Diversity patterns of ants along an elevation gradient at St. Catherine Protectorate, South Sinai, Egypt

(Hymenoptera: Formicidae)

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Abstract. Ants (Hymenoptera: Formicidae) captured in pitfall traps were compared within and among three altitudinal gradients in St. Catherine Protectorate, south Sinai, Egypt, to study the ant diversity patterns and their relationship with environmental factors. A total of 26,165 specimens of ants belonging to 17 different species were sampled. Our main findings were that (1) there were no significant differences in ant species richness, evenness and Shannon`s diversity index between the three elevation plots; while ant abundance was significantly different between low-elevation plots and both mid- and high-elevation plots, there was no significant difference between mid- and high-elevation plots in terms of ant abundance. (2) TWINSPAN analysis and detrended correspondence analysis (DCA) of the ant fauna indicated that the high-elevation plots were distinctly separated from both mid- and lower-elevation plots according to their ant species composition. (3) CCA showed that both the elevation and the two plant species *Acacia raddiana* and *Casuarina* sp. were the significant factors separating the ant species community along their altitudinal gradients. (4) *Lepisiota nigra* ((Dalla Torre, 1893) (P<0.01), *Tetramorium depressiceps* Menozzi, 1933 (P<0.05), and *Cataglyphis ruber* (Forel, 1903) were found at the high-elevation plots; while *Camponotus aegyptiacus* Emery, 1915 (P<0.02), *Cataglyphis sabulosus* Kugler, 1981 (P<0.03), and *Messor foreli* Santschi, 1923 (P<0.05) favoured the low-elevation plots.

Key words. Bioindicators, species richness, vegetation, arid ecosystem, Sinai, Egypt.

Introduction

Ants account for an estimated 30% of terrestrial animal biomass (Hölldobler & Wilson 1990) and play many important ecological roles, having direct interactions with the soil, plants and animals at all trophic levels. Many of these roles relate to paedogenesis, nutrient cycling (Hutson 1989), seed predation (Andersen 1990, Majer 1990) and seed dispersal (Majer 1990). Ants are considered to be an ideal candidate for use as an indicator group for a number of reasons: they are abundant and ubiquitous in areas of disturbance (Andersen 1990), they exhibit strong interactions with all trophic levels (Briese 1982), and most ants have stationary nests and restricted foraging ranges which reduce competition between ant species (Alonso 2000). They are highly sensitive to environmental conditions and disturbance and they respond rapidly to environmental change (Van der Woude et al. 1997, Andersen 1990). Furthermore, sampling is relatively easy, without requiring enormous expertise and experience.

Given the diversity and abundance of ants, identifying change in a community is more eas-

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ily noted following the grouping of species according to physical or behavioural characteristics, and identifying changes among these groupings. Allocation of ant species to a functional group can provide an immediate indication of the species' role and status in ant communities. These functional groups vary predictably in relation to environmental stress and disturbance (ANDERSEN 1995).

The result and conclusions drawn on the performance of ants as indicators often depend on the variables used to quantify and analyse responses to disturbance. Whereas species richness and abundance are some of the most commonly used measures (ANDERSEN et al. 2003), they do not necessarily signal a response to perturbations in the ecosystem. For example, species richness in disturbed sites can often remain at pre-disturbance levels as less adaptable species are replaced by species of more open conditions (BESTELMEYER & WIENS 2001, KALIF et al. 2001). For this reason, analyses should also be performed on variation in assemblage composition, in order to ascertain the real effects of disturbance and subsequent rehabilitation.

The main purpose of the present investigation was to study the diversity pattern of ants at ten arid sites in south Sinai, characterised by different elevation levels and habitat structure. A specific aim was to apply ant species in order to evaluate the bioindicator species-based approaches to ecological monitoring.

Material and Methods

Study Area. The southern Sinai is a mountainous area, covering about 7000 km². Several wadis (valleys) run through the mountains. These wadis are characterised by different climatic conditions due to the isolation effect. Ten sites arranged along altitudinal gradients were selected to sample the ant fauna: St. Catherine (28°33'N, 33°56'E, 1620-1730 m.a.s.l.), Sahab (28°43'N, 33°45'E, 950 m.a.s.l.), and El-Mafareq (28°42'N, 33°19'E, 120 m.a.s.l.). El-Mafareq is a lowland site (altitude 90 m) and lies 106 km from the St. Catherine sites (altitudes 1620-1730 m), while Sahab lies in between (altitude 900 m).

Sampling methods. The pitfall trap technique was adopted to measure the ant fauna over a period of one year in the study area. Ten sites were chosen to represent the three different localities. At each site, 20 pitfall traps (5.7 cm in diameter, 13 cm depth for each trap) were distributed systematically at 5-metre intervals within a 500 m^2 area. Each individual trap remained in exactly the same position during the entire period of study, allowing comparable results on the cumulative catches per trap. Traps were left open for 48 hours every month. The captured specimens in each trap were counted and then identified by M. Sharaf.

Environmental variables. Physical and chemical soil characteristics (Table 1) were analysed at the different study sites (organic matter, moisture, pH values, electric conductivity and soil texture) according to WILDE et al. (1979). The vegetation cover was measured at the study area, using the quadrate technique (three quadrate/site, each 5x5 metres). The number of plant species and the number of individuals of each species were recorded. The foliage cover was also measured. Plant species identification was carried out in Saint Catherine Herbarium, Suez Canal University.

Data analysis. Ant species richness, mean abundance Shannon`s diversity index and evenness were calculated using the PC-ORD program for Windows version 4.14 (MCCUNE & MEFFORD 1999). Differences in ant mean abundances, richness and evenness per plot between sites were compared using one-way analysis of variance (ANOVA) (ZAR 1999), using the SPSS for Windows 12 statistical software package.

Table 1. Site characteristics. CA1-CA4, St. Catherine sites 1-3; M1-M3, El-Mafareq sites 1-3; SA1-SA3, Sahab sites 1-3.

Variable	CA1	CA2	CA3	CA4	SA1	SA2	SA3	MA1	MA2	MA3
Elevation	1620	1640	1730	1640	900	900	900	90	90	90
pH	8.4	8.1	8.1	8.5	8.1	8.1	7.8	8.2	8.3	8.1
Conductivity (micro-mhos)	108	318	449	123	1810	181	3599	659	1818	2222
Organic Matter (%)	1.66	4.45	6.38	0.98	3.82	2.59	4.32	3.90	2.68	3.05
Moisture (%)	0.45	2.08	2.30	3.18	0.59	0.31	0.52	0.82	0.87	1.37
Gravel (%)	36.6	41.8	41.7	60.7	29.9	39.3	22.1	4.0	4.4	2.3
Coarse Sand (%)	48.7	43.2	51.6	80.7	31.4	46.2	39.5	21.7	19.1	8.3
Medium Sand (%)	29.9	23.8	21.7	13.2	31.1	22.7	28.5	27.9	35.6	27.7
Fine Sand (%)	15.3	23.4	18.2	5.0	27.5	22.9	22.3	44.4	39.8	55.3
Silt + Clay (%)	6.70	9.43	7.75	0.83	10.73	8.02	9.30	5.52	3.33	8.02
No. of Plant Species	17	17	5	7	2	1	0	5	5	1
No. of Cultivated Plant Species	0	0	5	0	1	1	0	1	1	1

Classification. Two-way indicator species analysis (TWINSPAN) was performed using the statistical package PC-ORD for Windows version 4.14 (McCune & Mefford 1999) using the following settings: maximum number of indicators per division = 5; maximum level of division = 3; minimum group size per division = 6; and maximum number of the species in the final table = 50. Classification by TWINSPAN was stopped at the third level, so that the size of the sites would demonstrate ecological meaning. Ordination was used in part to check whether the classification by TWINSPAN adequately reflected the ant species gradient composition in the data and also to detect the relations between environmental factors and the composition of the ant communities CA1, CA2, CA3 and CA4 (CA = St. Catherine, the four sites at St. Catherine), SA1, SA2, and SA3 (SA = Sahab, the three sites in Sahab), and MA1, MA2 and MA3 (MA = El-Mafareq, the three sites in El-Mafareq).

Ordination. Two ordination methods were applied: detrended correspondence analysis (DCA) (Hill & Gauch 1980) and canonical correspondence analysis (CCA) (Ter Braak 1987). DCA was carried out using the PC-ORD package. Only species that were found at three or more sites were included in the DCA analysis. The CCA was done in the forward selection mode of the CANOCO program (Ter Braak 1987), and the significance of each variable was tested in a sequential fashion using a Monte-Carlo simulation algorithm before it was added to the final model. All variables that were significant at $p<0.05$ were included in the final model. The environmental variables were log-transformed to compress high values and spread low values by expressing the value as an order of magnitude (McCune & Grace 2002).

Indicator species analysis. The analysis of indicator species by Dufrene & Legendre's (1997) method provided a simple, intuitive solution for identifying which species might serve as indicators of a particular environmental condition. This method calculated the proportional abundance of a particular species in a particular group, relative to the abundance of that species in all groups. Then, the method calculated the relative abundance of a certain species in a certain group and calculated the proportional frequency of the species in each group. These percentages were regarded as representations of the faithfulness or constancy of presence within a particular group.

Table 2. Ant species abundance (number of specimens) and distribution. CA1-CA4, St. Catherine sites 1-3; M1-M3, El-Mafareq sites 1-3; SA1-SA3, Sahab sites 1-3.

	Code	St. Catherine				Sahab			El-Mafareq		
		CA1	**CA2**	**CA3**	**CA4**	**SA1**	**SA2**	**SA3**	**MA1**	**MA2**	**MA3**
Camponotus aegyptiacus Emery, 1915	A1	0	0	0	0	0	0	0	519	86	91
Camponotus fellah Dalla Torre, 1893	A2	0	0	0	14	0	0	0	0	0	0
Camponotus oasium Forel, 1890	A3	13	12	26	0	28	5	21	1	4	1
Cardiocondyla mauritanica Forel, 1890	A4	0	0	0	0	0	13	7	12	7	2
Cataglyphis niger (André, 1881)	A6	172	4	56	23	224	2	394	0	0	0
Cataglyphis ruber (Forel, 1903)	A7	34	13	5	0	0	0	0	0	0	0
Cataglyphis sabulosus Kugler, 1981	A5	0	0	0	0	117	45	248	2700	1311	2267
Cataglyphis sp.	A8	1	0	3	7	0	0	0	0	0	0
Crematogaster aegyptiaca Mayr, 1862	A9	920	852	1462	0	0	151	16	0	0	0
Lepisiota nigra (Dalla Torre, 1893)	A10	144	111	50	19	0	0	0	0	0	0
Messor ebeninus Santschi, 1927	A11	2	0	0	0	0	0	0	0	0	0
Messor foreli Santschi, 1923	A12	0	0	0	0	4	18	4	133	1875	27
Monomorium niloticum Emery, 1881	A14	229	448	453	656	2811	10	92	1	0	0
Monomorium salomonis (Linnaeus, 1758)	A13	204	7	6	0	261	65	1214	2642	1500	1136
Pheidole sinaitica Mayr, 1862	A15	0	0	0	70	15	0	17	0	0	0
Plagiolepis maura Santschi, 1920	A16	0	0	0	0	1	0	7	1	0	4
Tetramorium depressiceps Menozzi, 1933	A17	33	4	2	0	0	0	0	0	0	0
Species richness		10	8	9	6	8	8	10	8	6	7
Mean Abundance		103.1	85.35	121.4	46.41	203.6	18.18	118.8	353.5	281.4	207.5
Diversity		1.488	1.012	0.868	0.675	0.728	1.468	1.201	1.033	1.173	0.795
Evenness		0.646	0.487	0.395	0.377	0.35	0.706	0.521	0.497	0.655	0.409

The two proportions were then multiplied to yield a percentage, which was used as an indicator value for each species in each group. Because the component terms are multiplied, both indicator criteria must be high for the overall indicator value to be high. The highest indicator value for a given species across groups is saved as a summary of the overall indicator value (IV) of that species and evaluated by the Monte Carlo method, with randomly reassigned SUs (sample units) to groups taking place 1000 times. The probability of a type I error occurring was the proportion of times that the IV from the randomized data set equals or exceeds the IV from the actual data set. The null hypothesis is that IV is no larger than would be expected by chance (McCune & Grace 2002).

Results

Differences in richness and abundance. Over the four seasons of collection, a total of 17 species of ants were identified from 26,165 ant specimens (Table 2) collected by pitfall traps during the study period. The site MA1 at El-Mafareq recorded the highest mean abundance; in contrast, SA2 at Sahab showed the lowest value. The lowest values for both ant species richness (6 & 7) and Shannon`s diversity index (0.675 & 0.795) were recorded by the El-Mafareq plot (MA3 90 m a.s.l) and St. Catherine plot (CA4 plot, 1640 m a.s.l). The lowest values for the species evenness (0.350 & 0.377) were recorded at the CA4 plot and Sahab plot (SA3 900 m a.s.l). The ant species richness peaked up at SA3 and CA1 (1640 m a.s.l). The highest values for Shannon`s diversity index (1.468 & 1.488) were recorded from the mid-elevation plot SA2 (900 m a.s.l.) and CA1 plot. The evenness high value (0.706) was recorded from SA2 plot (Table 2).

Species area curve. During the study period, our sampling method resulted in the collection of 17 species, which represent 95% of the estimated total species richness by the first-order jackknife estimate. The curve showed a considerable flattening after the fourth trip, which meant that all the common species were collected after the fourth trip (Fig. 1).

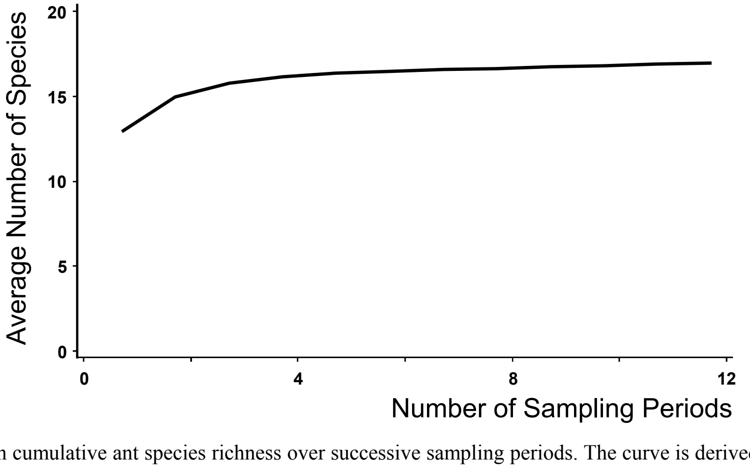

Fig. 1. Mean cumulative ant species richness over successive sampling periods. The curve is derived from 500 repeated subsamples from the data set.

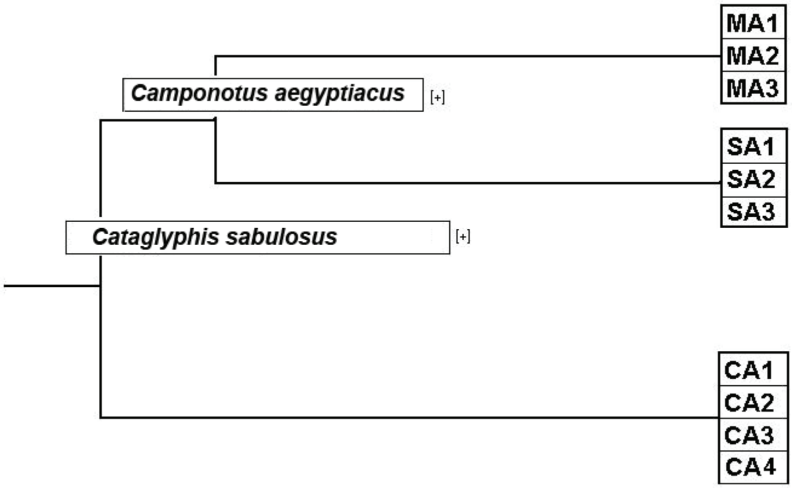

Fig. 2. Twinspan cluster Analysis (CA1-CA4, St. Catherine sites 1-3; M1-M3, El-Mafareq sites 1-3; SA1-SA3, Sahab sites 1-3).

Many interesting and rare ant species were collected from the surveyed sites. For example, *Tetramorium depressiceps* Menozzi, 1933 was collected from St. Catherine, which was previously recorded in Egypt only by MOHAMMED et al. (2001). *Cataglyphis sabulosus* Kugler, 1981 was collected from Sahab and El-Mafareq sites, and it was originally described from Sinai by KUGLER (1981). It is a species with a higher abundance at the second site.

One-way ANOVA revealed significant differences in ant abundance between El-Mafareq plots (MA1, MA2 and MA3) and both the St. Catherine plots (CA1, CA2, CA3 and CA4) and Sahab plots (SA1, SA2 and SA3) (P<0.05), where the ants were more abundant at the El-Mafareq plots. However, there were no significant differences between the St. Catherine plots and Sahab plots in terms of ant abundance. One-way ANOVA showed no significant differences in ant species richness, evenness and Shannon`s diversity index between all the plots.

Differences in assemblages. *TWINSPAN sites groups.* Two-way Indicator Species Analysis produced three cluster groups by two divisions (Fig. 2). The first division showed the ant species *Cataglyphis sabulosus* as a positive indicator species, separating the four plots CA1, CA2, CA3 and TA on the negative side from the other plots. The second division separated the three plots MA1, MA2, and MA3 on the positive side from the other three plots, SA1, SA2 and SA3 on the basis of the positive indicator ant species, *Camponotus aegyptiacus* Emery, 1915. Fig. 3 shows axes 1 and 2 of a DCA of ant species collected by pitfall trapping. The first two axes accounted for 61.1% of the total variance of the data. The ten sites are plotted along axes 1 and 2, and tend to cluster along axis 1 into the three groups, that resulted from the TWINSPAN analysis described above. The sites are spread out along the first and the second axes in approximate order of increasing altitude gradient.

*DCA analysis***.** The four plots, CA1, CA2, CA3 and CA4, are shown in the first two axes of this ordination (347, 46) near the right-hand end of the first axis, as were the species *Cataglyphis ruber* (Forel, 1903), *Lepisiota nigra* (Dalla Torre, 1893) and *Tetramorium*

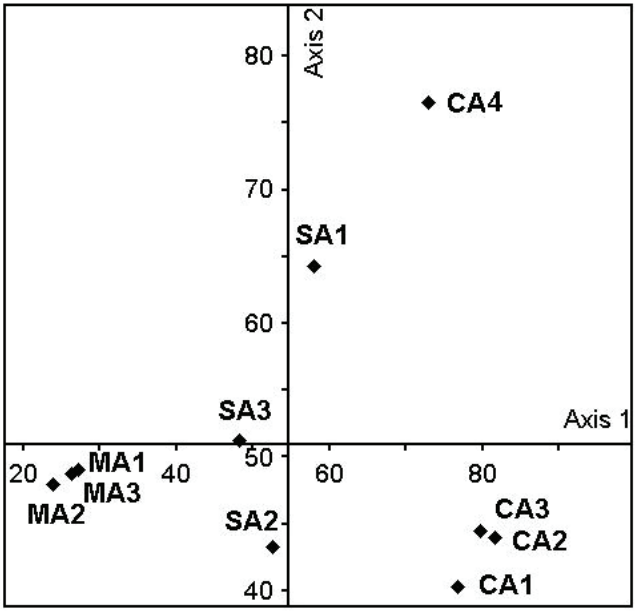

Fig. 3. Detrended correspondence analysis (DCA). CA1-CA4, St. Catherine sites 1-3; M1-M3, El-Mafareq sites 1-3; SA1-SA3, Sahab sites 1-3.

depressiceps (Table 2) which were mainly found at these sites. The El-Mafareq plots (MA1, MA2 and MA3) lie at the opposite end of the first axis, with their characteristics species *Camponotus aegyptiacus*, *Cataglyphis sabulosus* and *Messor foreli* Santschi, 1923 (Table 2). In between, are the Sahab plots (SA1, SA2 and SA3).

CCA analysis. The CCA for ants and soil variables are shown in Fig. 4. The forward selection procedure of CCA resulted in the maintenance of only one of the 12 soil environmental variables. Altitude was the most important factor in the analysis and was important on both CCA axes. The total variation explained by the first two CCA axes was 73.2% ($P < 0.002$). In general, the elevation increased towards St. Catherine plots (CA1, CA2, CA3, and CA4) and decreased towards the other plots.

The relationship of the ant species and the vegetation cover was carried out using CCA (Fig. 4). The forward-selected environmental variables of the CCA were *Acacia raddiana* Savi ($P<0.01$) and *Casuarina* sp. ($P<0.02$). The first axis grouped all the St. Catherine sites and Sahab sites together on the positive side of the biplot, while all the El-Mafareq sites were found on the negative side. The second axis separated the Sahab Sites on the positive side from the St. Catherine sites on the negative side. The first two CCA axes accounted for 55.5% of the total variation. The arrow representing the plant species *Acacia raddiana* pointed in the direction of El-Mafareq sites (MA1, MA2 and MA3), indicating that this variable has a more significant influence in these sites. The arrow representing the plant species *Casuarina* sp. pointed in the direction of the Sahab sites, indicating that this variable has more influence in the direction of these sites (SA1, SA2 and SA3).

Table 3. Ant species that are statistically significant indicators of the grouping produced by CCA (cf. Fig. 4). CA1-CA4, St. Catherine sites 1-3 (group = 0); M1-M3, El-Mafareq sites 1-3 (group = 2); SA1-SA3, Sahab sites 1-3 (group = 1).

	Group	Indicator value	P
Cataglyphis ruber (Forel, 1903)	0	75	0.05
Lepisiota nigra (Dalla Torre, 1893)	0	100	0.01
Tetramorium depessiceps Menozzi, 1933	0	75	0.05
Messor foreli Santschi, 1923	2	87.9	0.05
Camponotus aegyptiacus Emery, 1915	2	100	0.02
Cataglyphis sabulosus Kugler, 1981	2	80.3	0.03

Ant indicator species. Six ant species showed significant affinities with the plots (Table 3), three with the St. Catherine plots, and the others with the El-Mafareq plots. The abundance and occurrence of ant species *Lepisiota nigra* ($P<0.01$), *Tetramorium depressiceps* ($P<0.05$), and *Cataglyphis ruber* were significantly associated with the St. Catherine plots. The three species *Camponotus aegyptiacus* ($P<0.02$), *Cataglyphis sabulosus* ($P<0.03$), and *Messor foreli* ($P<0.05$) favoured the El-Mafareq plots.

Discussion and conclusions

The current work shows that both the sampling periods and the pitfall trap numbers are adequate for obtaining a complete picture of the ant fauna at the study sites. However, to continue using these methods in their current form to add the remaining uncollected species would be an inefficient use of resources.

Ant species richness along altitudinal gradients can exhibit one of three main patterns: (1) a decrease in species number with altitude (IPSER et al. 2004); (2) species richness peaking at intermediate elevations (FISHER 2002, SANDERS 2002); and (3) elevation with no measurable effect on species richness (FISHER 2004, MAETO & SATO 2004, RÍOS-CASANOVAA et al. 2006). In our study, while the ant species richness, evenness and diversity, peaked at intermediate elevation and at three of the high-elevated plots CA1, CA2 and CA3 (1620, 1640 and 1730 m a.s.l) respectively, there were no significant differences between the three elevation gradients in terms of ant species richness, evenness and diversity. On the other hand, the ant species abundance showed a significant difference between the low-elevation plots and both the high-elevation plots and the mid-elevation plots.

The results of this study along the three different patterns highlight the difficulties associated with relying on species richness or diversity alone to inform the assessments or the conservation priority-setting process (SPECTOR 2001). NOSS (1990) and others have pointed out that comparisons of species richness among sites may not necessarily convey much useful information about them or their relative conservation value, even for a single species. Worse still, because richness, diversity or biomass can be high in disturbed or otherwise degraded landscapes, uncritical reliance on richness could lead to unjustified levels in the assessment of conservation value (SPECTOR & FORSYTH 1998). Lower diversity, however, does not reflect a less specialized or less unique fauna (SIMBERLOFF 1999). The composition of the fauna in these habitats is extremely important, and the knowledge gained from species

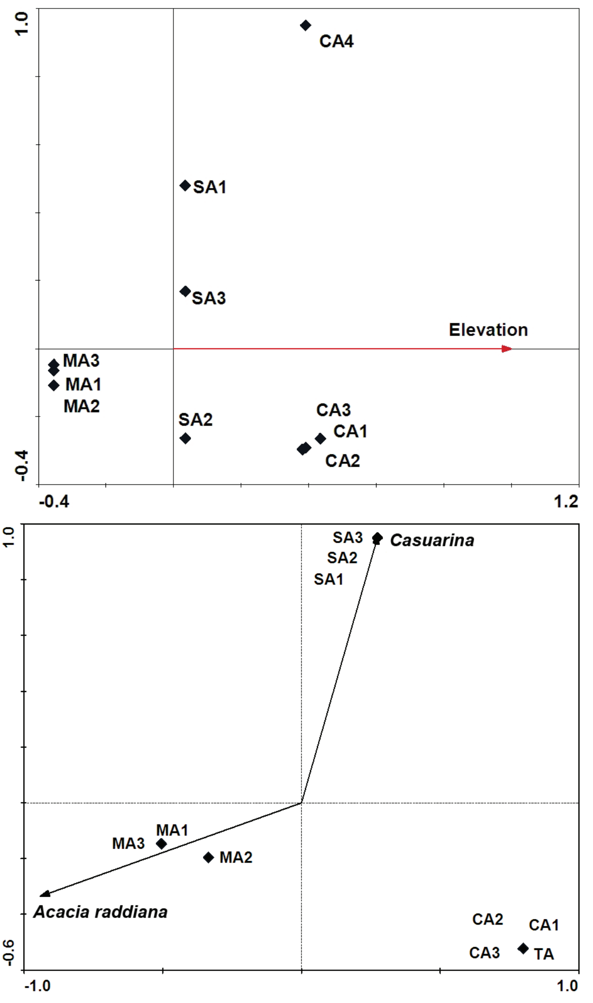

Fig. 4. Canonical correspondence analysis (CCA) ordination. Above: ant and elevation. Below: ant and vegetation. CA1-CA4, St. Catherine sites 1-3; M1-M3, El-Mafareq sites 1-3; SA1-SA3, Sahab sites 1-3.

identity and associated natural history offers deeper insights than species richness alone (SIMBERLOFF 1999, WORK et al. 2004). The identity and relative importance of species within communities are key components of the assessment, and are significantly more informative than measures such as richness or diversity (SPECTOR 2001).

The results of the TWINSPAN analysis and detrended correspondence analysis (DCA) of the ant fauna indicate that the high-elevation plots were quite distinct from both the mid-elevation plots and the low-elevation plots. Moreover, the mid-elevation plots were separated from low-elevation plots. The composition of the ant community in the high-elevation plots was distinct from both the mid-elevation plots and the low-elevation plots.

The CCA analysis of the ant fauna separated the high-elevation plots from the mid-elevation plots and the low-elevation plots. For the flora, the two plant species, *Acacia raddiana* and *Casuarina* sp., were the significant factors in separating the plots into three groups. *Acacia raddiana* was characteristic of the low-elevation plots, and their associated ant species. The *Casuarina* sp. was characteristic of the mid-elevation plots, with their indicative ant species. In fact, there were two plant species (*Acacia raddiana* and the Date Palm "*Phoenix dactylifera"*) which were significant indicators of the low-elevation plots and two plant species (Vine sp. and *Casuarina* sp.) which significantly correlated with the mid-elevation plots. Also, there were two species (*Artemisia inculta* and *Origanum syriacum*) which were characteristic of the high-elevation plots. The results are consistent with other studies (ANDERSEN 1993, MAJER & NICHOLS 1998, PARR et al. 2002, PIK et al. 2002), which all showed that differences in vegetation characteristics were mirrored by differences in ant community composition. Also, ANDERSEN et al. (2003) showed that the establishment of locally indigenous vegetation and appropriate ground cover conditions are essential ingredients for the convergence of ant communities at rehabilitated sites with those at reference sites.

The CCA result for the ant fauna using the soil environmental variables showed elevation to be the significant factor, which increased towards the St Catherine (high altitude) plots and decreased towards the low-elevation plots. From a species perspective, the clustering of sites on the ordination, on the TWINSPAN analysis, and also the indicator species analysis, provided the opportunity to identify several species that are indicative of a specific class of sites. Such species, including *Cataglyphis ruber*, *Cataglyphis niger* (André, 1881) and *Tetramorium depressiceps*, were all identified as favouring high elevation mountains sites. The defining environmental characteristics for this community are higher elevation, cold climate, higher proportion of medium sand, and increased shrub cover. *Messor foreli*, *Camponotus aegyptiacus* and *Cataglyphis sabulosus* were identified as favouring lower elevation sites. The environmental characteristics that define this community are lower elevation, hot climate, increased tree cover, and lower proportion of medium sand.

All the recorded indicator species fall into two groups according to their habitats, mountain species and desert species. The mountain species are represented by *Cataglyphis ruber*, *Cataglyphis niger* and *Tetramorium depressiceps*. All are restricted to the St. Catherine area with a relatively low abundance. The other group of desert species is represented by *Messor foreli*, *Camponotus aegyptiacus* and *Cataglyphis sabulosus*. This suggests that the lower elevations had real ecological differences that resulted in ant community differences. A drier moisture regime at the low elevation sites would affect soil texture, plant communities, and ant activity.

In conclusion, these findings highlight the importance of multivariate analysis (DCA and CCA analysis) and bioindicator species-based approaches to ecological monitoring, rather than the use of a diversity index approach in which species identity plays no part (COUSINS 1991).

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