BONE PROMINENCE AND SKIN-FOLD THICKNESS AS PREDICTORS OF BODY FAT AND REPRODUCTION IN AMERICAN BLACK BEARS

KAREN V. NOYCE, Minnesota Department of Natural Resources, 1201 East Highway 2, Grand Rapids, MN 55744, USA, e-mail: karen.noyce@dnr.state.mn.us
PAMELA L. COY, Minnesota Department of Natural Resources, 1201 East Highway 2, Grand Rapids, MN 55744, USA, e-mail: pam.coy@dnr.state.mn.us
DAVID L. GARSHELIS, Minnesota Department of Natural Resources, 1201 East Highway 2, Grand Rapids, MN 55744, USA, e-mail: dave.garshelis@dnr.state.mn.us

Abstract: Finding simple and reliable ways to document nutritional condition of animals in the field can help us increase our understanding of population dynamics and behavior. In American black bears (*Ursus americanus*), age-and-season-specific body mass is a good indicator of nutritional status and reproductive performance. However, mass also reflects an animal's skeletal stature, so is influenced by genetics as well as nutrition. Bioelectrical impedance analysis (BIA) and isotopic dilution provide direct estimates of body fat content, but require specialized equipment. In some species, body condition scores based on manual palpation, visual assessment, or skin-fold thickness provide reasonably good indications of body composition and reproduction. We used palpation for bone prominence and measurement of skin-fold thickness to assign body condition scores to black bears. Body mass, total length, bone prominence, and skin-fold thickness all were positively correlated, but the latter 2 condition scores were more independent of body length than was mass. Bone prominence and skin-fold thickness were strongly related to body fat measured by BIA in adult females. Maternal bone prominence and mass were similar as predictors of cub and yearling litter mass and the offspring's eventual age of first reproduction, although neither mass nor bone prominence score was related to the number of cubs/litter or first-year survival of cubs. Skin-fold thickness also correlated strongly with body fat, but not with cub or yearling litter weights. We suggest that bone prominence scores provide a reasonable index of nutritional condition in black bears. We encourage others to include this simple technique in their field protocols.

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Key words: American black bear, bioelectrical impedance, body condition, body fat, body mass, bone prominence, litter mass, litter size, reproduction, skin-fold thickness, *Ursus americanus*

Nutrition is the primary factor influencing reproductive rate in American black bears. In studies that compared reproductive success in 2 or more locations, bears reproduced at younger ages where food was more plentiful (Beecham 1980, McLaughlin 1998). In longitudinal studies documenting reproduction through time, reproductive maturity of bears was delayed (Rogers 1976, Eiler et al. 1989) and females more often failed to reproduce (Rogers 1976, Eiler et al. 1989, Elowe and Dodge 1989, McLaughlin 1998) following food shortages.

Nutritional condition is usually discussed in terms of body composition, specifically the percent of body mass that is fat, or the fat:nonfat ratio. Finding a reliable indicator of nutritional condition in bears, however, has not been simple. Various hematologic, serologic, and morphologic indices have been proposed (Schroeder 1987; Franzmann and Schwartz 1988; Hellgren et al. 1989, 1993; DelGiudice et al. 1991), but in only a few cases have attempts been made to link indices either to body composition (Cattet 1990, Gau and Case 1999) or to some manifestation of condition such as reproduction (Noyce and Garshelis 1994). Cattet (1990) developed an equation that accurately predicted non-fat body mass using body length, foreleg circumference, and age, but was less successful at predicting fat:nonfat ratio. Noyce and Garshelis (1994) tested a number of potential indices, including blood parameters and various combinations of body mass and length, and found that adult female body mass provided the most consistent correlate with reproductive parameters, including cub mass, total litter mass, cub growth rate, and age of first reproduction. Similarly, Garshelis (1994) found a strong correlation between mean yearling mass and mean age of first reproduction in 20 North American black bear populations.

Farley and Robbins (1994) introduced the use of 2 methods, isotopic dilution and bioelectrical impedance analysis (BIA), to directly determine body composition in live bears. Both methods estimate body water content, from which the percent body fat can be calculated with a high degree of accuracy (Farley and Robbins 1994, Hilderbrand et al. 1998). Previously, BIA had been used for over a decade and isotopic dilution for several decades in other species (Sheng and Huggins 1979, Jenkins et al. 1988, Swantek et al. 1992, Gales et al. 1994).

These techniques have rapidly found applications in field studies of bear ecology (Hilderbrand et al. 1998) and nutritional dynamics (Atkinson and Ramsay 1995; Hilderbrand et al. 1999, 2000). Neither procedure, however, is without shortcomings. Isotopic dilution requires long (2-hr) animal handling time, use of radio-isotopes, and laboratory support for analysis. BIA is a simpler, shorter (5–15 min) procedure, but requires expensive equipment and results can be influenced by weather, pre-existing injuries on the animal, and muscle activity during anesthesia. Both methods are subject to inherent error and neither can currently be used to assess condition of dead bears (Farley and Robbins 1994). It is unlikely that these procedures will become standard handling protocols in all or even most bear field studies in the near future.

For these reasons, it remains beneficial to continue developing other simple means of assessing nutritional condition in the field. Whereas previously, testing the efficacy of potential indices required killing study animals, now it can be tested on live animals using BIA or isotopic dilution. Gau and Case (1999) used BIA to confirm that blood parameters were poor indicators of body condition in brown bears.

In this paper we describe 2 methods that we used to score body condition in black bears, the first based on palpable bone prominence and the second on skin-fold thickness. In humans, the thickness of pinched skin-folds is used to predict body composition (Lee and Ng 1965, Durnin and Womersley 1974). Livestock producers have developed several body condition scores based on palpable bone prominence, visual assessment, and combinations thereof, which are better than body mass for predicting body composition, carcass quality, and reproductive performance (Russel et al. 1969, Wildman et al. 1982, Otto et al. 1991, Ruegg 1991). In wild caribou (*Rangifer tarandus*), a body condition score based on palpation can predict fat reserves and pregnancy, particularly when used in conjunction with body mass (Gerhart et al. 1996). Having previously established that season-specific body mass was a reasonable reproductive index in black bears (Noyce and Garshelis 1994), we wanted to evaluate whether body condition scoring could further improve our ability to predict reproductive success. We use recent data from BIA to test the accuracy of scores as indicators of body fat.

STUDY AREA

We conducted most field work in the Chippewa National Forest (CNF), Itasca County, north-central Minnesota. The CNF is >95% forested, with upland forests consisting primarily of aspen mixed woods (*Populus tremuloides, Betula papyrifera, Abies balsamea*), scattered pine (*Pinus resinosa, P. strobus*), and northern hardwoods (*Acer saccharum, A. rubrum, Tilia americana, Quercus rubra*), and lowland forests of conifer (*Picea mariana, Larix laricina, Thuja occidentalis*) and scattered black ash (*Fraxinus nigra*). We conducted additional work at Camp Ripley National Guard Training Camp, Morrison County, Minnesota, approximately 170 km southwest of the CNF study site. Vegetation at Camp Ripley is transitional between the northern mixed forests of the CNF and the hardwood forest types common south of camp. Oak woods (*Q. rubra, Q. macrocarpa, Q. alba, Q. ellipsoidalis*) cover approximately 25% of camp and provide a more abundant and consistent source of fall mast for bears than in the CNF.

METHODS

Starting in 1981, we radiocollared black bears either when we trapped them during summer or when we handled them as yearlings in dens with their radiocollared mothers. After initial capture, each radiocollared bear was handled at least yearly in its winter den, and in summer if it was caught during trapping. After 1990, most bears were handled only in winter, as we discontinued summer trapping except for limited efforts in the CNF during 1996 and 2000 and in Camp Ripley during 1998–2000.

Each time we handled a bear, we weighed and measured it, checked females for lactation (summer) or the presence of cubs or yearlings (winter), and collected a blood sample. Starting in 1992, we also assessed bone prominence and skin-fold thickness. To do so, we positioned the immobilized bear on its side and palpated through the skin for specific bones at 5 locations on the torso (Fig. 1), including the junction of the humerus and scapula at the front of the shoulder, the backbone midway between shoulder and rump, the ribs halfway down the bear's side, and the anterior and posterior points on the pelvis. We rated bone prominence at each location on a 1–4 scale, based on the following criteria: (1) bones feel prominent or sharp; (2) bones are distinct, but not sharp; (3) bones are detectable but not easy to distinguish; (4) bones are difficult or impossible to detect. To measure skin-fold thickness, we pinched a fold of skin at 4 locations on the body (Fig. 1) and measured the thickness (mm) with calipers. Skin-folds were measured over the backbone between the shoulder blades, over the backbone at the center of the back, over the center of the ribs, and on the flank halfway down the side, immediately anterior to the pelvis. Bone prominence and skin-fold assessments were nearly always performed by the same 3 observers during the study. If 2 of these observers were present when handling a bear, they periodically cross-checked their scoring, particularly if bone prominence seemed intermediate between 2 scores.

Starting in December 1999, we determined percent body fat on each bear handled using BIA, following the procedures and equations recommended by Farley and Robbins (1994). We placed bears in a sternal recumbent position, with anterior electrodes clipped to the upper lip and posterior needle electrodes inserted into the muscle to either side of the anus. We measured snout-to-tail resistance (STR) using a bioelectrical impedance analyzer (model 101A, RJL Systems, Detroit, Michigan, USA). Snout-to-vent length (SV) was measured along the backbone from the tip of the nose to the anus, following the contour of the body. Total body water (TBW) was estimated as:

$$TBW = -0.224 + 0.197(SV^2/STR) + 0.137(\text{body mass [kg]})$$

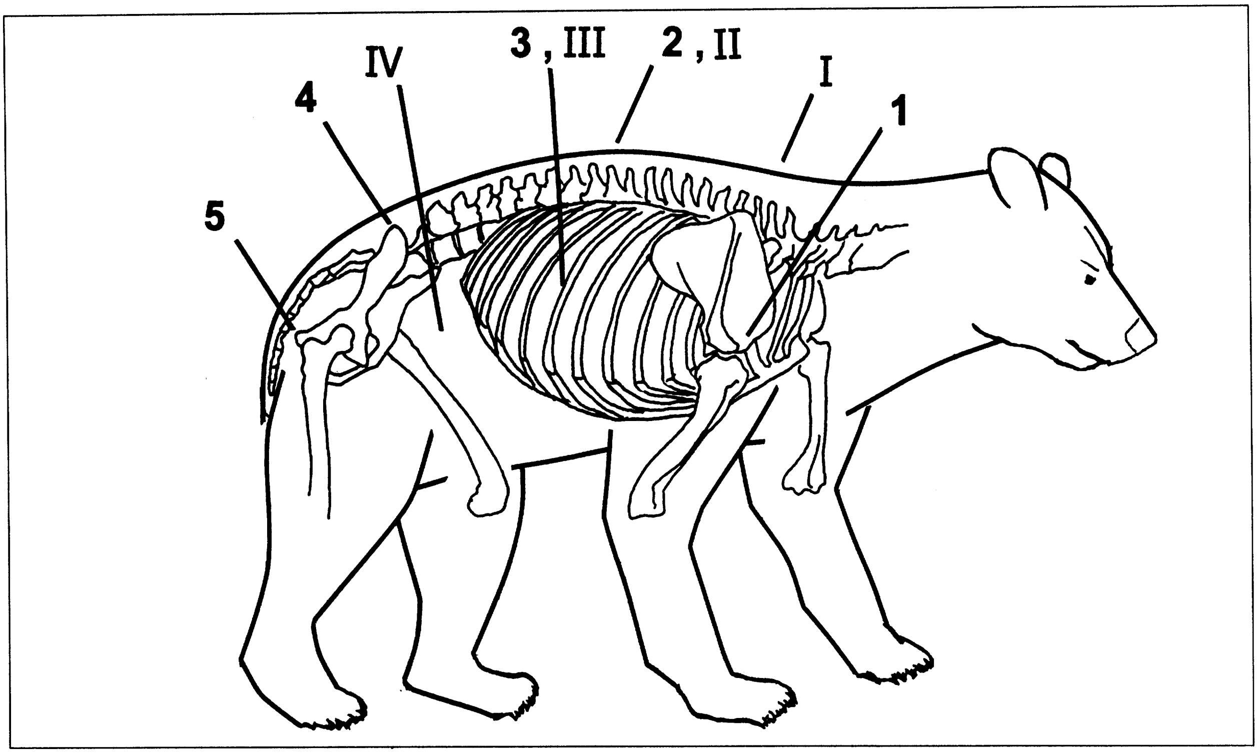

Fig. 1. Sites used for scoring bone prominence (sites 1–5) and measuring skin-fold thickness (sites I–IV) on black bears: (1) front of shoulder at the junction of the humerus and scapula; (2) backbone, midway between shoulder and rump; (3) ribs, halfway down the side directly below site 2; (4) anterior point of the pelvis; (5) posterior point of the pelvis; (I) along the backbone between the shoulder blades; (II) same as 2; (III) same as 3; (IV) flank, halfway down the side immediately anterior to the pelvis.

TBW was then converted to percent of body mass, and percent body fat was calculated as:

$$\text{Body fat (\%)} = 98.01 - 1.28 \text{ body water (\%)}$$

Data Analysis

We used simple and multiple regressions to test for relationships between bone prominence or skin-fold scores and various measures of reproductive output in adult females, including litter size, total litter mass at 2 months postpartum, litter mass at 1 year, cub survival, and the age at which a female's daughters produced their first cubs. We performed regressions using values for each of the body sites separately and for the summed values of all sites combined on each bear (i.e., 5 bone prominence sites or 4 skin-fold sites). Unless otherwise noted, references to bone prominence or skin-fold scores in this paper refer to summed scores. We used 1-way analysis of variance (AOV) to test for differences in condition scores among females giving birth to or weaning litters of different sizes and to test for seasonal changes in bone prominence and skin-fold thickness. We used simple and multiple regression to compare condition scores with BIA estimates of body composition.

Because growth rates and fatness of bears differed markedly between the CNF and Camp Ripley, we used only data from our primary study area (CNF) to describe seasonal changes in bone prominence and skin-fold scores. We pooled data from the 2 sites for examining relationships between condition scores, reproduction, and BIA estimates of body composition.

RESULTS

Bone prominence scores and skin-fold thickness varied seasonally (Table 1). Condition scores tended to be highest in early hibernation. Bears began denning during September–November, but we did not handle denning bears until December. In juveniles (1–3 years old), condition scores declined through winter to their lowest values in May–July ($F = 25.7$; 2, 168 df; $P < 0.0001$ for bone prominence; $F = 10.6$; 2, 161 df; $P = 0.0001$ for skin-fold thickness). In parturient females, bone prominence scores declined from early to late winter ($F = 4.8$; 1, 52 df; $P = 0.03$), but small sample size precluded detection of a trend from late winter to summer. In adult (≥4 years old) males and non-parturient adult females, condition scores changed little from early to late winter, but declined more markedly from late winter to early summer (in adult males, $F = 6.8$; 2, 35 df, $P = 0.003$ and $F = 4.0$; 2, 32 df; $P = 0.03$ for bone prominence and skin-fold thickness, respectively).

We compared body condition of 31 parturient females to their cub production (59 litters). The number of cubs per litter and their eventual first-year survival were unrelated to their mother's bone prominence scores, skin-fold thickness, or body mass at 2 months postpartum. However, total litter mass, both at 2 months of age and at 1 year, was positively correlated to maternal postpartum bone prominence and body mass, but only weakly to skin-fold score (Table 2). The best regressions were obtained using log-transformed values of these parameters. Bone prominence score for the mid-backbone site was somewhat better than the summed score (5 sites) for predicting litter mass, but slightly worse for predicting yearling litter mass. Regressions using scores from other sites were not as strong. Because litter size typically influences litter mass, we added litter size as an independent variable, which increased the strength of regressions in all cases (Table 2); partial r^2 values for litter size ranged from 0.41–0.49 and 0.12–0.18 in regressions with litter mass at 2 months and 1 year of age, respectively.

Table 1. Seasonal change in bone prominence and skin-fold scores in juvenile (1–3 year-old) and adult (≥4 year-old) black bears, north-central Minnesota, 1992–2000.

		Bone prominence score[a]			Skin-fold score (mm)[b]		
		$\bar{x}$	*SE*	*n*	$\bar{x}$	*SE*	*n*
Juveniles	Dec	10.3[c]	0.3	48	59.6[c x]	2.1	47
	Feb–Mar	7.8[d]	0.2	116	51.0[d x]	1.3	111
	May–Jul	5.7[e]	0.5	7	38.0[d x]	2.0	6
Adult males	Dec	15.6[c]	0.5	18	81.4[c x]	2.7	16
	Feb–Mar	15.0[c]	1.1	10	79.4[cd]	4.7	10
	May–July	11.4	1.2	10	65.6[d x]	5.9	9
Adult females (with yearlings or no offspring)	Dec	10.6[c]	1.0	8	58.4[c x]	4.7	7
	Feb–Mar	9.8[c]	0.4	51	62.4[c x]	3.0	45
	May–Jul	5.0		1	23.0[x x]		1
Adult females (with cubs)[f]	Dec	16.7[c]	2.0	3	92.0[c x]	10.1	3
	Feb–Mar	12.0[d]	0.5	51	78.0[c x]	2.5	44
	May–Jul	11.0[g]		1	54.0[x x]		1

[a] The sum of the subjective scores (each ranging from 1–4), assigned to 5 specific locations on the body, based on palpable bone prominence (potential range of the summed scores = 5–20). Scores were assigned as: (1) bones feel prominent or sharp through the skin; (2) bones distinct, but not sharp; (3) bones detectable but not easy to distinguish; (4) bones difficult or impossible to detect. Sites assessed were the shoulder, mid-backbone, middle of the ribs, and anterior and posterior points of the pelvis.

[b] The sum of 4 caliper measurements of the thickness of a pinched skin-fold, each from a specified location on the body. Measurements were taken between the shoulder blades, at the midpoint of the backbone, middle of the ribs, and flank.

[c,d,e] Different letters denote significant differences ($P < 0.05$) among seasonal means within sex–age groups (1-way AOV).

[f] Pregnant in Dec; nursing cubs Feb–Jul.

[g] Handled 1 Aug.

Table 2. Results of regressions between measures of maternal condition, including mass, bone prominence score[a], and skin-fold score[b], and the mass of black bear litters at 2 months and 1 year of age, north-central Minnesota, 1992–2000. Regressions were performed using 2 sets of data, the first including all cases when females with cubs were handled (each handling = 1 record), the second using across-year means for individual females to eliminate repeated measures (each female = 1 record).

		All cases			Across-year means for individual females		
Reproductive parameter	Independent variables[c]	r^2	*n*	*P*	r^2	*n*	*P*
Litter mass at 2 months	Body mass	0.39	59	<0.0001	0.46	31	<0.0001
	Bone prominence (summed)	0.25	55	0.0001	0.27	28	0.004
	Bone prominence (back)	0.31	36	<0.0001	0.31	29	0.002
	Skin-fold thickness (summed)	0.07	47	0.08	0.04	26	0.33
	Body mass and litter size	0.67	59	<0.0001	0.68	31	<0.0001
	Bone prominence (summed) and litter size	0.62	55	<0.0001	0.58	28	<0.0001
	Bone prominence (back) and litter size	0.62	56	<0.0001	0.60	29	<0.0001
Litter mass at 1 year	Body mass	0.34	44	<0.0001	0.45	22	0.0006
	Bone prominence (summed)	0.39	42	<0.0001	0.69	21	<0.0001
	Bone prominence (back) and litter size	0.37	42	<0.0001	0.57	21	0.0001
	Skin-fold thickness (summed)	0.11	35	0.05	0.32	20	0.009
	Body mass and litter size	0.52	42	<0.0001	[d]		
	Bone prominence (summed) and litter size	0.50	40	<0.0001	[d]		
	Bone prominence (back) and litter size	0.46	40	<0.0001	[d]		

[a] Bone prominence variables represent subjective scores (1–4) assigned to specific locations on the body, based on palpable bone prominence. Variables used in these regressions were (1) the sum of scores from 5 specified body sites, and (2) the individual score assigned at the center of the backbone.

[b] Skin-fold variable was the sum of 4 caliper measurements of the thickness of a pinched skin-fold, each from a specified location on the body.

[c] All independent variables except litter size were log-transformed for regressions.

[d] Litter size was not significant as an independent variable in these regressions.

We recognized that data points obtained from handling the same female in different years might not be independent, so we ran regressions a second time, eliminating repeated measures of individual females by regressing their across-year mean condition scores and mass against the across-year means of their litter masses (Table 2). Results were similar to those described above, except that in all regressions with litter mass at 1 year of age, r^2 values increased. The across-year mean of a femaleís postpartum bone prominence score explained nearly 70% of the variation in the mass of her litters at 1 year of age.

Eight females in our sample raised (or had previously raised) daughters that reached sexual maturity and gave birth to cubs during our study. We calculated the across-year mean postpartum body mass, bone prominence score, and skin-fold score for each of these 8 females. In simple regressions, bone prominence score, body mass, and skin-fold score accounted for 72, 77, and 92%, respectively, of the variation in their daughtersí mean age of first reproduction ($P < 0.0008$ in all cases; Fig. 2). In regressions using scores from individual sites, bone prominence at the anterior point of the pelvis and over the ribs performed better than the summed score ($r^2 = 0.78$ and 0.74, respectively), and skin-fold thickness on the back performed nearly as well as the summed skin-fold score ($r^2 = 0.88$). We could not correlate condition scores in juvenile females with their own eventual age of first reproduction, because few of the juveniles for which we assessed condition gave birth during the study. Most either died before reproducing, were not radiocollared and could not be monitored, or had not produced litters by the end of the study. However, data from bears handled before we started these condition assessments indicated that the (log-transformed) winter mass of yearlings was inversely related to their age of first reproduction ($r^2 = 0.37$, $n = 30$, $P = 0.0004$); that is, heavy yearlings eventually reproduced at a younger age than lightweight yearlings. Bone prominence and skin-fold scores tended to be strongly related to body mass in yearling females ($r^2 = 0.65$, $n = 52$, $P < 0.0001$ for both), so more years of data would likely reveal a relationship between condition scores in yearlings and their subsequent age of first reproduction.

We had anticipated that bone prominence scores and skin-fold thickness would be largely independent of body stature (represented in our data by total body length). This was true for the most part; relationships between condition scores and body length were typically weak (Table 3, $r^2 < 0.42$ in all cases), especially for pregnant ($r^2 = 0.05$) and nursing ($r = 0.14$) females. In contrast, body mass was highly correlated with body length (Table 3, Fig. 3), especially in young bears ($r^2 = 0.75$ñ0.79, $P < 0.0001$) and adult males ($r^2 = 0.84$, $P < 0.0001$). The relationship was weaker in adult females, however, especially those that were pregnant or nursing cubs ($r^2 = 0.31$, $P < 0.0001$), suggesting that in adult females, variations in body mass were more a reflection of nutritional condition than of length. Accordingly, the relationship between mass and bone prominence was strongest in these females (Table 3, Fig. 3).

We obtained BIA estimates of body fat in conjunction with body condition scores for 30 adult females, 25 juvenile females, and 14 juvenile males. Relationships between condition scores and percent body fat were strong ($r^2 = 0.83$ and 0.80 for summed bone prominence and skin-fold scores, respectively, Fig. 4). The best single site for predicting body fat from bone prominence was the

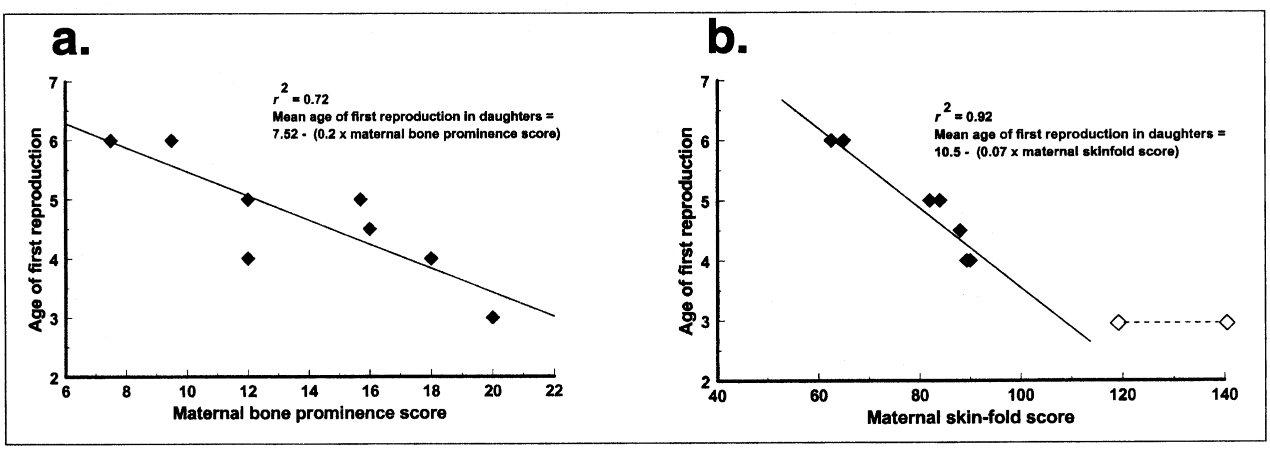

Fig. 2. Relationship between mean across-year body condition scores in adult female black bears and mean age of first reproduction of their daughters, north-central Minnesota, 1992ñ2000. (a) Bone prominence scores represent the sum of scores (range 1ñ4) assigned to 5 specified sites on the body, based on palpable prominence of bones. (b) Skin-fold scores represent the sum of skin-fold thickness measurements from 4 specified sites on the body. Regression line and equation are based on 7 females (represented by solid symbols) on whom all 4 sites were measured. We lacked the shoulder measurement on an eighth (very fat) female, but include here (represented by open symbols) the minimum and maximum possible value for her summed skinfold score, had we obtained a shoulder measurement.

Table 3. Relationships between body length, mass, and condition scores in north-central Minnesota black bears, 1992–2000.

			r^2		
		n	Bone prominence score[a]	Skin-fold score[b]	Body mass (kg)
Total length (cm)	All bears	346–417	0.34	0.36	0.94
	Yearlings	112–136	0.29	0.42	0.75
	Juveniles	73–89	0.13	0.27	0.79
	Ad females (with cubs)	56–69	0.14	0.05[c]	0.31
	Ad females (other)	60–69	0.14	0.15	0.41
	Ad males	39–53	0.30	0.22	0.84
Body mass (kg)	All bears	349–383	0.48	0.45	
	Yearlings	113–130	0.46	0.55	
	Juveniles	74–82	0.24	0.46	
	Ad females (with cubs)	56–66	0.74	0.49	
	Ad females (other)	60–69	0.58	0.52	
	Ad males	40–46	0.48	0.35	

[a] The sum of 5 subjective scores (1–4), assigned to specific locations on the body, based on palpable bone prominence. Sites assessed were the shoulder, mid-backbone, middle of the ribs, and anterior and posterior points of the pelvis.
[b] The sum of 4 measurements of the thickness of pinched skin-folds, each from a specified location on the body. Measurements were taken between the shoulder blades, at the midpoint of the backbone, middle of the ribs, and flank.
[c] Not statistically significant; $P > 0.05$.

back ($r^2 = 0.71$, $P < 0.0001$ in adult females, versus 0.53–0.66 for other sites), and the best skin-fold site was the ribs ($r^2 = 0.79$ versus 0.37–0.67 for other sites). In regressions between summed bone prominence score and body fat, regression slopes did not differ between adults and juveniles (Fig. 4, $P = 0.96$), but for a given fat content, bone prominence scores in juveniles were typically lower than in adults (Y-intercepts different, $P < 0.0001$). There was no difference between regression lines for juvenile males and females ($P = 0.92$ for comparison of slopes, $P = 0.99$ for comparison of intercepts). Body mass was not as accurate as either bone prominence or skin-fold score for predicting body fat in adult females ($r^2 = 0.58$, $P < 0.0001$). In juveniles, there was no relationship between body mass and fat.

DISCUSSION

Body condition scoring appeared to provide a useful way to quickly assess a bear's general nutritional condition. Especially in adults, correlation between body condition scores and body fat was strong, and bone prominence in particular appeared to be as good or better than body mass for predicting certain reproductive indices. In sheep (Russel et al. 1969) and in dairy cattle (Otto et al. 1991), bone prominence scores provide reasonable indicators of percent body fat ($r^2 = 0.88$) and rib fat ($r^2 = 0.57$), respectively. In caribou, total dissectable fat is accurately predicted from the depth of back fat ($r^2 = 0.97$; Adamczewski et al. 1987). In these and other species, surficial fat indices are commonly more sensitive to differences in body composition than is body mass (Russel et al. 1969, Reid and Robb 1971, Stribling et al. 1984, Ruegg 1991, Gerhart et al.1996).

Among the potential indices we tested, the sum of bone prominence scores from 5 body sites showed the most consistent relationship to body fat, offspring growth, and offspring age of first reproduction—more consistent than either skin-fold measurements or bone prominence scores from individual sites. A combination of sites probably describes total surficial fat better than a single location. For example, in polar bears (*Ursus maritimus*), the surficial extent of fat increases with increasing obesity, and distribution shifts in a posterior direction with increasing age (Pond et al. 1992), so fat thickness does not increase equally at all sites and a score combining sites may better capture that variation. Combining sites provides a wider range of scores, thus a more sensitive rating scale, than using only a single location (summed scores ranged from 5–20 versus 1–4 for individual sites). Individual sites that showed the most potential as nutritional indices in black bears were those near the center versus either end of the torso, i.e., the back, ribs, and anterior pelvis.

Skin-fold thickness, though closely related to body fat and to offspring age of first reproduction, did not show the same strong relationship to litter weights as bone prominence. Though used extensively in human health screening, accuracy of skin-folds for measuring subcutaneous fat varies among body sites and individuals due to variation in skin thickness and fat compressibility (Durnin and Womersley 1974, Himes et al. 1979), requiring careful standardization (Lee and Ng 1965, Himes et al. 1979) and perhaps limiting usefulness in other species; skin-fold thickness was not a reliable indicator of blubber thickness in young sea lions (*Eumetopias jubatus*; Jonker and Trites 2000). We noted that with increasing obesity in bears it became more difficult to pinch a fold of skin that included all of the underlying adipose tissue, much of which adhered to muscle rather than to skin. In 3 bears

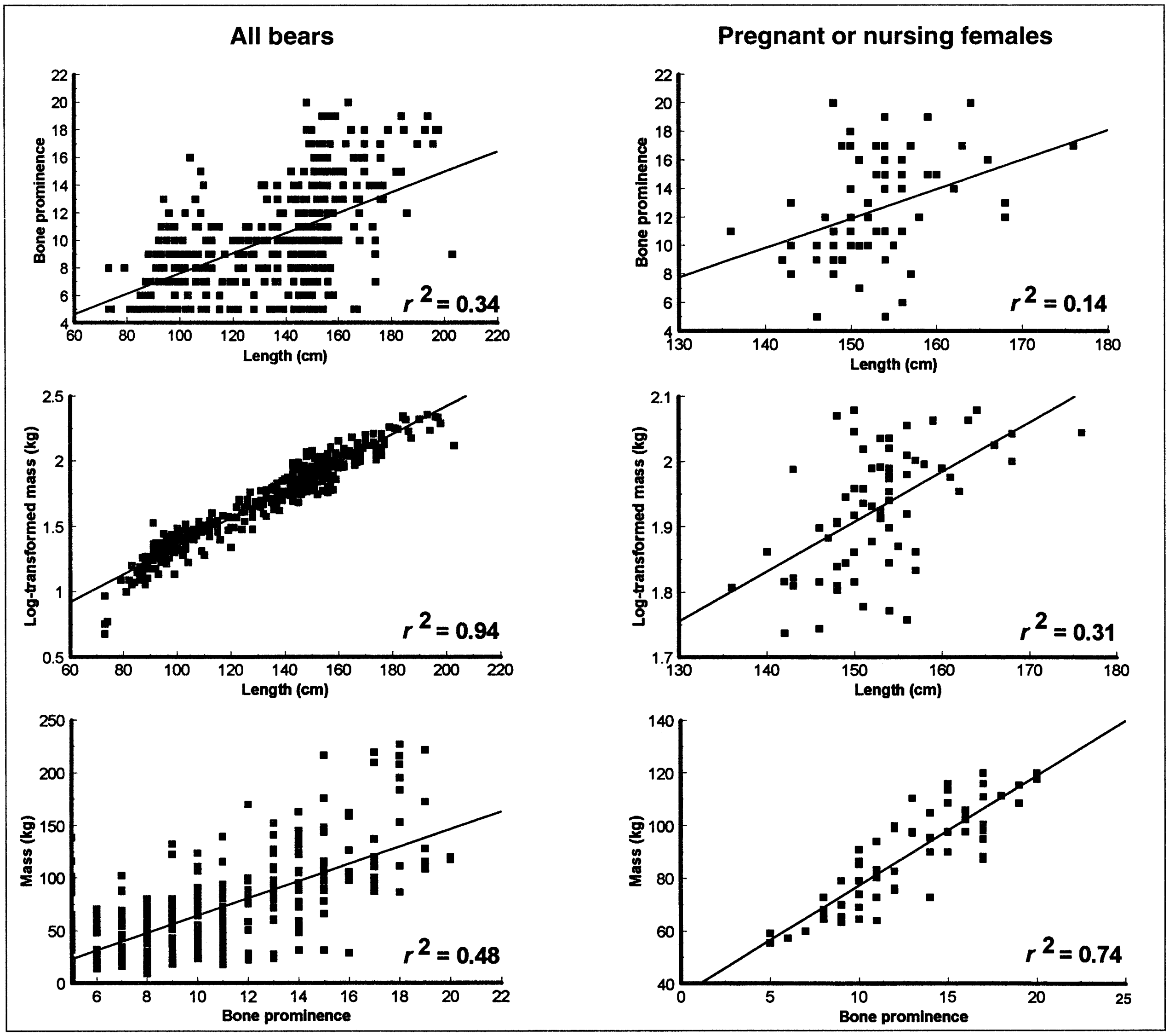

Fig. 3. Relationships between bone prominence score, body mass (kg), and length (cm) in black bears, north-central Minnesota, 1992–2000. Bone prominence scores represent the sum of subjective scores (scale 1–4) assigned to 5 locations on the body, based on palpation.

that we dissected, skin-fold thickness over the ribs measured 15, 16, and 19 mm, whereas the measured depth of rib fat was 34, 26, and 108 mm, respectively. Skin-fold measurements in adult males in late winter were nearly the same as in females with cubs, despite a substantial difference in bone prominence scores. Skin-fold measurement was more often hampered by thick fur or by pelts that were impregnated with sand from underground dens than was bone prominence scoring.

Ideally, parameters used as nutritional indices should be independent of the sex, age, or stature (length) of animals being assessed. Otherwise, they can only be useful if restricted to particular classes of animals that share the traits affecting those parameters, e.g. animals of a particular sex, age, or length. Previously, we found that despite the fundamental connection between body mass and length, body mass in adult female black bears was a surprisingly good predictor of reproductive output (Noyce and Garshelis 1994), likely because, at least within our study population, females were relatively uniform in length (80% were 143–160 cm), so most variation in mass reflected differences in fatness, not length. Though intuitively an index incorporating both mass and length would seem to be superior to mass alone, finding the appropriate mathematical expression for such an index has been problematic (Cattet 1990); simple mass:length ratios do not work because mass increases geometrically with increases in length, so even in bears of equivalent proportions and condition, the mass:length ratio increases with increases with body length.

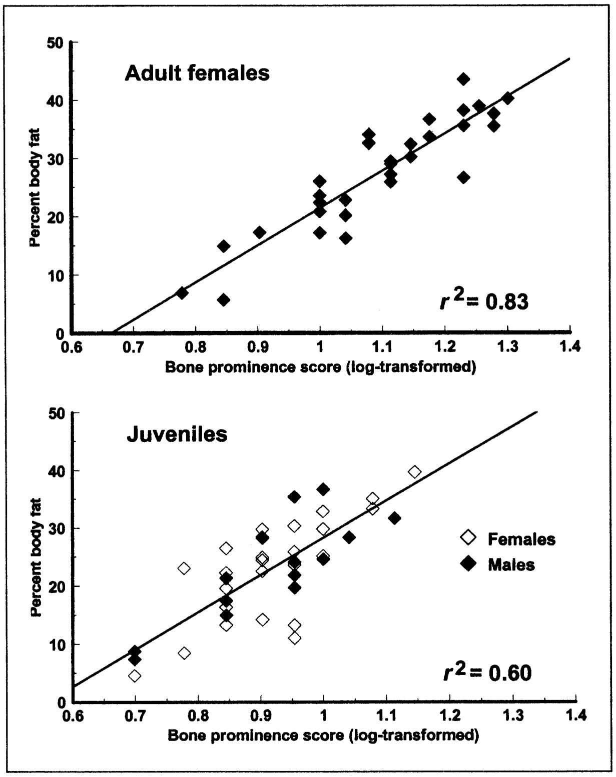

Fig. 4. Relationship between percent body fat, as determined by bioelectrical impedance analysis (BIA) and bone prominence scores in adult (≥4 years old) female and juvenile (1–3 year-old) male and female black bears, north-central Minnesota.

As anticipated, bone prominence and skin-fold scores were more independent of body length than was body mass; however, they were not entirely so. Pond et al. (1992) reasoned that in bears with similar body proportions and composition but different overall size (length), the absolute thickness of fat (and thus condition scores based on fat thickness) will be greater on larger animals. Also, nutrition can affect both growth and fat accumulation, so among bears of the same age, short individuals may be more likely to have a history of poor nutrition and thus to be thinner than long individuals.

Nevertheless, because bone prominence scores are relatively independent of body length and directly reflect information about the amount of fat a bear is carrying, they should provide more useful documentation of nutritional condition than body mass. The relationships we found between body condition scores and reproductive parameters corroborated previous conclusions (Noyce and Garshelis 1994) that, except in bears at the extremes of the nutritional spectrum, litter size and cub survival are affected relatively little by maternal nutrition. Rather, the primary influence of maternal nutrition on reproduction is through cub growth rates, which influence juvenile growth rates, and ultimately age of first reproduction. Previous conclusions were based on relationships between adult body mass and reproductive parameters and on the assumption that the link between a mother's mass and the mass of her litters was due to nutrition, rather than to shared genetics. Relationships between bone prominence and litter mass directly implicate nutritional factors. Bone prominence should be more useful than body mass for making nutritional comparisons across populations, because regional differences in mass may arise from genetic differences in size, whereas bone prominence more directly reflects regional differences in nutrition.

Like all nutritional indices, including estimates of body fat derived from BIA or isotopic dilution, bone prominence scores must be interpreted in the context of time of year, reproductive status, sex, and age. It would be inappropriate to pool hibernating and nonhibernating bears for comparing nutritional status across populations. Likewise, it would be inappropriate to pool pregnant and non-pregnant or young and old bears, because these groups are typified by different degrees of fatness. Twenty percent body fat might signify good condition in a juvenile in early spring but not in a female nursing cubs.

Given the potential usefulness of bone prominence scoring, we encourage those who routinely handle bears for management or research purposes to add this simple technique to their handling protocols, even if they also use BIA or isotopic dilution to determine body composition. Though clearly not as precise as these more sophisticated techniques, bone prominence scoring provides another tool for documenting an animal's nutritional plane and interpreting other aspects of its biology. An obvious weakness in the technique is the potential for inter-observer variability. Bias can be minimized by limiting the number of observers, adhering carefully to scoring criteria, and cross-checking frequently among observers. It may be possible to improve precision and further reduce the potential for bias by refining scoring criteria. Also, it is important to recognize that BIA and isotopic dilution, despite their utility, are not immune to error. We observed that measurements of electrical resistance (BIA) were disrupted by any muscle activity in the mouth and jaw and thus were affected by depth of anesthesia. Also, readings occasionally showed directional drift, possibly in response to cold ambient temperatures, and significant variation in SV measurements could occur between or within handlings, depending on positioning of the bear and the pressure applied to the measuring tape when following body contours. Variation in SV measurements affected calculations of body fat, particularly in small bears.

Because bone prominence scoring is simple, quick, and applicable to both live and dead bears, it can be more widely applied than more exacting techniques and thus useful for comparing across studies. Using bone prominence scoring in conjunction with BIA or isotopic dilution will help bear biologists further evaluate relationships between body fat, condition scores, and reproductive success.

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