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Prediction of the body mass of the bank vole *Myodes glareolus* from skull measurements

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Abstract. Regression equations were computed for determining body mass from skull measurements from 376 bank vole (*Myodes glareolus*) individuals trapped in seven sites of Lithuania during 1999–2005. The obtained linear and multiple regressions explained 38–58% of the body mass variation. The applicability of regressions was checked on 92 additional specimens. The error of the prediction of the body mass of bank voles was 1.2–4.4%. The obtained equations improve the accuracy of evaluation of biomass consumed and widen possibilities for the analysis of material containing small mammal skull remains. The method is applicable to investigations on the feeding ecology of owls and other myophagous birds.

Key words: bank vole, craniometry, body mass prediction.

INTRODUCTION

Small mammals are commonly preyed by various avian predators, and the bank vole (*Myodes glareolus*) is among the main prey species for owls (Balčiauskienė, 2006). Indigestible bones and teeth give a possibility for estimating prey composition. Also, it is possible to estimate the preyed small mammal body mass and age classes from cranial or mandible dimensions (Blem et al., 1993; Zalewski, 1996). The topic was explored several decades ago (Pagels & Blem, 1984; Stewart & Barss, 1985; Dickman et al., 1991), and recently it has come back onto the stage again (Balčiauskienė, 2006, 2007a, b, c; Borowski et al., 2008).

In this paper we will discuss possibilities of estimating the body mass of bank voles from several skull measures, with respect to the character preservation rates in owl pellets and prey remains.

MATERIAL AND METHODS

The skulls of 376 bank vole individuals trapped in seven sites of Lithuania from July to October 1999–2005 were used for our calculations. After dissection, based on their reproductive status, the trapped voles were divided into three age categories: juveniles, subadults, and adults. All overwintered and breeding individuals, i.e.

males with scrotal testes and lactating or pregnant females, were defined as adults. All individuals that stayed non-breeding during the year of birth (reproductive organs developed, but inactive – small nipples and closed vagina in females, abdominal testes in males) fell into the category of subadults. All individuals without expressed sex attributes (reproductive organs still developing – threadlike vagina or hardly visible testes) were treated as juveniles. The presence and the status of *glandula thymus* (*gl. thymus* involuted in adults, *gl. thymus* disappearing in subadults, *gl. thymus* functioning in juveniles) as well as animal mass were taken into account.

The skulls of trapped voles were cleaned by *Dermestes* larvae. We used 17 skull characters (Balčiauskienė, 2006, 2007a) measured under a binocular with a micrometric eyepiece with an accuracy of up to 0.1 mm. We measured the characters of the right set of the skull, the left set was measured only in the cases the skull was damaged.

The following skull (8 mandibular and 9 cranial) characters were measured (Fig. 1): X_1 – total length of mandible at *processus articularis* excluding incisors; X_2 – length of mandible excluding incisors; X_3 – height of mandible at, and including, first molar; X_4 – maximum height of mandible excluding coronoid process; X_5 – coronoid height of mandible; X_6 – length of mandibular diastema;

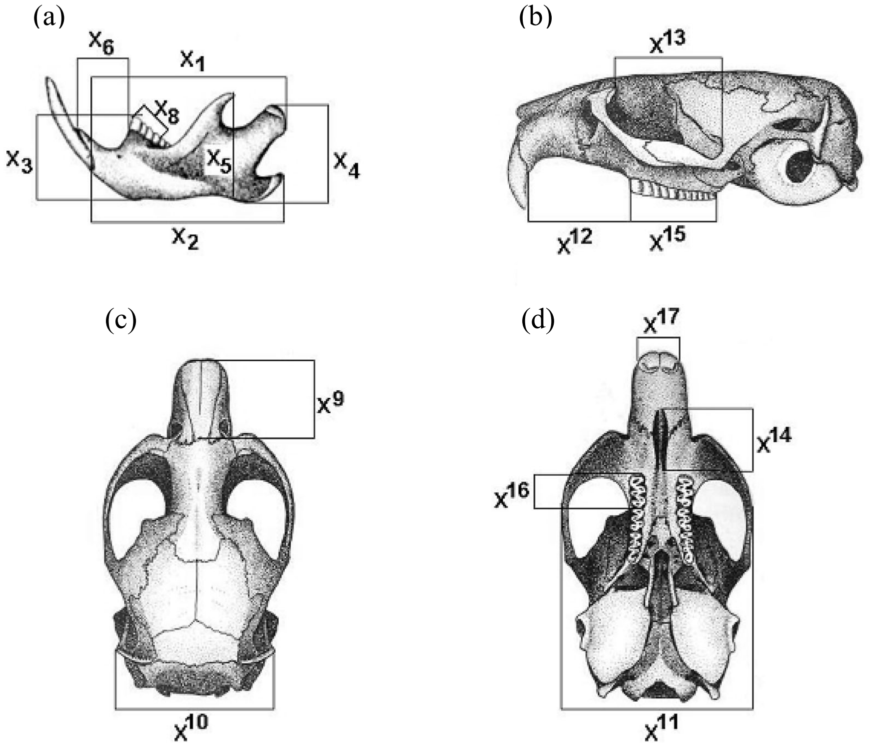


Fig. 1. Skull measurements taken: a – dorsal view, b – ventral view, c – lateral view, d – mandible (Balčiauskienė, 2007a).

X_7 – length of mandibular tooth row; X_8 – length of molar M_1; X^9 – length of *nasalia*; X^{10} – breadth of braincase measured in the widest part; X^{11} – zygomatic skull width; X^{12} – length of cranial (upper) diastema; X^{13} – zygomatic arc length; X^{14} – length of *foramen incisivum*; X^{15} – length of maxillary toothrow; X^{16} – length of molar M^1; X^{17} – incisor width across both upper incisors (Balčiauskienė, 2006, 2007a).

The rate of preservation of skull characters in bank voles was evaluated from the pellets and food remains of the Tawny Owl (*Strix aluco*) collected in Lithuania in 1997–2005 (Balčiauskienė, 2006).

Regression equations describing the relation of skull characters with body mass were calculated using the skull characters that correlated best with body dimensions. Multiple regressions were combined not only from the best-working characters, but also depending on character availability in food remains or pellets. Regressions were calculated separately for mandibular and maxillary characters. We used the stepwise forward regression method (StatSoft, 2004). The number of included characters was minimized deliberately, including only (i) characters with p-level < 0.05, and (ii) characters giving a significant increase of the determination coefficient, r^2, with no less than 50%.

The applicability of the obtained regressions was checked on 92 additionally trapped bank vole specimens. Differences between estimates (measured and calculated weights) were expressed as the ratio to the average body mass of individuals trapped and tested using Student's t test.

RESULTS AND DISCUSSION

In our sample, the average bank vole body mass was 18.42 ± 0.17 (6.0–34.0) g, and body length 84.7 ± 0.36 (61.9–105.4) mm. On average, females were heavier than males: 18.8 ± 0.28 (9.0–34.0) g vs 18.0 ± 0.20 (6.0–27.5) g, $t = 2.32$, $p < 0.02$, but their body length did not differ much: 85.2 ± 0.56 (65.0–105.4) mm vs 84.2 ± 0.46 (61.9–100.0) mm, $t = 1.47$.

According to our sample, all bank vole individuals with body mass $Q < 16.0$ g and length $L < 70$ mm can unmistakably be put among juveniles; those with $Q > 22.0$ g and $L > 95.5$ mm, among adults. The average body mass of subadults was 18.1 ± 0.08 (16.0–22.0) g, body length 84.6 ± 0.28 (70.9–95.5) mm, but the overlapping of body measures in this age category was very high (Fig. 2).

Visual examination of Fig. 2 confirms that the distribution and overlapping of body length in different age categories is much wider than those of body mass. For this reason, we base the determination of animal age on body mass only; body length being used as an additional measure.

Under condition that the linear regression should explain no less than 50% of the variation of the calculated body mass, the correlation coefficient must be $r > 0.70$. This is hardly achievable in bank voles with a single skull character.

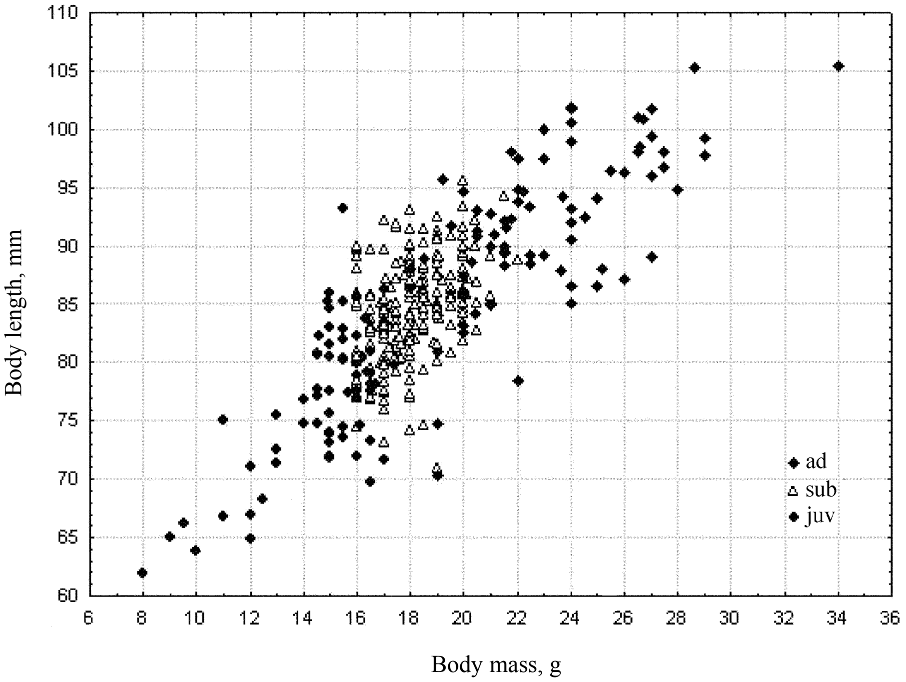


Fig. 2. Relation of body mass and body length to animal age in the bank vole (ad – adults, sub – subadults, juv – juveniles).

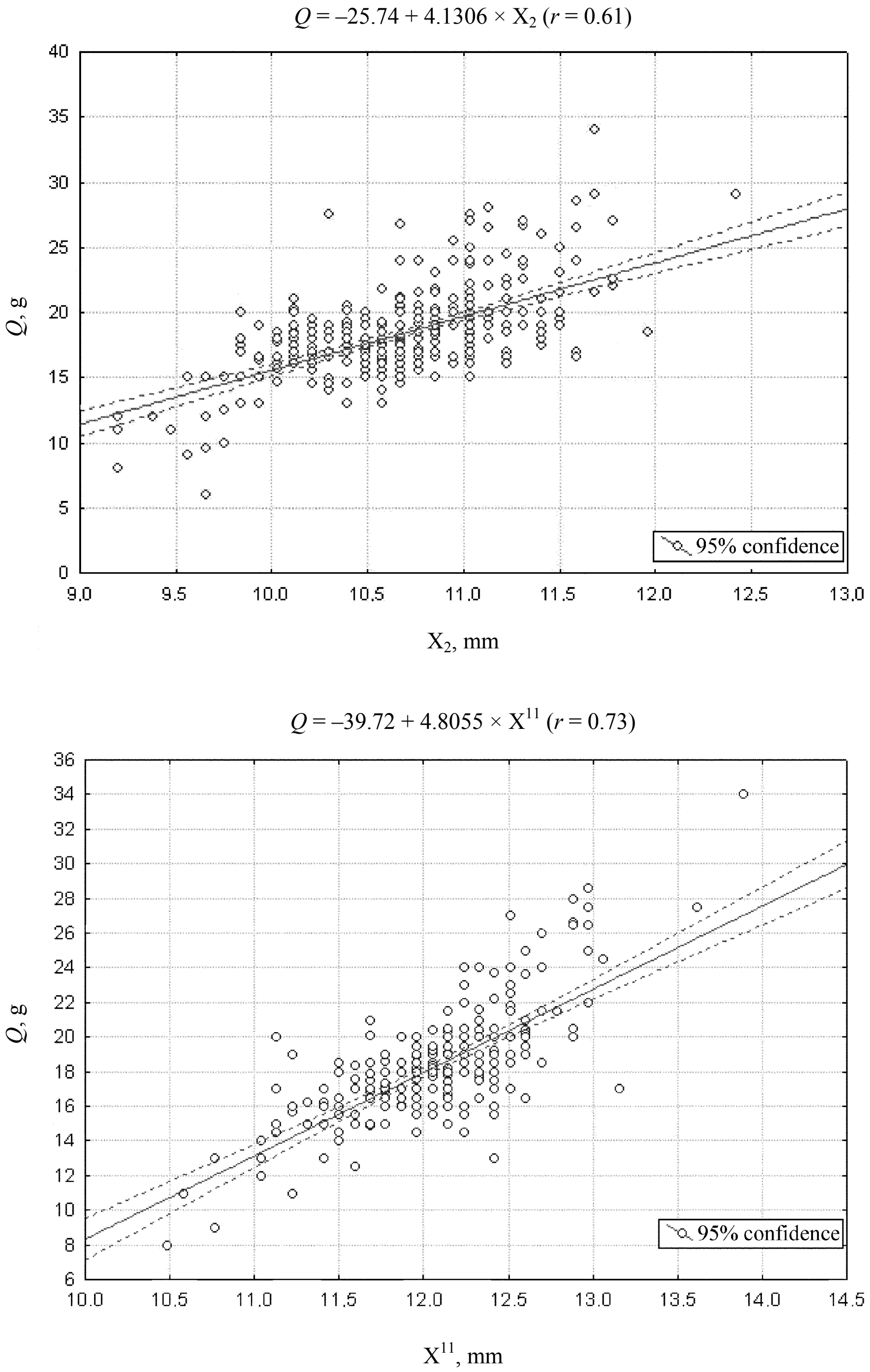
Correlation coefficients between body mass, body length, and skull characters in bank voles were medium strong, though very significant (Table 1).

Based on the presumption that the growth of small mammals continues throughout their lifespan, we initially tried to approximate the dependence of body mass on skull measurements by linear regression. The best correlations of body mass with mandibular (X_2 – length of mandible excluding incisors) and maxillary (X^{11} – zygomatic skull width) characters are shown in Fig. 3. We did not use X_2 character, as it yields a regression with an insufficient determination coefficient ($r^2 = 0.37$). The only sufficient linear regression was

$$Q = -39.72 + 4.81 \times X^{11}, \quad r^2 = 0.53. \tag{1}$$

Table 1. Correlation coefficients between body mass (*Q*), body length (*L*), and skull characters (X_1–X^{17}) in trapped bank voles (all $p < 0.001$, except X^{13} $p < 0.005$)

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X^9	X^{10}	X^{11}	X^{12}	X^{13}	X^{14}	X^{15}	X^{16}	X^{17}
Q	0.60	0.61	0.50	0.60	0.42	0.33	0.26	0.54	0.53	0.19	0.73	0.67	0.44	0.60	0.28	0.35	0.50
L	0.55	0.54	0.43	0.55	0.42	0.36	0.31	0.49	0.58	0.19	0.66	0.66	0.45	0.57	0.32	0.40	0.53



$Q = -25.74 + 4.1306 \times X_2$ ($r = 0.61$)

$Q = -39.72 + 4.8055 \times X^{11}$ ($r = 0.73$)

Fig. 3. Bivariate scatterplots of body mass against variables X_2 and X^{11}. Regression line and 95% confidence limits are given.

The inclusion of more characters into multiple regressions did not improve determination, but these equations are usable when other characters are destroyed. Equations of multiple regressions describing bank vole body mass relation to various mandibular and maxillary characters and explaining 38–58% of body mass variation are presented below (all these regressions are statistically significant with $p < 0.001$):

$$Q = 2.472X_2 + 3.43X_4 - 27.88 \quad (r^2 = 0.43), \tag{2}$$

$$Q = 3.48X^{11} + 3.495X^{12} - 44.85 \quad (r^2 = 0.58), \tag{3}$$

$$Q = 5.33X_3 + 13.03X_8 - 31.21 \quad (r^2 = 0.38), \tag{4}$$

$$Q = 4.786X_3 + 3.315X_6 + 12.26X_8 - 36.99 \quad (r^2 = 0.40). \tag{5}$$

Not all included characters are measurable in the skull fragments from pellets and food remains of the Tawny Owl due to different rates of preservation (Balčiauskienė, 2006). In the material retrieved from owl pellets, the rate of preservation was higher for mandibular than maxillary characters, excluding X_2 and X_5. It is impossible to take these measurements because of broken *processus angularis* and *processus coronoidus*. Maxillary characters X^9, X^{10}, and X^{13} were badly preserved due to broken zygomatic arcs, nasal bones, and the braincase (Table 2). A few characters – X^{16} (length of molar M^1), X_8 (length of molar M_1), X_6 (length of mandibular diastema), and X_3 (height of mandible at, and including, first molar) – were preserved to a greater extent, but only X_6 and X_3 correlated to body mass.

The suitability of the obtained regressions was tested on an additional sample of trapped individuals ($N = 92$). Due to destruction of skulls by snap-traps, the real number of character measurements used in calculations was smaller. Comparison of the measured and calculated body mass shows that there were no statistical differences (Table 3). In bank voles the error was small, just 1.2–4.4%. Thus, regressions 2–5 can be used for body mass predictions from skull measurements.

Table 2. Rate of preservation (%) of bank vole skull characters from Tawny Owl pellets and food remains (*n* – number of measured characters)

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X^9	X^{10}	X^{11}	X^{12}	X^{13}	X^{14}	X^{15}	X^{16}	X^{17}
n	49	30	87	60	23	92	63	97	3	n.d.	12	13	3	16	35	66	11
%	37.1	22.7	65.9	45.5	17.4	69.7	47.7	73.5	4.4	n.d.	17.6	19.1	4.4	23.5	51.5	97.1	16.2

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n.d. – no data.

Table 3. Comparison of body mass (g) of snap-trapped bank voles with the mass predicted from regression equations (NS – not significant)

Measured body mass		Calculated body mass				Difference	
Avg ± SE	Min–max	Equation	*N*	Avg ± SE	Min–max	in %	*p*<
17.14 ± 0.32	10.0–30.0	2	76	17.41 ± 0.25	12.1–23.7	1.6	NS
		3	61	17.89 ± 0.34	11.6–25.7	4.4	NS
		4	15	17.37 ± 0.74	13.4–23.3	1.3	NS
		5	15	17.34 ± 0.83	13.1–23.9	1.2	NS

Our data did not confirm Bashenina’s (1981: 211–226) statement of very high variability of body mass in bank voles. She stated that a rapid growth of body mass slows down already at the age of one month, and a slow rate of growth continues up to the age of 5–6 months. She also stated that the growth dynamics of body mass is the same both in captive bred voles and in wild ones. Our data on the growth of body mass of captive bank voles did not confirm these statements. In captive bank voles, we observed a rapid growth of body mass up to ca 17 g till 1.5 months of age, and such body mass did not change until ca 4 months of age. The body length of such animals was up to 88–90 mm. In older bank voles, especially those aged one year or more, we observed fluctuations in body mass and length (Balčiauskienė, 2007a). On the other hand, individuals of such old age are very rare among free-living bank voles.

From the maximum of observed body mass and body length in captive bank voles, we can presume that after bank voles reach 4 months in age their growth again slowly increases (Balčiauskienė, 2007a). This is the reason why we did not use exponential regressions, as was done by Borowski et al. (2008) for the root vole (*Microtus oeconomus*).

The bank vole is among the main prey species of myophagous (mouse eating) birds in Lithuania. For example, the food of the Tawny Owl in the breeding period in Lithuania comprises on average 25.2% of bank voles by numbers and 19.7% by biomass consumed (Balčiauskienė, 2006). In different districts of Lithuania, these figures range from 12.1% to 29.8% by numbers and from 7.9% to 24.9% by biomass consumed (Balčiauskienė et al., 2000–2001, 2005; Balčiauskienė & Naruševičius, 2006). From the content of Tawny Owl pellets collected year-round in eight districts of Lithuania, we concluded that predation on the bank vole was even more expressed: 34.4% by numbers and 27.6 % by biomass consumed (Balčiauskienė et al., 2006).

In the studies on the feeding ecology of myophagous birds, the age groups or the size of individuals preyed on are often identified (Goszczynski, 1977, 1981; Marti & Hogue, 1979; Skierczyński, 2003). Even the measurements of teeth of bank voles preyed by the pine marten and Tawny Owl may be sufficient for the identification of age groups (Zalewski, 1996).

Generally, the models including mandibular characters are preferred, since mandibles are most often retrieved from owl pellets (Goszczynski, 1977; Morris, 1979; Hamilton, 1980; Zamorano et al., 1986; Dickman et al., 1991). Other authors give preference to equations based on cranial (maxillary) measurements

(Pagels & Blem, 1984). In our sample, mandibular characters were better correlated with body mass than maxillary characters were.

At least 40 specimens are required for regression calculations (Pagels & Blem, 1984), but a smaller sample size can provide a reliable estimate of the body mass of northern pocket gophers *Thomomys talpoides* (Stewart & Barss, 1985). In this respect our sample size was sufficient. Compared to the study of Dickman et al. (1991), where eight test specimens of the house mouse (*Mus domesticus*) were used for validating regression equations and the calculated body mass differed from the actual by up to 8%, our results are more reliable.

Thus, the obtained and tested regression equations may be useful, as they give possibilities for a wider and more professional analysis of material on the feeding ecology of predators (i.e., myophagous birds), including evaluation of exact biomass consumed and prey selectivity in bank voles. For the use of the presented regressions on the material other than of Lithuanian origin, we suggest that predictability be tested on a local sample of bank voles first.

CONCLUSIONS

- Prediction of the body mass of bank voles is possible using regression equations including skull measures, which explain 38–58% of the body mass variation.
- The body mass of the bank vole is best correlated with three mandibular characters – total length of mandible at *processus articularis* excluding incisors, length of mandible excluding incisors, and maximum height of mandible excluding coronoid process, and three maxillary characters – zygomatic skull width, length of cranial (upper) diastema, and length of *foramen incisivum*.
- Due to a low preservation rate of best-correlated skull characters in the pellets and food remains of the Tawny Owl (22.7–45.5% for mandibular, 17.6–23.5% for maxillary characters), regressions were also computed using other skull characters.
- The prediction accuracy of the obtained regressions was very high, and the body mass prediction error was in the range of 1.2–4.4%. For body mass prediction, we recommend using the average value calculated with the help of several presented regressions if skull characters are available.

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Tava-leethiire (*Myodes glareolus*) kehamassi hindamine koljumõõtmete põhjal

Laima Balčiauskienė ja Linas Balčiauskas

On arvutatud regressioon kehamassi ja koljumõõtmete vahel 376 tava-leethiire (*Myodes glareolus*) mõõtmete põhjal. Loomad püüti Leedu seitsmest erinevast paigast aastatel 1999–2005. Saadud lineaar- ja multiregressioon seletab 38–58% kehamassi varieeruvusest. Tulemuste kasutuskõlblikkust kontrolliti 92 lisaisendi peal. Kehamassi ennustamise viga oli 1,2–4,4%. Saadud võrrandid võimaldavad kiskjate tarbitud biomassi täpsemalt hinnata ja pisiimetajate koljusid sisaldavat materjali paremini analüüsida. Meetod on kasutatav kakkude ja teiste hiiretoiduliste lindude toitumisökoloogia uurimiseks.