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Multivariate methods support the distinction of a new highland *Vaejovis* (Scorpiones: Vaejovidae) from the Sierra de los Ajos, Mexico

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Abstract: Multivariate analyses of morphological characters provide strong evidence that a highland *Vaejovis* from the Sierra de los Ajos, a Madrean 'sky island' in northern Sonora, Mexico, represents a distinct new species of the *V. vorhiesi* group. This new species is described and compared to other geographically adjacent species of the *V. vorhiesi* group, named *V. bandido*, and brief notes on ecology are provided. Results from this study provide evidence that multivariate analysis of morphological characters is a powerful tool to delimit small and otherwise cryptic scorpion species.

Keywords: Madrean pine-oak, scorpion, taxonomy, *Vaejovis mexicanus* group, *Vaejovis vorhiesi* group

Recent studies continue to reveal distinct new species of *Vaejovis* in the highlands of western North America (Graham 2007; Ayrey 2009; Graham & Bryson 2010; Ayrey & Soleglad 2011; Sissom 2011). The *V. vorhiesi* group, a related assemblage of these highland scorpions, is distributed throughout pine-oak-juniper woodlands from Utah south across Arizona and western New Mexico into northern Mexico (Sissom 2000, 2011). Until recently (Santibáñez-López & Francke 2010), the *V. vorhiesi* group was considered part of the *V. mexicanus* group, which includes other highland forms distributed in Mexico and western Texas (McWest 2009). As currently understood, the *V. vorhiesi* group consists of the following species: *V. vorhiesi* Stahnke 1940, *V. jonesi* Stahnke 1940, *V. lapidicola* Stahnke 1940, *V. paysonensis* Soleglad 1973, *V. cashi* Graham 2007, *V. feti* Graham 2007, *V. deboerae* Ayrey 2009, *V. crumpi* Ayrey & Soleglad 2011, *V. bigelowi* Sissom 2011 and *V. electrum* Hughes 2011. Although geographically proximate to these species and previously assigned to the *V. vorhiesi* group (Graham & Bryson 2010), preliminary genetic data suggest that *V. vaquero* Gertsch & Soleglad 1972 and *V. montanus* Graham & Bryson 2010 are not members of this group (L. Prendini pers. comm.).

The distribution of the *V. vorhiesi* group is often cited as including northern Mexico (e.g., Sissom 2000; Santibanez-Lopez & Francke 2010; Sissom 2011), but other than *V. montanus* and *V. vaquero*, no other montane *Vaejovis* have been documented from this region. The 'sky islands' of northern Mexico, together with those of adjoining southern Arizona and New Mexico, form an archipelago of mesic mountain habitat flanked by arid desert and grassland plains. Because of their isolation, the remote Sierra de los Ajos and other Madrean sky islands in Mexico, such as the Sierra El Tigre, may harbor distinct new highland species of scorpions.

We surveyed the Sierra de los Ajos in October of 2010. One day and two nights of searching the upper elevations of the Sierra de los Ajos revealed a large population of a small montane species of the *V. vorhiesi* group. We collected nine individuals, and measured morphological characters for comparison to *V. vorhiesi* group forms from six nearby mountain ranges. Measurements were analyzed using multivariate statistical analyses. Our results indicated that the scorpions from the Sierra de los Ajos represent a distinct new species, which we describe here. This study, as well as similar research on related species (Hughes 2011), suggests that multivariate analysis of morphological characters appears to be an effective strategy when delimiting small and otherwise cryptic montane vaejovid species.

METHODS

Sampling.—We scored 23 morphological characters from 54 female *Vaejovis* from seven different mountain ranges, including the Animas Mountains, New Mexico; Santa Catalina Mountains, Arizona (*V. deboerae*); Chiricahua Mountains, Arizona (*V. cashi*); Huachuca Mountains, Arizona (*V. vorhiesi*); Peloncillo Mountains, New Mexico; Sierra Elenita, Sonora; and Sierra de los Ajos, Sonora. Because sexual dimorphism in scorpions is strong, sexes should be analyzed separately. We therefore excluded male specimens due to inadequate sample sizes from several ranges. Female *Vaejovis* appear to be more morphologically conserved than males, which vary in size and chelal morphology, and based on studies of other scorpion taxa (e.g., van der Meijden 2010), this variation likely represents an adaptive difference between sexes. By measuring females only, we assumed that differences detected between groups most likely represented selectively neutral morphological divergence, which is arguably a better indicator of phylogeny, and thus species limits, than traits strongly biased by selection. All characters were measured with an ocular micrometer.

Morphology.—Measurements are as described by Stahnke (1970), pedipalp finger dentition follows Soleglad & Sissom (2001), trichobothrial patterns are as in Vachon (1974) and Soleglad & Fet (2003) and hemispermatophore terminology is from Soleglad & Fet (2008). Terminology follows Stahnke (1970) and Stockmann & Ythier (2010). For measurements, the words "length," "width," and "depth" are abbreviated as L, W, and D. We measured total lengths from the anterior margin of the carapace to the aculeus tip, with the telson fully extended.

Statistical analyses.—Multivariate statistical assessment largely followed Devitt et al. (2008), with a few notable modifications. We began by performing a principal component

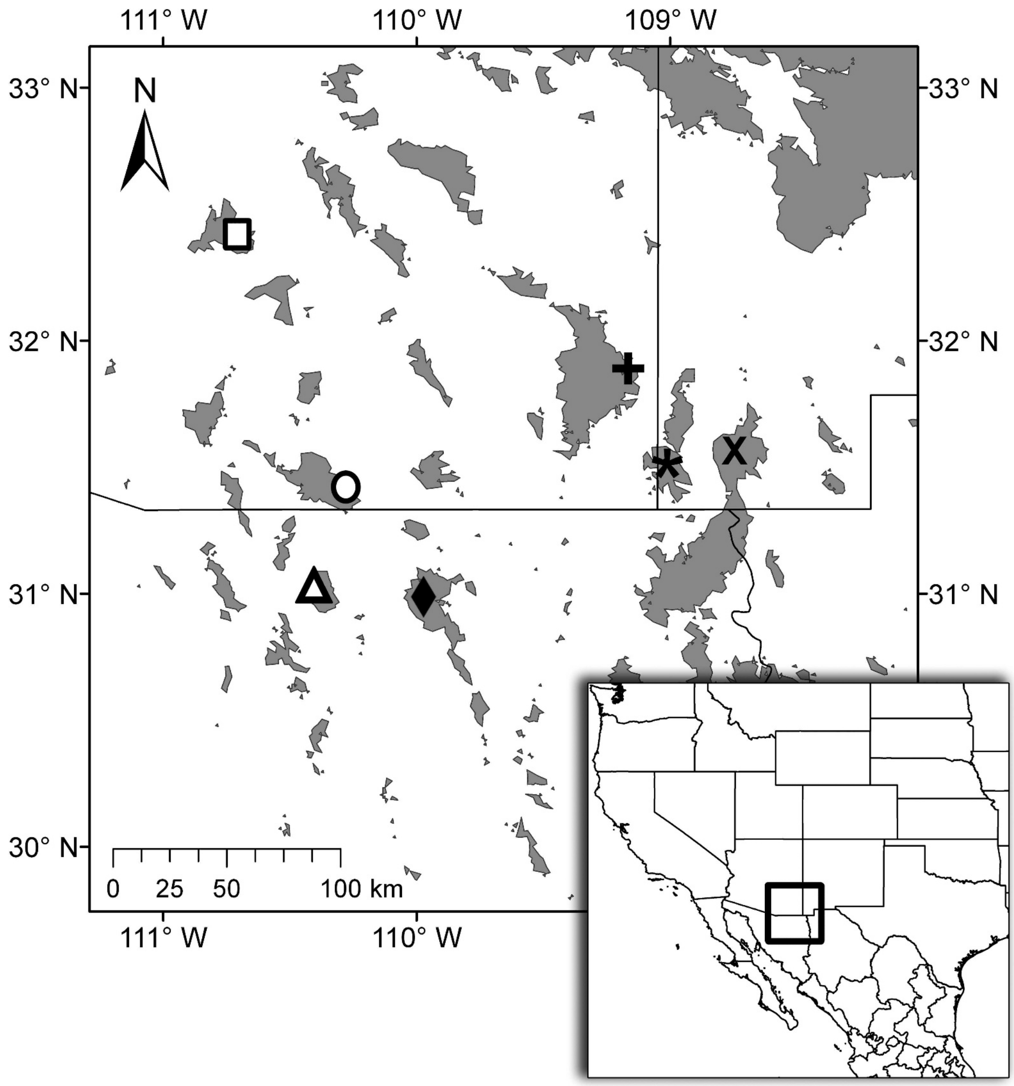


Figure 1.—Distribution of scorpions in the *Vaejovis vorhiesi* group from the southwestern 'sky island' region that were included in this study. Gray areas indicate elevations of 1,650 m and above. Symbols represent populations from the Santa Catalina Mountains (*V. deboerae*, square), Huachuca Mountains (*V. vorhiesi*, circle), Sierra Elenita (*V.* cf. *vorhiesi* triangle), Sierra de los Ajos (*V. bandido* new species, diamond), Chiricahua Mountains (*V. cashi*, cross), Peloncillo Mountains (*V.* cf. *cashi*, asterisk), and the Animas Mountains (*V.* cf. *cashi*, X). Symbols correspond to those used in Fig. 2.

analysis (PCA) to explore patterns of variation in the data and to delimit any natural groupings in the dataset, using mountain range as the grouping variable. Scatterplots were constructed for each pair of principal components and used to check for outliers. We then performed standard univariate descriptive statistics for each of the non-overlapping groupings identified by the PCA (mean ± 1 standard deviation, range, sample size), and used ANOVA to compare means. For post-hoc comparisons of means, we used Scheffé's F, which is robust to violations of the assumption of homogeneity of variances (Scheffé 1953; Devitt et al. 2008).

To determine which variables contribute the most to the disparity between groups, we then performed a discriminant function analysis (DFA), again using the natural non-overlapping groups specified by the PCA as the grouping variable. While PCA searches for the directions of highest variation without consideration of group membership, DFA examines variation among groups compared to the variability within them, thereby detecting those variables responsible for group differentiation. Because DFA can sometimes be sensitive to deviations from normality, we explored the effect of standardization and log transformation of non-normal data. Neither transformation noticeably altered the results, so we performed a final DFA on the raw data. Significance of canonical functions was assessed using a classification matrix with jackknife validation. We performed all statistical analyses with SYSTAT® v. 8.0 Statistics (SPSS Inc. 1998).

Abbreviations used in multivariate analyses are as follows: CARA_L = carapace length, METI_L = length of metasoma segment I, METI_W = width of metasoma segment I, METII_L = length of metasoma segment II, METII_W = width of metasoma segment II, METIII_L = length of metasoma segment III, METIII_W = width of metasoma segment III, METIV_L = length of metasoma segment IV,

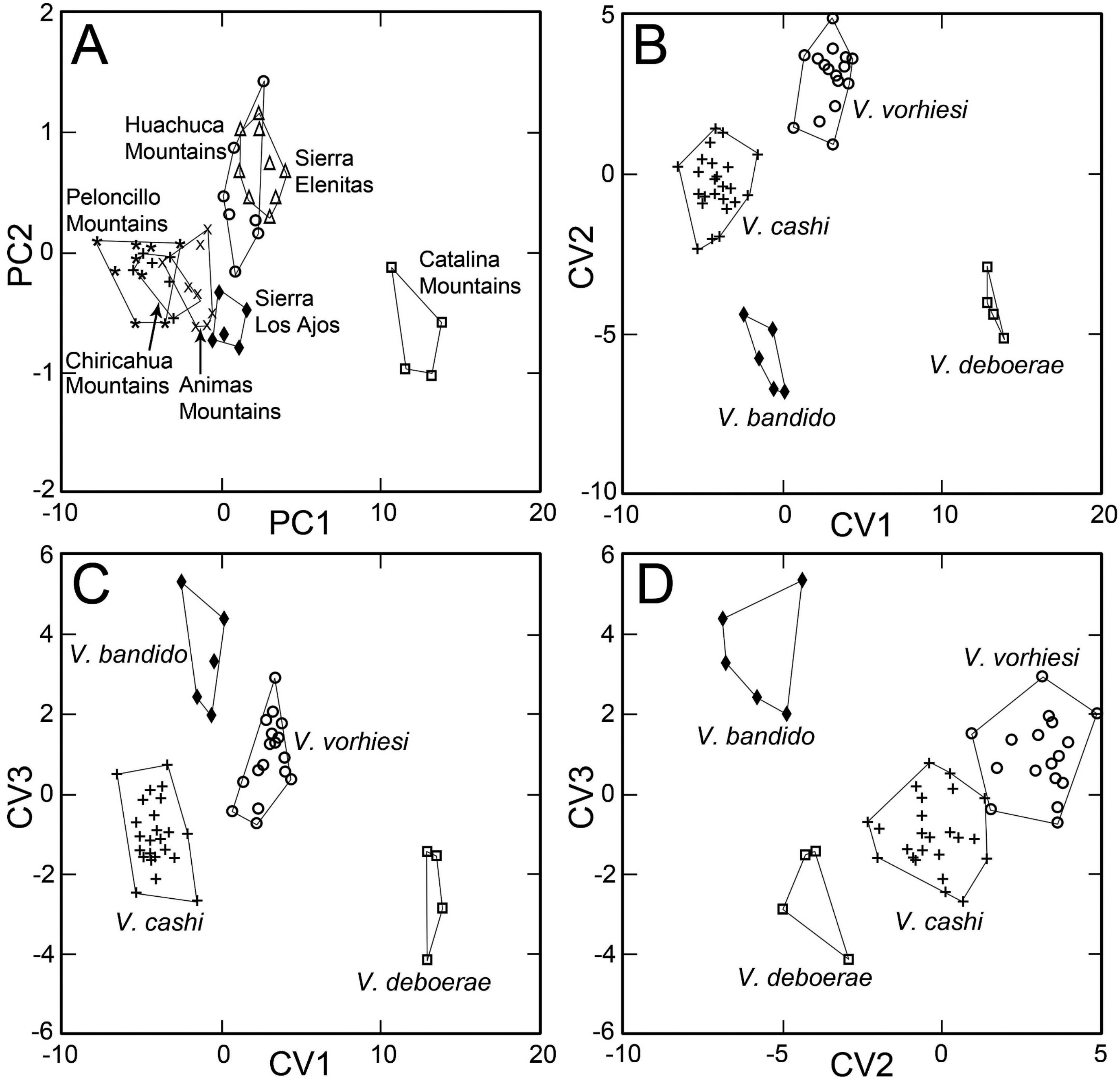


Figure 2.—Scatterplots of principal components (A) and canonical analysis of discriminance (B–D) for female 'sky island' scorpions. Individuals were grouped by mountain range in the PCA, and natural clusters were assigned to one of four species used as the grouping variable in the DFA.

METIV_W = width of metasoma segment IV, METV_L = length of metasoma segment V, METI_W = width of metasoma segment V, VES_L = length of telson vesicle, VES_W = width of telson vesicle, VES_D = depth of telson vesicle, FEM_L = femur length, FEM_W = femur width, PAT_L = patella length, PAT_W = patella width, PALM_L = length of chelal palm, PALM_W = width of chelal palm, PALM_D = depth of chelal palm, MF_L = length of pedipalp movable finger and FF_L = length of pedipalp fixed finger.

Acronyms of depositories.—AMNH, American Museum of Natural History; CAS, California Academy of Sciences; CNAN, Colección Nacional de Arácnidos, Instituto de Biologia, Universidad Nacional Autónoma de México, México, D.F.; UANL, Universidad Autónoma de Nuevo León, San Nicolas de los Garza, Nuevo León, Mexico; MRG, personal collection of Matthew R. Graham, Las Vegas, Nevada, USA; RFA, personal collection of Richard F. Ayrey, Flagstaff, Arizona, USA.

Table 1.—Morphological variation in females of four species in the *Vaejovis vorhiesi* group: *V. bandido* new species, *V. cashi*, *V. deboerae*, and *V. vorhiesi*. For each character, the mean ± standard deviation and range are provided in the first row. Values in the second row of each character indicate species with significant ($P < 0.05$) pairwise difference in means (species coded 1–4), as indicated from ANOVAs using Scheffé's F post-hoc procedure. Character abbreviations are defined in the Methods. Sample sizes are listed in the first row.

	V. bandido (1)	*V. cashi (2)*	*V. deboerae (3)*	*V. vorhiesi (4)*
N	5	24	4	17
CARA_L	3.23±0.10 (3.12–3.38)	2.80±0.22 (2.33–3.14)	4.30±0.17 (4.12–4.48)	3.38±0.15 (3.07–3.62)
	2, 3	1, 3, 4	1, 2, 4	2, 3
METI_L	1.38±0.06 (1.31–1.45)	1.23±0.10 (1.00–1.38)	2.05±0.05 (2.00–2.12)	1.54±0.07 (1.41–1.67)
	2, 3, 4	1, 3, 4	1, 2, 4	1, 2, 3
METI_W	1.814±0.04 (1.77–1.86)	1.57±0.11 (1.33–1.76)	2.43±0.08 (2.33–2.50)	1.88±0.08 (1.79–2.00)
	2, 3	1, 3, 4	1, 2, 4	2, 3
METIII_L	1.68±0.08 (1.57–1.79)	1.46±0.11 (1.24–1.67)	2.46±0.09 (2.41–2.60)	1.85±0.09 (1.69–2.00)
	2, 3	1, 3, 4	1, 2, 4	2, 3
METIII_W	1.68±0.06 (1.62–1.74)	1.46±0.10 (1.21–1.62)	2.22±0.06 (2.14–2.26)	1.69±0.06 (1.60–1.81)
	2, 3	1, 3, 4	1, 2, 4	2, 3
METV_L	3.32±0.13 (3.17–3.50)	2.79±0.21 (2.31–3.10)	4.59±0.17 (4.38–4.76)	3.47±0.15 (3.26–3.69)
	2, 3	1, 3, 4	1, 2, 4	2, 3
METV_W	1.58±0.04 (1.55–1.62)	1.37±0.09 (1.14–1.52)	2.06±0.10 (1.93–2.17)	1.57±0.05 (1.50–1.62)
	2, 3	1, 3, 4	1, 2, 4	2, 3
VES_L	1.82±0.04 (1.76–1.86)	1.58±0.10 (1.31–1.71)	2.55±0.09 (2.50–2.69)	1.95±0.13 (1.69–2.17)
	2, 3	1, 3, 4	1, 2, 4	2, 3
VES_W	1.11±0.05 (1.01–1.17)	0.98±0.07 (0.83–1.07)	1.45±0.10 (1.36–1.55)	1.12±0.07 (0.98–1.24)
	2, 3	1, 3, 4	1, 2, 4	2, 3
FEM_L	2.54±0.08 (2.45–2.64)	2.25±0.22 (1.81–2.60)	3.71±0.16 (3.52–3.86)	2.84±0.12 (2.67–3.14)
	3	3, 4	1, 2, 4	2, 3
FEM_W	0.86±0.03 (0.83–0.91)	0.78±0.07 (0.64–0.88)	1.18±0.05 (1.12–1.24)	0.91±0.04 (0.86–0.98)
	3	3, 4	1, 2, 4	2, 3
PAT_L	2.82±0.14 (2.69–3.05)	2.44±0.22 (2.02–2.81)	3.96±0.18 (3.79–4.14)	3.05±0.13 (2.83–3.33)
	2, 3	1, 3, 4	1, 2, 4	2, 3
PAT_W	0.95±0.01 (0.93–0.95)	0.84±0.06 (0.74–0.98)	1.33±0.05 (1.26–1.38)	0.99±0.04 (0.93–1.07)
	2, 3	1, 3, 4	1, 2, 4	2, 3
PALM_L	2.31±0.07 (2.21–2.41)	2.01±0.18 (1.67–2.29)	3.32±0.14 (3.19–3.50)	2.48±0.08 (2.33–2.69)
	2, 3	1, 3, 4	1, 2, 4	2, 3
PALM_D	1.12±0.04 (1.07–1.17)	0.97±0.09 (0.81–1.10)	1.61±0.08 (1.52–1.71)	1.11±0.07 (0.98–1.24)
	2, 3	1, 3, 4	1, 2, 4	2, 3
MF_L	2.71±0.11 (2.60–2.88)	2.37±0.26 (1.95–2.79)	4.05±0.16 (3.91–4.29)	3.09±0.13 (2.86–3.38)
	3	3, 4	1, 2, 4	2, 3
FF_L	2.16±0.09 (2.05–2.29)	1.9±0.22 (1.52–2.24)	3.33±0.13 (3.26–3.52)	2.55±0.12 (2.33–2.83)
	3, 4	3, 4	1, 2, 4	1, 2, 3

Material examined (other than types).—*Vaejovis bandido:* MEXICO: *Sonora*, Sierra de los Ajos, 30.98017°N, 109.96685°W, 1840 m, 12–13 October 2010, R.W. Bryson, Jr., 3 ♂ (1 CNAN, 2 UANL), 3 ♀ (1 CNAN, 2 UANL).

Vaejovis cashi Graham 2007: USA: *Arizona*, Cochise Co., Herb Martyr Canyon, Chiricahua Mountains, 31.8901°N, 109.1686°W, 1530 m, 15 March 2008, R.W. Bryson, Jr., 8 ♀ (MRG).

Vaejovis cf. *cashi:* USA: *New Mexico*: Hidalgo Co., Geronimo Pass, Peloncillo Mountains, 31.51725°N, 109.016917°W, 1718 m, 16 September 2010, R.W. Bryson, Jr., 6 ♂, 11 ♀ (MRG). Animas Mountains, 31.56433°N, 108.74416°W, 1835 m, 17 September 2010, R.W. Bryson, Jr., 1 ♂, 15 ♀ (MRG).

Vaejovis deboerae Ayrey 2009: USA: *Arizona*, Pima Co., Mount Lemon, Santa Catalina Mountains, 32.2313°N, 110.4145°W, 2142 m, 25 August 2008, R.F. Ayrey, 1 ♂, 6 ♀ (CAS).

Vaejovis vorhiesi Stahnke 1940: USA: *Arizona*, Cochise Co., Miller Canyon, Huachuca Mountains, 31.2497°N, 110.1657°W, 1757 m, 26 April 2009. R.F. Ayrey, 6 topotypes ♀ (RFA).

Vaejovis cf. *vorhiesi:* USA: *Arizona*, Santa Cruz Co., Cave Creek Canyon, Santa Rita Mountains, 31.7130°N, 110.8241°W, 1890 m, 20 March 2008, R.W. Bryson, Jr., 1 ♂, 3 ♀ (MRG). MEXICO: *Sonora*, Sierra Elenita, 31.02329°N, 110.37881°W, 1815 m, 14 October 2010, R.W. Bryson, Jr., 1 ♂, 9 ♀ (UANL).

RESULTS

PCA of female morphological characters revealed four non-overlapping groups that sorted geographically (Fig. 2). Female *V. cashi* from the Chiricahua Mountains grouped with specimens from the nearby Animas and Peloncillo Mountains, so we treated specimens from these three mountain ranges as *V. cashi*. Female scorpions from the Sierra Elenita clustered with those from the nearby Huachuca Mountains, so we treated specimens from those two ranges as *V. vorhiesi*. To the north, *V. deboerae* from the Santa Catalina Mountains formed the most distinct cluster in principal component space, and were treated as an individual species. Lastly, although close to *V. cashi* in component space, specimens from the Sierra de los Ajos also formed a non-overlapping group. Importantly, the means of these two

Figure 3.—*Vaejovis bandido* new species in life.

groups clearly separated in component space, so we treated specimens from the Sierra de los Ajos as a distinct new species, *V. bandido*, described below.

The majority of the variance (92.6%) was explained by PC1, with all factor loadings greater than 94%. Since the data were raw measurements and not ratios, which are more typical of taxonomic work on vaejovid scorpions, PC1 corresponded to variation associated with differences in size. PC2 then can be interpreted as variation associated with shape, although this component only explains 1.4% of the total variance. Therefore, PCA results suggested that *V. deboerae* differed from the other three species in overall size. This is clearly evident in raw values as adult female *V. deboerae* all ranged between 33.17 and 33.9 mm in total length, while total lengths of the other three species ranged only from 18.43 to 28.05 mm. The remaining three species were much more similar in PCA space, but varied from each other on both size (PC1) and shape (PC2) axes. PCA results suggested that female *V. bandido* were morphologically most similar to *V. cashi*, but differed in terms of overall size.

Canonical analysis of discriminance revealed highly significant differences among the four species (Wilks' $\lambda = 0.001$, $P < 0.0001$; Fig. 2B–D). Again, *V. deboerae* was the most distinct species in multivariate space, but all four species clearly segregated, with no overlapping points. *Vaejovis deboerae* was most distinct on canonical variate I (CV1), which was most strongly correlated with lengths of metasomal segments I to III and with telson width. The remaining three species differentiated most on CV2, which was most strongly explained by variation in the length of metasomal segment I, the length and width of metasomal segment II, and the width of the telson vesicle. Interestingly, although *V. bandido* overlapped considerably with *V. cashi* on CV1, it was clearly distinct on CV2 and CV3 (Fig. 2B–D). Length of metasomal segment V had the greatest factor loading on CV3, followed by femur length, metasomal segment I length, and metasomal segment II width. The classification function correctly classified 100% of the samples, and the jackknife validation correctly classified between 75% and 96% of the specimens (Table 3). Univariate statistics and ANOVA results based on these four species groupings are provided in Table 1.

TAXONOMY

Family Vaejovidae Thorell 1876
Genus *Vaejovis* Koch 1836

Vaejovis Koch 1836:51.

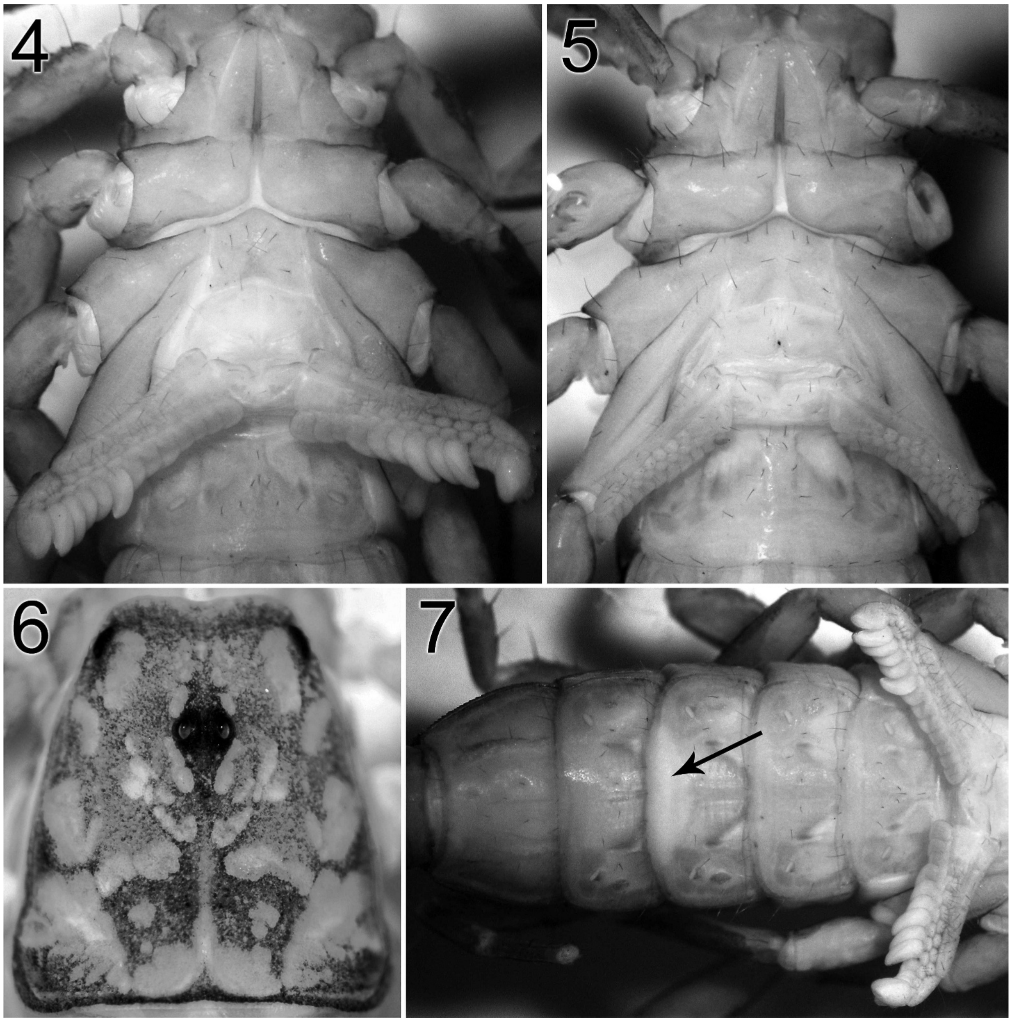
Type species.—*Vaejovis mexicanus* Koch 1836, by monotypy.

Vaejovis bandido new species
(Figures 3–18, Tables 1–3)

Type material.—MEXICO: *Sonora*, male holotype, Sierra de los Ajos, 30.98017°N, 109.96685°W, 1840 m, 12–13 October 2010, R.W. Bryson, Jr. (AMNH). Paratypes: same collection data as holotype, 2 ♀ (1 AMNH, 1 UANL).

Etymology.—The specific epithet refers to the historical use of the Sierra de los Ajos and surrounding mountains as hideouts for bandits ("*bandidos*" in Spanish) and outlaws during the early 1900s (Knight 1990).

Diagnosis.—Small in overall size with males smaller than females. Base color brown with darker mottling on the carapace, tergites, pedipalps, metasoma and legs. Median carinae of tergites I–VII obsolete. Moderate subaculear spine. Chelal tricobothria *ib* and *it* located at the base of the fixed finger; anterior margin of carapace slightly emarginated. Fixed finger ID denticles 5 and movable finger ID denticles 6, which distinguish *V. bandido* from *V. bigelowi, V. crumpi, V.*



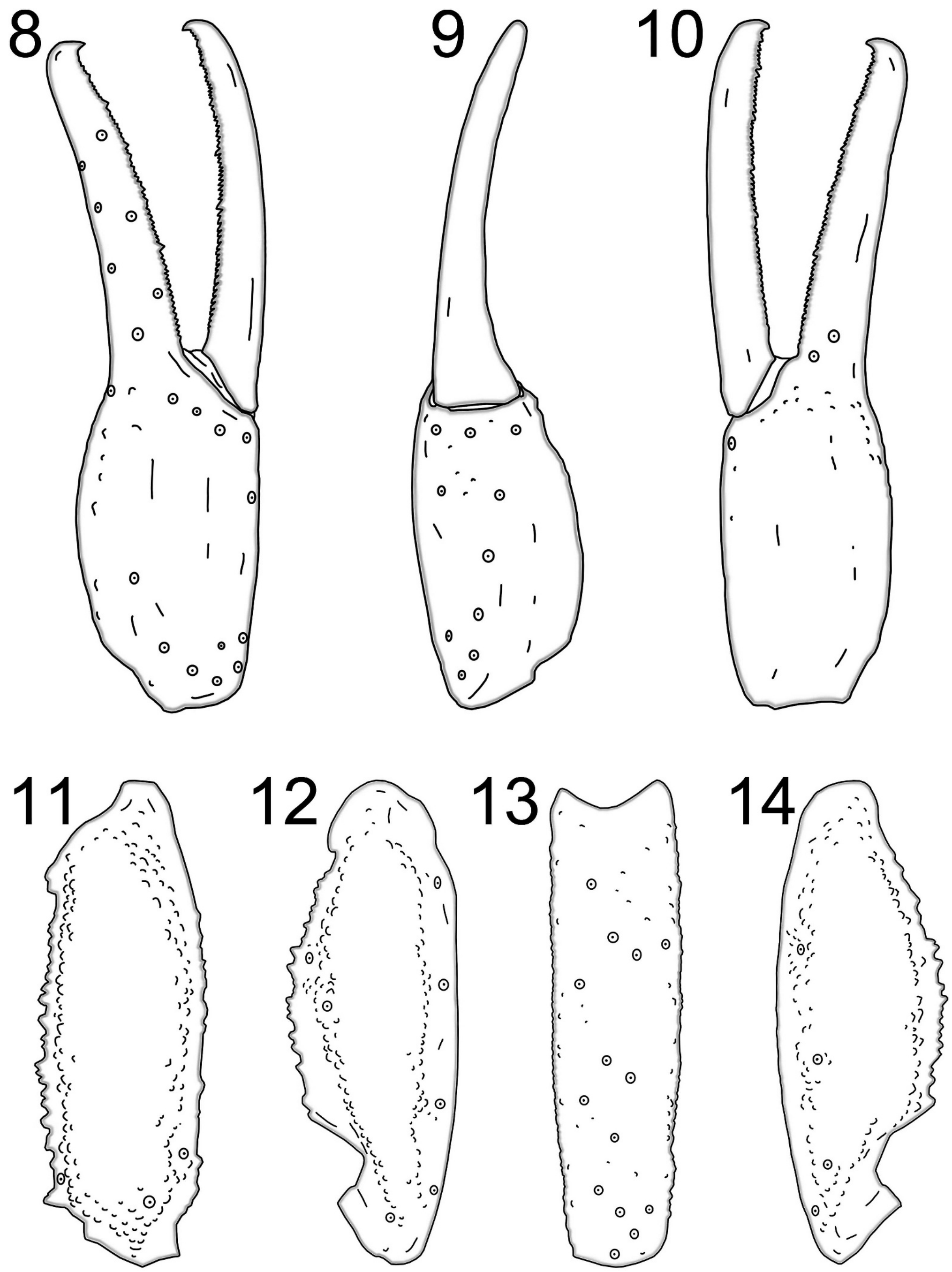
Figures 4–7.—*Vaejovis bandido* new species. 4. Pectines and sternum, male holotype. 5. Pectines and sternum, female paratype. 6. Carapace, male holotype. 7. White patch (arrow), an area of reduced pigmentation, on sternite V, male holotype.

jonesi, V. lapidicola, V. paysonensis, V. montanus, V. vaquero, and *V. mexicanus* group scorpions, which have 7 movable finger ID denticles. Single pair of distal spinules on ventral surface of leg tarsi, not 3 or more as in *V. vaquero* and all *V. mexicanus* group species (Santibanez-Lopez & Francke, 2010), and not 2–3 as in *V. montanus*. Differs from *V. electrum* by smaller body size and a palm width of 0.95–1.07 mm in females, instead of 1.05–1.28 in females. Trichobothrium *Db* ventral to *D1* carinae on chelal palm. Pectine count 13–14 in males and 11–12 in females.

Adult females can be distinguished from adult female *V. vorhiesi, V. cashi, V. feti*, and *V. deboerae* by the following ratios that overlap by less than 10%, as outlined in Hughes (2011): pedipalp fixed finger length/palm width, 19.6–2.19 in *V. bandido* and 2.35–3.03 in *V. vorhiesi* (0% overlap); pedipalp chela length/width, 4.09–4.45 in *V. bandido* and 4.67–5.78 in *V. vorhiesi* (0% overlap); metasomal segment V length/segment I length, 2.34–2.45 in *V. bandido* and 2.18–2.36 in *V. cashi* (7.4% overlap); chelal palm length/width, 2.10–2.16 in *V. bandido* and 1.95 in *V. feti* holotype; 2.13–2.31 in *V. bandido* and 1.68 in *V. feti* holotype; metasomal segment V length/width, carapace length/palm width 3.00–3.17 in *V. bandido* and 2.72–3.03 in *V. deboerae* (6.7% overlap). *Vaejovis bandido* can also easily be distinguished from *V. deboerae* by a conspicuous difference in overall size, the latter species being the larger. In the female specimens examined, carapace lengths, a commonly used proxy for overall size, ranged from 3.12 to 3.38 mm in *V. bandido* and from 4.12 to 4.18 mm in *V. deboerae*. In addition, female type specimen total lengths were much smaller for *V. bandido*: 27.75 mm compared to 33.14 and 32.21 mm in *V. deboerae* (Ayrey 2009). These differences, as well as other size characters in which *V. bandido* differs from *V. cashi, V. deboerae,* and *V. vorhiesi*, are summarized in Table 1.

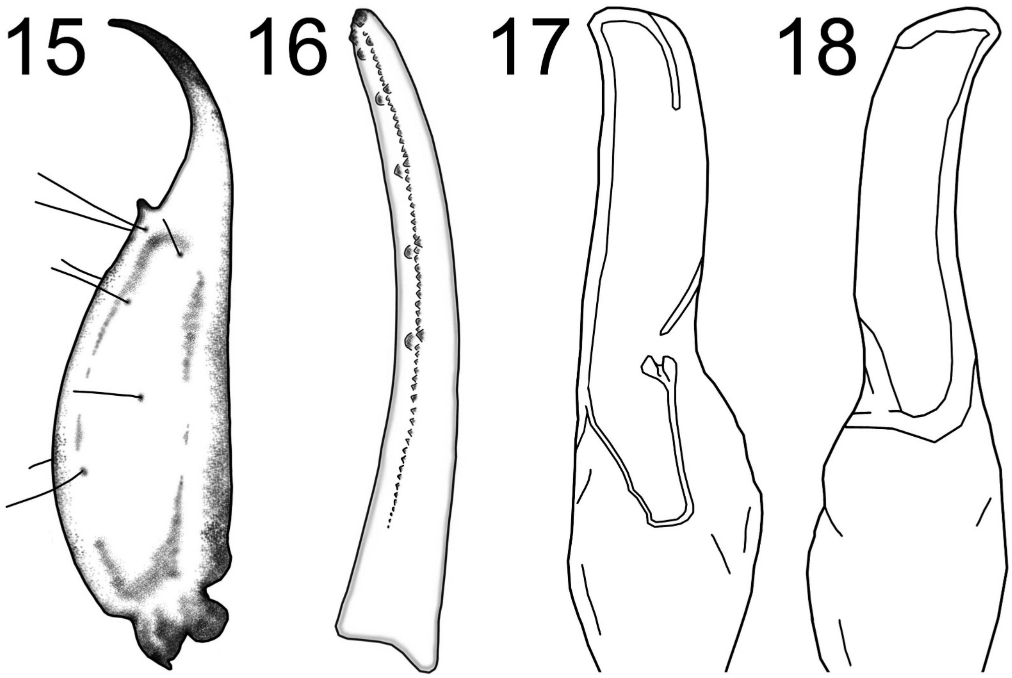
Description of holotype.—*Color:* Base color brown with darker mottling on the carapace, tergites, pedipalps, metasoma and legs (Figs. 3–7). White patch on the posterior 1/3 of sternite V (Fig. 7), similar to *V. deboerae, V. montanus*, and *V. bigelowi*.

Morphology: Carapace: anterior margin slightly emarginate, with three lateral eyes on each side; moderately convex dorsolaterally; finely granular with scattered small granules; median furrow moderate and traversing length of carapace, excluding the median eyes; ratio of median eyes location (distance from anterior edge)/carapace L = 0.33; carapace L/W at



Figures 8–14.—Trichbothrial patterns of *Vaejovis bandido* new species, based on male holotype. 8. Right pedipalp chela, external. 9. Right pedipalp chela, ventral. 10. Right pedipalp chela, internal. 11. Right pedipalp femur, dorsal. 12. Right pedipalp patella, dorsal. 13. Right pedipalp patella, external. 14. Right pedipalp patella, ventral.

median eyes = 1.46. Tergites: coarsely granular, median carinae obsolete; strong granular submedian and lateral carinae on posterior 4/5s of VII; pretergites very finely granular. Genital operculum: sclerites separated on posterior 1/5. Pectines: tooth count 13/13; sensorial areas present on all teeth (sensorial areas present on all teeth in females, but slightly reduced on the most basal tooth): middle lamellae 7/7. Sternites: III–VI smooth to very finely granular and without carinae; VII with granular lateral carinae on posterior 1/2. Spiracles: ovoid with median side rotated 35 degrees away from posterior sternite margin. Metasoma: ratio of segment I L/W 0.65; segment II L/W 0.94; segment III L/W 1.02; segment IV L/W 1.45; segment V L/W 2.18. Segments I–IV: dorsolateral carinae strong, serrate with distal denticle enlarged and spinoid; lateral supramedian carinae strong with serrated granules and enlarged spinoid distal denticle; lateral inframedian carinae moderate, granular on segment I, distal 1/2 of II and III, and obsolete on IV; ventrolateral carinae strong, granular; ventral submedian carinae weak, granular on I and II, on III weak basally and moderate distally, moderate



Figures 15–18.—*Vaejovis bandido* new species, male holotype. 15. Telson, lateral view. 16. Movable finger of right pedipalp. 17. Right hemispermatophore, ectal view. 18. Right hemispermatophore, ental view.

on IV; dorsal and lateral intercarinal spaces very finely granular; ventrolateral setation 2/2:1/2:2/2:3/3; ventral submedian setation 3/3:3/3:3/3:3/3. Segment V: dorsolateral carinae moderate, distally crenulate, basally granular; lateromedian carinae moderate and granular on basal 3/4, obsolete on distal 1/4; ventrolateral carinae moderate and serrate; ventromedian carinae moderate, granular; intercarinal spaces finely granular; dorsolateral setation 2/2; lateromedian setation 3/3; ventrolateral setation 4/4; ventromedian setation 3/3. Telson: smooth, with prominent subaculear spine; LAS denticles (Fet et al. 2006) lacking. Chelicerae: dorsal edge of movable cheliceral finger with two subdistal (sd) denticles; ventral edge smooth with well developed serrula comprised of approximately 20 tines on distal half. Pedipalps: trichobothrial pattern type C (Figs. 8–14); ratio of chela L/W = 4.33; femur L/W = 2.88; patella L/W = 2.93; fixed finger L/carapace L = 0.64. Chela: carinae weak with some weak to moderate granules; median (MD) denticles of fixed finger aligned and divided into six subrows by five outer (OD) denticles; flanked by five inner (ID) denticles; movable finger with six subrows,

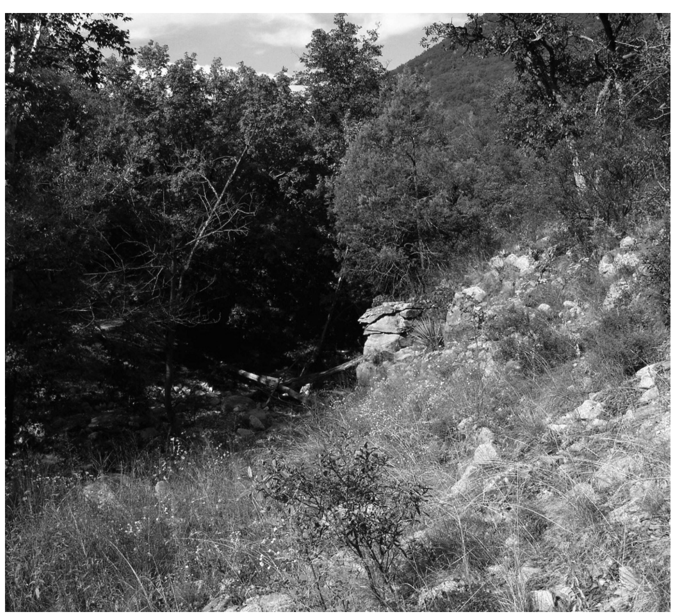


Figure 19.—Madrean pine-oak forest riparian habitat at the type locality of *Vaejovis bandido* new species, Sierra de los Ajos, Sonora, Mexico.

Table 2.—Factor loadings for the first and second principal components and canonical discriminant functions for the first, second, and third canonical variate scores. See Methods for character abbreviations.

	PC1	PC2	CV1	CV2	CV3
CARA_L	0.989	0.040	0.035	0.548	0.287
METI_L	0.989	0.103	2.039	2.896	−2.177
METI_W	0.986	−0.008	−0.371	0.284	0.029
METII_L	0.989	0.110	−2.294	−1.594	0.754
METII_W	0.984	−0.129	0.661	−1.665	−2.166
METIII_L	0.988	0.117	1.360	0.239	−1.483
METIII_W	0.984	−0.102	−0.736	0.724	−0.020
METIV_L	0.988	0.115	−0.260	0.002	−0.074
METIV_W	0.976	−0.154	0.879	−1.305	0.992
METV_L	0.994	0.044	0.094	−1.263	4.065
METV_W	0.979	−0.144	−0.630	−0.160	0.388
VES_L	0.971	0.108	0.742	0.116	−0.246
VES_W	0.968	−0.088	−1.451	−1.656	1.497
VES_D	0.982	0.019	0.740	1.128	−1.710
FEM_L	0.987	0.116	−0.046	−1.240	−2.286
FEM_W	0.978	−0.054	−1.091	1.050	−0.324
PAT_L	0.990	0.086	0.310	1.046	−0.025
PAT_W	0.980	−0.102	1.627	1.108	−0.060
PALM_L	0.992	0.022	0.045	−0.593	1.712
PALM_W	0.947	−0.235	−0.885	0.988	−1.528
PALM_D	0.966	−0.202	0.267	−1.774	−0.114
MF_L	0.982	0.143	−1.375	−3.630	1.145
FF_L	0.977	0.178	1.057	4.685	1.034
Eigenvalue	22.141	0.327	27.602	8.563	2.725
Total Variance (%)	96.264	1.421	–	–	–
Total Dispersion (%)	–	–	0.71	0.93	1

five OD denticles and six ID denticles; movable finger shorter than both the carapace and metasomal segment V. Femur: dorsoexternal, dorsointernal, and ventrointernal carinae crenulate, ventroexternal weak, granular. Patella: internal carinae oblique and granular; all other carinae moderate, crenulate. Legs: ventral surface of tarsus with single median row of spinules terminating distally with one spinule pair. Hemispermatophore (Figs. 17 & 18): Lamelliform type with well-developed distal lamina with a distinct distal crest about 1/3 the length of the lamina. Slight basal constriction located just proximal of lamina midpoint where it terminates in well-developed, bifurcated, lamellar hook. A sclerotized spermatocleutrum (= mating plug) was not found in either hemispermatophore, although it is possible that they could have been inadvertently removed during the dissection process. We did not find a mating plug in two additional males that were dissected.

Mensuration (mm).—Male holotype: total L = 24.35; carapace L = 2.93; mesosoma L = 6.86; metasoma L = 10.64 (excluding telson). Metasoma: segment I L/W = 1.43/1.76; segment II L/W = 1.67/1.69; segment III L/W = 1.76/1.62; segment IV L/W = 2.38/1.57; segment V L/W = 3.40/1.55. Telson: L = 2.95; vesicle L/W/D = 1.90/1.02/0.83; aculeus L = 1.05. Pedipalps: total L = 7.17; femur L/W = 2.43/0.83; patella L/W = 2.67/0.90; chela L = 4.05; palm L/W/D = 2.07/0.98/1.10; movable finger L = 2.43; fixed finger L = 1.98. Female paratype 1: total L = 26.10; carapace L = 3.21; mesosoma L = 9.52; metasoma L = 10.19 (excluding telson); Metasoma: segment I L/W = 1.36/1.79; segment II L/W = 1.60/1.71; segment III L/W = 1.69/1.62; segment IV L/W = 2.26/1.62; segment V L/W = 3.29/1.55. Telson: L = 2.93; vesicle L/W/D = 1.81/1.07/0.83; aculeus L = 1.12. Pedipalps: total L = 9.62; femur L/W = 2.48/0.86; patella L/W = 2.76/0.95; chela L = 4.38; palm L/W/D = 2.29/1.07/1.12; movable finger L = 2.60; fixed finger L = 2.10. Female paratype 2: total L = 27.75; carapace L = 3.17; mesosoma L = 9.00; metasoma L = 10.07 (without telson); Metasoma: segment I L/W = 1.36/1.79; segment II L/W = 1.55/1.69; segment III L/W = 1.64/1.67; segment IV L/W = 2.26/1.57; segment V L/W = 3.26/1.55. Telson: L = 2.90; vesicle L/W/D = 1.81/1.07/0.79; aculeus L = 1.12. Pedipalps: total L = 9.76; femur L/W = 2.55/0.86; patella L/W = 2.76/0.93; chela L = 4.45; palm

Table 3.—Classification matrix from the discriminant function analysis of female scorpions in the *Vaejovis vorhiesi* group. Jack-knife validation values that differed from those of the classification function are in parentheses.

Species	*V. bandido*	*V. cashi*	*V. deboerae*	*V. vorhiesi*	%correct
V. bandido	5 (4)	0 (1)	0	0	100 (80)
V. cashi	0	24 (23)	0	0 (1)	100 (96)
V. deboerae	0	0	4 (3)	0 (1)	100 (75)
V. vorhiesi	0	0 (1)	0	17 (16)	100 (94)
Total	5 (4)	24 (25)	4 (3)	17 (18)	100 (92)

L/W/D = 2.31/1.00/1.07; movable finger L = 2.74; fixed finger L = 2.19.

Variability.—Sexual dimorphism in *V. bandido* was strong. Of the adult specimens examined, the average female total length was 26.04 mm (n = 5), while the average male total length was 21.86 mm (n = 4). Characters that differed in size most between the sexes were as follows: carapace length 2.48–2.93 mm in males and 3.17–3.38 mm in females (0% overlap); mesosoma length 5.9–6.86 mm in males and 7.29–9.52 mm in females (0% overlap); patella length 2.29–2.52 mm in males and 2.76–3.05 mm in females (0% overlap); chela length 3.52–4.05 mm in males and 4.38–4.69 mm in females (0% overlap). The sexes also differed in the shape of the metasoma, which can be most easily seen in ratios of metasomal segment III length/width; 2.10–2.16 in females and 2.18–2.23 in males (0% overlap). Although there was some size variation within the sexes, intraspecific variation in shape (measured as ratios) appeared to be exceptionally low.

Distribution.—Known only from the type locality in the Sierra de los Ajos of northern Sonora, Mexico (Fig. 1).

Ecology.—Specimens were collected 12–13 October 2010. During diurnal searches, *V. bandido* were frequently found beneath small rocks along a riparian corridor at 1840 m (Fig. 19). This riparian area was covered in thickets of pine and oak trees, and much of the ground was covered with bunchgrass and oak leaf litter. Only two specimens were found under the same rock, and the vast majority of the scorpions encountered under rocks were female. At night, *V. bandido* were found active on the surface in the same habitat. During this time, scorpions, including numerous males, were found in large numbers along rock and dirt banks above the road.

To roughly estimate the local abundance of *V. bandido*, we conducted a one-hour survey on 13 October 2011 along a 0.8 km stretch of dirt road that paralleled the riparian area. From 1930 h to 2030 h, three people methodically searched the ground adjacent to the road with portable UV lights while a fourth person recorded observations. Care was taken to avoid counting the same scorpion more than once. During this time, 149 *V. bandido* were observed.

Additional scorpions observed in the area were *Centruroides sculpturatus* Ewing 1928, *Vaejovis spinigerus* Wood 1863, and *Diplocentrus* cf. *spitzeri* Stahnke 1970. With the exception of *C. sculpturatus*, most of these were found on the drier rocky slopes above the riparian area. Here, *D.* cf. *spitzeri* seemed most abundant, although no specific counts were made. Eight *C. sculpturatus* were observed during the one-hour nocturnal transect, and several were found under rocks within the riparian habitat.

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