

Habitat and Microhabitat Use by Scorpions in the Tucson Mountains, Pima County, Arizona

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Executive Summary

Using a black light, I conducted 1-hour visual surveys for scorpions at night among habitat and microhabitat types of the Tucson Mountains and adjacent Avra Valley, in Pima County, Arizona. Four basic topographic habitat types were selected that were thought to represent most habitats of the area, with the notion that ecotones between these areas would add little or nothing to the overall species mix typical of the selected habitats; ecotones would also add confusion to analyses. The habitat types were lower, middle, and upper bajadas, and arroyos (washes). Arroyos were generally in the middle bajada, and wide enough to have a distinctive channel that was constrained by sidewalls.

Microhabitats were physical structures near where each of the scorpions was found, including substrate type, such as soil and rocky materials (assigned by grain size), vegetation species and life forms, woodrat nests, and other features; cover objects (only when scorpions were visible from the surface); and vegetative canopy. Data were also collected on environmental parameters such as moonlight, precipitation, relative humidity, season, and so on, but these will be summarized at a later time (Phase II of the study, in 2018). This portion of the study (Phase I) was not ideal for analyzing environmental parameters, but the data will be included in Phase II, as appropriate.

There were a total of 2217 detections of at least six species during the 44 site visits. The species detected were Stripe-tailed Scorpion (*Paravaejovis spinigerus*), Yellow Scorpion (*P. confusus*), Arizona Bark Scorpion (*Centruroides sculpturatus*), Arizona Giant Hairy Scorpion (*Hadrurus arizonensis*), *Kochius* cf. *sonorae*, and a sand scorpion, presumably Stahnke's Sand Scorpion (*Paruroctonus stahnkei*). Each species was found to have differing habitat use patterns, and each habitat had its characteristic species, although there was overlap. The species in the Avra Valley were mostly silt to sand-dwelling types (psammophilic-arenicolous), including *P. stahnkei*, *H. arizonensis*, and *P. confusus*. *Centruroides sculpturatus* preferred vertical structures, so was mostly associated with the rocky upper bajada, and the rocky sidewalls and vegetation of arroyos. *Kochius sonorae* was found in the middle bajada, in both upland and arroyo situations, but was always numerically subdominant to *P. spinigerus*. *Paravaejovis spinigerus* was the most abundant and catholic species, being found in all habitat types, but was always the dominant species in the middle bajada.

Planned future portions of the study include the Phase II study in 2018 and Phase III study in 2019. Phase II will target patterns of surface activity of scorpions at three sites (one middle bajada, one arroyo, and one lower bajada). Surveys will be conducted at semi-regular intervals about a week apart (depending on my schedule), in pre-defined transects. During this phase, I should be able to tease out season patterns, and the influences of environmental parameters, as listed above. Phase III is an attempt to determine population densities, at least in a lower bajada site, given the relative ease of sampling in that habitat type. Also, the lower bajada types in sand dunes had the highest relative abundance among habitat types, and there is literature to compare results to similar habitat types elsewhere.

Introduction

Scorpions are biologically interesting animals that have survived since the Silurian Era, some 430 million years ago, yet they still remain relatively unstudied; in fact, new species are discovered every year, even in areas thought to be well explored. I started learning about scorpions back in college, about the time scorpions were crawling out of the sea, but have never had the opportunity to study these fascinating creatures until retirement. As part of a larger writing project for a book, *Venomous Animals of the American Southwest*, now called *Venomous Animals of North America (North of Mexico)* (Jones, In Review), I became familiar with the scientific literature, and even more interested in these arachnids. The American Southwest is the epicenter of U.S. scorpion diversity, and Arizona has the only species usually regarded as medically significant, the Arizona Bark Scorpion. Collectively, we know little about the natural history and resource partitioning of most species and habitat communities. To learn more about our local scorpion fauna, I decided to do an ecological comparison of scorpions near my home. These creatures are relatively unique because they glow under a black light, so can be studied by observing them on the surface at night, using a relatively non-invasive technique. They also lend themselves well to such a study because they are extremely abundant in the Tucson area.

In spring 2016, I conducted a pilot study in Tucson Mountain Park on habitat and microhabitat use by scorpions (Jones 2017). The sample size of sites and observations was not great, so the study was extended into 2017, with more sampling rigor. I expanded the area of coverage to include sites in Saguaro National Park (SNP) and Ironwood Forest National Monument (IFNM). These two years complete the first of a three phase study. Phase II will be conducted in 2018 at two previously sampled sites in Avra Valley (in IFNM) and the Tucson Mountains (in SNP). This second phase is to determine patterns of seasonal surface activity patterns and scorpions' responses to environmental factors (especially moonlight and precipitation). Phase III will be conducted in 2019. It will be a mark-recapture study to determine population density and possibly biomass; details of the third phase have yet to be determined.

This report addresses Phase I of the project, rather than specifically 2017, as the cumulative data from both years were needed to make comparisons. I am not going into great detail about results in this report because they will be incorporated into a manuscript to be submitted to a peer-reviewed scientific publication (possibly *Southwestern Naturalist* or *Euscorpius*).

Study Area

The study was conducted in the Tucson Mountains and adjacent Avra Valley, Pima County, Arizona. Survey sites in the mountains were located in Tucson Mountain Park (TMP), managed by Pima County, and SNP, Tucson Mountain District, managed by the Department of the Interior. Avra Valley sites were primarily on Arizona State Lands and IFNM, managed by the Bureau of Land Management. Most Arizona State Lands were unmarked, but those labeled as State Trust Lands were legally accessed because I had a hunting license and was always looking for records of reptiles while on these lands (hence, legally hunting reptiles). I had permits from Pima County and SNP to access their managed lands (Appendices 3 and 4). No permit was required for IFNM.

The vegetation community of the mountains is in the Arizona upland subdivision of the Sonoran Desert, and the Avra Valley sites more closely resembles the lower Colorado subdivision of the Sonoran Desert (Brown and Lowe 1994). In mountain sites, dominant overstory plant species included two species of palo verdes, velvet mesquite, ironwood, and giant saguaro cactus. Understory plants include creosote bush, triangle leaf bursage, jojoba, chainfruit cholla, staghorn cholla, Engelmann prickly pear, and numerous other cactuses, shrubs, and annuals. In the Avra Valley sites, creosote bush and/or velvet mesquite were the dominant species, although some Arizona upland plants were also present to varying degrees (e.g., the occasional saguaro).

The location of survey sites at parking areas and transect starts will be included as a separate file, as a means to “fuzz” data, so that interested public can read this report, but I do not want collectors to find my locations.

Materials and Methods

The technique I used was a visual encounter transect method (e.g., Glaudas 2013), conducted in a systematically repeatable 1-hour timed survey. During site selection, I recorded site name, habitat type, topography, and GPS coordinates (WGS 84) of the parking area. Site names were based on identifiable features that would help me remember exactly where I was, and if needed, my direction of travel. Sites were tiered to reflect four major topographic feature types that I believed would encompass the breadth of conditions of the study area:

- Lower bajada (upland)
- Middle bajada (upland)
- Upper bajada (upland)
- Arroyo (xeroriparian; there are no perennial washes in the study area)

General physical attributes of these habitat types are briefly described in Table 1. Ecotones between these types were avoided to make distinctions more clear. For example, arroyos (washes) were only selected if they contained a wide floodplain with distinct, often steep, sides; otherwise, they would be expected to harbor upland species because of the same upland characteristics. The types of habitat not surveyed included the elevationally highest upper bajadas (e.g., Goldengate, Bushmaster, and Wasson peaks), perennial river reaches (e.g., the nearby Santa Cruz River), anthropogenic structures, and disturbed areas. These habitat types were avoided for a variety of the reasons. For example, many potential sites in Avra Valley were in a disturbed condition, but the range of the nature of the disturbances was great. Some areas were converted, active agricultural fields, groundwater holding ponds, housing developments, or trash heaps, so were not physically similar enough to allow comparison. The highest points in the Tucson Mountains were primarily avoided because access was difficult and dangerous.

Table 1. Qualitative characteristics of the four habitat types surveyed.

	Lower Bajada	Middle Bajada	Upper Bajada	Arroyo (Wash)
Topography	Valley bottom; Avra Valley	Foothills of mountains	Prominent protrusive features	Washes with wide channel
Slope	Low gradient; nearly flat	Moderate gradient	High gradient	Variable
Characteristic Vegetation	Creosote bush and/or velvet mesquite; Arizona lowlands of Sonoran Desert	Desert trees and shrubs of the Arizona uplands of Sonoran Desert	Desert trees and shrubs of the Arizona uplands of Sonoran Desert	Desert trees and shrubs of the Arizona uplands of Sonoran Desert
Predominant Soil Grain Size	Fines (silts, clays, sands, and small gravel)	Mostly a mix of pebble to cobble on or mixed with gravel and pebble	Boulders, cobbles, and outcrops on gravel to cobble substrate	A mix of all of all grain sizes. Arroyo bottoms generally sand to pebble, and sides cobble to outcrop

Drainage Pattern	Sheet flooding or ill-formed, often temporary channels	Surface runoff, although may be intersected by arroyos	Surface runoff, although may be intersected by arroyos	Wide xeroriparian channel, with steep sideslopes
Notes	Some sites were in relatively hard-packed, stabilized sand dunes	This is the primary area where arroyos bisected, but these were upland sites	Arroyos here are constrained (narrow), but these were upland sites	These were usually bisecting middle bajadas or sometimes upper, but never lower

Before each survey began, I recorded some header information on the data form (App. 1), using standard entries on the code sheet (App. 2). The forms changed slightly since 2016 (Jones 2017), but the years were completely compatible. Recorded information included the site information listed above, plus observer, period, date, Julian date, habitat, moon percent, moonrise, moonset, site name, topography, previous precipitation, and visit number. Before each survey, I recorded some environmental header information, including relative humidity, dew point, barometric pressure, and wind speed. These data were gathered from the Tucson Estates weather station from Weather Underground ®.

Field gear consisted of:

- Field vest
- Heavy leather boots
- Leather gloves
- Snake gaiters
- Headlamp
- Two additional sources of white light
- Two 50-LED and one 100 LED black lights
- UV-protection glasses
- Spare batteries
- Voice recorder
- Close-focus binoculars
- Temperature gun
- Live-collection vials (not in SNP; these were actually removed before leaving the house to go to SNP)
- Water
- Cell phone
- GPS
- Field notebook

I did not start the survey until at least 30 minutes past last light, roughly 1.5 h after sundown. Just before I started the survey, I placed my parking permit on the dash and then recorded header information on starting temperature, precipitation, cloud cover, and wind. When I conducted the survey, the data form was left in the car because all subsequent data were recorded on a voice recorder and GPS.

To conduct a survey, I noted starting time, recorded the survey start in UTM's, and tracked the distance traveled. These data were recorded on the data form when I got back to my vehicle. In most cases, I followed a linear path (wash, trail, gravel road), observing, but not gravitating to the actual path. In habitats without a path, I walked toward or away from a light source or GPS coordinate. When I got to 30 minutes from the start of normal survey time, I turned around and surveyed the other side or adjacent area, heading back to my car, for a total of 60 minutes normal survey time. If I got back early to my vehicle, I merely added the few minutes by surveying adjacent, unsurveyed habitat for the required number of minutes. By "normal survey time" I am

referring to the elapsed time it took to walk and normally record encounters. If I took additional time out, say to photograph or capture an animal, I did not include that time.

With this method, I standardized a gross time-effort, and adjusted the estimated net time-effort back at the office. Per-unit effort was also determined by recording the distance traveled (usually; I sometimes lost satellite connections). On open terrain where there was no natural path, I walked for the prescribed hour, keeping the light on my car (or GPS) as a center point, being careful not to walk over the same area (thereby avoiding the double-counting of observations).

As I zigged and zagged, I recorded information on all scorpions encountered that I saw with a black light. Along a path, I limited observations to within 5 m of my path, so that I wasn't spending time glancing off in the distance. Scorpions that were farther away are less detectable and less identifiable, so search effort was visually constrained. In easily accessible areas (especially uplands and wash bottoms or bottom side slopes), I would walk right up to the scorpion. In other situations (e.g., when the animal was farther up the side slope), I had to identify and record information from up to 5 m away.

When a scorpion was detected, I identified it to species, whenever possible. If not readily identifiable under a black light, I switched to white light (usually my headlamp) and observed the animal through binoculars. The binoculars I used (Pentax Papilio ® 8.5 X 21) are an extreme close-up model that will focus from 0.5 m to infinity. Even small scorpions can usually be identified to species. I also recorded substrate temperature when a scorpion was detected, using an infrared temperature gun, by pointing at the scorpion, generally from a distance of about 0.5-2 m. The following microhabitat features were also recorded into the voice recorder:

- **Microhabitat:** this is primarily the subcategory of physical features. For example, in a wash, it could be the bottom, island, side slope, or a vertical wall.
- **Substrate:** this is what the scorpion was physically on, such as sand, gravel, or vegetation.
- **Cover:** this is what was directly over the scorpion, shielding it from exposure above, such as a cobble or in a crevice or under a prickly pear pad. I did not turn any cover objects, so some could not be identified, and those completely under cover went undetected.
- **Vegetation:** this was the species or lifeform of plant that formed a canopy over where the scorpion was. If the plant's canopy was not directly over the scorpion (i.e., "shading from above"), it was considered exposed.
- **Surface temperature:** recorded to the nearest 0.1 degree Fahrenheit, as recorded by a temperature gun. I usually aimed directly at the scorpion with the infrared aiming beam, at a range close enough to include the scorpion in the cone of reading (when possible). I will not analyze temperature data until Phase II.

Before I began the study, I obtained a potential species list of the scorpions of the Tucson Mountains from Kari McWest (pers. comm.), a researcher with extensive experience in scorpion identification, both locally and nationally. As per the Pima County permit stipulations, I collected some vouchers on county land, but not NPS land. The animals were collected alive in small plastic jars. They were either coaxed into the jars or I picked them up while wearing leather gloves. At home, specimens were prepared by immersion in super-hot water. This was humane because it killed the specimen immediately, and retained a good "pose" for fluid preservation. They were fixed in a mixture of formalin and ethanol, and then stored in ethanol, per Polis (1990). Each specimen had accompanying collection data for cataloging later museum disposition. At the time of this writing, specimens have not been delivered to an accredited museum, as at least some are being retained for study, although I did contact the University of Arizona's Entomological Museum and mentioned I would ultimately deposit specimens there. Right now museum staff members are still in the process of moving, and all of the fluid arachnid specimens were still in boxes (same status in 2016); none had been catalogued or databased, so I do not know what species are deposited there. No specimens were collected or handled in SNP.

Per-unit effort figures were detection rates for one hour survey time, minus any time spent doing something besides recording an encounter, such as taking time out to photograph or collect a specimen. I did determine net-encounter rates by subtracting an estimated 20 seconds of processing time (average approximate time to record an observation into the voice recorder) per detection, from 60 minutes (the standard gross time), but these are not used in this report. Another per-unit effort measure (also not used in this report) was number of detections per distance walked, as recorded on the GPS. In other words, in an upland situation, or along a wide wash, more ground could be covered by walking than along a steep trail or in complex habitats.

I knew from previous experience that an important safety precaution was to wear protection against rattlesnakes, as on two separate occasions before this study I encountered rattlesnakes while surveying for scorpions (and only one of them rattled). In 2017, I was very close to trodding on a Tiger Rattlesnake in a wash, and a Western Diamond-backed Rattlesnake was encountered on another walk. Wearing protective gear is a common practice among scorpion researchers (see Graham Lab online resource). Rattlesnakes don't glow under a black light. I wore rattlesnake gaiters with heavy leather boots as a safety precaution during every survey, and required others that joined me to follow suit. Leather gloves were also used when I needed to collect vouchers. I have never been stung by a scorpion, but I also had an asthma inhaler with me and an epinephrine kit in my car or vest, just in case there was sensitization to a scorpion sting from cross-sensitivity (more on this in Jones, In Review). There was telephone coverage in the study area, so I always carried a mobile phone with me as an added safety precaution.

Moonlight seemed to be an important factor in surface activity. I did not attempt to calibrate detectability in moonlight in 2016, although I feel that scorpions were detectable in full moonlight, as the distance surveyed is within the 5 m. In 2017 when most of the survey effort was conducted, I only surveyed during $\frac{1}{4}$ moon or less, or when the moon was hidden (e.g., by cloud cover or in canyons). Although other environmental parameters were recorded (e.g., wind, cloud cover, precipitation, previous precipitation), these are not going to be analyzed; these metrics are better suited for Phase II of the study, and indeed, were part of the decision to move on to a Phase II.

Terminology for scorpion anatomy is pretty well standardized and the basic topology is illustrated in Figs. 2. Detailed anatomical structures (e.g., trichobothrial patterns) are not necessary to illustrate for this report.

Data were entered, proofed, and analyzed using SPSS/PASW software (18.0 version), primarily looking at summary statistics and non-parametric comparisons by ANOVA. However, for this report, to keep it simple, I mostly discuss detection rates, frequencies, central tendencies, and percentages by types and species. More detailed analyses will be used for the subsequent publication in a peer-reviewed scientific journal.

Results

A total of 44 site-visits were conducted; there were eleven 1-hour surveys conducted at each of the four habitat types. A total of 2217 scorpions were detected. Of these, 253 (11.4%) were considered unidentifiable to species level in the field; the remaining were identified. Those not identified to species included individuals with questionable characters, those that were difficult to see well, or were small instars. Some of the unidentifiable specimens were collected, and later identified, or are awaiting identification. A total of six species were identified (Table 2). These include, in order of overall detections: *Paravaejovis spinigerus* (Stripe-tailed Scorpion, $n = 667$); *Centruroides sculpturatus* (Arizona Bark Scorpion, $n = 548$); *Hadrurus arizonensis* (Arizona Giant Hairy Scorpion, $n = 319$); *Paravaejovis confusus* (Yellow Scorpion, probably a species complex, $n = 251$); *Paruroctonus stahnkei* (presumably; see species summary discussion, $n = 128$), and *Kochius* cf. *sonorae* (probably an undescribed species, $n = 37$). These are shown in Figures 4-9. One specimen was identified as an additional species in the original dataset: Superstition Mountains Scorpion, *Superstitionia donensis*; however, that record was questionable and it could not be collected from SNP to identify at the lab (I had conjunctivitis at the time, and my visual acuity was poor for tiny scorpions), so it was converted to "unidentified," pending confirmation of that species in the study area.

Table 2 also shows differences among habitat use by species. Two species (*C. sculpturatus* and *K. sonora*) were never found in the lower bajada, while *P. stahnkei* was only found in that habitat type. It is possible, however, that *P. stahnkei* could have been counted as “unidentified” in other habitats, given its proclivity to disappearing into its burrow when approached or it detects movement. *Hadrurus arizonensis* and *P. confusus* were primarily lowland species that decreased in abundance as elevation and topography increased. Arizona Bark Scorpions were often the dominant species in upper bajadas and arroyos. *Paravaejovis spinigerus* was the most catholic species, being found in all habitat types, although it was uncommon in the lower bajada. It was the most common species in the middle bajada, and second to *C. sculpturatus* in the upper bajada and arroyos. *Kochius* was the least-encountered species, accounting for only 1.9% of the detections. It was found primarily in the middle bajadas and arroyos.

Total detections per site-visit, including unidentified, ranged from 5-101 scorpions per gross-hour ($\bar{x} = 50.4 \pm 23.9$ SD). Total detections between habitat types varied, but was not significant (Kruskal-Wallis, $P = 0.14$, both raw and net time effort-adjusted numbers). The lowest number of detections by habitat type was in the middle bajada ($n = 436$ detections, $\bar{x} = 39.6$ detections/site-visit), followed by upper bajada ($n = 492$, $\bar{x} = 44.7$). The highest was lower bajada ($n = 672$, $\bar{x} = 61.1$), followed by arroyo ($n = 617$, $\bar{x} = 56.1$). Sites with >90 detections were in three lower bajada sites and one arroyo site. The highest-detection lower bajada sites were all in the sand dune portion of IFNM. Relative abundance between habitat types should be viewed with caution, anyway, in case there were seasonal or environmental covariates influencing surface activity—part of the reason to address those factors in Phase II.

The number of taxa by site ranged from 2-5 with these central tendencies in increasing diversity (upper bajada, $\bar{x} = 2.55$ species/habitat type ± 0.82 SD; arroyo, $\bar{x} = 3.00 \pm 0.89$; lower bajada, $\bar{x} = 3.36 \pm 0.67$; middle bajada, $\bar{x} = 3.45 \pm 0.67$), which was significant (Kruskal-Wallis, $P = 0.04$). The overall diversity averaged 3.09 scorpion species per site ± 0.13 SE. Putting diversity and abundance (although not significant) together, the middle bajada had the highest diversity, but the lowest relative abundance, suggesting the intermediate elevations with moderate topography favored high species richness, but did not appear to be optimal habitat for an assemblage of species. Arroyos were usually in the middle bajada, but had the highest numbers of a few adapted species (notably *C. sculpturatus* and *P. spinigerus*). The dunes of IFNM had the highest relative abundance, primarily of the three fine substrate-adapted species (*P. confusus*, *H. arizonensis*, and *P. stahnkei*).

Physical microhabitat features were those where the scorpion was found in the immediate vicinity of detection. These were the features that they were on, in, amongst, or under. Of course, they were always found on some sort of substrate, and if completely under something, went undetected. Scorpions were detected on a variety of substrates, including rocky features that ranged in grain size from fine soils to rock outcrops or cliff faces, and vegetative features, such as shrubs and trees. Most of the detections of identifiable species were on rocky substrates (89.8%). Of these, 38% were on fine soils (silt, clay, and sand), 40% were on small substrates (gravel and pebble), 7% were on medium substrates (cobble), and 15% were on coarse substrates (boulder to solid rock). All species had preferences for grain size classes. Of those using rocky substrates, the species largely dwelling on fines included *P. stahnkei* (100% of their rocky-substrate detections), *H. arizonensis* (76%), and *P. confusus* (68%). Those seemingly preferring small rock substrates were *K. sonora* (73%) and *P. spinigerus* (70%). *Centruroides sculpturatus* dominated the medium and large rocky substrates (75%, cumulatively). Vegetation was only used as a substrate 8.5% of the time by all species combined.

I found it surprising that 41.6% of all scorpion detections were of individuals out in the open, having no direct cover or plant canopy. This may be due, in part to surveys in 2017 being limited to low-moonshine nights, based on findings of 2016 (see Fig. 3). There was much more sampling in 2017, and several nights in 2016 were dark, so the influence of moonshine, shade, canopy, and cover is better addressed in Phase II. Anyway, using 2016-2017 combined data, the most likely species to be in the open were *K. sonora* (65%), *P. confusus* (57%), and *H. arizonensis* (53%). The latter is surprising, given that it is a burrowing species, although it appears to be a facultative burrower, or at least is prone to nightly excursions to forage. *Paruroctonus stahnkei* is more of an obligate burrower, and was only found in the open on 16% of the time. The other two species were not uncommon in the open (*C. sculpturatus*, 33%, and *P. spinigerus*, 41%), but more likely to be found under some sort of cover or canopy.

When used, cover was usually in the form of rock, vegetation, or burrows or crevices. Rocky structures only accounted for 7% of the cover objects, while vegetation accounted for 38%. They were also found using woodrat nests, but 32/33 of the detections (97%) were *C. sculpturatus*. Burrows were usually used by clay and sand dwelling species. Burrows were sometimes made by the scorpion themselves, or they were using those made by small mammals or other animals. *Paruroctonus stahnkei* was usually found in burrows (84% of their detections), presumably of their construct, in a typical pose with their claws and forelegs poised in front of them at the entrance. If I got too close or moved too quickly, they would slip back into the burrow, so I had to use my binoculars to confirm the shape of the scorpion at the entrance of the burrow (not too hard in open ground). *Hadrurus arizonensis* was found in burrows 17.6% of the time. The use of rock crevices was a microhabitat feature used almost exclusively by *C. sculpturatus* (17.4% of their detections). However, this is an errant species that was frequently on the move, so were often seen on the surface of rocks, where they were foraging or seeking mates, but they also visited crevices and were under overhangs and between boulders. Undoubtedly, they rested and sought refuge within crevices or under cover objects.

Vegetation was used as cover in 38% of all detections. In general, this meant the scorpion was close to the base of a live plant, or there was plant material over it (e.g., twig or prickly pear pad). When live vegetation was used for both substrate and cover, it meant the animal was on the bole or among the branches or leaves. All but *P. stahnkei* were found in vegetation on occasion, but it was rare except for Arizona Bark Scorpions (15% of all their detections was up and in live vegetation) and somewhat, Stripe-tails (5% of their detections). The life form of plants used by *C. sculpturatus* included shrubs (52% of their in-live plant detections), trees (34%), cactus (13%), and herbs/grasses (1%). Ironwoods and palo verdes were the most commonly used trees, and these are frequently encountered in arroyos and upper bajadas, where bark scorpions predominate. They were rarely seen in velvet mesquites (2%), presumably because this tree, while common in the study area, is usually in the middle to lower bajada, and less common in upper bajada and arroyos. Stripe-tails were seen in triangle-leaf bursage in 9/27 (33%) of live-shrub detections; this was also the most common shrub used as cover and canopy by *P. spinigerus*. Unfortunately, I do not have use vs. availability data, so cannot say if they use bursage above its availability, but I think it is worth looking into. All six *P. confusus* uses of plant foliage were in creosote bush, a species that can occur in a near-monoculture in sandy habitats of the lower bajada.

There were many species of plants that were scored as canopy, and 43% of all detections were under the canopy of one or more species of plants. Said canopy plants did not necessarily provide moon shade during 2016, but they usually did, and shade was also provided by arroyo walls. In Phase II, the use of canopy (and arroyo walls) for moon shade will be teased out.

Another aspect of physical microhabitat analysis was to determine which part of arroyos scorpions were found in. Arroyos are more complex habitat types than the other categories. The microhabitat variables recorded were lumped for analysis into three categories: channel (the channel bottom + islands in the channel), sideslope (a sloping, rather than more-or less vertical sideslope, and upland-like conditions); and vertical slope (more-or less vertical or steep slope of bedrock + outcrops). Other categories were left out of the comparison, but were rare, anyway. All species were detected in arroyos, except *P. stankei*. Of these, only *C. sculpturatus* (n = 291) and *P. spinigerus* (n = 179) were abundant. *Kochius sonora* used both arroyos and middle bajadas, but were uncommon, with only 13 detections in arroyos. However, additional data were gleaned when I collected specimens outside of normal surveys, and the findings were consistent with the 13 *Kochius* records. This species appears to use channel, sidewalls, and lower parts of vertical walls almost equally (i.e., never well up the wall like *C. sculpturatus*). *Hadrurus* (n = 33) was uncommon in arroyos, except that at one site, they were relatively abundant in the extensive sandy areas of the wash (which included channel, islands, and terraces). Yellow Scorpions were rare in washes, and 6/7 detections was in the channels, where fines and gravels accumulate. Stripe-tails were found in all microhabitats that were not steep: channel (34%), sideslope (63%); vertical slope (3%). Vertical slopes, however, accounted for 45% of the arroyo detections by bark scorpions, which were also common on sideslopes (44%), but not channel (11%). It should be noted that when on sideslopes, *C. sculpturatus* often selected a more vertical feature embedded in the slope, such as a tree (roots, bole, and foliage) boulder, or woodrat nest. Another note is that many scorpions appeared to be near the interface of the channel and the sideslope or vertical wall (especially *P. spinigerus*, but sometimes *C.*

sculpturatus), but my categories did not account for that. I often recorded in comments how high up the wall the scorpion was from the channel intersection (or up in a tree or shrub), and suffice to say *C. sculpturatus* could be near the base to several meters up, and everywhere in between.

A more detailed analysis of habitat and microhabitat use will be teased out in a subsequent paper to be submitted to a peer-reviewed scientific journal (e.g., some environmental attributes will be taken into account, although that is largely the point of the Phase II study). Also, in Phase II, I will continue to record some of the same variables, and add new ones (e.g., if in arroyo, add a code for interface of wall and channel, which seemed to be a hotspot).

Table 2. Distribution of detections and percentages of detections by habitat type. Species and habitat (HAB) codes are given in [Appendix X](#). Unidentified scorpions are not included in this table (see text).

Species * HAB Crosstabulation							
			HAB				Total
			LO	MI	UP	WA	
Species	CESC	Count	0	22	233	293	548
		% within Species	.0%	4.0%	42.5%	53.5%	100.0%
		% within HAB	.0%	5.8%	52.8%	55.2%	28.1%
		% of Total	.0%	1.1%	11.9%	15.0%	28.1%
	HAAR	Count	197	88	3	31	319
		% within Species	61.8%	27.6%	.9%	9.7%	100.0%
		% within HAB	32.8%	23.3%	.7%	5.8%	16.4%
		% of Total	10.1%	4.5%	.2%	1.6%	16.4%
	KOSO	Count	0	15	9	13	37
		% within Species	.0%	40.5%	24.3%	35.1%	100.0%
		% within HAB	.0%	4.0%	2.0%	2.4%	1.9%
		% of Total	.0%	.8%	.5%	.7%	1.9%
	PACO	Count	212	32	0	7	251
		% within Species	84.5%	12.7%	.0%	2.8%	100.0%
		% within HAB	35.3%	8.5%	.0%	1.3%	12.9%
		% of Total	10.9%	1.6%	.0%	.4%	12.9%
	PARU	Count	128	0	0	0	128
		% within Species	100.0%	.0%	.0%	.0%	100.0%
		% within HAB	21.3%	.0%	.0%	.0%	6.6%
		% of Total	6.6%	.0%	.0%	.0%	6.6%
	PASP	Count	63	221	196	187	667
		% within Species	9.4%	33.1%	29.4%	28.0%	100.0%
		% within HAB	10.5%	58.5%	44.4%	35.2%	34.2%
		% of Total	3.2%	11.3%	10.1%	9.6%	34.2%
	Total	Count	600	378	441	531	1950
		% within Species	30.8%	19.4%	22.6%	27.2%	100.0%
		% within HAB	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	30.8%	19.4%	22.6%	27.2%	100.0%

Summary by Species and Habitat

Stripe-tailed Scorpion (*Paravaejovis spinigerus*). Identification: Under a black light, it was usually observed in an ambush pose with the metasoma over its mesosoma. It has a reasonably thick metasoma and moderate chelae. However, in most instances I was most comfortable making a species assignment after illuminating in white light and (sometimes) observing through the binoculars (e.g., large *P. spinigerus* and small *H. arizonensis* were similar from a distance under a UV light). Under a white light, the dark, contrasting stripes on the underside of the metasoma were most diagnostic, although other species have lighter colored ridges. Also, it typically had mottling on the carapace. Dark-phase individuals were sometimes encountered, a situation that Kari McWest (pers. comm.) alerted me to. **Habitat/Microhabitat.** Stripe-tails were the most generalized species, as they were found in most study sites, often in abundance. They were most often observed in middle bajadas and along the edges of washes, but not on rock faces. They were usually seen on gravelly to pebbly substrates. They were often under the moonshade of vegetation (from 2016 data). It seemed to have some loose association with triangle-leaf bursage, often being under or up in it. However, my study was not designed to determine availability of vegetation, so I cannot say with certainty it wasn't just near bursage because that is often the most common shrub in the middle bajada, where this was the only commonly encountered scorpion. I think it warrants further investigation, but that is not in my immediate plans.

Yellow Scorpion (*P. confusus*). Identification: Under a black light, this species typically had a narrow, rectangular, and sometimes striated appearance, due to the separation of sclerites. Under a white light, they were pale yellow to straw colored, without markings. They were superficially similar to Arizona Bark Scorpions when around the same size, but never had stripes, the extremely narrow claws, and did not usually coil to metasoma to the side. They were also similar to light-colored *P. spinigerus*, but had a daintier appearance and a more rectangular body. **Habitat/Microhabitat.** They were particularly abundant in areas of fine substrates, as in the flats and dunes of the lower bajada. In these areas they were frequently seen under twigs at the base of creosotes and other plants, although sometimes they were out in the open. They sometimes sought refuge into a sandy burrow when disturbed. They were occasionally encountered in the middle bajadas and arroyos. In arroyos, they were most often encountered in the channel bottom where fines accumulate.

Arizona Bark Scorpion (*Centruroides sculpturatus*). Identification. Under a black light, large individuals were unmistakable, as they were easily recognized by the slender chelae and metasoma (especially the males, which have a tail even longer than females). When these scorpions were in an ambush pose, they often had the tail coiled to the side, and resting on the substrate, rather than behind them or over the metasoma. Under a white light, they were straw-colored to yellowish or sometimes orangish. Some individuals had a pair of dorsal stripes. Behaviorally, they differed from the other species because they were more frequently seen actively prowling than other species (*Centruroides* are known as “errant” taxa because of this behavior).

Habitat/Microhabitat. Bark scorpions were most abundant in upper bajadas and in washes. They seemed to require vertical structures, being largely absent from flat upland and arroyo bottom habitats. They had much more proclivity for climbing in shrubs and trees than other species, sometimes several meters above the ground. They were commonly found along rocky uplands climbing on boulders, walls (e.g., supports of steps, culverts, and trails), as well as vegetation. In washes, they were less common in composite rock sidewalls than bedrock walls, except where there were cavities and overhangs. They were invariably common in bedrock sidewalls, provided there were crevices. They were also abundant in less vertical arroyo sidewalls having trees, where they were often found among the exposed roots, boles, or in foliage. They were also found in woodrat nests—sometimes up to several individuals—which were often situated in overhangs and amongst boulders and vegetation in arroyo walls. Although my study did not target use of woodrat nests, I do not hesitate to say there is a loose association, and a more targeted study of scorpion use of woodrat nests is warranted. This could be done as an ad hoc study if I am not busy enough on Phase II or III.

Arizona Giant Hairy Scorpion (*Hadrurus arizonensis*). Identification. Large individuals were unmistakable under a black light, due to size alone. These are the largest and heaviest scorpions in the study area, the Southwest, and the U.S. I usually had to use a white light to differentiate large *P. spinigerus* from smaller *H. arizonensis*. Under white light, the distinctive yellowish area of the head between the eyes was diagnostic, although *P. stahnkei* were similarly marked, but lacked the dense setae on the telson, also present in very small *Hadrurus*. **Habitat/Microhabitat.** Arizona Giant Hairy Scorpions were most abundant in the lower bajadas, and sometimes the bottoms or edges of certain arroyos, where fine sediments accumulated. They were often seen in the entrances of burrows, or near their burrows, but were more common away from burrows.

Stahnke's Sand Scorpion (*Paruroctonus stahnkei*). Identification. According to Ayrey (website: <http://azscorpion.com/>), there are (at least) eleven species of this genus in Arizona, and the species in my study area is assumed to be *P. stahnkei*, based on distribution; this species is found in Maricopa and Pima counties, and has been reported from Tucson. Also, it matches the general description of Gertsch and Soleglad (1966) and the REVSYS online description (<http://www.vaejovidae.com/Paruroctonus%20stahnkei.htm>). However, I have not closely examined voucher specimens under a microscope yet. Under a black light, I typically only saw the pincers, in front of the head, in the entrance of the burrow. They have a distinctive, characteristic pose at the entrance, with the pincers and forelegs showing in the entrance of their burrow, which is not much wider than they are. To me, the gestalt of the pose looks like a tiny lobster filling the entrance. No other scorpions in burrows look the same. When approached too closely or too quickly, they invariably backed down into the burrow. On occasion, they were out in the open. This seemed to be more frequent later in the season, so Phase II of the project should help shed light on surface activity observations though the active season. This is a small, tan species that has a darker body than anterior head, with dark median eyes, so is superficially similar to *Hadrurus* instars, but it lacks the dense setae on the telson and is not as heavily built. The chelae are light colored, robust, and ridged. **Habitat/Microhabitat.** As best I can tell, these only occurred in the lower bajada habitat types in the Avra Valley. They were present in some, but not all, sandy/silty habitats. When present, they *seemed* to be aggregated in specific areas, and absent from others. For example, when walking my transect routes, I would have areas where none would be seen, then happen upon “colonies” of several individuals clustered to specific areas. Some sites that looked perfect for this species had none, and I am not sure why there was such a spotty distribution. In Phase II and/or III, I hope to get a better handle on possible aggregation. Right now, my circumstantial evidence is that I often have several individuals clustered on the data form, then interrupted by blocks when they are not detected.

***Kochius cf. sonora*. Identification.** This species is easily recognizable under a black light due its small size and proportions, particularly the diagnostic, heavy chelae. It is moderately dark, uniform brown with darker “fingers.” **Habitat/Microhabitat.** In 2016, I only found this species in xeroriparian colluvium, usually associated with gravel and pebbles. In 2017, I continued to find some in that microhabitat, but they were also found in the middle (especially) and upper bajadas. They were always numerically subdominant to other species, particularly *P. spinigerus*. The seeming rarity of this species (I have yet to find a “hotspot,” with more than 4 individuals), needs an explanation. My reigning theory is that it competes or is preyed upon the larger *P. spinigerus*, which share the same habitat and microhabitat features, but this needs to be tested. Although it has been suggested *Kochius* is a burrower, I saw no indication of this, as it was usually out in the open; on the occasions it sought refuge, it was never into a burrow, so this suggests it is saxicolous. It was never found in areas of extensive fine substrates (i.e., lower bajada and sandy terraces, islands, and channels in arroyos).

Future Direction

Year three of this study will change focus from the Phase I inventory and habitat use study to the Phase II surface activity patterns study. In Phase II, I will survey scorpions throughout the active season (approximately April through October, depending on nighttime temperatures). In order to do this, I will only monitor three sites, so that I can usually obtain weekly visits to each site. This should show patterns in activity

through the spring, summer, and fall seasons; the dry period vs. the monsoon; effects of moonlight; and effects of precipitation and other environmental factors. One site will be in the Avra Valley, a lower bajada, in IFNM. This area is characterized by fines (particularly silt, clay, and sand) in a dune habitat stabilized by creosote bush. The second area is tentatively planned to be a middle bajada and adjacent arroyo transect in SNPW. When surveying this area, I will walk the middle bajada, then drop down into the arroyo. Between these three sites, most or all of the species can be targeted. In each site, I will establish a walking transect covering a specific area so that each visit is repeatable and detections will be standardized to detections/unit area (e.g., m² or per linear transect distance).

I had considered also doing mark-recapture study at the Avra Valley site to determine a density and some other attributes, but that would complicate survey efforts, so that is tentatively planned as Phase III during 2019.

Acknowledgments

I thank Tom Anton, Rich Ayrey, Andy Baldwin, Kerry Baldwin, Chris Brown, Chris Brown (a different one!), Bill Commins, Margarethe Brummermann, R.C. Clark, Victor Fet, Julia Fonseca, Matthew Graham, Gene Hall, Janet Jones, Kari McWest, Brian Powell, Iris Rodden, Warren Savary, Michael Sologlad, Adam Springer, and Don Swann.

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Appendices

Scorpion Survey Data Form, Tucson Mountains P____ of ____

Obs:	Period:	Date:	Julian:
Start T:	Temp:	Hab:	Moon%:
Finish T:	Temp:	Moonrise:	Moonset:
Elaps T:	RH:	DewP:	Press:
Site:	Topo:	GPS:	GPS:
Precip:	P Precip:	Wind:	Cloud:
Visit:	Distance:	Area:	

Last update, LLC Jones, 12 November 2016

Notes _____

[illegible]

Appendix 2. Code Sheet for scorpion survey data form. Updated for 2017 season, with latest entries just being additional plant codes.

Code Sheet, Tucson Mts Scorpion Study. *Last update Aug 2017*

Header

Obs(erver): initials and last name

Period: 1 = pre-monsoon, 2 = durante monsoon, 3 = post-monsoon, 4 = “winter”

Date: DD-Month-YYYY

Julian: Julian date

Start T(ime): 24 h clock, to minute

Temp(eration): Degrees F at start of survey, to whole number

Hab(itat): WA(sh)/arroyo, LB (lower bajada), MI (middle bajada), UB (upper bajada)

Moon%: Percent of moon shining, to nearest one

Finish T(ime): 24 h clock, to minute

Temp(eration): Degrees F at end of survey, to whole number

Moonrise: Time of moonrise at unobscured horizon (e.g., Weather Underground)

Moonset: Time of moonset at unobscured horizon

Elaps(ed) T(ime): number of minutes between start and finish; default = 60

RH: Relative Humidity at nearest station (e.g., Tucson Estates)

DewP(oint): in degrees F, to nearest degree

Pres(ure): From nearest station at start of survey with up or down arrow for rising, falling

Site: Name of site

GPS: coordinates in meters UTM, WGS 84

Precip(itation): During survey. 0 = None, 1 = sprinkle, 2 = light rain, 3 = heavy rain, 4 = showers

P(revious) Precip(itation): Same as Precip

Wind: mph, to nearest one

Cloud: Percent cover to nearest 10%, but 1 = trace

Visit: Sequential visit number (usually fill out later)

Distance: Distance surveyed, from GPS, in m.

Area: Area covered in m², if known.

Comments: On general information of site and conditions.

Detection Data

SPP: = species 4-letter code, 2 of genus, 2 of species, Q = questionable (see below)

Micro(habitat): 1 = wash bottom; 2 = side slope; 3 = upland; 4 = vertical face; 5 = outcrop etc. 6 = artificial wall; 7 = trail; 8 = road; 9 = island

Subs(strate): What the scorpion is on. 1 = fines (clay, silt, siltstone); 2 = sand;; 3 = gravel; 4 = pebble; 5 = cobble; 6 = boulder; 7 = bedrock/caliche/cliff; 8 = vegetation; 9 = small wood debris; 10 = large wood debris; 11 = roots; 12 = woodrat nest; 13 on tree; 14 = composite; 15 = wall; 20 = hole/burrow; 21 = crevice; 22 = leaf litter; 23 = biotic crust; 24 = human debris

Cover: What is over the scorpion same as Subs, except that 0 = none

Veg(etation): species of nearby vegetation, or lifeform (e.g., shrub).

s(ubstrate)TEMP(eration): temperature reading in °F, using temperature gun of scorp area, to nearest 0.1

Moon(light): 0 = no moonlight present at detection time. 1 = in moonlight; 2 = in shadow of moonlight. No entry, no moonlight visible.

Notes: Anything that helps to explain this entry. General notes are above in the header.

Four-letter Codes

SPP (add as needed)

CESE = *Centruroides sculpturatus*
HAAR = *Hadrurus arizonensis*
KOSO = *Kochius c.f. sonora*
PACO = *Paravaejovis confusus*
PASP = *Paravaejovis spinigerus*
PARU = *Paruroctonus* sp., till I confirm (assume *P. stahnkei*)
SERR = *Serradigitus* sp.
SUDO = *Superstitionia donensis*
UNID = Unidentified

Veg (for canopy and/or substrate-cover)

ACAC = Acacia
BRIT = Brittlebush
CACT = Cactus
COUR = *Coursetia glandulosa*
CREO = Creosote
FAIR = Fairyduster
GRAS = Grass
HACK = Hackberry
HERB = herbaceous growth
IRON = Ironwood
JOJO = Jojoba
LIMB = Limberbush (= FLEX)
MESQ = Mesquite
MOSS = Moss
NONE = No plant canopy
OCOT = Ocotillo
PALO = Paloverde
PRIC = Prickly pear
RAGW = Ragweed
RATA = White ratany
SAGU = Saguaro
SHRU = Shrub
SNAG = Unidentified standing dead
STAG = Staghorn cholla
TBCH = Teddy bear cholla
TRBU = Triangle-leaf bursage
TREE = Unidentified tree

Appendix 3. Permit from Pima County to conduct this survey, 2017. The 2016 form was attached with that report.



**NATURAL RESOURCES,
PARKS AND RECREATION DEPARTMENT**

3500 West River Road Tucson, Arizona 85741 (520) 724-5216 Fax: (520) 724-5000

Scientific Research and Collecting Permit

1. **Proposed Activity:** Scorpion habitat use in Tucson Mountain Park
2. **Location(s):** NRPR Natural Resource Parks:
Tucson Mountain Park
3. **Authorized Time Frame:**

Start date: March 2, 2017

End date: December 31, 2017

4. **Primary Investigator(s):**
Larry Jones
Southwest Zoologists League
Tucson, AZ
gilaman@comcast.net
520 730-5254

The permittee OR the agents MUST be present at all activities conducted under authority of this permit and must have a copy of the permit and stipulations present at all times while conducting activities.

5. **Authorized Agents:**
TBD

6. **Project Stipulations:**

All research and collecting authorized by Pima County Natural Resources, Parks and Recreation must be conducted consistent with local, state and federal law. The primary investigator is responsible for having in their possession all necessary permits and authorizations. The primary investigator is required to have current and valid permits covering collection, handling, transportation and disposition of plants and animals. This permit only covers those lands administered by Pima County Natural Resources, Parks and Recreation.

Appendix 4. Permit from Saguaro National Park (first page) to conduct this survey, 2017.

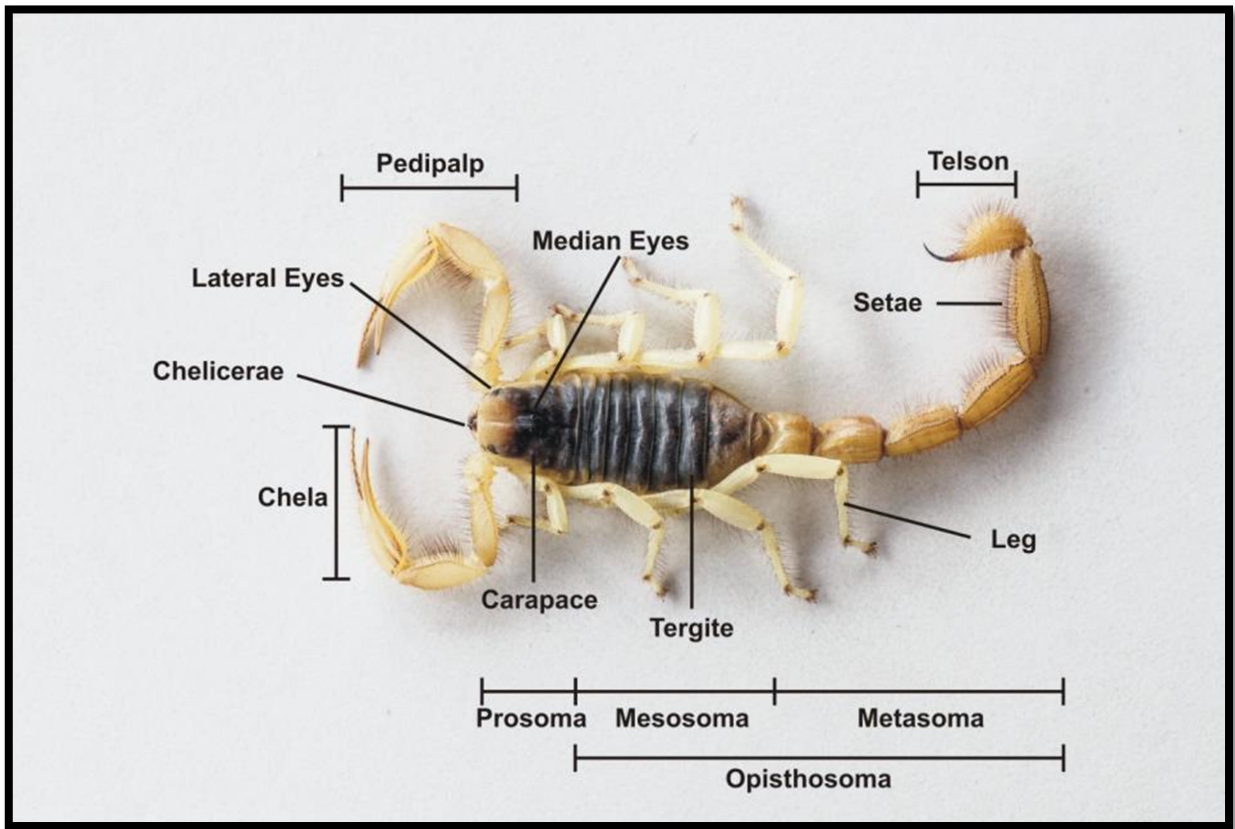
 SCIENTIFIC RESEARCH AND COLLECTING PERMIT Grants permission in accordance with the attached general and special conditions United States Department of the Interior National Park Service Saguaro	Study#: SAGU-00147 Permit#: SAGU-2017-SCI-0005 Start Date: Apr 10, 2017 Expiration Date: Oct 31, 2017 Coop Agreement#: Optional Park Code:
Name of principal investigator: Name: Lawrence Jones Phone: 520-730-5254 Email: gilaman@comcast.net	
Name of institution represented: Southwest Zoologists' League	
Co-Investigators:	
Study Title: Habitat and Microhabitat Use by Scorpions in the Tucson Mountains	
Purpose of study: This study is partly an inventory of scorpions in the Tucson Mountains, Pima County, Arizona. This will involve surveying in various areas around the mountains, in Saguaro National Park, Tucson Mountain Park, and adjacent Avra Valley. In addition to an inventory that will give information on geographic distribution, I will quantify habitat and microhabitat use by scorpions, as well as the environmental parameters allowing surface activity. This is the second year of the study; the first year (2016) was essentially a pilot study conducted in Tucson Mountain Park (Pima County managed).	
Subject/Discipline: Invertebrates (Insects, Other)	
Locations authorized: I will supply a list of specific GPS coordinates (i.e., where I will park, which is usually very close to the start of the survey) after some reconnoiter, but below are the areas on a map that can be retrieved. The access roads will be Hohokam Rd, Golden Gate Rd, Picture Rocks Rd, and Kinney Rd. I may also survey likely habitat for the newly discovered species in Saguaro NP East, accessed by Cactus Forest Drive East. Trails will be accessed from Sus Picnic area, Signal Hill, Hugh Norris trailhead, Ez-Kim-In-Zin, Sendero-Esperanza trailhead, King Canyon trailhead, Dobe Wash, Contzen Pass trailhead, and Desert Discovery trail.	
Transportation method to research site(s): I will drive my Jeep Wrangler (red, 4 door, AZ license "Lagarto") or Ford Fiesta (red hatchback, license 2AH1819) to park at the places mentioned above, to do surveys on foot. In most cases, the start of the survey will be very near the parking area, although I might have to walk to reach appropriate habitat. For example, when parked at Hugh Norris trailhead, I will have to walk on the trail to reach the steep, upper bajada--i.e., survey starts when the trail climbs.	
Collection of the following specimens or materials, quantities, and any limitations on collecting:	
Name of repository for specimens or sample materials if applicable:	
Specific conditions or restrictions (also see attached conditions): PARK SPECIFIC CONDITIONS For SCIENTIFIC RESEARCH AND COLLECTING PERMITS at Saguaro National Park United States Department of the Interior - National Park Service These conditions apply to all research and collecting permits at Saguaro National Park Mandatory 1. All research and collecting will be conducted, as much as possible, away from roads, trails, and developed areas, and out of sight of park visitors unless such localities are specified in the permit. The collecting shall be done in such a manner as not to attract attention or to cause damage to the environment. 2. The names of all assistants and descriptions and license plate numbers of all vehicles must be given to park staff before any research is started. The park will provide a vehicle permit, which must be placed in the windshield of each participating vehicle for identification purposes. 3. The area of the park where research will be conducted shall be marked on 7.5 minute topographic maps, or other maps as necessary,	

Photo Pages

Figure 1. Arizona Giant Hairy Scorpion in defensive stance, under a black light, IFNM. The aculeus is not broken off—it just doesn't glow under a black light.



Figure 2. Scorpion anatomy, dorsal aspect. Shown is *H. arizonensis*. From Jones (In Review).



Scorpion anatomy, ventral aspect. Shown is *H. arizonensis*. From Jones (In Review).

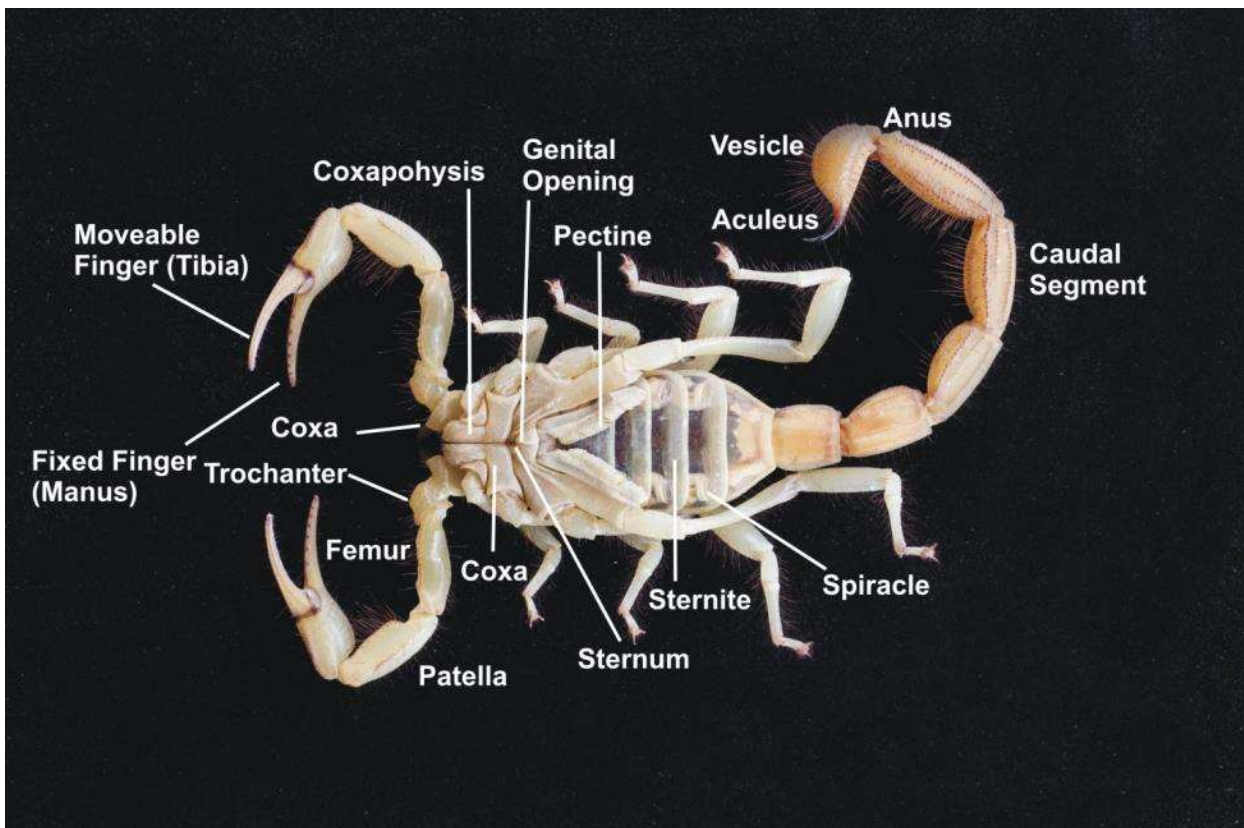


Figure 3. Pie chart showing moonlight variables for all scorpion encounters in 2016. Often scorpions in moonlight were covered at least by twigs. In 2017, surveys were only done during no to low moon evenings.



Figure 4. Stripe-tailed Scorpion, *Paravaejovis spinigerus*, during day and under black light. This species was found in most habitats and was the numerically dominant species in middle bajadas and some other sites (e.g., along arroyo sideslopes that weren't too steep).



Figure 5. Yellow Scorpion, *P. confusus*. Shown on a rock for contrast, but usually occurring on silt, sand, and gravel in lower bajadas and arroyo bottoms.



Figure 6. Arizona Bark Scorpion, *Centruroides sculpturatus*. Note the extremely narrow pincers and long “tail” curled by its side when resting or in ambush pose. This is a male, which has a longer “tail” than females. They were most abundant in areas of vertical structure, such as steep walls and trees of arroyos and upper bajadas.



Figure 7. Arizona Giant Hairy Scorpion, *Hadrurus arizonensis*, in defensive pose. It is usually associated with silt, sand, and gravel, near or away from its burrow. These microhabitats are mostly found in the lower bajada and some arroyo bottoms where fines accumulate, as in terraces and islands in the channel.



Figure 8. A silt and sand-dwelling, burrowing scorpion, *Paruroctonus stahnkei* (presumed), from Avra Valley. This species was only observed in the lower bajada, and only at some sites, even when seemingly good habitat was in other nearby sites. They also appeared to be aggregated on the landscape.



Figure 9. *Kochius* cf. *sonorae*. Often associated with gravel to pebbles in the middle bajada, be they uplands or colluvial side slopes of arroyos. Note the stout, ridged chelae with dark fingers—diagnostic for identification of this small species.



Figure 10. Example of a lower bajada habitat type, Avra Valley. Note dominance of creosote bush, gentle slope, fine grains, and sheet flooding pattern. Substrate here is dominated by gravel, with patches of fines.



Figure 11. A lower bajada site in sand dunes in IFNM in the Avra Valley. This site and the others in this area had the highest detection rate in the Phase I study, with sand-dwelling species dominating the scorpion fauna, including *H. arizonensis*, *P. confusus*, and *P. stahnkei*. The Tucson Mountains are in the background. This site will probably be used in both Phase II and III.



Figure 12. Example of middle bajada upland transect trail of Arizona upland habitat. *Paravaejovis spinigerus* was usually the dominant species and it was one of two habitat types typically harboring *K. sonorae*. The Tucson Mountains in the background represent upper bajada.



Figure 13. Example of an upper bajada habitat type, with Arizona upland vegetation. The Brown Mountain trail was the transect. *Centruroides sculpturatus* and *P. spinigerus* dominated the scorpion fauna on these steep hillsides. The Arizona Bark Scorpion was usually on rock faces and boulders.



Another example of an upper bajada in SNP. This and similar sites were difficult to survey due to the steep, uneven terrain and the lack of a bisecting trail. There will be no upper bajada sites in Phase II because arroyos are easier and safer to access and have the same general species mix, due to similar features.



Figure 14. Example of arroyo habitat type. Note the wide channel and steep side slopes. Arizona Bark Scorpions were usually abundant on rock faces such as these. There were relatively few scorpions of any type in the wide, open channels. Most congregated on the side slopes or near the channel interface.



Arroyo habitat type. This is a variously wide wash with generally steep sides and abundant terraces, islands, and thick vegetation, making it a diverse habitat harboring several sympatric species.



Arroyo habitat type, showing a colluvial sideslope. *Pasravaejovis spinigerus* and *K. sonora* were found in these situations, although *C. sculpturatus* was abundant where there was thick and heavy vegetation.



Arroyo sidewall. The side slopes are low, but have structure with vertical tree surfaces and nooks and crannies for *C. sculpturatus*.



This section of an arroyo had steep, exposed bedrock that harbored large numbers of *C. sculpturatus*—and Africanized Honey Bees—which chased me out of the site!



Figure 15. The caliche-composite walls of an arroyo provide overhangs used by woodrats to protect their nests. Up to five *C. sculpturatus* were observed in or on a single nest, as well as in the cracks and overhangs in the walls; they were often seen hanging upside-down from the ceiling of the overhang. In general, composite walls were not as productive as bedrock walls for bark scorpions, and colluvial slopes less so.



Figure 16. Middle bajada in Sus Picnic area. This trail above the Bajada Wash will probably to be used in Phase II.



Figure 17. Bajada Wash, near Sus Picnic area, probably to be used as the arroyo site in Phase II. It can be done on the same night as the middle bajada trail above it.

