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SHORT COMMUNICATION

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Predicting body mass from chest circumference in moose *Alces alces*

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Weighing large animals in the field is often labourious and expensive. Alternative methods which replace direct measurements of body mass are, therefore, of practical value. In order to predict body mass in moose *Alces alces*, an allometric model based on chest circumference, sex, age and population was applied. A model to predict body mass based on chest circumference and a truncated age measurement is suggested. Impact of sex and population was weak. The ability to predict body mass was mostly influenced by chest circumference. The proportion of carcass mass to total body mass varied between 45% and 51% among age-classes. In addition, there was a slight effect of sex on this variation, males having a proportionally larger carcass mass than females. The model's predictions of body mass are adequate for describing the distribution of body mass in moose populations and for comparing moose populations.

Key words: Morphometrics, body mass, carcass mass, chest circumference, mass prediction, moose, Sweden

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Body mass is often used to characterise the physical state of an animal's condition (e.g. Albon et al. 1983, Clutton-Brock et al. 1988) as well as the condition among populations (e.g. Haigh 1981, Huot 1988). As such, body mass has been applied in several different aspects of behavioural and ecological studies, for instance fertility (e.g. Albon et al. 1983, Sæther & Haagenrud 1983), production of offspring (e.g. Kojola & Eloranta 1989), sexual size-dimorphism (e.g. Sæther & Haagenrud 1985), environmental gradients (e.g. Sæther 1985), and male reproductive success (e.g. Clutton-Brock et al. 1982).

Although the weighing of large animals in the field is often labourious and expensive, the knowledge of mass may be necessary (e.g. when estimating correct drug doses for immobilisation and in physiological investigations). Alternative methods which replace direct measurements of body mass are, therefore, of practical value. Several studies have used morphometric measurements in order to predict mass of domestic as well as free-living large mammals (e.g. Brody et al. 1937, McCulloch & Talbot 1965, Kelsall et al. 1978, Weckerly et al. 1987). Chest circumference is known to be sensitive to differences in

skeletal size as well as muscles and adipose tissues (Bandy et al. 1956, McEwan & Wood 1966).

In this study we analyse the capacity to determine: 1) body mass of moose from knowledge of chest circumference, sex, age, and population; and 2) the relationship between body mass and carcass mass and the impact of age and sex. The analyses were made on five geographically separated moose populations in Sweden. We applied an allometric model which was tested using a Jackknife procedure.

Material and methods

Sample

Data on age, sex and carcass mass (defined as the mass after head, skin, lower legs, kidneys and viscera had been removed) were collected from 420 moose (215 females, 205 males), shot during 1973-1990 at Grimsö in south-central Sweden. Animals were shot throughout the whole year except for July, but most of the samples were collected during the autumn hunt (October-November). Furthermore, we collected data on chest circumference from 173 of these animals.

Data on body mass, chest circumference and age were collected from 435 moose immobilised in late winter and early spring in five different areas in Sweden during 1987-1995 (Table 1).

Variables and measurements

Chest circumference was measured in the field on 435 live and 173 dead animals. Measurements were obtained with a steel tape (to the nearest mm), placed immediately behind the forelegs and over the highest point of the backbone above the shoulder (Fig. 1). Dead animals were measured in the field, and then processed in the laboratory and weighed. Mass was measured to the nearest kilogram. Immobilised animals were weighed using a winch and tripod or helicopter. The ages of dead animals were determined by counting cementum annuli in the first molar (M1) or incisor (I1, Sergeant & Pimlott 1959), and the ages of immobilised animals were determined by tooth wear and eruption.

Table 1. Data composition of 435 moose from which data on body mass, chest circumference and age were collected in five areas in Sweden during 1987-1995.

Area	Sex		Years	Position
	females	males		
Mark	41	18	1994-1995	57°25'N, 12°40'E
Grimsö	14	15	1987-1988	59°40'N, 15°20'E
Orsa	28	17	1994-1995	61°40'N, 14°50'E
Robertsfors	145	110	1990-1995	64°15'N, 20°50'E
Bågede	33	14	1995	64 20'N, 14°20'E
Total	261	174	1987-1995	

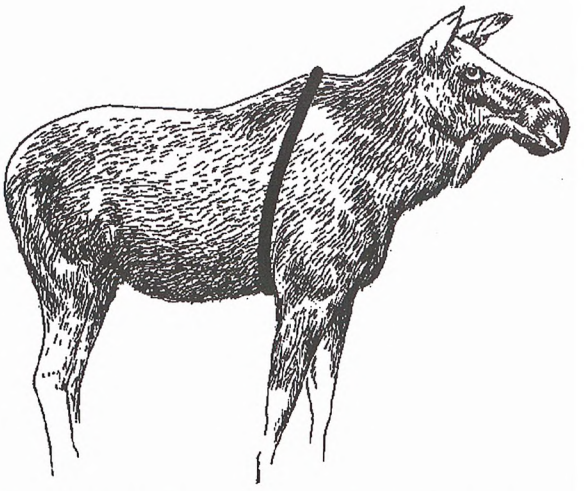

Figure 1. Chest circumference of moose was measured immediately behind the foreleg and over the highest point above the shoulder.

Statistical analysis

The analyses on the relationship between body mass (m), chest circumference (c) and age (a) were based on an allometric growth model. Thus, we assume that the growth percentage per time unit (t) is proportional to mass and chest circumference or $\delta m/(m\delta t)=p\delta c/(c dt)$. Solving these differential equations results in the relationship: $\ln(m) = p \ln(c) + k$, where k is an integration constant (e.g. Cullen 1983). This linear equation forms the basis of the following analyses.

When both age and chest circumference are considered as independent variables we allow age to interact with chest circumference, but not vice versa - the reason for this should be obvious. The meaning of interaction here is that p will change with age:

$$p = \alpha+\beta a, \text{ or}$$

$$\ln(m)= (\alpha+\beta a) \ln(c) + \gamma \ln(a) + k$$
$$= \alpha\ln(c)+\beta\, a \ln(c) + \gamma \ln(a) + k \quad (1)$$

Actual body mass can be estimated by finding the antilogarithm of the last equation, which yields $m = e^{k}e^{(\alpha+\beta a)\ln(c)}e^{\gamma\ln(a)} = Kc^{\alpha+\beta a}a^{\gamma}$. In the case of no interaction, $\beta = 0$.

As body mass in moose does not increase over the entire life span, we replace the ordinary age measurement by a truncated age measurement. We also include sex due

to the known sexual dimorphism in moose (e.g. Peterson 1974, Sæther & Haagenrud 1985, see also Fig. 2). In addition we analyse the importance of the location of the populations. Sex and location were treated as 'dummy' variables.

Results

Age-dependent body mass and chest circumference

Body mass increases until the age of five years in females and the age of six years in males (Fig. 2), whereafter body mass remains fairly constant (at these ages, the growth rate was only 3% of the maximum mass). Beyond these ages the relationship between age and body mass became independent, which motivated the truncation of the age variable.

The allometric growth model assumes a linear relationship between body mass and chest circumference. In agreement with this assumption the observed relationship seems to be a 'classic' allometric relationship (Fig. 3). Regression analyses show highly significant results (females: $\ln(m) = -14.6 + 2.73 \ln(c)$, $R^2 = 0.85$, $P < 0.0001$; males: $\ln(m) = -15.2 + 2.81 \ln(c)$, $R^2 = 0.91$, $P < 0.0001$).

Correlation between body mass and carcass mass

For many hunted species, measurements of carcass mass are more easily obtainable than measurements of total body mass. A close relationship between these two body measurements means that they are exchangeable.

The crude correlation between total mass and carcass mass was 0.993 ($P < 0.0001$, $N = 247$). A corresponding analysis, but separated on the sexes, reveals the same close correlation (females: $r = 0.992$, $P < 0.0001$, $N = 120$; males: $r = 0.994$, $P < 0.0001$, $N = 127$).

The average proportion of carcass to body mass was estimated at 47.3%, but depends on sex and age (Table 2). There is a significant sex difference in the percentage of carcass mass among adults, but not among younger age-classes (adults: Mann-Whitney U-test, $P = 0.0029$, see Table 2). There were significant differences between the three age-classes (calf vs. yearling: Mann-Whitney U-test, $P < 0.0001$; yearling vs. adult: Mann-Whitney U-test, $P = 0.0052$). Thus, it seems as if males have a larger percentage of carcass mass than females. Males also show a larger age dependency than do females.

Predicting body mass

Body mass

To predict body mass from related variables there are a

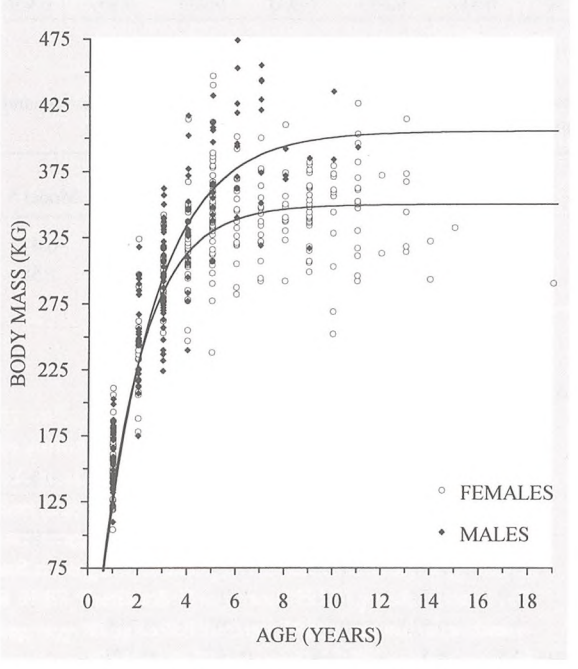

Figure 2. Relationship between body mass and age. The lines represent the fitted non-linear model: body mass = $k(1-e^{-b*age})$. Growth was considered as having ceased when the yearly growth rate dropped to 3% of the estimated maximum mass, which occurred at five years for females and six years for males.

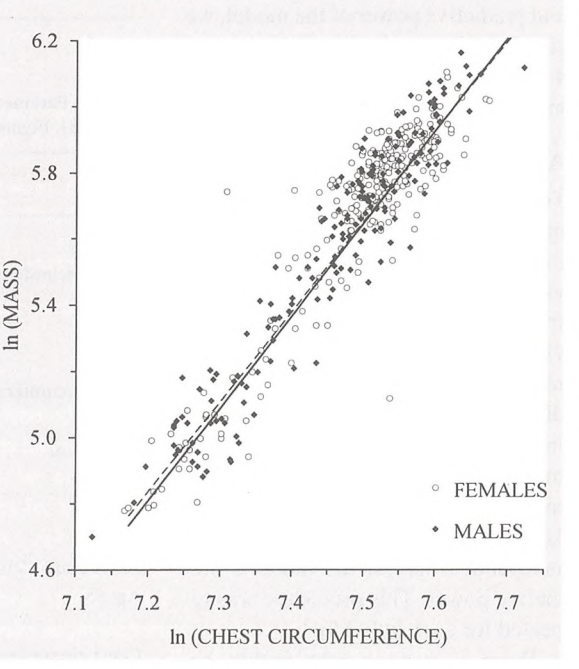

Figure 3. Allometric relationship between the natural logarithm of chest circumference (c) and body mass (m) for females (broken line) and males (solid line).

set of possible models with varying degree of complexity. Parameter estimates for a subset of models (Tables 3 and 4) can be directly applied to equation 1 above.

When age and chest circumference are single variables in a model, the predictive power of the latter appears to be slightly stronger (see Table 3). For sex-specific models the predictive power is slightly improved (see Table 4).

In a model including both age and chest circumference, the coefficient of determination, R^2, increases to 0.929 - 0.942 (see Tables 3 and 4). In this case sex-specificity does not result in any general improvement. For females the predictive power slightly decreases, but for males there is a slight increase (see Tables 3 and 4).

Adding an interaction term (see the Statistical analysis section above), sex or population variables, does not improve the predictive power of the model. Still, the parameters of the two last-mentioned variables are statistically significant (see Tables 3 and 4).

Taking into account the complexity and predictive power of the model, we conclude that model 3 in Tables 3 and 4 seems to be the most appropriate model.

Accuracy of prediction

To evaluate the accuracy with which model 3 predicts body mass, we performed the following Jack-knife analysis: One individual was excluded from the data set and a regression analysis of model 3 was performed on the remaining individuals. We then predicted the body mass of the excluded individual, using the parameter estimates from the regression analysis made on the non-excluded individuals. Using this procedure we obtained an independent test of the model's predictive power. This procedure was repeated for each individual.

There is a good relationship between observed body mass and predicted body mass (Fig. 4). The coefficient of determination, R^2, was 0.896 for females and 0.928 for males, which

Table 2. Carcass mass percentage of total body mass in 247 moose according to sex and age-classes. Sample sizes are given in parentheses.

Sex		Age-class						Total	
		Calf		Yearling		Adult			
Female	Mean	45.4%	(62)	48.6%	(28)	49.4%	(30)	47.1%	(120)
	SD	2.9%		2.9%		2.2%		3.3%	
Male	Mean	45.8%	(68)	49.4%	(31)	51.1%	(28)	47.9%	(127)
	SD	3.4%		1.9%		1.5%		3.6%	
Total	Mean	45.6%	(130)	49.0%	(59)	50.2%	(58)		
	SD	3.2%		2.4%		2.1%			

Table 3. Parameter estimates and sum of square (SS, up to type III) for different linear regression models predicting moose body mass. All individuals are included, independent of sex. The only exception is model 5, which uses sex as a 'dummy variable'. Figures in italics indicate significant estimates with $P < 0.001$.

		Parameter estimates					
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	k	-14.9	5.07	-6.79	-6.48	-6.45	-7.28
Chest circumference	α	2.77		1.64	1.6	1.59	1.7
	SS	*40.5*		*3.71*	*3.38*	*3.43*	*3.53*
Age	γ		0.499	0.24	0.326	0.254	0.231
	SS		*40.7*	*2.42*	*0.625*	*2.54*	*2.05*
Chest circ.*Age	β				-0.00409		
	SS				*0.0511*		
Sex	SS					*0.121*	
Population	SS						*0.136*
	R^2	*0.881*	*0.853*	*0.933*	*0.935*	*0.937*	*0.936*

Table 4. Parameter estimates similar to those in Table 3 including only females (A) and males (B). Figures in italics indicate significant estimates with $P < 0.001$.

		Parameter estimates				
A		Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	k	-14.6	5.04	-5.78	-5.51	-6.43
Chest circumference	α	2.73		1.49	1.46	1.58
	SS	*20.3*	*1.88*	*1.69*	*1.86*	
Age	γ	0.504	0.27	0.355	0.257	
	SS	*21.9*	*1.87*	*0.264*	*1.54*	
Chest circumference*Age	β	-0.00410				
	SS	0.0165				
Population	SS	*0.145*				
	R2	*0.851*	*0.853*	*0.929*	*0.930*	*0.935*
B						
Intercept	k	-15.2	5.08	-7.68	-7.41	-7.83
Chest circumference	α	2.81	1.76	1.73	1.78	
AgeSS	19.2	*1.54*	*1.44*	*1.36*		
	γ	0.523	0.224	0.291	0.218	
Chest circumference*Age	SS	*18.5*	*0.685*	*0.285*	*0.579*	
	β	-0.00313				
	SS	0.0200				
Population	SS	*0.0354*				
	R^2	*0.910*	*0.869*	*0.942*	*0.943*	*0.944*

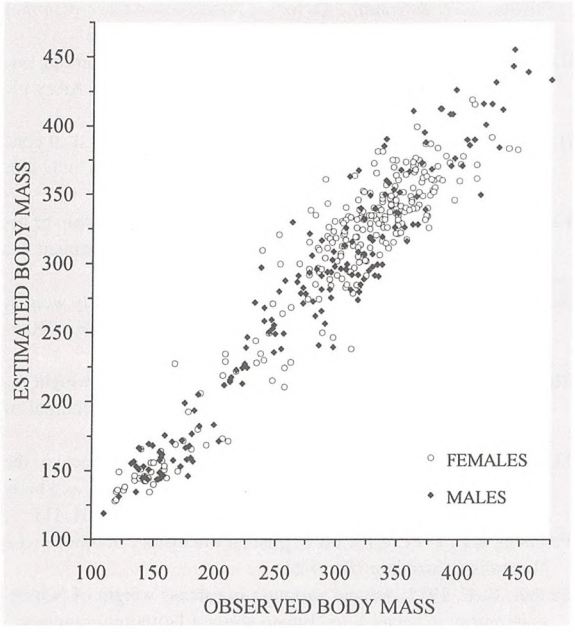

Figure 4. Relationship between observed body mass and predicted body mass using model 3 in Table 4.

is slightly lower than the estimates of the original regression model (see Table 4). Thus, the independent test seems to give a slightly lower estimate than that in the original regression analysis.

Even though about 90% of the observed body mass was predicted from the model, the question remains: How accurately does the model predict the body mass of each individual animal? The answer can be seen from the estimated distribution function of the difference between observed body mass and predicted body mass (Fig. 5). The estimated body mass deviated more than 25 kg from the observed body mass in 20% of the individuals, and the error could be as large as 75 kg and was not related to sex (see Fig. 5).

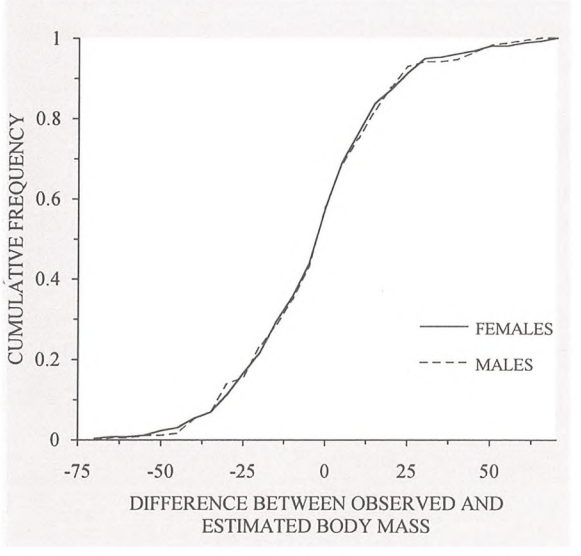

Figure 5. The sex-specific distribution function for the difference between observed and predicted body mass using model 3 in Table 4.

Discussion

Models on the relationship between morphological and body mass measurements in moose have shown varying degrees of agreement. Hanks et al. (1976) showed that a model including total length and chest girth raised to the second power gave the best prediction of body mass (R^2 = 0.83, N = 32). Franzmann et al. (1978) found that total length and chest girth made good predictions of body mass (total length: R^2 = 0.88, N = 502, and chest: R^2 = 0.81, N = 496). As in this study, they concluded that sex did not improve the ability to predict body mass. Unfortunately, Franzmann et al. (1978) used a simple, linear measurement of chest circumference. Consequently, the maximal dimensional capacity of this morphological measurement was not evaluated, which resulted in a lower coefficient of determination than that of the present study (see Table 3).

The models applied in our study describe most of the body mass variation observed in the moose. We therefore consider the models as good instruments for predicting body mass, which may replace weighing in many situations. We noticed that neither chest circumference alone nor age alone appeared to be good predictors of moose body mass. A model including both these variables is to be preferred because together they significantly improve the predictive power of the model. However, making the model more complicated by including sex, population and interaction effects only improved its predictive powers marginally. Thus, the model could safely be used with different populations and without knowledge of sex. We conclude that a model including age (up to five years) and chest circumference, without interaction effects, is to be preferred (model 3, see Tables 3 and 4).

Several of the models used can easily be used to provide information on the mass distribution at the population level. However, like all indirect measurements, some caution has to be taken before some of the models are applied. Despite the large coefficient of determination of the models (see Tables 3 and 4), when used for determining an individual's body mass, it should be kept in mind that there will still be a fairly large total error (see Fig. 5). The importance of these errors should always be evaluated before using any of the models. To get an effective, indirect method for measuring body mass at the individual level,

further analyses are required which might include other morphological measurements than chest circumference.

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References

Albon, S.D., Mitchell, B. & Staines, B.W. 1983: Fertility and body weight in female red deer: a density-dependent relationship. - Journal of Animal Ecology 52: 969-980.

Bandy, P.J., Cowan, I.McT., Kitts, W.D. & Wood, A.J. 1956: A method for the assessment of nutritional status of wild ungulates. - Canadian Journal of Ecology 34: 48-52.

Brody, S., Davis, H.P. & Ragsdale, A.C. 1937: Estimating live weight from chest girth of dairy cattle of unknown age. - Journal of Dairy Sciences 20: 403-405.

Clutton-Brock, T.H., Guinness, F.E. & Albon, S.D. 1982: Red deer: Behaviour and ecology of two sexes. - University of Chicago Press, Chicago, 378 pp.

Clutton-Brock, T.H., Albon, S.D. & Guinness, F.E. 1988: Reproductive success in male and female red deer. - In: Clutton-Brock T.H. (ed.); Reproductive success - Studies of individual variation in contrasting breeding systems. University of Chicago Press, Chicago, pp. 325-343.

Cullen, M.R. 1983: Mathematics for the biosciences. - PWS - Kent Publishing Company, Boston, 712 pp.

Franzmann, A.W., LeResche R.E., Rausch, R.A. & Oldemeyer, J.L. 1978: Alaskan moose measurements and weights and measurements-weight relationships. - Canadian Journal of Zoology 56: 298-306.

Haigh, J. 1981: Characterizations of population condition. - In: Fowler, C.W. & Smith, T.D. (eds.); Dynamics of large mammal populations. John Wiley & Sons, New York, pp. 47-73.

Hanks, J.C., Stewart, R.R. & Mutton, W. 1976: Relations among linear measurements and weights for mass (Alces alces). - Alces 12: 1-10.

Huot, J. 1988: Review of methods for evaluating the physical condition of wild ungulates in northern environments. - Collection Nordicana 50. University of Laval, Laval, 30 pp.

Kelsall, J.P., Telfer, E.S. & Kingsley, M. 1978: Relationship of bison weight to chest girth. - Journal of Wildlife Management 42: 659-661.

Kojola, I. & Eloranta, E. 1989: Influences of maternal body weight, age, and parity on sex ratio in semidomesticated reindeer (Rangifer t. tarandus). - Evolution 43: 1331-1336.

McCulloch, J.S.G. & Talbot, L.M. 1965: Comparison of weight estimation methods for wild and domestic livestock. - Journal of Applied Ecology 2: 59-69.

McEwan, E.H. & Wood. A.J. 1966: Growth and development of the barren ground caribou. I. Heart girth, hind foot length, and body weight relations. - Canadian Journal of Zoology 44: 401-411.

Peterson, R.L. 1974: A review of general life history of moose. - Le Naturaliste Canadien 101: 9-21.

Sæther, B.-E. 1985: Annual variation in carcass weight of Norwegian moose in relation to climate along a latitudinal gradient. - Journal of Wildlife Management 49: 977-983.

Sæther, B.-E. & Haagenrud, H. 1983: Life history of the moose (Alces alces) fecundity rates in relation to age and carcass weight. - Journal of Mammalogy 64: 226-232.

Sæther, B.-E. & Haagenrud, H. 1985: Geographical variation in body weight and sexual size-dimorphism of Norwegian moose (Alces alces). - Journal of Zoology London (A) 206: 83-96.

Sergeant, D.E. & Pimlott, D.H. 1959: Age determination in moose from sectioned incisor teeth. - Journal of Wildlife Management 23: 315-321.

Weckerly, F.W., Leberg, P.L. & van den Bussche, R.A. 1987: Variation of weight and chest girth in white-tailed deer. - Journal of Wildlife Management 51: 334-337.