Predictive Relationships Between Age and Size and Front-foot Pad Width of Northeastern Minnesota Black Bears, *Ursus americanus*

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Front-foot pad width, age, body length, weight, and skull width were measured on 139 Black Bears (*Ursus americanus*) from northeastern Minnesota. We developed regression models using these data to predict body length, weight, and skull width from pad width measurements.

Key Words: Black Bears, *Ursus americanus,* pad width, body length, weight, skull width.

Foot prints or tracks are a common sign of the occurrence of a wildlife species. By understanding the relationship between foot size and other physical dimensions of an individual animal, researchers and managers may be able to remotely and inexpensively extract useful information on the size and age distribution of a population from animal tracks (Piekielek and Burton 1975; Beck 1991), especially if tracks could be taken under controlled conditions (Zielinski 1995). We examined the relationships between front-foot pad width and age and physical dimensions of Black Bears, *Ursus americanus,* from northeastern Minnesota to investigate the potential use of track dimensions for the prediction of these attributes.

Methods

Data were collected from bears in the Superior National Forest, northeastern Minnesota. The study area and capture methods were fully described by Rogers (1987). Each captured bear was sexed and weighed. The front-foot pad was measured across its greatest width, taking care to flatten the pad to approximate its shape when bearing weight. Maximum pad width was measured between the hairlines at the edges of the pad. Total body length was measured along the contour of the back, from the tip of the nosepad to the tip of the bone in the tail, taking care to position the muzzle, head, back, and tail in as straight a line as possible. Skull width was measured at the zygomatic arches, including skin and any fat, using calipers. Length and width measurements were taken to the nearest 0.0625-inch and converted to metric units for analysis and reporting. Bears were uniquely marked with eartags when first captured and remeasured upon recapture.

Year of birth was determined by cementum annuli from a first upper premolar (Willey 1974). We calculated a measure of continuous age as the age, in years at the time of capture, plus a decimal value accounting for the time between 1 January (presumed date of birth) and the date of capture. Bears were classified as: (1) cubs: < 1.0 year old; (2) yearlings: 1.0-1.9 years; (3) subadults: 2-3.9 years; and (4) adults: ≥ 4.0 years (Rogers 1987).

The predictive relationships between continuous age and other physical dimensions and pad width were examined using linear and nonlinear regression models. Regressions were run separately for each sex and for the combined sexes. We evaluated linear, linear with $\log_e$-$\log_e$ transformation, and nonlinear regression models. We selected a simple linear model of the transformed data, corresponding to $E(y) = b_0(x)^{b_1}$ for measured data, based on regression statistics and plots of residuals, as the best model for all regression analyses. Confidence intervals on estimates from a single additional observation were calculated following Zar (1974: 211-212; equation 16.27). Analysis of variance was used to explore the relationship between pad width and ageclass. Classification intervals for ageclass based on a new observation of pad width were calculated using Sokal and Rohlf's (1981) single-sample comparison and appropriate sample statistics.

To use all the data, and yet avoid the repeated-measures nature of the multiple observations, we used the mean of all measurements of each variable for each bear as a single data point. We then weighted these data points in the analyses by the number of observations included in each mean. Because the multiple measurements of pad width and the response variables for each individual bear were taken over a relatively short interval of a few years and the relationships were essentially linear, this procedure did not bias the analyses.

Results and Discussion

Two hundred eleven measurements of age, foot-pad widths, and other physical dimensions were obtained from 139 Black Bears in northeastern Minnesota between 1969-1982. Some measurements were missing for some bears, so sample sizes vary among analyses.

Regression models between Black Bear continuous age, body length, weight, and skull width and pad width were significant ($p < 0.001$) for both sexes individually and combined (Table 1). The adjusted r^2 for the regressions ranged between 0.363 to 0.915. Pad width differed significantly by ageclass ($F = 136.8$, d.f.=3, 195, $p< 0.001$).

We identified two general quantitative relationships between the four individual independent variables and pad width. The constant (b_0) for the relationship between continuous age and pad width and weight and pad width was close to zero with a power coefficient (b_1) of about 3. These models described a steeply ascending curve where small increases in pad width result in increasingly greater gains in age or weight with larger pad widths. This result was similar to that of Piekielek and Burton (1975) who reported a power coefficient of 3.5 for the relationship between Black Bear weight and a six-part composite foot measurement. The relationships between body length and pad width and skull width and pad width were essentially linear as the power coefficients were close to one. Body length and skull width increased at a constant rate with increasing pad width.

The models developed from these data allow for the estimation of body length, weight, and skull width from pad widths (Table 2). If the sex of a new observation is known, the appropriate single-sex model or tabular entry can be used for estimation. If sex is unknown, the combined sex models or tabular entries should be used.

The use of the regression models for estimation of continuous age from pad width was inappropriate because of their poor fit, which resulted in excessively large confidence intervals on the estimates. The classification of ageclass for a new observation of pad width could not be made at 95% confidence because of extensive overlap of classification intervals for all ageclasses. The classification intervals for ageclass at 75% confidence were: cubs <7.65cm; yearlings 7.38-9.02 cm; subadults 8.37-10.54 cm; and adults > 9.15 cm. These results allow for the age classification of many tracks with an intermediate degree of certainty but there is still considerable overlap between intervals where classification is uncertain.

The results from this study suggest that further investigation of the relationship among Black Bear pad width, foot-print width, and physical dimensions is warranted. The application of these prediction models in the field, that is to front-foot prints, introduces additional variability related to the relationship between pad width and foot-print width, which is not accounted for in this study (Beck 1991). Piekieiek and Burton (1975) found the composite foot measurements taken from tracks were

TABLE 1. Regression statistics[1] from the analysis of pad width and continuous age, body length, weight, and skull width by sex and for both sexes combined for Black Bears from northeastern Minnesota, 1969-1982.

Dependent variable	n measurements/ n bears	b_0	b_1	Adjusted r^2	F
Continuous age					
Males	88/68	0.001	3.502	0.805	359.4
Females	115/69	$3.8 * 10^{-6}$	6.404	0.581	158.8
Combined	203/137	0.005	2.947	0.363	116.3
Body length					
Males	90/71	10.4	1.103	0.869	590.8
Females	111/66	5.795	1.411	0.771	371.5
Combined	201/137	12.9	1.03	0.771	675.2
Weight					
Males	91/71	0.013	3.645	0.915	966.0
Females	113/68	0.007	4.101	0.789	421.1
Combined	204/139	0.037	3.253	0.806	843.7
Skull width					
Males	85/66	1.39	1.043	0.858	508.4
Females	104/61	1.63	1.0	0.677	217.3
Combined	189/127	1.79	0.944	0.792	719.0

[1]for the general model: $E(Y) = b_0 * (\text{pad width})^{b_1}$

TABLE 2. Estimated body length, weight, and skull width (with a 95% confidence interval in parentheses) by sex and for both sexes combined from regression models (from Table 2) of Black Bear pad width, northeastern Minnesota, 1969-1982.

Pad width classes	Estimated Body length			Weight			Skull widith		
	Males	Females	Combined	Males	Females	Combined	Males	Females	Combined
-cm-		-cm-			-kg-			-cm-	
5	61.6 (56.6-67.0)		67.6 (61.9-73.8)	4.6 (3.0-7.1)		7.0 (4.9-10.1)	7.4 (6.3-8.8)		8.2 (7.6-8.9)
6	75.3 (64.0-88.5)	72.6 (63.4-83.1)	81.6 (74.9-88.9)	8.9 (5.9-13.5)	10.3 (6.9-15.3)	12.7 (9.0-18.0)	9.0 (7.6-10.6)	9.8 (8.5-11.2)	9.7 (9.0-10.5)
7	89.2 (76.2-104.6)	90.3 (79.3-102.7)	95.6 (87.8-104.1)	15.6 (10.4-23.5)	19.4 (13.2-28.4)	21.0 (15.1-29.4)	10.5 (9.0-12.4)	11.4 (10.0-13.0)	11.3 (10.4 12.2)
8	103.4 (88.4-120.9)	109.0 (96.0-123.7)	109.7 (100.9-119.3)	25.4 (17.0-38.1)	33.5 (23.0-48.7)	32.5 (23.5-44.9)	12.1 (10.4-14.2)	13.0 (11.5-14.8)	12.8 (11.8 13.8)
9	117.7 (100.8-137.5)	128.7 (113.4-145.9)	123.9 (113.9-134.7)	39.1 (26.2-58.3)	54.3 (37.4-78.7)	47.6 (34.7-65.3)	13.7 (11.7-16.0)	14.6 (12.9-16.6)	14.3 (13.2-15.4)
10	132.3 (113.3-154.4)	149.3 (131.5-169.5)	138.1 (126.9-150.1)	57.3 (38.5-85.5)	83.6 (57.5-121.6)	67.1 (49.3-91.4)	15.3 (13.1-17.9)	16.3 (14.3-18.5)	15.8 (14.6-17.1)
11	146.9 (125.8-171.5)		152.3 (140.0-165.7)	81.2 (54.4-121.0)		91.5 (67.6-123.8)	16.9 (14.5-19.7)		17.3 (16.0-18.7)
12	161.7 (138.4-188.9)		166.6 (153.1-181.2)	111.4 (74.6-166.4)		121.4 (90.2-163.5)	18.5 (15.8-21.6)		18.7 (17.3-20.3)

about 10% less than the true value obtained from the animal.

Track measurements from designed surveys, possibly using scent stations (Lindzey et al. 1977) with track plates (Zielinski 1995) or other media (Wemmer et al. 1996), and combined with camera systems (Jones and Raphael 1993) and/or DNA fingerprinting (Woods et al. 1996) could provide useful and inexpensive information about a Black Bear population. By controlling for substrate and gait conditions, extraneous foot-print variability should be reduced. Additional measurement and analyses of sex, age, pad width, and other physical dimensions and of foot-print width would create a data and knowledge base to increase the information available from standardized track surveys.

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Literature Cited

Beck,T. B. I. 1991. Black bears of west-central Colorado. Colorado Division of Wildlife, Technical Publication number 39.

Jones, L. L. C., and **M. G. Raphael.** 1993. Inexpensive camera systems for detecting martens, fishers, and other animals: guidelines for use and standardization. U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-306.

Lindzey, F. G., S. K. Thompson, and **J. I. Hodges.** 1977. Scent station index of black bear abundance. Journal of Wildlife Management 41: 151-153.

Piekieiek, W., and **T. S. Burton.** 1975. A black bear population study in northern California. California Fish and Game 61:4-25.

Rogers, L. L. 1987. Effects of food supply and kinship on social behavior, movements, and population growth of black bears in northeastern Minnesota. Wildlife Monograph, number 97.

Sokal, R.R., and **F.J. Rohlf.** 1981. Biometry, Second edition. W. H. Freeman and Co., San Francisco, California.

Wemmer, C., T. H. Kunz, G. Lundie-Jenkins, and **W. J. Mcshea.** 1996. Mammalian sign. Pages 157-176 *in*

Measuring and monitoring biological diversity: standard methods for mammals. *Edited by* D. E. Wilson, F. R., Cole, J. D. Nichols, R. Rudran, and M. S. Foster. Smith-sonian Institution Press, Washington D. C.

Willey, C. H. 1974. Aging black bears from first premolar tooth sections. Journal of Wildlife Management 38:97-100.

Woods, J. G., B. McLellan, D. Paetkau, C. Strobeck, and **M. Proctor.** 1996. DNA fingerprinting applied to mark-recapture bear studies. International Bear News 5(1): 9-10.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Zielinski, W. J. 1995. Track plates. Pages 67-89 *in* American marten, fisher, lynx, and wolverine: survey methods for their detection. *Edited by* W. J. Zielinski, and T. E. Kucera. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. General Technical Report PSW-GTR-157.

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