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Effects of Fire on Soil Macroinvertebrates in a Mediterranean Phryganic Ecosystem

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Abstract. The effect of a summer wildfire on the abundance and community composition of soil macroinvertebrates of a phryganic ecosystem was studied. The numerical responses of macroinvertebrates to fire were variable, most notably the reduction of the saprophagous fauna. The magnitude of the changes in abundance due to fire was comparable or even lower than the variations imposed by the seasonality of the mediterranean climate. Fire did not seem to affect strongly the community composition of the soil inhabiting fauna, but caused considerable changes in the composition of the litter-dwellers. Furthermore, seasonal changes in community composition were less pronounced in the burnt site compared to those in the control. The observed effects of fire should be attributed to the destruction of the litter layer and the above ground vegetation cover, rather than to the immediate death of the animals, since most of them were absent from the upper soil layers during summer, that is when fire occured.

Keywords: Phrygana, soil macrofauna, wild fire, seasonality, community changes.

Introduction

The response of soil fauna to fire shows an enormous variability and depends on the intensity, frequency and season of burning (Ahlgren 1974). Wild forest fires are the most destructive (Buffington 1967, Buck 1979, Bornemissza 1969), while the effects of controlled burning of low intensity are less pronounced (Metz and Farrier 1973, Majer 1984). Finally, the effects of fire on soil arthropods in shrublands and pasture lands vary from a small reduction of the abundance of some taxa to a significant increase of the abundance of several taxa in the short term (Luxton 1982, Saulnier and Athias-Binche 1986, Seastedt 1984, De Izarra 1977, Lussenhop 1976, Pomeroy and Rwakaikara 1975, Greenslade and Mott 1983). Knowledge regarding the effect of fire on fauna in Greek Mediterranean-type ecosystems is limited (Sgardelis and Margaris 1992, 1993).

In this paper we study the effect of a wild fire on the soil macroinvertebrate community of a phryganic ecosystem. Phrygana (synonyms: coastal sage, California; tomilares, Spain; batha, Israel) occupy areas towards the dry end of the precipitation gradient of the Mediterranean climate. These formations cover about 13% of Greek land (Diamantopoulos 1983) and are mostly used for grazing. The climatic conditions as well as the vegetation characteristics (thorny plants usually producing volatile oils, accumulation of dead plant material) favour burning of these systems.

It is generally agreed that fire is of decisive importance for the structure and dynamics of Mediterranean-type ecosystems (Trabaud 1981). In this context, the knowledge of the behaviour of ecosystems' components following fire is considered necessary.

Materials and Methods

Study site

The fire took place on a hill about 50 km SE of Athens (Attiki, Greece) in August 1980. A zone of the initial phryganic vegetation, about 1 km long and of varying width (100-500 m), was not affected by the fire and was used as a control area. This unburnt zone was dominated by *Genista acanthoclada* Dc., *Sarcopoterium spinosum* Scop. and *Coridothymus capitatus* (L.) Reinchenb. fil. Details concerning the formation of the soil organic layers in the study site and the recovery of the vegetation after the fire are given by Sgardelis and Margaris (1993).

The climate of the area is characterised as semi-arid Mediterranean, according to UNESCO-FAO classification (Anonymous 1963). Variations in mean monthly temperature display the characteristic seasonal pattern of the Mediterranean climate (Figure 1). Mean monthly precipitation shows minimum values in summer and maximum values in Autumn-Winter. We should note that Spring was exceptionally dry in 1981 and rather rainy the next year. This interannual variation is a common aspect of the Mediterranean climate and it has been estimated that variations of the temperature-humidity complex exhibit an interannual periodicity (Iatrou and Stamou 1991).

Sampling

Sampling was carried out at monthly intervals from November 1980 to May 1982. Five randomly distributed soil samples were taken in each site (burnt and unburnt), by means of a metal square sampler of 50 x 50 cm and 30 cm in depth. The animals were sorted from soil by hand in situ. We should note that the distance between the two sites, where sampling was carried out, was about 600 m.

During the dry period (i.e. from June to October 1981), this sampling procedure was inadequate, because most soil macroinvertebrates were not active at the upper soil layers. Thus, in order to determine community composition, during summer, we sampled only for surface dwelling macroarthropods, as follows: Ten sampling points were taken at random in each site (burnt and unburnt). The sampling area was expanded around each sampling point until ten or more (in cases of aggregations) active individuals (excluding ants) were collected. Data gathered by this sampling procedure were used only to estimate relative (%) abundance of macroarthropods.

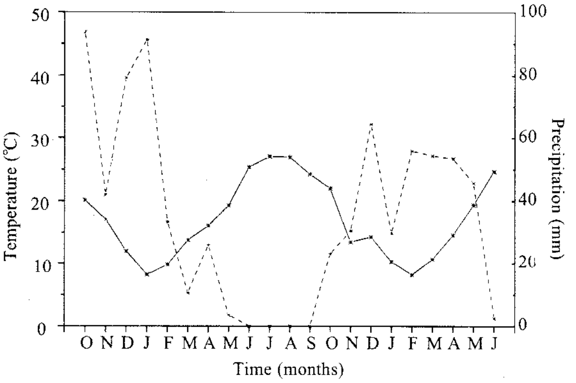

Figure 1. Mean monthly air temperature (°C) and precipitation (mm) recorded by the meteorological station of Hellinikon airport (Attiki, Greece) during the period October 1980 - May 1982. Solid line: air temperature, dotted line: precipitation.

Data analysis

A t-paired test was used to evaluate differences in groups' abundance between sites. Canonical analysis (James 1985) was used to separate groups of samples formed a priori by site (Burnt, Unburnt), season (Winter, Spring) and year of study (1, 2). Detrended Correspondence Analysis (Hill and Gauch 1980) and a fuzzy K-means classification method (Equihua 1990) were employed to detect patterns of community composition changes. The fuzzy classification assigns to each sample degrees of membership (ranging from 0 to 1) to each cluster formed. The clusters produced are not mutually exclusive, that is their boundaries are not well defined as in ordinary classification methods. The method is appropriate in order to approach both the concept of communities as recognisable entities, and the concept of composition changes along a continuum (Equihua 1990).

Results

Effects of fire on the abundance of the main taxa

In both the burnt and the unburnt sites, animals were active during the wet season of the year and exhibited peaks of their abundance either in autumn or in spring (Figure 2). Scarabaeiform larvae were separated from all the others, because they displayed a different phenology, peaking during winter and not during spring, as is the case with most of the other larvae. In the unburnt site, the abundance of Julida, Lumbricidae, Araneae and Coleoptera increased during the second year of study. In the case of Julida and Araneae, this increase was obvious also in the burnt site.

The abundance of Julida was significantly reduced (t-paired test, $P<0.05$) by fire and remained lower in the burnt site until the end of the study. The abundance of insect larvae was significantly reduced ($P<0.05$) due to fire the first year of the study but the difference between sites was not significant during the second year. The abundance of Lumbricidae and Coleoptera did not differ significantly between sites the first year after the fire. However, there was a significant reduction in the abundance of these taxa ($P<0.05$) during the second post fire year. Finally, the abundance of Isopoda, Geophilomorpha, Araneae and Scarabeidae larvae was not affected significantly by fire.

Canonical Analysis was used to detect trends in abundance variations. Eight sample groups were prefixed according to site (burnt=BR, unburnt=UN), sampling year (1, 2) and season (winter=WR, spring=SPR).

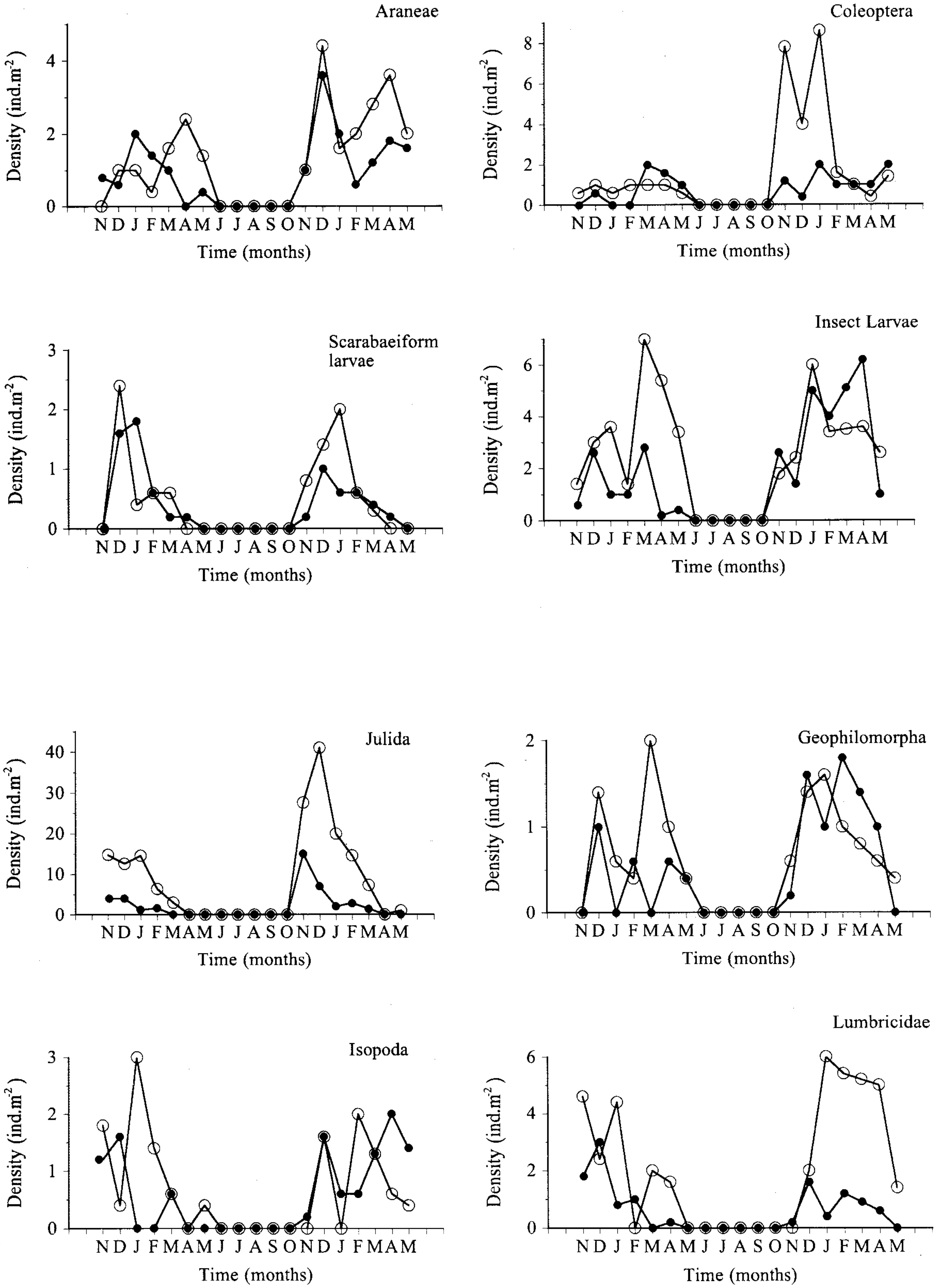

Figure 2. Monthly variations in abundance (ind./m^2) of the main macroinvertebrate taxa in the unburnt (open cycles) and the burnt (full cycles) sites, from November 1980 to May 1982.

Summer samples were excluded from this analysis, because the abundance of soil inhabitants in them was zero. The separation of the groups is depicted on the plan of the two first axes of CA (Figure 3). The first axis contributes for 38% and the second for 30% to group separation. The distances between group centroids on the plane of the two CA axes were considered to detect the following trends of soil macroinvertebrate abundance variations: (a) Seasonal: there is a good separation between winter and spring samples of the unburnt site. In the burnt site, there is also a seasonal separation of samples but it is less wide. (b) Interannual: In the unburnt site, interannual changes are wider than those in the burnt site. Furthermore, in the burnt site interannual changes are wider than the seasonal ones, while the inverse is evident in the unburnt site. (c) Effects of fire: there is adequate separation of sites, which is more obvious for the spring samples of the first year and especially for the winter samples of the second year. In general, seasonal changes in the unburnt site are the most pronounced among all changes.

On the basis of the above results, it is possible to describe changes in macroinvertebrate abundance in the study area. During the period November 1980-February 1981 (2.5 to 5.5 months after the fire) discrimination of the two sites is clear, mainly due to the reduction of Julida in the burnt site, but it is not very pronounced. During the transition from winter to spring 1981 considerable changes occurred in the unburnt site. The most important was the increase in the numbers of insect larvae and Araneae and the reduction of Julida. Relevant changes in the burnt site were minor, so that the separation of the sites became wider. Next winter, the abundance of some animals, such as Julida, Lubricidae and Coleoptera increased in the unburnt site. In the burnt site the corresponding interannual change was less evident. Furthermore, the direction of the change was towards the increase of insect larvae and Araneae, that is towards the spring composition of the community in the unburnt site. This resulted in the wider separation of the two sites during winter of the second year. Finally, in spring 1982 (19 months after the fire) dissimilarity between samples decreased, mostly due to the recovery of insect larvae in the burnt site.

Community composition

During the wet period of the year (November to May), diplopods, insect larvae (including the Scarabeiform ones) and lumbricids were the most numerous in both sites (Table 1). Julida contributed 40-50% to the macroinvertebrate community of the unburnt site and 20-30% to that of the burnt site. The great reduction of Julida during the first year after fire and that of Julida, Lumbricidae and Coleoptera during the second post fire year resulted in the increase of the

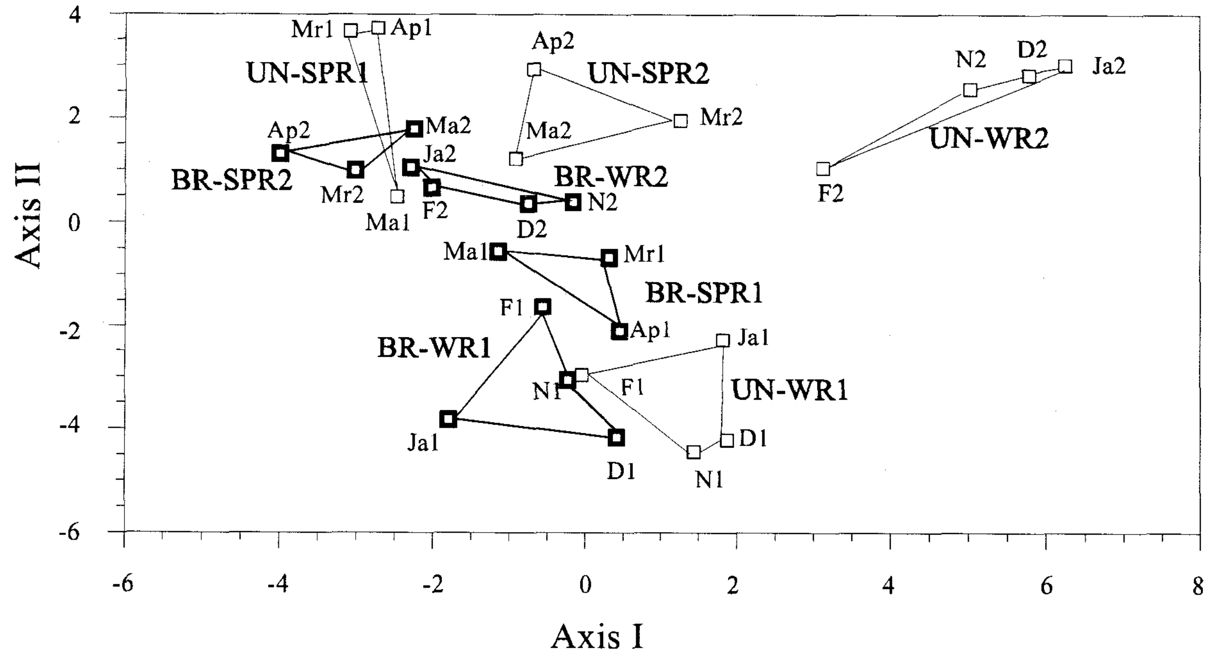

Figure 3. Canonical Analysis two axes plane for the discrimination of sample groups prefixed by site (UN: unburnt, BR: burnt), season (WR: winter, SPR: spring) and sampling year (1, 2). Monthly samples of each group are connected by line segments.

Table 1. Relative (%) abundance of the main taxa and mean total density (ind x m^{-2}) of soil macroinvertebrates in the Unburnt and the Burnt site of the study area.

Period	Nov. 80 - May 81		June 81 - Oct. 81		Nov. 81 - May 82	
Taxon	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt
Earthworms						
Lumbricidae	11.2	13.55	0.00	0.00	9.65	4.54
Diplopods						
Julida	42.86	21.54	0.00	0.00	50.79	30.48
Polydesmida	1.49	2.37	0.00	0.00	1.75	0.22
Chilopods						
Geophilomorpha	4.32	5.16	0.00	0.00	2.73	6.37
Lithobiomorpha	1.49	0.80	0.00	0.00	0.29	1.35
Arachnids						
Araneae	5.81	12.36	43.80	48.90	7.11	11.99
Crustaceans						
Isopoda	5.67	6.77	0.00	0.00	2.24	7.29
Insects						
Scarabeiform larvae	3.31	8.74	0.00	0.00	2.33	3.11
Larvae (other)	18.49	17.16	0.00	1.50	9.66	22.83
Heteroptera(nymphs)	0.74	1.18	13.80	14.40	0.68	3.18
Coleoptera (adults)	4.32	10.37	9.80	20.10	11.60	0.64
Thysanoura	0.30	0.00	26.20	0.60	1.17	0.00
Misc.	0.00	0.00	6.40	14.5	0.00	8.00
Mean density (ind x m$^{-2)}$	40.13	16.71	-	-	73.83	32.15

percent contribution of the less numerous taxa. Despite the changes in relative abundances, fire does not seem to affect strongly the composition of the invertebrate fauna during the wet period, since the rank of the taxa, ordered by their relative abundance, did not change considerably between the two sites. The dominant taxa of the unburnt site remained dominant in the burnt site as well. During the dry period only litter dwelling animals were recorded and, among them, Araneae were the most abundant in both sites. However, considerable changes in the composition of the xerophilous epiedaphic fauna resulted from fire, favouring the relative abundance of Coleoptera against that of Thysanoura.

Monthly changes in the composition of the community were studied by means of Detrended Correspondence Analysis. The ordination of monthly samples and macroinvertebrate taxa is depicted on the plane of the two first axes of DCA (Figure 4). The first axis accounts for 39% and the second for 16% of the total data variability. Along the first axis, the ordination of samples follows the seasonality of the Mediterranean climate. Winter samples of both study years along with diplopods, chilopods and Scarabaeiform larvae are ordinated towards the right end point, while summer samples along with Thysanoura and Heteroptera are ordinated towards the left end point of the axis. Spring samples are ordinated towards the middle of the axis. Furthermore, no interannual trend on samples' ordination is revealed. The effect of fire appears as a shift of both the winter and summer samples towards the middle of the first axis.

Fuzzy classification resulted in the formation of three fuzzy groups giving the best partition of the data set. The membership value of each monthly sample to each group is given in Figure 5. For the sake of clarity, we present separately the classification of samples from the two different sites, although all samples were treated together. In the unburnt site, the partition of the samples into groups is very pronounced. The groups formed are easily identified as the winter group (I) (including March 1982), the spring group (II) and the summer group (III). In the burnt site, the results appear rather complicated. As regards the first post fire year, most samples taken during winter are classified to both Winter and Spring groups (I and II), while from the spring samples only that of March belongs to Spring group. The rest exhibit faunistic characters of all three groups (mostly of Groups II and III). Regarding the second year, the winter samples are either classified to Winter group I (November and December) or to Spring group II (January and February). Two of the spring samples are classified into Spring group, but that of May exhibits faunistic features of the Summer group as well. In summary, it appears that faunistic features of the unburnt-spring samples (Group II) and of the unburnt-summer samples (Group III) are displayed earlier in time in the burnt site.

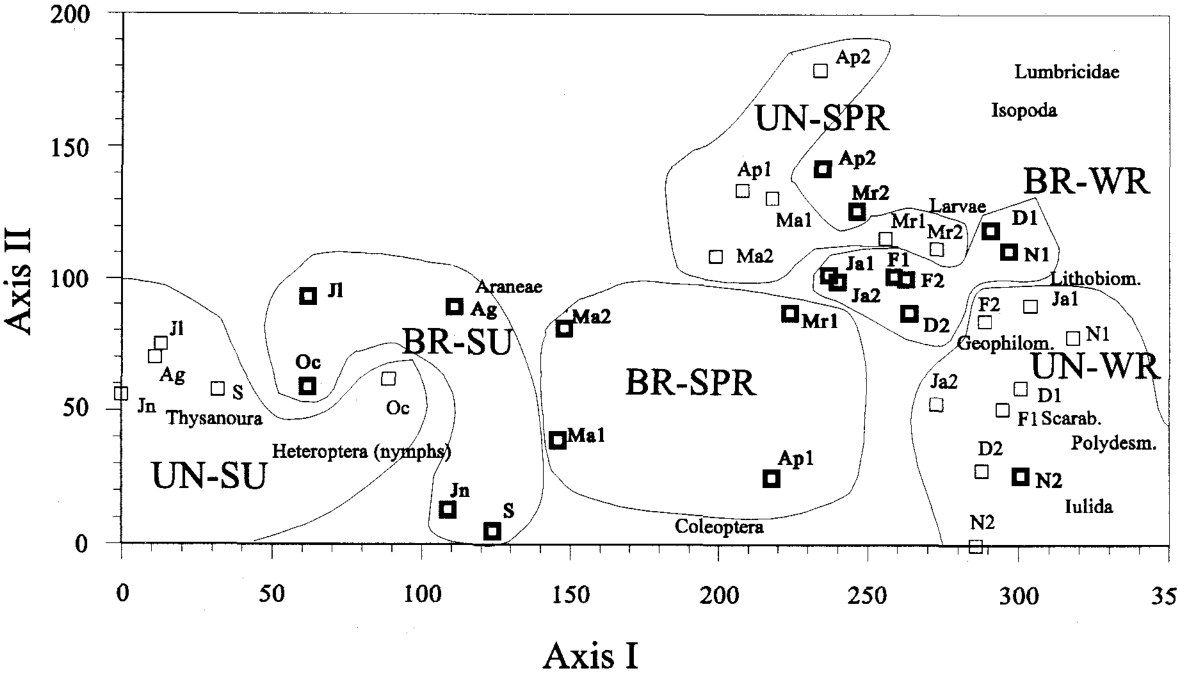

Figure 4. Ordination of monthly samples and macroinvertebrate taxa. Groups of samples from the same site (UN: unburnt, BR: burnt) and season (WR: winter, SPR: spring, SU: summer) are enclosed by lines for the sake of clarity and named accordingly. Numbers (1,2) associated with the abbreviations of the months' names denote the year of sampling.

Discussion

The two main periods of activity of the macroinvertebrate taxa in the study area, that is winter and spring, are characterized by the dominance of different taxa. In some cases, there is an interannual difference regarding the season where the peak of abundance is displayed. This could be related to the interannual differences of the precipitation pattern recorded during the two year study period in our site.

During the dry period of the year, only litter-dwelling animals were recorded. The absence of soil inhabitants from our samples during this period is probably due to vertical movements to deeper soil layers (this was evident for Julida and Lumbricidae; personal observation), while the absence of insect larvae may be because most of them mature by the end of spring, as recorded in temperate forests (Altmuller 1979, Mollon 1982).

The effects of fire on the abundance of soil invertebrates may be either direct, through the immediate death of the animals, or indirect, through microhabitat and microclimatic changes, mainly caused by the destruction of the above ground vegetation cover and the litter layer. In cases where fire occurs in the season when the soil invertebrates are active in the organic horizons, the immediate effects could be considerable (Bornemissza 1969, Metz and Farrier 1973). In this study, the direct effect of fire can be considered less important, since most animals where absent from the upper soil layers at the time of burning. Moreover, fire affected mainly the abundance of saprophagous animals (e. g. Julida), which depends on the amount of accumulated litter. Saulnier and Athias- Binche (1986) also suggest a reduction of the saprophagous fauna after fire in an evergreen-sclerophyllous formation. Fire also caused changes in the phenology of some taxa. Analogous observations have also been reported by Huhta et al. (1969) and Luxton (1982) for coniferous forest and peat soils, respectively. These changes should also be attributed to changes in microclimatic conditions due to fire.

In general, the numerical responses of the several taxa to fire are the following: (a) Significant reduction with no sign of recovery until the end of the sampling period, as was found for Julida. (b) Significant reduction after fire with a tendency to recover the second post fire year, as was found for insect larvae. (c) No reduction of abundance until the second post fire year, as is apparent for Lumbricidae. This indicates a delayed effect of fire, as reported by Majer (1984). However, the interannual differences in climatic pa-

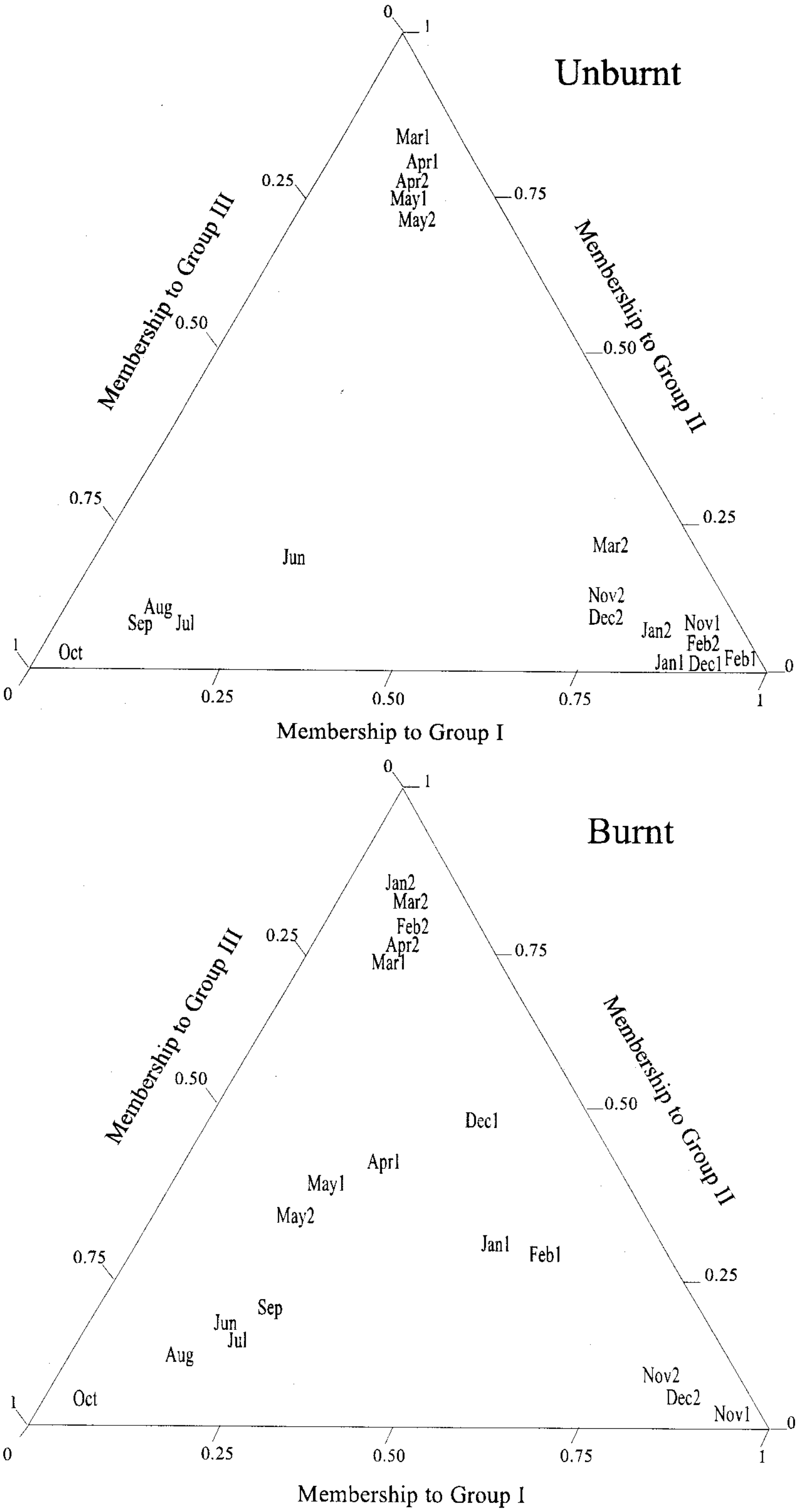

Figure 5. Fuzzy classification of the monthly samples of soil macroinvertebrates. For the sake of clarity, the classification of the samples from the burnt site is given separately from that of the unburnt. Numbers (1,2) associated with the abbreviations of the months' names denote the year of sampling.

rameters, recorded in the study site, may confuse the interpretation of such results. For example, for Coleoptera, the differences in abundance between the unburnt and the burnt site the second sampling year should be considered a response to climatic variations and not a delayed effect of fire, since they result from the increase of abundance in the unburnt site. (d) No significant changes in abundance due to fire. This was evident for the rest macroinvertebrate taxa in the study area. An analogous variability of numerical responses of macroinvertebrates to fire has been reported in cases of fires of low intensity (Abbott 1984, Majer 1984, Seastedt 1984).

Canonical analysis indicated that the main trends of macroinvertebrate abundance variations are the seasonal ones occuring in the unburnt site. These variations are as large or larger than the variations imposed by fire. Moreover, both the seasonal and the interannual changes of abundance in the burnt site were less pronounced than the ones observed in the unburnt site.

The results drawn from the analysis of community composition are similar to the above. DCA disclosed that the temporal distribution of the taxa in our study area is determined by the seasonality of the mediterranean climate. This seasonal effect was obvious in both sites. However, fire resulted in a more even distribution of taxa the whole year round. The fuzzy classification revealed also a clear-cut seasonal effect in the unburnt site but a more complex pattern of community changes in the burnt site.

The fluctuations of the climatic parameters constitute inhibiting factors for the activity of soil animals in the upper soil layers (Argyropoulou et al. 1993). However, the vertical or horizontal movements of the animals towards protected sites are important for the synchronization of their activity with the environmental imperatives (Stamou et al. 1993). According to Sgardelis and Margaris (1993), fire results in a less heterogenous and less divided environment for the soil animals. Thus, the differences between the burnt and the unburnt site recorded in the present study seem to be associated with the microhabitat differences, resulting from fire. Another result of this study, supporting the above suggestion, is that the effect of fire was more pronounced on the composition of the litter dwelling fauna, while soil inhabitants were affected to a lesser extent. The different effects of fire on the epiedaphic and the soil inhabiting fauna have been reported also by Abbott (1984), Majer (1984), Seastedt (1984) and Sgardelis and Margaris (1993).

In conclusion, the absence of the soil inhabitants from the upper soil layers during the dry period enables them to avoid the immediate effects of wild summer fires. Thus, in most cases, the observed effects of fire can be attributed either to the reduction of the accumulated litter or to the microclimate changes, resulting from the reduction of the above ground vegetation cover. Based on the above, we suggest that the recovery of the soil invertebrate populations after fire depends on the recovery of the vegetation and the associated litter layer.

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