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SEXUAL DIMORPHISM AND MORPHOMETRIC VARIATION IN THE TEXAS KANGAROO RAT (*DIPODOMYS ELATOR* MERRIAM 1894)

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ABSTRACT—Variation was evaluated in 206 adult *Dipodomys elator* from three populations in northern Texas. Males were significantly larger then females for 10 of 20 characters, and significant geographic variation occurred in 11 of 19 characters for males and 9 of 19 characters for females. Males from Hardeman Co. were significantly larger than females for total length, body length, hind foot length, greatest depth of cranium, and zygomatic width, whereas those from Wichita Co. were significantly larger for basal length of cranium and nasal length. Females from Wilbarger Co. averaged larger than those from Hardeman and Wichita counties in most characters but those from Hardeman Co. were significantly largest for total length and tail length and smallest for basal length of cranium. Sexual differences were greater in specimens from Hardeman and Wichita counties than in specimens from Wilbarger Co.

The Texas kangaroo rat (*Dipodomys elator*) occupies a small range in north-central Texas (Martin and Matocha, 1972; Cokendolpher et al., 1979) and southwestern Oklahoma (Bailey, 1905). Its distribution is almost entirely limited to Texas; only one specimen is known from Oklahoma (Bailey, 1905). Carter et al. (1985) recently summarized what is known of this species, and Webster and Jones (1985) presented new data on nongeographic variation, reproduction, and demography.

Apparently, the preferred habitat of *D. elator* is specific (Dalquest and Collier, 1964; Martin and Matocha, 1972; Roberts and Packard, 1973). Martin and Matocha (1972) did not observe this species more than half a mile from mesquite. Primarily because of agricultural practices (clear-cutting and brush-control) and construction, habitat available to *D. elator* has been greatly reduced and fragmented within the past 50 years. The present study was initiated because of the small range and limited habitat of *D. elator*, the habitat destruction that is now in progress, the need to know more about this threatened species (see Carter et al., 1985), and the desire to enhance our knowledge of the degree of sexual dimorphism and geographic variation in kangaroo rats. The specific purposes of this study were to analyze the degree of secondary sexual dimorphism, the amount and pattern of geographic variation, and phenetic relationships among populations of *D. elator* using a suite of external and cranial measurements.

MATERIALS AND METHODS—A total of 331 *Dipodomys elator* was examined. Specimens were aged according to the criteria of Best and Schnell (1974). The 206 adult specimens (Appendix I) were grouped as follows: Population 1 was represented by specimens from the Pease River northward to the Red River in Hardeman Co. (57 males and 38 females, referred to as Hardeman Co. hereafter); Population 2 contained specimens from Beaver Creek northward to the Pease and Red rivers in Wilbarger County (29 males and 20 females, referred to as Wilbarger Co.); and Population 3 included specimens from the Wichita River northward to the Red River in Wichita Co. (34 males and 28 females, referred to as Wichita Co.). The latter two samples are about 20

TABLE 1—Secondary sexual dimorphism in the Texas kangaroo rat. Means (mm) of each character for each sex are listed with the degrees of freedom and *F*-ratio derived from single classification analysis of variance. Minimally significant sexual dimorphism is assumed where $P \leq 0.05$ (one asterisk) and $P \leq 0.01$ (two asterisks).

Character	Character-state means		Analysis of variance	
	Males (N=120)	Females (N=86)	df	*F*-ratio
External				
Total length	306.2	303.0	1,195	1.786
Body length	124.3	124.0	1,204	0.046
Tail length	182.0	178.9	1,195	2.943
Hind foot length	45.7	45.4	1,203	0.891
Ear length	13.4	13.7	1,204	1.672
Body weight	85.2	76.1	1,77	15.274**
Cranium				
Basal length	23.7	23.5	1,203	5.480*
Greatest length	40.4	40.2	1,192	5.153*
Maxillary arch spread	23.7	23.4	1,199	8.794**
Interorbital width	11.6	11.6	1,202	0.031
Nasal length	16.0	15.9	1,194	1.388
Intermaxillary width	7.9	7.8	1,204	3.205
Alveolar length	5.6	5.5	1,199	5.868*
Lacrimal length	4.4	4.3	1,186	5.259*
Maxillary arch width	6.4	6.3	1,203	12.675**
Basioccipital length	5.7	5.5	1,195	9.452**
Greatest depth	13.4	13.4	1,199	2.695
Greatest width	24.8	24.5	1,200	12.959**
Zygomatic width	19.8	19.6	1,204	6.960**
Nasal width	4.3	4.2	1,194	2.798

km apart; the Hardeman Co. population is more than 40 km to the northwest and separated from them by the Pease River.

The 19 morphologic characters examined in this study were described previously (Best, 1978). For intersexual comparisons among all specimens, body weight was added to the character set. Character heterogeneity (between sexes and among the three populations) was tested with a one-way analysis of variance, and the sums of squares simultaneous test procedure (SS-STP) was used to determine maximally nonsignificant subsets (Gabriel and Sokal, 1969). For analyses of the effect of sample size on geographic variation in sexual dimorphism, sample sizes for Populations 1 and 3 were reduced by deleting every other specimen in the data sets until samples sizes were the same as the Wilbarger Co. population. Correlation and distance matrices (Sneath and Sokal, 1973) were computed from the standardized locality means for each character for each population. Clusters of populations were obtained with the unweighted pair-group method using arithmetic averages. Analyses were performed using the IBM computer system at The University of New Mexico and the programs UNIVAR (D. M. Power, unpubl.) and NT-SYS (Rohlf et al., 1972).

RESULTS—Males were significantly larger than females for 10 (50%) of the 20 morphometric characters examined when all specimens were pooled (Table 1). These sexually dimorphic characters included body weight and nine cranial measurements. The Hardeman Co. population is more dimorphic than either of the others (Table 2). That population exhibited significant sexual dimorphism in 9 of 19 characters, the Wilbarger Co. population showed none, and only five characters differed between sexes in the Wichita Co. population.

Since the effect of sample size on the detection of sexually dimorphic characters is unknown (Best, 1983*b*), the sample sizes for Hardeman Co. and

TABLE 2—Geographic variation in sexual dimorphism of the Texas kangaroo rat. *F*-ratios resulting from single-classification analysis of variance are presented for each character of each population for unequal and equal sample sizes.

	Unequal sample sizes			Adjusted sample sizes	
Character	Hardeman (57 males, 38 females)	Wilbarger (29 males, 20 females)	Wichita (34 males, 28 females)	Hardeman (29 males, 20 females)	Wichita (29 males, 20 females)
External					
Total length	0.901	0.028	1.047	0.066	1.786
Body length	1.607	1.817	0.013	0.268	0.330
Tail length	0.154	1.162	2.359	0.000	5.508*
Hind foot length	7.661*	0.634	0.042	1.413	0.106
Ear length	0.959	1.130	0.538	1.309	0.069
Cranium					
Basal length	8.880*	0.675	4.014*	9.484*	2.934
Greatest length	11.797**	0.929	2.126	8.080**	1.339
Maxillary arch spread	10.505**	0.031	1.562	11.751**	0.102
Interorbital width	4.067*	2.196	0.464	2.930	2.048
Nasal length	2.565	2.257	4.742*	1.380	6.726*
Intermaxillary width	2.579	0.817	0.239	1.939	0.178
Alveolar length	6.433*	0.303	2.387	5.059*	1.246
Lacrimal length	0.037	0.134	10.990**	0.316	8.143**
Maxillary arch width	10.179**	0.043	7.749**	5.645*	3.927
Basioccipital length	3.217	1.199	5.736*	0.321	4.579*
Greatest depth	2.659	0.118	0.216	1.270	−0.068
Greatest width	15.000**	0.036	2.424	13.623**	0.372
Zygomatic width	7.538**	0.309	0.939	6.857*	0.292
Nasal width	3.910	0.000	0.139	5.561*	0.293

*$P \leq 0.05$; **$P \leq 0.01$.

Wichita Co. populations were reduced to those for the Wilbarger Co. population. The number of sexually dimorphic characters was changed only slightly after this alteration (Table 2). In the Hardeman Co. population, hind foot length and interorbital width no longer exhibited significant variation, and nasal width was different between sexes. For the Wichita Co. sample, basal length of cranium and maxillary arch width now showed no differences, but tail length was now different between sexes. Although sample size appeared to have an effect on which characters were dimorphic, the number of dimorphic characters remained relatively stable.

Significant interlocality character variation was found in a total of 14 of 19 characters when the three populations were examined ($P \leq 0.05$); 11 characters were significantly different for males and 9 for females (Table 3). As evidenced by the *F*-ratios for males, total length, body length, greatest depth of cranium, and zygomatic width exhibited the most interlocality variation (*F*-ratio > 10) and, for females, total length, tail length, basal length of cranium, lacrimal length, and maxillary arch width exhibited the most interlocality variation (*F*-ratio > 5).

Neither sex had significant differences among the three populations for ear length, maxillary arch spread, interorbital width, alveolar length, and basioccipital length. For hind foot length, nasal length, intermaxillary width, greatest width of cranium, and nasal width only males differed among populations, and for greatest length of cranium, lacrimal length,

TABLE 3—Geographic variation in means of 19 external and cranial characters of the Texas kangaroo rat. Statistically homogeneous subsets derived from sums of squares-simultaneous test procedure analyses are shown by lines below the population number (1 = Hardeman, 2 = Wilbarger, 3 = Wichita) and ranked means for each character (mm).

Character	Males			Females		
	Results of SS-STP			Results of SS-STP		
External						
Total length	1	3	2	1	2	3
	314.7	299.2	298.4	311.7	297.4	295.5
Body length	1	2	3	1	2	3
	129.2	120.3	119.5	127.1	123.7	119.9
Tail length	1	3	2	1	3	2
	185.5	179.8	178.1	184.6	175.1	173.9
Hind foot length	1	3	2	1	2	3
	46.3	45.2	45.0	45.5	45.4	45.3
Ear length	2	1	3	2	1	3
	13.6	13.6	12.9	14.0	13.8	13.3
Cranium						
Basal length	3	1	2	2	3	1
	23.9	23.6	23.6	23.7	23.7	23.3
Greatest length	3	1	2	2	3	1
	40.5	40.5	40.2	40.4	40.3	40.0
Maxillary arch spread	1	2	3	2	3	1
	23.7	23.7	23.6	23.7	23.4	23.2
Interorbital width	1	3	2	3	2	1
	11.7	11.6	11.5	11.8	11.8	11.5
Nasal length	3	1	2	2	3	1
	16.2	15.9	15.8	16.1	15.9	15.7
Intermaxillary width	1	3	2	1	3	2
	7.9	7.8	7.8	7.8	7.8	7.7
Alveolar length	1	2	3	2	1	3
	5.6	5.6	5.6	5.6	5.5	5.4
Lacrimal length	2	3	1	2	1	3
	4.4	4.4	4.3	4.4	4.3	4.2
Maxillary arch width	3	2	1	2	3	1
	6.5	6.5	6.4	6.4	6.3	6.2
Basioccipital length	1	3	2	1	2	3
	5.7	5.7	5.6	5.6	5.5	5.5
Greatest depth	1	2	3	1	2	3
	13.5	13.4	13.3	13.4	13.3	13.2
Greatest width	1	2	3	2	1	3
	25.0	24.7	24.6	24.7	24.5	24.4
Zygomatic width	1	2	3	1	2	3
	20.2	19.6	19.5	19.8	19.5	19.3
Nasal width	1	3	2	2	1	3
	4.3	4.2	4.2	4.2	4.2	4.2

and maxillary arch width only females differed among populations. Males from Hardeman Co. averaged largest for 13 of the 19 characters and those from Wilbarger Co. were smallest for 10 characters. Females exhibited a somewhat different pattern of variation. Those from Wilbarger Co. had largest mean measurements for 10 of the 19 characters and those from Wichita Co. had 11 of the smallest mean values.

Statistically significant differences that separated one population from the other two were present in seven characters for males, but in only three for females; total length and tail length were significantly larger and basal length of cranium was significantly smaller in the Hardeman Co. population of female *D. elator*. For males, the Hardeman Co. population was significantly largest in total length, body length, hind foot length, greatest depth of cranium, and zygomatic width. The Wichita Co. population differed from the other two in being significantly larger for basal length of cranium and nasal length. These data indicate a large amount of morphologic variation over a rather small geographic area, as well as considerable differences between sexes in patterns of variability.

Cluster analyses of correlation matrices for males and females separated the Hardeman Co. population from the Wilbarger and Wichita County populations ($r = -0.630$ for males; $r = -0.729$ for females). Correlations between the Wilbarger Co. and Wichita Co. populations were higher; Wilbarger Co. was separated at $r = -0.193$ for males and $r = 0.072$ for females. Cophenetic correlation coefficients were 0.936 for males and 0.990 for females. Clusters based upon the phenetic distance matrices for males and females had cophenetic correlation coefficients of 0.973 and 0.981, respectively. In both correlation and distance analyses, the Hardeman Co. population was placed well apart from the others (phenetic distance = 1.560 for males and 1.508 for females). The phenetic distances between Wilbarger and Wichita County populations were 1.060 and 1.203 for males and females, respectively. Although some clinal variation in size may be present among the samples, Hardeman Co. *D. elator* were again shown to be morphologically quite distinct from more eastern populations.

Discussion—Webster and Jones (1985) found that males of *D. elator* were significantly larger than females in 9 (69%) of 13 characters examined. Best (1983*b*) recently summarized information on sexual dimorphism in kangaroo rats, and a survey of that literature indicates that *D. elator* is in the mid-range of percentage of sexually dimorphic characters for *Dipodomys*. When compared to *D. gravipes*, a species of similar geographic range size (Best, 1983*a*), the percentage of secondary sexual dimorphic characters observed in *D. elator* is greater. This indicates that similar range size does not influence the number of sexually dimorphic characters.

Geographic variation in sexual dimorphism was detected previously in heteromyid rodents (Hoffmeister and Lee, 1967; Williams, 1978; Schmidly, 1971; Baumgardner and Schmidly, 1981; Weckerly and Best, 1985). Although the samples of *D. elator* are small, the data reported here indicate not only that geographic variation exists, but that there are greater differences between sexes on the margins (west and east) of the range of this kangaroo rat than in the middle of its range. There are peripheral populations of *D. elator* in other counties of northern Texas, e.g., Archer, Baylor, Foard, and Motley, but samples were too small to analyze. Geographic variation in sexual dimorphism deserves further consideration, perhaps with a species whose morphologic data set is larger than the one available for *D. elator*.

In *Dipodomys gravipes*, six characters for each sex showed at least one population statistically different from the others (Best, 1983*a*). Although the characters differed, this indicated a similar degree of differentiation for each sex. In *D. elator*, males differed significantly in more characters (seven) than females (three). This suggests that different selective pressures may be operating on each sex.

Numerous scenarios could be proposed to explain the varying degrees of sexual dimorphism across the range of *D. elator*. These differences may result from selective pressures brought about by limited resources (e.g., food, burrow sites), or there are extreme environmental factors in peripheral areas (e.g., temperature, precipitation). There may be physiological advantages for females to be smaller than males, and that the factors affecting those advantages may vary geographically. Perhaps the differences between sexes and populations are reflections of the events that led to the present distribution of *D. elator*, or that the differences are due to chance. Because nothing is known about the causes of geographic variation in sexual dimorphism, it might be informative to investigate the relationships between a suite of environmental parameters and the degree of sexual dimorphism of kangaroo rats.

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APPENDIX I—Specimens examined are from the mammal collections at Midwestern State University (unless otherwise indicated) and Texas Tech University (TTU). Population 1—*Hardeman Co.*: 1 mi S, 1 mi E Acme (1 male, 0 females TTU); 4.7 mi N jct FM 2006 & US 287 (1, 0 TTU); 3 mi N, 1.9 mi E jct FM 2006 & US 287 (1, 0 TTU); 3.1 mi N, 1.3 mi E intersec FM 2006 & US 287 (1, 0 TTU); 3.1 mi N, 1.7 mi E intersec FM 2006 & US 287 (1, 0 TTU); 3.2 mi N, 0.7 mi E jct FM 2006 & US 287 (0, 1 TTU); 3.2 mi N, 1.2 mi E jct FM 2006 & US 287 (0, 1 TTU); 3.2 mi N, 1.8 mi E jct FM 2006 & US 287 (1, 0 TTU); 3.2 mi N, 1.9 mi E jct FM 2006 & US 287 (1, 0 TTU); 4.2 mi N, 2.1 mi E jct FM 2006 & US 287 (1, 0 TTU); 2.3 mi N, 4.2 mi W jct FM 2006 & US 287 (1, 0 TTU); 2.4 mi N, 4.1 mi W jct FM 2006 & US 287 (0, 1 TTU); 2.5 mi N, 2.7 mi W jct FM 2006 & US 287 (1, 0 TTU); 2.5 mi N, 3.5 mi W jct FM 2006 & US 287 (1, 0 TTU); 4.5 mi N, 2.0 mi W jct FM 2006 & US 287 (0, 1 TTU); ¼ mi N, 7 ¾ mi E Quanah (1, 0 TTU); ¾ mi N, 9 ½ mi E Quanah (1, 0 TTU); 1 mi N, 8.3 mi E Quanah (2, 0 TTU); 1 mi N, 9 mi E Quanah (2, 1 TTU); 1 mi N, 9 ½ mi E Quanah (1, 0 TTU); 1.1 mi N, 9.2 mi E Quanah (0, 1 TTU); 1¼ mi N, 8¾ mi E Quanah (1, 0 TTU); 1½ mi N, 2½ mi E Quanah (8, 9 TTU); 1.6 mi N, 8.8 mi E Quanah (1, 1 TTU); 2 mi N, 9½ mi E Quanah (1, 0 TTU); 2¼ mi N, 7½ mi E Quanah (1, 0 TTU); 2¼ mi N, 8¾ mi E Quanah (1, 0 TTU); 2½ mi N, 6½ E Quanah (1, 0 TTU); 2½ mi N, 7¼ mi E Quanah (1, 0 TTU); 2½ mi N, 7½ mi E Quanah (0, 1 TTU); 2.6 mi N, 6.7 mi E Quanah (1, 0 TTU); 3½ mi N, 7½ mi E Quanah (0, 1 TTU); 2½ mi N, 5¼ mi W Quanah (1, 0 TTU); 3 mi NE Quanah (1, 0 TTU); 3 mi NE Quanah, Claude Holcomb Ranch (18, 15 TTU); 0.5 mi S, 9½ E Quanah (2, 0 TTU); 5 mi S, ½ mi E Quanah, (1, 0 TTU); 5 mi S, 3½ mi E Quanah (0, 1 TTU); 5 mi S, 5½ mi E Quanah (0, 2 TTU); 9¼ mi S, 6½ mi E Quanah (0, 1 TTU); 11 mi S, 2 mi E Quanah (1, 0 TTU). Population 2—*Wilbarger Co.*: 6.5 mi SW Electra (1, 0); 2.7 mi S, 1 mi E Harrold (0, 1 TTU); 5 mi S Harrold (1, 0); 7 mi S Harrold (21, 14); 7 mi SSE Lockett (0, 1); 10 mi S, 5 mi E Vernon (0, 1); 16 mi SSE Vernon (6, 3). Population 3—*Wichita Co.*: Buffalo Creek Reservoir (1, 0); Buffalo Creek Reservoir, 12 mi NW Iowa Park (1, 0); Buffalo Lake, 3 mi N, 2 mi W Iowa Park (0, 1); Buffalo Lake, 5 mi NW Iowa Park (1, 0); 12 mi E Electra (1, 0); 3 mi N Iowa Park (0, 1); 6 mi N Iowa Park (1, 1); 8 mi N Iowa Park (2, 7); 9 mi N Iowa Park (4, 0); 20 NE Iowa Park (1, 0); 10.5 mi NNE Iowa Park (1, 0); 3 mi NNW Iowa Park (1, 1); 15 mi NNW Iowa Park (1, 0); 3 mi NW Iowa Park (0, 1); 5 mi NW Iowa Park (3, 7); 6 mi NW Iowa Park (4, 0); 6½ mi NW Iowa Park (1, 1); 7 mi NW Iowa Park (1, 0); 7½ mi NW Iowa Park (1, 0); 9 mi NW Iowa Park (1, 0); 1 mi W Iowa Park (1, 0); 3 mi W Iowa Park (1, 1); 5 mi W Iowa Park (0, 1); 6 mi W Iowa Park, then 1 mi NW (1, 0); 7 mi W Iowa Park, (1, 1); 7 mi WNW Iowa Park (0, 1); 12 mi WNW Iowa Park (0, 1); Iowa Park Lake (1, 1); Iowa Park Lake, 12 mi WNW Iowa Park (0, 1); Lake Buffalo (1, 0); ½ mi E Lake Buffalo (0, 1); Wichita Falls (1, 0); 20 mi W Wichita Falls (1, 0).