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Spatial and temporal relationships of soil microarthropods on a desert watershed

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With 6 figures

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1. Introduction

SANTOS *et al.* (1978) found that the spatial differences in population density and numbers of taxa of soil microarthropods were directly related to surface litter accumulations and soil organic matter across a desert watershed. FRANCO *et al.* (1979) found a similar relationship between population density of most taxa and organic matter following the winter rainy season. WALLWORK (1972) examined seasonal fluctuations in populations of soil acari under *Juniperus* sp. in the Mojave desert where a large litter layer existed. SANTOS & WHITFORD (1983) also examined spatial and seasonal variation in soil microarthropod populations on the gypsum dunes at White Sands National Monument in southern New Mexico and reported a direct relationship between organic matter and density and taxonomic diversity of soil microarthropods. All of the above studies were limited to a single soil type and only SANTOS *et al.* (1978) and SANTOS & WHITFORD (1983) addressed the problem of spatial variability.

Based on the studies cited above, we hypothesized that microarthropod densities and numbers of taxa would be highest at the base of a closed basin watershed where organic matter and water accumulate (run-on area) and lowest at the top of the watershed (run-off area), providing the soils sampled were under the same plant species. WHITFORD *et al.*, (1981a) studied the numerical responses of soil microarthropods as soil dried following both stimulated and natural rainfall. They found that four days after a rainfall of approximately 25 mm, virtually the only microarthropods present in litter or the sandy soil below the litter were nanorchestid mites and that densities decreased by a factor of 3—8. Sandy desert soils have high infiltration rates and upper layers dry rapidly. Therefore we hypothesized that as the soils dried following a rain event, the number of taxa and population densities of microarthropods would remain high for longer periods at the base of the watershed than at the top.

2. Study site

This study was conducted on the Jornada Long Term Ecological Research (LTER) Site on the New Mexico State University Ranch, 40 km NNE of Las Cruces, Dona Ana County, New Mexico. The site is a desert watershed that drains into a small, dry lake bed (playa). The watershed varies in elevation from 1,200 to 2,000 m. The 100-yr annual rainfall average at the New Mexico State University Station, Las Cruces, New Mexico is 211 ± 77 mm (HOUGHTON 1972), with most of the rainfall occurring in the summer (July—October) from convectional rainstorms. Maximum summer temperatures reach 40 °C and freezing temperatures are recorded from October through mid-April.

3. Methods

Soil samples including the surface leaf litter were collected from under mesquite shrubs *Prosopis glandulosa* growing along the major drainage (arroyo) of the watershed. Three areas were sampled: (1) top of the watershed where the dominant vegetation is creosotebush, *Larrea tridentata*,

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on shallow gravelly soils; (2) mid-slope where the river bed disappears and water flow to the playa is sheet flow; and (3) edge of the playa where mesquito 3—4 m tall, form a dense border around the edge of the area that periodically floods. Sampling was conducted over a full year at 1-month intervals with more frequent sampling in August and January as described below. On each sampling date, eight soil cores, 8 cm deep and 9 cm in diameter, were collected from each topographical area. The soil samples were collected within 1 hour of sunrise, placed in plastic ziplock bags and transported to the laboratory in an insulated container. Microarthropods were extracted from five samples from each area and the remaining three samples were used for water content and organic matter estimation.

Microarthropods were extracted into water in modified Tullgren funnels (Santos *et al.* 1978). The extractor provided a temperature gradient of 38—31 °C in the soil column and a humidity gradient from nearly dry to nearly 100% RH at the lower air-sample interface. Samples were counted immediately after extraction. Representatives of each taxon were mounted in Hoyers and kept in a reference collection. We could identify most mites only to family but some of the cryptostigmatids were determined to genus. Soil samples for water content were weighed immediately upon return from the field and oven dried at 60 °C to obtain gravimetric water content. These samples were then used to estimate total organic content by ashing in a muffle furnace at 720 °C for six hours.

In August and January, we took a series of soil samples at 2 day intervals over a 24 day period in order to evaluate the effects of summer and winter precipitation events on the soil microarthropod fauna on the watershed. Samples were processed as described above.

The common hydrometer method of determining particle size distribution of the soil was used to classify the soils for each of the locations (Bowles 1978). Data were analyzed by ANOVA and significant differences between sites and across time evaluated by Tukey's Q (Sokal & Rohlf 1969).

4. Results

4.1. Soils

The soils of the three locations were classified into two groups based on the silt content. The flood plain soils were determined as sandy loams, with a content of 58.4% sand, 13.3% clay and 28.3% silt. The middle and the upper watershed soils fell into the loamy sand category with 76.2% and 79.2% sand, 10.6% and 6.8% clay, and 13.2% and 14.0% silt, respectively. The average organic matter in the flood plain soils ($\bar{X} = 7.4\%$) was significantly greater than in soils from the mid- $\bar{X}(= 3.1\%)$ and upper slope ($\bar{X} = 2.8\%$) locations ($F = 4.3$, $p < 0.05$) throughout the year.

The change in percentage of soil water (Fig. 1) before and after rain events was similar in the top and middle locations where means ranging from 2.1—2.3% were significantly lower ($p < 0.05$) than that of the flood plain soils (3.9%). The changes in percentage of organic matter and soil moisture content (Fig. 1) were correlated ($F = 6.7$, $p = 0.02$, $r^2 = 0.40$) in the flood plain area, in contrast to the middle and upper watershed where there was no correlation.

4.2. Microarthropods

Collembolan population densities (Fig. 2) varied directly with soil moisture ($r^2 = 0.48$, $p < 0.001$). As soils dried, collembolan numbers decreased ($p < 0.001$, r^2 between 0.42 and 0.48). Mesostigmatid and astigmatid mites occurred at very low population densities throughout the study. Acaridae were the only taxa of these orders that were found on more than one sampling date in any of the sample areas.

We found species representing 13 families of prostigmatids and 6 genera of cryptostigmatids (Table 1). Only nanorchestids occurred in every sampling period; other frequently encountered taxa included: tydeids, stigmaeids, bdellids, and cunaxids. In the cryptostigmatids the genera *Aphelacarus*, *Cosmochthonius*, were found between 8—12 times during the year (Table 1).

Microarthropod density (Fig. 3) during June through September was relatively low: under 10,000 microarthropods m^{-2} with no significant differences between the locations. In September, total microarthropod densities increased by factors of 3, 4 and 11 at the base, middle and top of the watershed, respectively, when compared with the population densities estimated in August. On the flood plain the microarthropod population density was 2 times lower than in the other two locations ($F = 4.19$, $p < 0.05$) during the entire study (Fig. 3).

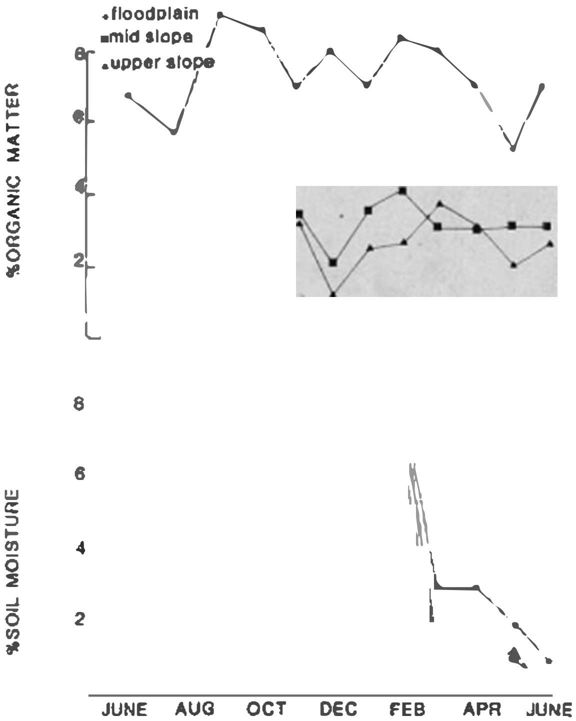


Fig. 1. Variation in soil moisture and percent organic matter in the soil at sampling locations under mesquite plants (*Prosopis glandulosa*) on a desert watershed.

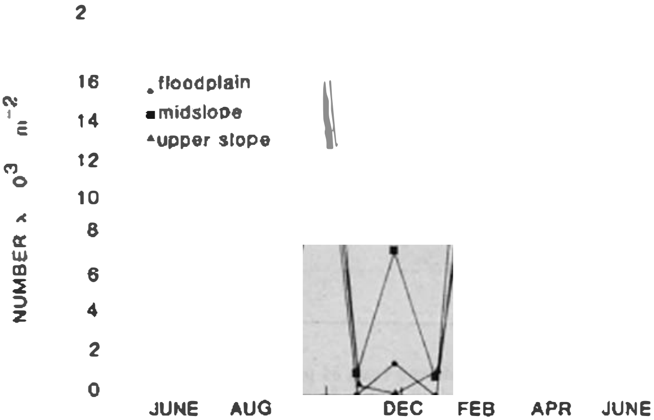


Fig. 2. Densities of soil collembolans at three sampling locations under mesquite plants (*Prosopis glandulosa*) on a desert watershed.

Table 1. Frequency of occurrence of soil Acari in soil samples from three areas on a desert watershed

	Flood plain	Mid-slope	Upper slope
Tydeidae	1.0	0.92	0.92
Nanorchestidae	1.0	1.0	1.0
Linotetranidae	0.7	0.42	0.25
Pyemotidae	0.25	0.3	0.3
Tarsonemidae	0.3	0.5	0.58
Raphignathidae	0.42	0.25	0.17
Stigmaeidae	0.83	0.83	0.7
Bdellidae	0.7	0.75	0.83
Cunaxidae	0.75	0.7	0.83
Scutacaridae	0.17		0.08
Trombidiidae	0.58	0.58	0.5
Teneriffiidae	0.25	0.17	0.25
Nematalycidae		—[1])	
Gymnonota	0.92	0.75	0.83
Passalozetes sp.	0.25	0.3	0.25
Joshuella sp.	0.25	0.17	0.08
Cosmochthonius sp.	0.75	0.7	0.83
Aphelacarus sp.	1.0	0.92	0.92
Galumnidae	0.08	0.08	0.17
Rhodacaridae	0.83	0.5	0.25
Acaridae	0.5	0.25	0.75

[1]) Occurred during the rain only, not at the regular sampling date.

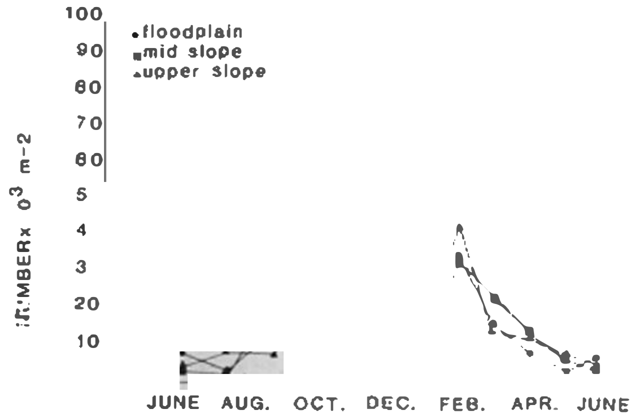
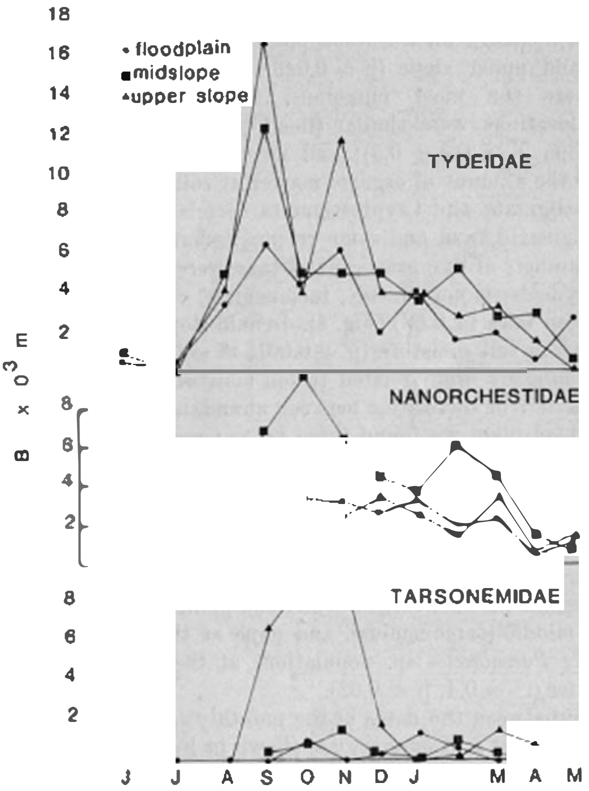


Fig. 3. Densities of soil microarthropods at three sampling locations under mesquite plants (*Prosopis glandulosa*) on a desert watershed.

Fig. 4. Densities of the three most abundant taxa of prostigmatid mites at three sampling locations under mesquite plants (*Prosopis glandulosa*) on a desert watershed.

Fig. 5. Densities of two genera *Aphelacarus* and *Cosmochthonius* and Gymnonota (cryptostigmatid mites) at three sampling locations under mesquite plants (*Prosopis glandulosa*) on a desert watershed.



18
16
14
12
10
8
6
4
2
• floodplain
■ midslope
▲ upper slope
TYDEIDAE
NANORCHESTIDAE
B x 0³ m
8
6
4
2
TARSONEMIDAE
8
6
4
2
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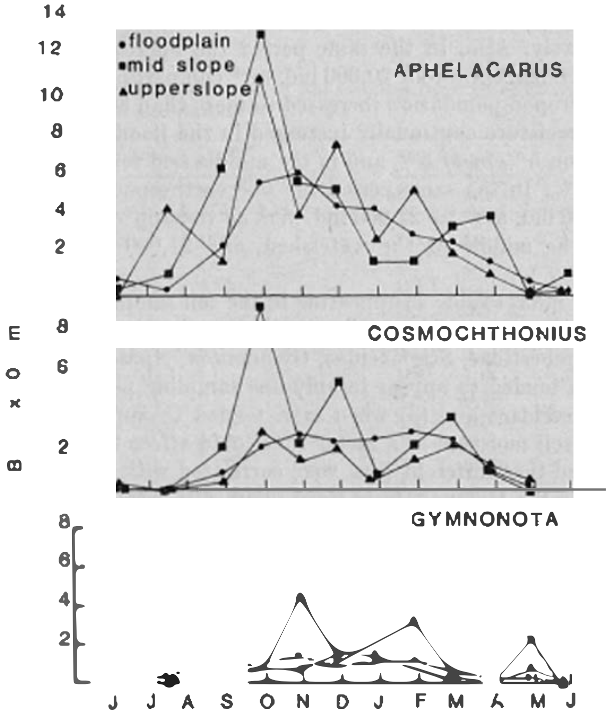

14
12
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2
• floodplain
■ mid slope
▲ upperslope
APHELACARUS
COSMOCHTHONIUS
B x 0 m
8
6
2
GYMNONOTA
8
6
4
2
J J A S O N D J F M A M J

A significant correlation was found between the total microarthropod population size and the percent soil moisture on the flood plain (p 0.043, $r^2 = 0.21$); mid-slope ($p = 0.0006$, $r^2 = 0.35$) and upper slope (p 0.023, $r^2 - 0.25$). The prostigmatids and the cryptostigmatids were the most numerous. The ratios of Prostigmata/Cryptostigmata in the three locations were similar (flood plain $\bar{X}$ 0.6 ± 0.3; mid-slope $\bar{X}$ 0.7 ± 0.2; upper slope $\bar{X}$ 0.5 ± 0.3); and no significant correlations were found between this ratio and the amount of organic matter or soil moisture. The fluctuation in the total number of Prostigmata and Cryptostigmata correlated with the soil moisture is the result of some prostigmatid taxa and some cryptostigmatid genera that responded to soil moisture. Average numbers of five prostigmatid taxa were correlated with the soil moisture in the flood plain: tydeids, nanorchestids, tarsonemids, cunaxids and trombids ($p < 0.05$ throughout, r^2 between 0.34 to 0.68) (Fig. 4). In mid-slope only the prostigmatid bdellid numbers were related to soil moisture ($p < 0.001$, $r^2 = 0.75$), and at the top of the watershed only cunaxid numbers were related to soil moisture content (p 0.002, r^2 0.64). There was a similar pattern of correlation between abundance and soil moisture in the Cryptostigmata. In the flood plain we found three taxa, Gymnonota, *Cosmochthonius* sp. and *Aphelacarus* sp. in which numbers correlated with soil moisture (p between 0.03 and 0.05, r^2 between 0.4 and 0.6, r^2 0.40). At mid-slope only the genus *Passalozetes* had population size correlated ($p = 0.0005$, $r^2 = 0.72$) with soil moisture. At the top of the watershed only the numbers of *Aphelacarus* sp. were correlated with soil moisture (Fig. 5).

Population densities of four families of prostigmatids were significantly correlated with the amount of soil organic matter: three in the flood plain (tydeids, nanorchestids and stigmaeids), one in the middle (tarsonemids), and none at the top of the watershed. In the cryptostigmatids only *Passalozetes* sp. populations at the top watershed were correlated with the organic matter ($r^2 = 0.4$, $p < 0.02$).

Soil samples taken between the dates of the monthly sampling schedule following rains during the months of August and January are shown in Fig. 6. The soil moisture decreased continually during August. On the flood plain the highest soil moisture was 10.8% after rain and that dropped to 4.4% at the end of the month. During the same period in the middle and the top of the watershed soil moisture changed from 10% and 8.8% to 2% and 1.5%, respectively. Also, in the same period the microarthropod population in the flood plain location remained under 20,000 ind. m^{-2} comparison to the other two locations where the microarthropod population increased to more than 30,000 ind. m^{-2}.

In January the moisture continually increased in the flood plain during the first three sampling periods from 5% to 11.3% and in the middle and top locations the changes were between 3.5% to 7%. In the same period the microarthropod population oscillated from a minimum of 8,000 ind. m^{2} to 27,000 ind. m^{-2} at the top of the watershed, 27,000 to 48,000 ind. m^{-2} in the middle of the watershed, and 21,000 to 37,000 ind. m^{-2} in flood plain (Fig. 6).

The frequency of mites (Table 2) appearing in the soil samples after rain exhibited three patterns: (1) where taxa were present in all the samples during both sampling periods, e.g. Tydeidae, Nanorchestidae, Stigmaeidae, Gymnonota, *Aphelacarus* sp., and *Cosmochthonius*; (2) where taxa tended to appear in only one sampling period such as Tarsonemidae, Teneriffiidae, and Acaridae; and (3) when taxa tended to appear apparently at random. When we examined soil moisture as a factor that could affect the frequency of appearance of soil Acari we found that different taxa were correlated with the soil moisture in the different locations. Only the Gymnonota in flood plain soils were related to the soil moisture during August ($r^2 = 0.68$, $p < 0.04$), at mid-slope the Pyemotidae and the *Aphelacarus* sp., and at the top of the watershed numbers of Tydeidae, *Cocmochthonius* sp., and *Aphelacarus* sp. were correlated with soil moisture (r^2 between 0.68 and 0.94, $p < 0.04$ to $p < 0.001$).

In January the Tydeidae were correlated with the soil moisture only at the top of the watershed ($r^2 = 0.99$, $p < 0.001$) and Linotetranidae in the flood plain were correlated with the soil moisture ($r^2 = 0.90$, $p < 0.05$).

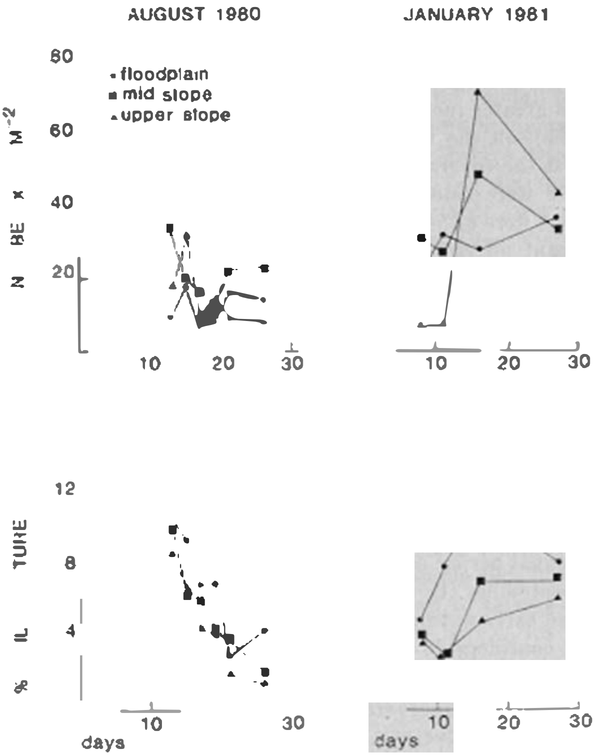

Fig. 6. Variation in densities of soil microarthropods in relation to soil moisture following large rainfall events in August and January at three sampling locations under mesquite plants (*Prosopis glandulosa*) on a desert watershed.

Table 2. Frequency of occurrence of soil acari in soil samples from three areas on a desert watershed following rain events in August and January

	Flood plain		Mid-slope		Upper slope	
	Aug.	Jan.	Aug.	Jan.	Aug.	Jan.
Tydeidae	1.0	1.0	1.0	1.0	1.0	1.0
Nanorchestidae	1.0	1.0	1.0	1.0	1.0	1.0
Linotetranidae	1.0	0.75	1.0	0.5	0.2	0
Pyemotidae	0.8	0	1.0	0.5	0.7	0
Tarsonemidae	0	0.5	0	0.25	0	0.5
Raphignathidae	0.3	1.0	0	0.5	0	0.25
Stigmaeidae	1.0	1.0	1.0	1.0	1.0	0.75
Bdellidae	0.8	0.5	0.8	0.75	1.0	0.5
Cunaxidae	0.8	0.75	0.7	1.0	0.8	1.0
Scutacaridae	0	0.25	0	0	0	0
Trombidiidae	0.2	0.75	0.8	0.75	0.5	0.5
Teneriffiidae	0.3	0	0.3	0	0.3	0
Nematalycidae	0	0	0.2	0	0	0
Gymnonota	0.7	1.0	1.0	1.0	0.8	0.75
Passalozetes sp.	0.7	0.5	0.5	0.5	0.5	0.25
Joshuella sp.	0.3	0.25	0.3	0.25	0.3	0
Cosmochthonius sp.	1.0	1.0	1.0	1.0	1.0	1.0
Aphelacarus sp.	0.7	1.0	0.7	1.0	0.5	1.0
Galumnidae	0.2	0.5	0.5	0.25	0.3	0
Rhodacaridae	0	0.5	0	0	0	0.25
Acaridae	0	0.5	0	0.5	0	0.75

5. Discussion

The data collected in this study force us to reject our original hypotheses, i.e., that microarthropod populations densities and number of taxa should be higher at the base of the watershed, exhibit a greater increase in size in response to precipitation and remain active for a longer time than on the upper slopes of the watershed. The relationships found in this study are almost the reverse of those hypothesized. Although soil organic matter and percent soil moisture were consistently higher at the base of the watershed, soil microarthropod populations were either lower than or equal to those found on the upper slopes.

The only significant differences in population densities occurred October through December when the young of the year were being recruited into the population. The soil characteristics could affect egg maturation, survivability and survival of the nymphs. The larger accumulations of leaf litter at the base of the watershed also serve as habitat for predators that could reduce populations of microarthropods in this area. However, the population densities of bdellids, cunaxids, stigmaeids and Gamasina were not significantly higher at the base of the watershed than on the upper slopes. Thus, it seems unlikely that differential predation by soil acari could account for this reduction.

This study also demonstrates a distinct seasonal component to numbers of microarthropods. Only the collembolans peaked when soil moisture reached or exceeded 5 %. The Acari all achieved highest population numbers in October and exhibited gradual decline in density following the annual period of recruitment. These data suggest that these mites breed between July and September. In the Chihuahuan desert, the predictable season of rainfall is in late summer and early autumn, i.e., July through September and, although the rainfall quantity varies considerably among years, the period of rainfall remains relatively constant.

The peak densities of soil microarthropods recorded in this study fall in the range of population densities reported for soil arthropods in North American mesic hardwood forests (data summary in Franco *et al.* 1979). Average densities are higher than reported for an Australian desert (Wood 1971) the Mojave (Wallwork 1972; Franco *et al.* 1979) and under creosotebushes (*Larrea tridentata*) or arroyo edge vegetation on the same watershed (Santos *et al.* 1978). Litter under mesquite resembles that of a forest litter layer, ie., 1 to 2 cm of leaf material mixed with unidentifiable organic debris. The absence of consistent correlation between microarthropod abundance and organic content of the soil suggests that factors other than the physical nature of the leaf litter are important for these desert microarthropod populations. The mesquite on the flood plain are the largest most tree-like of the mesquite on the watershed and the soil under these mesquite has the thickest litter layer. However, maximum population densities on the flood plain were considerably less than on the upslope sites.

While the causal factors for these apparent anomalies remain obscure, the importance of such high population densities of microarthropods cannot be overemphasized. The presence of large populations of cryptostigmatids in addition to the more numerous prostigmatids may partially explain the rapid disappearance of litter in large litter accumulations in this desert (Whitford *et al.* 1981 b, Whitford *et al.* 1982).

The data on frequency of occurrence of soil acari in the soil samples show that some taxa like tydeids, nanorchestids, stigmaeids, cunaxids, Gymnonota, *Aphelacarus* sp. and *Cosmochthonius* are not only numerically dominant but also present and active throughout the year. Taxa present at frequencies below 0.25 represent seasonal taxa or taxa occurring at such low abundance that they are infrequently collected. However, until we know more about the feeding relationships of desert soil Acari we can only speculate as to the reasons for the differences in abundance of the soil microarthropod fauna.

The results on numerical responses of the soil microarthropod fauna during or following natural rainfall events revealed an interesting pattern. Although the soils gradually dried following the early August rain, the microarthropod populations remained relatively constant. This is further indirect evidence for our contention that the numerical responses of these desert soil Acari is seasonal and relatively independent of the vagaries of rainfall. Although some soil moisture between 2% and 4% appears to be necessary to initiate reproduction and activity of the soil microarthropods, once initiated these processes apparently continue regardless of soil moisture changes. Winter rainfall had a different effect and there was good correspondence between soil moisture and numbers of soil microarthropods. **Franco** *et al.* (1979) reported peak numbers in the Mojave desert in December, the "predictable" wet period in that desert whereas the peak populations in our Chihuahuan desert study occurred in October at the end of the "predictable" wet period in that desert even though the soils were wetter in January and February. Thus, the "predictable" season of rainfall appears to be more important for North American desert soil acari than quantity of rainfall or soil moisture level of any period other than the predictable season.

Usher (1976) has stated that perhaps the most important environmental influence acting on soil arthropods is the soil water. Certainly this would intuitively seem to be the case in desert soils. However, our results do not support this idea. Further, **Vannier** (1970) has suggested that the most important element in predicting responses of soil microarthropods is soil moisture tension which he expressed in pF units. In our desert soils cryptostigmatids, prostigmatids and mesostigmatids were active at soil moisture tensions below and above pF 5[1]) and exhibited no response to changing soil moisture tension as soils dried during August. **Vannier** (1970) states that oribatid (cryptostigmatid) populations irreversibly migrate toward deeper soil layers when soil moisture tension reaches pF 5 (approximately 80 bars $\triangleq 0.8 \cdot 10^5$ hPa in our soil). However in these same soils it was found that cryptostigmatids and other mites exhibit diurnal migration up to surface litter and then back into soil at soil moisture tensions greater than pF 5 (>150 bars $\triangleq 1.5 \cdot 10^5$ hPa) **Whitford** *et al.* (1981a). Thus moisture appears less important than temperature as a factor affecting spatial distribution in the soil of desert soil microarthropods.

Collembolan numbers probably reflect the ability of these organisms to enter a cryptobiotic state as described by **Poinsot-Balaguer** (1976). The collembolans apparently remain inactive until activated by high soil moisture. This behavior was also suggested by similar responses to simulated rainfall in the studies of **Whitford** *et al.* (1981a).

The variability in correlations between rainfall/soil moisture and numbers of individuals in the most frequently encountered microarthropods suggests that these were chance correlations rather than cause and effect relationships. Similarly, the ratio of prostigmatid to cryptostigmatid mites was the same at all watershed sampling points and showed no correlation with soil moisture and/or organic matter. The absence of reliable correlations of this kind suggests two important conclusions with respect to the distribution and abundance of soil Acari on a desert watershed: (1) fluctuations in population numbers is largely seasonal and the Acari do not respond to moisture inputs outside the "predictable" wet period; and, (2) if sufficient leaf litter is present, numbers of soil Acari will be similar at any time regardless of location on the watershed.

6. Acknowledgements

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[1]) A moisture tension of pF 5 is nearly adaequat to 100 bar $\triangleq 10^5$ hPa $\triangleq$ tension of 10^5 cm water level [1 bar $\triangleq 1 \cdot 10^5$ Pa $\triangleq 10^3$ hPa; 1 Pa $\triangleq$ 1 N $m^{-2} \triangleq m^{-1}$ kg s^{-2}].

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Synopsis: *Original scientific paper*

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The hypothesis was tested that microarthropod populations would exhibit greater increases in population densities and remain active longer under the same plant species at the base of a watershed where water and organic matter accumulate, than they would upper watershed locations. Only collembolans exhibited numerical responses as a function of moisture. Although soil moisture and organic content were greater in soils at the base of the watershed, soil microarthropods there exhibited less increase following rains than they did in upper watershed locations. Numerical responses of soil Acari were seasonal with maximum numbers in October at the end of the normal wet season (July—September) and were not correlated with soil moisture or soil organic matter.

Key words: Acarina, Collembola, desert, rainfall, Prosopis glandulosa, mesquite shrub, season, soil, moisture, watershed.