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BACULAR VARIATION IN KANGAROO RATS (GENUS *DIPODOMYS*) OF THE *HEERMANNI* GROUP IN BAJA CALIFORNIA, MEXICO

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ABSTRACT. Variation in kangaroo rat *(Dipodomys)* bacula was evaluated using 124 specimens collected from 11 localities in Baja California, Mexico. There was significant interlocality variation in the three characters analyzed. Populations of *D. gravipes* were readily separable from *D. agilis* on the basis of bacular length. Comparisons of similarity matrices based upon bacular characters with those of various sets of skin and skeletal characters yielded highest correlations with post-cranial skeletal characters. Bacular length had a significant linear correlation with body length.

Kangaroo rats (genus *Dipodomys*) of the *heermanni* group occur throughout much of the peninsula of Baja California, Mexico (Huey 1951, Hall and Kelson 1959, Lackey 1967, Best 1976). They occupy various habitats including the chaparral and cactus covered slopes of the north and central regions, and the barren deserts to the south (Huey 1951). Studies of the bacula of these and other forms of *Dipodomys* have been summarized by Best and Schnell (1974), who studied 20 of the 23 species, including *Dipodomys agilis, D. peninsularis,* and *D. gravipes* from Baja California. The present study includes these three Baja California species as well as *D. antiquarius* and *D. paralius* (= *D. agilis pedionomus* and *D. agilis plectilis*, respectively, see Best 1978). Of the Baja California species only bacula of *D. insularis* remain to be examined.

Best and Schnell (1974) pointed out the possible effects of geographic variation upon interspecific bacular comparisons. Such variation in bacula had not been considered in detail, but their subjective analysis of limited data indicated that since differences between species are considerably greater than within, the similarity values they found between species probably would not be changed by more detailed sampling. In the present study I have analyzed bacular measurements for a group of closely related taxa, the *heermanni* group of kangaroo rats in Baja California, to determine: (1) the degree of interlocality variation in bacular measurements; (2) patterns of variation in bacula; (3) phenetic affinities of populations in Baja California based upon bacular measurements; and (4) relationships between variation observed in bacular and other morphologic measurements.

MATERIALS AND METHODS. During the summer of 1972, bacula were collected from kangaroo rats as they were prepared into museum study specimens. Bacula were allowed to dry in small vials and upon returning to the laboratory were prepared and stored in glycerin following Lidicker's (1960*b*) method. Bacular length, height, and width were measured as described by Best and Schnell (1974), and each specimen was aged according to their four cranial criteria; only data from fully adult males are presented.

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The 124 specimens were collected from 11 localities in Baja California (Table 1). At two of these collecting sites, two taxa of kangaroo rats of the *heermanni* group occur sympatrically—*D. gravipes* and *D. agilis* (Table 1, Nos. 2, 3 and 5, 6). I divided specimens from these localities into two samples, for a total of 13 populations. Current taxonomic designations (Best 1978) are as follows: (population 1) *D. agilis martirensis;* (2) *D. agilis simulans;* (3) *D. gravipes;* (4) *D. agilis simulans;* (5) *D. agilis plectilus;* (6) *D. gravipes;* (7) *D. agilis pedionomus;* (8) *D. agilis plectilis;* (9) *D. agilis pedionomus;* (10) *D. agilis eremoecus;* (11) and (12) *D. agilis peninsularis;* and (13) *D. agilis australis.* Best (1978) found that only *D. gravipes* was readily separable from the other taxa using skin and skeletal characters. The other previously recognized species—*agilis, antiquarius, paralius,* and *peninsularis*—were not distinguishable on morphologic grounds (Best 1978).

TABLE 1. *Population numbers, code names, collecting localities, and bacular measurements (mm) of kangaroo rats* (Dipodomys) *from Baja California.*

Pop. No.	Code Name	Collecting Localities	LENGTH mean (n; SD)	WIDTH mean (n; SD)	HEIGHT mean (n; SD)
1	TRINIDAD	Valle de Trinidad (n = 3)			
		4 mi. S Valle de Trinidad (6)	9.40 (10; .502)	2.07 (10; .285)	2.16 (10; .239)
		W end Valle de Trinidad (1)			
2	ESCOAGIL	2 mi. E Colonia Guerrero (1)	9.27 (2; .559)	1.72 (2; .141)	1.94 (2; .127)
		8.5 mi. N San Quintín (1)			
3	ESCOGRAV	8.5 mi N San Quintín	12.74 (4; .647)	1.42 (4; .202)	1.94 (4; .225)
4	SOCORRO	12 mi. N El Rosario	8.98 (2; .044)	1.62 (2; .113)	1.67 (2; .120)
5	ROSAAGIL	6 mi. E El Rosario	9.00 (4; .208)	1.57 (4; .262)	1.73 (4; .275)
6	ROSAGRAV	6 mi. E El Rosario	12.76 (17; .267)	1.68 (17; .229)	2.14 (17; .182)
7	AGUSTINE	San Agustine	9.14 (17; .424)	1.78 (17; .214)	1.96 (17; .236)
8	CATARINA	Santa Catarina Landing	8.80 (7; .493)	1.71 (7; .306)	1.89 (7; .223)
9	SANBORJA	Mission de San Borjas	9.67 (8; .431)	1.94 (8; .227)	2.07 (8; .107)
10	ELBARRIL	7 mi. W San Francisquito Bay	9.44 (2; .219)	1.67 (2; .016)	1.89 (2; .304)
11	R.ALEGRE	2.5 mi. W Mesquital	9.97 (18; .461)	1.86 (18; .285)	1.82 (18; .226)
12	IGNACIO	10 mi. E San Ignacio	9.29 (10; .402)	1.65 (10; .190)	1.79 (10; .226)
13	REFUGIO	4.5 mi. N El Refugio	9.29 (22; .558)	1.58 (23; .283)	1.63 (23; .244)

Mean and standard deviation were calculated for each character for each population (Table 1). I tested interlocality heterogeneity of each character with a one-way analysis of variance, and used a sums of squares simultaneous test procedure (SS-STP; Gabriel and Sokal 1969) to determine the maximally non-significant subsets. Correlation and distance matrices (Sneath and Sokal 1973) were computed from the standardized locality means for each population. Clusters of populations were obtained with the unweighted pair-group method using arithmetic averages (UPGMA). Further explanation of these techniques, plus the rationale for use of only three characters in bacular studies, are given elsewhere (Best and Schnell 1974).

For comparisons of bacular measurements with other morphologic data sets I also computed correlations and distances from the standardized population means for each morphologic data set. These included the following sets: 21 skin, skull, and mandibular characters (SKIN + SKULL/CORR and DIST); 21 post-cranial skeletal characters (P-CRAN SKEL/CORR and DIST); 42 skin and skeletal characters (42 CHAR/CORR and DIST); and the 19 "selected" characters from Best, 1978 (SEL CHAR/CORR and DIST). Descriptions of each character, as well as sample size, mean, and standard deviation for each population are presented elsewhere (Appendix I, Best 1976). Analyses were performed using the IBM 360 computer at the University of Oklahoma Computation Center and the programs UNIVAR (Power 1969) and NT-SYS (Rohlf et al. 1972).

RESULTS AND DISCUSSION. There is significant interpopulation heterogeneity in

all three of the bacular characters (Length, $F=86.0$, d.f. $=12{,}110$; Width, $F=3.9$, d.f. $=12{,}111$; Height, $F=6.9$, d.f. $=12{,}111$).
Bacular length varies more than either bacular width or height as shown by the F-ratios. Most of this length variation results from the difference between *D. gravipes* and the remaining taxa (Table 1). Table 2 shows the pattern of variation in means of the three bacular measurements. Populations 3 and 6 (both *D. gravipes)* are significantly different from the remaining populations in bacular length, but not in width or height. Bacular height and width measurements for *D. gravipes* are well within the range of means observed for the remaining populations. Population 1 is of medium length but largest in both width and height of bacula; also population 9 is one of the largest in all measurements.

TABLE 2. *Variation in means of three bacular measurements in Baja California kangaroo rats* (Dipodomys). *Statistically homogeneous subsets derived from SS-STP analysis are shown by lines below the population numbers and ranked means.*

Character	Results of SS-STP Analysis												
Length	6	3	11	9	10	1	13	12	2	7	5	4	8
	12.76	12.74	9.97	9.67	9.43	9.40	9.29	9.29	9.27	9.14	9.00	8.98	8.80
Width	1	9	11	7	2	8	6	10	12	4	13	5	3
	2.07	1.94	1.86	1.78	1.72	1.71	1.68	1.67	1.65	1.62	1.58	1.57	1.42
Height	1	6	9	7	3	2	8	10	11	12	5	4	13
	2.16	2.14	2.07	1.96	1.94	1.94	1.89	1.89	1.82	1.79	1.73	1.67	1.63

Distinct patterns of geographic variation were not evident from the SS-STP analyses (Table 2). The only non-overlapping homogeneous subset was for bacular length—*D. gravipes* was significantly different from the other populations. Bacular length could thus serve in distinguishing *D. gravipes* from the other taxa. Notably absent in the SS-STP analyses of bacular measurements was north to south or east to west clinal variation.

The correlation phenogram (Fig. 1A) contains an upper cluster, a middle cluster made up of the two *D. gravipes* populations, and a lower cluster. The distance phenogram (Fig. 1B) can be considered as two clusters. The lower cluster contains populations 3 and 6 (both *D. Gravipes)* and the upper cluster includes the remaining members. Both are among the largest in bacular width and height as indicated by the SS-STP analysis.

In the three-dimensional plot of bacular measurements (Fig. 2), a close correspondence to the two primary clusters and sub-clusters in the distance phenogram (Fig. 1B) is apparent. It is clear that the phenetic separation of *D. gravipes* (populations 3 and 6) from the other populations is primarily based on bacular length, and that there is overlap in bacular height and width between all the populations.

I expected bacula to vary in a way similar to other morphologic characters. In comparisons of bacular and other morphologic features, the bacular correlation matrix (BAC/CORR) was not highly correlated with any of the morphologic matrices. In

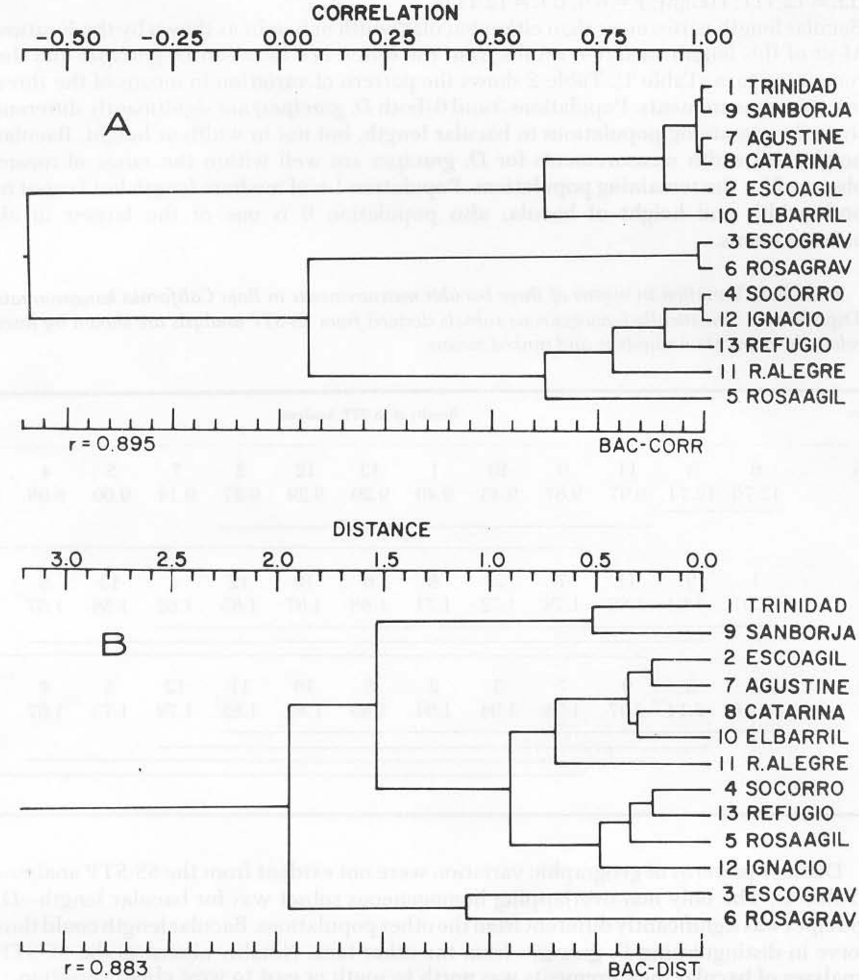

Fig. 1. Correlation (A) and distance (B) phenograms indicating similarities between the 13 populations of kangaroo rats *(Dipodomys)* from Baja California. Similarities were calculated on the basis of the three mean bacular measurements for each population. The cophenetic correlation coefficients (r) for A and B indicate that the phenograms give an accurate representation of their similarity matrices.

contrast, the distance matrix (BAC/DIST) had higher loadings for all matrix comparisons, particularly with the distance matrices. Highest values were for P-CRAN SKEL/DIST (0.609) and 42 CHAR/DIST (0.536). The matrices with skin and skull measurements (SKIN + SKULL/CORR and DIST) were the least correlated with BAC/DIST (-0.236 and 0.402, respectively). These skin and skull characters are very similar to those used in many mammalian morphologic studies. The correlation between BAC/CORR and BAC/DIST was -0.418.

The correlation coefficient of 0.801 ($P \leqslant 0.01$) between mean bacular length and mean

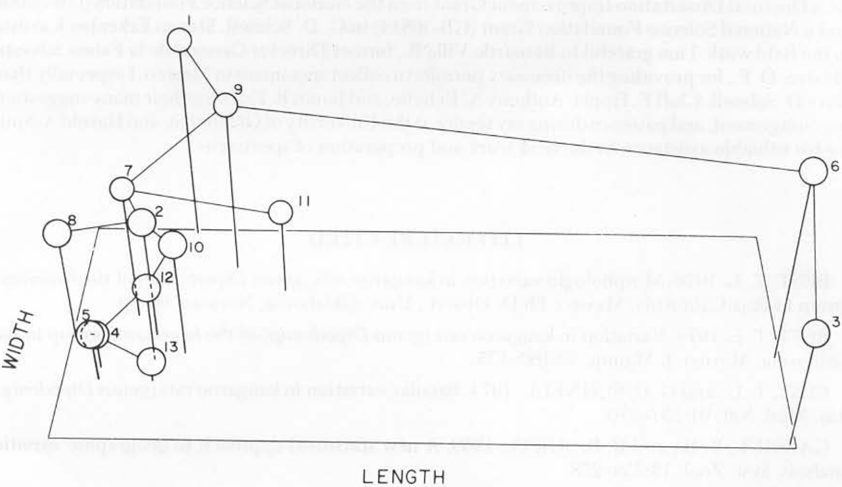

Fig. 2. Three-dimensional plot of average bacular measurements for each of the 13 populations of kangaroo rats *(Dipodomys)* from Baja California. The vertical axis represents height of bacular base.

length of body for each of the 13 populations indicates a very close relationship between body size and bacular size. Within the 11 *D. agilis* populations, the correlation coefficient was also significant ($r=0.699$, $P\leqslant 0.05$). This is contrary to Best and Schnell's (1974) conclusion when they compared phenograms with and without body size considered. A linear correlation performed on their data (bacular length vs. body length) was not significant ($r=0.340$, $P\leqslant 0.05$), supporting their conclusions. However, the correlation value is significant ($r=0.599$, $P\leqslant 0.05$) if *D. deserti* and *D. nitratoides* are removed from their data set. It appears that generally in *Dipodomys* there is a significant relationship between bacular and body length. Certainly this is true in the Baja California forms studied here.

CONCLUSIONS. My data show significant interlocality variation in bacula of kangaroo rats of the *heermanni* group in Baja California. Bacular length is the only character I examined that can be used to clearly differentiate between populations of *D. gravipes* and *D. agilis*. Bacular width and height are not useful in differentiating populations between or within either species. Multivariate analyses elucidated the phenetic affinities of populations in Baja California. However, no clinal variation was distinguishable in the bacular characters.

The significant relationship between bacular length and body length suggests the selective factors affecting body length may indirectly affect bacular length, i.e., as body length increases, bacular length increases proportionally. Therefore, wide ranging species of *Dipodomys* that exhibit considerable geographic variation in body length (e.g., *D. merriami*, Lidicker 1960*a; D. ordii*, Kennedy and Schnell 1978) would be expected to exhibit significant variation in bacular length. Further studies are needed to elucidate the relationship between bacular length and body length in other species of *Dipodomys*.

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