Spider diversity in relation to habitat heterogeneity and an altitudinal gradient in South Sinai, Egypt

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ABSTRACT
Using pitfall traps, wandering spiders (Arachnida: Araneae) were sampled in a nested design from three different localities in the mountainous arid ecosystem of South Sinai at low, middle, and high altitudes. Habitat type and altitude were clearly different among the three localities. Spider diversity per trap varied spatially and temporally among and sometimes within localities. Altitude, relative humidity, and temperature had different effects, either positive or negative with the abundance of different families. Habitat heterogeneity within a locality may also affect spider diversity. The different localities had distinct and characteristic groups of spiders responding to altitude and habitat characteristics.

INTRODUCTION

The Sinai Peninsula (61,100 km^2) is a desert belonging to the Saharan type (MacGinnies *et al.* 1968), linking Asia with Africa and lying between the Mediterranean Sea to the north, and the Gulfs of Suez and Aqaba to the south. It has three main sections: the low northern part is covered with sand; the central section is predominantly limestone hills and gravel plains; while the southern part is mountainous magmatic and metamorphic rocks. According to Danin (1978), the climate of Sinai belongs to the Arabian type, characterized by aridity, winter precipitation and moderate temperature.

Spiders are found almost everywhere, particularly abundantly in areas with rich vegetation. However, spiders are also found in rather barren environments such as sand dunes, tidal zones (Lamoral 1968), or mountain tops. It is no exaggeration to say that spiders have occupied virtually all possible ecological niches on land, limited only by extremes of physical and biological factors (Turnbull 1973). Spiders are considered to be one of the most important components of the ecosystem they live in, as they are some of the most abundant predators in many agricultural systems (Carter & Rypstra 1995). Because of their ubiquity and abundance, spiders are potentially useful biological indicators of the quality of natural habitats, or for determining how communities react to environmental changes or disturbance (Marc & Canard 1997).

Despite their importance and abundance, they have been insufficiently studied in Egypt and in Sinai. The current work aims to explore variation in spider communities with season, habitat and altitude.

MATERIALS AND METHODS

The field work was conducted in South Sinai. A total of twelve plots (15 ×20 m each) were selected in three sites for sampling of spiders, chosen to represent different altitudes and habitats. There were 12 traps per plot. Plots were paired to cover both the desert (outside gardens) and cultivated areas (inside gardens). The study sites were:
Mafareq (M) is situated at the junction of Wadi Feiran with the El-Qaa plain, about 106 km east of St. Katherine with an altitude of 90 m above sea level (28º 42$^/$ 84$^{//}$ N, 33º 14$^/$

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81$^{//}$ E). The mean maximum temperatures varied between 17.5C^o (Jan) and 39° (Aug), and the relative humidity between 70% (Jan) and 62% (Aug). There were two subsites (M1 and M2), each with a pair of plots. The dominant desert plants were *Acacia raddiana* Savi (Leguminosae), *Tamarix nilotica* (Ehrenb) Bge (Tamaricaceae), *Zizyphus spinachristi* (L.) Willd (Rhammaceae), and *Zygophyllum simplex* L. (Zygophyllaceae). Cultivated areas had palms and various fruit trees and vegetables.

Wadi Feiran (WF) is 60 km from St. Katherine (28° 42$^/$ 28$^{//}$ N, 33° 40$^/$ 15$^{//}$ E, altitude 900 m), and somewhat cooler (mean minimum temperature between 10.7 C^o (Jan) and 32 ºC (Aug)). There were two subsites (WF1 and WF2), each with a pair of plots. The dominant desert flora were *Achillea fragrantissima* (Forssk) Sch. Bip and *Artemisia inculta* Del., while plant cover in the cultivated habitat was mainly palm trees in WF1 and various vegetables and fruit trees in WF2.

Wadi El-Arbaein (WA) (28˚ 32´ 13″ N, 33˚ 57´ 91″ E, alt. 1670 m) runs from St Katherine, and is cooler still (mean min temperature between 10 ºC (Jan) and 26 ºC (Aug)). The high mountains make the climate continental, augmenting the temperature difference between day and night. In the chosen sites (WA1 and WA2) the most common desert flora was *Achillea fragrantissima* (Forssk.) Sch. Bip., *Artemisia inculta* Del., *Echinops glaberrimus* DC., *Tanacetum santalinoides* DC. *Onopordum ambiguum* Fresen. (Compositae), *Alkanna orientalis* (L.) Boiss. (Boraginaceae), *Asclepias sinaica* (Boiss) Muschl. (Asclepiadaceae), *Fagonia mollis* Del., *Peganum harmala* L. (Zygophyllaceae), *Mentha longifolia* L. *Origanum syriacum* L., *Phlomis aurea* Decne., *Salvia spinosa* L., *Stachys aegyptiaca* Pers., *Ballota undulata* (Fresen.) Benth. (all Labiatae), *Verbascum sinaiticum* Benth. (Scrophulariaceae), *Diplotaxis harra* (Forssk.) Boiss. and *Zilla spinosa* (L.) Prantl. (Cruciferae). Cultivated plants inside the gardens were mainly olive and fruit trees and various vegetables.

Spiders roving on the ground were sampled from October 2000 to September 2001. In each plot, 12 pitfall traps were placed (rounded plastic bottles, 13 cm deep with an opening of 5.7 cm diameter), filled one–third full of water with a little detergent (Samu & Lovie 1995). Traps were arranged in four rows with 5m intervals between lines and among traps. Trapping continued for three consecutive days to obtain both diurnal and nocturnal species (Green & Berry 1999). Although not all spiders can be sampled in this way, the systematic method of sampling results in comparable data.

Simpson's diversity (D) was calculated using the following equation (Lande 1996):

$$\lambda = \Sigma \ p_i^{\ 2} \qquad D = 1 - \lambda$$

where p_i is the proportion of the community occupied by the ith species. "s" was used to determine the characteristic spider families for each site.

RESULTS

Summer was the season of highest abundance (Table 1). The 334 individual spiders caught belonged to 15 families and 27 genera (16 identified, 11 unidentified), and more were caught in El-Mafareq (126 individuals) than in the other sites (Wadi Feiran 102, St. Katherine 106). A one-way analysis of variance was used to test for differences among locations in their diversity. No significant differences among locations were apparent ($F_{2,130} = 0.741$, $P > 0.05$); while among months of the year regardless of sites, significant differences ($F_{11,130} = 21.357$, $P < 0.001$) were found.

Table 1: Seasonal abundance of collected spiders' families with reference to genera and/or species recorded.
G1-G11: referred to unidentified genera.

Family	No. of Individuals	Season				Genera and/or species
		Winter	Spring	Summer	Autumn	
Gnaphosidae	109	4	41	30	34	*Pterotricha* sp., *Zelotes* sp., G1, G2
Salticidae	54	2	17	17	18	*Plexipus paykulli*, *Menemerus* sp., G3, G4, G5, G6
Scytodidae	6	0	0	6	0	*Scutodis* sp.
Liocranidae	4	0	0	4	0	*Mesiotelus tenussimus*
Philodromidae	18	3	7	6	2	*Thanatus* sp., *Philodromus* sp.
Sparassidae	21	3	0	17	1	*Eusparassus* sp.
Zodaridae	5	0	3	2	0	G7
Lycosidae	37	0	4	28	5	G8, G9, G10
Theridiidae	21	0	4	9	8	*Latrodectus* sp.
Dysderidae	5	0	1	3	1	*Dysdera crocata*
Loxoscelidae	35	0	20	13	2	*Loxosceles* sp.
Hersiliidae	6	0	0	6	0	*Hersiliola* sp.
Filistatidae	6	0	3	1	2	*Filisitata* sp., G11
Oecopiidae	6	0	3	3	0	*Uroctea* sp.
Theraphosidae	1	0	0	1	0	*Chaetopalma olivaceum*
Total	334	12	103	146	73	

To explore the spatial pattern of diversity of the spider assemblage, three different parameters were measured: family abundance, family richness, and the Simpson diversity index. These were calculated overall, and at the level of the total catch in each trap over the year. A nested design for the analysis of variance was adopted, with factors of habitats (inside or outside gardens), localities, and sites within localities. There were no significant differences in general diversity among the localities ($F_{2,137}=0.74$, $P>0.05$), and also in the mean diversity per trap ($F_{2,137}=0.48$, $P>0.05$). There were significant differences in family richness among the localities ($F_{2,137}=4.5$, $P<0.05$), and highly significant differences in family abundance among the localities ($F_{2,137}=115.5$, $P<0.001$) (Figure 1 a & b). Among sites within localities, there were no significant differences in general diversity ($F_{3,137}=0.46$, $P>0.05$), in the mean diversity per trap ($F_{3,137}=1.01$, $P>0.05$), or in family richness ($F_{3,137}=0.61$, $P>0.05$), but there were highly significant differences in family abundance ($F_{3,137}=1227.2$, $P<0.001$) (Figure 2 a & b). Among habitats (inside, and outside gardens), there was a highly significant difference in general diversity ($F_{1,137}=121.5$, $P<0.001$), and in family abundance ($F_{1,137}=6936.0$, $P<0.001$), but no differences in the mean diversity per trap ($F_{1,137}=0.121$, $P>0.05$), and in family richness (Figure 3 a & b).

Fig (1a): The Simpson diversity index, and families richness among the three localoties; El-Mafareq, Feiran, and St.Katherine
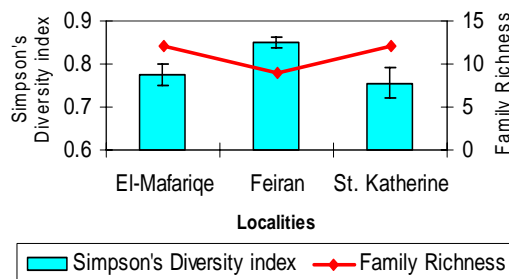

Fig (1b): The Simpson diversity index of the mean catch per trap over the year in El-Mafareq, Feiran, and St. Katherine.
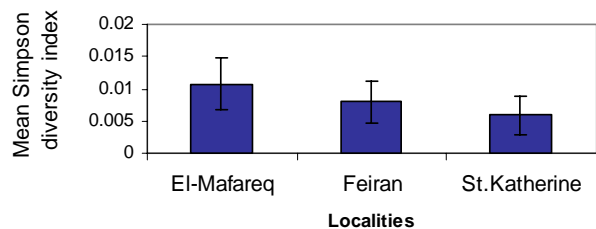
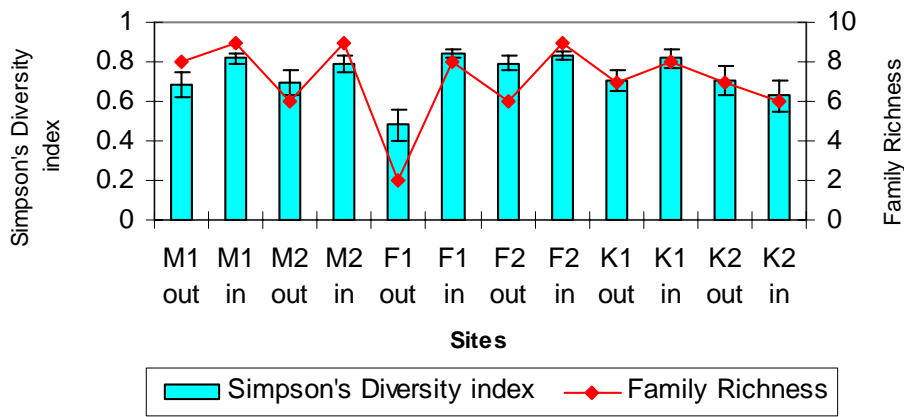Fig (2a): The Simpson diversity index, and families richness of all sites through the year of the study

Fig (2b): The Simpson diversity index of the mean catch per trap in all sites through the year of the study
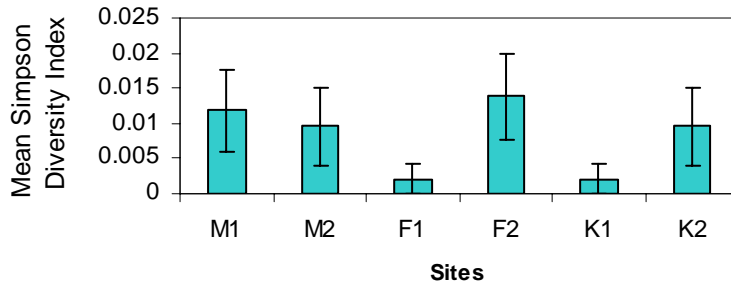

Fig (3b): The Simpson diversity index for mean catch per trap in different habitat types through the year of the study
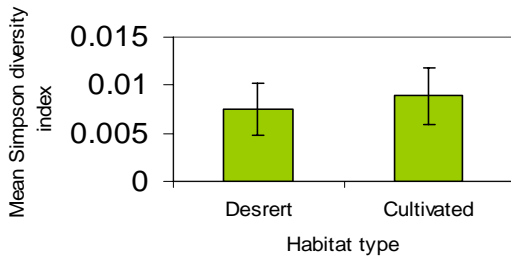

Fig (3a): The Simpson diversity index, and families richness among different habitat types through the year of the study
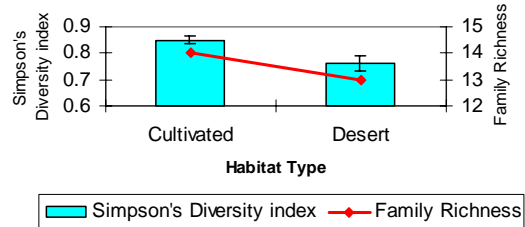

Fig (4a): The Simpson diversity index, and families richness among different monthes through the year at all
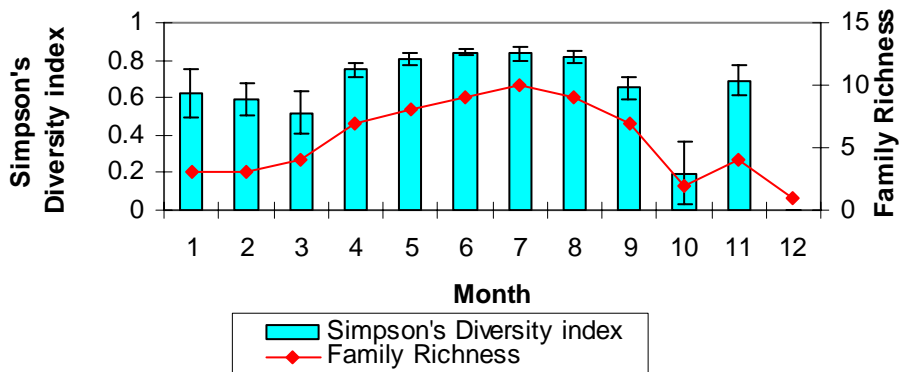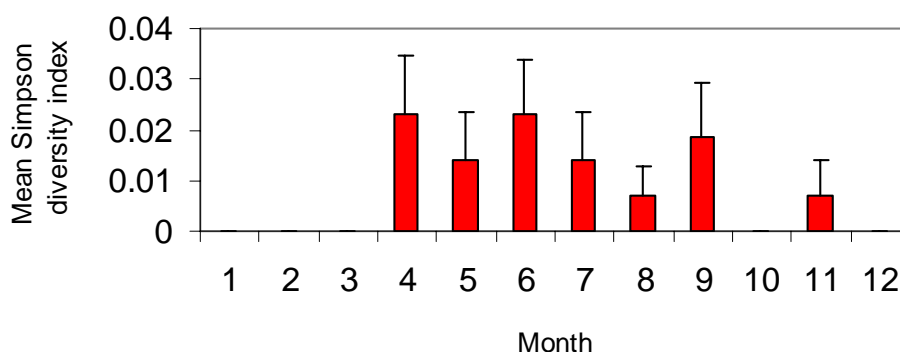
Fig (4b): The Simpson diversity index of mean catch per trap among different monthes through the year at all localities

There were significant temporal patterns of variation in the spiders' assemblage in general diversity ($F_{11,126}$=21.357, P<0.001), in family abundance ($F_{11,126}$=1547.9, P<0.001), family richness ($F_{11,126}$=28.6, P<0.001), and in the mean diversity per trap ($F_{11,126}$=1.791, P<0.05) (Figure 4 a & b).

Similarity indices between sites were calculated (Table 2): the largest similarities were between El-Mafareq 1 (M1), and El-Mafareq 2 (M2), St. Katherine 1 (WA1), and St. Katherine 2 (WA2), and between El-Mafareq 2 (M2), and Wadi Feiran 1(WF1). The lowest similarities were between Wadi Feiran 2 (WF2), and St. Katherine 2 (WA2), followed by that between El-Mafareq 2 (M2), and Wadi Feiran 2 (WF2).

Table 2: Similarity index in spiders' assemblage between the six sites of the study area.

Sites	Mafareq 1	Mafareq 2	Feiran 1	Feiran 2	St.Kath. 1	St.Kath. 2
Mafareq. 1	1					
Mafareq. 2	.958	1				
Feiran. 1	.896	.914	1			
Feiran. 2	.566	.491	.733	1		
St.Kath. 1	.714	.742	.807	.557	1	
St.Kath. 2	.694	.726	.706	.388	.936	1

To picture the differences in spider assemblage composition among localities, a Discriminant Function Analysis (DFA) was used for analysis. The first axis, which represents 46.1% of the discrimination, separates El-Mafareq (positive values) from Feiran and St. Katherine (negative). Positive values along this axis are correlated mainly with the occurrence of the families Salticidae, Scytodidae, Hersiliidae, Philodromidae, Teraphosidae, and Filistatidae. The second axis, which represents 38.5% of variation, separates off St. Katherine, correlated with the occurrence of the families Oecopidae, Dysderidae, Loxoscelidae, Liocranidae, and Sparassidae. The third axis contrasts Feiran with other localities, and represents 15.4% of the discrimination; it is correlated with the occurrence of the families Lycosidae and Theridiidae (Figure 5).

Logistic regression analysis was applied to determine how altitude, temperature, and relative humidity affected the distribution and abundance of different spider families obtained by pitfall traps. In Table 3 the correlation between these three factors and the presence of the fifteen wandering-spider families are given with the reference to the significance of F values. The directions of the correlations are also given for the localities.

Fig. 5: Plot of the different localities of the study area at south Sinai along the first three axis of the discriminant function analysis of the abundance of the spider families (El-Mafareq, Feiran, and St. Katherine).
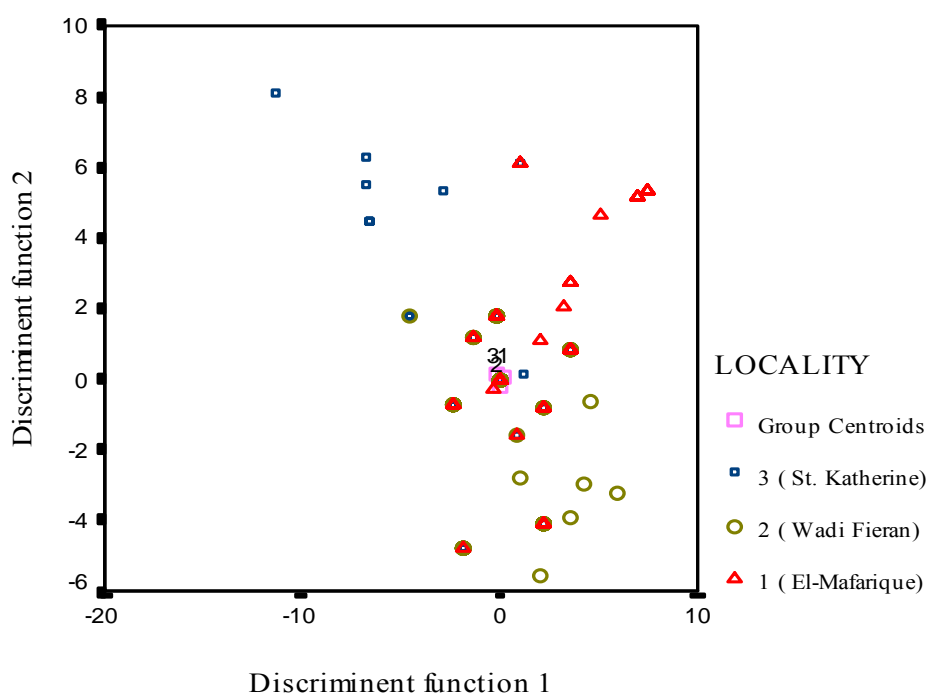

Table 3
Factors affecting spider diversity represented by the Wald F values from the logistic regression analysis for altitude, temperature, and relative humidity. Significance was represented by (*) for significant, (**) for highly significant, (***) for very highly significant differences, and (NS) for non-significant. Localities were expressed as (M) for El-Mafareq, (F) for Wadi Feiran, and (K) for St. Katherine.

Family	Altitude	Temperature	RH%
Gnaphosidae	$8.3*_{(2)}$ K>M>F	$8.6**(1)_{+ve}$	$4.5*(1)_{-ve}$
Salticidae	$7.3*_{(2)}$ K<F<M	$6.3*(1)_{+ve}$	NS
Scytodidae	NS	$4.9*(1)_{+ve}$	NS
Liocranidae	NS	NS	NS
Philodromidae	NS	$4.7*(1)_{+ve}$	NS
Sparassidae	$5.9*_{(2)}$ K>F>M	$7.9**(1)_{+ve}$	NS
Zodaridae	NS	$4.2*(1)_{+ve}$	NS
Lycosidae	$11.7**_{(2)}$ F>K>M	$21.9***(1)_{+ve}$	NS
Theridiidae	$13.4***_{(2)}$K>F>M	$14.6***(1)_{+ve}$	NS
Dysderidae	$2.2*_{(2)}$ K>F>M	NS	NS
Loxocelidae	NS	NS	$10.7***(1)_{-ve}$
Hersiliidae	NS	$0.34*(1)_{+ve}$	NS
Filiatatidae	NS	NS	NS
Oecopidae	NS	NS	$6.8**(1)_{-ve}$
Theraphosidae	NS	NS	NS

DISCUSSION

Wandering spiders are important components of food webs and biological cycling in desert habitats. All spiders are carnivorous, and can have a potent effect on the communities in which they are found. They have an associated fauna of predators, prey, and parasites. Biodiversity is generated and maintained by a complex of factors such as altitude, productivity, climatic variability, age of ecosystem, predation, competition, spatial heterogeneity, or the stage of biological succession (Fjeldsa & Lovett 1997). Human factors also are important in managed or semi-natural habitats. However not only local habitat features determine local diversity, but other processes are acting at coarse scales also influential (Caley & Schulter 1997).

In the current study, we found differences between the cultivated habitats inside the gardens, and the desert habitats outside the gardens: these differences were evident in spider diversity and abundance, and can be attributed to the habitat heterogeneity, especially in plant cover, and availability of resources for these spiders. According to Cloudsley & Thompson (1983), desert spiders belong to two main ecological groups: large, long-lived, tube-dwelling Mygalomorphae, Lycosidae, and Sparassidae; and small, short-lived, nomadic hunting spiders of the Gnaphosidae, Salticidae, and Thomisidae. Because the principal adaptations of spiders to live in desert environments are the burrowing habit and metabolic compensation to high temperature, these can be considered as limiting factors for the spider fauna in desert ecosystems. A very important reason for the high abundance and diversity of spiders inside gardens is the presence of high amounts of litter, used as shelters as well as good hunting sites for wandering spiders. Experimentally, mean spider densities were significantly higher on plots with increased litter compared with natural conditions (Stippich 1989), and under no-litter conditions the abundance of spiders was strongly reduced: this mimics what happens in desert ecosystems. No significant differences were found among different habitats in family richness, or mean diversity per trap: this may be because of the low number of spiders caught by each individual trap. Spider abundance and diversity are often correlated with specific vegetation characteristics (Carter & Rypstra 1995), which suggests that the availability of habitat is an important factor for spider colonization and establishment in an ecosystem like South Sinai.

Only spider abundance showed differences among sites within localities, while overall diversity, mean diversity per trap, and family richness showed no such differences. This could be explained by that sites within localities had more or less similar micro-environmental conditions and availability of resources. Possibly the reason behind the difference in spider abundance among sites can be attributed to differences in prey availability. Sites inside the gardens of El-Mafareq and Wadi Feiran have a rich and diverse prey fauna. Similar suggestions were introduced by McIver *et al.* (1992).

The similar micro-environmental conditions may also account for the lack of differences among localities in some variables, i.e. general diversity, and mean diversity per trap. However, localities showed highly significant differences in spider abundance and family richness; such differences might be attributed to the structural complexity of the local environment in the studied localities, as well as agricultural practices that enhance both the density and species richness of spiders (Rypstra *et al.* 1999). Human factors are also likely to induce changes in spider densities in localities such as Wadi Feiran, and Wadi El-Arbaein in St. Katherine. Jeanneret *et al.* (2000) showed that spider species richness is not necessarily higher in unmanaged meadows than in intensively managed ones, and perhaps this also accounts for why Wadi Feiran showed a lower species richness than both El-Mafareq and St. Katherine.

There were clear seasonal patterns of trap catches; such differences are correlated to the climatic changes occurred through different seasons of the year, in such an arid area as south Sinai. Spider activity certainly responds to dramatic changes in temperature through the year (Daiqin *et al.* 1996). Like other animals, spiders have a preferred range of climatic conditions, but because of their mobility they can change altitude to maintain their preferred range (Evans 1997). Spiders may constitute a perfect example among groups of mobile animals for studying temporal variation in diversity and abundance.

The different localities had distinctive assemblages of spiders. Most of these differences are related to habitat heterogeneity, and altitude and its effect on the climate; mainly temperature, and relative humidity. Although now a Protectorate, the area needs much more attention in order to promote its conservation. Spider taxonomy and identification need more attention and effort in an area like Sinai, because this group of arachnids is relatively poorly known and little is known about its conservation.

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