Proceedings of the First International Conference (Egyptian British Biological Society, EBBSoc)
Egyptian Journal of Biology, 2001, Vol. 3, pp 147-156
 Egyptian British Biological Society (EBB Soc)

Spatial variation in the biodiversity of Bedouin gardens in the St.Katherine Protectorate

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Abstract

Three wadi systems in the St. Katherine Protectorate (south Sinai, Egypt) were surveyed for spatial variation in the biodiversity of plants, flying insects and ground insects in August- September, 2000. Plant diversity and species richness were significantly different among the systems (the St. Katherine and Gebal systems were more diverse than the Gharaba system), and each system had characteristic groups of plant species. There were no significant differences in the diversity of flying insects among systems, perhaps because of their mobility: nevertheless the St. Katherine system had the highest diversity, and Gharaba the lowest. In contrast, ground insects showed a different pattern of diversity: there were significant differences among systems, with the highest diversity and species richness recorded in the Gharaba system. The results indicate that the St. Katherine Protectorate is biologically very heterogeneous even among adjacent wadi systems that are physically very close and apparently have similar physical structure. This has important implications for conservation and management.

Keywords: insects, plants, conservation

Introduction

The St. Katherine Protectorate was gazetted in 1988 and established in 1994 by the Egyptian Environmental Affairs Agency (EEAA) to protect a unique part of the Peninsula of Sinai. The Protectorate encompasses virtually the entire massif of high mountains in southern Sinai. The natural conditions and geographical position of Sinai makes it a distinctive biological region, a bridge between Asia and Africa, with its own characteristic fauna and flora. Floristically it belongs to the Saharo-Arabian phytogeographical region, but is classified as a separate subcategory as the Irano-Turanian chorotype. The Protectorate supports about 800 plant species, almost two-thirds of the total of 1285 for the whole of Sinai (Ayyad et al., 2000). The climate of the St. Katherine Protectorate is extremely arid with long, hot rainless summers and cool winters. Southern Sinai lies in low rain belt of Egypt with an average rainfall of 57 mm per year, but the high mountains of area immediately around St. Katherine receives higher amounts of precipitation (100 mm per year) as rain and sometimes snow.

A good understanding of the spatial pattern of biodiversity is fundamental to understanding ecosystem quality. In a region as large as the St. Katherine Protectorate (about 4350 km^2), there may be strong habitat heterogeneity, and thus different spatial locations may have quite different biodiversities. A high diversity within the plant and insect communities of a habitat is an important indicator of the overall quality of that system (Primack, 1993), and knowledge about spatial variation in habitat quality is important as the Protectorate management develops its conservation programmes. The vegetation of wadis is the primary focus for conservation and management in the area, and elsewhere in Egypt it is known to support an interesting desert soil fauna (Ghabbour & Mikhail, 1993). The wadis are also home to Bedouin communities that utilise them as range-land for camels, goats and sheep (Briggs et al., 1993), and thus the management plan for the Protectorate needs to promote the quality of at least some wadis as forage for domestic animals. Both habitat diversity and size of an ecosystem influence the number of species supported, but other variables are also important.

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Current ecological theory suggests that a moderate degree of stress or disturbance tends to maximise species diversity; in Wadi Allaqi in Upper Egypt, three variables (plant cover, soil moisture and grazing intensity) predicted more that 50% of species richness (Ali et al., 2000).

The mountainous environment of the Protectorate consists of different drainage systems, each made up of a number of connected wadis; within each wadi there are scattered walled Bedouin gardens of different sizes, each built around a well that provides a source of permanent water. The Bedouin grow various cultivated vegetable and fruit crops in the gardens, which are regularly irrigated but are hardly if ever grazed. Wild plants are weeded immediately around the crop plants in spring, but rarely elsewhere. Thus these gardens constitute replicate fenced enclosures with much greater potential for plant growth than outside. The current study aims to explore the value of these gardens to the Protectorate, looking particularly at spatial variation in the biodiversity of Bedouin gardens through different wadi systems and among wadis within the system.

Materials & Methods

We carried out the study during August- September, 2000 in the arid wadi systems of the St Katherine Protectorate, around the town of St. Katherine, south Sinai, Egypt. The general area has been described by Willmer et al (1994), Semida (2000), Gilbert et al. (1996, 1999), Stone et al (1999) and Ayyad et al (2000).

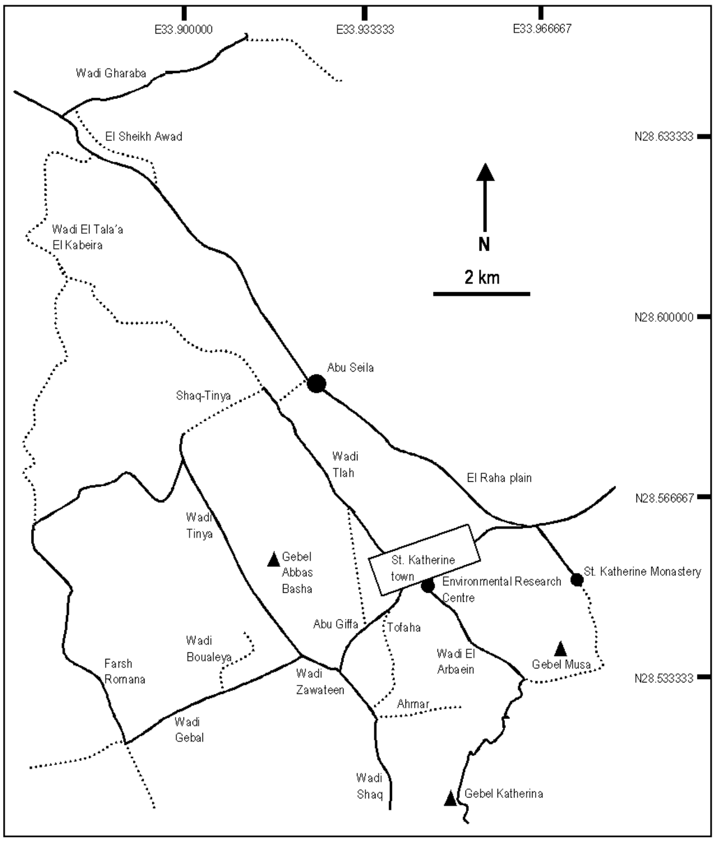

Fig 1: Map of St Katherine showing the study sites

We selected three wadi systems for detailed study: the wadi Gebal system (represented by the wadis Boualeya, Farsh el Romana, Tobouq and Zawateen), the Gharaba system (wadis Gharaba, Boreka and Naqb El Hawa) and the St. Katherine system (wadis El Arbaein, Tofaha, Rasis and Tlah) (see Fig 1). Each garden was visited in turn, and its position, area and altitude recorded using a hand-held GPS receiver (Trimble Navigation Europe., Hampshire, UK).

Seventy-one gardens were surveyed quantitatively, recording the number of plant species and the number of individuals in each garden. Preliminary identification of the plants was made in the field using Täckholm (1974), with more critical identifications made later using a herbarium at Suez Canal University. Insects associated with the plants were surveyed using a standard sweep net; the ground entomo-fauna were sampled using pitfall traps (30 traps per garden: 15 inside and 15 outside the garden) in the Gebal and Gharaba systems.

The diversity of each site was assessed using a Simpson diversity index, since this is the most tractable and statistically useful calculation (Lande 1996); the species richness and total abundances were also calculated. For the insect data, the total Simpson diversity was partitioned into within-site and among-site components, following Lande (1996): the within-site diversity is the community structure of the site itself, the α-diversity, whereas the among-site component is equivalent to the β-diversity, the turnover of community structure among sites. Unless stated otherwise, all diversities mentioned in the text are α-diversities. Statistical calculations were done using the programs Statistica version 4.5 and SPSS version 9.

Results

The Bedouin gardens: all gardens contain fruit trees, and most have vegetable crops as well. The largest garden is about 20 ha in size, and contains a large number of old olive trees; it belongs to St Katherine's Monastery, and was described by Burkhardt as a "pleasant place to rest" among the olive trees almost 200 years ago. However, the gardens also contain large numbers of wild plants: the full list of plants collected from these gardens is given in Appendix 1.

System	Wadi	Species richness	Overall abundance	Simpson diversity	Area
St Katherine	Arbaein	19.2 ± 3.1	1598 ± 795	0.86 ± 0.04	58816
	Rasis	22.4 ± 1.4	857 ± 123	0.82 ± 0.03	9041
	Tlah	14.1 ± 1.4	378 ± 121	0.74 ± 0.05	3160
	Tofaha	15.4 ± 1.6	361 ± 071	0.81 ± 0.04	6829
Gebal	Boualeya	19.2 ± 1.9	601 ± 178	0.83 ± 0.03	1709
	Farsh Romana	17.0 ± 3.6	1027 ± 658	0.81 ± 0.02	2469
	Tobouq	13.0 ± 4.0	369 ± 164	0.63 ± 0.11	1500
	Zawateen	18.3 ± 1.9	549 ± 217	0.88 ± 0.01	1471
Gharaba	Boreka	26.7 ± 2.0	1011 ± 394	0.63 ± 0.11	7488
	Gharaba	13.4 ± 1.7	465 ± 199	0.62 ± 0.07	2734
	Naqb El Hawa	12.8 ± 1.6	322 ± 118	0.71 ± 0.04	1977

Overall patterns of plant diversity: gardens can be regarded as replicated samples of the surrounding wild plants from the wadi in which they are located, except that they differ in area. The most obvious question is whether there are differences among systems, or among wadis within systems; we would also like to know how much of the variation in diversity appears at these different levels. We therefore used a nested Anova with garden area as a covariate. Most of the variation (>64%) in diversity, species richness and total abundance was due to differences among gardens (Table 1). For species richness and total abundance, much (>17%) of the remaining variation was due to garden area, as one might predict. There was no effect of garden area on species diversity, on the other hand, with most of the remaining variation shared equally among systems (14%) and wadis within systems (12%). This suggests the sampling areas (the gardens) from which our recordings were made were sufficient to estimate the diversity of the plants accurately.

After adjusting for the significant effect of area ($F_{1,61} = 16.2$, $p<0.001$), the number of plant species per garden did not differ significantly among systems ($F_{2,61} =0.41$, n.s.), although the means for Gebal and St Katherine systems were higher than for Gharaba (Fig 2a). There were significant differences in species richness among wadis within systems ($F_{6,61} = 4.3$, $p<0.001$), with both the highest (Wadi Boreka) and the lowest (Naqb El Hawa) in the Gharaba system (see Table 1). For total abundance of plants (Fig 2b), only the area covariate was a significant effect ($F_{1,61} = 23.2$, $p<0.001$).

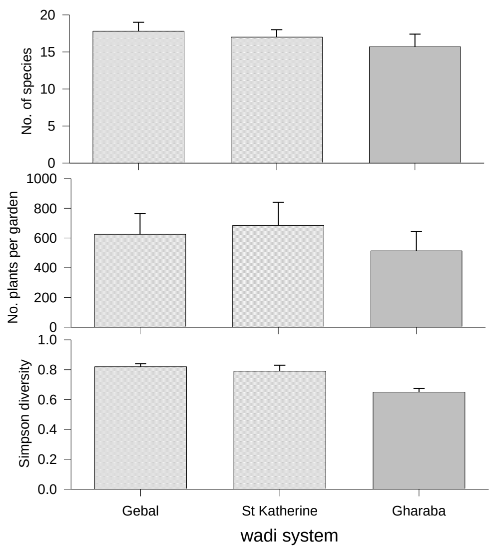

Figure 2: The average (a) species richness, (b) number of plants, and (c) Simpson diversity per garden for the wild plants of Bedouin gardens in three drainage systems of the St Katherine Protectorate, southern Sinai.

There was no area effect on Simpson diversity ($F_{1,61}$ = 2.2, n.s.), but the diversity of the wild plants differed significantly among systems ($F_{2,61}$ = 6.02, p<0.01) (Fig 2c); the Gebal and St Katherine systems are more or less equal and high in diversity, but the Gharaba system has a much lower diversity. There were no significant diffferences among wadis within systems. The increased diversity of the Gebal-St Katherine systems could be due to their increased altitude and isolation; it is therefore interesting that the diversity of plants in the gardens of the wadi connecting Gharaba with St Katherine (Naqb El Hawa) is intermediate between the high diversity of St Katherine and the lower diversity of Gharaba.

Differences among systems in plant diversity: to look for differences among the wadi systems, we excluded rare species by choosing all plant species with more than 100 individuals recorded overall. We then applied a square-root transform and analysed for differences among systems using Discriminant Function Analysis (DFA). The three wadi systems were very distinct along both the first two axes (χ^2_{76} = 230.2, p<0.001) and the second alone (χ^2_{37} = 102.6, p<0.001) (Fig 3). Along the first axis, which contains 64% of the discrimination, the Gharaba system has positive values and the Gebal system negative ones, St Katherine wadis being in between. Positive values along this axis are correlated most with the abundance of *Artemisia judaica*, *Raetama raetam*, *Ochradenus buccatus*, *Anabasis articulata* and *Fagonia arabica*, the negative values being associated with the abundance of *Euphorbia peplus*, *Lactuca orientalis*, *Plantago arabica*, *Malva parviflora*, *Achillea frgrantissima*, *Alkanna orientalis* and *Deverra tortuosa*. The second axis contains 36% of the discrimination, and contrasts the St Katherine system with a negative mean with the other two with positive means values. Positive values along this axis are associated with the abundance of *Artemisia judaica* and *Raetama raetam*, and negative values with *Fagonia mollis*, *Peganum harmala*, and *Asclepias sinaica*.

Plant diversity of wadis within systems: in the St Katherine system, we analysed four wadis (36 gardens) using DFA. All three axes contained significant amounts of the discrimination, but most (82%) was in the first axis, which contrasted Tlah (mean 13.3) and Arbaein (5.4) with Tofaha (-4.5) and Rasis (-25.0). Positive scores were weakly associated with *Raetama*, whereas negative values were associated with *Ballota undulata*, *Asclepias sinaica*, *Lactuca orientalis* and *Verbascum sinaiticum*.

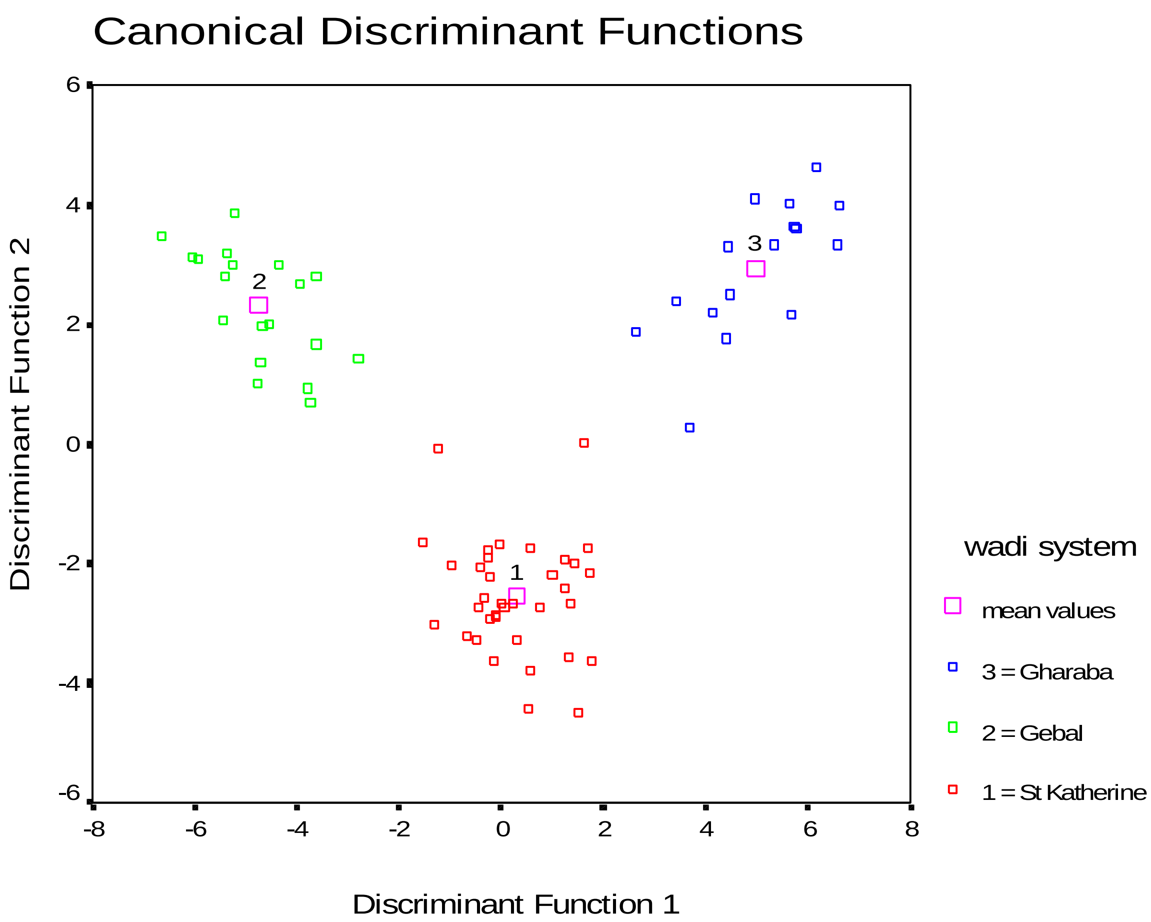

Figure 3: Plot of the Bedouin gardens along the first two axes of a discriminant function analysis of the abundance of the commoner species of plants.

The four wadis of the Gebal system (19 gardens) did not quite separate significantly; the axis contrasted *Mentha* in Tobouq (negative) with *Phragmites* in Boualeya (positive). In the three wadis of the Gharaba system, there was significant discrimination, virtually all along the first axis, which contrasted *Ochradenus* in Wadi Boreka (positive) with the *Teucrium* and *Mentha* in Wadi Gharaba and Naqb El Hawa (negative).

Insect diversity: two types of data were gathered, by sweep-netting within gardens, and by pitfalls traps inside and outside gardens. The Simpson diversity of aerial insects from sweep netting showed very little variation among wadi systems (β = 0.0015). Within sites, the diversity of the Gharaba system was lower than those of the Gebal and St. Katherine systems (Fig. 4a). A total of 56 different insect species were collected from the three systems using sweep nets. Species richness in the Gebal system was the highest, similar to the St. Katherine system, while Gharaba system had the lowest richness (Table 2). The diversity of the ground entomofauna sampled with pitfall traps showed that the Gharaba system had significantly greater diversity than Gebal (Fig 4b), and more species caught per trap (Gharaba 2.4, Gebal 0.8) and higher number of individuals (Gharaba 16.1, Gebal 2.9).

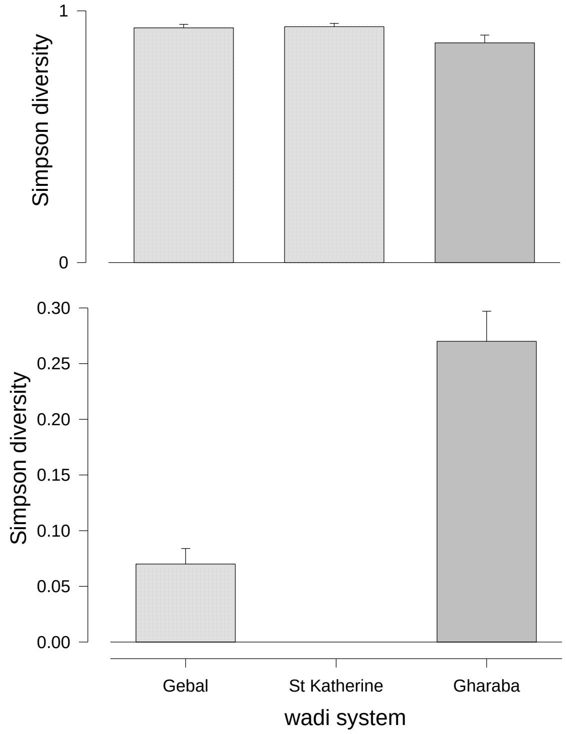

Figure 4: Simpson diversity of (a) flying and (b) gound insects of the wadis systems. Ground insects were not surveyed in the St Katherine system

Table 3: Insects caught by sweep netting from on or near the plants of Bedouin gardens in the St Katherine Protectorate, Sinai.

Insect order	Insect family	Insect species	Gebal	St Katherine	Gharaba	Total
Coleoptera	Carabidae	sp1	0	1	1	2
		sp2	1	0	0	1
		sp3	1	0	0	1
	Coccinellidae	*Coccinella septempunctata*	1	0	1	2
		Coccinella undeseptempunctata	1	0	1	2
	Tenebrionidae	*Pimelia* sp.	0	1	0	1
Diptera	Bombyliidae	*Exoprosopa* sp	0	1	0	1
	Calliphoridae	*Calliphora* sp.	1	0	0	1
		Lucilia sericata	3	0	0	3
	Muscidae	*Musca domestica*	2	0	0	2
	Sarcophagidae	*Sarcophaga* sp.	2	0	0	2
	Syrphidae	*Eristalis aeneus*	0	1	0	1
		Eupeodes corollae	1	0	0	1
		Ischiodon aegyptiaca	0	3	0	3
		sp1	0	2	0	2
		Syritta sp.	0	4	0	4

Hemiptera	Lygaeidae	*Spilostethus pandurus*	12	0	0	12
	Pyrrhocoridae	*Pyrrhocoris apterus*	0	1	0	1
	Reduvidae	sp1	1	0	0	1
Hymenoptera	Andrenidae	*Andrena* sp	0	1	0	1
	Anthophoridae	*Melecta* sp.	0	2	0	2
		Xylocopa sulcatipes	2	0	0	2
	Chalcididae	sp1	0	0	1	1
	Eumemidae	*Odynerus* sp.	2	0	0	2
		Delta hottentatum elegans	0	3	0	3
		Euodynerus sp	1	0	0	1
		Ischnogasteroides leptogaster	2	1	0	3
		Rhynchium cyanopterum	0	0	0	0
	Evaniidae	*Evania* sp.	5	0	0	5
	Halictidae	*Halictus* sp	1	1	1	3
	Megachilidae	*Anthidium* sp.	1	2	0	3
		Coelioxys sp	1	0	0	1
		Megachile sp	1	1	0	2
	Mutilidae	sp1	1	0	0	1
	Pompilidae	*Ctenogenia vespiformis*	0	4	0	4
	Sapygidae	*Sapyga* sp	0	1	0	1
	Scoliidae	*Scolia morio*	0	0	0	0
	Sphecidae	*Ammophila* sp.	2	0	0	2
		Bembex oculatum	0	0	5	5
		Cerceris fisheri	1	1	0	2
		Philanthus triangulum	1	2	0	3
		Podalonia sp.	2	0	0	2
		sp1	1	0	1	2
		Tachysphex sp.	3	0	0	3
	Vespidae	*Vespa orientalis*	0	0	1	1
Lepidoptera	Hesperidae	*Carcharodes stauderi*	1	3	0	4
		Gomalia elma	0	0	2	2
		Spialia doris	0	1	0	1
	Lycaenidae	*Freyeria trochylus*	0	1	0	1
		Lampides boeticus	1	0	3	4
		Tarucus balkanicus	0	2	1	3
		Zizeeria karsandra	3	6	2	11
	Pieridae	*Colias croceus*	0	1	0	1
		Madais fausta	0	1	0	1
		Pontia glauconome	0	2	0	2
	Satyridae	*Pseudotergumia pisidice*	3	1	0	4
		total	61	51	20	132

Discussion

In the St. Katherine Protectorate, as in most of the natural reserves or protected areas, management practices carried out are normally based on the protection of large vertebrate species . The elimination of traditional farming in many natural reserves may have a negative impact on the flora and invertebrate fauna (Samways, 1994), and the consequence is the loss of both (alpha) diversity (of a community within a uniform habitat) and β diversity (the change in community structure as a function of changing habitat) (cf. Verdu et al., 2000).

Human impacts continue to push natural systems in the direction of increasing patchiness and variability, and patchy habitats can affect ecological patterns and processes. MacArthur & Wilson's (1967) theory of island biogeography predicts that the smaller and more patchy habitat, the lower the equilibrium level of diversity it will achieve. Metapopulation theory (Hanski 1997; Hanski & Simberloff 1997) predicts that species may become extinct regionally if patches of their habitat become fewer or more isolated. Caswell & Cohen (1991) showed that local extinction, colonization and competition in a patchy environment can lead to high total species richness by promoting variation in species composition among patches (β diversity), but fragmentation can lead to the loss of the dominant species in a metacommunity (Tilman et al., 1994). Harrison (2000) studied population persistence and community diversity in a naturally patchy habitat in California, USA, and produced strong support for the island biogeography and metapopulation theories.

The pattern of species richness and endemism at the global and regional scales received more attention in the past (Major 1988). Recently, awareness of the looming biodiversity crisis (Myers 1990) has emphasised the need for local floristic and faunistic studies to determine biologically important areas, which will enhance the value of conservation management programmes of such areas. The current study emphasises the value of the spatial variation in biodiversity on a local scale.

The high ridged mountains of the St Katherine Protectorate separate wadis into different systems. There may be differences in the environmental elements of these systems (soil type, soil moisture, precipitation, altitude, etc.) which may affect biodiversity. However, differential extinction and colonisation in different localities may also lead to variation among habitats, and thus habitat patchiness will promote differences in species diversity, species richness and abundance. In wadi systems like the St. Katherine or Gebal systems, which are higher in altitude and receive a higher rate of precipitation than the Gharaba system, we found a higher plant species diversity. While the St. Katherine system has the largest gardens among the three systems, garden areas do not have a significant effect on α-diversity, but do have direct positive effects on species richness and abundance. Thus the differences among systems in α-diversity are not caused by differences in the average size of the gardens.

The effects of isolation among systems lead to the appearance of distinctive plant groups at different wadi systems. Probably many of these differences resulted from differential extinctions in the different wadis after climate changes from the cooler wetter periods of the past, but others may be caused by altitudinal gradients in climate. The St. Katherine system is characterised by the presence of *Alkanna orientalis*, *Asclepias sinaica*, *Ballota undulata* and *Tanacetum santalinoides,* while the Gebal system has a different group of characertistic species, *Artemisia herba-alba*, *Phragmites australis*, and *Mentha longifolia*. These differences are probably extinction-based. The Gharaba system has yet different species, *Artemisia judaica*, *Raetama raetam*, *Ochradenus baccatus*, *Anabasis articulata* and *Fagonia arabica*, but these differences are probably altitudinally related.

Flying insects undoubtedly play an important role in desert food webs and nutrient cycling. Many are herbivores and have a significant effect upon the vegetation, especially when locally abundant (Tiger & Osborne 1999). These insects usually have an associated fauna of predators and parasites, and thus may determine community composition beyond their own trophic level. Such insects are often strong fliers, capable of dispersing long distances over patchy desert environments in search of their host plant or prey. Such activity may mean that patterns in diversity and abundance observed for ground fauna are obscure or absent when compared to their aerial counterparts. The high mobility of flying insects may enable them to cross the ridged mountain barriers and sometimes move between adjacent wadi systems, although this ability may often be more apparent than real: a local bee *Anthophora pauperata* is a powerful flier, and yet does not seem to disperse even to adjacent wadis (Willmer et al., 1994). Mobility thus may or may not be a factor limiting the effect of patchiness on diversity among systems. Flying insects show a slightly higher diversity in the St. Katherine and Gebal systems than that of the Gharaba system. In contrast, the ground entomofauna shows a very different pattern of diversity, species richness and abundance. The Gharaba system has a higher diversity, species richness and number of individuals caught per trap compared with both the St. Katherine and Gebal systems. This may be an effect of altitude, with fewer ground-dwelling insects able to tolerate winter conditions; however, a much more extensive year-long study using pitfall traps shows the reverse, a positive relationship between diversity and altitude (Semida et al., unpublished data).

This study shows that the St. Katherine Protectorate has a biologically very rich and important system of wadis that are strongly heterogeneous in the communities of plants and insects that they contain. The management plan for the Protectorate will clearly be more complicated by these findings, since wadis are not equivalent to each other biologically.

Acknowledgements

Special thanks to the British Council in Egypt who fund and support this work through the link activity between Nottingham and Suez Canal Universities. We thank Professor M Fouda and Dr John Grainger for logistic and financial help with this project. Thanks are also due to Tarek El-Kanawaty, Muhammed El-Haj, Dr Philip Harris, Anja Bajer, Dr Magda Gazara, Dr Wafaa Kamel, Laura Cliffe, Alex Rhoades, Mike Lamb, Jane Hurst, Amir Mohamed and Eman Ali for participating in the data collection. Special thanks are due to the Bedouin of St Katherine for their generous hospitality and great help during the course of this study.

Appendix 1: Structure matrix of the Discrminant Function Analysis of the abundance of the commoner plants of Bedouin gardens of three wadi systems. The values represent the correlations between the first two functions and each of the original variables (plant abundances, square-root transformed).

Original variable	Discriminant Function	
	1	**2**
Artemisia judaica	.322	.336
Raetama raetam	.203	.171
Ochradenus buccatus	.196	.041
Anabasis articulata	.145	.149
Fagonia arabica	.143	.078
Deverra tritadiata	.088	.091
Fagonia mollis	.087	-.263
Caylusea hexagyna	.060	-.197
Phragmites australis	.047	.132
Salvia aegyptiaca	.029	-.083
Graminae	.023	.031
Peganum harmala	.020	-.246
Ballota undulata	.018	-.185
Asclepias sinaica	.015	-.227
Matthiola longipetala	.011	-.173
Scrophularia deserti	.008	-.120
Ephedra sp	.007	-.103
Juncus	-.007	.023
Origanum syriacum	-.036	-.099
Phlomis aurea	-.043	-.041
Zilla spinosa	-.055	-.076
Varthemia montana	-.071	-.058
Mentha longifolia	-.076	-.010

Artemisia herba-alba	-.080	-.096
Teucrium polium	-.082	-.038
Tanacetum santalinoides	-.091	-.001
Ephedra foemina	-.103	.085
Echinops glaberrimus	-.103	-.034
Verbascum sinaiticum	-.105	-.035
Stachya aegyptiaca	-.107	-.143
Silene vivianii	-.110	.074
Deverra tortuosa	-.123	.095
Alkanna orientalis	-.123	-.141
Achillea frgrantissima	-.124	-.131
Malva parviflora	-.132	-.007
Plantago arabica	-.157	.140
Lactuca orientalis	-.182	.130
Euphorbia peplus	-.183	.157

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