BONE MARROW FAT AS AN INDICATOR OF UNGULATE CONDITION --HOW GOOD IS IT?

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ABSTRACT: Bone marrow fat has been widely used for assessing physical condition of ungulates at time of death. I review femur marrow fat levels of wolf (*Canis lupus*)-killed moose (*Alces alces*) and caribou (*Rangifer tarandus*) from several areas of North America, compare them with fat content of wolf-killed ungulates from northwest Alaska, and identify factors which should be considered when evaluating bone marrow fat. Assessment of relative condition based upon bone marrow fat should consider type of mortality, season of mortality, vulnerability, and the relative condition of the population in relation to the individual being examined.

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Marrow fat of longbones has been widely used as an index of physical condition of ungulates at time of death (Cheatum 1949, Baker and Leuth 1966, Neiland 1970, Franzmann and Arneson 1976, Peterson 1977, Peterson *et al.* 1984, Ballard *et al.* 1987, Mech *et al.* 1995). For predator-killed animals, the hypothesis has been that animals with relatively high bone marrow fat values were not predisposed to predation, whereas those with low fat values may have been. However, both Mech and DelGiudice (1985) and Ballard *et al.* (1987) have pointed out that statements about the health of an animal near death, based on marrow fat data, are "one way"; it can be stated more confidently that an animal had debilitations than to state it was completely "healthy." In addition to this uncertainty, predator-killed animals seldom provide sufficient evidence for evaluation of body condition because often carcasses are fully consumed, and only a few bone fragments (e.g., inedible ramuses) remain (Ballard *et al.* 1981).

Both Snider (1980) and Ballard *et al.* (1981) examined the relationships between mandible marrow fat and longbone marrow fat in moose. There was a significant positive correlation between marrow fat levels in ramuses and other longbones. Ballard *et al.* (1981) combined the Ontario (Snider 1980) and Alaska data and developed a deterministic equation to estimate marrow fat in longbones based upon that found in ramuses. Davis *et al.* (1987) provided similar equations for caribou longbones and ramuses. They found that evaluation of the amount of marrow fat in other bones besides femurs was a valid indicator of relative condition, but that it was useful to regress the values from other bones to the "femur standard".

I report on bone marrow fat levels found in wolf-killed ungulates during 1989 and 1990 in northwest Alaska, compare them to several other areas of North America, and reexamine the paradigm that bone marrow fat is a reliable indicator of condition.

STUDY AREA

The study was conducted in northwest Alaska in game management unit 23. The 12,000-km^2 study area was located approximately 200 km east of Kotzebue, Alaska. Topography, vegetation, and climate have been throughly described by Ballard *et al.* (1996).

METHODS

I collected ramuses and longbones of wolf-killed ungulates found while daily relocating several wolf packs during March and April 1989 and 1990 (Ballard *et al.* 1996) for determining percent marrow fat (Nieland 1970) and prey age (Sergeant and Pimlott 1959, Skoog 1968). Samples were collected within 2 weeks after wolves left carcasses and were stored frozen in plastic sealed bags. Samples were processed during May and June of the year they were collected. I regressed the marrow fat content in other bones to the femur standard and then compared the average values (± SE) with those reported in the literature.

RESULTS

Twelve adult caribou (7F, 1M, and 4 unknown sex) and 10 yearling or adult moose carcasses (3F, 2M, 2 calves, 3 unknown sex or age) were examined. Average age of adult caribou and adult moose was 8.1 ± 0.6 and 7.0 ± 2.6 years, respectively. I combined carcasses of unknown sex with females, because sex ratios in the populations were weighted towards females (J. R. Dau, Alas. Dep. Fish and Game, unpubl. data).

Adult caribou killed by wolves during 1989 and 1990 had an average femur fat content of 79 ± 5.8% (n = 12). Marrow fat ranged from 13 to 96%, depending on type of bone examined. Adult female moose (n = 6) killed by wolves averaged 64 ± 3.6% (range = 6-94%) femur fat. Two adult males and 2 calves of unknown sex averaged 29 ± 2.6 and 55 ± 27.6% femur fat, respectively. Average fat content by bone type for caribou and moose suggested that fat mobilization proceeded more quickly in proximal than in distal bones (Ballard 1993). Peterson *et al.* (1982) and Davis *et al.* (1987) have previously reported this trend.

DISCUSSION

Franzmann and Arneson (1976) and Peterson *et al.* (1984) considered calf and adult moose with femur marrow fat levels of <10% and <20, respectively, to be near death from starvation. However, several authors have reported marrow fat levels >10% for calves that starved to death (Franzmann and Arneson 1976, Ballard *et al.* 1987). Mech *et al.* (1995) suggested that use of <10% and <20% femur marrow fat as a threshold level for starvation was probably conservative, that such low contents ignored starvation physiology, and that using them could lead to erroneous conclusions. They suggested femur marrow fat contents ≤70-87% should be thought of in terms of body fat and muscle depletion, and reflected individuals in marginal condition. Watkins *et al.* (1991) determined that for white-tailed deer (*Odocoileus virginianus*) fawns, marrow fat had limited usefulness as an index of fawn condition because marrow fat was not depleted until body fat declined to about 15%. Below 87% femur fat large differences in fat reflected only small differences in body fat concentrations.

Franzmann and Arneson (1976) described the annual cycle of bone marrow fat deposition and depletion in Alaskan moose. Typically, marrow fat values increase during late summer and autumn, then decline throughout winter. I suggest that many ungulate populations at northerly latitudes undergo this seasonal variation in marrow fat during most years. If correct, most moose populations should exhibit relatively low marrow fat values by late winter unless they occurred on excellent winter range with extremely mild weather conditions. If this prediction holds true, then what constitutes a healthy animal may be relative to other members of the population each year. I suggest that animals which exhibit bone marrow values similar to those of animals killed by unnatural causes (i.e., road-kills, hunter-kills) during late winter might be considered as "relatively healthy." Animals suffering from parasitism, physical injuries, or other abnormalities should exhibit additional fat mobilization beyond that which occurs during the normal rigors of winter. These animals should differ significantly from those in the population at large. On the other hand, if the entire population is exhibiting relatively low bone marrow fat values then the entire population may be exhibiting food stress, however, they are not necessarily predisposed to death. In these cases predation can exert a significant effect on the population because the animals may be more vulnerable to predation.

Timing of death and cause of death are important factors which can determine the assessment of whether an animal is suffering from malnutrition based on bone marrow fat. For example, Ballard *et al.* (1987) determined that there was no significant difference in marrow fat values between wolf-killed moose and those killed from accidental causes but that those known to have died from starvation had significantly lower fat values. The inference being that wolves were killing moose that were not malnourished or at the least, in better condition than those known to have died from starvation. Animals which have relatively low marrow fat values in relation to the population during late summer and autumn could probably be considered in poor condition.

I compared marrow fat contents of moose and caribou that died from starvation, wolf predation, and accidental causes from several areas in Alaska and the Yukon Territory (Table 1). Based upon marrow fat, Franzmann

Table 1. Comparison of average percent femur marrow fat (n) during late winter for moose and caribou by cause of death from several study areas in North America.

		Cause of death			
Age-Species	Location	Starvation	Wolf-killed	Accidental	Source
Moose-calf	Kenai Peninsula, Alas.	7.3 (86)	22.1 (8)	28.3 (21)	Franzmann and Arneson (1976)
	South-central Alas.	12 (20)	31 (49)	24 (8)	Ballard *et al.* (1987)
	Yukon Territory		60 (17)		Hayes *et al.* (1991)
	Denali Nat Park, Alas.		32-67[a] (19)		Mech *et al.* (1995)
	Northwest Alas.		54.8 (2)		This study
Moose-adult	Kenai Peninsula, Alas.	7.3 (11)	69.9 (11)	69.2 (44)	Franzmann and Arneson (1976)
	South-central Alas.	52 (10)	77 (106)	79 (13)	Ballard *et al.* (1987)
	Yukon Territory		80 (32)		Hayes *et al.* (1991)
	Denali Natl. Park, Alas.		62-74[b] (26)		Mech *et al.* (1995)
	Northwest Alas.		64.3[c/] (6)		This study
Caribou-calf	Northwest Alas.	8 (7)	50 (2)	70 (6)	Davis and Valkenburg calf (1985)
	Denali Natl. Park, Alas.		31-45[a] (14)		Mech *et al.* (1995)
Caribou-adult	South-central Alas.		81 (21)		Ballard *et al.* (1987)
	Northwest Alas.	5.3[c] (7)	60[c] (15)	51[c] (18)	Davis and Valkenburg (1985)
	Denali Natl. Park, Alas.		62-86[b] (33)		Mech *et al.* (1987)
	Northwest Alas.		80.6 (13)		This study

[a]February through April.
[b]Adult Females, February through April.
[c]Adult females.

and Arneson (1976), Ballard *et al.* (1987), and Hayes *et al.* (1991) concluded that wolves were preying on adult moose that were not malnourished. Peterson *et al.* (1984) concluded that wolves preyed upon relatively old adults that were not malnourished, but exhibited a high frequency of debilitations. However, as pointed out earlier, low bone marrow fat is only an indicator that an animal is near starvation. High fat content does not provide definitive data that an animal is necessarily healthy (Mech and DelGiudice 1985, Ballard *et al.* 1987) and does not provide any information concerning vulnerability. For example, deep snow during 1978-1979 in south-central Alaska subjected apparently healthy caribou to heavy levels of wolf predation (Eide and Ballard 1982). Comparison of data from northwest Alaska during 1989 and 1990 with data from other studies suggests that wolves in northwest Alaska preyed upon caribou which were not malnourished and upon moose which may have been malnourished or in declining condition.

I believe that bone marrow fat is a useful tool for population assessment that should not be discarded by field biologists. Mech *et al.* (1995) have suggested that animals with fat contents approaching 70-87% are in a downward trend in physical condition. Although I believe they are correct, I suspect this decline may be a normal condition in many northern moose populations. Additional research in this area is warranted.

Assessment of the meaning of various levels of bone marrow fat is imperative to our understanding of the interpretation of bone marrow fat contents. Collection of these data would seem to lend itself to study through use of captive animals. Experiments should be conducted with animals on several nutritional levels and experimentally infected with parasites and diseases, and the fat content of various animals determined. We should continue to measure fat content in a variety of bones because often these are the only clues we have as to the condition of the animal at death.

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