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# MENSURAL DISCRIMINATION BETWEEN *REITHRODONTOMYS MEGALOTIS* AND *R. MONTANUS* USING CRANIAL CHARACTERS

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We assessed the utility of cranial measurements to discriminate between the western harvest mouse (*Reithrodontomys megalotis*) and plains harvest mouse (*R. montanus*). We tested four combinations of measurements using discriminant function analysis to determine if several measurements could be used together to identify individuals of the two species regardless of age. Individual cranial measurements could not be used to correctly identify all individuals of the two species when relative age was disregarded. When age was considered, adults and old adults, but not subadults, could be identified correctly based on univariate statistical data from cranial characters. All specimens of the two species, regardless of age, were identified correctly by discriminant function analysis using three of the four combinations of measurements.

Key words: *Reithrodontomys megalotis, Reithrodontomys montanus,* cranial morphometrics, discriminant function analysis, sympatry, Kansas

Where the western harvest mouse (*Reithrodontomys megalotis*) and plains harvest mouse (*R. montanus*) occur sympatrically, certain individuals are difficult to identify. *R. montanus* typically differs from *R. megalotis* as follows: dorsal pelage paler, with a more distinct, darker mid-dorsal stripe; tail shorter and more sharply bicolored; dorsal stripe on tail narrower; post-auricular patches more conspicuous; size averaging smaller both externally and cranially; rostrum shorter and weaker; braincase narrower; baculum shorter and thinner (Armstrong, 1972; Bee et al., 1981; Benson, 1935; Caire et al., 1989; Cockrum, 1952; Davis and Schmidly, 1994; Findley et al., 1975; Fitzgerald et al., 1994; Hall, 1981; Hall and Kelson, 1959; Hoffmeister, 1986; Hooper, 1952; Jones, 1964; Jones et al., 1983, 1985; Webster and Jones, 1982; Wilkins, 1986). Consideration of all those characters enables correct identification of most adults but, to identify subadults, one often must rely on intuition, which can lead to misidentification. Even with adults, no one character can be used with absolute confidence to identify all individuals of the two species where they occur sympatrically because their characters often parallel each other (Hall, 1981; Hooper, 1952).

Two previous studies (Hoffmeister, 1986; Stangl et al., 1993) used cranial morphometrics to identify individuals of *R. megalotis* and *R. montanus.* Hoffmeister (1986) employed two methods to differentiate specimens from Arizona. He compared several cranial measurements of like-aged individuals using univariate statistics and, for those not thereby identified, using cluster analysis. He was able to identify nearly all specimens examined with these methods. However, he compared few subadults and did not attempt to account for geographic variation. Moreover, it is unlikely that curators will go to the trouble of conducting cluster analysis to identify troublesome specimens. Stangl et al. (1993) attempted to discriminate between *R. megalotis* and *R. montanus* using just one cranial measurement, interorbital breadth. Although that measurement proved useful for identification of problematic specimens such as those recovered from owl pellets, it could not be used to identify all specimens in their study (Stangl et al., 1993).

Analyses of mensural characters using multivariate statistical techniques designed specifically for maximum separation between closely related groups have not been used in studies of harvest mice. Our purpose was to develop a method to distinguish individuals of the two species of *Reithrodontomys* irrespective of age using either or both univariate and multivariate data from cranial characters.

## Materials and Methods

We initially selected random series of *R. megalotis* and *R. montanus* (10 specimens/species) from Kansas to test the criteria for species identification reported by Hoffmeister (1986) and Stangl et al. (1993). Because measurements overlapped (Hoofer, 1996), we were unable to correctly identify about one-half of the specimens using those criteria. We then selected additional specimens from Ellis, Finney, Jewell, Osborne, Rawlins, Rooks, Russell, and Trego counties of Kansas. We chose those counties primarily because specimens of both species from those counties were well represented in the Sternberg Museum of Natural History and also to minimize effects of geographic variation. Those eight counties are in central and western Kansas where, according to the range maps of Hall (1981), both *R. megalotis* and *R. montanus* occur as single subspecies (*R. megalotis dychei* and *R. montanus albescens*). Furthermore, no major land or water barriers are present, and all but two of the counties (Rawlins and Finney) are contiguous.

All specimens selected originally had been identified by external characters. *R. megalotis* (2n = 42—Blanks and Shellhammer, 1968; Matthey, 1961) and *R. montanus* (2n = 38—Robbins, 1981; Robbins and Baker, 1980) differ karyotypically, but we were unable to check identifications based on karyotypes because we relied on previously captured museum specimens. Therefore, to ensure that the a priori groups (=species) were correctly identified, we were careful to exclude from the samples any troublesome specimens with questionable identifications.

We assigned all specimens to one of three relative age classes (subadults = S; adults = A; old adults = O) based on degree of attrition of upper molar teeth: subadult—$M_3$ fully erupted and usually worn slightly, $M_1$ and $M_2$ typically unworn; adult—$M_3$ worn extensively, $M_1$ and $M_2$ typically worn slightly to moderately; old adult—all molars worn extensively (nearly to cingulum). We found only one "juvenile" (with $M_3$ not fully erupted to level of $M_1$ and $M_2$) and did not include it in the analyses. Hoffmeister (1986) employed a similar method to age specimens of these species but recognized five age classes.

A total of 157 specimens of harvest mice (both males and females) was available for study. Those included 95 *R. megalotis* (30 S, 59 A, 6 O) and 62 *R. montanus* (24 S, 30 A, 8 O). We selected the following nine mensural characters, as defined by Hooper (1952), because of their repeatability: greatest length of skull, zygomatic breadth, breadth of braincase, interorbital breadth, breadth of rostrum, length of incisive foramen, length of molar tooth row, length of rostrum, and depth of braincase. We measured one of those characters, breadth of rostrum, differently than Hooper (1952), who included the bony nasolachrymal capsules in the measurement (we measured breadth of rostrum dorsal to the nasolachrymal capsules because one or both of the capsules frequently are damaged or missing altogether). We added two other measurements because preliminary observations suggested those features might differ significantly between the species: breadth of occipital condyles—least distance between lateral margins of occipital condyles; length of nasal—greatest distance from anteriormost to posteriormost margins of nasal bone (Hoofer, 1996).

We used the mainframe version of the Statistical Analysis System (SAS Institute, Inc., 1989, 1990) for all of the following statistical analyses except discriminant function analyses. We estimated percent contribution to total variance by gender, age, gender-by-age interaction, and unexplained variation for each mensural character as described by Straney (1978) and Leamy (1983) using the VARCOMP procedure. We used the sums-of-squares approach, rather than variance components, because both factors (gender and age) are equal in number of levels for both species (Leamy, 1983). To obtain actual percentages, we divided each factor by its summed total. As suggested by Leamy (1983), we entered gender first and then age because gender is more clearly a fixed factor than is age. We tested for significant ($P \leq 0.05$) sexual dimorphism within species for each mensural character using the Student's *t*-test (PROC TTEST). In addition, we used a one-way analysis of variance of the GLM procedure to ascertain if age classes differed significantly ($P \leq 0.05$) for each character within species. When needed, we used Tukey's studentized range test (HSD) of the TUKEY option of the GLM procedure to determine maximally nonsignificant subsets ($P \geq 0.05$) of relative age classes within species. We computed descriptive statistics ($\bar{X} \pm SE$, range, and *CV*) for each age class of each species (PROC UNIVARIATE).

We performed two discriminant function analyses (independent and stepwise) on all mensural characters using SPSS (SPSS, Inc., 1990). We included all 157 specimens in the analyses. For the independent analysis, all 11 variables (i.e., measurements) were used together, whereas one variable at a time (beginning with the most heavily weighted and progressing to the least heavily weighted) was added for the step-wise analysis. In the step-wise analysis, SPSS automatically performed a new discriminant analysis after each variable was added. For both analyses, SPSS computed a discriminant multiplier for each measurement, a constant, and a discriminant score for each of the 157 specimens.

Additionally, we performed two other discriminant function analyses using SPSS, one for an eight-character combination (zygomatic breadth, breadth of braincase, interorbital breadth, breadth of rostrum, length of incisive foramen, length of molar tooth row, breadth of occipital condyles, and depth of braincase) and another for a three-character combination (interorbital breadth, breadth of rostrum, and length of incisive foramen). We selected those combinations because we thought that they might provide a useful alternative to identify individuals of the two species at times when all 11 cranial characters are difficult or impossible to measure accurately. The eight-character combination comprised all measurements, of the 11 used in this study, that did not include the nasal bone. Hoofer (1996) noted that the anteriormost margin of the nasal occasionally was chipped or partially broken, which rendered three (greatest length of skull, length of rostrum, and length of nasal) of the 11 measurements impossible to obtain. The three-character combination included characters that were measurable on moderately damaged skulls, such as those recovered from owl pellets (Hoofer, 1996; Stangl et al., 1993).

We measured the same cranial characters on 99 additional specimens (males and females) of *R. megalotis* (12 S, 41 A, 4 O) and *R. montanus* (10 S, 31 A, 1 O) from other regions of sympatry (i.e., Chihuahua, Colorado, Nebraska, New Mexico, North Dakota, Oklahoma, and Texas). Those specimens included three subspecies (as mapped by Hall, 1981) of both *R. megalotis* (*aztecus, dychei,* and *megalotis*) and *R. montanus* (*albescens, griseus,* and *montanus*). We used those data to compare univariate statistical data from mensural characters between samples from Kansas and from other areas of sympatry and determine if the discriminant multipliers and constant, computed from all combinations of measurements of the Kansas sample, could be used to identify individuals from areas other than Kansas. To test discriminant multipliers, we multiplied each measured value from the 99 additional specimens by the respective discriminant multiplier, summed the values, and added the constant to produce a discriminant score for each specimen. We then compared those discriminant scores with those computed for the Kansas sample.

## RESULTS

Variance partitioning yielded similar results for both species. Effects of age accounted for most of the explained variation for nine of the 11 cranial characters (all except breadth of braincase and interorbital breadth) in *R. megalotis* and for seven of the 11 characters (all except breadth of braincase, interorbital breadth, breadth of rostrum, and breadth of occipital condyles) in *R. montanus.* On average, effects of age were responsible for ca. 19% of the total variation in *R. megalotis* and 13% of the total variation in *R. montanus.* Gender alone and gender-by-age interaction contributed little to the total variation in both species, although slightly more in *R. montanus* (gender = 4.03%; gender by age =

5.64%) than in *R. megalotis* (gender = 1.06%; gender by age = 1.45%). Unexplained variation, defined as all sources of unstudied variation (geographic, seasonal, individual, and procedural error), contributed more than explained variation to the total variation in both species, averaging ca. 76% in *R. megalotis* and 77% in *R. montanus*.

Males and females of both species averaged essentially the same size for all cranial characters. A Student's *t*-test indicated that genders did not differ significantly for any character in *R. megalotis*. Jones and Mursaloğlu (1961) and Hoffmeister (1986) likewise found no significant sexual dimorphism in *R. megalotis*. In *R. montanus*, males were larger than females for three characters (breadth of braincase, $P \leq 0.01$; length of molar tooth row, $P \leq 0.05$; and depth of braincase, $P \leq 0.01$). Significant differences between genders in *R. montanus* could have resulted from the relatively few females ($n = 16$) included in the analysis. In his study of *R. montanus* from Kansas, Smith (1964) found no significant gender dimorphism for any cranial character, which included these three measurements; however, he compared only adult males with adult females, whereas we compared both subadult and adult individuals.

One-way analysis of variance indicated significant differences ($P \leq 0.05$) among relative age classes for all but four measurements in *R. megalotis* and for all but five measurements in *R. montanus* (Table 1). Tukey's studentized range test (HSD) indicated that subadults and adults differed significantly for six characters in *R. megalotis* and four characters in *R. montanus*; subadults and old adults differed significantly for seven characters in *R. megalotis* and six characters in *R. montanus* (Table 1). Adults and old adults differed significantly for five characters (greatest length of skull, zygomatic breadth, length of molar toothrow, length of rostrum, and depth of braincase) in *R. megalotis* and just one character (depth of braincase) in *R. montanus*.

Descriptive statistics showed that, for every cranial character except length of molar tooth row, *R. megalotis* averaged slightly larger than *R. montanus* (Table 1). If relative age was disregarded, ranges for every measurement overlapped considerably between species. When we compared like-aged individuals of the two species, ranges for some measurements did not overlap. Ranges for old adults of the two species did not overlap in five measurements (greatest length of skull, zygomatic breadth, length of incisive foramen, length of rostrum, and breadth of occipital condyles) and overlapped only slightly (0.01 mm) in another (depth of braincase). Fully-grown old adults of *R. megalotis* apparently were appreciably larger than fully-grown old adults of *R. montanus* in Kansas. In addition, ranges for adults of the two species did not overlap in breadth of braincase. Ranges for subadults, however, overlapped between species in every character.

Discriminant multipliers computed from discriminant function analysis using all variables together (independent analysis) reflect the relative effectiveness of each mensural character in discriminating between the two species (Table 2). The greater the absolute value of the multiplier, the more effective that character was in discriminating between species where they occur sympatrically in Kansas. Discriminant scores for every specimen plotted as a frequency histogram illustrated that, regardless of age, all specimens studied were identified correctly by discriminant function analysis (Fig. 1a). Seven of the 11 cranial characters (breadth of braincase, length of molar row, depth of braincase, breadth of occipital condyles, zygomatic breadth, length of incisive foramen, and greatest length of skull) were more effective in discriminating between the two species than the other four (breadth of rostrum, interorbital breadth, length of nasal, and length of rostrum). Breadth of braincase was the most effective character (Table 2). In fact, discriminant function analysis using the stepwise method to enter each variable showed that only the seven most highly diagnostic characters (hereafter referred to as the seven-character combination) were needed to correctly classify 100% of the specimens studied. Accordingly, because the stepwise analysis excluded four of the 11 measurements, the discriminant multipliers and constant (Table 2) were weighted differently than in the independent analysis. Furthermore, a different discriminant score was computed for each specimen (Fig. 1b). Irrespective of age, individuals with a discriminant score less than ca. −1.0 were *R. montanus,* whereas individuals with a discriminant score greater than ca. −1.0 were *R. megalotis* (Figs. 1a and 1b).

All specimens also were classified correctly with the eight-character combination (Fig. 1c). Breadth of braincase again was the most heavily weighted character (Table 2) and, thus, the most effective character with which to identify individuals of the two species. Interorbital breadth and breadth of rostrum were the least effective characters. About 95% of the specimens were identified correctly with the three-character combination. Discriminant scores overlapped from ca. −1.5 to +1.5 (Fig. 1d), and interorbital breadth was the most heavily weighted character (Table 2).

For the univariate statistical data computed for the samples from areas other than Kansas, we investigated only measurements for which ranges in the Kansas samples did not overlap between species. All old adults were identified correctly using either length of incisive foramen, length of rostrum, or breadth of occipital condyles, and just one specimen (*R. megalotis aztecus*) was misidentified using either greatest length of skull or zygomatic breadth. All but six adults (two *R. montanus albescens* and four *R. montanus griseus*) were identified correctly using breadth of braincase.

Discriminant multipliers computed from the Kansas sample proved effective to identify individuals from areas other than Kansas. All but three of the 99 specimens (ca. 97%) were identified correctly using discriminant multipliers and constants computed from the 11-character (independent analysis) and seven-character (stepwise analysis) combinations. In both instances, the same three specimens were misidentified. Discriminant scores ranged from −1.367 to 4.886 for *R. megalotis* and from −5.181 to −0.541 for *R. montanus* when we used all 11 discriminant multipliers. They ranged from −1.204 to 4.800 for *R. megalotis* and −5.277 to −0.528 for *R. montanus* when we used seven discriminant multipliers. Although both sets of discriminant multipliers (using seven or 11 measurements) yielded identical identifications for each specimen and extremely similar discriminant scores for each specimen, slightly better separation between the two species was achieved using all 11 measurements and their respective discriminant multipliers and constant.

In addition, all but three specimens (ca. 97%) in the sample from areas other than Kansas were identified correctly using discriminant multipliers and constant for the eight-character combination. Discriminant scores ranged from −1.202 to 4.658 for *R. megalotis* and −4.867 to −0.315 for *R. montanus*. Discriminant multipliers and constant computed for the three-character combination were less effective, correctly identifying ca. 55% of the specimens.

## Discussion

External characters, such as pelage color, overall size, and width of tail stripe, serve well to identify most individuals of *R. megalotis* and *R. montanus.* All too often, however, these characters are less than definitive, rendering some identifications questionable. For example, we excluded 18 specimens (12 S and 6 A) from the samples because their external characters were ambiguous (Appendix I). Without karyotypic data, which are not always available, specimens such as these previously could not be identified with confidence.

Individual cranial measurements cannot

TABLE 1.—*Descriptive statistics* ($\bar{X} \pm$ SE, *range, and* CV) *for cranial measurements (in mm) for subadult (S), adult (A), and old adult (O)* Reithrodontomys megalotis *and* R. montanus *as well as for each species regardless of age (RA).* F-*values* (*P < *0.05) from one-way analysis of variance are shown parenthetically adjacent to character names, with the value for* R. megalotis *given before that for* R. montanus. *Common superscript letters adjacent to means indicate nonsignificant* (P > *0.05) subsets formed within each species as determined by Tukey's studentized range test (HSD).*

| Age class | *R. megalotis* | | | | | *R. montanus* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | $\bar{X}$ | *SE* | Range | *CV* | *n* | $\bar{X}$ | *SE* | Range | *CV* |
| Greatest length of skull (27.55*, 11.16*) | | | | | | | | | | |
| S | 30 | 20.59[a] | 0.09 | 19.33–21.25 | 2.31 | 24 | 19.25[a] | 0.10 | 18.28–19.55 | 2.57 |
| A | 59 | 21.32[b] | 0.07 | 19.79–22.65 | 2.62 | 30 | 19.73[b] | 0.08 | 19.03–20.53 | 2.15 |
| O | 6 | 22.02[c] | 0.22 | 21.38–22.92 | 2.40 | 8 | 20.03[b] | 0.19 | 19.12–20.92 | 2.70 |
| RA | 95 | 21.13 | 0.07 | 19.33–22.92 | 3.15 | 62 | 19.59 | 0.07 | 18.28–20.92 | 2.76 |
| Zygomatic breadth (12.41*, 7.10*) | | | | | | | | | | |
| S | 30 | 10.62[a] | 0.06 | 9.97–11.15 | 3.05 | 24 | 10.18[a] | 0.06 | 9.60–10.69 | 2.72 |
| A | 59 | 10.89[b] | 0.04 | 10.08–11.50 | 2.77 | 30 | 10.40[b] | 0.05 | 9.92–10.99 | 2.69 |
| O | 6 | 11.20[c] | 0.08 | 10.91–11.53 | 1.86 | 8 | 10.54[b] | 0.07 | 10.17–10.76 | 1.96 |
| RA | 95 | 10.82 | 0.03 | 9.97–11.53 | 3.14 | 62 | 10.34 | 0.04 | 9.60–10.99 | 2.87 |
| Breadth of braincase (0.83, 1.63) | | | | | | | | | | |
| S | 30 | 10.16[a] | 0.04 | 9.64–10.50 | 2.36 | 24 | 9.36[a] | 0.05 | 8.77–9.86 | 2.81 |
| A | 59 | 10.19[a] | 0.03 | 9.76–10.69 | 2.27 | 30 | 9.33[a] | 0.03 | 8.92–9.67 | 1.99 |
| O | 6 | 11.30[a] | 0.13 | 9.77–10.65 | 3.15 | 8 | 9.49[a] | 0.09 | 9.04–9.86 | 2.72 |
| RA | 95 | 10.19 | 0.02 | 9.64–10.69 | 2.35 | 62 | 9.36 | 0.03 | 8.77–9.86 | 2.46 |
| Interorbital breadth (0.39, 0.26) | | | | | | | | | | |
| S | 30 | 3.21[a] | 0.02 | 3.02–3.58 | 3.74 | 24 | 2.97[a] | 0.03 | 2.65–3.22 | 5.00 |
| A | 59 | 3.18[a] | 0.01 | 2.88–3.40 | 3.42 | 30 | 3.00[a] | 0.02 | 2.79–3.22 | 3.88 |
| O | 6 | 3.21[a] | 0.04 | 3.09–3.35 | 2.92 | 8 | 2.97[a] | 0.05 | 2.82–3.30 | 5.05 |
| RA | 95 | 3.19 | 0.01 | 2.88–3.58 | 3.48 | 62 | 2.98 | 0.02 | 2.65–3.30 | 4.43 |
| Breadth of rostrum (3.36, 0.13) | | | | | | | | | | |
| S | 30 | 2.55[a] | 0.02 | 2.35–2.79 | 4.23 | 24 | 2.44[a] | 0.02 | 2.19–2.65 | 4.11 |
| A | 59 | 2.50[a] | 0.01 | 2.29–2.77 | 4.57 | 30 | 2.45[a] | 0.02 | 2.30–2.65 | 3.49 |
| O | 6 | 2.59[a] | 0.04 | 2.48–2.73 | 3.75 | 8 | 2.43[a] | 0.06 | 2.11–2.60 | 6.60 |
| RA | 95 | 2.52 | 0.01 | 2.29–2.79 | 4.53 | 62 | 2.44 | 0.01 | 2.11–2.65 | 4.15 |
| Length of incisive foramen (26.59*, 9.56*) | | | | | | | | | | |
| S | 30 | 4.21[a] | 0.03 | 3.89–4.52 | 4.14 | 24 | 3.84[a] | 0.03 | 3.61–4.18 | 3.80 |
| A | 59 | 4.43[b] | 0.02 | 3.98–4.72 | 3.21 | 30 | 4.01[b] | 0.04 | 3.61–4.38 | 4.87 |
| O | 6 | 4.57[b] | 0.06 | 4.34–4.72 | 3.06 | 8 | 4.08[b] | 0.05 | 3.87–4.30 | 3.27 |
| RA | 95 | 4.37 | 0.02 | 3.89–4.72 | 4.35 | 62 | 3.95 | 0.02 | 3.61–4.38 | 4.89 |
| Length of molar tooth row (6.76*, 4.68*) | | | | | | | | | | |
| S | 30 | 3.34[a] | 0.02 | 3.16–3.54 | 2.84 | 24 | 3.37[a] | 0.02 | 3.21–3.65 | 3.48 |
| A | 59 | 3.40[a] | 0.02 | 2.97–3.66 | 3.76 | 30 | 3.44[a,b] | 0.03 | 3.22–3.77 | 4.09 |
| O | 6 | 3.52[b] | 0.03 | 3.44–3.62 | 1.90 | 8 | 3.54[b] | 0.06 | 3.26–3.80 | 5.00 |
| RA | 95 | 3.39 | 0.01 | 2.97–3.66 | 3.62 | 62 | 3.43 | 0.02 | 3.21–3.80 | 4.23 |
| Length of rostrum (25.12*, 7.44*) | | | | | | | | | | |
| S | 30 | 6.9[a] | 0.05 | 6.3–7.3 | 3.82 | 24 | 6.4[a] | 0.05 | 5.9–6.8 | 3.89 |
| A | 59 | 7.3[b] | 0.04 | 6.5–8.3 | 4.31 | 30 | 6.6[b] | 0.05 | 6.4–7.1 | 3.85 |
| O | 6 | 7.7[c] | 0.09 | 7.4–8.0 | 2.95 | 8 | 6.7[b] | 0.11 | 6.3–7.2 | 4.62 |
| RA | 95 | 7.2 | 0.04 | 6.3–8.3 | 5.05 | 62 | 6.5 | 0.04 | 5.9–7.2 | 4.37 |

TABLE 1.—*Continued.*

| Age class | *R. megalotis* | | | | | *R. montanus* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *n* | $\bar{X}$ | *SE* | Range | *CV* | *n* | $\bar{X}$ | *SE* | Range | *CV* |
| Length of nasal (25.13*, 2.94) | | | | | | | | | | |
| S | 30 | 7.75[a] | 0.07 | 6.99–8.45 | 4.64 | 24 | 7.37[a] | 0.08 | 6.79–8.24 | 5.26 |
| A | 59 | 8.23[b] | 0.04 | 7.50–8.96 | 4.11 | 30 | 7.53[a] | 0.06 | 6.93–8.19 | 4.05 |
| O | 6 | 8.57[b] | 0.15 | 7.98–9.06 | 4.22 | 8 | 7.68[a] | 0.10 | 7.27–8.12 | 3.56 |
| RA | 95 | 8.10 | 0.04 | 6.99–9.06 | 5.26 | 62 | 7.49 | 0.04 | 6.79–8.24 | 4.63 |
| Breadth of occipital condyles (2.79, 0.05) | | | | | | | | | | |
| S | 30 | 4.96[a] | 0.03 | 4.64–5.25 | 2.97 | 24 | 4.64[a] | 0.02 | 4.46–4.84 | 2.18 |
| A | 59 | 5.02[a] | 0.02 | 4.69–5.22 | 2.43 | 30 | 4.65[a] | 0.03 | 4.32–4.86 | 3.30 |
| O | 6 | 5.07[a] | 0.07 | 4.92–5.31 | 3.31 | 8 | 4.66[a] | 0.05 | 4.42–4.85 | 3.10 |
| RA | 95 | 5.00 | 0.01 | 4.64–5.31 | 2.71 | 62 | 4.65 | 0.02 | 4.32–4.86 | 2.84 |
| Depth of braincase (8.80*, 11.90*) | | | | | | | | | | |
| S | 30 | 7.64[a] | 0.04 | 7.25–8.00 | 2.70 | 24 | 7.30[a] | 0.04 | 7.01–7.64 | 2.59 |
| A | 59 | 7.76[b] | 0.03 | 7.28–8.23 | 2.88 | 30 | 7.39[a] | 0.03 | 7.11–7.68 | 2.12 |
| O | 6 | 8.03[c] | 0.09 | 7.81–8.32 | 2.60 | 8 | 7.64[b] | 0.06 | 7.38–7.82 | 2.06 |
| RA | 95 | 7.74 | 0.02 | 7.25–8.32 | 3.03 | 62 | 7.39 | 0.03 | 7.01–7.82 | 2.68 |

be used to correctly identify all individuals of *R. megalotis* and *R. montanus* from central and western Kansas unless relative age is known. If relative age is known, adult individuals can be identified by just one cranial measurement (breadth of braincase). Based on small sample sizes (six *R. megalotis* and eight *R. montanus*), old adults can be identified by five measurements (greatest length of skull, zygomatic breadth, length of incisive foramen, length of rostrum, and breadth of occipital condyles). However, additional study using more old adults might show that ranges for some, if not all, of those measurements overlap between species. Therefore, we are hesitant to conclude that any measurements can be used with confidence to identify old adult indi-

TABLE 2.—*Discriminant multiplier for each cranial character and the constant computed from discriminant function analysis. All specimens were classified correctly with the 11-character, seven-character, and eight-character combinations, whereas ca. 55% were classified correctly with the three-character combination. The greater the absolute value of the multiplier, the more effective that character is to discriminate between* Reithrodontomys megalotis *and* R. montanus.

| Character | Character combination | | | |
|---|---|---|---|---|
| | 11 | 7 | 8 | 3 |
| Breadth of braincase | 4.632 | 4.611 | 4.550 | |
| Length of molar tooth row | −2.672 | −2.603 | −2.458 | |
| Depth of braincase | −2.594 | −2.527 | −1.324 | |
| Breadth of occipital condyles | 2.011 | 2.083 | 2.636 | |
| Zygomatic breadth | −1.826 | −1.907 | −1.379 | |
| Length of incisive foramen | 1.576 | 1.717 | 3.202 | 4.012 |
| Greatest length of skull | 0.993 | 1.094 | | |
| Breadth of rostrum | −0.604 | | −0.133 | 0.147 |
| Interorbital breadth | 0.525 | | −0.328 | 5.040 |
| Length of nasal | 0.284 | | | |
| Length of rostrum | −0.010 | | | |
| Constant | −36.554 | −36.932 | −36.725 | −32.910 |

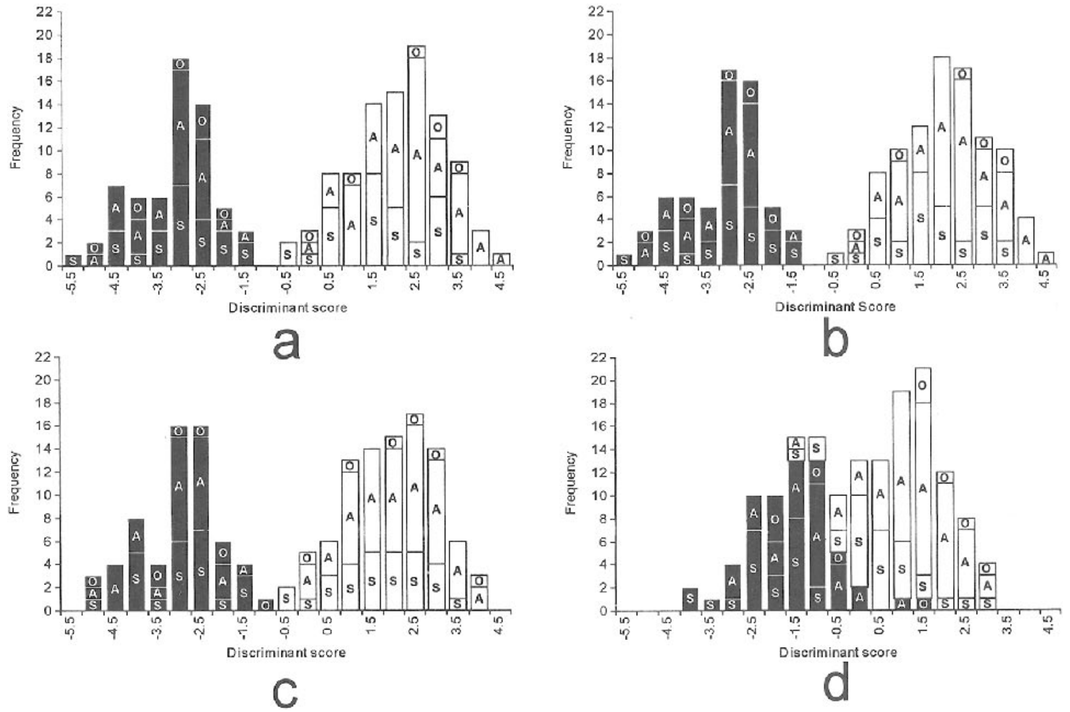


FIG. 1.—Frequency histograms of discriminant scores for *Reithrodontomys megalotis* and *R. montanus* (shaded) computed by discriminant function analysis using a) all 11 cranial characters and b) the seven-character, c) eight-character, and d) three-character combinations. All specimens were classified correctly with the first three combinations (a, b, and c); ca. 55% were classified correctly with the last combination (d). Relative age classes are abbreviated as follows: S = subadult; A = adult; O = old adult.

viduals of the two species. For subadults, ranges for all cranial measurements overlapped between species. Thus, subadults cannot be identified using univariate statistical data from cranial characters.

Regardless of age, comparisons of discriminant scores, using discriminant multipliers and constant computed for either the 11-character or the seven-character combinations, facilitates identification of all specimens of the two species from central and western Kansas. Either set of discriminant multipliers provides a dependable method to identify individuals of *R. megalotis* and *R. montanus*. Individuals with a discriminant score less than ca. −1.0 should be regarded as *R. montanus*, whereas those with a discriminant score greater than ca. −1.0 should be regarded as *R. megalotis*.

All specimens also were identified correctly using discriminant multipliers and constant for the eight-character combination. Therefore, even if it is impossible to accurately obtain all 11 measurements or the seven most highly diagnostic measurements (e.g., when the nasal bone is damaged), the eight-character combination can be used with confidence to identify individuals of *R. megalotis* and *R. montanus*. Again, individuals with a discriminant score less than ca. −1.0 should be regarded as *R. montanus*, and those with a discriminant score greater than ca. −1.0 should be regarded as *R. megalotis*. Most individuals (ca. 95%) were identified correctly by discriminant function analysis using the three-character combination. Use of the discriminant multipliers and constant computed for this combination of characters, although not absolutely accurate, provides an alternative method for identification when dealing with moderately damaged specimens (e.g., specimens recovered from owl pellets).

Juveniles and more old adults need to be included before any conclusions can be drawn as to whether or not individuals of the two species of these age categories can be identified with confidence by discriminant function analysis. However, it would be difficult to sample large numbers of juveniles and old adults because most harvest mice trapped are of medium age (Hooper, 1952). Comparison of discriminant scores of old adults still could facilitate identification. For example, if the discriminant score of a troublesome specimen was much greater than −1.0 (e.g., 3.0), we feel confident that it would be *R. megalotis*; if it was about equal to −1.0 (e.g., −1.1), we would not feel confident about its identification. The greater the absolute value of the discriminant score, the greater the likelihood that the specimen is identified correctly. Incidentally, the discriminant scores for most old adults of *R. megalotis* were much greater than −1.0, whereas those of *R. montanus* were much less than −1.0 (Figs. 1a, 1b, and 1c).

Using selected measurements in Table 1, we were able to correctly identify most of the 72 adults and five old adults from areas other than Kansas. For the five old adults, length of incisive foramen, length of rostrum, and breadth of occipital condyles proved slightly more valuable for this purpose than greatest length of skull and zygomatic breadth. However, we again emphasize the fact that, unlike adults, few old adults were available for analysis. These measurements should be used with caution when differentiating between old adults of *R. megalotis* and *R. montanus.*

Comparison of discriminant scores, using the discriminant multipliers and constant computed for either the 11-character, the seven-character, or the eight-character combinations facilitated identification of all but three (ca. 97%) of the specimens of the two species from areas other than Kansas. This not only underscores the effectiveness of the discriminant analysis to identify individuals from central and western Kansas but also indicates that any one of these three combinations of cranial measurements and their respective discriminant multipliers and constant (derived from Kansas samples) can be used with confidence to identify troublesome individuals of the two species wherever they occur sympatrically. However, only ca. 50% of the specimens from areas other than Kansas were identified correctly when we used the discriminant multipliers and constant for the three-character combination. That is, only ca. 50% (61.9% for *R. montanus,* 49.1% for *R. megalotis*) of the discriminant scores computed for the 99 additional specimens fell outside the region of phenetic overlap (ca. −1.5–1.5). Clearly, whenever possible, the seven most highly diagnostic characters (seven-character combination), if not all 11 measurements, should be used to identify troublesome individuals of *R. megalotis* and *R. montanus* where they occur sympatrically.

The additional specimens from areas other than Kansas served well to evaluate the relative effectiveness of the results. Even with the added variability of size associated with the various subspecies from those areas, overall results of both univariate and multivariate statistical analyses were extremely effective in identifying individuals of *R. megalotis* and *R. montanus* wherever they occur sympatrically. To resolve problematic identifications of the two species, independent researchers can measure a combination of cranial characters and incorporate the values into our formula for identification: multiply each measured value by the respective discriminant multiplier, sum the values, and add the constant to produce a discriminant score. In general, the discriminant scores range from −5.0 to 5.0. Those >−1.0 should be regarded as *R.*

*megalotis,* and those <−1.0 should be regarded as *R. montanus.*


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## APPENDIX I

We used the methods described in this paper to identify the 18 troublesome specimens excluded from the original analyses. We were able to measure all 11 cranial characters for 16 of the 18 specimens; for the other two, we used the 8-character combination because their nasal bones were disarticulated. Based on the discriminant scores, 17 of the 18 specimens were identified as *R. megalotis* (six previously had been identified as *R. montanus*) and one as *R. montanus* (previously identified as *R. megalotis*).

We found four additional *Reithrodontomys* with ambiguous identifications in the collection of the Sternberg Museum of Natural History, one from Phillips County, Kansas, and three from Morton County, Kansas. We identified the Phillips County specimen as *R. megalotis* (it previously had been identified as *R. montanus*) based on all 11 measurements and their respective discriminant multipliers. The Morton County specimens were salvaged from owl pellets, so we used the 3-character combination to identify them. Only one of the specimens yielded a discriminant score (2.856) outside the region of phenetic overlap in Fig. 1d. We regarded it as *R. megalotis*. We identified the other two specimens (discriminant scores were 0.521 and −1.230), but with less confidence. We regarded the specimen with the discriminant score greater than −1.0 as *R. megalotis* and the other as *R. montanus*.