BONE MARROW FAT CONTENT FROM MOOSE IN NORTHEASTERN MINNESOTA, 1972-2000

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ABSTRACT: Percent fat in femur bone marrow has been used as an indicator of animal condition at time of death. However, femur bone marrow is not always available for collection. We used linear regression to examine relationships among marrow fat values for long bones (i.e., femur, tibia, mandible, humerus, radius, tarsal and carpal bones) of moose (*Alces alces*) from northeastern Minnesota during 1972-2000. Linear regressions for bone marrow fat in each set of bones (paired with femur) in calves and adults were significant and highly correlated (r^2 = 0.83-0.99). Linear regressions for femur bone marrow fat for yearling moose were significant and highly correlated for tibia, humerus and radius bones (r^2 = 0.86-0.93), and less so for tarsal bones (r^2 = 0.63). Bone marrow fat deposition appeared first in proximal and distal bones and was mobilized last in distal bones. Calves had higher femur fat in fall and early winter than late winter and spring. Month, season, and year had no significant effect on femur marrow fat percent for yearlings or adults. Percent femur marrow fat was lower in accidentally killed calves than accidentally killed yearlings or adults. Adults killed by disease had lower percent femur fat than those killed by accident or wolves (*Canis lupus*). Amount of adult male femur fat was loosely correlated to a winter severity index for the previous winter. Our results suggest that fat deposition and mobilization were similar to that found in other studies and that bone marrow fat content may be a good indicator of relative moose health within a population.

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Key words: *Alces alces*, bone marrow, death, deposition, fat, femur, Minnesota, moose, wolves

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Bone marrow fat percentages have been widely used as an index of ungulate condition at time of death (Cheatum 1949, Baker and Leuth 1966, Neiland 1970, Franzmann and Arneson 1976, Peterson 1977, Peterson and Bailey 1984, Ballard et al. 1987, Mech et al. 1995). Marrow fat is mobilized after other body fat reserves are depleted or exhausted (Cheatum 1949, Smith and Jones 1961). Reduction in bone marrow fat may therefore be a good indicator of decreased fitness of an individual. However, the percentage of marrow fat depletion indicating a stressed animal has been debated (Mech and DelGiudice 1985, Ballard 1995). Moreover, what constitutes a healthy animal may be relative to other members of the population each year (Ballard 1995), and a high marrow fat content would not necessarily indicate an animal in good condition (Mech and DelGiudice 1985, Ballard et al. 1987). Despite discrepancies in conclusions regarding stage of individual health, bone marrow fat depletion often remains the only indicator of individual condition at time of death (Ballard 1995).

Fat levels from the femur have typically been used to draw conclusions regarding the condition of individual moose at time of death (Cheatum 1949, Franzmann and Arneson 1976, Peterson et al. 1982, Ballard et al. 1987, Hayes et al. 1991, Ballard 1995, Mech et al. 1995). However, predators often consume proximal leg bones (Ballard et al. 1981, Peterson et al. 1982), and frost wedging may expose femur marrow to the air, rendering the sample useless (Peterson et al. 1982). Researchers must often settle for collection of other bones for analysis, and the correlation of marrow fat in these bones with that of the typically used femur is desirable.

While investigating natural and human-caused mortality of moose (*Alces alces*) in Minnesota during 1972-2000, amount of marrow fat was estimated in femur, tibia, mandible, humerus, radius, tarsal, and carpal bones of individual moose. We examined correlations between femur marrow fat and marrow fat in the above bones for moose divided into 3 age classes to determine their usefulness as indices of health as related to the femur marrow fat standard. We also present data on the annual cycle of bone marrow fat deposition and mobilization in moose, and examine differences in amount of femur bone marrow fat among seasons, years, cause of death, and age class.

STUDY AREA AND METHODS

The study was conducted from 1972-2000 in Cook and Lake counties in northeastern Minnesota. The majority of moose examined were within 65 km of Poplar Lake, located in Superior National Forest, Cook County, Minnesota. A description of the study area was provided by Nelson and Mech (1981).

We sexed moose by examining sex organs or by the presence or absence of antlers or pedicles. Age of calves and yearlings was determined by tooth eruption and replacement. Dental cementum was used to determine adult ages. A femur, tibia, humerus, radius, tarsal, carpal, and mandible was collected from each moose carcass if possible, usually within several hours after death. Bone samples from each moose were stored frozen for up to a few months before being processed. Bones were broken with a hammer. Marrow samples were removed by hand from the central portion of the marrow tube. Marrow fat content was determined by the oven drying technique described by Neiland (1970).

We separated bone marrow fat data by age class of individual due to possible differences of marrow fat mobilization at different stages of life (Ballard et al. 1981). Moose within 1 year of birth were classified as calves, 1-2 years of age as yearlings, and $\geq$2 years of age as adults. All moose were assumed born 1 June (Schwartz 1998).

We classified causes of death as automobile or train collision, natural accidental death, hunter-kill, killed intentionally as a danger to humans, diseased (brainworm [*Parelaphostrongylus tenuis*] confirmed or suspected, or heavy tick load with heavy hair loss), wolf (*Canis lupus*)-kill, or unknown. Marrow fat content means are given $\pm$ SD. Fat was analyzed by month and season of death. Month of death was lumped into 1 of 4 seasons: 1 = December-February, 2 = March-May, 3 = June-August and 4 = September-November.

We calculated regression lines and Pearson's Product-Moment correlations for each comparison between an individual's femur and other bones examined within each age class. We assumed the simple linear model: $Y = B + MX + \varepsilon$, where Y = marrow fat value of bone being correlated, X = marrow fat value of femur, B = the value of Y when X = 0, M = best-fit slope of comparison line, and ε = residual error unaccounted for by the model. *F*-tests were calculated to determine whether models of similar bone pair regressions differed significantly among age classes (Graybill 1976).

F-statistics were calculated to examine differences in femur marrow fat content among age classes. F-statistics were also calculated to examine effects of month, season, and cause of death on bone marrow fat content in femurs within each age class. Where F-tests were significant, Student's t-test was used to determine differences in femur marrow fat means among age classes, causes of death, and seasons. Following Ballard et al. (1981) and Davis et al. (1987), we used paired t-tests to examine differences in marrow fat content between femurs and all other bones examined, as well as humerus-tibia,humerus-carpal, and proximal-distal bone pairs. Welch's approximate t values and associated degrees of freedom were used in cases where variances between Student's t-test groups were not homogeneous (Zar 1999).

A winter severity index (WSI) was calculated for each winter from weather data collected at Poplar Lake in Cook County, Minnesota (Minnesota Department of Natural Resources, Section of Wildlife, Grand Marais, Minnesota). The WSI was defined as: sum of number of days $\leq$-17.8 degrees Celsius + number of days with $\geq$38.1 cm of snow. F-tests were calculated to examine relationships between femur marrow fat content and WSI the preceding winter. All computer regressions, t-tests, and F-test calculations were completed using Statistica 2000 (StatSoft, Tulsa, OK).

RESULTS

One-hundred four adults (37M, 67F), 47 yearlings (26M, 21F) and 45 calves (26M, 19F) were examined. Calf marrows were obtained for all months except July, and marrows from only the femur and mandible were collected from October death samples. Yearling samples were collected in all months except February, April, and December. Adult marrows were collected in every month except March.

Linear regressions for bone marrow fat in each set of bones (paired with femur) in calves were highly correlated and significant (Table 1). Linear regressions for marrow fat in yearling moose femurs were significant and highly correlated for tibia, humerus, and radius bones. Regressions in marrow fat between femur and mandible,

Table 1. Regression equations for bone marrow fat percentage comparisons among bones in calf moose (<1 year old) from northeastern Minnesota, 1972-2000.

Bone Pair	$\bar{X}$ (SD)	n pairs	Regression Equation	r^2	P
Femur- Tibia	48.2 (24.7) 53.0 (26.3)	30	T = 4.8820 + 0.9976 (F)	0.94	<0.001
Femur- Mandible	50.0 (24.8) 50.0 (19.6)	35	M = 14.574 + 0.70435 (F)	0.91	<0.001
Femur- Humerus	48.2 (24.7) 49.9 (25.6)	30	H = 0.49474 + 1.0243 (F)	0.99	<0.001
Femur- Radius	48.2 (24.7) 50.8 (27.2)	30	R = 0.2615 + 1.0579 (F)	0.96	<0.001
Femur- Tarsal	48.2 (24.7) 53.8 (22.0)	30	T = 15.012 + 0.80347 (F)	0.90	<0.001
Femur- Carpal	48.2 (24.7) 57.1 (20.2)	30	C = 23.639 + 0.69442 (F)	0.85	<0.001

tarsal, and carpal bones were significant but less correlated (Table 2). For adults, linear regressions for marrow fat in each set of bones were significant and highly correlated (Table 3; Figs. 1-6). Regression models (i.e., either slopes, intercepts, or both) among adults, yearlings, and calves differed for all bone pair comparisons except for the yearling-calf comparison in the femur-humerus bone pair (Table 4).

Mean marrow fat in calves was lower in the femur than tarsal, humerus, carpal, and tibia bones and lower in the humerus than carpal (Table 5). Mean marrow fat in yearlings was lower in the femur than tarsal, humerus, and carpal bones, higher in the femur than mandible, and higher in the humerus than carpal (Table 6). Mean marrow fat in adults was lower in the femur than tarsal and carpal bones, higher in the femur than mandible, and lower in the humerus than carpal (Table 7).

Femur marrow fat did not differ among moose killed by vehicle, accident, hunters, or unknown causes in calves ($F_{2,29} = 0.195$; $P = 0.824$), yearlings ($F_{3,35} = 1.081$; $P = 0.370$), or adults ($F_{3,58} = 2.372$; $P = 0.080$). These mortality categories were therefore combined as accidental deaths. No relationship existed between age in years and femur fat in accidentally killed males ($F_{1,61} = 0.042$; $P = 0.838$). Femur marrow fat in accidentally killed females increased with age (Y = 72.202 + 1.702(age); $r^2 = 0.112$; $F_{1,67} = 8.429$; $P = 0.005$). Femur marrow fat was lower in accidentally killed calves than accidentally killed yearling or adult moose (Fig. 7).

Femur marrow fat and sample size in each age class by month is shown in Figure 8. Femur marrow fat in calf moose ($\bar{X} = 52.500 \pm 24.035$; range = 5-88) differed by month ($F_{10,31} = 4.117$; $P = 0.001$) and season ($F_{3,38} = 5.020$; $P = 0.005$), but not year ($F_{20,21} = 1.342$; $P = 0.254$). Femur fat content differed among months ($F_{10,31} = 4.117$; $P = 0.001$) and seasons in calves killed accidentally. Calves had higher femur fat in seasons 3-4 ($\bar{X} = 64.250 \pm 19.461$; $n = 16$) than 1-2 ($\bar{X} = 42.269 \pm$

Table 2. Regression equations for bone marrow fat percentage comparisons among bones in yearling moose (1-2 years old) from northeastern Minnesota, 1972-2000.

Bone Pair	$\bar{X}$ (SD)	n pairs	Regression Equation	r^2	P
Femur- Tibia	78.5 (11.1) 80.7 (11.1)	28	T = 16.739 + 0.815 (F)	0.81	<0.001
Femur- Mandible	78.7 (10.5) 65.0 (6.7)	31	M = 44.191 + 0.265 (F)	0.42	0.028
Femur- Humerus	78.9 (11.1) 80.4 (10.7)	27	H = 0.9519 + 0.899 (F)	0.93	<0.001
Femur- Radius	78.9 (11.1) 80.2 (11.3)	27	R = 11.156 + 0.8759 (F)	0.86	<0.001
Femur- Tarsal	78.9 (11.1) 85.0 (7.9)	27	T = 49.722 + 0 .445 (F)	0.63	<0.001
Femur- Carpal	78.8(11.1) 87.4 (5.1)	27	C = 68.058 + 0.24492 (F)	0.53	0.004

Table 3. Regression equations for bone marrow fat percentage comparisons among bones in adult moose (>2 years old) from northeastern Minnesota, 1972-2000.

Bone Pair	$\overline{X}$ (SD)	*n* pairs	Regression Equation	r^2	*P*
Femur-	71.0 (26.3)	62	T = 5.2776 + 0.94322 (F)	0.96	<0.01
Tibia	72.3 (25.9)				
Femur-	71.3 (26.2)	63	M = 19.277 + 0.60666 (F)	0.86	<0.001
Mandible	78.4 (19.7)				
Femur-	70.2 (27.1)	70	H = 0.98791 + 0.99693 (F)	0.99	<0.01
Humerus	61.6 (18.8)				
Femur-	70.7 (26.4)	61	R = 4.3726 +0.94837 (F)	0.97	<0.01
Radius	71.4 (25.8)				
Femur-	71.3 (26.2)	63	T = 32.581 + 0.64246 (F)	0.85	<0.001
Tarsal	78.4 (19.7)				
Femur-	71.3 (26.2)	63	C = 36.891 + 0.59844 (F)	0.83	<0.001
Carpal	79.6 (19.0)				

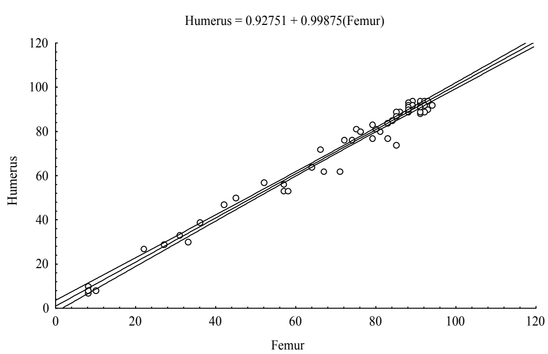


Fig. 1. Relationship between percent marrow fat in the femur and humerus for adult moose from northeastern Minnesota, 1972-2000.

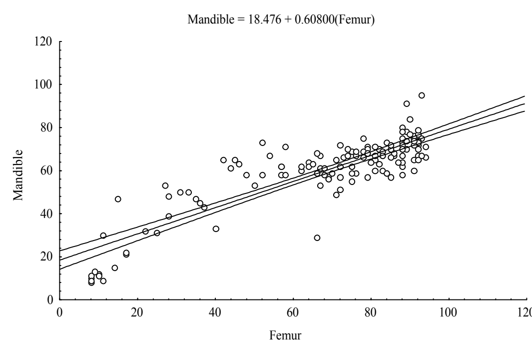


Fig. 3. Relationship between percent marrow fat in the femur and mandible for adult moose from northeastern Minnesota, 1972-2000.

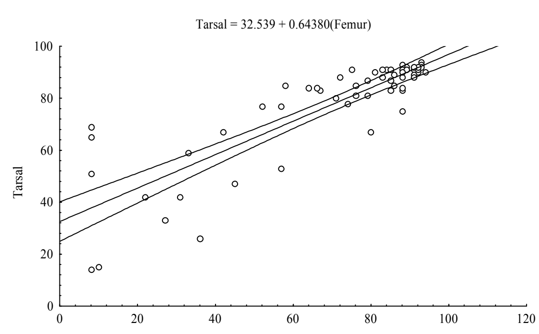


Fig. 2. Relationship between percent marrow fat in the femur and tarsal for adult moose from northeastern Minnesota, 1972-2000.

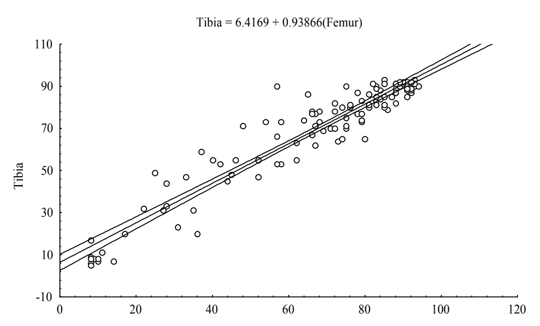


Fig. 4. Relationship between percent marrow fat in the femur and tibia for adult moose from northeastern Minnesota, 1972-2000.

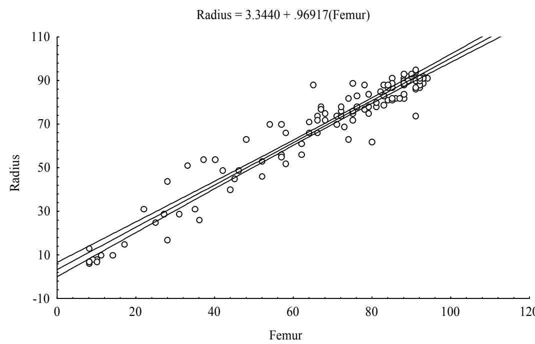


Fig. 5. Relationship between percent marrow fat in the femur and radius for adult moose from northeastern Minnesota, 1972-2000.

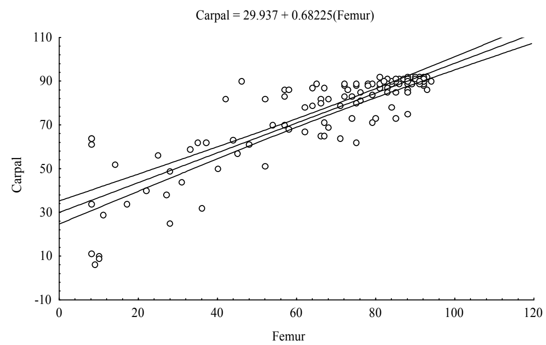


Fig. 6. Relationship between percent marrow fat in the femur and carpal for adult moose from northeastern Minnesota, 1972-2000.

24.029; *n* = 26) (t_{40} = -2.664; *P* = 0.011). Calves killed by accident ($\bar{X}$ = 60.563 ± 18.371; *n* = 32) had more femur fat than those killed by disease ($\bar{X}$ = 24.222 ± 22.174; *n* = 9) (t_{39} = 5.013; *P* <0.001). Only one calf killed by wolves was examined. Femur marrow fat for this individual was 49%.

Femur marrow fat among all yearling moose killed ($\bar{X}$ = 77.732 ± 11.194 range = 46-92) did not differ by month ($F_{8,32}$ = 1.453; *P* = 0.213), season ($F_{3,37}$ = 0.634; *P* = 0.598), or year ($F_{14,26}$ = 0.898; *P* = 0.571). Femur fat did not differ among months ($F_{7,30}$ = 1.627; *P* = 0.166), seasons ($F_{3,34}$ = 0.598; *P* = 0.620), or years ($F_{14,23}$ = 0.825; *P* = 0.638) for yearlings accidentally killed. Only one yearling killed by wolves and one killed by disease were examined. Femur marrow fat for yearling moose killed accidentally averaged 78% ± 11.4 (*n* = 38). Femur marrow fat content was 68% for the wolf-killed yearling and 73% for the yearling dying of disease.

For adults, number of moose examined

Table 4. *F*-test degrees of freedom and *F*-values for tests of equality of models in moose bone pairs from northeastern Minnesota, 1972-2000. All tests evaluated at alpha = 0.05.

	Adults vs. Yearlings		Adults vs. Calves		Yearlings vs. Calves	
Bone Pair	df	*F*	df	*F*	df	*F*
Femur-Humerus	2, 85	5.50	2, 88	138.60	2, 53	0.04[1]
Femur-Mandible	2, 97	592.45	2, 101	741.30	2, 62	11.81
Femur-Tibia	2, 208	2864.60	2, 114	999.70	2, 148	2381.40
Femur-Carpal	2, 86	94.3	2, 89	134.86	2, 53	321.37
Femur-Tarsal	2, 86	83.55	2, 89	111.48	2, 53	159.23
Femur-Radius	2, 84	13.57	2, 87	141.73	2, 53	5.14

[1]Failed to reject H_o: models tested are equal.

Table 5. Means, standard deviations, differences between, and *t*-tests for mean differences of fat content in calf moose (<1 year old) bones from northeastern Minnesota, 1972-2000.

Bone Pair	*n* pairs	$\bar{X}$	SD	Diff	SD Diff	*t*	*P*
Femur-	30	48.233	24.713				
Tarsal		53.767	21.970	-5.533	10.582	-2.864	0.008
Femur-	35	49.971	24.823				
Mandible		49.771	19.629	0.200	11.552	0.102	0.919
Femur-	30	48.233	24.713				
Humerus		49.900	25.578	-1.667	3.717	-2.456	0.020
Femur-	30	48.233	24.713				
Radius		50.767	27.211	-2.533	7.678	-1.808	0.081
Femur-	30	48.233	24.713				
Carpal		57.133	20.190	-8.900	13.044	-3.737	<0.001
Femur-	30	48.233	24.713				
Tibia		53.000	26.265	-4.767	9.058	-2.882	0.007
Humerus-	30	49.900	25.578				
Radius		50.767	27.211	-0.867	7.776	-0.610	0.546
Humerus-	30	49.900	25.578				
Carpal		57.133	20.190	-7.233	13.723	-2.887	0.007

Table 6. Means, standard deviations, differences between, and *t*-tests for mean differences of fat content in yearling moose (1-2 years old) bones from northeastern Minnesota, 1972-2000.

Bone Pair	*n* pairs	$\bar{X}$	SD	Diff	SD Diff	*t*	*P*
Femur-	27	78.851	11.128				
Tarsal		84.963	7.862	-6.111	8.657	-3.668	0.001
Femur-	31	78.677	10.537				
Mandible		65.032	6.681	13.645	9.841	7.720	<0.001
Femur-	27	78.852	11.128				
Humerus		80.444	10.714	-1.593	3.983	-2.078	0.048
Femur-	27	78.852	11.128				
Radius		80.222	11.274	-1.370	5.832	-1.221	0.233
Femur-	27	78.852	11.128				
Carpal		87.370	5.123	-8.519	9.456	-4.681	<0.001
Femur-	28	78.500	11.077				
Tibia		80.679	11.049	-2.179	6.700	-1.721	0.097
Humerus-	27	80.444	10.714				
Radius		80.222	11.274	0.222	5.199	0.222	0.826
Humerus-	27	80.444	10.714				
Carpal		87.370	5.122	-6.926	9.583	-3.755	<0.001

Table 7. Means, standard deviations, differences between, and *t*-tests for mean differences of fat content in adult moose (>2 years old) bones from northeastern Minnesota, 1972-2000.

Bone Pair	*n* pairs	$\bar{X}$	SD	Diff	SD Diff	*t*	*P*
Femur-	63	71.254	26.175				
Tarsal		78.413	19.727	-7.159	13.860	-4.100	<0.001
Femur-	70	70.157	27.103				
Mandible		61.600	18.787	8.557	14.017	5.108	<0.001
Femur-	62	71.016	26.320				
Humerus		71.855	26.522	-0.839	3.521	-1.875	0.066
Femur-	61	70.721	26.435				
Radius		71.443	25.821	-0.721	6.330	-0.890	0.377
Femur-	63	71.254	26.175				
Carpal		79.603	18.966	-8.349	14.917	-4.443	<0.001
Femur-	62	71.016	26.320				
Tibia		72.290	25.895	-1.274	7.446	-1.347	0.183
Humerus-	62	71.790	26.472				
Radius		71.758	25.729	0.032	6.724	0.038	0.970
Humerus-	63	72.143	26.406				
Carpal		79.603	18.966	-7.460	15.169	-3.904	<0.001

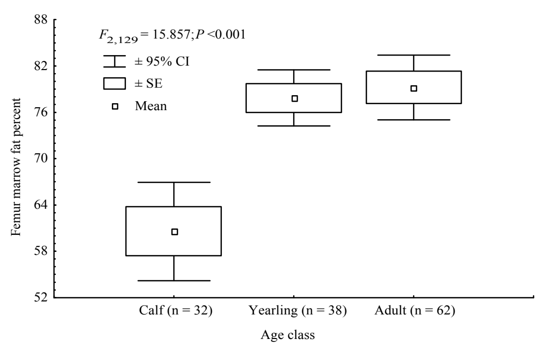


Fig. 7. Femur marrow fat percent and age class in moose kills classified as accidental from northeastern Minnesota, 1972-2000.

and mean femur marrow fat percentages by season, month, and cause of death are given in Table 8. Femur marrow fat percent in adult moose ($\bar{X}$ = 69.477 ± 26.202; range = 8-95) did not differ among months ($F_{10,75}$ = 1.47; P = 0.167), seasons ($F_{3,82}$ = 2.355; P = 0.078), or years ($F_{24,61}$ = 1.43; P = 0.133). Femur fat did not differ among months ($F_{9,52}$ = 1.325; P = 0.247), seasons ($F_{3,58}$ = 0.737; P = 0.534), or years ($F_{21,40}$ = 1.746; P = 0.064) for adults dying from accidental causes. Femur marrow fat was higher in adult moose dying accidentally ($\bar{X}$ = 79.210 ± 16.861; n = 62) than those dying from disease ($\bar{X}$ = 45.380 ± 28.409; n = 21) (t_{25} = 5.158; P <0.001). Femur marrow fat did not statistically differ between adult moose dying from accidental causes or those killed by wolves ($\bar{X}$ = 37.00 ± 42.673; n = 3) (t_2 = 1.707; P = 0.228), or between those killed by wolves or disease (t_{22} = 0.453; P = 0.655) (Fig. 9). Mean adult male femur fat within years was loosely related to yearly WSI (Fig. 10). Mean yearly adult female femur fat content was not related to yearly WSI ($F_{1,18}$ = 0.3692; P = 0.551).

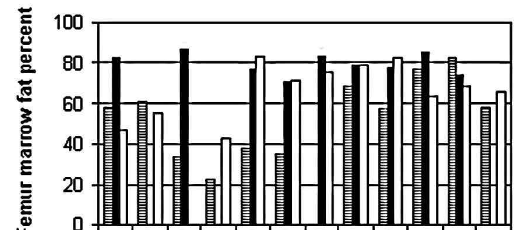
DISCUSSION

The relationships among moose femur bone marrow fat and other examined moose

Table 8. Mean femur bone marrow fat percentages of adult moose (>2 years old) by season, month, and cause of death from northeastern Minnesota, 1972-2000 (standard deviations in parentheses; sample sizes appear below marrow fat percentages).

	Mortality			
	All	Accidental	Disease	Wolf kill
Season				
Dec-Feb	56.55 (33.99)	79.78 (16.40)	35.44 (31.05)	47.00 (55.15)
	20	9	9	2
Mar-May	76.83 (19.67)	83.60 (11.84)	43.00 (0.00)	
	6	5	1	
Jun-Aug	73.76 (22.73)	81.56 (15.47)	43.83 (25.79)	
	33	27	7	
Sep-Nov	71.04 (22.62)	74.37 (20.65)	65.60 (23.19)	17.00 (0.00)
	27	19	5	1
Month				
Jan	46.71 (26.20)	76.20 (20.52)	15.00 (9.90)	8.00 (0.00)
	8	5	2	1
Feb	55.20 (24.50)	88.00 (0.00)	46.20 (25.47)	
	6	1	5	
Mar				
Apr	43.00 (0.00)		43.00 (0.00)	
	1		1	
May	83.60 (11.84)	83.60 (11.84)		
	5	5		
Jun	71.36 (24.45)	78.33 (18.26)	29.50 (3.54)	
	14	12	2	
Jul	75.50 (21.60)	80.44 (15.81)	31.00 (0.00)	
	10	9	1	
Aug	79.00 (23.01)	89.67 (2.25)	57.67 (32.89)	
	9	6	3	
Sep	82.44 (11.61)	84.57 (6.92)	78.33 (18.90)	
	9	7	2	
Oct	64.08 (26.55)	66.45 (23.97)	85.00 (0.00)	17.00 (0.00)
	13[1]	11	1	1
Nov	64.08 (26.55)	83.33 (6.43)	46.50 (14.85)	
	5	3	2	
Dec	66.00 (35.06)	85.25 (11.07)	33.67 (42.74)	86.00 (0.00)
	8	4	3	1

[1]Includes 2 unknown causes of death.



	1	2	3	4	5	6	7	8	9	10	11	12
Calf	7	4	2	5	7	3		4	3	3	3	3
Yearling	2		1		4	14	5	5	3	8	5	
Adult	8	6		2	7	18	11	9	11	17	6	8

Fig. 8. Femur bone marrow fat percent by month from moose in northeastern Minnesota, 1972-2000. Sample sizes are given in table below graph.

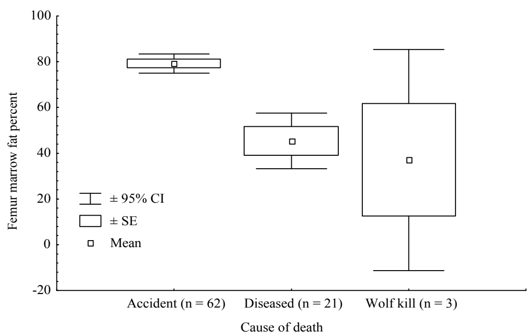


Fig. 9. Femur marrow fat percent and cause of death of adult moose from northeastern Minnesota, 1972-2000.

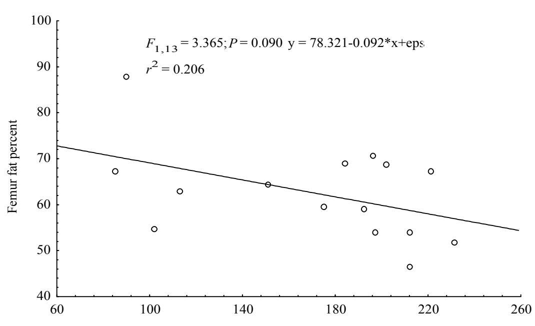


Fig. 10. Yearly average adult male femur fat percent vs. the preceding winter's Winter Severity Index for moose from northeastern Minnesota, 1972-1999.

bones were significant and highly correlated for calves, yearlings, and adults. Our study corroborates findings by others that bone marrow fat in the mandible and leg bones can be just as useful as that of the femur in determining relative health of moose individuals (Snider 1980, Ballard et al. 1981). Unlike Davis et al.'s (1987) findings in caribou (*Rangifer tarandus*), we found significant differences among regression lines of adults, yearlings, and calves in all bone pair comparisons except for the yearling-calf comparison in the femur-humerus bone pair (Table 4). This is in agreement with Ballard et al. (1981), suggesting that calves, yearlings, and adults may deposit and mobilize bone marrow fat differently.

Our study corroborated previous findings that bone marrow fat was deposited first and mobilized last in distal bones in ungulates (Cheatum 1949, Peterson et al. 1982, and Ballard 1995). Femur and humerus (proximal) fat was lower in all age classes than fat in tarsal and carpal (distal) bones, respectively, suggesting that fat is deposited in distal bone marrow first in calves, and depleted first from proximal bone marrow in older moose. However, femur fat did not differ from tibia fat in yearlings or adults, and humerus fat did not differ from radius fat in any age class. Peterson et al. (1982) indicated that while marrow fat withdrawal was sequential from proximal to distal bones in many ungulates, this pattern was not as marked in moose.

Overall, calf femur marrow content increased after birth (1 June) and peaked in November, a trend also observed in moose in southcentral Alaska (Ballard and Whitman 1987). Femur fat significantly decreased following the first winter, and increased as moose became yearlings. Yearling femur marrow fat remained relatively constant throughout the year. Although not statistically different, average femur marrow fat values seemed to increase in the spring and summer months while declining throughout the winter months for adult moose, corresponding to the timing of increased and decreased availability of high-quality forage (Schwartz and Renecker 1998). This trend was also observed in moose in Alaska (Franzmann and Arneson 1976).

Previous authors suggested that bone marrow fat content can be used as an index of relative health for individuals within a population (Cheatum 1949, Ballard 1995). Assuming marrow fat values (as an index of animal condition) had no bearing on moose killed by accident, we can use marrow fat content in these random animals as an index for animals of normal health (or "healthy") within the population. Calf and adult moose we examined killed by disease had lower femur marrow fat than that of healthy individuals, supporting the use of femur marrow fat as a relative health index.

We were only able to examine 1 calf and 1 yearling killed by wolves, and were therefore unable to statistically compare femur marrow fat content in calves and yearlings killed by accident or disease and wolves. Using femur fat as an index of health for adults, we did not find statistical evidence that wolves hunting moose were singling out sick individuals from this population. Our results were similar to Franzmann and Arneson (1976) and Ballard et al. (1987), which found no difference in marrow fat values between wolf-killed and accidentally-killed adult female moose in Alaska. However, our low sample size of wolf-killed adult moose examined here (n = 3) may not be a good indication of moose-wolf interactions in this population.

Several studies suggested universal femur marrow fat content ranges that indicate animals that are healthy or are in poor condition. Bischoff (1954) classified most mule deer (*Odocoileus hemionus*) individuals with 80-100% bone marrow fat as in fair or poor condition. Mech et al. (1995) suggested that caribou individuals with ≤70-87% femur fat content had depleted muscle or fat reserves, and were in marginal condition. Franzmann and Arneson (1976) and Peterson and Bailey (1984) suggested that moose with <20% femur marrow fat were dying of starvation. Mean femur fat for normal representative moose calves we examined was 64% before their first winter and 42% after. Femur marrow fat content did not statistically change throughout the year for yearling or adult moose we examined and used as normal representatives. Mean values for these animals were 77% and 79%, respectively. Given that these animals were representative of normal individuals, our results are in contrast with suggestions by previous authors that these animals may be in an abnormal sub-healthy state. Ballard (1995) indicated that a declining trend in bone marrow fat content by late winter and early spring was common for many northern ungulate populations and relatively low values might be considered normal for many populations. Alternatively, the relative condition of this moose population as a whole may be diminished due to factors we did not examine, such as a possible lack of highly nutritious forage or other stressors.

Marrow fat content has been observed at or near 100% in caribou, moose, and deer individuals (Bischoff 1954, Peterson et al. 1982, Davis et al. 1987, this study). However, a baseline marrow fat content for healthy animals has not been established against which to judge individuals from different populations. A universal baseline for using marrow fat content in moose as an overall index of health may only be determined through examination of total body fat depletion patterns in animals at different states of health (Ballard 1995).

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