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Cellulose decomposition rates and soil arthropod community in a *Pinus halepensis* Mill. forest of Greece after a wildfire

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Abstract – Decomposition rate and composition of the soil arthropod community were studied in a severely and a less-severely burned patch of a Mediterranean Aleppo pine forest burned by a large-scale summer wildfire. Decomposition rates were estimated from the dry mass loss of pure cellulose enclosed in coarse (7 mm) and fine (0.9 mm) mesh bags. The composition of the soil arthropod community was investigated by collecting samples of the burned organic horizon and extracting the animals. The decomposition of cellulose followed the same pattern in both burned patches and mesh bag treatments indicated a similar pattern of decomposer biota activity. Twenty-one arthropod taxa were collected in the less-severely burned patch and sixteen taxa in the severely burned patch; the annual density of their populations was 571.8 and 382.0 ind·m^{-2}, respectively. Season, post-fire age and fire severity were the determinants for the composition of soil arthropod community. Under the conditions studied, the role of soil arthropods in the decomposition process seems to be less critical as decomposition was successfully accomplished despite both the low number and density of soil arthropod taxa. © 2000 Éditions scientifiques et médicales Elsevier SAS

Mediterranean / Greece / pine forest / wildfire / soil arthropods / mesh bags / cellulose mass lass / decomposition

1. INTRODUCTION

Pine forests constitute one of the three dominant Mediterranean-type ecosystems of the Mediterranean basin [4], the other two being the tall shrublands with evergreen plant species (maquis) and the low shrublands with seasonal dimorphic plants (phrygana). *Pinus halepensis* Mill. (Aleppo pine) forests cover approximately 3·10^6 ha [15, 32] in the Mediterranean basin. The main Aleppo pine forests are found in Spain, in France and in North Africa in a relatively medium rainfall regime, which generates an annual evapotranspiration under 1 250 mm [10, 32]. In Greece, Aleppo pine forests cover 371 984 ha, which constitute 8.72 % of its total forested area.

Fire incidents are very common in the Mediterranean. It has long been accepted that fire is an environmental factor shaping the Mediterranean landscapes. In the eastern Mediterranean region, fire regime may be connected to the long human intervention in this region [28]. In more recent years, the fire regime has changed dramatically. It is estimated that during the period between 1989–1993, 225 000 fires consumed 26 000 000 ha forests in the south of the European Union [19], including Greece, Italy, Spain, France and Portugal. In Greece, between 1965 and 1990, almost one-fifth (~ 21%) of the registered fire events have occurred in *Pinus halepensis* forests, consuming 122015 ha which constitute approximately 17 % of the total burned areas. Considering that *P. halepensis* forests correspond to 8.7 % of the total forested area in Greece, this amount becomes increasingly important.

Decomposition processes are very important in all terrestrial ecosystems as they mediate the essential nutrient cycling. Published data concerning the effects of fire on decomposition processes in Mediterranean-type ecosystems are rather scarce. There is some information concerning the decomposition rate of organic matter from *Eucalyptus marginata* (jarrah) forests and pine plantations [37, 38], and phrygana (low shrublands) [5] in Australia and Greece, respectively. These papers reveal great variability in the

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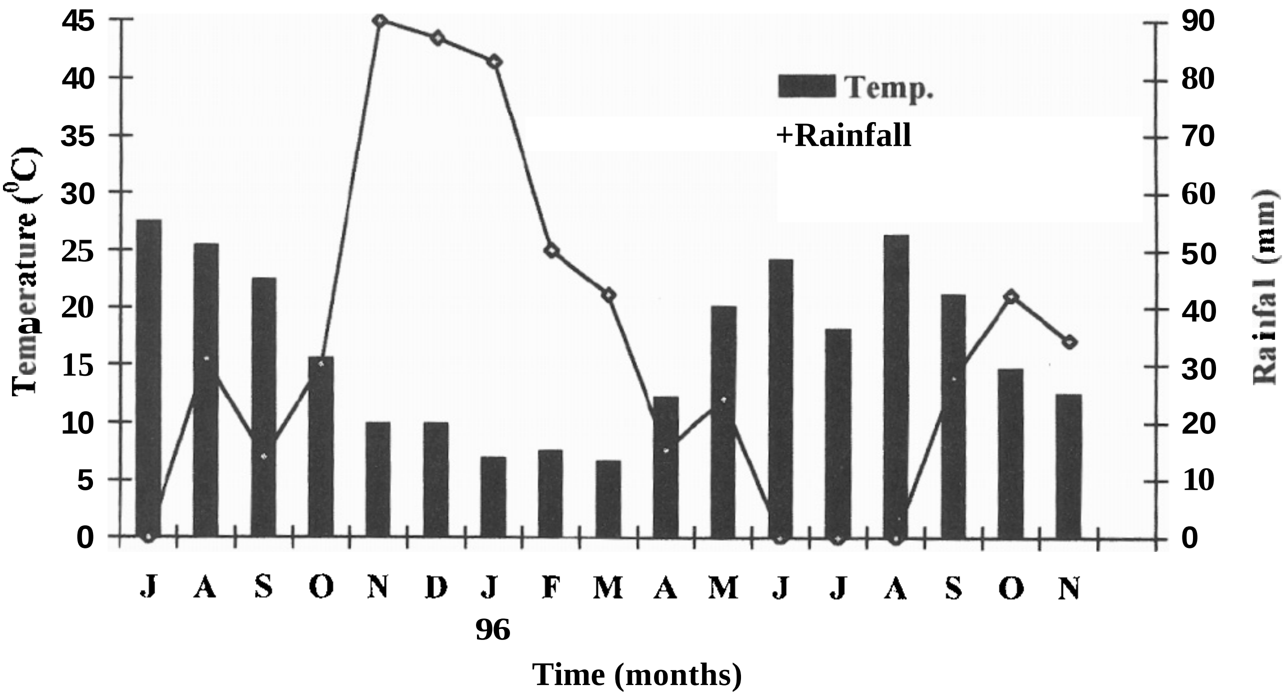

Figure 1. Ombrothermic diagram of the study site.

decomposition rates recorded. In the Greek low shrubland ecosystem, no significant change in the decomposition rate of cellulose was detected a few months after the fire event [5] whereas in the Australian ecosystems fire caused a marked decrease in the decomposition rate [37, 381.

The soil fauna plays an important role in the mineralisation of organic matter through its feeding and locomotory activities. Saprophagous invertebrates eat the dead organic matter, assimilate a part of it [26] and egest the remainder. which may preferentially be invaded by microflora 1391. Invertebrates also control the growth and the dispersion of the microflora population [3, 11-33, 34] and ameliorate the microenvironment where the decomposing activities take place by contributing to better aeration, drainage, fragmentation and mixing of the substrate [3, 30, 41].

A literature review of the effects of fire on soil invertebrates reveals a series of studies in various ecosystem types, e.g. grasslands [24, 251, low shrublands [35, 36], evergreen and deciduous forests [1, 6–8, 13, 31, 37, 38]. According to these studies, it is Are regime (frequency [1, 37], intensity [2, 38] and season of burning [36]) that mostly affects the soil biota, in which a reduction in both the number of taxa and the density of taxa dwelling in the organic horizon occurs after the fire event.

So far, there is no published work on the decomposition rate of cellulose and the composition of the soil arthropod community in burned Aleppo pine forests. The present study was designed to investigate the decomposing activity of the soil biota and to describe the composition of the soil arthropod community in two differentially burned patches of a *Pinus halepensis* forest of Greece.

2. MATERIALS AND METHODS

A large-scale wildfire, which occurred on moun Penteli (Attica) in late July 1995, consumed 7 000 h of a ***Pinus halepensis*** forest. The physiography of th area burned is quite heterogeneous in terms of th geological substrate, slope and aspect. land use and th number of fire events experienced. Within this highl heterogeneous landscape, one flat site, which had nc been previously burned for at least 50 years, wa selected as a study site. The site overlies on tertiar deposits and it has a typical Mediterranean clima (*figure* 1). The vegetation of the mature *P. halepens* forest with a relatively dense understorey shrub lay consisted mainly of *Quercus coccifera*, *Phillyrea m dia*, ***Pistacia*** *lentiscus* and *Cistus* spp. Evidence f this composition was provided from the individua regenerating in the burned site.

This large fire created differentially burned patch because of the dissected physiography of the area a the continuously changing direction of the wind blo ing during the fire episode. Two differentially burn adjacent patches separated only by a narrow path we identified and selected for the present study. In t severely burned patch (S), no needles remained on t burned pine trunks while the soil was covered by a thick ash layer (A layer) of white-grey colour. Microsites of bare ground without ashes were scarcely found. In this patch, the organic horizon was completely consumed by fire. In the less-severely burned (LS) patch, yellow-brownish needles were still remaining on the standing burned pine trees 2 months after fire while several shrubs were partially damaged by fire. In this patch, three distinct layers covered the mineral soil. The lowest layer was thin and consisted of humus which was not completely consumed by fire, the middle layer was a thick black ash layer while the upper layer, being also thin consisted of yellow needles that have fallen after the fire event (H, A and L layers, respectively).

The study was carried out from October 1995 to November 1996. During this period, the site was visited six times covering all seasons of the year, i.e. December 1995, April, June, July, September and November 1996.

The decomposition rate in the two patches was studied by estimating the rate of cellulose mass loss. Filter paper of high quality, that is pure cellulose, was cut in pieces, oven-dried at 70 °C for 48 h and then weighed; pieces of approximately 1 g dry weight of the weighed cellulose were enclosed in 10 × 10 cm nylon mesh bags with mesh size of 0.9 and 7 mm, respectively. The mesh sizes were selected so as to separate the cellulose mass losses due to microflora and microarthropods (fine mesh) and to microflora and micro-, meso- and macroarthropods (coarse mesh). Early in October 1995, the litterbags were placed in the field. In each patch, the bags were placed into the A layer in five blocks in a randomized design covering the whole area of each patch. Each block consisted of six bags of coarse mesh size and six bags of fine mesh size. On each sampling occasion, one bag of each mesh size was collected from each of the five blocks of the relevant patch. Overall, five bags of fine mesh size and five bags of coarse mesh size per patch were collected on each sampling occasion. The hags were placed in small containers and transported to the laboratory. The filter papers were removed from the hags, weighed, oven-dried at 70 °C for 48 h and re-weighed for the estimation of their water content. The weighed samples were then put in porcelain vials of known weight and incinerated in a muffle furnace at 500 °C for 4.5 h. The final estimation of the net cellulose mass loss (soil free) was based on the difference between the weight of the vial and filter paper sample before and after incineration.

The study of the soil arthropod community was conducted by collecting randomly chosen sample units with a sharp edge quadrant of 25 x 25 cm. Sampling was performed on the same dates as the mesh bag collections. On each sampling date, five samples per patch were collected. In the severely burned patch, each sample unit consisted of A layer. In the less-severely burned patch, the sample units comprised the L, A and H layers. The arthropods were extracted from the samples by means of a Berlese-Tullgren apparatus. The specimens were collected in 75 % ethanol solution with 5 % glycerin, identified to the level of order and counted under a stereomicmscope (Zeiss Stemi 2000-C). The water content of A and L+A+H layers was estimated by weighing the soil samples before and after arthropod extraction.

Differences in the pattern of cellulose mass loss between the patches and the mesh size of bags were detected by Kruskal-Wallis non-parametric analysis of variance [43] by means of the software package STATISTICA 4.3.

The statistical program CANOCO^{TM} 4.0 for Windows was used for the ordination of patches based on the response of arthropods to several environmental variables, namely season of the year (winter, spring, summer, autumn), fire severity (severe fire, less-severe fire) and post-fire age (months). The values for the first two environmental variables are in nominal scale while for the last variable are in ordinal scale. A preliminary detrended correspondence analysis (DCA) showed short gradient lengths (i.e. for axis 1, the gradient length was 2.810 < 3 SD). Consequently, among the available models, a linear one was the most appropriate to use [40]. Thus in the forest studied, redundancy analysis (RDA) was successfully performed using the data concerning the abundance of soil arthropods and the environmental variables mentioned above.

3. RESULTS

The mean water content of the A layer in the severely burned patch and of L+A+H layers in the less-severely burned patch is 8.8 and 14.1 %, respectively for the period lasting from December 1995 to November 1996. During the same period, the mean water content of cellulose was 20.9 % in the fine mesh hags and 9.1 % in the coarse bags in the (LS) patch whereas the mean annual water content of cellulose was 12.5 % in the fine bags and 8.0 % in the coarse hags in the (S) patch.

The mean mass loss of cellulose observed in the fine mesh hags was about two times lower than that from the coarse ones in both patches at the first sampling date. After that, in the (LS) patch, the greatest mass loss of cellulose was recorded from the fine mesh bags, whereas in the (S) patch, the greatest loss was derived from the coarse ones during almost the whole sampling period. The mass loss of cellulose from the different mesh size bags in the two study patches was of the following order: (LS) fine mesh > (LS) coarse mesh > (S) coarse mesh > (S) fine mesh ***(figure** 2)*. However, no statistically significant difference was found in the patterns of cellulose mass loss between the patches and mesh size of bags ($H = 4.48$, $P = 0.21$).

Twenty-one and sixteen soil arthropod taxa were found in the (LS) and in the (S) patches respectively ***(table** I)*. One taxon, (Dermaptera), was collected only

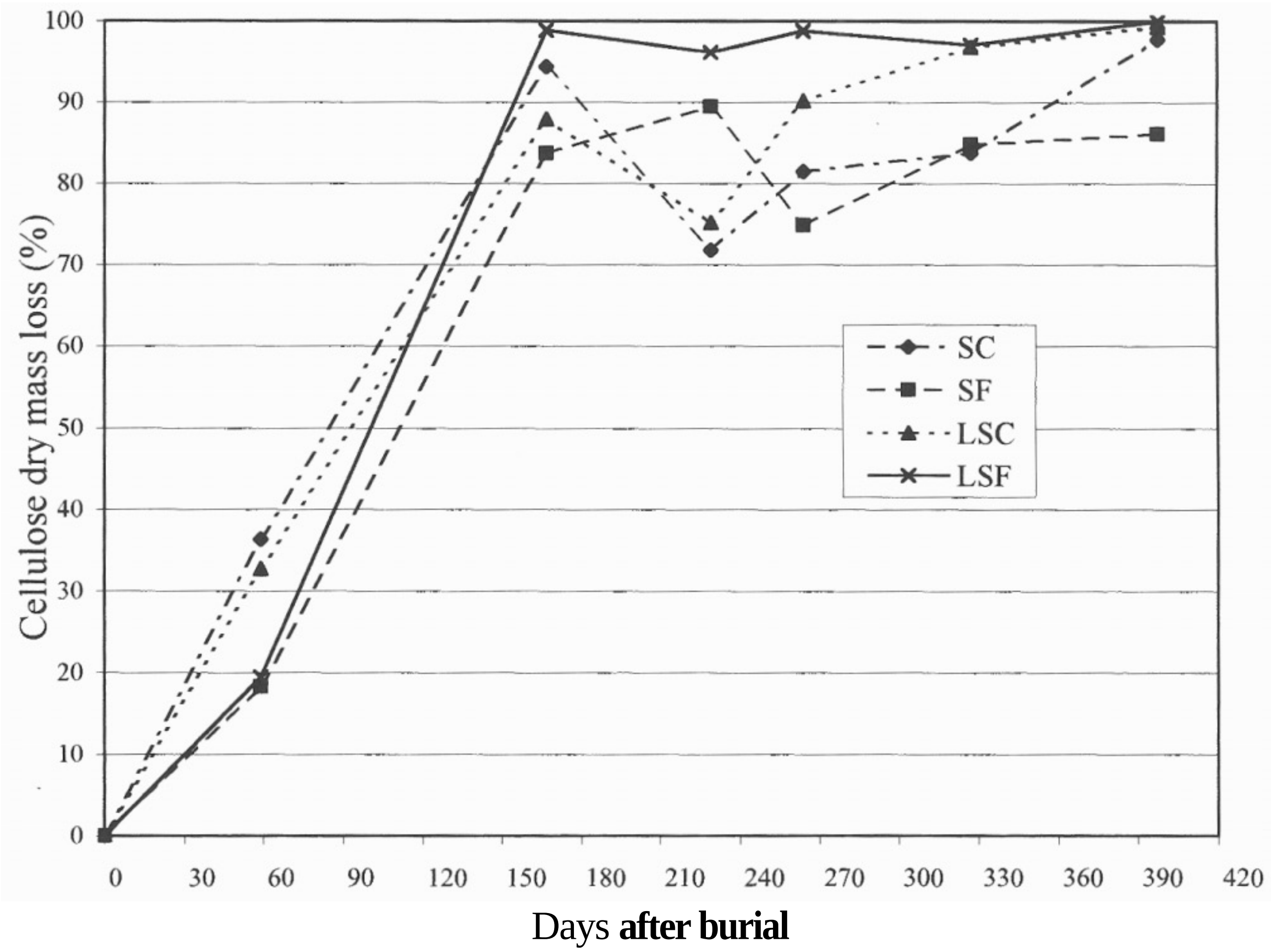

Figure 2. Dry mass loss of cellulose (ash-free) from the coarse (C) and the fino(F) mesh bags in the severely (S) and less-severely burned (LS) patch during the sampling period. Date of burial (day 0 at the diagram): 18/10/1995.

from the severely burned patch and six taxa (Thysanura, Embioptera, Iulida, Isopoda, Lepidoptera and Neuroptera larvae), were collected only from the less-severely burned patch.

The mean annual density of all arthropod taxa in the (LS) patch was 571.8 ind·m^{-2} while in the (S) patch was 382.0 ind·m^{-2}. Over all six sampling occasions, the most abundant arthropods in the (LS) patch were Acarina (from which 43.3 % were Cryptostigmata), Collembola, Psocoptera and Coleoptera. In the (S) patch, Acarina (from which 38.2 % were Cryptostigmata), Collembola, Diplnra and Coleoptera larvae dominated.

The results of RDA applied on the soil arthropod abundance and the environmental variables are shown in *figure* 3 and in ***table II***. This analysis showed that axis I accounted for 26.8 % of the total variance in taxa data and was correlated with the season of the year (t= 2.92). Axis 1 was a gradient from the wet to the dry period. In both patches, the composition of the arthropod community during the wet period was qualitatively and quantitatively richer than that in the dry period of the year. Axis 2 accounted for 6.5 % of the total variance and was correlated with the post-fire age (t= –2.05). This means that the composition of the soil arthropod community was not constant during the study period, that is the interval between five and sixteen months after the fire event. Axis 3 accounted for 5.2 % of the total variance in taxa data and was correlated with the fire severity (t = 3.02), i.e. this axis was a gradient of fire severity. This fact means that the composition of soil arthropod community differed between the severely and the less-severely burned patch.

It is accepted that arrows pointing roughly in the same direction indicate a high positive correlation between the variables tested [40]. Therefore, *figure* 3 clearly shows that the abundance of all arthropod taxa (with the exception of Diplura) depends mainly on the season of the year and the post-fire age of the stand, while the role of fire severity seems to be of less importance.

Table I. **Moan annual density** (± SE) **of arthropods** (ind·m^{-2}) in **the severely** (*n* = 30) **and** the **less-severely burned** patch (n = 30).

Arthropod taxa	Less-severely burned patch	Severely burned patch
Pseudoscorpionida	5.7 ± 4.1	3.0 ± 1.9
Araneae	5.0 ± 2.2	1.6 ± 1.1
Acarina	146.0 ± 57.2	193.7 ± 171.4
Geophilomorpha	2.7 ± 1.7	2.1 ± 1.6
Iulida	1.6 ± 1.1	–
Polyxenida	1.1 ± 0.7	2.1 ± 2.1
Symphyla	3.2 ± 3.2	2.1 ± 1.6
Isopoda	1.1 ± 0.7	–
Collembola	340.5 ± 295.6	151.0 ± 119.0
Thysanura	0.5 ± 0.5	–
Protura	1.1 ± 1.1	4.3 ± 3.7
Hemiptera	7.5 ± 3.8	1.1 ± 1.1
Psocoptera	26.0 ± 18.8	4.9 ± 3.2
Coleoptera	13.7 ± 7.1	1.1 ± 1.1
Diplura	0.9 ± 0.9	5.7 ± 4.2
Embioptera	0.5 ± 0.5	–
Dermaptera	0.0 ± 0.0	2.7 ± 2.7
Coleoptera larvae	8.0 ± 2.3	5.3 ± 4.7
Diptera larvae	2.1 ± 1.3	1.4 ± 1.4
Lepidoptera larvae	4.3 ± 2.1	–
Neuroptera larvae	0.5 ± 0.5	–
Mean annual density	571.8	382.0

4. DISCUSSION

The fire we studied was a large one. It consumed the mature *Pinus halepensis* forest occurring on Mt Penteli, Attica, leaving unburned only a few patches of previously hurned areas (regenerating forest sites approximately 15 years old or sites which had been reforested by the Forest Service). The only mature Aleppo pine stands that escaped the fire were extremely small patches, surrounded by housing blocks and suffering from human activities (trampling, waste disposal, etc.). In these patches, no reliable scientific sampling could he performed. This fact caused a difficulty in our study for the simple reason that no actual comparison between burned and unburned (control) site could be synchronically performed over the same mountain rim. In order to overcome this shortcoming, the comparison between burned and unburned sites was based only on data from literature. Consequently, data for unburned forests were retrieved either from publications concerning other regions of Greece having *Pinus halepensis* forests (e.g. the cases of the islands of Skopelos and Euboea [27, 33]) or unpublished data gathered by the authors from another mountain of Attica, Mt Parnitha (Arianoutsou and Radea, unpuhl. data).

In both burned patches, the existing decomposer biota seemed to be able to start the breakdown of cellulose shortly after the fire event (*figure* 2). It is known that soil microorganisms can effectively tolerate heat, especially under dry conditions [18] and heavy structured soil [9]. It is therefore assumed that soil decomposer microorganisms under the studied conditions – summer fire and tertiary heavy soil – were not affected by the action of the heat induced by the fire. Similar results in the initiation of decomposition have been reported for other hurned Mediterranean-type ecosystems (phrygana [5] and jarrah forests [38]). On the contrary, in a burned Australian pine plantation, the initiation of this process required a longer period [37]. The overall pattern of cellulose decomposition recorded in both present burned patches seems to resemble that observed for a burned phryganic ecosystem too [5].

In both patches, cellulose decomposition is almost accomplished within one year in both types of mesh bags (*figure* 2). This time period is shorter than the relevant one in the unburned mature Aleppo pine forest of Mt Pamitha, Attica, where this process took place in more than 400 d (Arianoutsou and Radea, unpuhl. data). In all the above-mentioned cases, the time required for the completion of cellulose decomposition was much longer than that reported for a hurned phryganic ecosystem of Greece [5].

The number of soil arthropod taxa and the mean annual density of their populations in both patches of the burned forest studied are much lower compared with those estimated in two unburned mature Aleppo pine forests of Greece (7 430.3 and 4 651.6 ind·m^{-2} [27, 33] respectively). The same data, i.e. lower number of taxa and lower density of their populations in burned sites, were also recorded in other Mediterranean-type ecosystems such as Aleppo pine forest in Israel [11], phrygana in Greece [35, 36], and jarrah forests in Australia [37].

In both patches, Acarina and Collembola dominate as they do in the unburned Aleppo pine forests mentioned above [23, 26]. The dominance of these taxa even after fire has been recorded in various ecosystems such as phrygana [35], *Eucalyptus regnans* forests [14] and dry sclerophyllous forests [42]. In both burned patches, the low mean annual density of Coleoptera and Araneae and that of saprophagous-microphytophagous Psocoptera and Polyxenida can be explained by the temporal distribution of these taxa and the fire season. The above taxa, chitinized or hairy xerophilous-mesophilous groups, show the maximum of their abundance and activity in the litter layer during the aestival period of the year [16] when fire takes place and, thus, fire directly causes their death.

Redundancy analysis *figure* 3, *fable II*) revealed that in the burned patches studied the most important environmental factor affecting the composition of the arthropod community and the temporal distribution of soil arthropod populations are the following: seasonality of climate, post-fire age of the stand and fire severity in a descending order.

The seasonality of climate plays the principal role because in both burned patches the highest number of taxa and individuals has been recorded during the wet period of the year (*figure* 3), as has also been observed in unburned Aleppo pine forests in Greece ([27, 331,

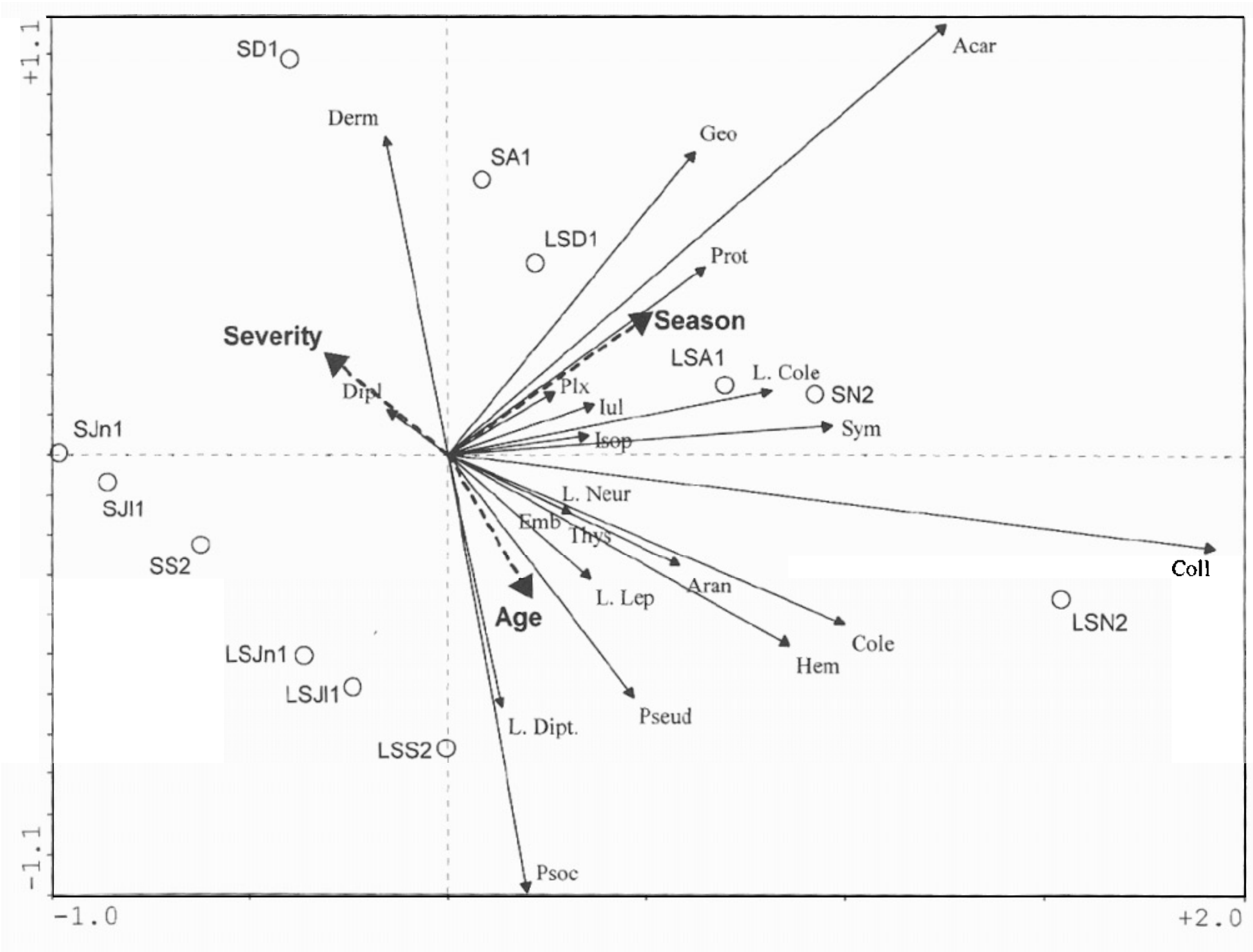

Figure 3. Ordination of samples and arthropod taxa collected from the severely (S) and less-severely burned patch (LS). D1, December 1995; A1, April 1995; Jn1, June 1996; Jl1, July 1996: S2, September 1996: N2, November 1996. L. Lep, larvae of Lepidoptera; L. Cole, larvae of Coleoptera; L. Dipt, larvae of Diptera; L. Neur, larvae of Neuroptera; Psoc, Psocoptera; Dipl, Diplura; Hem, Hemiptera; Cole. Coleoptera; Isop, Isopoda; Geo, Geophilomorpha; Acar, Acarina; Plx, Polyxenida; Iul, Iulida; Ann, Araneae; Prot, Protura; Coll, Collembola; Emb, Embioptera; Thys, Thysanura; Pseud, Pseudoscorpionida; Sym. Symphyla.

Arianoutsou and Radea (unpubl. data)) or in burned and unburned Aleppo pine forests of Israel [11] and finally in burned phryganic ecosystems [35, 36]. According to Sgardelis et al. [36], the seasonality of Mediterranean climate imposes variations of arthropod abundance greater than those caused by fire.

Post-fire age of the stand is another important factor for the soil fauna. Even in the severely burned patch, the arthropod fauna seems to recover gradually as it is deduced from the increase in the number of taxa and abundance of their populations recorded at the last sampling campaign. The gradual recovery of the soil

Table II. Results of redundancy analysis.

Axis variable	Axis 1	Axis 2	Axis 3	Total inertia
Eigenvalues	0.268	0.065	0.052	1.000
Taxa-environment correlations	0.770	0.820	0.819	
Cumulative percentage variance				
of taxa data	26.8	33.3	100.0	
of taxa-environment	69.7	86.5	38.4	
Sum of all unconstrained eigenvalues				1.000
Sum of all canonical eigenvalues				0.384

arthropod fauna can be attributed to the recovery of vegetation occurring in both patches studied. However, in a burned Aleppo pine forest of Israel, soil arthropod populations had not completely recovered after five post-fire years [11].

The low mean annual densities of the other arthropod taxa may he attributed to an indirect effect of fire. It is known that the higher the severity of a wildfire the greater the alterations in the environment and, consequently, in the soil arthropod community [1, 37, 38]. In Mediterranean type ecosystems, the quantity of organic matter in the soil constitutes the 'key factor' controlling the community structure and population dynamics of soil fauna [17]. Fire consuming the accumulated organic matter either reduces or eliminates the available food for saprophagous arthropods [6, 36]. Thus, the populations of saprophagous and saprophagous-microphytophagous taxa are either at much lower density (e.g. Collembola, Acarina Cryptostigmata, larvae of Diptera, etc.) or absent (e.g. Iulida, Isopoda) in the severely burned patch where the food resources are considerably reduced. Fire changes the structural complexity and the physicochemical properties of the soil organic horizon [20] resulting in a less heterogeneous habitat [29] with modified microclimatic conditions [7, 8]. Taxa such as Araneae which depend on the stmctural complexity of the organic horizon [12] and Pseudoscorpionida, Diptera larvae, Collembola, Iulida and Isopoda whose densities are significantly related to the moisture content of the organic horizon in unburned Aleppo pine forests [27, 33] have been found in lower numbers or are absent in the severely burned patch.

In conclusion, it is suggested that the overall decomposition of cellulose follows the same pattern in both burned patches and mesh hag treatments indicating a similar pattern of decomposer biota activity too. Under the conditions studied, the role of soil arthropods in the decomposition process seems to be less critical as decomposition was successfully accomplished despite the obvious reduction in the number and the density of soil arthropod taxa. Concerning the factors affecting the composition of the soil arthropod community, the findings of the present work confirm the results of other studies on burned Mediterranean-type ecosystems. Although the composition of the arthropod community was found to be richer in the less-severely burned patch, the seasonality of the Mediterranean climate constituted the principal environmental factor affecting the composition of the soil arthropod community during the period of study.

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