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## EFFECT OF CRYPTOBIOTIC CRUST TYPE ON MICROARTHROPOD ASSEMBLAGES IN PIÑON-JUNIPER WOODLAND IN CENTRAL NEW MEXICO

S.L. Brantley<sup>1</sup> and U.L. Shepherd<sup>2</sup>

**ABSTRACT.**—Cryptobiotic crusts make up an important part of the ground cover in arid systems. Along with their roles of retarding soil erosion and enhancing soil fertility, crusts may also be supporting local and regional arthropod biodiversity. We inventoried arthropod species in mossy, lichen, and mixed (lichen and mossy) cryptobiotic crusts at 2 sites in central New Mexico piñon-juniper habitat. We collected 240 crust samples and used a heptane flotation technique to extract the microarthropods. We found 39 species of microarthropods and small macroarthropods, with significantly fewer species on lichen. Species richness was higher in March than in August, but diversity was lower because of dominance by the mite *Neonanorcheptes* sp. Mean area differed significantly for different crust types, but arthropod species richness did not follow the pattern of more species on crusts with larger area. Arthropod species may be influencing such processes as nutrient cycling; therefore, the crust/arthropod interaction may be critical to aridland health.

*Key words:* microarthropods, cryptobiotic crusts, community structure, biodiversity.

Cryptobiotic crust communities are ecologically important in arid systems worldwide, particularly in retarding soil erosion; increasing soil fertility, water infiltration, and nitrogen fixation; and interacting with vascular plant germination (Evans and Johansen 1999). These crusts are highly threatened in the western United States, where they can make up as much as 70% of soil cover (Belnap and Lange 2001).

Crusts may provide important resources to a large segment of unexplored aridland soil biota. Soils have been described as the “poor man’s rainforest” (Giller 1996) due to the large range of taxa and their abundance. Soil animals are major regulators of decomposition and mineralization (Santos et al. 1981). Several studies in the Arctic and Antarctic have shown a number of species associated with the extensive moss and lichen cover present in those cold, arid habitats (Block 1979, Behan and Hill 1980, Booth and Usher 1986, Block and Convey 1995). Much less is known about microarthropods of crusts in warm, arid environments.

Shepherd et al. (2002) demonstrated that there is a specific community of arthropods associated with bryophytic (mossy) crusts in piñon-juniper habitat. Our present objective is to expand on that work through an inventory

of arthropod species richness and species identities in 3 crust types (bryophytic, lichen, and mixed) at 2 sites in central New Mexico. We wished to determine whether arthropods utilize the less structurally developed lichen crust and, if so, whether those species represent the same or a different fauna from that found in 1999. In addition, we wondered whether mixed patches contain species found on either moss or lichen or whether some other pattern might emerge. Based on structure and crust species composition, we proposed that different crusts might provide different resources, resulting in different faunal associations. Quite possibly the seasonal preference we reported in 1999 was an anomaly or perhaps arthropods using either lichen or mixed patches are more abundant in summer than in winter.

To investigate these relationships, we explored 2 questions: (1) Are there differences in microarthropod richness, abundance, diversity, or species composition on different crust types? and (2) Do these factors differ by season? We predicted that species composition would differ by crust type, with mixed crusts having communities composed of species found on both mossy and lichen. We also predicted that richness, abundance, and diversity would be greatest on mixed patches because these were

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composed of both mossy and lichen crusts. And finally, we predicted, based on results from our previous work (Shepherd et al. 2002), that richness, abundance, and diversity would be greatest in March.

#### STUDY AREA

We chose 2 study sites in the Cibola National Forest near Placitas, New Mexico, approximately 30 km north of Albuquerque. Both sites are located at the base of the Sandia Mountains. They are approximately 3 km apart and are located in different arroyo drainages. Lower Arroyo (LA; N35°17'13.8", W106°30'4.3") is at an elevation of approximately 1775 m and the dominant tree species is *Juniperus monosperma* (Engelmann) Sargent. Other vegetation at this site consists of grasses, several *Opuntia* species, and numerous shrubs including *Fallugia paradoxa* (D. Don) Endlicher ex Torrey (Apache plume) and *Ericameria* (formerly *Chrysothamnus nauseosus* (Pallas ex Pursh Nesson and Baird) (chamisa or rabbitbrush). Piedra Lisa (PL; N35°16'43.0", W106°28'40.0") is at an elevation of approximately 1950 m. Both *Pinus edulis* Engelmann and *J. monosperma* occur at this site. Other vegetation is similar to that of Lower Arroyo except that there are more shrubs and relatively little grass cover.

Each site contained a variety of crust types, including bryophyte-dominant, lichen-dominant, and mixed patches. At each site crusts were most abundant along the arroyo bed on rocky or pebbly soil. We chose crust types according to their gross morphological traits (i.e., differences obvious to the eye). These included 1 type of bryophytic crust, 1 lichenized crust, and patches that contained the 2 types together.

#### METHODS

##### Field Collections

We sampled in March and August 2000. Based on 1999 results, in which almost no microarthropods were found prior to precipitation in either March or August (Shepherd et al. 2002), we sampled from 36 to 72 hours after a precipitation event and between 0700 and 1200. We used the same protocol reported in that earlier paper (i.e., we took one sample of approximately 8 cm<sup>3</sup> from patches with an area ≤30 cm<sup>2</sup>, two samples from patches 31–300

cm<sup>2</sup>, three from patches 301–3000 cm<sup>2</sup>, etc., representing an additional sample for each tenfold increase in area). Where samples came from on a patch was determined randomly and in the case of very small patches the entire crust was taken. Because individual crust patches were often quite small, we hoped to reduce damage by avoiding collection of larger samples. We collected samples from 20 patches of each crust type for each collection period at each site for a total of 240 patches. Sampling for both studies occurred during La Niña (drought) years. All crust samples were preserved in 70% ethanol until ready for processing.

##### Extraction Technique

We harvested animals on return to the lab using a modified version of the heptane flotation method (Shepherd et al. 2002), originally described by Walter et al. (1987) and Kethley (1991). We chose this extraction method because, unlike funnel methods that depend on animals being alive (MacFadyen 1962, Edwards and Fletcher 1971), flotation methods recover microarthropods from soil and litter samples whether they are dead or alive by capturing them in a nonpolar solvent through which the sample has passed. Comparative studies show the flotation method is ideally suited to harvesting suites of desert-adapted arthropods that, due to their life history traits, may not respond to moisture gradients set up by funnel techniques (Walter et al. 1987, Andre et al. 2002). Results of our earlier work support the finding that this method is well suited to work in highly mineralized soils. Samples were scanned at 90X magnification and slide mounts were made for further identification using a phase contrast compound microscope.

##### Data Analysis

Since we could not standardize crust patch size across types when we sampled, and since such differences might account for differences in species richness or abundance, we thought it important to determine whether patch size differed significantly by crust type. Because the data were highly skewed, we used a Kruskal-Wallis (PROC RANK and PROC ANOVA, SAS Institute, Inc. 1999) in which the dependent variable was patch size and the main effects were site and crust type. Patch size differed among crust types, with mixed patches significantly larger than either lichen or mossy

( $df = 2$ ,  $P = 0.001$ ), but not among sites ( $df = 2$ ,  $P = 0.96$ ).

To test whether there were differences in richness across crust types, we first asked whether there were differences in richness by site. We constructed a  $2 \times 3$  contingency table for each crust type for chi square analysis and ran a Bonferroni adjustment ( $P = 0.02$ ) of these results. Since there were no differences among sites (lichen,  $n = 79$ ,  $df = 2$ ,  $\chi^2 = 1.6$ ,  $P > 0.5$ ; mossy,  $n = 81$ ,  $df = 2$ ,  $\chi^2 = 0.7$ ,  $P > 0.75$ ; mixed  $n = 80$ ,  $df = 2$ ,  $\chi^2 = 0.2$ ,  $P > 0.9$ ), we pooled site data for further richness comparisons. We then used ANOVA in which the main effects were season and crust type.

To address differences in abundance among species (and because so many species were rare; see Appendix), we asked whether the 4 most abundant varied among site, crust type, and season by means of individual Kruskal-Wallis tests (PROC RANK and PROC ANOVA, SAS Institute, Inc. 1999). In each case abundance was the dependent variable, while site, crust type, season, and their interactions were the independent variables. Because these tests were based on abundance rather than richness, site was included as a main effect.

For both the richness and abundance analyses, the independent variables were treated as fixed. Significance tests were constructed using type I sums of squares.

We examined the relationship between diversity and season and crust type using the Shannon index ( $H'$ ) and Simpson's index of dominance ( $D$ ) and the Hill numbers for species richness ( $N_0$ ), numbers of abundant species ( $N_1$ ), and numbers of very abundant species ( $N_2$ ; Ludwig and Reynolds 1988).

To determine whether there were differences in species composition, we used the Jaccard similarity index ( $C_j$ ; Magurran 1988) on pooled richness data (i.e., with sites combined) to compare crust types in each season. Six macroarthropod taxa (Appendix) were omitted from this analysis because we considered them to be incidental users of crusts. These included lygaeids (seed bugs), mirids (plant bugs), and cixiids (planthoppers), and a geometrid caterpillar (all of which are generally found on living vascular plants), as well as a beetle larva and chalcidoid wasp. Most of these species occurred as single individuals in our sampling.

To test how well species composition and abundance separated the 3 crust types and the

2 seasons, we used the nonparametric Multi-Response Permutation Procedures (MRPP), which is similar to discriminant analysis used for parametric data (McCune and Mefford 1999). The value of  $\delta$  (delta, the weighted mean within-group distance) was used to calculate the test statistic  $T$ , which described the separation between groups and was associated with a corresponding  $P$  value. The test also provided a measure of within-group heterogeneity ( $A$ ):  $A = 0$  when within-group heterogeneity equals that expected by chance;  $A < 0$  when within-group heterogeneity is greater than that expected by chance. For our data  $A = 0.034$  for crust types in March and 0.015 in August.

## RESULTS

We found arthropods in patches of all crust types: 34 species in 3 classes and 7 orders. Mites and collembolans were the dominant groups with 21 and 5 species, respectively. In addition, we found diplurans, pseudoscorpions, thrips, tardigrades, and at least 2 species of nematodes (Appendix). Species richness was significantly greater on mossy and mixed (Fig. 1;  $F = 7.80$ ,  $P = 0.02$ ) than on lichen, and in March (32) than in August (20; Fig. 1;  $F = 10.31$ ,  $P = 0.02$ ). There was no interaction effect for crust type by season.

Although we collected few individuals of most species, the 4 most abundant (the endostigmatid mite *Neonanorches* sp., the oribatid mite *Zygoribatula* sp., and 2 collembolans [*Cryptopygus ambus* and *Tullbergia iowensis*]) had more than 100 individuals each. Both *Neonanorches* sp. (Fig. 2a;  $F = 21.95$ ,  $P = 0.0001$ ) and *C. ambus* (Fig. 2c;  $F = 2.85$ ,  $P = 0.06$ ) preferred mossy crusts. *Zygoribatula* sp. (Fig. 2b;  $F = 14.94$ ,  $P = 0.0001$ ) was more abundant at Lower Arroyo (LA) than at Piedra Lisa (PL), while both collembolans were more abundant at PL (*C. ambus*:  $F = 45.5$ ,  $P = 0.0001$ ; *T. iowensis*:  $F = 6.83$ ,  $P = 0.0001$ ; Figs. 2c-d). All 4 species were more abundant in March (Fig. 2).

There were significant interaction effects among the 3 factors for all 4 species. For *Neonanorches* sp. season  $\times$  crust type, site  $\times$  crust type and season  $\times$  site  $\times$  crust type were significant ( $P < 0.0001$  for all; Fig. 2a). For *Zygoribatula* sp. only site  $\times$  season  $\times$  crust type was significant ( $P = 0.04$ ; Fig. 2b). For *C.*

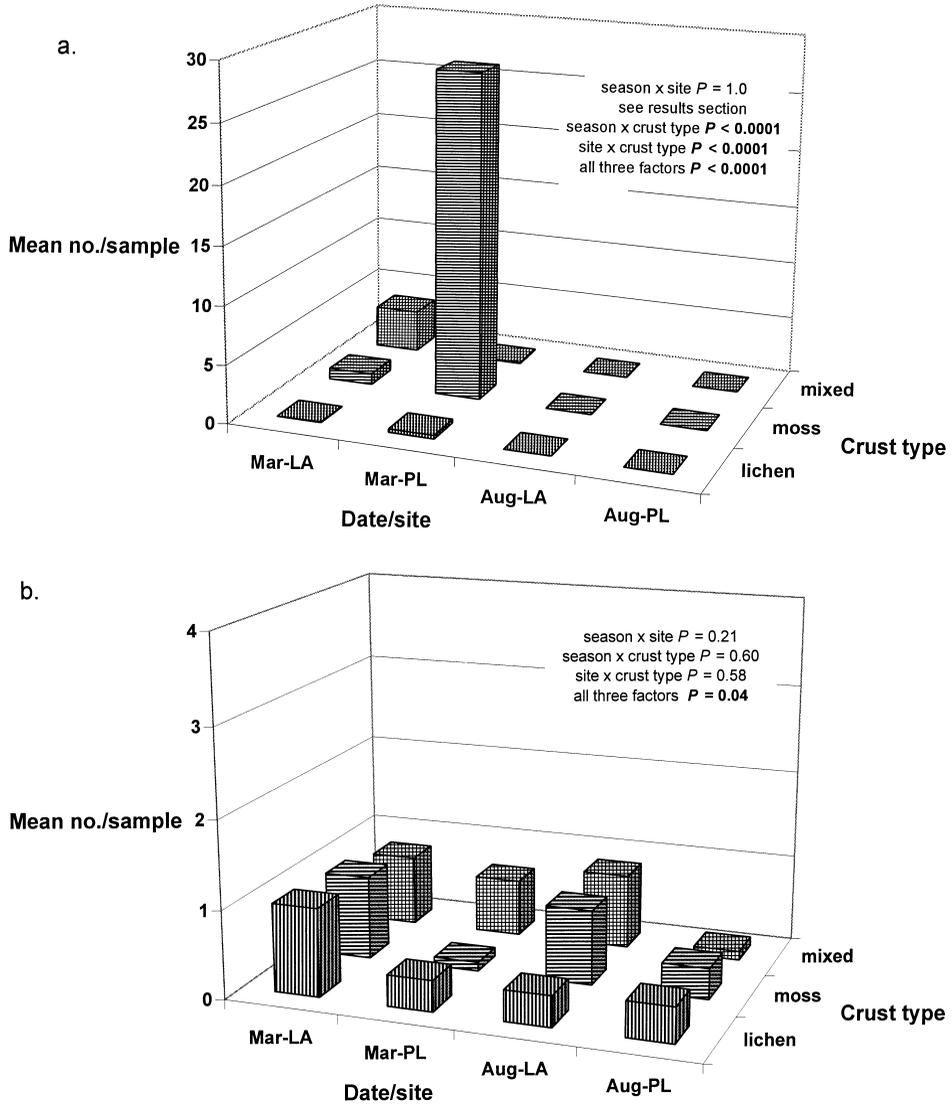


Fig. 1. Total arthropod species richness by crust type and season. Letters indicate significant differences. For crust type, mossy and lichen differed from each other ( $P = 0.02$ ), while mixed did not differ from either mossy or lichen. Richness from the 2 seasons differed significantly ( $P = 0.02$ ). There was no significant interaction effect of crust type and season on richness.

*ambus* season  $\times$  site, season  $\times$  crust type, site  $\times$  crust type, and season  $\times$  site  $\times$  crust type were significant ( $P = 0.0001, 0.08, 0.02, 0.04$ , respectively; Fig. 2c). For *T. iowensis* season  $\times$  site was significant ( $P < 0.0001$ ; Fig. 2d).

Numbers of other arthropods were too low to show clear patterns, but it is worth noting where several species were found. The mesostigmatid mite, *Hypoaspis* (*Geolaelaps*) sp., the prostigmatids *Penthaleus* sp. and *Raphigna-*

*thus* sp., the acarid, and the pseudoscorpion occurred only on moss. *Speleorchestes* sp. (an endeostigmatid) showed a weak preference for mosses, and the prostigmatid *Tydeus* sp. also preferred mossy crusts. *Eupodes* sp. was more common on mixed crusts. It is unclear whether these species were herbivorous or predaceous.

Although collembolans have been reported to feed on lichens more than mosses (Lawrey 1987), at our sites *C. ambus*, *T. iowensis*, and

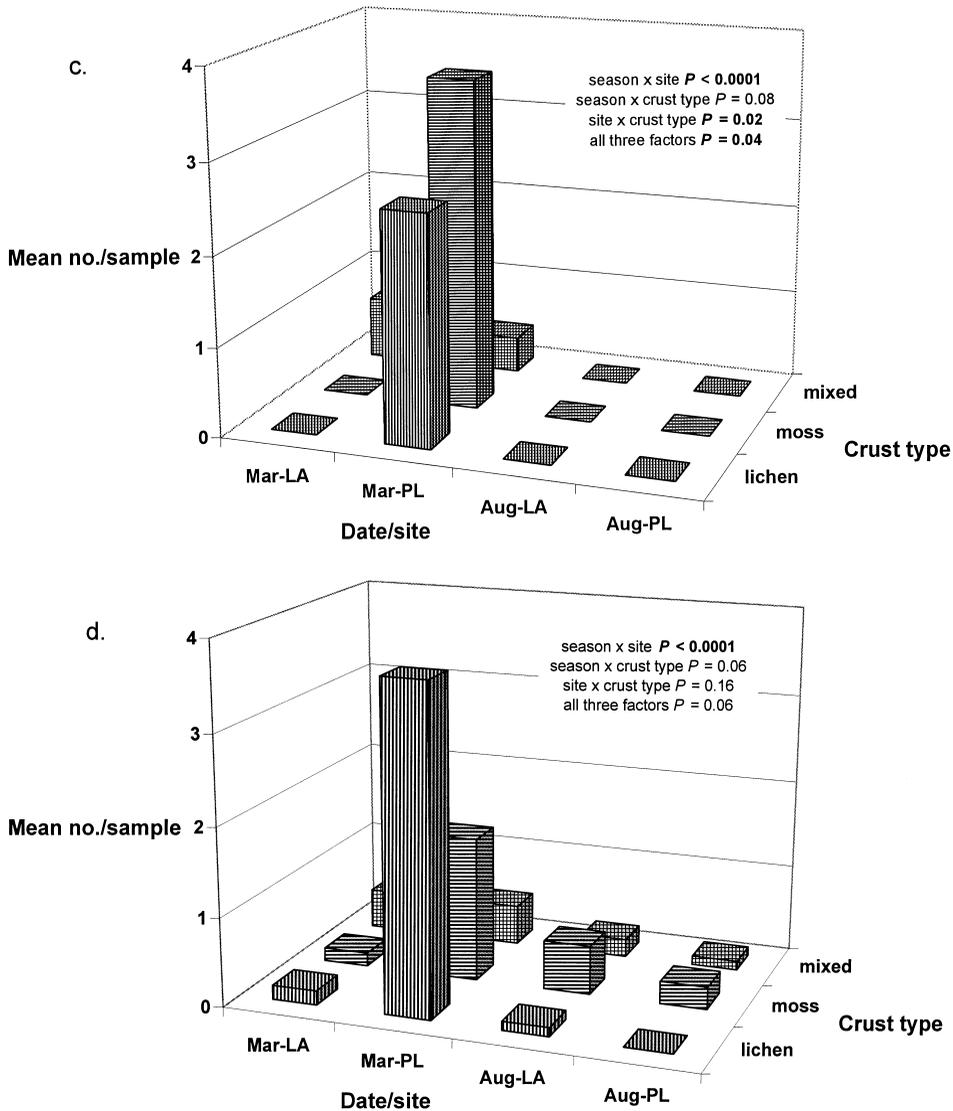


Fig. 1. Continued.

*Bourletiella* sp. were rather evenly distributed among crust types (Appendix). The entomobryid was found only on lichen.

Overall abundance (total number of arthropods) was highest on moss, due largely to its preference by *Neonanorches* sp. mites. Diversity was lower in March (Table 1), due to the dominance of *Neonanorches* sp. (687 individuals out of a total of 1402 in March). In August more species were classified as common (Hill  $N_1$ ) or very common (Hill  $N_2$ ).

Similarities in species composition among crust types were moderate when sites and sea-

sons were ignored: lichen and mossy = 61%, mossy and mixed = 62%, lichen and mixed = 57%. We found the least similarity between mossy and mixed patches in August (44%) and between mixed patches in March and August (44%; when richness was high, abundance was high and there was a strong dominance of *Neonanorches* sp.; Table 2). The greatest similarity was found between mossy and mixed in August (74%) followed by mixed and lichen in August (64%; when richness and abundance were low and no species was dominant). The MRPP test showed that differences in species

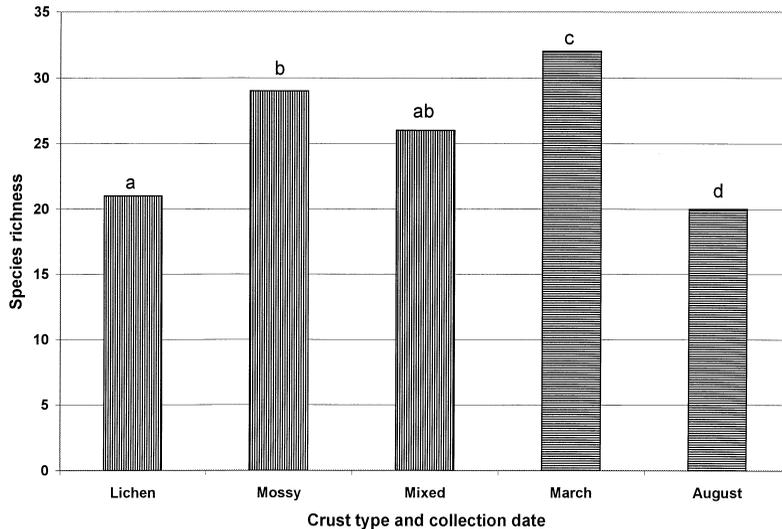


Fig. 2. Mean number of individuals/sample collected for the 4 most abundant arthropod species by site, season, and crust type: (a) *Neonanocheilus* sp., (b) *Zygoribatula* sp., (c) *C. ambus*, (d) *T. iowensis*. Note that the mean abundance of *Neonanocheilus* sp. was greater than for the other 3 species, so that the y-axis is not on the same scale. *P*-values of the interaction effects are shown on the graphs (significant results marked with \*). *P*-values of main effects are given in the Results section.

composition and abundance were great enough to significantly separate the 3 crust types in March ( $T = -3.865$ ,  $P = 0.001$ ), but not in August ( $T = -1.585$ ,  $P = 0.070$ ).

#### DISCUSSION

We predicted that microarthropod richness and abundance would be greater on mixed crust than on mossy or lichen because of greater structural and taxonomic heterogeneity, but we found that richness did not differ significantly between mixed and mossy, or between mixed and lichen. Richness was significantly lower on lichen than on mossy (Fig. 1). Abundance of 2 of the 4 dominant species was also greater on mossy crusts than on mixed (Fig. 2). Because crust components vary widely (including cyanobacteria, fungi, algae, bryophytes), we expected microarthropod species composition to vary by crust type. Similarities among season/crust type combinations were indeed low to moderate (44%–64%), with a high similarity (74%) found only between mossy crust in August and mixed crust in August (Table 2).

The current study expanded on work conducted in 1999 (Shepherd et al. 2002), when we sampled mossy crusts 7 times throughout

the year. In the present study we collected only in March and August, and only after precipitation (the periods of peak activity in 1999), but we increased crust types to include lichen patches and patches with both moss and lichen (mixed). In 1999 we found 20 mite and 4 springtail species on mossy crust; in 2000 we collected 17 and 3, respectively. From the lichen crusts we added an entomobryid collembolan, and from mixed crusts we added the nanorcheistid mite *Bimichaelia* sp. and a hypogasturid collembolan. Because the numbers of individuals collected were low, we do not assume that these added taxa are specialists on lichen or mixed crusts. Species that had not been collected from mossy crust in 1999 were *Raphignathus* sp. and *Bryobia* sp. (Appendix). Missing from the collections in 2000 were 5 rare species found in 1999: *Dactyloscirus* sp., *Erythraeus* sp., *Passalozetes* sp., *Pygmephorus* sp., and a galumnid oribatid.

In our earlier work we compared our list of microarthropod species found on crusts with species lists for microarthropod communities recorded at other locations across our region (cited in Shepherd et al. 2002). All of those studies dealt with mites and collembolans found in soil and/or on litter; none mentioned the

Table 1. Diversity indices (Shannon  $H'$ , Simpson's dominance  $D$ , and Hill numbers  $N_0$  (species richness),  $N_1$  (number of abundant species),  $N_2$  (number of very abundant species) for arthropod species by season and crust type (lichen, mossy, mixed).

	Crust type			Collection month	
	Lichen	Mossy	Mixed	March	August
$H'$	2.43	1.45	2.20	1.73	2.35
$D$	0.13	0.64	0.11	0.27	0.14
$N_0$	21	29	26	32	20
$N_1$	11.36	4.20	9.03	5.64	10.49
$N_2$	7.69	1.56	9.09	3.70	7.14

Table 2. Jaccard similarity index ( $C_j$ ) of arthropod species composition by season and crust type (lichen, mossy, mixed).

	Lichen		Mossy		Mixed	
	Mar	Aug	Mar	Aug	Mar	Aug
Lichen – Mar	1.00	0.52	0.61	0.54	0.60	0.62
Lichen – Aug		1.00	0.44	0.63	0.55	0.64
Mossy – Mar			1.00	0.52	0.57	0.52
Mossy – Aug				1.00	0.50	0.74
Mixed – Mar					1.00	0.44
Mixed – Aug						1.00

presence of crusts. We found very low similarity between our species lists and those recorded elsewhere in the region (Chihuahuan Desert 19%, shortgrass prairie 11%). Even with the addition of lichen and mixed crusts, and an added year of sampling, the similarities we previously reported between our sites and adjoining biomes did not change substantially.

We note that there is some difficulty in comparing our abundance or density results with others in the literature because our questions were about the microarthropods using crusts, not the soil habitat in general. We collected smaller samples than those customarily reported in the literature, which often include cores to depths of 10 cm or more, as well as the soil surface. The small samples may have also contributed to the low numbers of individuals we collected and may mean there are several rare species still undetected. Because of the long recovery time of crusts, we felt this technique was warranted (Belnap and Lange 2001).

Nonetheless, differences in species identities reflect real differences in community structure between our habitat and these others in the region. Overlap was too low to be accounted for only by sampling differences. In addition, the extraction method used to harvest these

species has been demonstrated to have recovery rates of 78% of known soil microarthropods in desert systems from a single flotation cycle (Walter et al. 1987). Recovery of specific groups was shown to be 39% for prostigmatids, 84% for oribatids, 89% for collembolans, 95% for astigmatids, and 69% for mesostigmatids. Based on these recovery values we conclude that mesostigmatids and astigmatids occur only rarely on crusts in our area and that the richness and abundance of prostigmatids are probably underrepresented.

For our 4 most abundant species, several interactions among habitat factors were of interest (Fig. 2). *Neonanorches* sp. was the most abundant species we collected (Appendix) and yet was the most restricted by site (PL), season (March), and crust type (mossy; Fig. 2a, Appendix). All interactions were significant at 0.0001, except season  $\times$  site  $P = 1.0$ , because the mean abundances were equal for PL and LA in August. Numbers were also high in 1999 (at both PL and LA) in mossy crust, but were very low in February 1999, which was a dry period. The sampling in March 1999 was after snowfall and we collected large numbers again after precipitation in 2000. These results suggest that *Neonanorches* sp. is strongly impacted by moisture and cool temperatures,

since PL was generally observed to be the wetter site, with more mossy patches turning green than at LA following the same precipitation event (personal observations). *Zygoribatula* sp. was the most evenly distributed across sites, seasons, and crust types in 1999 and 2000, making the species interesting for its overall lack of habitat preferences. This species seems to be less affected by moisture and temperature and may be actively in the system most of the time. The only significant interaction effect was for site, crust type, and season combined (Fig. 2b, Appendix). The different patterns for these 2 mites may result from their feeding strategies: *Neonanorches* sp. feeds on vegetation or nematodes and has a body size of approximately 400  $\mu\text{m}$ , while *Zygoribatula* sp., with a body size of almost 1 mm, can feed on larger particles such as hyphae or spores (Behan and Hill 1978). Perhaps *Neonanorches* sp. requires wetter crust tissues than *Zygoribatula* sp. Both collembolan species were more abundant in March at PL and occurred on all crust types (Figs. 2c–d), even though the species vary in body size, coloration, and mobility. *Cryptopygus ambus* is the larger of the 2 with a body length of 1.5 mm, dark pigmentation, and a well-developed springing structure (furcula) used for walking or for jumping. *Tullbergia iowensis* is <1 mm in length, is pale and eyeless, and has no furcula, showing that it spends more time in soil or crust layers than at the surface (Christiansen and Bellinger 1980).

From results in this paper and in Shepherd et al. (2002) several consistent patterns emerged: (1) we found high numbers of mites during cool seasons following precipitation, (2) *Neonanorches* sp. occurred primarily in mossy crusts rather than in the other 2 types, (3) *Zygoribatula* sp. occurred in low numbers throughout the year in all 3 crust types, (4) *C. ambus* was collected primarily during the spring, and (5) *T. iowensis* occurred in both spring and fall, and so far, *C. ambus* has not been collected from LA. This last point is intriguing because the 2 arroyos are separate drainages and yet contain the same kinds of crusts and are close enough to experience the same weather conditions.

The many rare species and large variance in abundance in samples within a season or crust type suggest that this system may respond very quickly to changes in moisture and pro-

ductivity. We may need to sample more thoroughly following precipitation to discover the response time of the community and the specific ecological factors that govern use of crusts by these organisms.

One focus of this study was the influence of habitat heterogeneity on microarthropod richness and abundance. However, from our field observations and later tests (see Data Analysis section) we also discovered that mean area differed for crust types and could be responsible for species richness and abundance patterns we obtained. If area alone accounted for species richness (species-area relationship reviewed in Rosenzweig 1995) on a crust type, we would have expected richness to follow the pattern of mixed > mossy = lichen, because mean area followed that pattern. If habitat heterogeneity drove richness, we still would have expected mixed crust to be the richest, because we saw it offering a mixture of 2 distinct habitat types. In this region lichen crusts are not as well developed vertically as the mosses; therefore, if habitat heterogeneity were responsible, we would have also expected the lowest richness on lichen.

We found that richness on mixed crust did not differ significantly from mossy (Fig. 1, Table 1), so neither area nor habitat heterogeneity alone or in concert explains the patterns seen at our sites. These results, along with amount of species overlap observed and seasonal differences in richness and abundance, allow us to propose mechanisms that might account for these patterns: (1) secondary chemical compounds, such as phenolic acids in lichens and lignin-like compounds in mosses, may influence their palatability (Lawrey 1987) and therefore presence/abundance of microarthropods; (2) seasonal moisture may be available longer in winter than in summer because of low air temperatures, which may increase production in crusts, offering more water and food resources to microarthropods; and (3) species overlap of 57%–62% suggests that the fauna is made up more of generalists than specialists. Nevertheless, the 4 dominant species revealed significant crust type and seasonal preferences (Fig. 2).

Crusts may provide resources when vascular plant growth is slowed or stopped, as in winter. This time of year is less commonly sampled in ecological studies but may be important for crust systems, which can function even at temperatures near freezing (Lange 2001).

The array of taxa and trophic groups we have found suggests that use of this habitat is not accidental, although it is probably not exclusive. Two of our results suggest that crusts do contribute to microarthropod diversity: (1) our species composition in crusts overlapped only slightly (approximately 20%) with that for neighboring regions from studies based on soil and litter (Shepherd et al. 2002), and (2) several of our predominant taxa (*Cryptopygus*, *Zygoribatula*, and members of the Nanorchestidae) are associated with mosses and lichens in other arid systems (Behan and Hill 1978, 1980, Block 1979, Block and Convey 1995).

Microarthropod species may be influencing such processes as nutrient cycling and decomposition directly through herbivory on crusts or indirectly through predation and detritivory. Our current studies help establish a baseline to compare with other habitat types and to track species changes that may be due to changing land use practices or climate change (Wolters et al. 2000). The crust/arthropod relationship is found worldwide in arid environments and is probably an ancient association, perhaps 400 million years old (Walter and Proctor 1999). Crusts may act as a conduit between above- and belowground processes, linking soil fauna (micro- to mesoscale) with surface fauna (meso- to macroscale).

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APPENDIX. Arthropod species and relative abundance by season and crust type. a = “accidental” species, l = found only on lichen, m = found only on mossy, x = found only on mixed.

TAXON	Lichen		Mossy		Mixed	
	Mar	Aug	Mar	Aug	Mar	Aug
MITES						
Mesostigmata						
Family Hypoaspidae						
<i>Hypoaspis (Geolaelaps) sp.</i> <sup>m</sup>			1			
Endeostigmata						
Family Nanorchestidae						
<i>Bimichaelia sp.</i> <sup>x</sup>					1	
<i>Neonanorchestes sp.</i>	7	2	606	4	74	1
<i>Speleorchestes sp.</i>	12	1	27	10	8	4
Prostigmata						
Family Anystidae						
<i>Erythracarus sp.</i>	1	2	1	3	7	5
Family Bdellidae						
<i>Spinibdella cronini</i>						
Baker & Blalock	1		2	3		1
Family Caeculidae						
<i>Caeculus sp.</i> <sup>m</sup>					1	
Family Eupodidae						
<i>Eupodes sp.</i>	5		4	1	20	
Family Penthaleidae						
<i>Penthaleus sp.</i> <sup>m</sup>			1			
Family Raphignathidae						
<i>Raphignathus sp.</i> <sup>m</sup>			1			
Family Teneriffiidae						
<i>Neoteneriffiola uta</i> (Tibbetts)			2	3		1
Family Tetranychidae						
<i>Bryobia sp.</i>	1		1			2
Family Tydeidae						
<i>Tydeus sp.</i>	7	4	45	8	17	6
Oribatei						
Family Brachychthoniidae						
<i>Neobrachychthonius sp.</i>	6		10		1	
Superfamily Carabodoidea						
carabodoid sp.	10	14	11	5	19	4
Family Ceratozetidae						
ceratozetid sp.			3	1	4	
Family Cymbaeramaeidae						
<i>Scapheramaeus sp.</i> <sup>x</sup>					1	
Family Gymmodamaeidae						
<i>Joshuella striata</i> Wallwork		1	3		1	
Family Oribatulidae						
<i>Zygoribatula sp.</i>	26	15	21	24	19	47
Family Trhypochthoniidae						
<i>Trhypochthonius sp.</i> <sup>x</sup>					2	
Astigmata						
Family Acaridae						
acarid sp. <sup>m</sup>			1			

## APPENDIX. Continued.

TAXON	Lichen		Mossy		Mixed	
	Mar	Aug	Mar	Aug	Mar	Aug
COLLEMBOLA						
Family Entomobryidae						
entomobryid sp. <sup>l</sup>	4					
Family Hypogastruridae						
hypogastrurid sp. <sup>x</sup>						2
Family Isotomidae						
<i>Cryptopygus ambus</i>						
Christiansen & Bellinger	51		77		22	
Family Onychiuridae						
<i>Tullbergia iowensis</i> Mills	74	2	37	16	18	6
Family Sminthuridae						
<i>Bourletiella</i> sp.	18	7	10	5	10	10
NON-MITE ARACHNIDA						
Pseudoscorpiones						
Family Opiidae						
<i>Serianus dolosus</i> Hoff <sup>m</sup>					1	
Araneae						
Family Gnaphosidae						
<i>Drassyllus</i> sp. <sup>l</sup>	1					
Family Linyphiidae						
linyphiid sp. <sup>m</sup>			1			
INSECTA						
Diplura						
Family Campodeidae						
<i>Metriocampa</i> sp. <sup>x</sup>					1	
Family Japygidae						
japygid sp.		1		2		
Heteroptera						
Family Lygaeidae						
lygaeid sp. <sup>a</sup>		1			1	
Family Miridae						
mirid sp. <sup>a</sup>					1	
Homoptera						
Family Cixiidae						
cixiid sp. <sup>a</sup>	1					
Thysanoptera						
Family Thripidae						
<i>Arorathrips</i> sp.	4		5		3	
<i>Frankliniella</i> sp.	4	2	5	5	2	1
Coleoptera						
undetermined larva <sup>a</sup>					1	
Lepidoptera						
Family Geometridae						
geometrid larva <sup>a</sup>				1		
Hymenoptera						
Superfamily Chalcidoidea						
chalcidoid sp. <sup>a</sup>	1		1			
Family Formicidae						
<i>Forelius pruinus</i> (Roger)				2		4
TARDIGRADA	1	5	1	2	4	4
NEMATODA	7	5	39	12	12	7