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Scorpion Biodiversity and Patterns of Endemism in Northern Mexico

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Although comprising a relatively small group of terrestrial arthropods, scorpions are subjects of considerable interest to both the scientist and layperson. In some areas of the world, including much of Mexico, they are feared by the general public because of their highly toxic venoms. To those uneducated about them, scorpions are all assumed to be lethal; the truth of the matter is, only about two dozen of the 1200 or so species are considered dangerous by medical experts. About 7 species of *Centruroides* in Mexico are known to cause human mortality; Simard and Watt (1990) estimated that about 100,000 stings occur in Mexico each year, and possibly as many as 800 people die. Most mortality involves young children and the elderly.

Scorpions are ancient arthropods, derived from aquatic ancestors that lived in the Silurian Period, more than 400 million years ago. These ancient forms closely resemble modern scorpions in details of basic anatomy. Apparently, the scorpion body plan that developed so long ago is a highly successful one. It is interesting to note that a few of the fossil scorpions were approximately 1 m in length, far greater in size than the largest of today's species, which are just longer than 20 cm.

Scorpions are also interesting animals because of their reproductive biology and ecology. All species are viviparous, with embryos developing in the female's reproductive tract and receiving nourishment from maternal tissues (Francke 1982). Polis and Farley (1980) and Polis (1990) have suggested that scorpions have very low reproductive rates in comparison with most animals. A low r_{max} (maximum rate of population increase) for several species is in part due to long generation times and low survivorship among sexually immature females. Gestation periods may be quite long, ranging from several months in many buthids to more than a year and a half in certain scorpionoids (Polis and Sissom 1990). The young are fairly large at birth, and time to maturity is at the minimum about 2 years (in some species, maturity may not be reached for at least 6–8 years). Average longevity is probably around 4 years, but *Hadrurus* spp. may live 25 years (Polis 1990). In general, then, scorpions resemble long-lived vertebrate species in their life-history traits and should be regarded as "K-selected." Such species are often of great concern to conservation biologists because they cannot replace their populations rapidly.

Scorpions are important components of arid and semiarid ecosystems, but they are not limited to these areas. Other habitats in which they may be found include deciduous and pine forests, grasslands, the floors and trees of tropical jungles, high mountain slopes in the Himalayas and Andes (up to 14,000 feet elevation), deep subtropical and tropical caves, and even certain rocky intertidal habitats at the ocean's edge. Despite this, we still tend to think of scorpions as desert animals, and current evidence suggests that deserts harbor more species than other ecosystems. Scorpions may be very abundant; Levy and Amitai (1980) measured densities of $1.12/m^2$ in the Middle Eastern *Leiurus quinquestriatus*, and Polis (1990) reported densities of $8–12/m^2$ in *Serradigitus littoralis*, an intertidal scorpion from the Baja California peninsula.

The diversity of scorpions in Mexico, as judged by world standards, is exceptional. Currently, more than 200 species and subspecies of scorpions are known from Mexico, more than any other country in the world (Lourenço and Sissom 2000). Mexico is a land of great diversity in landforms, elevation, climate, and vegetation (chapters 1 and 2). Opportunities for prolific speciation of Mexican scorpions have undoubtedly resulted from the country's complex geological history (chapter 1), which must have repeatedly fragmented ancestral scorpion populations.

Our purpose here is to review scorpion biodiversity of the Baja California peninsula and the states of Sonora, Sinaloa, Durango, Chihuahua, Coahuila, Nuevo León, and Tamaulipas on the mainland of Mexico. First, a brief history of taxonomic research and a synopsis of the scorpion fauna are provided, followed by an assessment of the patterns of distribution and endemism (as currently understood) and the role scorpions might play in future conservation strategies. Needs for further studies of scorpion biodiversity in northern Mexico are identified.

Status of Biodiversity Research in Northern Mexico

Brief Historical Review of Efforts to Catalog Diversity

Pocock (1898, 1902) was among the earliest taxonomists to work extensively with scorpions from Mexico. The first comprehensive assessment of scorpion biodiversity in Mexico was published by Hoffmann (1931, 1932); in his monograph, Hoffmann synthesized all of the information known about Mexican scorpions, described a number of new taxa, and listed 15 species from the northern states (several of which were misidentified and 4 for which he relied solely on literature reports). Hoffmann focused primarily on mainland Mexico and had very little material from the Baja California peninsula.

Only a handful of papers pertaining to the Mexican fauna were published in the next few decades after Hoffmann's monograph, but during the 1960s and 1970s, several U.S. taxonomists (O. F. Francke, W. J. Gertsch, M. E. Soleglad, H. L. Stahnke, and S. C. Williams) took an interest in the scorpions of Mexico, including those of the northern states. The publications of Stanley Williams, in particular, were based on extensive fieldwork on the Baja California peninsula using ultraviolet detection techniques. He culminated this research with an important monograph of the Baja California fauna (Williams 1980), representing one of the most thorough studies of a regional scorpion fauna ever conducted. Considering only currently valid species, Williams nearly tripled the number known from the peninsula, describing as new 35 (58.3%) of the species.

The study of the mainland fauna has consisted largely of sporadic papers describing newly discovered species. Williams (1968a) partially described the vaejovid fauna of the Cuatrociénegas area in Coahuila; of 5 species reported, 1 is apparently endemic. Mitchell (1968) described the remarkable troglobytic genus *Typhlochactas*, with 1 of its original species (*T. rhodesi* Mitchell) recorded from La Cueva de la Mina in Tamaulipas. Díaz Najera (1964, 1975) published numerous new distributional records for many species in Mexico. Since the 1980s, a few papers have dealt with the scorpion biodiversity of mainland Mexico. These papers described new species and/or provided partial taxonomic revisions. Two papers provided assessments of the fauna of the state of Sonora (Sissom 1991; Sissom and Stockwell 1991). Relatively detailed distributional information for 2 species in northern Mexico has also been presented (Shelley and Sissom 1995; Yahia and Sissom 1996).

A number of complete studies of the Mexican scorpion fauna have appeared in the last few years: catalogs of the world fauna (Fet et al. 2000) and of the Mexican fauna (Beutelspacher 2000), as well as a synoptic review of the entire Mexican fauna (Lourenço and Sissom 2000). Two additional species of *Vaejovis* have been described from Sonora (Capes 2001; Hendrixson 2001) since publication of the *Catalog of the Scorpions of the World (1758–1998)* (Fet et al. 2000).

Approaches to Biodiversity Analysis

Almost all of the early information on scorpion diversity was obtained by the conventional rock-rolling technique, which entails looking underneath rocks, logs, and other surface cover to find scorpions. In using this method it is important to return these objects to their original positions after rolling them to look for scorpions. Many different kinds of organisms are dependent on surface objects for food and shelter (because of the favorable microclimate offered). Failure to replace such surface objects will cause many of these organisms to die unnecessarily.

The rock-rolling technique appreciably underestimates the total scorpion diversity in an area, but diversity assessment can be greatly improved by using the ultraviolet light detection method (Williams 1968b). The method enables researchers to locate scorpions when they are active at night and, consequently, provides more information on ecology and behavior than do other methods. Use of this tool throughout Mexico will reveal significant numbers of new species, especially in the genera *Diplocentrus* and *Vaejovis*. UV light detection, although the method of choice for most scorpion researchers, is nevertheless dependent on the activity patterns of the scorpions. Owing to the sporadic nature of nightly and seasonal surface occurrence of some species, not all of the species at a given location may be collected unless sampling is conducted periodically. Some species are only sporadically active on the surface throughout the warmer months of the year, whereas others exhibit brief periods of intense activity. In general, if sampling large areas (e.g., one or more geopolitical states) black-lighting gives more return per unit effort than the other methods (both in numbers of species and numbers of individuals). In our UV light-sampling regime for roadside collecting in the United States, for example, we have sampled at least 5 localities per night (double that if we are able to divide into 2 separate collecting parties). Consequently, a 2-week collecting trip can yield large numbers of specimens from many localities, as demonstrated by the work of S. C. Williams on the Baja California peninsula.

Pitfall trapping, a more labor-intensive method, is also quite productive. There are some limitations to this method as well. In montane habitats and other rocky soils, it may be difficult to dig the holes necessary to set up the traps. Lithophiles and burrowing forms, which typically wait near their crevices or burrows for prey without moving around much on the surface, are not as likely to be taken by this method, except during the mating season when males are actively moving in search of females. Pitfall trapping is also affected by seasonal activity patterns of species; trapping must be conducted throughout the warm season to maximize the species catch at a given location. Unlike UV-light sampling, it is not feasible to thoroughly sample large geographical areas with pitfall trapping, each trap transect takes considerable time to set up, and this factor restricts the number of localities that can be sampled on a collecting trip. The traps must be left open long enough to generate a catch, and the sites must be revisited to obtain the specimens. Pitfall trapping seems most useful when the investigator is working at 1 or several study sites over an extended period. Another limitation of the method is that specimens collected in antifreeze/alcohol traps (necessary to prevent cannibalism) are generally not well preserved.

Obtaining a complete accounting of the species present is only one of the problems in assessing scorpion biodiversity in northern Mexico. Accurate estimates of the geographical distributions of most species in mainland Mexico are lacking. This is primarily due to inadequate sampling, but it is also due in part to the rarity or sporadic surface occurrence of some species. Given that few sites have been intensively investigated, mainly isolated records of individual species have accumulated. The problem can be illustrated by fieldwork conducted at Big Bend Ranch State Park in southwestern Texas (Sissom and Henson, unpubl. data), an area similar to many mountainous sites in neighboring states of northern Mexico. At this site, a series of transects were monitored for 4 years. Based on observations made on a 20 m × 100 m rocky slope transect over 63 nights, the probability of finding the uncommon *Vaejovis intermedius* Borelli on a given night was 11.1%, and no more than 3 individuals were seen on any night. On the same transect, the probability of finding another uncommon species, *Pseudouroctonus apacheanus* (Gertsch and Soleglad), was 22.2%. Of the 2 species, at least *V. intermedius* occurs in northeastern Mexico, and both taxa possibly exhibit similar densities over much of their range. It is interesting that, although 8 species were observed on that transect over the 4 years, an average of only 2.7 species (range 0–6) were observed nightly.

As sampling in Mexico continues, some species currently thought to be endemics may be found to exhibit a broader geographical distribution. Therefore, to understand patterns of endemism more fully, filling out the distributional data for the scorpion species in northern Mexico should be given high priority.

Scorpion Diversity in Mexico

Mexico is a medium-sized country, and its scorpion diversity is still impressive when one standardizes species diversity according to area. An arbitrary measure of species density used here is the number of species per 100,000 km^2. Scorpion diversity of 15 representative countries from 5 continents is tabulated in table 6.1 to facilitate raw and standardized comparisons.

The present state of knowledge suggests that Mexico has more families, genera, and species than any other country in the world (table 6.1). Species density, however, falls below that of several small countries, namely Cuba, Venezuela, and Ecuador. At the same time, it should be noted that the species density of the Baja California peninsula is approximately twice that of the most scorpion-rich country listed in the table. The scorpion fauna of the peninsula appears to be the most diverse in the world (at least among areas > 10,000 km^2). It is likely that other parts of Mexico will exhibit similar species densities once they become better sampled; based on existing museum collections, states such as Oaxaca, Guerrero, and Michoacan show considerable promise. However, it is difficult to say with any degree of certainty what percentage of the fauna remains to be discovered and described.

Several factors should be considered in making these comparisons. First, whereas estimates of species

Table 6.1. Comparison of world scorpion diversities using representative countries.

Region	No. of Families	No. of Genera	No. of Species	No. of Species/10^5 km^2
North America and Antilles				
Mexico (total)	7	22	197	10.06
Baja California peninsula	6	14	60	41.64
United States (total)	5	12	84	0.9
Southwestern states (TX, NM, AZ, CA)	5	12	80	4.67
Cuba	2	10	24	21.65
South America				
Argentina	2	9	50	1.81
Brazil	4	16	93	1.09
Colombia	4	9	41	3.60
Ecuador	4	8	36	12.70
Venezuela	4	18	124	13.60
Africa				
Egypt	3	10	20	2.00
Namibia	4	7	58	7.04
South Africa and Lesotho	3	10	101	8.07
Asia				
India	6	21	98	2.98
Saudi Arabia	4	14	19	0.88
Yemen	4	14	32	6.06
Australasia				
Australia	4	6	29	0.38

Numbers of species are based on existing published records and do not include known introduced species. The list also does not include subspecies (see text). Scorpions are very unevenly distributed across the United States, with 80 of 84 species occurring in the southwestern border states. For this reason, separate species densities are given for the country as a whole and for those southwestern states.

density will likely increase considerably in Mexico, the smaller countries that have been reasonably sampled will have a larger percentage of their species already known; with less geographical area, there is less potential to contain many large unexplored areas that can hold a sizable number of endemics. Second, subspecies and synonyms are not considered in this analysis. There seems to be a general trend to reconsider the status of subspecies (e.g., Prendini 2001), and it is expected that many subspecies will eventually be considered valid species, whereas others will be synonymized; in addition, some old synonyms will be revived and considered valid species. Subspecies were especially proliferated over the years by taxonomists who worked with Old World scorpions (e.g., according to Fet et al. [2000], the genus *Scorpio* Linnaeus currently has 1 species divided into 19 subspecies, and *Euscorpius* Thorell has 5 species and 42 subspecies). This trend was not as prevalent in the New World (including Mexico), and only a moderate number of subspecies has been described. Adjustments in subspecies and synonymies will influence species density calculations, but because subspecies typically make up a minor percentage of a country's fauna, this influence will not be great. As an example, South Africa represented a country with a large number of subspecies. Prendini's (2001) reassessment of described *Opistophthalmus* scorpions (which constitute about one-third of the known South African scorpion fauna) raised the total number of recognized species in that country from 92 to 101 and changed the species density from 7.35 to 8.07. There are 20 remaining subspecies from other genera in South Africa; in comparison, Mexico has 18.

Obviously, the scorpion faunas of some parts of the world are better known than those of others. The fauna of the Baja California peninsula is certainly one of the best known (although not completely inventoried), but there are areas outside of Mexico that have also enjoyed a great amount of taxonomic attention (e.g., Cuba, Namibia, South Africa, Venezuela). Generally speaking, however, most of the countries listed in table 6.1 are inadequately sampled, and the mainland of Mexico is certainly comparable to any of those.

Lourenço (1994) suggested that the tropics (particularly in South America) will eventually hold the greatest scorpion diversity, and perhaps this will eventually be proven true as in many other taxonomic groups. In fact, Lourenço proposed that an endemic area in the tropical Andes encompassing all of Ecuador, about 40% of Colombia, and about 25% of Peru has the highest diversity in the world, even compared directly to that of the Baja California peninsula. The tropical Andean area indeed demonstrates high diversity (6 families, 12 genera, and 68 species), but its estimated surface area is approximately 1,060,000 km^2—more than 7 times the area of the Baja California peninsula. Calculating species density as above, the known diversity of the tropical Andes endemic area is 6.4 species/100,000 km^2. Even if the cataloged diversity of this area triples, as Lourenço suggests is possible once the fauna is more completely known, it will still reach only half the species density of Baja California (assuming no additional species are found on the peninsula, which is unlikely).

Scorpion Diversity in Northern Mexico

A current checklist of scorpions known from the states of northern Mexico is provided in table 6.2. The fauna in this part of Mexico comprises 6 families, 16 genera, and 109 species. Based on the number of known species, northern Mexico has more than half the total species (109 out of 197) in the country. The better sampled fauna of the Baja California peninsula contributes 60 of the 109 species in the north.

Family Buthidae

The family Buthidae is represented in northern Mexico by a single genus, *Centruroides* Marx (fig. 6.1, *1*). In eastern border states (i.e., Chihuahua, Coahuila, Nuevo León, Tamaulipas) there are only 3 species, *C. vittatus* (Say), *C. rileyi* Sissom, and *C. gracilis* (Latreille). *Centruroides vittatus* is also widely distributed in the central United States, and *C. gracilis* has a very wide range, occurring in Florida, the Caribbean, Central America, and northern South America. In the westernmost areas of northern Mexico (states of Durango, Sonora, and Sinaloa, and the Baja California peninsula), 6 species are recorded: *C. exilicauda* (Wood), *C. infamatus* (Koch), *C. pallidiceps* Pocock, *C. suffusus* Pocock, *C. margaritatus* (Gervais), and *C. vittatus*. Several of these are highly venomous and are known to contribute to human mortality. The taxonomy of the genus is poorly understood, with highly variable species diagnosed primarily on the basis of color and morphometrics. Evaluating the fauna of Durango

Table 6.2. Checklist of the scorpion species of northern Mexico.

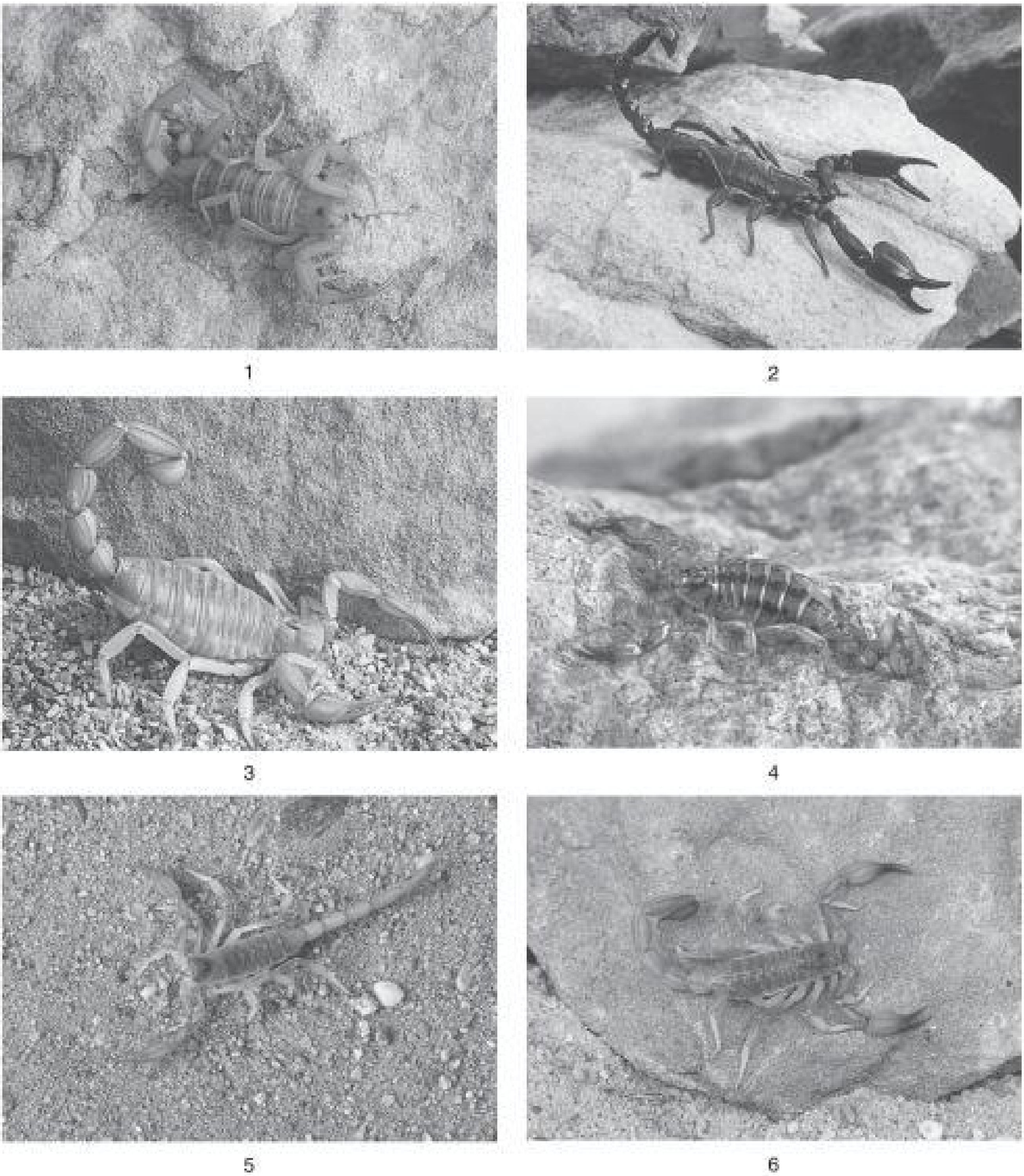
Taxon	BC	BCS	SON	SIN	DGO	CHIH	COAH	NL	TAMPS
Family Buthidae									
Centruroides exilicauda	BC	BCS	SON			?			
Centruroides gracilis									TAMPS
Centruroides infamatus					DGO				
Centruroides margaritatus				SIN					
Centruroides pallidiceps			SON	SIN					
Centruroides rileyi									TAMPS
Centruroides suffusus					DGO				
Centruroides vittatus					DGO	CHIH	COAH	NL	TAMPS
Family Chactidae									
Nullibrotheas allenii		BCS							
Family Diplocentridae									
Bioculus caboensis		BCS							
Bioculus cerralvensis		BCS							
Bioculus comondae		BCS							
Bioculus cruzensis		BCS							
Diplocentrus colwelli								NL	
Diplocentrus diablo									TAMPS
Diplocentrus ferrugineus								NL	
Diplocentrus gertschi			SON	SIN					
Diplocentrus lindo							COAH	NL	
Diplocentrus spitzeri			SON						
Diplocentrus whitei						CHIH	COAH	NL	
Diplocentrus williamsi			SON						
Family Iuridae									
Anuroctonus phaiodactylus	BC								
Hadrurus arizonensis	BC		SON						
Hadrurus concolor	BC	BCS							
Hadrurus hirsutus		BCS							
Hadrurus pinteri	BC	BCS							
Family Superstitioniidae									
Superstitionia donensis	BC	BCS	SON						
Typhlochactas cavicola									TAMPS
Typhlochactas rhodesi									TAMPS
Family Vaejovidae									
Paravaejovis pumilis		BCS							
Paruroctonus arnaudi	BC								
Paruroctonus baergi			SON						
Paruroctonus bajae	BC								
Paruroctonus borregoensis	BC		SON						
Paruroctonus coahuilanus							COAH		
Paruroctonus gracilior							COAH		
Paruroctonus luteolus	BC								
Paruroctonus nitidus	BC								
Paruroctonus pseudopumilis		BCS							
Paruroctonus silvestrii	BC								
Paruroctonus stahnkei			SON						
Paruroctonus surensis		BCS							
Paruroctonus utahensis						CHIH			
Paruroctonus ventosus	BC								
Paruroctonus xanthus			SON						
Pseudouroctonus andreas	BC								
Pseudouroctonus cazieri	BC								
Pseudouroctonus chicano						CHIH			
Pseudouroctonus lindsayi		BCS							
Pseudouroctonus rufulus	BC								
Serradigitus bechteli		BCS							
Serradigitus adcocki		BCS							
Serradigitus agilis			SON						

(continued)

Table 6.2. Continued

Taxon	BC	BCS	SON	SIN	DGO	CHIH	COAH	NL	TAMPS
Serradigitus allredi			SON						
Serradigitus armadentis		BCS							
Serradigitus baueri	BC								
Serradigitus calidus							COAH		
Serradigitus dwyeri		BCS							
Serradigitus gertschi	BC	BCS							
Serradigitus gigantaensis		BCS							
Serradigitus haradoni		BCS							
Serradigitus harbisoni	BC								
Serradigitus hearnei	BC	BCS	SON						
Serradigitus littoralis	BC	BCS							
Serradigitus minutus		BCS							
Serradigitus pacificus	BC								
Serradigitus polisi			SON						
Serradigitus subtilimanus			SON						
Serradigitus yaqui			SON						
Smeringurus grandis	BC								
Smeringurus mesaensis	BC		SON						
Syntropis macrura		BCS							
Vaejovis bilineatus							COAH	NL	TAMPS
Vaejovis bruneus		BCS							
Vaejovis cazieri							COAH	NL	
Vaejovis coahuilae					DGO	CHIH	COAH		
Vaejovis confusus	BC		SON						
Vaejovis crassimanus					DGO			NL	
Vaejovis decipiens			SON			CHIH			
Vaejovis diazi		BCS							
Vaejovis eusthenura		BCS							
Vaejovis galbus		BCS							
Vaejovis globosus					DGO		COAH		
Vaejovis gravicaudus	BC	BCS							
Vaejovis hirsuticauda	BC								
Vaejovis hoffmanni	BC	BCS							
Vaejovis insularis		BCS							
Vaejovis intermedius					DGO	CHIH	COAH	NL	
Vaejovis janssi		BCS							
Vaejovis magdalensis		BCS							
Vaejovis mauryi			SON						
Vaejovis minckleyi							COAH		
Vaejovis pattersoni		BCS							
Vaejovis peninsularis		BCS							
Vaejovis pequeno			SON						
Vaejovis platnicki									TAMPS
Vaejovis punctipalpi		BCS							
Vaejovis puritanus	BC	BCS							
Vaejovis rossmani								NL	TAMPS
Vaejovis rubrimanus								NL	
Vaejovis sonorae			SON						
Vaejovis spinigerus	BC		SON						
Vaejovis sprousei								NL	TAMPS
Vaejovis vaquero						CHIH			
Vaejovis viscainensis	BC	BCS							
Vaejovis vittatus		BCS							
Vaejovis waeringi	BC								
Vaejovis waueri					DGO	CHIH	COAH	NL	
Vejovoidus longiunguis		BCS							
Total Species/State	32	41	24	3	8	9	13	13	10

Subspecies are not included. Abbreviations for state names: BC = Baja California (northern state of the Baja California peninsula); BCS = Baja California Sur; SON = Sonora; SIN = Sinaloa; DGO = Durango; CHIH = Chihuahua; COAH = Coahuila; NL = Nuevo León; TAMPS = Tamaulipas.



Figures 6.1. Representative scorpions from northern Mexico. *1*, Buthidae: *Centruroides exilicauda* (Wood) from Arizona, New Mexico, the Baja California peninsula, and Sonora. *2*, Diplocentridae: *Diplocentrus whitei* (Gervais) from Texas, Chihuahua, Coahuila, and Nuevo León. *3*, Iuridae: *Hadrurus concolor* Stahnke from the Baja California peninsula. *4*, Superstitioniidae: *Superstitionia donensis* Stahnke from the southwestern United States, Sonora, and the Baja California peninsula. *5*, Vaejovidae: *Paruroctonus gracilior* (Hoffmann) from Texas and New Mexico southwest to Aguascalientes (in northern Mexico documented only in Coahuila). *6*, Vaejovidae: *Vaejovis crassimanus* Pocock from Texas, New Mexico, Arizona, Durango, and Nuevo León. (All photos by W. D. Sissom.)

should be especially interesting. A map generated by Hoffmann (1938) indicated that the ranges of *C. suffusus* and *C. infamatus* were contiguous, but no precise localities were published to support the distributional boundaries. Most recently (de Armas and Frias 2000), *C. suffusus chiaravigli* Borelli was proposed as a junior synonym of *C. vittatus*, placing a third species in Durango.

Centruroides scorpions, which range in adult body size from about 35 to 110 mm, have slender pedipalps and metasomas ("tails"; fig. 6.1, *1*); the metasoma is especially elongated in the male. Most species have a tooth or tubercle underneath the curvature of the stinger. Many *Centruroides* species are yellowish, with or without dark stripes or mottling on the dorsum; some of the larger species (such as *C. gracilis* and *C. margaritatus*) are dark brown to blackish in coloration. The species tend to be ecologically plastic, occurring in a wide range of habitats, including desert flats and rocky slopes, arid and semiarid grasslands, scrubland, deciduous woods, and montane slopes at least up to 2500 m in elevation. Unlike most other scorpions in North America, they are active foragers and are commonly encountered climbing in vegetation. In daytime, they use surface cover, cracks and crevices, or existing burrows of other animals as retreats. Their high population densities and their climbing tendencies often place them on the walls and roofs of human habitations, and they are among the most common scorpions encountered in households.

Family Chactidae

The family Chactidae is primarily South American, but 1 genus is endemic to Baja California Sur. *Nullibrotheas* Williams is represented there by a single species, *N. allenii* (Wood). This is a small brownish, burrowing scorpion with robust pedipalps. Its closest relatives are in South America.

Family Diplocentridae

In northern Mexico, there are 2 genera of diplocentrid scorpions, *Bioculus* Stahnke and *Diplocentrus* Peters. *Bioculus*, recently revalidated as a monophyletic group (Stockwell 1992; Prendini 2000), consists of 4 species endemic to southern Baja California. *Diplocentrus* (fig. 6.1, *2*) is a heterogeneous assemblage of species widely distributed from the southern United States (southern parts of Arizona, New Mexico, and Texas) throughout Mexico and into Central America. Eight species occur in northern Mexico (table 6.2).

In diplocentrids, the pedipalp chelae are robust, often bearing strong carinae and reticulations in the male (mostly smooth and lustrous in the female), and the telson bears a pronounced cone-shaped tubercle underneath the curvature of the sting. Adults are commonly reddish brown to blackish in coloration; juveniles are yellowish. Most species are around 45–60 mm in length, but a few reach 80 mm or more in length. Diplocentrid scorpions are obligate burrowers with a more K-selected life history (i.e., low reproductive rates, long gestation periods, long time to reach maturity, longer life spans). The natural history of only a few species has been examined.

Family Iuridae

The family Iuridae consists of 2 genera in northern Mexico: *Anuroctonus* Pocock and *Hadrurus* Thorell. *Anuroctonus* is currently recognized as monotypic. The species *A. phaiodactylus* (Wood) is distributed in Arizona, California, Nevada, and Utah in the United States and into the state of Baja California. *Hadrurus* (fig. 6.1, *3*) is represented by 4 species in northern Mexico: *H. arizonensis* Ewing, *H. concolor* Stahnke, *H. hirsutus* (Wood), and *H. pinteri* Stahnke (the latter 3 endemic to the Baja California peninsula). These "giant desert hairy scorpions" are the largest scorpions in the region, with several species reaching a length of approximately 120 mm; they are also robust in body form. Despite their large size, their venom is not very potent.

Family Superstitioniidae

The Superstitioniidae Stahnke includes the genus *Superstitionia* Stahnke and the remarkable Mexican troglobites of the genera *Typhlochactas* Mitchell, *Sotanochactas* Francke, and *Alacran* Francke. *Superstitionia* (fig. 6.1, *4*), a small scorpion with a median dark stripe on the tergites, is known to occur in Baja California (both states) and Sonora. Two of the species of *Typhlochactas* are known from caves in Tamaulipas. These troglobites are small, whitish, eyeless scorpions with moderate attenuation of the appendages.

Family Vaejovidae

The Vaejovidae is the most diverse family of North American scorpions (Sissom 2000), with 147 species (14 of which are polytypic) distributed from southern Canada to Guatemala. Approximately three-fourths of the scorpion species in the northern states of Mexico are vaejovids.

Most *Paruroctonus* Werner (fig. 6.1, *5*) are psammophiles and consequently exhibit a certain degree of endemism in various sand dune systems. The genus is well known on the Baja California peninsula, where 7 species have been recorded in the northern state and 2 in Baja California Sur. One of these species and 3 more are also recorded from Sonora; all 4 species are also known from dunes of southeastern California and southwestern Arizona. The records in Sonora are based on materials collected mainly in the Puerto Peñasco area; there are apparently no published records for the extensive dunes of the Gran Desierto in the extreme northwestern corner of the state. The fauna of the rest of the northern mainland states is less well known; in fact, outside of the Baja California peninsula, only 3 species are known from a small handful of records. A fourth species, *P. boquillas* Sissom and Henson, described from Boquillas Canyon in Big Bend National Park in Texas (Sissom and Henson 1998), would be expected to occur in the sand dunes across the Rio Grande in Mexico.

Vaejovis C. L. Koch (fig. 6.1, *6*) is a large genus (71 total species), clearly not monophyletic (Sissom 1985), which is very widely distributed in North America. A little more than half of the species in this genus are recorded in the area under consideration here. The genus includes burrowing forms (e.g., the *eusthenura*, *intrepidus*, and *punctipalpi* groups) and crevice dwellers (the *mexicanus* group [*sensu lato*] and the *nitidulus* group). Preliminary phylogenetic analysis (Sissom 1985) suggests that at least several of these species groups should be elevated to genus level.

Other vaejovid genera in northern Mexico include *Pseudouroctonus* Stahnke (5 of 13 total species in North America), *Serradigitus* Stahnke (19 of 24 species; all lithophiles), *Smeringurus* Haradon (2 of 4 species; large species closely related to *Paruroctonus*, although only 1 is a true psammophile), *Syntropis* Kraepelin (containing a single large lithophilic species from the Baja California peninsula and several islands in the Gulf of California), *Vejovoidus* Stahnke (a single psammophilic species endemic to the sand dunes of the Vizcaino Desert on the Baja California peninsula), and *Paravaejovis* Williams (with 1 species endemic to Baja California Sur).

Patterns of Diversity and Endemism

Although it is biologically more proper to regard endemism in relation to true biogeographical units, rather than in relation to geopolitical boundaries, it is a fact that conservation issues (e.g., setting aside reserves for protection of species and/or habitats) are decided by governments. Consequently, the following discussion refers to both natural biogeographical areas and geopolitical states.

General Patterns

Scorpions typically do not exhibit high vagility, although some species are readily transported by humans to new areas (e.g., several *Centruroides* spp., *Isometrus maculatus*). In general, specialized burrowing forms (especially psammophiles) and montane species are more likely to exhibit restricted distributions and high levels of endemism. Psammophilic forms are restricted to loose, sandy soils, and their occurrence in a particular area can usually be predicted if sand dunes are present. As seems typical of the biota of this region, mountains harboring species restricted to higher elevations often represent isolated "islands" surrounded by inhospitable habitats.

Some large-scale geographical trends in the fauna of northern Mexico and the southwestern United States are evident. Common to both geographical areas are the Sonoran and Chihuahuan deserts. The 2 deserts more or less interdigitate in southeastern Arizona and southwestern New Mexico, and there the faunas overlap. Interestingly, in this area there is a general tendency for the Sonoran forms (e.g., *Centruroides exilicauda*, *Vaejovis spinigerus*, *Superstitionia donensis*) to inhabit rocky outcrops, and the Chihuahuan forms (*Paruroctonus gracilior*, *Vaejovis coahuilae*, *V. crassimanus*, *V. russelli*) to inhabit the low, often sandy, scrub habitats. The habitat associations to the south of Arizona and New Mexico in northern Mexico remain unknown at this time. Overall, however, the Sonoran and Chihuahuan deserts are very different in species composition, and they consequently represent 2 distinct, major areas of scorpion endemism in northern Mexico and the southwestern United States. Although there is very little overlap in the species, most of the genera are held in common and possess certain species counterparts in the 2 regions. For example, *Centruroides exilicauda* is the Sonoran counterpart of the Chihuahuan (actually, central U.S.) species *C. vittatus*, and *Vaejovis spinigerus* appears to be the Sonoran counterpart of *V. coahuilae*.

Significant endemism is expected in the mountainous areas within the deserts. In particular, the members of the *Vaejovis vorhiesi* complex seem to have responded evolutionarily to mountaintop isolation in Arizona and New Mexico. These species are generally restricted to elevations above 2000 m, commonly on steep slopes forested with pines and oaks. It is expected that related forms will be found in the northern part of the Sierra Madre Occidental and nearby isolated ranges. A very small amount of unprocessed museum material documents this expectation. The lower arid and rocky slopes over the same area are inhabited by *Serradigitus* spp. and members of the *Vaejovis nitidulus* group. New species of these groups should be found in significant numbers in northwestern Mexico. Most of the known species of *Serradigitus* are found on the Baja California peninsula and in Sonora, with a single isolated species in the Cuatrocienegas area. In the case of the *V. nitidulus* group, there are 3 species from the northeastern states, 2 from southwestern Chihuahua and southeastern Sonora, and 1 from the Baja California peninsula. The area east of the Continental Divide to Coahuila contains a great deal of suitable habitat for species of both groups.

Baja California Peninsula and the Islands in the Gulf of California

Due primarily to the works of Stanley Williams, the scorpion fauna of the Baja California peninsula and its associated islands, with 60 known species, is perhaps the most thoroughly assessed scorpion fauna in the world (Williams 1980). (Note: Williams [1980] counted *Vaejovis janssi* from Isla Socorro in the Islas Revillagigedos as part of the Baja California fauna and its associated islands. This island is technically part of the state of Colima, and *V. janssi* is omitted from the peninsular fauna in this discussion.) Baja California seems quite extraordinary compared to adjacent areas (table 6.3), but this will prove in part to be a sampling artifact. The northern states of mainland Mexico have been the focus of limited sampling with the UV technique (the fauna of the southwestern United States, in contrast, is relatively well sampled with the UV technique, but many new species and new state records await publication).

In any case, the fauna of the Baja California peninsula is very diverse, especially considering the size of its geographical area (60 species in an area consisting of approximately 140,000 km^2). Using the previously recognized 8 biogeographic provinces of the peninsula, Williams (1980) pointed out that the highest diversity was observed in the Island Province (32 species, omitting *V. janssi*) and the Volcanic Province (25 species); least diversity was seen in the Vancouveran (6 species) and Magdalena Plain provinces (10 species).

Forty-five (75%) species of scorpions are endemic to the Baja California peninsula and the islands in the Gulf of California (Williams 1980). The highest levels of endemism are observed in the Magdalena Plain (90%), Cape (87%), Volcanic (80%), and Island (76%) provinces. The Californian, Vancouveran, and Colorado Desert provinces exhibit the lowest degree of endemism (collectively, 7 of 30 species; 23%), as they share species with adjoining southern California.

Mainland Mexico

Despite our still-fragmentary knowledge of the scorpion fauna of northern mainland Mexico, some general biogeographical observations can be made. The fauna of Sonora is better known than that of the rest of the northern states, but the data derive mostly from rock-rolling. Some UV searches have been conducted in the Alamos area in the southeastern part of the state and along the coast. In particular, the mountainous interior has been poorly sampled, and this area has the greatest potential for the discovery of additional species. Most of Sonora lies within the Sonoran Desert and, consequently, shares two-thirds of its 24 known species with either Arizona or northern Baja California, or both. Several other species are shared with Sinaloa or Chihuahua, leaving only 5 species that are potential endemics (based on current distributional information).

Little is known of the fauna of Sinaloa and Durango (tables 6.2 and 6.3). For both, but especially the former, there is only a small to moderate amount of material available in museums, and much

Table 6.3. Comparison of scorpion diversities across northern Mexico and the southwestern United States.

Region	No. of Families	No. of Genera	No. of Species	No. of Species/10^5 km^2
Northern Mexico (total)	6	16	109	10.39
Baja California	4	9	32	44.68
Baja California Sur	6	12	41	56.58
Chihuahua	3	5	9	3.66
Coahuila	3	5	13	8.64
Durango	2	2	8	6.48
Nuevo León	3	3	13	19.97
Sinaloa	2	2	3	5.13
Sonora	5	7	24	13.15
Tamaulipas	4	4	10	12.56
Southwestern U.S. border states (total)	5	12	80	4.67
Arizona	4	9	35	11.85
California	4	11	49	11.92
New Mexico[a]	4	7	12	3.81
Texas	3	6	19	2.75

Numbers of species are based on existing published records, and the list does not include subspecies (see text). The data point out the great disparity in the known faunas of the states of northern Mexico.
[a]With misidentifications corrected.

of it is unstudied. For example, there are no published records for *Vaejovis* in Sinaloa, although a few Sinaloan specimens of that genus have been observed in collections (D. Sissom per obs.). As already indicated, the Sierra Madre Occidental should be rich in species of the genus *Serradigitus* and members of the *Vaejovis vorhiesi* complex. The vicinity of Durango City is home to the highly venomous species *Centruroides suffusus*. Another highly venomous species, *C. infamatus*, occurs in the southern part of the state. Eastern Durango is in the southwestern part of the Chihuahuan Desert, and some of the species known from there (*Centruroides vittatus*, *Vaejovis coahuilae* Williams, *V. crassimanus* Pocock, *V. globosus* Borelli, *V. intermedius* Borelli, and *V. waueri* [Gertsch and Soleglad]) are the same as those that occur over much of the Chihuahuan Desert to the north (i.e., southeastern Arizona, southern New Mexico, and Trans-Pecos Texas). Undoubtedly, other species common in the northern Chihuahuan Desert, such as *Paruroctonus gracilior* (Hoffmann) and *V. russelli* Williams, should also occur there. The apparent disjunction of these Durango populations is clearly not real, but rather is the result of our poor knowledge of the scorpion fauna of the states of Chihuahua and Coahuila.

In the central part of northern Mexico, occupied by the expansive Chihuahuan Desert and its associated nondesert sky islands, there is a strong tendency for species of the lowland scrub desert areas to be widely distributed. These species include *C. vittatus*, *V. coahuilae*, *V. crassimanus*, and *P. gracilior* (*C. vittatus*, an ecologically plastic species, is usually more abundant in rocky outcroppings within this area). Another common species of rocky, arid slopes is the small *Vaejovis waueri*. Possible endemics occur in biogeographic islands within the Chihuahuan Desert Region—for example, *Pseudouroctonus chicano* (Gertsch and Soleglad) and *V. vaquero* in Chihuahua and *V. minckleyi* Williams and *S. calidus* Soleglad in the Cuatrociénegas area (Williams 1968a; Gertsch and Soleglad 1972; Soleglad 1974). *Paruroctonus coahuilanus* Haradon is also currently known only from the Cuatrociénegas area (Haradon 1985), an area of outstanding interest that has been investigated for many years. A complete assessment of the scorpiofauna of Cuatrociénegas is unfinished, although it was begun by Williams (1968a); this author made significant collections at the site, but only published on the vaejovids. Once a faunal inventory is completed for Cuatrociénegas, this area will undoubtedly prove to harbor very high local diversity.

The easternmost part of northern Mexico lies in the coastal plain of the Gulf of Mexico. This plain meets the Sierra Madre Oriental in southern Nuevo León and western Tamaulipas. The coastal plain appears to be quite depauperate in terms of species diversity, with only *Centruroides vittatus*, *Diplocentrus diablo* Stockwell and Nillson, and *Vaejovis bilineatus* Pocock (the eastern counterpart of *V. waueri*) currently known (in the adjoining Rio Grande Valley in Texas, *V. crassimanus* and *V. waueri* are also found). From the foothills of the Sierra Madre Oriental westward, however, several endemic forms are encountered: *Vaejovis rossmani* Sissom, *V. sprousei* Sissom, *Diplocentrus colwelli* Sissom, *D. ferrugineus* Fritts and Sissom, and *V. rubrimanus* Sissom. The large, black *Centruroides gracilis*, a common species that ranges into Central America (and introduced to Venezuela) also gets into extreme southern Tamaulipas, as does the small, mottled *C. rileyi*.

Patterns of Local Diversity

Another way to consider diversity is to examine the number of species in small localized areas (i.e., the number of sympatric species that might occupy 1 km²). Typically, small localized areas in the Sonoran and Chihuahuan deserts harbor between 4 and 8 species, but some localities have fewer or more. For example, on the Baja California peninsula, the vicinity of El Faro in the extreme northeast has 5 species; the Santo Tomas area, 7; San Borja area, 7; Bahía de los Angeles area, 9; La Paz area, 8; Todos Santos area, 6; and the Cabo San Lucas area, 9 (Polis 1990). In the vicinity of Puerto Escondido/ Loreto there is extraordinary local diversity (by scorpion standards), with 13 sympatric species. In contrast, some locations in the Sierra de San Pedro Mártir have as few as 3 species (Polis 1990).

The islands in the Gulf of California commonly exhibit high diversity. One of the most remarkable sites is Isla Danzante just off the coast from Puerto Escondido; this small island, only 4.49 km² in size, has been documented to harbor 10 species (Williams 1980; Due 1992). Some of the other (larger) islands also have high diversity: Isla San Jose, 12 species; Isla Partida Sur, 10 species; Isla Carmen, 10 species; and Isla San Marcos, 10 species. Some of the largest islands (e.g., Isla Angel de la Guarda, Isla Cerralvo, Isla Tiburón) have fewer species—this may reflect inadequate sampling, but in the case of Angel de la Guarda, the degree of isolation may also be a contributing factor.

On the mainland, local diversity is poorly understood, with only a few tentative examples worth presenting. In Sonora, there are 3 reasonably well-sampled sites: the areas around Puerto Peñasco in the north and Alamos in the southeast are known to have 6 species, and the vicinity of Guaymas has 7 species (Williams and Hadley 1967; Haradon 1984; Sissom 1991; Sissom and Stockwell 1991; Sissom and Wheeler 1995). The Cuatrociénegas Basin in Coahuila has at least 10 species and, based on knowledge of the surrounding areas, undoubtedly more will be documented (Williams 1968a; Soleglad 1974; Haradon 1985). Comparable regions in southwest Texas may give additional insight: the Sauceda Ranch Headquarters of Big Bend Ranch State Park has 9 species, and in Big Bend National Park, the Chisos Mountains and Basin and Rio Grande Village each have 9.

Some of the sites listed above exhibit the highest known local diversities in the world, with the record apparently being 13 in the Loreto area in Baja California Sur (Polis 1990). Unfortunately, little has been published on local scorpion diversity for the rest of the world, and to generate estimates would require scouring the records sections of numerous taxonomic descriptions, revisions, and regional studies. Polis (1990), however, reported that some tropical localities (e.g., in Trinidad, Venezuela, Brazil, French Guiana, and Costa Rica) have between 3 and 7 sympatric species.

Scorpions as Subjects of Conservation Biology

Scorpions are certainly not the "warm fuzzy" animals that the average person finds so appealing, and it is doubtful that the lay community will ever be much concerned about their conservation. Despite this, some scorpion species may eventually be threatened with extinction due to habitat destruction. Of particular concern would be the troglobites; these species are known only from single caves or cave systems and are typically rare. Cave environments can suffer ill effects from pollution and development, and species might be lost in localized situations. General habitat destruction, such as the clearing of thornscrub and tropical deciduous forest habitats, probably contributes to the demise of certain scorpion species, but may promote others. Lourenço and Cloudsley-Thompson (1996) demonstrated that habitat destruction in eastern Brazil associated with urbanization led to a marked decrease in abundance of the buthid *Tityus stigmurus*, but a dramatic increase in *T. serrulatus* (a dangerous, parthenogenetic species). Given the ecological plasticity of *Centruroides* spp. and the highly venomous nature of some, habitat destruction might warrant concern in parts of Mexico.

A large problem in assessing the need for conservation is the paucity of ecological data available for scorpions. Only a few common species have been studied extensively enough to understand their population dynamics. As mentioned above, an interesting fact of scorpion life-history is that these animals tend toward K-selected characteristics (Polis and Sissom 1990). There is, of course, a gradient in these life-history characteristics, with the members of the Scorpionoidea (Diplocentridae, Scorpionidae, Ischnuridae, etc.) exhibiting the strongest K-selected traits. *Hadrurus* (Iuridae), with most of its species in northern Mexico and the southwestern United States, also appears to fit in this category. A potential concern with these species is their appearance in the pet trade. Almost all, if not all, of the scorpions sold in the pet trade are wild-caught specimens. Currently, the more exotic species (e.g., the African *Pandinus* Thorell and *Hadogenes* Kraepelin; the Asian *Heterometrus* Ehrenberg) are the most popular, but *Hadrurus* is not uncommon in pet stores. At this time, we have no data to indicate whether collecting for the pet trade has any impact on the populations of scorpions, but the volume of trade for some species is significant. Approximately 105,000 *Pandinus imperator* (Koch) were exported in 2 years time (1995–1996) from 3 small countries in western Africa (M. Haywood, pers. comm.), indicating the magnitude of trade in this particular species. Although it seems doubtful that levels of trade in *Hadrurus* will reach that of *Pandinus*, one should remember that trade in the Mexican *Brachypelma* tarantulas was judged significant enough to warrant listing of these spiders on Appendix II of CITES (containing species whose trade is to be rigorously monitored).

Scorpions also have potential use as tools for identifying areas of endemism to be considered for conservation efforts. They can and should be added to the growing number of taxa suitable for this approach to conservation biology. Scorpions exhibit a number of features that would make them useful in this regard. First, although some species are easily and widely transported by humans (e.g., *Isometrus maculatus* [De Geer], certain species of *Centruroides*), many species typically exhibit low vagility and often have restricted distributions. Second, scorpions in most habitats are readily surveyed by the ultraviolet detection technique, which renders sampling and monitoring relatively easy and inexpensive. This would be especially true of the desert areas of northern Mexico.

Based on more than a decade of research by W. R. Lourenço in tropical South America (Lourenço 2001), scorpions exhibit geographical patterns of endemism comparable to woody plants, birds, butterflies, and other organisms. The knowledge of scorpion endemism, combined with similar data for other taxa, has contributed to the recognition of 25 refugia in the Neotropics. In fact, endemism of scorpions and other indicator species has played a role in proposing several conservation areas in Guyana, French Guiana, and the tropical Andes (Lourenço 2001). Whether scorpions realize their potential to contribute to conservation efforts in northern Mexico will most likely depend on the interest and efforts of future researchers.

Conclusions

In conclusion, the scorpion fauna of Mexico is one of the richest in the world, if not the richest. It currently has more families, genera, and species of scorpions than any other country. The fauna of the Baja California peninsula and its associated islands is very well known, but additional species should be collected there in the future. In comparison, the fauna of the mainland is very poorly known, and a more complete assessment of its species diversity should be treated as a priority. In this regard, there should be 3 specific objectives: (1) generating a more accurate species list; (2) mapping out the distributions of all species; and (3) obtaining information on population biology and life-history patterns. As these goals are reached, it will be possible to determine centers of endemism and which, if any, species may potentially be threatened with extinction. Scorpions can play a significant role in shaping conservation strategies, as has already been shown in Amazonia. The low vagility and habitat specialization exhibited by many species may prove useful in helping to identify general areas of endemism.

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