if the calculated mean total mortality rate of 17% had occurred from a 17% rate for females and a 17% rate for males. Because of the biases and limitations discussed, further modeling of the WACH's population dynamics should utilize computer simulations. Such modeling will be of use to both elucidate the mechanics of observed population dynamics and to predict herd growth.

Although the linear model depicted in Fig. 1 is the best fit model of census data, other models may be equally credible in explaining the herd's population dynamics. Validity of the linear model requires increasing rates of natural mortality over time because our data show no declining recruitment rate or increasing dispersal rate. Our empirically derived mortality rate data only equivocally support an increasing trend in mortality. Progressive liberalizations in hunting regulations, including expanding bag limits from 1977-78 through 1984-85 and legalizing the take of females in 1981-82, provide a mechanism to explain a hypothetically increasing mortality rate. However, estimates of harvest rates inadequately support the hypothetically increasing harvest rate. Harvest data are sufficiently inaccurate to allow opposing interpretations; consequently, rather than harvest rate increasing annually, one could argue that legalized cow harvests after 1980 could account for 2 contrasting periods of harvest rates: a relatively constant rate from 1976 through 1980 and an increased rate post-1980. Given these possibilities and recognizing the relative imprecision of census results, alternate models equally credible to the linear model in Fig. 1 can be generated. The alternate models imply vastly different mechanics to explain population changes, and predictions for future herd growth are also different. For example, the linear model predicts a population of 224,000 in 1985 vs. 245,000 predicted by a hypothetical model assuming exponential growth of $\underline{r}$ = 0.11 after 1980.

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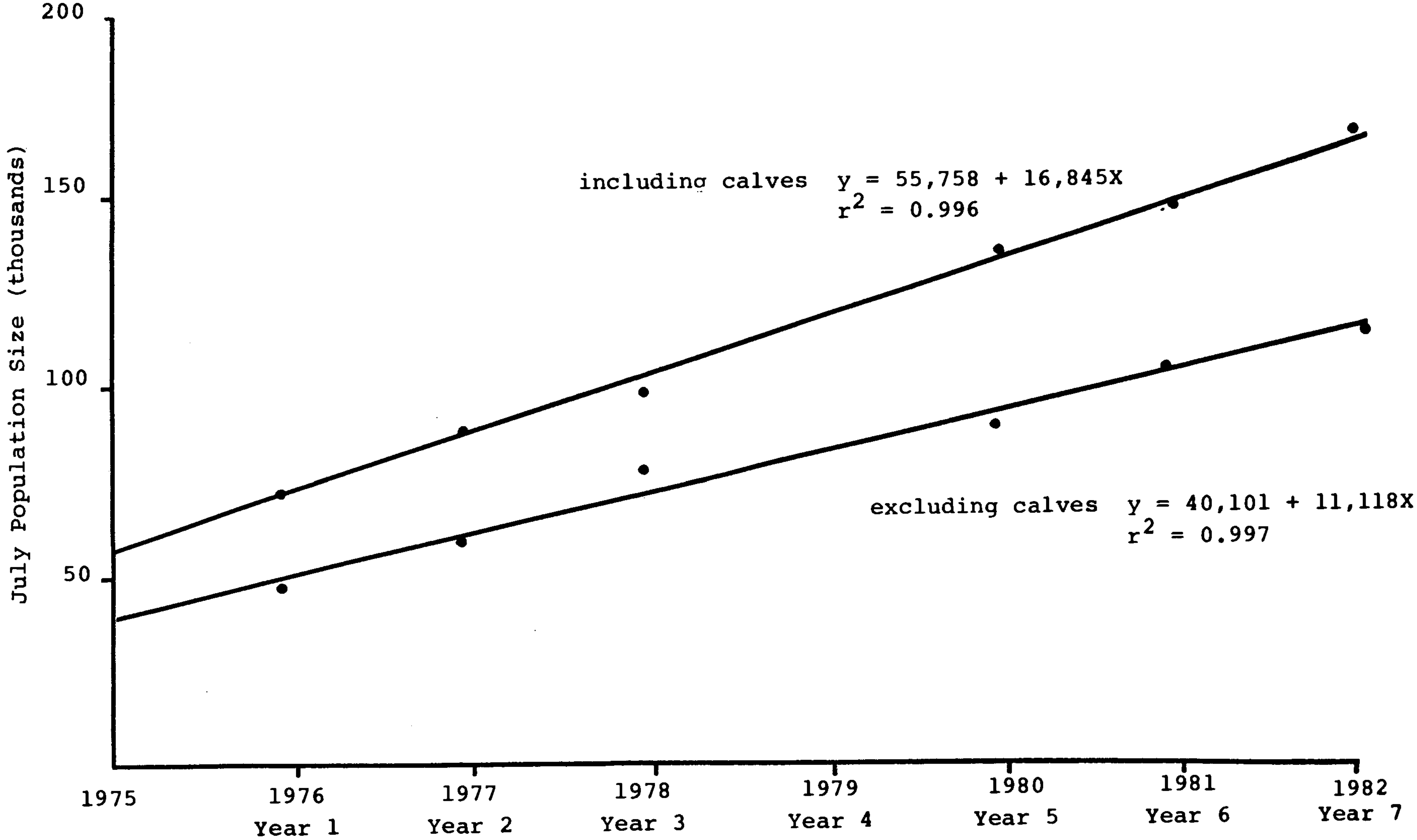

Fig. 1. Growth of the Western Arctic Caribou Herd, 1976-82.

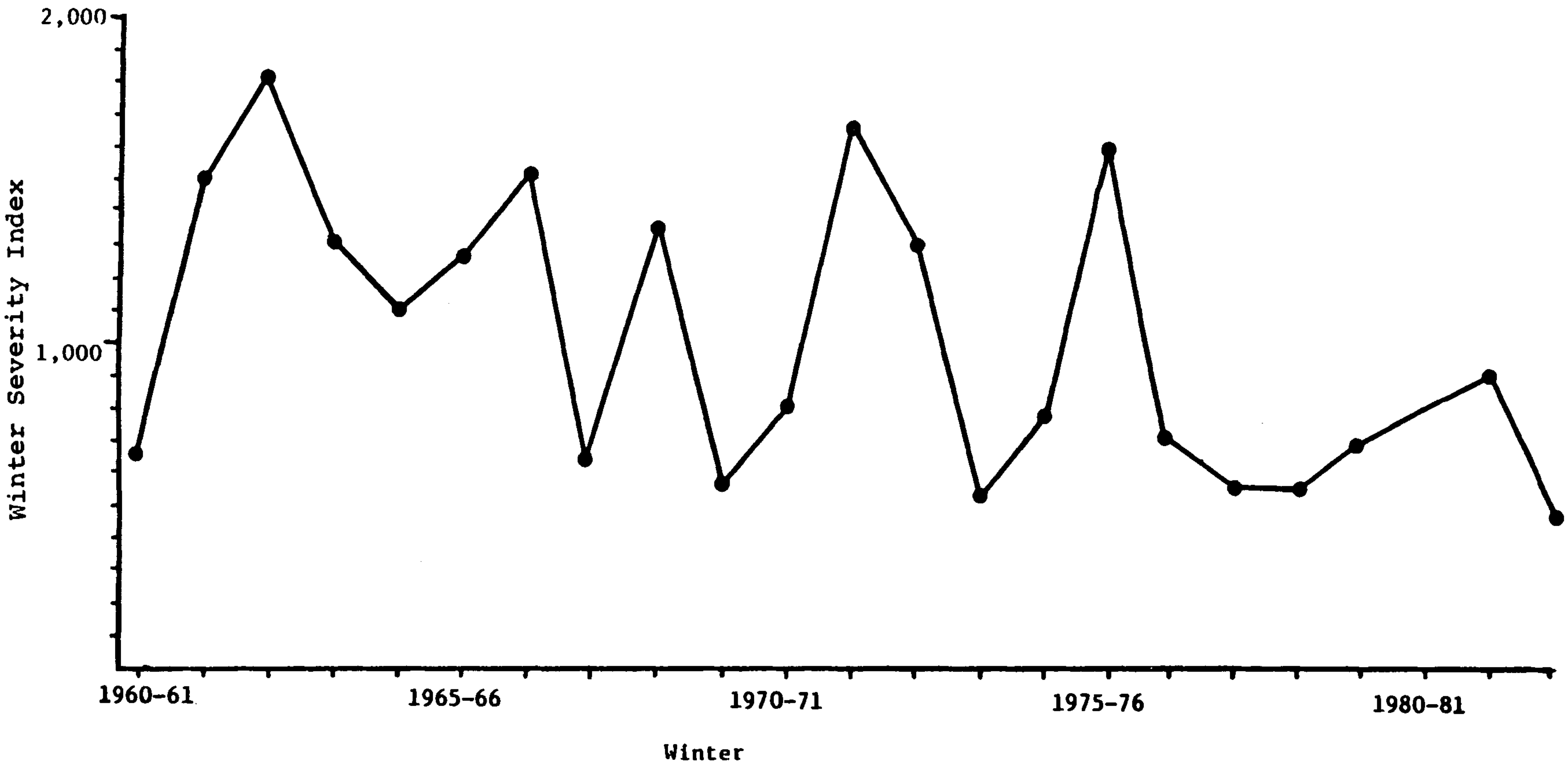

Fig. 2. Winter severity index for northwestern Alaska from 1960-61 through 1982-83.

Table 1. Capture location of caribou radio-collared in the range of the Western Arctic and Teshekpuk Herds in Alaska, April 1979 through April 1982.

Permanent accession number	Collar number	Location and date collared	Age/sex[a]
102,393	55	Oumalik R. 4/26/81	Adult F
102,353	54	Selawik Hills 3/26/81	Adult F
102,394	89	Oumalik R. 4/26/81	Adult M
102,358	24	Selawik Hills 3/27/81	Adult F
102,378	25	Price R. 4/25/81	Adult F
102,351	26	Selawik Hills 3/27/81	Adult F
102,359	27	Selawik Hills 3/27/81	Adult F
102,379	99	Price R. 4/25/81	Young M
102,380	19	Price R. 4/25/81	Adult F
102,381	13	Price R. 4/25/81	Adult F
102,382	28	Price R. 4/25/81	Calf F
102,383	29	Price R. 4/25/81	Young F
102,384	40	Price R. 4/25/81	Adult F
102,385	43	Price R. 4/25/81	Adult F
102,386	44	Price R. 4/25/81	Adult F
102,356	45	Selawik Hills 3/26/81	Adult F
102,355	46	Selawik Hills 3/26/81	Adult F
102,395	57	Oumalik R. 4/26/81	Adult F
102,387	58	Price R. 4/25/81	Adult F
102,353	59	Selawik Hills 3/26/81	Young F
102,396	91	Oumalik R. 4/26/81	Adult M
102,397	96	Oumalik R. 4/26/81	Adult M
102,354	98	Selawik Hills 3/26/81	Adult F
102,388	17	Price R. 4/25/81	Young M
102,389	14	Price R. 4/25/81	Audlt F
102,390	15	Price R. 4/25/81	Adult F
102,391	12	Price R. 4/25/81	Adult F
102,392	16	Price R. 4/25/81	Adult F
102,398	18	Oumalik R. 4/26/81	Adult F
102,407	30	Teshekpuk 5/1/81	Adult F
102,408	31	Teshekpuk 5/1/81	Adult F
102,409	32	Teshekpuk 5/1/81	Adult F
102,410	33	Teshekpuk 5/1/81	Adult F
102,428	34	Teshekpuk 7/5/81	Adult F
102,411	35	Teshekpuk 5/1/81	Adult F
102,412	36	Teshekpuk 5/1/81	Adult F
102,413	37	Teshekpuk 5/1/81	Adult F
102,414	38	Teshekpuk 5/1/81	Adult F
102,415	39	Teshekpuk 5/1/81	Adult F
102,416	40	Teshekpuk 5/1/81	Adult F
102,417	41	Teshekpuk 5/1/81	Adult F
102,420	70	Teshekpuk 7/5/81	Adult M
102,421	71	Teshekpuk 7/5/81	Adult M
102,422	72	Teshekpuk 7/5/81	Adult M

Table 1. Continued.

Permanent accession number	Collar number	Location and date collared	Age/sex[a]
102,423	73	Teshekpuk 7/5/81	Adult M
102,424	74	Teshekpuk 7/5/81	Adult M
102,425	75	Teshekpuk 7/5/81	Adult M
102,426	76	Teshekpuk 7/5/81	Adult M
102,427	77	Teshekpuk 7/5/81	Adult M
102,262	81	Tinayguk 4/17/80	Adult M
102,220	62	Ambler 10/2/79	Young M
101,999	69	Kevuk 4/19/79	Young M
102,264	82	Tinayguk 4/17/80	Adult M
101,998	64	Kevuk 4/19/79	Adult M
102,203	32	Ambler 9/28/79	Young M
102,269	31	Anaktuvuk 4/18/80	Adult F
102,263	60	Tinayguk 4/17/80	Adult M
102,004	34	Hunt R. 5/2/79	Adult F
102,003	63	Hunt R. 5/2/79	Young M
102,206	61	Ambler 9/29/79	Adult F
102,204	78	Ambler 9/28/79	Young M
102,001	68	Selawik Hills 5/1/79	Young M
102,279	39	Chandler 4/23/80	Old Ad F
102,202	73	Ambler 9/28/79	Young M
102,205	77	Ambler 9/28/79	Young M
102,207	74	Ambler 9/29/79	Young M
102,209	37	Ambler 9/29/79	Adult F
102,201	76	Ambler 9/28/79	Young M
102,218	2	Ambler 10/1/79	Young M
102,273	2	Chandler 4/23/80	Young F
102,006	1	Driftwood 5/9/79	Adult F
102,213	66	Ambler 9/30/79	Adult M
102,210	75	Ambler 9/29/79	Adult M
102,208	36	Ambler 9/29/7 9	Adult F
102,274	3	Chandler 4/23/80	Adult F
102,005	9	Driftwood 5/9/80	Adult F
102,215	71	Ambler 9/30/79	Adult M
102,216	6	Ambler 10/1/79	Young F
102,268	30	Anaktuvuk 4/18/80	Adult F
102,276	10	Chandler 4/23/80	Adult F
102,007	33	Driftwood 5/9/79	Adult F
102,007	67	Kevuk 4/19/79	Young M
102,217	0	Ambler 10/1/79	Adult F
102,211	38	Ambler 8/29/79	Adult F
102,275	5	Chandler 4/23/80	Adult F
102,214	65	Ambler 9/30/79	Adult M
102,221	79	Ambler 10/2/79	Adult M
102,260	79	Tinayguk 4/17/80	Adult M
102,277	35	Chandler 4/23/80	Adult F

Table 1. Continued.

Permanent accession number	Collar number	Location and date collared	Age/sex[a]
102,266	11	Anaktuvuk 4/18/80	Adult F
102,219	4	Ambler 10/2/80	Adult F
102,212	72	Ambler 9/30/79	Adult M
102,278	72	Chandler 4/23/80	Adult M
102,222	80	Ambler 10/2/79	Adult M
102,523	48	Umiat 4/18/82	Adult F
102,524	24	Umiat 4/18/82	Young F
102,525	48	Umiat 4/18/82	Young F
102,526	17	Umiat 4/18/82	Adult F

[a] "Young" refers to caribou that were thought to be less than 3 years old based on dentition and tooth wear.

Table 2. Collar-months of operation and fate of 45 female radio-collared caribou from the Western Arctic Herd, Alaska, 1979-84.

				Months on the air			
Accession No.	Collar No.	Date of collaring	Age when collared	Through July 1981	After July 1981	Total	Fate
102,004	34	5/2/79	Ad	27	33	60	Last heard 4/23/84
102,206	61	9/29/79	Ad	22	32	54	Last heard 4/9/84
102,279	39	4/23/80	8	15	28	43	Killed by predator (11/15/83)[a]
102,393	55	4/26/81	3	3	23	26	Last heard 7/1/83
102,352	54	3/27/81	Ad	4	8	12	Likely shot (4/1/82)
102,209	37	9/29/79	Ad	22	31	53	Last heard 3/29/84
102,273	2	4/23/80	1	15	24	39	Last heard 7/2/83
102,006	1	5/9/79	Ad	27	8	35	Likely shot (4/1/82)
102,208	36	9/29/79	Ad	22	23	45	Last heard 7/1/83
102,274	3	4/23/80	7	13	0	13	Breech birth, died 6/2/81
102,005	9	5/9/79	Ad	27	32	59	Last heard 3/19/84
102,268	30	4/18/80	1+	15	33	48	Last heard 4/9/84
102,276	10	4/23/80	Ad	15	33	48	Last heard 4/9/84
102,524	24	4/18/82	2-3	0	23	23	Last heard 3/29/84
102,007	33	5/9/79	Ad	27	2	29	Killed by bear or wolf (10/1/81)
102,217	0	10/1/79	Ad	22	32	54	Shot 3/29/84
102,211	38	9/29/79	Ad	22	27	49	Killed by bear or wolf (11/1/83)
102,275	5	4/23/80	4	15	21	36	Dead, natural cause (4/30/83)[b]
102,277	35	4/23/80	8	15	9	24	Poor condition, killed by wolf (4/15/82)
102,266	11	4/18/80	Ad	15	8	23	Killed by wolf or wolverine (3/1/82)
102,219	4	10/2/79	Ad	6	0	6	Collar dropped (4/1/80)
102,358	24	3/27/81	7	4	28	32	Killed by predator (11/15/83)
102,378	25	4/25/81	6-10	3	27	30	Last heard 10/20/83
102,351	26	3/27/81	2	4	1	5	Died (hoofrot) (8/23/81)
102,359	27	3/27/81	5	4	8	12	Last heard 3/20/84

Table 2. Continued.

Accession No.	Collar No.	Date of collaring	Age when collared	Months on the air			Fate[a]
				Through July 1981	After July 1981	Total	
102,523	48	4/18/82	Ad	--	23	23	Last heard 3/20/84
102,380	19	4/25/81	3	3	11	14	Likely shot (3/1/82)
102,382	28	4/25/81	Calf	3	27	30	Last heard 10/25/83
102,383	29	4/25/81	Ad	3	18	21	Shot (2/1/83)
102,384	40	4/25/81	Ad	3	32	35	Last heard 3/29/84
102,385	43	4/25/81	Ad	3	23	26	Last heard 7/2/83
102,386	44	4/25/81	4	3	32	35	Last heard 3/30/84
102,356	45	3/26/81	3	4	28	32	Dead, natural cause (11/15/83)
102,355	46	3/26/81	6	4	32	36	Last heard 3/19/84
102,395	57	4/26/81	4	3	32	35	Last heard 3/30/84
102,387	58	4/25/81	4	3	27	30	Last heard 10/25/83
102,525	48	4/18/82	Young[c]	--	23	23	Last heard 3/30/84
102,353	59	3/26/81	2+	4	32	36	Last heard 3/19/84
102,354	98	3/26/81	12	4	32	36	Last heard 3/20/84
102,389	14	4/25/81	5	3	32	35	Last heard 3/30/84
102,390	15	4/25/81	6	3	32	35	Last heard 3/30/84
102,391	12	4/25/81	2-3	3	32	35	Last heard 3/30/84
102,392	16	4/25/81	6-9	3	30	33	Last heard 2/13/84
102,398	18	4/26/81	3	3	32	35	Last heard 3/21/84
102,526	17	4/18/82	Ad	--	16	16	Last heard 7/27/83
Total collar months for all females (n = 45)				419	1040	1459	

[a] Dates in parentheses are the assigned dates of death or collar shedding for calculations of collar-months. In these cases, the actual date of death was unknown and had to be estimated.

[b] Natural cause indicates that the cause of death was unknown, but humans were not implicated.

[c] "Young" refers to caribou that were thought to be less than 3 years old based on dentition and tooth wear.

Table 3. Collar-months of operation and fate of 24 male radio-collared caribou from the Western Arctic Herd, Alaska, 1979-84.

Accession No.	Collar No.	Date of collaring	Age when collared	Months on the air: Through July 1981	Months on the air: After July 1981	Months on the air: Total	Fate
102,262	81	4/17/80	3	16	24	40	Last heard 7/1/83
102,219	62	10/2/79	2	12	0	12	Killed by grizzly bear 9/13/80
101,999	69	4/19/79	Young[a]	--	--	--	Missing since 7/79
102,264	82	4/17/80	4	16	5	21	Probably killed by wolves (12/31/81)[b]
101,998	64	4/19/79	Ad	7	0	7	Dropped collar ca. 11/79 (11/15/79)
102,203	32	9/28/79	Young	22	14	36	Shot (10/1/82)
102,263	60	4/17/80	4	16	28	44	Last heard 11/15/83
102,204	78	9/28/79	Young	7	0	7	Dropped collar (4/15/80)
102,001	68	5/1/79	Young	27	5	32	Probably killed by wolves (12/31/81)
102,205	77	9/28/79	Young	6	0	6	Dropped collar (4/1/80)
102,207	74	9/29/79	Young	6	0	6	Dropped collar (3/15/80)
102,201	76	9/28/79	Young	3	0	3	Killed by wolves (12/15/79)
102,218	2	10/1/79	Young	1	0	1	Shot 10/25/79
102,213	66	9/30/79	Ad	5	0	5	Shot 3/1/80
102,210	75	9/29/79	Ad	6	0	6	Dropped collar 4/80 (4/1/80)
102,216	6	10/1/79	Young	22	32	54	Last seen 3/19/84
102,394	89	4/26/81	Ad	3	18	21	Natural mortality (2/1/83)
102,000	67	4/19/79	Young	28	8	36	Shot (4/1/82)
102,221	79	10/2/79	Ad	2	0	2	Dropped collar (12/1/79)
102,260	35	4/17/80	Ad	11	0	11	Likely dropped (3/15/81)
102,212	72	9/30/79	Ad	13	0	13	Dropped (11/1/80)
102,278	72	4/23/80	Ad	--	--	--	Died unknown date before winter 80-81, suspected tagging mortality

Table 3. Continued.

Accession No.	Collar No.	Date of collaring	Age when collared	Months on the air: Through July 1981	After July 1981	Total	Fate
102,379	99	4/25/81	3-4	3	7	10	Shot (3/1/82)
102,396	91	4/26/81	5	3	7	10	Dead, malnutrition (3/1/82)
102,397	96	4/26/81	7	3	32	35	Last heard 3/30/84
102,388	17	4/25/82	3	3	28	31	Last heard 11/15/83
Total collar months for all males (n = 24)				241	208	449	

[a] "Young" refers to caribou that were thought to be less than 3 years old based on dentition and tooth wear.

[b] Dates in parentheses are the assigned dates of death or collar shedding for calculations of collar-months. In these cases, the actual date of death was unknown and had to be estimated.

Table 4. Calculated mortality rates for 45 female radio-collared caribou from the Western Arctic Herd, Alaska, after Trent and Rongstad (1974).

Time period[a]	Number of collar months	Deaths from natural causes	Natural mortality rate (%)	Deaths from hunters	Hunting mortality rate (%)	Total deaths	Total mortality rate (%)
Summer 1979	31	0	0	0	0	0	0
Winter 1979-80	58	0	0	0	0	0	0
Summer 1980	104	0	0	0	0	0	0
Winter 1980-81	117	0	0	0	0	0	0
Summer 1981	233	3	7.7	0	0	3	7.7
Winter 1981-82	217	2	5.6	3	7.8	5	13.4
Summer 1982	210	0	0	0	0	0	0
Winter 1982-83	204	1	2.9	1	2.9	2	5.8
Summer 1983	171	0	0	0	0	0	0
Winter 1983-84	114	4	19.3	1	5.2	5	24.5
Total	1,459	10		5		15	

Mean natural mortality rate approximately 7%

Mean man-caused mortality rate approximately 3%

[a] Summer = May, June, July, August, September, and October
Winter = November, December, January, February, March, and April

Table 5. Calculated mortality rates for 24 male radio-collared caribou from the Western Arctic Herd, Alaska, after Trent and Rongstad (1974).

Time period[a]	Number of collar months	Deaths from natural causes	Natural mortality rate (%)	Deaths from hunters	Hunting mortality rate (%)	Total deaths	Total mortality rate (%)
Summer 1979	29	0	0	1	19.1	1	19.1
Winter 1979-80	65	1	8.9	1	8.9	2	17.8
Summer 1980	59	1	9.8	0	0	0	9.8
Winter 1980-81	46	0	0	0	0	0	0
Summer 1981	74	0	0	0	0	0	0
Winter 1981-82	59	3	26.9	2	18.7	5	45.6
Summer 1982	35	0	0	1	16.0	1	16.0
Winter 1982-83	33	1	16.9	0	0	1	16.9
Summer 1983	33	0	0	0	0	0	0
Winter 1983-84	14	0	0	0	0	0	0
Total	447	6		5		11	

Mean natural mortality rate approximately 13%

Mean man-caused mortality rate approximately 13%

[a] Summer = May, June, July, August, September, and October
Winter = November, December, January, February, March, and April

Table 6. Adult natural mortality rates calculated from estimates of population size, recruitment, and human harvest in the Western Arctic Caribou Herd, Alaska, 1976-82.

Year	July population (older than calves)	Recruitment[a] (% short-yearlings in April)	Projected population before mortality[b] (older than calves)	Total mortality[c] (%)	Human harvest (%)[d]	Annual adult natural mortality[e] from previous July to July (%)
1976	(51,750)					
1977	(63,450)	17,449 (27.5)	69,199	5,749 (11.1)	3,100 (6.0)	2,649 (5.1)
1978	(72,114)	12,043 (16.7)	75,493	3,379 (5.3)	3,000 (4.7)	379 (0.6)
1979	(77,744)[f,g]	19,902 (25.6)	92,016	14,272 (19.8)	4,000 (5.6)	10,272 (14.2)
1980	(94,000)[g,h]	25,192 (26.8)	102,936	8,936 (11.5)	5,000 (6.4)	3,936 (5.1)
1981	(108,360)	29,040 (26.8)	123,040	14,680 (15.6)	5,000 (5.3)	9,680 (10.3)
1982	(119,318)[g]	36,988 (31.0)	145,348	26,030 (24.0)	7,000 (6.5)	19,030 (17.6)

[a] Recruitment = July population (older than calves) X proportion of short-yearlings in April (i.e., 1977 recruitment = 63,450 X 0.275 = 17,449).

[b] Projected population = previous July population (older than calves) + recruitment (i.e., 1977 projected population = 51,750 + 17,449 = 69,199).

[c] Total mortality = projected population (older than calves) - July population (older than calves).

[d] Calculated from harvest figures and estimates of illegal kill. Harvest begins in the previous year (i.e., 1977 harvest is that which occurred in 1976-77).

[e] Natural mortality = total mortality less human harvest.

[f] Probably low because this was a calving ground census; all other censuses were aerial photo censuses of postcalving aggregations.

[g] In 1979, 1981, and 1982, the percentage of calves in the herd in July was not determined, so the mean value (31.2%) for other years was used.

[h] Interpolated from 1980 and 1982 censuses.

Table 7. Summary of composition counts of Western Arctic Herd caribou in Alaska, 1952-83.

Date (mo/yr)	Bulls/ 100 cows	Yrlgs/ 100 cows	Calves/ 100 cows	% Yrlg	(n)	% Calves	(n)	% Cows	(n)	% Bulls	(n)	Total
10/52	--	--	--	--	--	26	(83)	--	--	--	--	320
10/53	--	--	--	--	--	24	(39)	--	--	--	--	164
9/54	--	--	--	--	--	28	(110)	--	--	--	--	393
6/60	--	--	73	--	--	42	(1,680)	58	(2,300)	--	--	3,980
7/60	41	25	71	20	(197)	30	(568)	42	(797)	18	(323)	1,885
7/61	81	37	42	14	(440)	16	(495)	38	(1,179)	31	(959)	3,073
10/61	55	8	37	4	(42)	19	(187)	50	(501)	27	(276)	1,006
7/62	--	22	--	18	(630)	--	--	82	(2,899)	--	--	3,529
5/63	--	--	--	20	(162)	--	--	78	(639)	2	(12)	813
6/63	--	--	75	--	--	33	(769)	--	--	--	--	2,351
6/64	--	--	80	--	--	39	(1,971)	49	(1,971)	--	--	3,541
6/65	--	--	69	--	--	41	(3,431)	59	(4,940)	--	--	8,371
7/68	61	27	41	12	(485)	18	(725)	44	(1,767	27	(1,085)	4,062
10/68	62	23	34	11	(235)	16	(345)	45	(1,010)	28	(627)	2,217
6/69	--	--	56	--	--	37	(2,187)	63	(3,798)	--	--	5,985
7/70	58	37	48	15	(4,043)	20	(5,171)	41	(10,789)	24	(6,247)	26,250
10/70	64	20	44	9	(543)	19	(1,198)	44	(2,732)	29	(1,746)	6,219
6/71	--	--	78	--	--	44	(4,085)	56	(5,184)	--	--	9,269
7/75	8	15	61	8	(396)	32	(1,617)	53	(2,673)	7	(383)	5,069
10/75	31	13	48	7	(154)	25	(558)	52	(1,171)	16	(360)	2,243
6/76	1	15	73	8	(577)	39	(2,884)	53	(3,936)	0	(19)	7,416
7/76	5	14	54	8	(766)	31	(3,037)	58	(5,636)	3	(309)	9,748
10/76	58	26	48	11	(807)	21	(1,471)	43	(3,077)	25	(1,785)	7,140
4/77	34	--	48	--	--	26	(3,204)	56	(6,947)	19	(2,366)	12,517
6/77	0	7	69	4	(174)	39	(1,771)	57	(2,586)	0	(0)	4,531
7/77	9	16	52	9	(1,852)	30	(6,071)	57	(11,647)	5	(1,031)	20,601
10/77	43	29	42	13	(922)	20	(1,342)	47	(3,227)	20	(1,397)	6,888
4/78	19	--	25	--	--	17	(1,567)	70	(6,557	13	(1,248)	9,381
6/78	0	5	68	3	(119)	39	(1,731)	58	(2,550)	0	(31)	4,431
7/78	36	17	63	8	(1,635)	29	(6,062)	46	(9,538)	17	(3,455)	20,690
10/78	51	25	50	11	(556)	22	(1,137)	44	(2,258)	22	(1,146)	5,097

Table 7. Continued.

Date (mo/yr)	Bulls/ 100 cows	Yrlg/ 100 cows	Calves/ 100 cows	% Yrlg	(n)	% Calves	(n)	% Cows	(n)	% Bulls	(n)	Total
4/79	--	--	--	--	--	26	(1,035)	--	--	--	--	4,027
6/79	5	13	71	7	(699)	38	(3,922)	53	(5,534)	2	(267)	10,402
3/80	--	--	--	--	--	25	(2,559)	--	--	--	--	10,382
6/80	1	22	82	11	(225)	40	(875)	49	(1,062)	0	(11)	2,173
7/80	17	16	66	8	(1,467)	33	(5,940)	50	(8,982)	8	(1,504)	17,893
11/80	53	30	53	15	(407)	22	(711)	39	(1,354)	24	(715)	3,217
3/81	91	--	56	--	--	23	(414)	40	(735)	25	(669)	1,818
6/81	0	24	82	12	(258)	40	(885)	49	(1,079)	--	--	2,222
10/81	--	--	--	--	--	22	(1,129)	--	--	--	--	5,050
4/82	84	--	48	--	--	21	(49)	43	(102)	36	(86)	237
6/82	--	11	76	6	(151)	40	(1,033)	54	(1,368)	--	--	2,552
10/82	59	--	60	--	--	27	(1,923)	46	(3,189)	27	(1,886)	6,998
3/83	--	--	--	--	--	25	(1,648)	--	--	--	--	6,727

Table 8. Percent femur fat of caribou dying from various causes in interior and northwestern Alaska.

Source of mortality	Femur fat values: Adult Females			Adult Males			Adult sex unknown			Yearlings (both sexes)			Calves (both sexes)			
	$\bar{x}$ ±	[Range]	(n)	$\bar{x}$ ±	[Range]	(n)	$\bar{x}$ ±	[Range]	(n)	$\bar{x}$ ±	[Range]	(n)	$\bar{x}$ ±	[Range]	(n)	Total
Hunters	84±7	[68-91]	(12)	85±16	[45-99]	(9)	78±13	[58-91]	(8)	81±4	[78-87]	(4)	82±10	[65-89]	(5)	38
Accidents/ scientific collection	51±25	[6-89]	(18)	69±24	[39-98]	(6)	60±22	[34-92]	(7)		--		70±15	[50-84]	(6)	37
Malnutrition	5±3	[1-16]	(7)	8±2	[5-11]	(6)	--			15±1	[14-16]	(2)	8±4	[4-13]	(7)	22
Wolf	60±31	[8-99]	(15)	59±26	[14-99]	(16)	54±25	[14-92]	(8)	56±17	[56-80]	(2)	50±8	[43-63]	(2)	46
Bear	54±25	[15-75]	(5)	--			75±3	[73-77]	(2)		--			--		7
Wolverine	31		(1)	10		(1)	--				--			--		2
Lynx		--			--		--				--		69±18	[56-82]	(2)	2
Total (n)			(58)			(38)			(25)			(8)			(25)	

Table 9. Temperature, snowfall, and winter severity indices for northwestern Alaska, 1960-83.

Year	Barrow			Bettles			Kotzebue			Kobuk			Umiat			Combined WSI[d]
	Temp[a]	Snow[b]	WSI[c]	Temp	Snow	WSI	Temp	Snow	WSI	Temp	Snow	WSI	Temp	Snow	WSI	
1960-61	15,929	17	271	13,547	9	122	12,505	22	275	--[e]	--	--	--	--	--	668
1961-62	14,457	30	433	13,897	54	750	12,758	25	319	--	--	--	--	--	--	1,502
1962-63	14,660	29	425	13,086	86	1125	12,343	22	272	--	--	--	--	--	--	1,822
1963-64	16,296	10	163	14,160	60	850	14,174	21	298	--	--	--	--	--	--	1,311
1964-65	15,734	16	262	13,494	51	688	12,758	13	166	13,188	--	--	--	--	--	1,116
1965-66	15,497	19	294	14,456	37	535	13,271	34	451	13,841	30	415	--	--	--	1,280
1966-67	14,319	14	200	13,694	56	767	12,029	47	565	12,816	52	666	--	--	--	1,532
1967-68	14,956	13	194	13,821	20	276	12,175	16	195	12,779	12	153	--	--	--	665
1968-69	15,468	18	278	12,873	48	618	12,718	37	471	12,849	60	771	--	--	--	1,367
1969-70	15,302	6	92	13,376	30	401	12,827	5	64	13,422	30	403	--	--	--	557
1970-71	16,265	10	163	15,134	29	439	13,897	15	208	15,120	48	726	--	--	--	810
1971-72	15,587	8	125	15,138	59	893	13,560	49	664	14,610	39	570	--	--	--	1,682
1972-73	14,696	11	162	13,583	35	475	12,584	53	667	13,150	49	644	--	--	--	1,304
1973-74	15,110	6	91	14,271	17	243	13,150	15	197	13,954	23	321	--	--	--	531
1974-75	16,220	8	130	14,271	18	257	13,608	29	395	14,434	40	577	--	--	--	782
1975-76	16,522	4	66	14,278	26	371	13,953	28	391	13,782	34	469	--	--	--	828
1976-77	15,398	7	108	12,536	31	389	12,135	19	239	12,700	36	457	16,987	26	442	736
1977-78	14,411	7	101	12,768	29	370	11,888	9	107	--	--	--	15,465	15	232	578
1978-79	15,020	8	120	13,434	21	282	11,686	14	164	12,121	39	473	15,947	19	303	566
1979-80	14,551	16	233	12,495	19	237	11,964	19	227	--	--	--	15,255	13	198	697
1980-81	15,146	11	167	12,074	27	326	11,575	28	324	--	--	--	15,378	14	215	817
1981-82	14,555	16	233	13,243	34	450	12,370	19	235	--	--	--	-[f]	16	-[f]	918
1982-83	15,542	6	93	13,191	17	224	11,860	15	178	--	--	--	17,315	12	208	479

[a] Temp = the number of Farhenheit heating degree days from 1 October through 30 April.
[b] Snow = the amount of snow on the ground at the end of April in inches.
[c] WSI = temp x snow/1000.
[d] Combined WSI = the sum of the WSI at Barrow, Bettles, and Kotzebue.
[e] No data available.
[f] No applicable entry.

Table 10. Comparison of winter severity index and estimates of calf survival for the Western Arctic Caribou Herd, Alaska, 1960-83.

Year	Combined winter severity index[a]	Calves/ 100 cows in spring[b]	Calves/ 100 cows in summer[c]	% Calves in fall[d]	% Yearlings in fall
1960-61	668	--	42	19	4
1961-62	1502	--	--	--	--
1962-63	1822	25	75	--	--
1963-64	1311	--	80	--	--
1964-65	1116	--	69	--	--
1965-66	1280	--	--	--	--
1966-67	1532	--	--	--	--
1967-68	665	27[e]	41	16	11
1968-69	1367	--	56	--	--
1969-70	557	37[e]	48	19	9
1970-71	810	--	78	--	--
1971-72	1682	--	--	--	--
1972-73	1304	--	--	--	--
1973-74	531	--	--	--	--
1974-75	782	15[e]	61	25	7
1975-76	828	14[e]	73	21	11
1976-77	736	48	69	20	13
1977-78	578	25	68	22	11
1978-79	566	50[f]	71	--	--
1979-80	697	16[e]	66	22	15
1980-81	817	56	82	22	--
1981-82	918	48	76	27	--
1982-83	479	50[f]	--	--	--
Correlation coefficient (r^2)		0.05	0.11	0.40	0.01

[a] Combined for Kotzebue, Bettles, and Barrow.

[b] Spring means the March, April, or May following the winter in Column 1.

[c] Summer means the June or July following the winter in Column 1.

[d] Fall means the September, October, or November following the winter in Column 1.

[e] Taken from July estimate of yearlings.

[f] Converted from % calves in April.

Table 11. Heating degree days (Fahrenheit), average wind speed, and summer weather index at Barrow, Alaska for June and July 1960-83.

Year	June			July			August			July and August SWI
	Heating degree days	Average wind speed	SWI[a]	Heating degree days	Average wind speed	SWI	Heating degree days	Average wind speed	SWI	
1960	936	10.5	9.8	848	10.8	9.1	953	12.8	12.2	21.2
1961	904	12.0	10.8	825	11.1	9.1	911	15.7	14.3	23.4
1962	906	10.8	9.8	758	10.9	8.3	691	10.7	7.4	15.7[b]
1963	928	12.0	11.1	864	12.6	10.9	877	14.4	12.6	23.5
1964	987	12.3	12.1	831	10.7	8.9	926	11.8	10.9	19.8
1965	1019	14.0	14.3	821	11.8	9.7	825	10.2	8.4	18.1
1966	891	10.7	9.5	850	11.0	9.4	928	-[c]	--	--
1967	939	10.1	9.5	848	9.6	8.1	887	11.4	10.1	18.2
1968	953	5.4	5.1	697	16.3	11.4	718	12.7	9.1	20.5
1969	942	12.6	11.9	935	10.9	10.2	1023	11.3	11.6	21.8
1970	959	9.5	9.1	835	9.6	8.0	921	10.0	9.2	17.2
1971	891	12.4	11.0	755	11.8	8.9	970	10.7	10.4	19.3
1972	968	12.2	11.8	681	11.7	8.0	750	10.9	8.1	16.1
1973	950	11.2	10.6	778	11.1	8.6	772	10.9	7.9	16.5
1974	1045	11.3	11.8	795	10.1	8.0	695	9.1	6.3	14.3
1975	934	10.7	10.0	850	11.3	9.6	931	11.3	10.5	20.1
1976	943	11.2	10.5	816	11.2	9.1	844	9.6	8.1	17.2
1977	922	10.4	9.6	802	13.8	11.1	632	12.6	8.0	19.1[b]
1978	954	12.3	11.7	772	12.5	9.7	874	11.9	10.4	20.1
1979	970	11.4	11.0	676	9.2	6.2	579	12.4	7.2	13.4
1980	835	9.6	8.0	902	13.2	11.9	961	11.8	11.3	23.7[b]
1981	906	10.9	9.9	777	11.2	8.7	968	10.4	10.1	18.8
1982	925	--	--	833	--	871	--	--	--	--
1983	906	--	--	830	--	941	--	--	--	--

[a] SWI = heating degree days X average wind speed/1000.

[b] Necrobacillosis outbreak reported.

[c] No data available.

Table 12. Prevalence of serologic brucellosis reactors in Western Arctic caribou, Alaska, 1961-81.[a]

Year	Sample size	Number positive (%)
1961	145	20 (14)
1962	117	28 (24)
1963	58	14 (24)
1964	61	17 (28)
1965	128	16 (13)
1968	162	9 (5)
1969	69	9 (13)
1970	18	3 (17)
1971	42	9 (22)
1977	10	0 (0)
1978-79	18	4 (22)
1980	4	1 (25)
1981	20	6 (30)

[a] From McGowan (1966), Neiland (1966, 1969, 1970, 1972, 1978), Neiland et al. (1968), Skoog 1963, and Zarnke (unpubl. data).

Table 13. Chi-square test statistics for brucellosis reactors as shown in Table 12.

Year	61	62	63	64	65	68	69	70	71	77	78/79	80	81
61													
62	4.45												
63	3.18	0.00											
64	5.77	0.33	0.21										
65	0.10	5.42	4.00	6.77									
68	6.07	19.94[a]	15.75[a]	21.42[a]	4.38								
69	0.02	3.23	2.62	4.45	0.01	3.78							
70	0.11	0.47	0.44	0.92	0.24	3.21	0.16						
71	1.45	0.11	0.10	0.55	2.01	10.45	1.35	0.18					
77	1.58	3.07	3.04	3.66	1.41	0.59	1.47	3.98	2.59				
78/79	0.91	0.03	0.03	0.23	1.26	6.72	0.95	0.18	0.00	2.59			
80	0.40	0.00	0.00	0.02	0.54	2.61	0.46	0.15	0.03	2.69	0.01		
81	3.48	0.34	0.27	0.03	4.19	14.07[a]	3.18	0.93	0.54	3.75	0.30	0.04	

[a] Values are significantly different ($\alpha = 0.05$, $\chi^2 > 13.0$, 1 df).

Table 14. Prevalence of placental retention in the Western Arctic Caribou Herd, Alaska, 1963-82.

Year[a]	Sample size	Retained placentas (%)
1963	2,130	107 (5.0)
1965	787	25 (3.2)
1966	2,075	33 (1.6)
1967	2,846	6 (0.2)
1968	2,037	52 (2.6)
1969	4,357	44 (1.0)
1970	2,217	28 (1.3)
1971	3,331	67 (2.0)
1975	1,877	20 (1.1)
	180	5 (2.8)
1976	1,847	9 (2.8)
	249	3 (1.2)
1977	1,483	14 (0.9)
1979	1,394	7 (0.5)
1981	1,079	2 (0.2)
1982	1,546	12 (0.8)

[a] Data for 1963 through 1977 from Neiland (1978).

Table 15. Chi-square test statistics for retained placenta data as shown in Table 14.

Year	63	65	66	67	68	69	70	71	75	76	77	79	81	82
63														
65	4.54													
66	38.49[a]	7.23												
67	127.14[a]	64.10[a]	29.05[a]											
68	17.32[a]	0.83	4.70	55.48[a]										
69	101.36[a]	23.65[a]	4.00	15.94[a]	22.34[a]									
70	51.05[a]	12.27	0.82	20.68[a]	9.57	0.87								
71	38.21[a]	3.96	1.25	42.61[a]	1.71	13.31	4.43							
75	50.93[a]	14.88[a]	2.05	15.09[a]	11.97	0.04	0.34	6.54						
76	71.88[a]	31.33[a]	11.22	2.69	26.73[a]	4.18	6.72	19.09[a]	4.03					
77	44.95[a]	15.18[a]	2.77	11.40	12.07	0.05	0.81	7.07	0.12	2.50				
79	55.02[a]	24.89[a]	8.66	2.60	20.59[a]	3.10	5.16	14.52[a]	3.10	0.00	1.94			
81	51.09[a]	28.55[a]	12.77	0.02	23.21[a]	7.01	9.34	17.65[a]	7.19	1.66	5.79	1.68		
82	51.59[a]	19.25[a]	4.78	7.85	15.81[a]	0.66	2.05	10.11	0.77	1.14	0.25	0.86	4.18	

[a] Values are significantly different ($\alpha = 0.05$, $\chi^2 > 13.3$, 1 df).

Table 16. Reported harvest of wolves in the range of the Western Arctic Caribou Herd, 1975-82.

Year	GMU 23[a]	GMU 24[b]	GMU 26[c]	Total
1974-75	47	65	6	118
1975-76	144	45	34	223
1976-77	150	55	35	240
1977-78	64	55	38	157
1978-79	45	102	31	181
1979-80	16	49	15	80
1980-81	70	69	42	152
1981-82	19[d]	33[e,f]	39[g]	91

[a] Kobuk River, Noatak River, Selawik River areas.

[b] Upper Koyukuk drainage, central Brooks Range. Up to 20% of these animals are from areas outside the WAH caribou range.

[c] Arctic slope. Although this Unit includes the entire arctic slope east to the Canadian border, more than 90% of the wolves taken came from the area between Anaktuvuk and Etivluk Rivers.

[d] ADF&G Area Biologist D. James estimated that about 25 additional wolves were taken but not reported.

[e] Up to 25 of these were not in the range of the WAH.

[f] ADF&G Area Biologist T. Osborne estimated that up to 100 additional wolves were taken illegally but many may have come from Unit 21.

[g] Of these, 24 were in the range of the WAH.

APPENDIX A.

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CORRELATIONS AND DEPLETION PATTERNS OF MARROW FAT IN CARIBOU BONES[1]

RH: MARROW FAT CORRELATIONS • Davis

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Abstract: We used linear regression to correlate femur marrow fat against marrow fat of the other five long leg bones (tibia, metatarsus, humerus, radius, and metacarpus) and mandibles using paired bones from individual caribou (*Rangifer tarandus granti*). Correlations were high in all regressions (range: $r = 0.90$ to 0.98) and suggested that all bones were useful as gross indices to relative body condition. However, when interpreting fat content of other bones and making between bone comparisons, there is merit in indexing fat values to a "femur standard." The percent marrow fat in all leg bones of individual caribou was more uniform than in moose (*Alces alces*). The general pattern of fat depletion in caribou long bones was closer to that of moose than other wild ungulates. Fat depletion in both moose and caribou advances more rapidly in proximal long bones than in more distal ones. Mandible marrow fat can be used as a relative condition index if limitations are recognized.

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Key words: body condition, bone marrow, caribou, fat, femur, long bones, mandibles.

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Field biologists are frequently faced with assessing the cause of death in large mammals when only skeletal parts remain. This situation is particularly common in predator-prey studies. Inferences about the physical condition of prey selected by predators have major implications, particularly when the condition of the prey population at large is known.

For a number of reasons (Cheatum 1949), marrow fat in the femur has emerged as the relative condition index of choice to estimate relative body condition at death in many ungulate species. The substantial interest in femur marrow fat as a relative condition index has stimulated much investigation and refinement of techniques for femur marrow fat determinations, since Harris (1945) reported that advancing malnutrition changed the bone marrow fat content in white-tailed deer (Odocoileus virginianus) and mule deer (O. hemionus).

Femur marrow fat has been estimated by at least six general approaches (1) ether extraction (AOAC method in Horwitz 1965:346, cited by Greer 1968); (2) visual estimation (Harris 1945, Cheatum 1949); (3) compression (Greer 1968); (4) oven-drying (Neiland 1970); (5) reagent-dry assay (Verme and Holland 1973); and (6) freeze drying (Hunt 1979).

Ether extraction techniques yield reliable quantitative data, but are tedious, expensive, and potentially dangerous. Consequently, they are used infrequently in wildlife studies. Subjectiveness of the visual estimation technique limits its usefulness. The compression method is only quasiquantitative. The several drying techniques are relatively fast, inexpensive, and sufficiently accurate for most wildlife work (Hunt 1979).

A logical extension of the femur relative condition index has been the use of marrow from other leg bones (Ballard et al. 1981, Fong 1981, Peterson et al. 1982) and from mandibles (Baker and Leuth 1966, Purol et al. 1977, Snider 1980, Ballard et al. 1981).

Use of these additional bones as relative condition indices is appealing for many reasons. On frozen intact carcasses, femurs are much more difficult to extract than other bones. Large carnivores often consume all or portions of the femurs but frequently leave distal bones and mandibles intact. Mandibles, in particular, are often available in large numbers from hunter-killed animals.

While investigating natural mortality in Alaska's Western Arctic Caribou Herd, we found many caribou carcasses that were missing femurs, but contained other long bones or mandibles. To determine if these other bones were useful as indices of relative body condition, we tested the correlation between paired marrow values for femurs vs. other leg bones and mandibles. Those correlations and fat depletion patterns of those bones are the subject of this paper.

Many Alaska Department of Fish and Game employees and cooperators contributed specimens and/or aided in laboratory processing, and we thank them all. W. Ballard contributed raw data for long bone vs. mandible fat correlations (ref. Ballard et al. 1981). A. Magoun, W. Regelin, and S. Peterson critiqued the manuscript.

STUDY AREA

All marrow samples were collected from caribou herds in Interior and Arctic Alaska, i.e., those distributed north of the Alaska Mountain Range (Davis 1980). Most samples were from the Western Arctic Herd. Skoog (1968) and Hemming (1971) have previously described environmental conditions in the study area.

METHODS

From 1977 through 1983, we collected femurs and one or more other long leg bones or a mandible from caribou of both sexes and from calf, yearling, and adult age classes. A few samples from earlier dates were included in our analysis (unpubl., Alaska Department of Fish and Game). Our data are from 75 caribou from which two or more long bones or at least one long bone and a mandible were collected. The sample contained 17 male, 33 female, and eight unknown sex adults; two male, one female, and one unknown sex yearlings; and four male, three female, and six unknown sex calves. From the 75 caribou, the number from which we obtained one or more of the following bones (e.g., right and left femur) included as follows: femurs = 69, tibia = 52, metatarsus = 44, mandible = 21, metacarpus = 18, radius = 18, humerus = 15.

All collections were opportunistic and were made while working on projects with varied principal objectives. Many of the bones were collected from dead caribou located primarily by aerial search in winter.

We analyzed only intact bones with no cracks. Most bones were collected from frozen carcasses. From October through March, it is rare for the ambient temperature in the study area to be above freezing. All bones were stored intact in sealed plastic bags in a freezer at -35°C until analysis, usually a few weeks after collection. These steps minimized the problems associated with dehydration prior to fat analysis (Kie 1978, Peterson et al. 1982).

Samples of marrow for analysis were taken from the central portion of the femur and usually amounted to 10-30 g fresh weight. The other long bones were treated similarly and consequently the fresh weight was considerably less from some bones because of smaller marrow cavities. The entire mandible marrow was used for fat analysis.

We used a band saw to cut the midsection from long bones and then placed the bone on a concrete floor and struck it with a hammer to fracture the bone without damage to the marrow. Cracked bones were carefully separated from the marrow. For mandibles, we used the same procedure, but most were not precut before splitting. We scraped off bone dust and fragments from the frozen marrow samples and were careful to keep all bones well frozen while extracting the marrow. Care must be taken with marrows containing little fat because fluid could be lost from the marrow cavity prior to weighing.

Once the marrow samples were extracted from the bone, the procedure used was identical to that described by Neiland (1970). The percent bone marrow fat was determined by immediately weighing the extracted marrow and then oven drying it at 55°C to 65°C until no water remained, as determined by repeated weighing until weight of the sample stabilized. Drying time averaged 3 to 6 days. Percent fat was calculated as dry weight divided by fresh weight times 100. Neiland (1970) demonstrated that the dry weight "fat" determined this way actually contained a small fraction of mineral residue. We ignored this residue similarly to Franzmann and Arneson (1976) and Snider (1980).

When possible, the sex of caribou was determined by genitalia; when genitals were lacking, other diagnostic anatomical features were considered. Age was determined by tooth eruption and wear for calves and yearlings and by cementum annuli for older animals (Miller 1974).

Regression analysis was used to investigate the relationships between marrow fat content in the various bones analyzed. We assumed a simple linear model

$$Y = \beta_o + \beta_1 X + \varepsilon$$

where:
- Y is femur marrow fat content;
- X is marrow fat content of the bone being correlated with femur;
- β_o is the value of Y when $X = 0$;
- β_1 is the slope of the relationship; and
- ε is the random error term for individual observations.

For each set of bone pairs analyzed, we tested the significance of the slope ($H_o : \beta_1 = 0$) and whether the relationship was significantly different from a model with an intercept of zero and slope of one (H_o : $\beta_o = 0$, $\beta_1 = 1$). The full versus reduced model approach (Neter and Wasserman 1974) was used to evaluate the effect of sex and age and to compare our results with those of Ballard et al. (1981).

Acceptance or rejection of null hypotheses was based on an F test. The Student's t-test was used to test the significance of the mean difference between paired bones (Snedecor and Cochran 1967). All test statistics were evaluated at the $\alpha = 0.05$ level.

RESULTS

Correlations of Paired Bones

Previous papers that have examined correlations between marrow in various paired bones from both moose and caribou have generally pooled data from the sexes and different age classes (Snider 1980, Ballard et al. 1981, Peterson et al. 1982). Reasons for pooling the data have varied from unstated, to pooling because of small sample size, to having tested variances between sex and age groups which indicated pooling was warranted. We acknowledge the potential influence of age and sex on bone marrow relationships and patterns but have pooled all data for our analysis. We tested the effect of age (calves and yearlings vs. adults) on the regression lines for the paired bones but found no significant difference. We also tested the effect of sex (male vs. female) on the regression lines. The test for the femur vs. metacarpus regression showed a significant influence by sex ($P < 0.05$), but we were comparing only two male values to 12 female values and overall believed that we had no strong reason not to pool all samples irrespective of sex and age.

We obtained paired bones from individual caribou from nearly the entire range (0-100%) of possible marrow fat values enabling us to compare the paired values by linear regression techniques. For the regressions, we paired femur values with the other five long leg bones (tibia, metatarsus, humerus, radius, metacarpus) and with mandibles from individual caribou.

Linear regressions for each set (e.g., femur vs. mandible or femur vs. long bone) of paired bones showed good correlation between fat content. Correlations ranged from r = 0.98 for femur vs. tibia and metatarsus to r = 0.90 for femur vs. metacarpus (Figs. 1-6). For each of the respective correlations, a prediction equation was generated and the slopes of the regression lines were tested (Figs. 1-6).

Fat Depletion Patterns

Similarly to Peterson et al.'s (1982) work with moose, we investigated the pattern of fat depletion among bones and the individual variation within bones from the same individual by examining 163 pairs (Table 1) of bones from 75 individual caribou. We compared proximal and distal bones, hind and front limb bones, and bones from right and left sides (Table 1). Peterson et al. (1982) assumed that a fat content of 80% or less indicated active fat mobilization and used only bones in that category to determine the pattern of depletion. We analyzed our data both for all bones and for those with one bone of the pair with 80% or less fat (Table 1). Results from both treatments were similar. The only mean differences in Table 1 that were significantly different from 0 were femur vs. tibia ($P < 0.001$).

Peterson et al. (1982) found that proximal bones (femur and humerus) contained less fat than adjacent bones (tibia and radius) and that there were no differences between the tibia and metatarsus or radius and metacarpus. Our results were the same except we demonstrated no significant difference between the humerus and radius mean fat values.

Peterson et al. (1982) found that distal bones of the hind limb (tibia and metatarsus) contained less fat than the corresponding bones of the front limb (radius and metacarpus). We found no significant differences between the tibia and radius, or the metatarsus and metacarpus.

We found much individual variation even in bone pairs that exhibited no overall differences in fat content (Table 1). In individual caribou, bone pairs that showed most agreement were the tibia vs. metatarsus and the radius vs. metacarpus (absolute mean difference 0.9%). Pairs that showed the greatest mean difference were femur and tibia (mean difference -5.2%) and humerus and radius (mean difference -5.7%).

The mean difference in fat content between paired bones was consistently greater in Peterson et al.'s (1982) moose data than in our caribou data (c.f. Table 1, Peterson et al., and our Table 2). Mean difference in fat content between paired bones in Peterson et al. (1982) ranged from 2.8 to 13.3% with a mean of 7.7% compared to our range of 0.9 to 5.7% and mean of 3.2%.

DISCUSSION

Correlation of Fat in Paired Bones

The correlations demonstrated between caribou femurs and the five other leg bones and mandibles suggest that bones other than femurs may be valid indicators of relative condition as previously concluded by others (Franzmann and Arneson 1976, Ballard et al. 1981, Fong 1981). Furthermore, the accuracy in all facets of determining fat values and inferring their importance to animal condition suggest that often regressing other bones to the "femur standard" will be unnecessary to solely decide if relative condition is good or poor. However, for comparative purposes, regressing marrow values for bones other than femurs back to femur values may be useful.

For our regressions of femur vs. mandible, metatarsus, tibia, and metacarpus we rejected the null hypothesis $H_o: \beta_o = 0, \beta_1 = 1$. The lack of significant differences from this null hypothesis for the femur vs. humerus and femur vs. radius regressions may be due to sample size. Hence, we concluded that there is merit in regressing marrow values for all long bones and mandibles to the femur standard.

Our correlation (r = 0.93) between femur and mandible marrow fat suggests that mandibles have considerable potential as a relative condition index throughout the possible range of marrow values (0-100%). Though workers have utilized leg bones other than femurs as indices to relative condition (Ballard 1981 et al., Fong 1981, Peterson et al. 1982), the use of mandibles for a condition index appears less researched (Snider 1980, Ballard et al. 1981). The utility of mandibles has been considered and evaluated for deer (Baker and Leuth 1966, Purol et al. 1977) and moose (Snider 1980, Ballard et al. 1981). Ballard et al. (1981) reported that their initial data from caribou on fat mobilization in mandibles and long bones suggested a positive correlation, but recommended that comparative data be collected from other populations.

We compared Ballard et al.'s (1981) regression of marrow fat in long bones and mandibles of caribou and found no significant difference between Ballard's results and our regression of femur on mandible marrow fat. Ballard et al.'s (1981) sample contained no long bones with marrow fat values less than 50% (Fig. 7).

Fat Depletion Patterns

Patterns of fat depletion in the caribou we studied were more similar to those of moose than to other ungulates discussed in the literature. Fat depletion in moose (Peterson et al. 1982), several African ungulates (Brooks et al. 1977), and caribou apparently advances more rapidly in the proximal bones than in the distal bones. Fat is apparently almost simultaneously mobilized from all limb bones, although mobilization may be initiated or may proceed more quickly in proximal bones (Dauphine 1976). Caribou showed less difference in fat depletion among bones than did moose.

Cheatum (1949) suggested that fat depletion might be more advanced in proximal bones because they are closer to the body core and warmer in winter, the period of marrow fat withdrawal. However, Peterson et al. (1982) reported that differences among bones in moose caused by progressive fat depletion were not as great as in some African ungulates and white-tailed deer. Though Peterson et al. (1982) thought it reasonable to expect reduced circulation within capillary networks and retarded metabolism processes in colder extremities, they pointed out that temperature variation does not adequately explain the progressive depletion evident in African ungulates or the small differences they noted between hind and front limbs of moose.

To fully understand fat depletion patterns, we believe that fat deposition patterns must be simultaneously understood (i.e., fat mobilization can involve both depletion and deposition). Peterson et al. (1982) assumed that a marrow fat value of 80% or less indicated that fat depletion was occurring. Without actually knowing the animal's current energy balance, either fat depletion or deposition could be occurring (albeit seasonal energy balance patterns may have few exceptions for most ungulates). Time lags between depletion and deposition between various bones could contribute to some of the inconsistencies noted between species and data sets for the same species. The relative imprecision of the dry method for fat determination undoubtedly contributes a degree of precision error that can confound interpreting small apparent differences between mean fat values for different bones. The individual paired values in the correlations in Fig. 1-6 suggest more complicated patterns of fat depletion in individual bones than suggested in our and Peterson et al.'s (1982) discussion based on mean differences in fat values of paired bones.

The limited sample of mandibles we analyzed suggested that mandible marrow fat can be used as a relative condition index. However, the actual relationship between femur fat and mandible fat throughout the range of conditions (0-100% marrow fat) is less well understood than for femur and other leg bones. One possible major adjustment that a mandible fat index may require is that the percentage of mineral in the dried residue of mandibles may be significantly greater than Neiland (1970) demonstrated for dry method analysis of femur marrow fat. The relatively easy procurement of mandibles (e.g., from hunter-killed caribou) makes their use attractive, and the correlation with femur fat suggests they can be satisfactorily used as a relative condition index if limitations are recognized.

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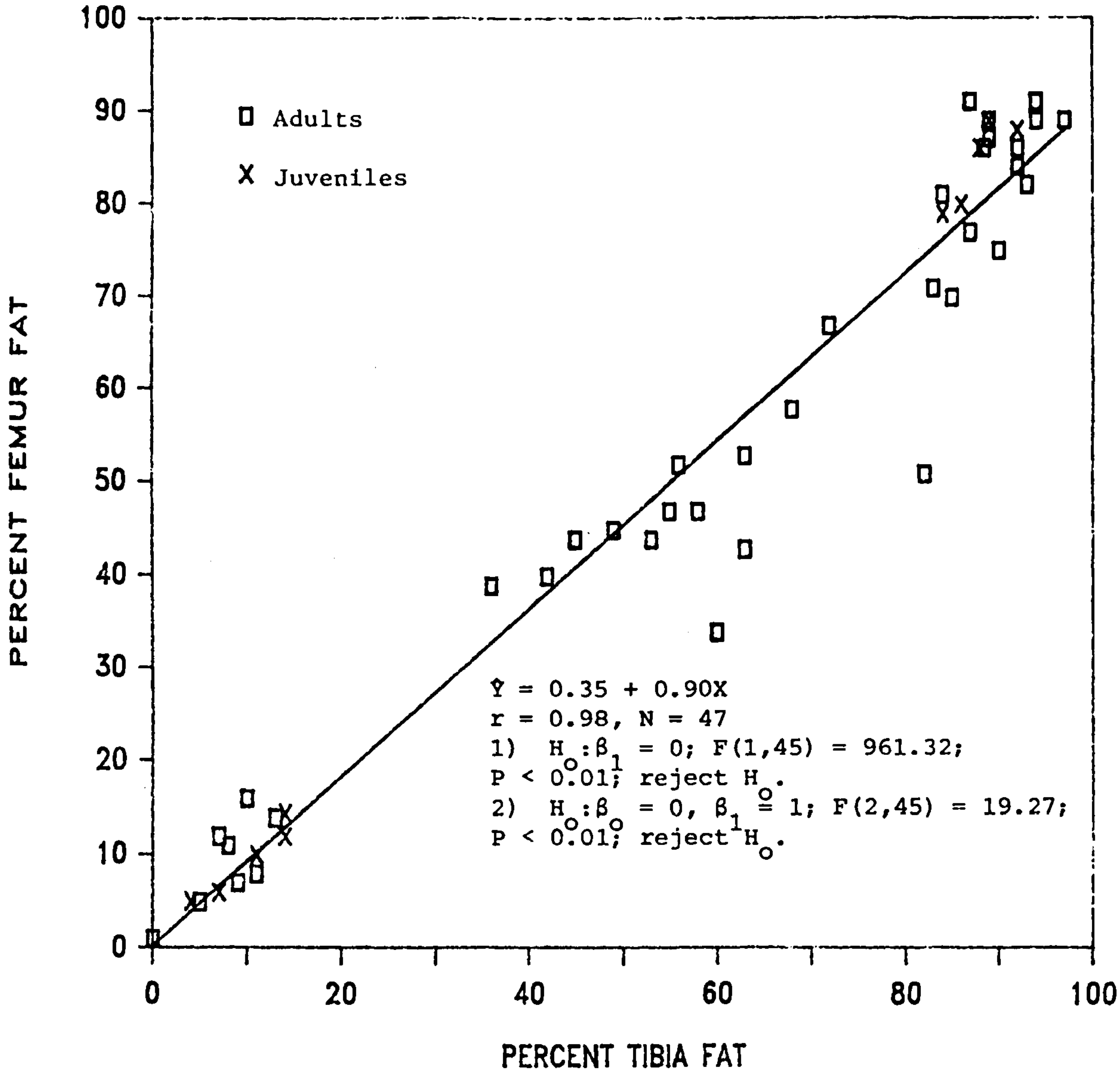

Fig. 1. Relationship between percent marrow fat in the femur and tibia from the same caribou.

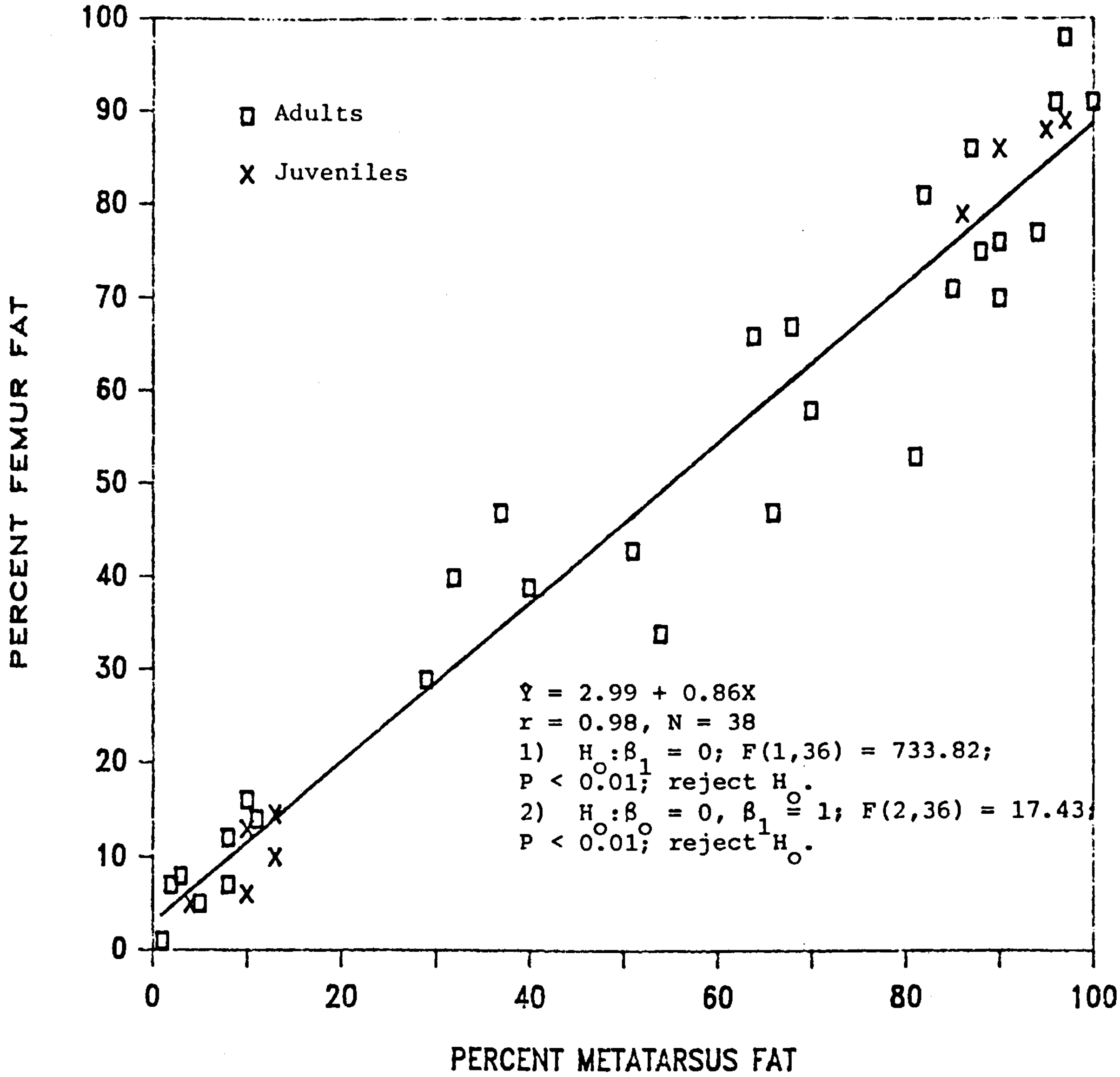

Fig. 2. Relationship between percent marrow fat in the femur and metatarsus from the same caribou.

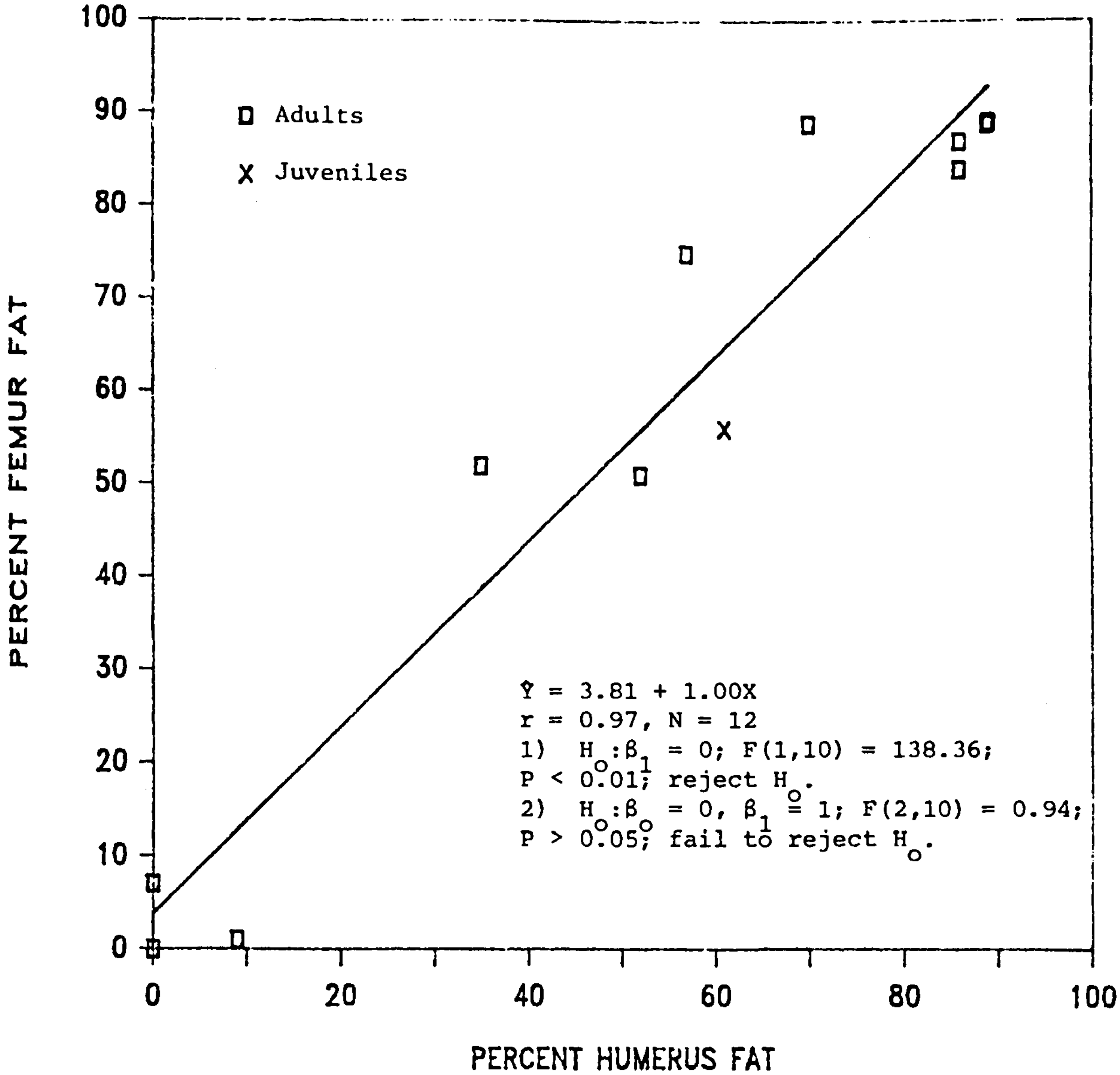

Fig. 3. Relationships between percent marrow fat in the femur and humerus from the same caribou.

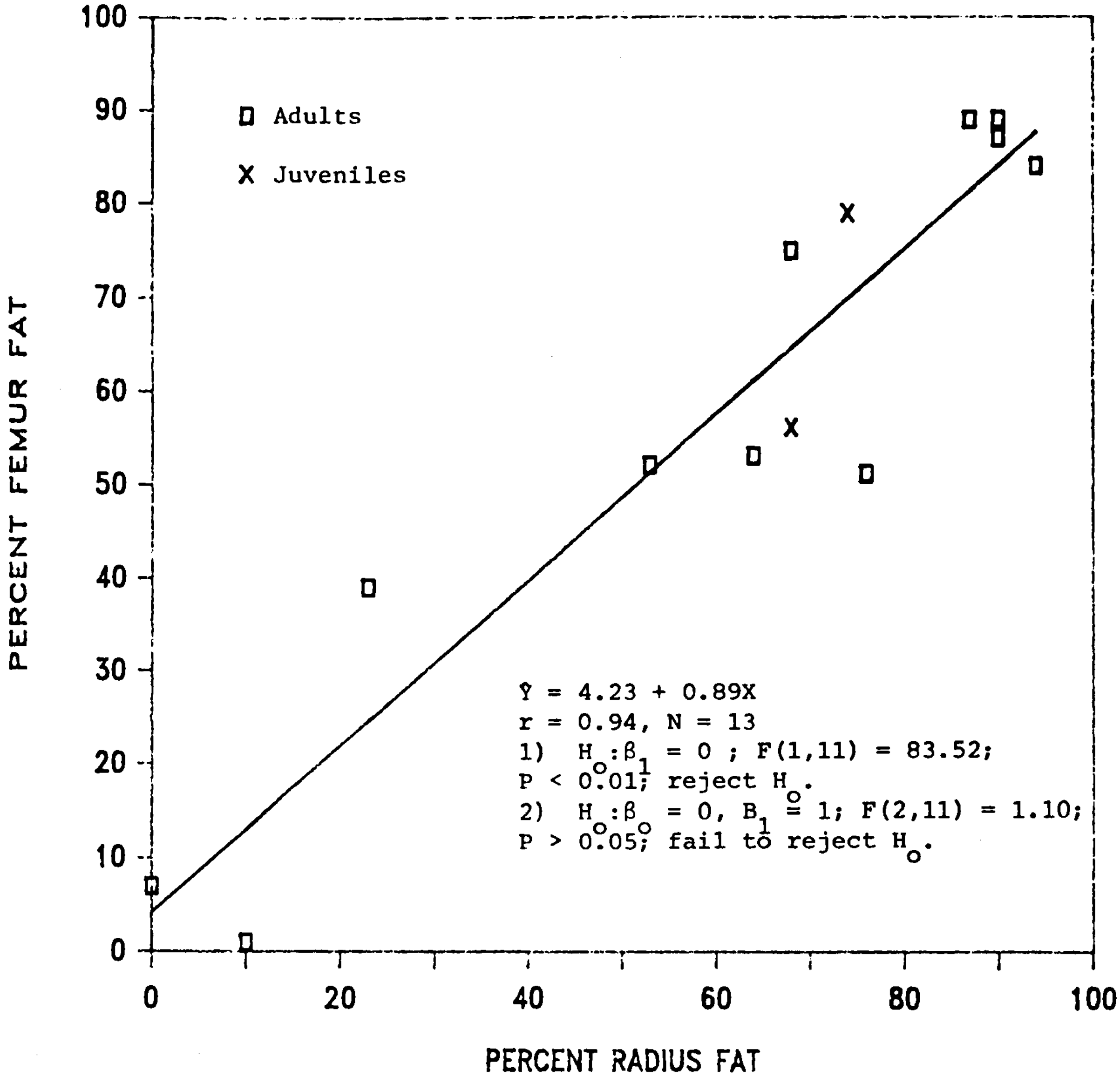

Fig. 4. Relationship between percent marrow fat in the femur and radius from the same caribou.

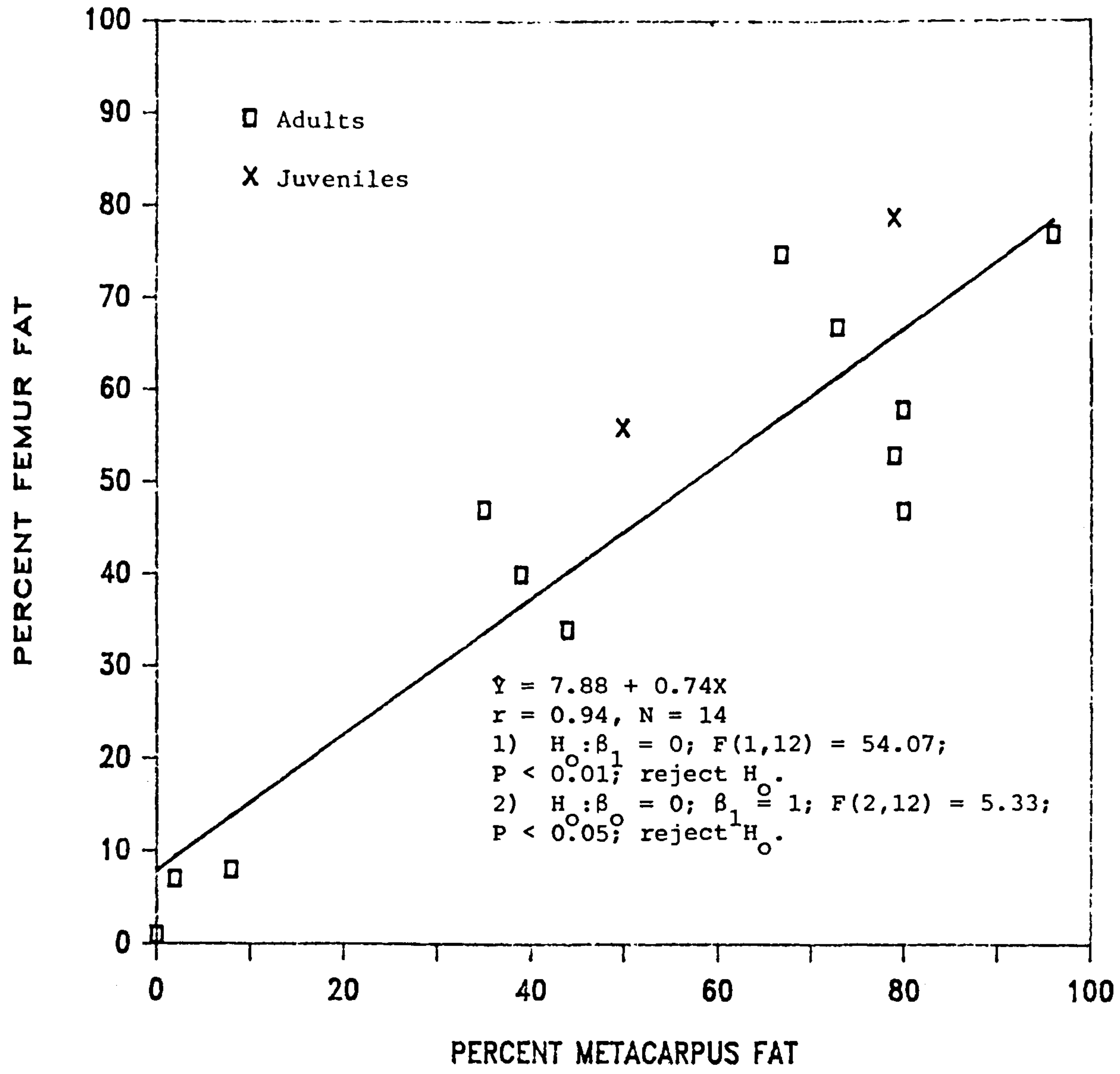

Fig. 5. Relationship between percent marrow fat in the femur and metacarpus from the same caribou.

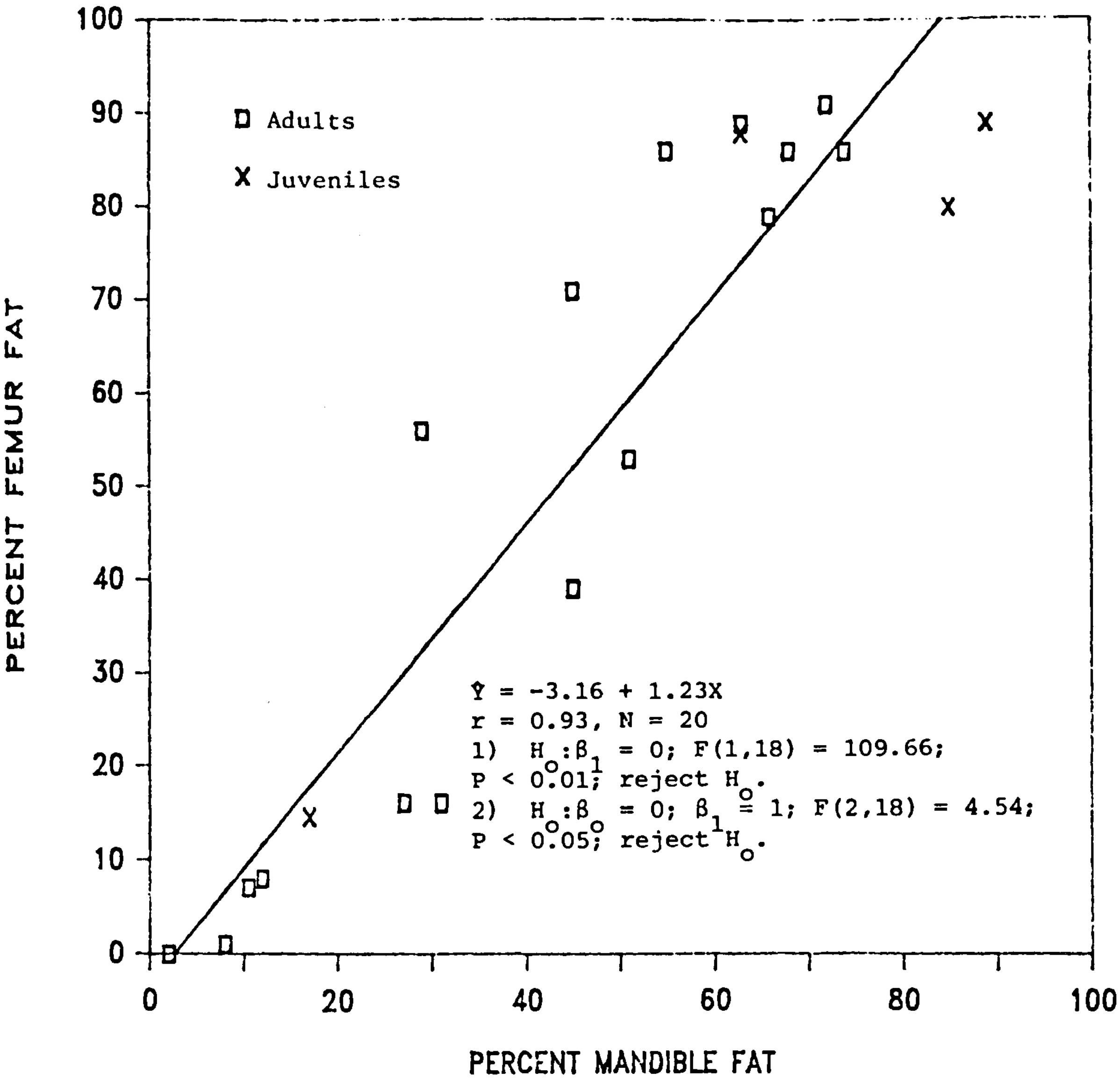

Fig. 6. Relationship between percent marrow fat in the femur and mandible from the same caribou.

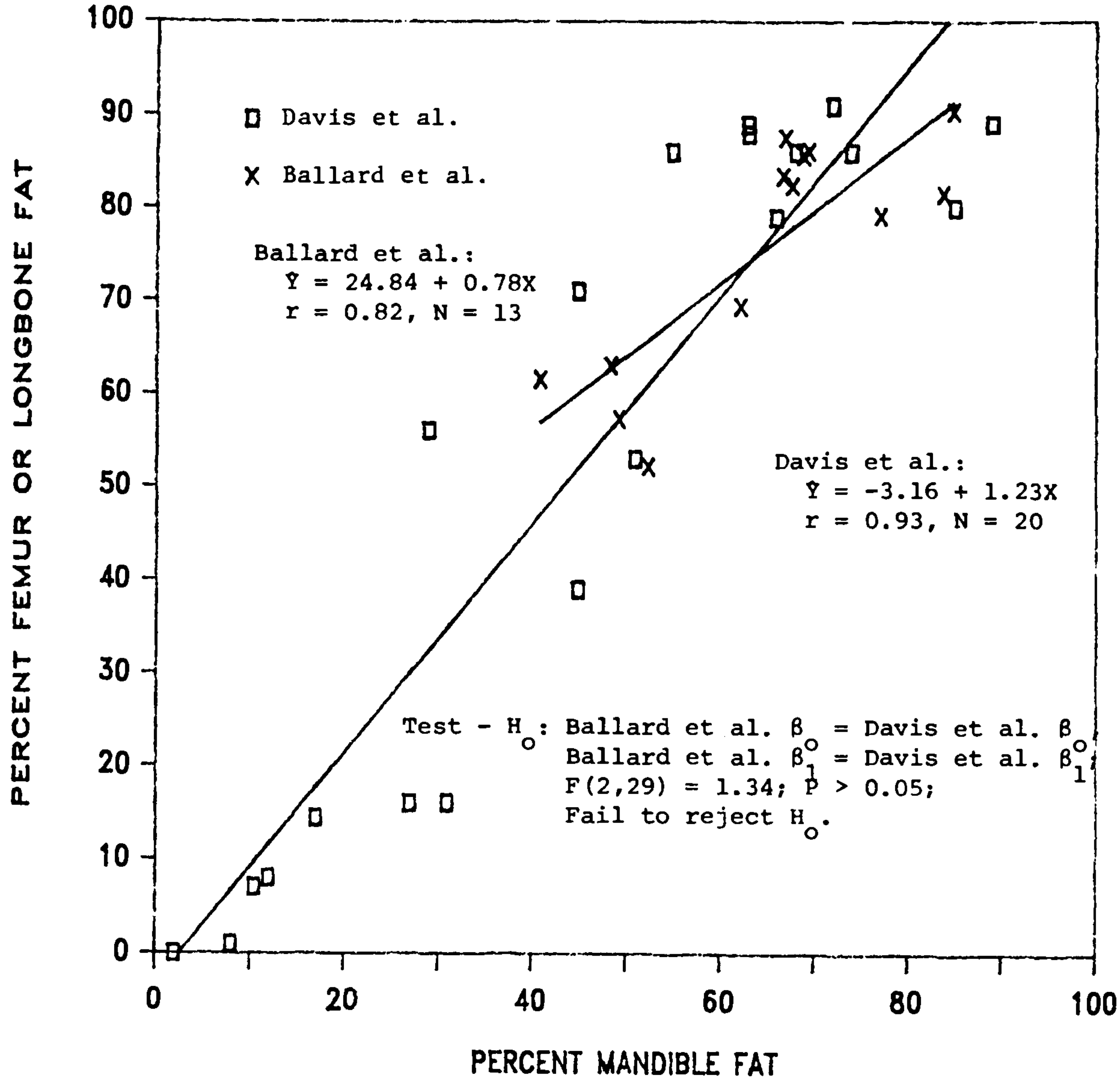

Fig. 7. Comparison of percent marrow fat relationship between femur and mandible from the same caribou and Ballard et al.'s (1982) percent marrow fat relationship between long bones and mandible from the same caribou.

Table 1. Percent fat in bone marrow of paired bones from individual caribou.

Bone pair X Y	No. pairs	Mean % fat		d = x - y	
		$\bar{x}$ (sd)	$\bar{y}$ (sd)	$\bar{d}$ (sd)	range
Femur-	47[a]	52.2(31.5)	57.4(34.1)	-5.2(7.4)	-31 to 6
tibia	33[b]	37.5(25.9)	43.3(31.3)	-5.8(8.5)	-31 to 6
Tibia-	37	51.2(35.3)	50.3(36.6)	0.9(9.3)	-18 to 35
metatarsus	24	31.5(27.9)	28.4(25.7)	3.1(10.6)	-18 to 35
Humerus-	13	55.4(33.6)	61.1(33.5)	-5.7(11.3)	-24 to 22
radius	10	45.9(32.7)	52.0(33.2)	-6.1(12.7)	-24 to 22
Radius-	10	50.8(31.5)	51.7(33.1)	-0.9(9.3)	-15 to 18
metacarpus	10	50.8(31.5)	51.7(33.1)	-0.9(9.3)	-15 to 18
Femur-	12	56.7(35.6)	52.8(34.4)	3.8(9.3)	-8 to 19
humerus	8	41.4(34.5)	35.5(28.8)	5.9(10.9)	-8 to 19
Tibia-	13	66.2(32.3)	62.1(31.6)	4.2(8.6)	-10 to 22
radius	9	54.9(33.0)	49.6(30.4)	5.3(9.6)	-10 to 22
Metatarsus-	14	51.9(32.3)	54.4(32.8)	-2.5(14.2)	-41 to 21
metacarpus	13	48.7(31.2)	51.2(31.8)	-2.5(14.8)	-41 to 21
Femur left-	17	48.4(29.3)	45.8(27.0)	2.6(7.8)	-10 to 21
femur right	16	45.9(28.3)	43.4(25.9)	2.6(8.0)	-10 to 21

[a] Includes all pairs regardless of percentage fat.

[b] Includes only bone pairs where the percentage fat is less than 80% in one or both bones.

APPENDIX B. Observations on the relative severity of winter weather in the range of the Western Arctic Caribou Herd, 1975-83.

Winter	Observation
1975-76	This was a relatively severe winter in northwest Alaska. Snow was deep on the arctic coastal plain.
1976-77	Snow was relatively deep in the northern foothills of the Brooks Range but shallow on the arctic coastal plain. About 12 winter-killed caribou were found in the Umiat area but the overall effect of the winter on caribou was thought to be slight. Elsewhere, the winter was mild, although snow was locally deep in the Koyukuk drainage.
1977-78	Winter conditions were average, and many caribou wintered on the arctic coastal plain. Some dead caribou with heavy warble infestations were found.
1978-79	Snow was deep on the arctic coastal plain but low in the northern foothills of the Brooks Range.
1979-80	Two heavy rains in November formed 2 ice layers in the snow at Nuiqsuit and Driftwood at least. Snow was relatively deep in the northern foothills of the Brooks Range. Some WACH caribou were seen moving from the coast to the foothills in November. Fewer caribou wintered on the coastal plain than in any year since 1975-76. Spring composition counts in WACH caribou indicated that survival of calves was lower on the arctic coastal plain than on the Selawik/Kobuk/Buckland winter range.
1980-81	Winter was mild and snow was relatively light on the southern winter range and on the arctic coastal plain. Snow was relatively deep in the northern foothills of the Brooks Range, but few caribou wintered there.
1981-82	Caribou had little trouble feeding on the coastal plain despite a freezing rain in January. Few carcasses were found there despite the most extensive search of any winter so far.
1982-83	About one-third of the herd wintered on the arctic coastal plain. There were extensive ice-covered areas especially around Teshekpuk and Wainwright due to 2 freezing rains. Some radio-collared caribou left the

coastal plain in February and went to the northern foothills. Some winter-killed caribou were found, including 2 of 14 radio-collared caribou, but overall the winter mortality was not high, and many caribou remained on the coastal plain.