Seasonal patterns of activity of *Scolopendra cretica* and *S. cingulata* (Chilopoda, Scolopendromorpha) in East Mediterranean maquis ecosystems

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Abstract

The seasonal activity patterns of *Scolopendra cingulata* and *S. cretica* in relation to abiotic factors and microhabitat preferences in five eastern Mediterranean maquis formations were studied. The abundance of both species proved to be spatially non-variant, suggesting a uniform distribution of populations, which exhibited a statistically similar phenological pattern, peaking in early-midsummer. The variability of the temporal activity patterns in Crete, Naxos and Cyprus denotes the influence of insularity and rapid change of environmental conditions to the phenology of both species. The annually consistent seasonal activity represents an invariant pattern in continental areas such as Attiki and Samos. Although young and large adults were more abundant than juveniles, the microhabitat preferences of scolopendrids did not differ between the two species and in relation to age class and study site and did not change temporally. The correlation of abundance with high air temperature and low air relative humidity and precipitation shows that both species are thermophilous and xerophilous, well adapted to the environmental conditions of the eastern Mediterranean region.

Introduction

The ecosystems in the Mediterranean basin are insufficiently studied (Trihas and Legakis 1991) and little information also exists on the ecology of arthropods in the eastern Mediterranean (Iatrou and Stamou 1989). Most of the existing data concern the systematic and faunistic studies (Poulakakis et al. 2006; Parmakelis et al. 2006; Triantis et al. 2008). However, there are some works conducted in the eastern Mediterranean region dealing with the seasonal variation and temporal patterns of activity of millipedes (Iatrou and Stamou 1989), beetles (Trihas and Legakis 1991), scorpions (Kaltsas et al. 2006, 2009), oribatid mites and springtails (Stamou et al. 1993), as well as other arthropods (Pantis et al. 1988).

The centipedes of genus *Scolopendra* Linnaeus, 1758 are soil predators, living in moist surroundings, and are found mostly under stones and beneath the bark of decayed logs. In the field they are rarely seen above ground during daylight and are mainly active during the wet periods (spring and autumn). They live in all tropical and warm temperate areas (southern Europe, Asia, the Americas, Africa, Australia) (Lewis 1981). Current molecular insights confirm that this genus is most likely polyphyletic (Vahtera et al. 2011). There are nine species occurring in the Mediterranean region (Lewis 1985; Akkari et al. 2008), five of which are known from mainland and insular Greece and Cyprus (Zapparoli 2002, but see Lewis 2010).

Herewith we present the results of a study on the seasonal activity of *Scolopendra cretica* Lucas, 1853 and *S. cingulata* Latreille, 1829 carried out from 2006 to 2008. The former is known from Crete and its satellite islets (Simaiakis & Mylonas 2008) and its taxonomic status has been revised recently (Würmli 1980). Records from Turkey, Cyrenaica and western Libya (Würmli 1980) are most likely referable to the sibling species *S. canidens* and not to *S. cretica* (Simaiakis et al. 2004; Lewis, 2010). *S. cingulata* is Mediterranean – west Asiatic species, widely distributed in the Mediterranean Basin, with the exception of the Balearic Islands, Crete, Corsica, and Sardinia (Zapparoli 2002; Zapparoli and Minelli 2005; Simaiakis and Mylonas 2008; Lewis 2010). The species was recorded from Crete (see Lewis 2010) but this record needs verification. Minelli (1983) supports the notion that *S. cingulata* may have invaded the western European peninsulas (Iberian and Apenninian) relatively recently, but there is still little evidence for that. It seems that the geotectonic events shaping the Aegean region (e.g., the formation of the Mid-Aegean trench about 12 Myr ago) have had a significant effect on the present distribution of *S. cingulata* in continental and insular Greece and caused its absence in Crete (Simaiakis et al. 2012).

Maquis is a typical formation in the Mediterranean ecosystems and especially the eastern Mediterranean where it is usually mixed with phryganic species. Despite its high conservation value (Dimopoulos et al. 2006), the relict patches of *Juniperus phoenicea* L. (Blondel and Aronson 1999) have not yet been studied in terms of their fauna.

Pitfall trapping was used to study the seasonal activity of *S. cingulata* and *S. cretica* in five continental and insular ecosystems dominated by the Phoenician juniper. The role of age, microhabitats and certain climatic features (air temperature, relative hu-

midity, and precipitation) on the seasonal activity patterns was investigated. This is the first thorough study on the phenological patterns of scolopendromorph species in the eastern Mediterranean region.

Materials and methods

The study sites

The study was conducted in five areas of the eastern Mediterranean, four of which are located in Greece and one in Cyprus. The localities of the sites are: a) Pacheia Ammos in NE Crete (35°6'35"N, 25°49'9"E), b) Moutsouna in E Naxos (37°2'46"N, 25°34'27"E), c) Agia Marina in NE Attiki (38°10'57"N, 24°3'12"E), d) Psili Ammos in SE Samos (37°42'26"N, 27°1'29"E), and e) Kourio in S Cyprus (34°40'3"N, 32°51'48"E) (Figure 1). All study sites were close to the coast (50–100 m), at an altitude of approximately 40 m. The substrate at the sites is limestone and the vegetation is characterized by the dominance of the typical maquis species *Juniperus phoenicea* (relative cover - RC_i%: 38.4–60.9%) and *Pistacia lentiscus* (RC_i%: 11.5–29.1%)).

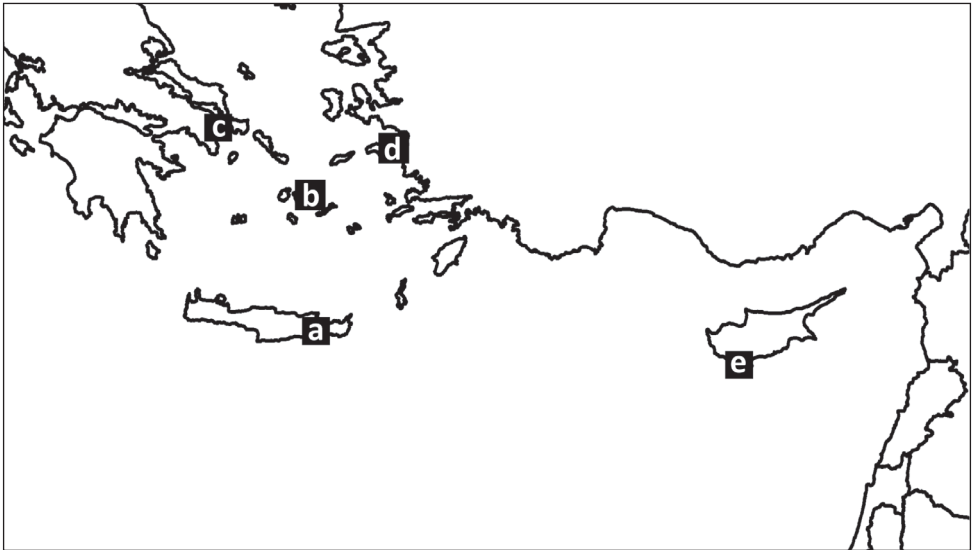**Figure 1.** The location of the five study sites in a map of the Eastern Mediterranean. **a** Pacheia Ammos (Crete) **b** Moutsouna (Naxos) **c** Agia Marina (Attiki) **d** Psili Ammos (Samos) **e** Kourio (Cyprus).

Sampling design

At all sites material was sampled using pitfall traps (depth: 11.5 cm; diameter: 9.5 cm) containing propylene glycol as a preservative. The traps at the five study sites were sam-

pled bimonthly. The collection of material took place over two years, from the beginning of May 2006 to the beginning of May 2008. The study consisted of two phases: a) May 2006–May 2007: 20 pitfall traps were placed with 10 m trap spacing; b) May 2007–May 2008: three groups of seven traps, with 10 m trap spacing at all sites. The minimum distance between the groups was 60 m. The three groups were introduced in order to test whether the abundance of scolopendrids differed statistically within each study site. The traps covered the three major microhabitat types of the study areas; dense vegetation and litter cover (dv), scarce vegetation (sv) and open areas (o).

Climate

During the study air temperature and air relative humidity were measured using a MicroLog® Compact Data Logger (Fourier Systems), and precipitation using WS-7038U 433 MHz Wireless Rain Monitor® (La Crosse Technology) (see Appendix 1 for detailed climate data). Generally, the climate was typical Mediterranean with high mean monthly air temperature (20 °C) and low annual precipitation (445 mm/year), 65% of which occurred during the cold months (November-February) at all study sites.

Morphometric age traits

Because it could be risky to determine the age for each individual, we measured two age related characters namely i) the body length and ii) the number of antennomeres of the captured scolopendrids. Both characters were measured with an ocular micrometer using a Leica MZ6 stereomicroscope. Body length from the anterior margin of the head shield to the end of the telson was measured on a millimetre paper. Regarding antennomeres, we counted the number of articles of the right antenna. Samples were split into three classes of body size: (i) juveniles (body length < 40 mm), (ii) young adults (40 < body length < 60 mm) and, (iii) large adults (body length > 60 mm). We excluded specimens of less than 16 and more than 21 antennomeres, because such measurements are considered as abnormal (Lewis 2010). All specimens were preserved in 95% ethanol and deposited in the Natural History Museum in Crete (NHMC).

Statistical analyses

Differences in activity density of the scolopendrids (no. of individuals per 100 trap-days) at the five study sites were tested using Kruskal-Wallis ANOVA and post-hoc multiple comparisons test. To examine whether the abundance of scolopendrids differed in relation to their age class and microhabitat preference in the five sites, we used repeated measures MANOVA. We set the abundance of scolopendrids per sampling as dependent variables and age classes, microhabitat types and the study sites or the two

species, as categorical predictors. The relation between the abundance of scolopendrids and classes of each abiotic factor was analyzed using Correspondence Analysis.

The phenological patterns of the two studied species were analyzed using circular statistics (Zar 1999) in ORIANA 2.02 software (Kovach 2004). Sampling time intervals were converted to angles (intervals of 60°) and activity density was included in the analyses as the frequency of angle interval. Rayleigh Uniformity test was used to calculate the probability of the null hypothesis that the data are uniformly distributed around the analyzed cycle by assessing the significance of the mean vector length (r). A significant result of the Rayleigh test indicates a significant mean angle (Kovach 2004), i.e. a statistically significant phenological pattern. The phenologies of scolopendrids were compared using the Watson-William F-test, which compares the equality of the mean angles (μ) between samples (sites).

Results

The absolute numbers of collected specimens per site and collecting periods are presented in Table 1. The abundance of active scolopendrids differed significantly between the five study sites (Kruskal-Wallis ANOVA: H = 31.047, p < 0.001), in particular between *S. cretica* (Crete) and *S. cingulata* in Samos (p < 0.001), as shown by the post-hoc multiple comparisons test. However, species-level analysis did not result in significance (H = 7.538, p = 0.06). The activity density of the two species differed neither temporally between the two years of study (8 < H < 20, 0.095 < p < 0.844) nor spatially among the three subsites within each sampling site (0 < H < 4.964, 0.084 < p < 0.95) in any of the five sampling stations. Furthermore, the abundance of scolopendrids did not differ statistically between the three microhabitat types (Table 2) in any of the study areas (0.106 < H < 1.043, 0.594 < p < 0.948); thus there was no evidence of microhabitat preference for the two species.

Young adult scolopendrids were the most abundant age class in Crete, Attiki and Cyprus, whereas large adults were dominant in Naxos and Samos, and juveniles were the least abundant age class at all study sites (Figure 2). The difference in catchability among the three age classes in relation to study site was proved statistically by repeated measures MANOVA (F = 1.99, p = 0.001). The same analysis showed that the microhabitat preferences of scolopendrids did not differ in relation to site, species or age class (0.803 < F < 1.044, 0.41 < p < 0.815).

The Watson-William F-test showed that Attiki (F = 1.479, p = 0.225) and Samos (F = 1.647, p = 0.201) were the only sites, where the phenological patterns of scolopendrids were identical in the two years of study, peaking during late summer (July-September). In the other three sites, scolopendrid activity peaked during early summer (May-July) in the first year of study (Crete, Naxos), or over a longer period (May-September) in the second year (Cyprus) (Figure 3). However, the Rayleigh test showed that the cumulative phenological patterns of both species were statistically significant at all sites (Table 3). The mean period of maximal activity of *S. cingulata* was midsummer

Table 1. Absolute numbers of collected specimens per period in the five sampling sites.

	Crete	Attiki	Naxos	Cyprus	Samos
May 06 - Jul. 06	9	19	24	5	76
Jul. 06 - Sept. 06	0	33	10	8	70
Sept. 06 - Nov. 06	0	5	0	6	23
Nov. 06 - Jan. 07	0	0	0	0	0
Jan. 07 - Mar. 07	0	0	0	0	3
Mar. 07 - May 07	3	6	4	3	9
May 07 - Jul. 07	4	19	11	12	35
Jul. 07 - Sept. 07	8	22	40	8	84
Sept. 07 - Nov. 07	6	5	3	3	4
Nov. 07 - Jan. 08	0	0	0	1	0
Jan. 08 - Mar. 08	0	0	0	2	0
Mar. 08 - May 08	6	5	4	6	0
Total specimens	36	114	96	54	304

Table 2. Average catchability (number of individuals per trap per 2 years) in each of the three microhabitat types in the five sampling sites. o: open field, sv: scarce vegetation, dv: dense vegetation and litter cover.

	Crete	Attiki	Naxos	Cyprus	Samos
o	2.111	9.204	4.750	4.604	13.417
sv	3.000	5.458	5.000	2.516	15.932
dv	3.008	7.150	4.313	3.100	21.000

Table 3. Circular statistics results for temporal activity patterns of scolopendrids in the five study sites.

	Crete	Attiki	Naxos	Cyprus	Samos
Mean Vector (μ)	48.422°	71.891°	61.115°	66.587°	71.625°
Length of Mean Vector (r)	0.574	0.788	0.807	0.548	0.806
Median	May–Jul	Jul–Sep	Jul–Sep	Jul–Sep	Jul–Sep
Concentration	1.407	2.721	2.954	1.312	2.931
Circular Variance	0.426	0.212	0.193	0.452	0.194
Standard Error of Mean	6.376°	3.913°	3.711°	6.758°	3.729°
Rayleigh Test (Z)	32.943	62.058	65.172	30.004	64.887
Rayleigh Test (p)	< 1E-12	< 1E-12	< 1E-12	< 1E-12	< 1E-12

(early-mid July), whereas the activity of *S. cretica* peaked during early summer (mid June) (Figure 4). The Watson-William F-test affirmed a statistical difference of the phenology of *S. cretica* and the respective pattern of *S. cingulata* in Attiki and Samos (Table 4). The same test also showed that the temporal patterns of microhabitat preference did not differ for any of the study sites ($1.65E-4 < F < 1.732$, $0.19 < p < 0.99$).
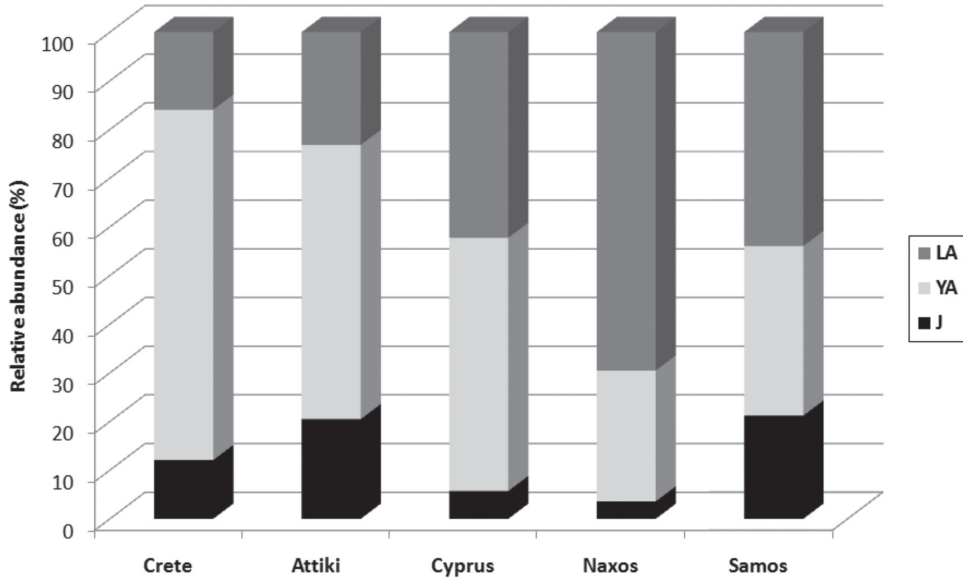
Figure 2. Relative abundance of scolopendrid age classes in the five study sites. J; juvenile, YA; young adult, LA; large adult.
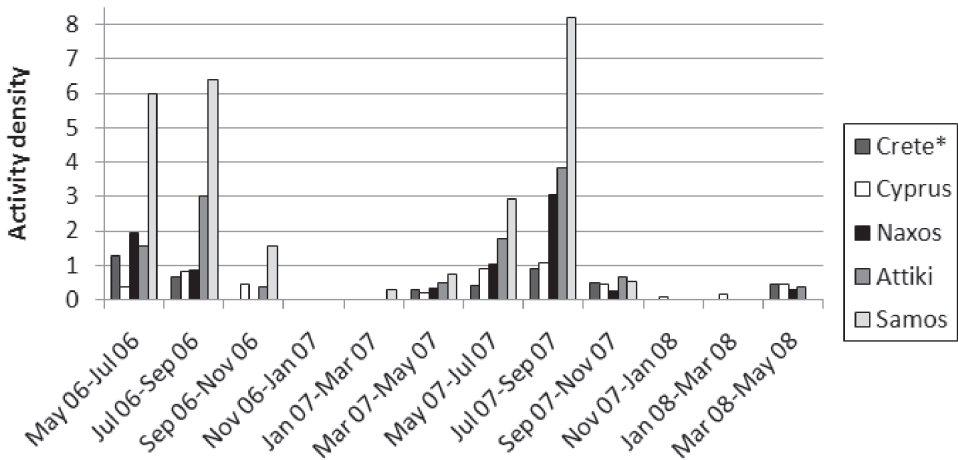

Figure 3. Activity density (number of individuals/100 trap-days) of *S. cretica* (Crete*) and *S. cingulata* per sampling period.

Correspondence analysis (total chi-square = 167.98, d.f. = 44, p < 0.001) showed that there was no differentiation in the influence of abiotic factors on the activity of both species at all five sampling stations (Figure 5). The abundance of both the species was maximal under very low average precipitation (0–2.6 mm), low average air relative humidity (46.4%–59.3%), and high average air temperature (*S. cingulata*: 25.2–25.5°C; *S. cretica*: 23.6°C).
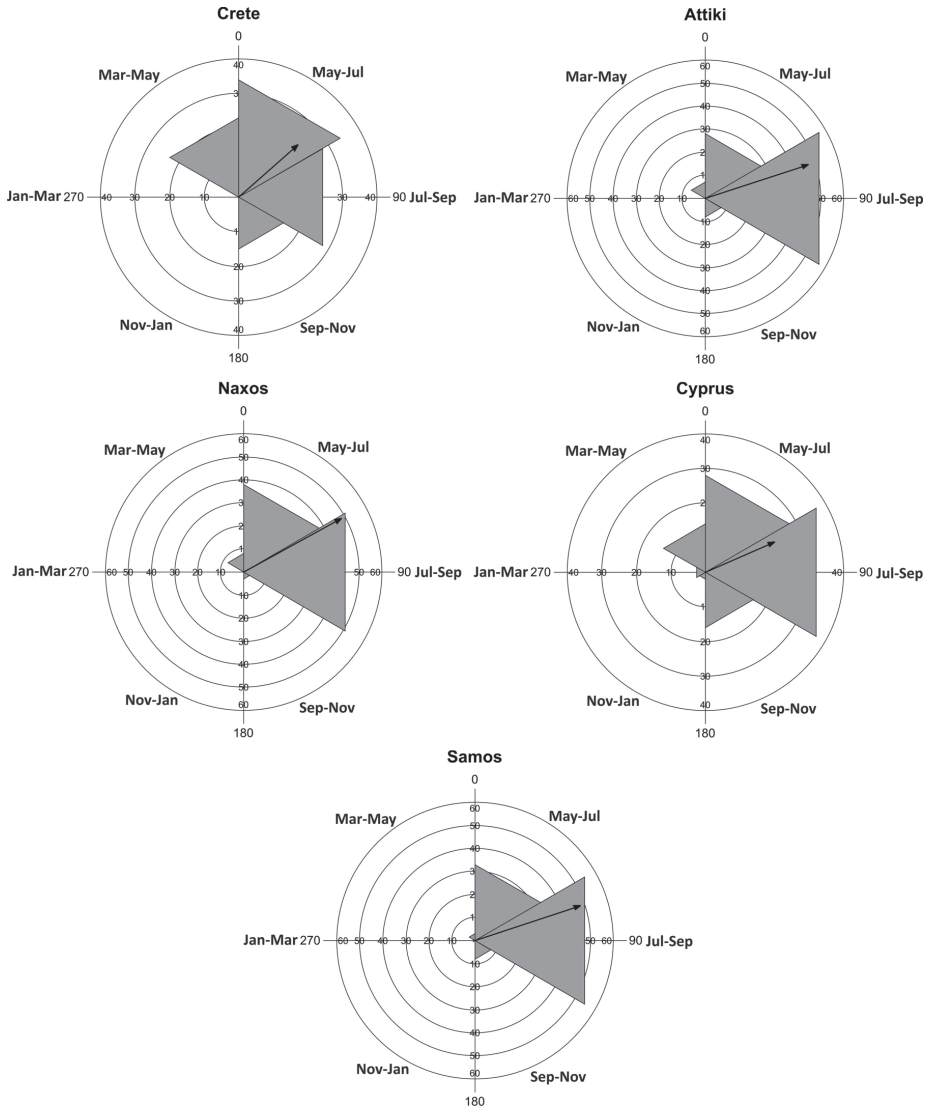
Figure 4. Rose diagrams of of circular analysis of abundance of scolopendrids during the whole study. The angles represent the bimonthly sampling intervals. The length of the mean vector (*r*) is a measure of concentration of data around the year.

Table 4. Watson-William F-test results on the comparison of temporal activity patterns during the whole study. Significant differences are shown in bold type.

	Attiki		Naxos		Cyprus		Samos	
	F	**p**	**F**	**p**	**F**	**p**	**F**	**p**
Crete	9.122	**0.003**	2.764	0.098	3.706	0.056	9.185	**0.003**
Attiki			3.22	0.074	0.442	0.507	0.002	0.965
Naxos					0.485	0.487	3.198	0.075
Cyprus							0.41	0.523

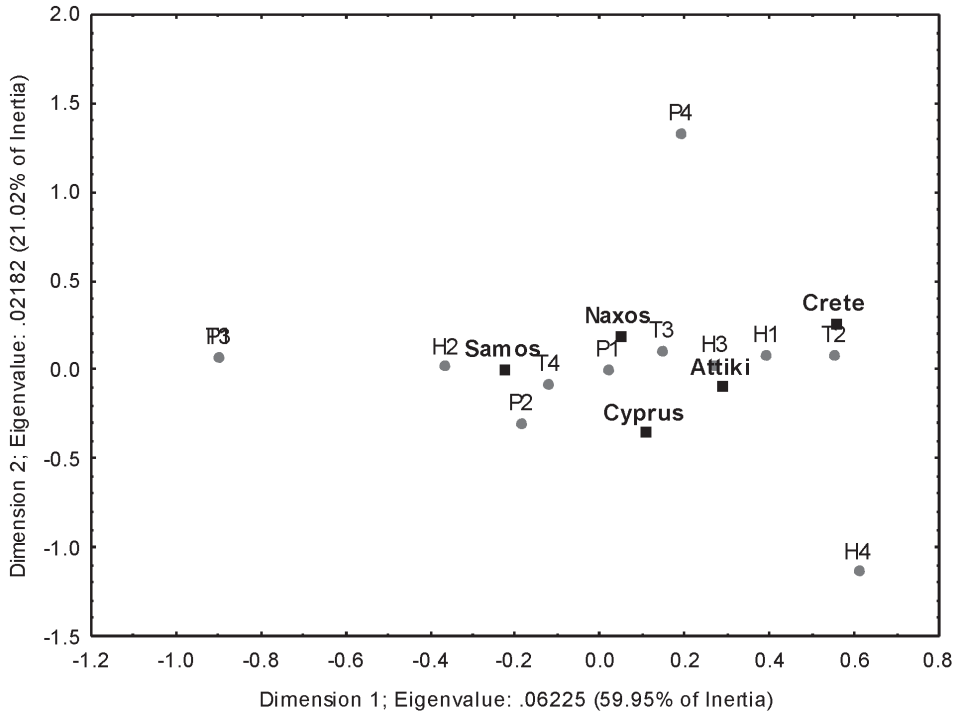**Figure 5.** Correspondence analysis plot. T1–T4: air temperature (in °C) classes (8.43 ≤ T1 < 14.24 ≤ T2 < 20.05 ≤ T3 < 25.86 ≤T4 < 31.67); H1–H4: air relative humidity (%) classes (44.67 ≤ H1 < 52.78 ≤ H2 < 60.89 ≤ H3 < 69 ≤ H4 < 77.12); P1–P4: precipitation (in mm) classes (0 ≤ P1 < 39.33 ≤ P2 < 78.66 ≤ P3 < 117.99 ≤ P4 < 157.32).

Discussion

Scolopendra cretica and *S. cingulata* are among the dominant arthropod species in the Aegean and continental Greece (*S. cretica* only in Crete and its adjacent islets) (Simaiakis et al. 2005; Kaltsas et al. 2006). They are both very common in the maquis-phryganic mosaic-like formations in the eastern Mediterranean (Zapparoli 2002; Simaiakis et al. 2004, 2005). The abundance of both species proved to be annually and spatially non-variant within all study sites, indicating that their populations are uniformly distributed in the maquis formations, independent of sampling design. Both species were more or less equally abundant in the three microhabitat types at all study sites. The high percentage of *Scolopendra* individuals trapped in the open field shows their errant character and possibly a broad home range, far from their burrows. The microhabitat preferences did not differ between the two species and in relation to age class and site, even though the captures of the three age classes were significantly different among the five study areas and adults were generally more abundant that juveniles. However, the fact that microhabitat preference was temporally consistent at all sites and did not affect the activity of the two

studied scolopendromorph species suggests that activity of the two scolopendrids is probably due to intrinsic factors and less influenced by the abiotic factors. This evidence reinforces our notion that *S. cretica* and *S. cingulata* have a long history in the east Mediterranean area (Simaiakis et al. 2012), resulting in a considerable relaxation period at least for *S. cretica* (see also Triantis et al. 2008 and Trichas et al. 2008), during which *S. cretica* remained isolated in Crete for about 5.5 Ma (Simaiakis and Mylonas 2008) and *S. cingulata* in a wider area that cause congruent ecological demands.

Lewis (1972) stated that "centipedes of the family Scolopendridae have attracted little attention from ecologists and little work has been done on their life histories". Similarly, there are no previous studies on the phenology of scolopendromorph species in the eastern Mediterranean area. Our results showed that both species exhibited a statistically significant phenological pattern at the five studied sites. The peak of activity occurred during early summer for *S. cretica* and midsummer for *S. cingulata*. Our results are in accordance with observations of Simaiakis et al. (2004) on the late spring-early summer peak of activity of *S. cretica*. The lack of statistical significance of the Watson-William F-test between the mean vectors for *S. cingulata* in Naxos and Cyprus and *S. cretica* (Crete) shows the similarity of the temporal activity patterns of the two species. However, except for Attiki and Samos, the phenological patterns of both species differed between the two years of study. This shows that there can be a shifting of the period of maximal activity of both species from the beginning of June to the beginning of July. The variation in the temporal activity patterns in Crete, Naxos and Cyprus denote the influence of insularity and the rapid change of ecological conditions in islands of the eastern Mediterranean region. The isolation of Crete and Naxos from the continental mass of Greece and Turkey since Pleistocene is well recorded (Dermitzakis 1989), and there is still no evidence of land-bridge connections between Cyprus and either Anatolia or the Levant (Gass 1968; Garfunkel 2004; Pavlíček and Csuzdi 2006). On the other hand, Samos was still a part of Asia Minor 10,000 years ago (Sondaar et al. 1986; Perissoratis and Conispoliatis 2003). Consequently, the activity of *S. cingulata* followed a more or less temporally consistent, equilibrial continental pattern in Attiki and Samos, whereas insularity caused a slight fluctuation of the phenological patterns of *S. cretica* in Crete and *S. cingulata* in Naxos and Cyprus.

The correspondence of the number of active scolopendrids with high air temperature, low air relative humidity and almost zero precipitation implies that *S. cretica* and *S. cingulata* are thermophilous and xerophilous species. This is in agreement with Simaiakis et al. (2004, 2005), where both sexes of *S. cretica* reached peak of activity in spring to early summer (at the beginning of the dry/hot season). The sibling species *S. canidens*, is also eurythermic-thermophilous-xerophilous as shown by a study in Israel (Negrea 1997). *S. cretica* and *S. cingulata* are mostly active during the warm and dry period of the year affirming their good adaptation to the climatic conditions of the eastern Mediterranean.

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Appendix 1

Climate data per period in the five sampling sites. T: average air temperature (in °C), H: average air relative humidity (%), P: average precipitation (in mm).

	Crete			Attiki			Naxos			Cyprus			Samos		
	T	H	P	T	H	P	T	H	P	T	H	P	T	H	P
May 06 - Jul. 06	23.6	51.2	0.3	23.3	55.9	10.6	23.8	52.3	2.5	23.1	68.8	0.5	24.1	59.6	0.5
Jul. 06 - Sept. 06	28.6	45.4	0.0	28.6	46.3	0.3	29.1	44.7	2.1	27.4	72.8	0.0	29.3	46.6	4.0
Sept. 06 - Nov. 06	22.4	71.3	21.8	20.5	76.8	54.4	22.0	69.8	33.2	23.8	77.1	35.5	23.2	62.1	54.0
Nov. 06 - Jan. 07	16.5	77.0	35.8	11.1	93.9	70.7	13.3	79.0	64.5	14.2	83.8	25.3	13.8	70.9	102.0
Jan. 07 - Mar. 07	12.4	88.4	45.1	9.2	92.0	68.1	12.1	76.6	75.3	12.2	85.6	68.3	12.4	71.6	89.9
Mar. 07 - May 07	15.2	64.3	21.1	14.4	72.3	24.2	17.2	64.2	39.4	17.6	68.5	40.3	19.0	58.5	11.3
May 07 - Jul. 07	23.6	51.6	1.5	24.3	53.4	20.2	25.9	59.0	12.7	25.9	58.2	22.1	28.1	57.6	22.3
Jul. 07 - Sept. 07	28.9	45.1	1.0	29.8	46.4	0.0	29.4	58.7	3.0	31.6	45.8	0.0	31.7	53.1	0.0
Sept. 07 - Nov. 07	22.0	72.3	17.2	20.9	72.3	31.3	23.3	64.4	46.6	27.1	64.9	0.1	26.2	65.9	35.5
Nov. 07 - Jan. 08	16.0	79.7	35.3	11.5	78.4	69.3	13.5	67.6	96.1	19.4	70.1	75.5	16.6	80.1	155.4
Jan. 08 - Mar. 08	11.2	72.1	46.1	8.4	77.7	61.0	10.4	68.5	157.3	16.2	61.2	33.3	10.6	81.4	72.3
Mar. 08 - May 08	17.9	71.9	16.4	15.4	66.2	52.5	16.5	61.3	102.2	22.8	63.6	7.8	17.0	75.6	50.5