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CHARACTERIZATION OF FIRE VULNERABLE *PINUS HALEPENSIS* ECOSYSTEMS IN SPAIN AND GREECE

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Abstract

The knowledge of factors that govern a system's vulnerability permits the establishment of priority action zones immediately *after a* fire to mitigate its effects.

An extensive survey of several burned areas in Spain and Greece has been arranged, in order to identify vulnerable patches in terms of low vegetation cover and low pine regeneration. After visually identifying the patches, a data base has been elaborated, including the most relevant information. A combination of factors related to bedrock, slope, aspect, soil stoniness and forest type were found to be associated *with* the poorest vegetation recovery. Furthermore, the crucial role of short fire interval was established.

In order to obtain an early, short-term characterization of the vulnerable patches, vegetation structure had been analysed no later than two years after the last fire event. In both regions vegetation cover and pine sapling density was less than expected from reference data. The tendency seems to be towards the formation of shrublands instead of woodlands with increased levels of erosion risk.

INTRODUCTION

Forest fires constitute one of the most important ecological factors in mediterranean ecosystems, where they are considered natural perturbations that play a fundamental role in the distribution, organization and evolution of these ecosystems [1,2,3]. For mediterranean pine forests and woodlands, in particular, the importance of fire towards the maintenance of their structure and biodiversity has been recognized [4]. The short-, mid-, and long-term post-fire regeneration patterns of *Pinus* halepensis communities has been studied elsewhere [e.g., 5,6,7,8,9,10,11] showing that in most cases these communities are resilient to fire. Still, *Pinus* halepensis forests are not homogeneous across a forested landscape, since differences in site characteristics are reflected to differences in the composition and the structure of the understorey [12, 13]. Similarly, resilience to fire may differ among the various patches of the forested landscape, following the ability of several key plant species to regenerate after fire under the specific biotic and abiotic interactions developed within the various patches [14]. Differences in fire and land use history increase this diverse response to fire [15,16].

Forest fires increase the susceptibility of the affected areas to degradation processes and soil erosion [17, 18]. The determinant factor in the extension of these processes is the disappearance of the vegetation cover, which leaves the soil exposed and unprotected [19].

During the last decade, large fire events are a common phenomenon in the European Mediterranean consuming thousands of hectares of *Pinus* halepensis forests and woodlands. Mostly affected countries are primarily Spain, France and Greece. As a result, there is an increased public demand for effective post-fire ecosystem management. Given the above-mentioned heterogeneity in ecosystem resilience across large burned areas and the limitations in personnel and financial support, it is essential for the Forestry Department Officials to be able to identify patches vulnerable to fire, so as to apply management practices only to those parts that actually require them. Towards this direction, the characterization of fire vulnerable ecosystems would permit the establishment of priority action zones immediately after a fire to mitigate its effects. In this framework and in the context of a EU-funded project, we surveyed vulnerable areas corresponding to *Pinus* halepensis patches in order to determine the role of several environmental factors (slope, aspect, geology) towards poor recovery (long term, 4 to 10 years after fire) and to investigate plant community characteristics (shortterm, less than 2 years afterfire).

LANDSCAPE LEVEL APPROACH: **MID AND** LONG-TERM STUDY

Study Sites

Spain

The area of study is the Valencia Region, located in the far east of the Iberian Peninsula (Figure 1). The climate is typically Mediterranean, with average annual precipitation varying between 400 and 600 mm. Several bedrock materials predominate: limestones and dolomites (41%) and limestone and calcarenites with a larger or smaller proportion of marls (29%). Limestones and dolomites are calcareous rocks that produce shallow, decarbonated substrates with abundant cracks and outcroppings. Marls produce deeper soils that are very carbonated and without cracks. Forest vegetation in this area is influenced by a long history of fires [20] and land uses (sheep and goat grazing together with the terracing of slopes for agricultural purposes, among others). *Pinus halepensis* stands, present throughout the territory, are predominant in the forested areas [21].

This study is centred on the forest fires that occurred in the Valencia Region in 1994. In that year a very large surface area was affected by lire (140000 ha) and a great deal of data was accumulated on the areas burned. Most of the areas affected by these fires are located at altitudesfrom 300-1500 m asl.

In some of these areas there is high fire recurrence. In Millares, for example, 70% of the surface area had already suffered wildfires in the previous 26 years: 32% in 1978-79 and 38% in 1980-91. Depending on the characteristics of the affected areas and their land-use history, some of the fires encompassed wide areas ofterraced slopes that were once cultivated but are now abandoned and in various degrees of deterioration

Fig. 1. Map of the European countries of the Mediterranean Basin, where the study regions of Valencia (V) and Attica (A), in Spain and Greece, respectively, are indicated.

Greece

The Greek study area is Attica region, i.e. the geographical district around Athens metropolis (Figure 1). The whole study area fits within the limits of Mediterranean climate, with average annual precipitation varying between 300 and 700 mm. The altitude of the surveyed burned lands rises from 110 m to 830 m asl. The dominating bedrock materials are limestone and schist (a siliceous, waterproof rock), while tertiarydeposits of alluvial origin are commonest at lowlands.

Partially because of intense human pressure for urbanization of the mountains surrounding Athens, numerous fire events have been affecting the pine forests of Attica within the last 25 years. As a result, averagefire recurrence has changedfrom >50 years to <20 years in several cases.

Other past uses of the forests in question by humans include resin collection, grazing of the understorey, logging and honey production.

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Methodology

All the available information on forest fires in the study areas of Spain and Greece has been compiled for the respective years. The main data available were physiographical and geological characteristics, cartography, pre-firevegetation, post-fire management (if any), land use and fire history.

At the same time, the parts of the burned areas that corresponded to Aleppo pine communities were surveyed, so as to identify patches where regeneration was poor. In the context of this survey, poor regeneration was evaluated in terms of vegetation cover and pine abundance. Both parameters have the advantage of being visually estimated, thus permitting the appraisal of large areas within the, usually restricted, available time. Low vegetation cover strongly indicates the negative fire effects on one or more plant groups, given the fact that, apart from the first year, post-fire regenerating *P. halepensis* plant communities are characterized by high soil vegetation cover, due to the complexity of vegetation structure (consisting of a variety of plant groups) [10, 11]. Furthermore, low vegetation cover is important for land managers since it is related to risk of erosion and soil degradation [15, 22, 23]. On the other hand, adequate pine regeneration is essential for the resilience of these ecosystems, since the pine is the species that defines the physiognomy of the vegetation. It is expected that immediately after fire pine density reaches certain levels which ensure forest recovery [24, 25]. Therefore, if this is not the case (low pine regeneration) there is strong evidence of poor ecosystem recovery.

By combining field data with information on site characteristics for the identified vulnerable to fire patches, a database has been elaborated. Using this database, the patches were grouped into different categories (cases).

Results and Discussion

Spain

Approximately 4% (1718 ha) of the total burned area explored 9-10 years after the last wildfire in the Valencia Region has been categorised as vulnerable to fire. 28 such patches have been identified and grouped into 7 different cases, on the basis of several factors, mainly related to bedrock type and pre-fire vegetation. The relative surface for each of the groupsareshown in Figure 2.

The largest vulnerable surface was found for Case II, representing 32% of the total vulnerable surface area. This case corresponds to scattered pine masses with an understorey of mainly seeder species, a low cover, poorly developed vegetation and scant pine regeneration. The substrate is limestone, marl and clays; the proportion of each of these materials will determine the vulnerability of the soil to erosion. The climates represented are Meso and Thermo Mediterranean with dryombroclimate.

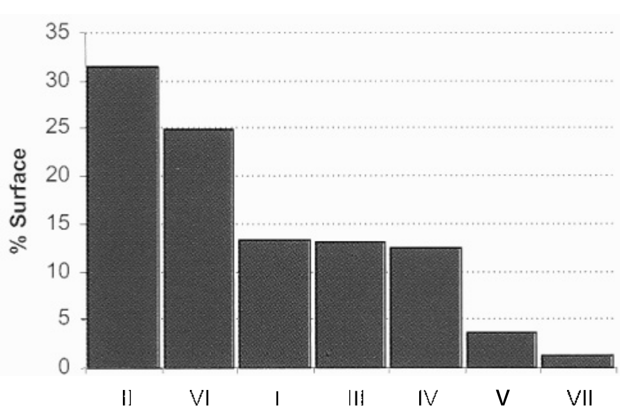

Fig. 2. Surface of selected vulnerable areas grouped in categories. Percentage of each case relative to total vulnerable surface.

The second group with the largest vulnerable surface area corresponds to Case VI (25%). This group consists of scattered pine masses on substrates of clay, sandstone and marls with outcroppings of gypsum and conglomerates. This substrate type is not the commonest in the Valencia Region, representing only about 20% of the forested surface, but it seems to be one of the most problematic, especially with respect to phenomena such as erosion combined with a poorvegetation response.

In reference to the total vulnerable surface studied, steep slopes characterize the 72% and high stoniness the 47% of the surface. Regarding slope aspect, 17 of the 28 areas selected asvulnerable were oriented towards thesouth; this corresponds toapproximately 46% of the totalvulnerable surface.

Greece

In Attica, the environmental factors were found to play a secondary role towards poor ecosystem response to fire, since the main driving force of vulnerability was fire history and in particular, short fire interval. More than 80% of the area surveyed 6 to 9 years after the last wildfire corresponded to patches that had been burned twice within the last 20 years. However, a combination of factors such as parent rock material, slope, rock cover and *Pinus* halepensis forest type were found to be associated with the poorest vegetation recovery.

According to our results, under the scenarios of frequent fire events, more prone to poor ecosystem regeneration and resilience are those pine patches that develop on sites with limestone, high ground steepness and soil stoniness. Furthermore, pine communities which correspond to the lowland forest type [26], where seeding species dominate the understorey (e.g. Coridothymus *capitatus,* Phagnalon graecum, Helichrysum stoechas), were proved to be more vulnerable to short fire interval than the upland forest type, where understorey is dominated by evergreen woody resprouters (e.g. Quercus coccifera, Arbutus andrachne, Phillyrea media).

Still, some cases of vulnerable patches have been encountered among the once burned forested area. These cases can be grouped into 3 categories. The first is the case of patches typical of the upper zone (close to the ridges) of low-altitude (less than 900 m) mountains developed on limestone, in sites with high rocky outcrops and stone cover (more than 50%). Pine stands on these locations have rather undeveloped woody understorey, characterized by the presence of sparse, cushion-like, individuals of Quercus coccifera.

The other two cases can be regarded as examples of how the pre-fire vegetation structure affects post-fire resilience. In pine stands with high abundance of the shrub Juniperus phoenicea in the understorey, the regeneration of all species is satisfactory but for this species, which is known to be unable to regenerate [27]. The highest the abundance of this species in the understorey, the lowest the resilience capacity of the overall system.

The second is the case of stands with high abundance of Quercus coccifera in the understorey, a species that is characterized by vigorous resprouting even from the first few days after the fire event [28,29]. Accordingly, it is expected that by the time pine seedlings will make their appearance, competition for light and space with the resprouts will affect in a negative way pine seedlings survival.

CONCLUSIONS

The statistics of fire vulnerable ecosystems in the two study regions (Valencia and Attica) where found to be rather different. This can be attributed to different characteristics of the regions in question, namely abiotic (meteorological conditions, geomorphology), biotic (vegetation type distribution) and anthropogenic (human population, extension of urban/wildland interface, pressure for land use change) characteristics.

Nevertheless, for each of the study regions, the mentioned factors can be used as a tool for the rapid identification of sensitive patches so that post-fire actions can be quickly applied to mitigate the effects of the fire.

COMMUNITY LEVELAPPROACH: SHORT-TERM STUDY

Methodology

In order to obtain an early, short-term characterization of the vulnerable patches, such patches within the limits of recent fire events have been identified and vegetation characteristics have been analyzed during the first andior second post fire year. Vegetation analysis provided us with data on total and specific vegetation cover, pine regeneration, specie richness and diversity. Here, only data related to vegetation cover and pine regeneration will be discussed.

Taking into consideration that each scientific group (Spain and Greece) had been applying different sampling techniques in the past, no common protocol has been followed. In such a way, the collected data would have been comparable to the past (reference) data of each scientific group.

Spain

Within all the patches considered for sampling, a plot has been established. Total and specific plant cover was recorded across 20-m-long line transects, with contact points every 10 cm. Pine regeneration was estimated by measuring pine seedling (the 1st year aflerfire) and sapling density in 6 quadrats of 1 m^2 per plot.

Greece

At each of the patches considered for sampling three 50-m-long transects have been established. Total and specific vegetation cover was recorded with contact points every 50 cm (i.e., 100 contact points per transect). Pine regeneration was measured by means of linear density, afler recording all individuals growing along the transects.

Study Sites

Spain

Two fire events have been selected for the community level approach in the Valencia Region, Torre de Maçanes (2002) and Buñol (2003). The most relevant characteristics of these fires are:

Torre de les Maçanes (province of Alacant): Fire occurred in November 2002, The climate is mesomediterraean, with a mean annual precipitation of 558 mm. Soils were developed over marls with altitudes ranging between 800 and 1100 m.

Buñol (province of Valencia): Fire occurred in August 2003 and 1707 ha were burned. The climate was mesomediterraean, with a mean annual precipitation of 450 mm. Soils were developed over limestones and marls with altitudes ranging between 500 and 800 m. There was a high recurrence of fires, namely in the years 1986, 1991, 1993 and 2001.

Within these fires, 12 plots considered vulnerable were established. Their characteristics are shown in Table 1.

Different vegetation types, representative of the fire conditions, were present in the study area. In the Buñol fire, a large part of the vegetation represented very sparse *Pinus halepensis* forest, found in small areas where the pine trees were not burned in the previous fires of 1991 and 1993. The understorey in these reduced areas was dominated by seeder species. The vegetation in the rest of the areas burned is shrubland. As for the fire in Torre de les Maçanes, the affected area was a *Pinus* halepensis woodland with mature masses in zone 1 and young pine wood (of about 3m in height) in the other zones. In all the areas studied, the soil developed on Jurassic marls and limestone.

Table 1. Main characteristics of selected plots in vulnerable areas <2 years afler fire.

FIRE	ZONE	VEGATION TYPE	SLOPE (%)	ASPECT	ALTITUDE (m)	PREVIOUS FIRE (year)
BUÑOL	Bco Peñamala S	Pine *forest*	43	160" SE	690	1991
	Bco Peñamala N	Pine *forest*	40	10°N	730	1991
	Carreteras S	Pine forest	35	220°SW	670	1991
	Carreteras N	Pine forest	32	320°NW	680	1991
	Peñas Albas S	Pine forest	20	150°SE	700	1993
	Peñas albas N	Pine forest	35	330°NW	650	1993
	Caseta S	Shrubland	45	145°SE	630	1993
	Caseta N	Shrubland	40	0° N	620	1993
	Retura S	Shrubland	25	160° SE	660	1993
TORRE MAAÇNES	1	Pine forest	22	100°E	950	>20 years
	2	Pine forest	20	170°SE	1000	>15 years
	3	Pine forest	15	170°SE	1075	>15 years

Greece

In Attica, the sampling campaign has taken place at the area burned by the Sounion National Park (N.P.) tire event (summer 2000). It was a hilly area that had been covered by a dense, old growth *Pinus halepensis* forest. In the summer of 1985 a fire burned most of the forest. Thereafter, pine regeneration was quite vigorous and abundant. The summer 2000 fire event burned a large part of this regenerating community.

The area in question is one of the most diverse, in terms of geological substrata, in continental Greece, but two types of bedrock are the most frequent, allowing us to have an adequate number of replicates, that of limestone and schist. Limestone is always found on the medium and upper altitudinal zones of the hills, while schist is expanding in all altitudinal zones. This explains the inexistence of limestone sites with low slope (plains). Consequently, five groups of communities have been sampled within the limits of the area affected by fire both in 1985 and 2000 (fire interval: 15 years). These groups refer to patches on limestone, with moderate (15–Lime–m) and high ((15_Lime_h) slope inclination, and patches on schist, with low (15_Sch_l), moderate (15_Sch_m) and high (15_Sch_h) slope inclination.

For control, the only 'mature forest stand that was burned in the same 2000 fire was considered for sampling. It had been developed on schists and it consisted of two parts, the one with moderate (50_Sch_m) and theotherwith high (50_Sch_h) slope inclination.

Results and Discussion

Spain

One year after the Buñol tire, the vegetation recovery values on the selected plots were very low; values between 9 and 30 % have been calculated, with an average of 19.2 %. No significant difference in vegetation response between the south slope (17.6 %) and the north slope (21.25 %) has been detected.

These values are much lower than those found in other studies under similarconditions. In one study carried out in the Valencia Region [7], it has been reported a 50 %vegetation recovery 10 months afler a fire in a dry mesomediterranean bioclimate with a south-facing slope on marls. In the same study and in areas with similar characteristics, but on limestone, the vegetation recovery was 32 %for the southern slopes and 52 % for the shady slopes. In the latter case, therefore, the differences derived from slope orientation were significant.

The reference threshold for effective soil protection is oflen considered a vegetation cover of 30-60 % [30, 31]. In Buñol, the very low vegetation cover values, together with the high amount of bare soil (29-60% of total soil, with an average of 47.3 %; Figure 3) and the inherent characteristics of this soil, are clear indicators of the fragility of these plots, especially with respectto erosive processes.

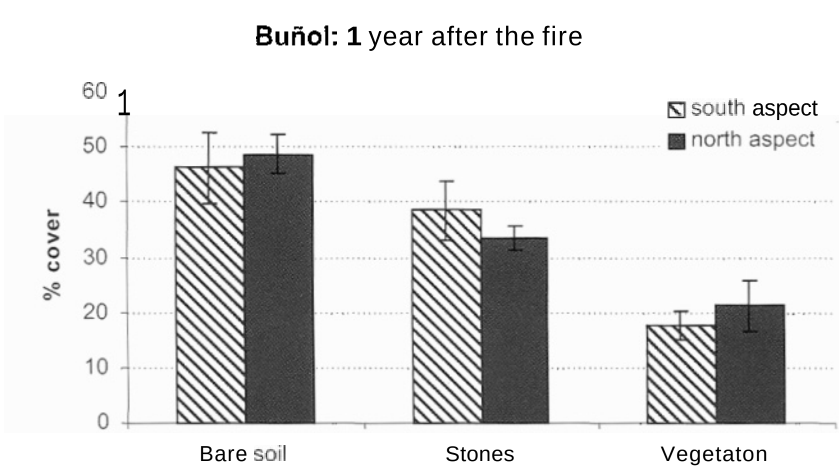

Fig. 3. Mean cover of bare soil, stones and vegetation on selected plots with different aspects, 1 year after the Buñol fire.

To evaluate the temporal dynamics of the vegetation cover and bare soil for the Torre de les Maçanes fire we collected data at two different times (Figure 4): 7 months afler the fire, i.e., afler the first spring (June 2003), and 19 months after the fire (June 2004).

In the first spring after the fire, vegetation cover on the plots studied was very low with covervalues of 11.7%. It should be noted that the tire had occurred in the previous autumn (only 7 months before). A substantial increase in the overall cover value was found at 19 months after the fire (46%). although this value can still be considered low, especially in some areaswhere it was only 29%.

Stoniness on the plots was 11%. The first measurements taken in the spring following the fire revealed a high percentage of totally unprotected soil (69.5%); a year later, this percentage dropped to 40% as a result of the increase in vegetation cover.

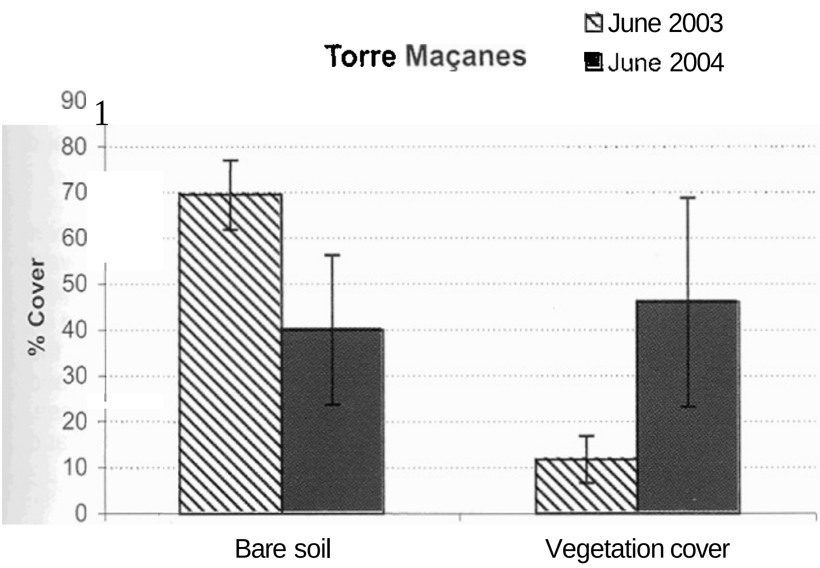

Fig. 4. Mean cover of bare soil and vegetation on selected plots, 7 and 19 months after the Torre Maçanes tire

In the two burnt areas studied, similar species have contributed to the post-fire vegetation cover. The herbaceous species Brachypodium retusum constitutes the most extensive cover in both areas, along with Brachypodium phoenicoides in the case of the Bufiol, but only on its north slopes. Other species showing significant cover values are *Ulex parviflorus*, Erica *multiflora* and various Cistaceae from the genera *Helianthemum* and Fumana. The tendency seems to be towards forming gorse shrublands (dominated by *Ulex parviflorus*) with Brachypodium, Cistaceae and an occasional resprouter like Erica.

In relation to pine regeneration, we found an average value of 0.22 0.1 ind/m^2 in the north slopes areas and of 0.17 0.17 ind/m^2 in the south slopes areas (non-significant differences) on the Bufiol fire plots. This value was higher (0.28 0.20 ind/m^2) 19 months after the fire in Torre de les Maçanes. Regeneration was very heterogeneous among the various areas (notice the high standard error value), being non-existent in some areas (Figure 5).

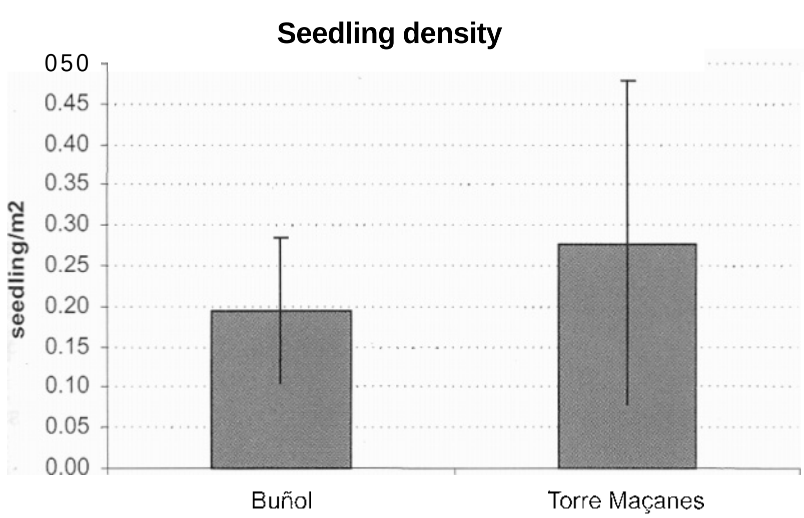

Fig 5. Seedling density (individuals /m^2) in two fires (12 and 19 months after fire)

The values found in this study can be considered low when compared with similar studies. An extensive study over a wide range of burnt sites in the Valencia Region reported values of 1.70-9.17 ind/m^2 at one year afterafire, with an averagevalue of 2.96 ind/m^2 [7]. In the same work and in areas under similar conditions to our plots (dry mesomediterranean;one year post-fire) values of 0.72 and 0.49 indlm^2 were obtained for sunny and shady slopes respectively. In another burnt area values of 0.42 and 0.63 indlm^2 have been recorded in thermomediterraneanpine forests on marls, 13 months aflerafire [32].

Greece

The response of vegetation to fire across the burned landscape resulted in high heterogeneity a fact related to the high diversity of the geomorphologyand geology of the area in question that defines species composition, in particular woody species composition. Data from two adjacent pine communities that escaped the 2000 fire and which develop on schists and limestone respectively, showed that the 'schist' community was characterized by lower woody species richness and diversity and higher cover and dominance of the pine on the physiognomy of the plant community [11, 26].

Twenty two months after the last fire event (spring of the second post fire year), vegetation cover values from the patches burned at short fire interval ('15 years') varied from 75% to 20%. The lowest values have been recorded in patches characterized by limestone and high ground inclination ('15_Lime_h' group, see Figure 6). On the contrary, from the schist group communities those found on locations with low slope showed the minimum vegetation cover ('15_Sch_l'). In the former case, the under-developed vegetation was dominated by *Pistacia lentiscus*, Genista acanthoclada and Brachypodiumramosum, all of them having the capacity of regenerating by resprouts. In the latter case, the vegetation was dominated by the obligate seeders *Cistus monspeliensis*, Fumana thimifolia and Helianthemumspp., all members of the hard-seeded Cistaceaefamily.

Maximum values were recorded in patches of moderate slope, both of limestone and schist bedrock type. Nevertheless, even those values are lower than what has been recorded from resilient pine communities. According to data from *Pinus* halepensiscommunitiesofthe same region, that were burned at afire interval longerthan 50 years, thus regarded as resilientto fire, vegetation cover during the second post-fire year was quite high, exceeding 80% for total vegetation and 40% for the woody component [10, 26]. With these values into consideration, it should be mentioned that, at least for the woody component, the vegetation cover values that correspond to the burned once studied patches ('50_Sch_h' and '50_Sch_l' in Figure 6) are lower that the expected. This could be the effect of the slope inclination factor and in any case it highlights the required considerationstowardsthe expressionofgeneral assumptions.

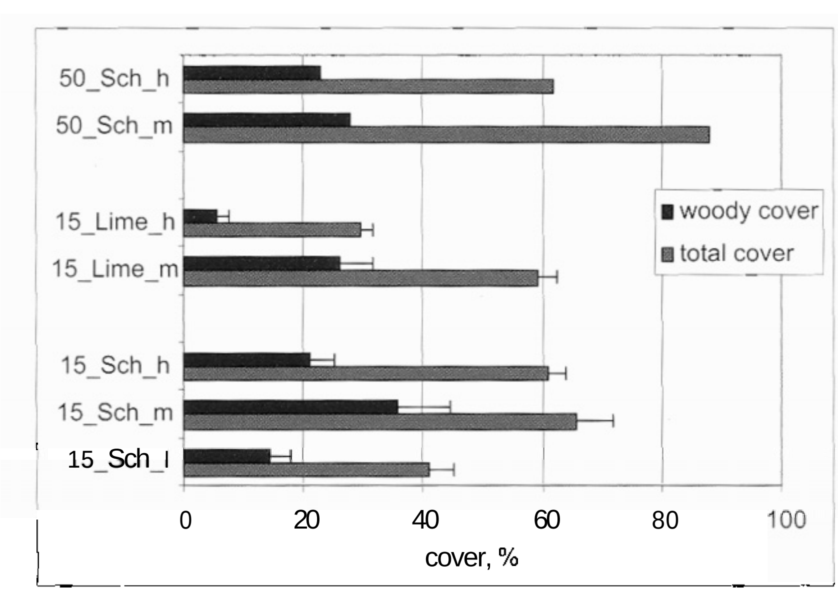

Fig. 6. Mean total and woody vegetation cover, 22 months aflerfire for the differentgroupsofcommunities of Sounion N.P.

Herbaceous legumes and in particular annual herbaceous legumes form the dominant vegetation component in burned *Pinus* halepensis forests during the early post-fire years [9, 11, 33], with average cover values varying from 20% to 40%, during the 2'' postfire year [26]. Throughout the twice burned studied area of Sounion, average herbaceous legume cover was less than 5% (Figure 7), a fact that is associated with the low regeneration capacity of this key-functional group under the given fire regime (interval of 15 years). This under-representation of legumes explains partly the lowervalues of vegetation cover in the studied vulnerable patches.

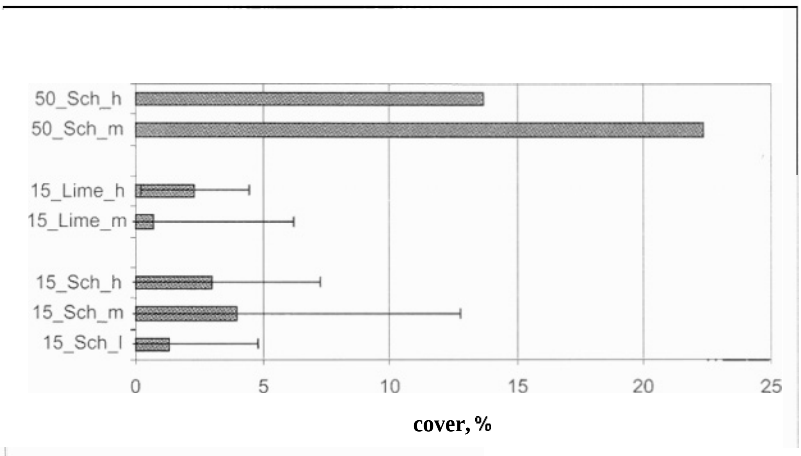

Fig. 7. Mean herbaceous legume vegetation cover 22 months after fire for the different groups of communities of Sounion N.P.

Pine regeneration was low to zero throughout the twice-burned area (Figure 8). Low densities of young pine samplings were recorded in the "15_Sch_l" communities. The 'time-window' of 15 years is inadequate for the *Pinus* halepensis population to form such a canopy seed bank that will ensure regeneration [34, 35]. Accordingly, the appearance of the pine saplings must be attributed to the neighbouring presence of unburned, mature trees that have acted as a seed source. This is a typical example of 'regeneration by migration'sensu Grubb and Hopkins [36]. These trees escaped both fires by being next to dirt roads (present in all the plain sitesof the area) that ensure quickarrival of firefighters.

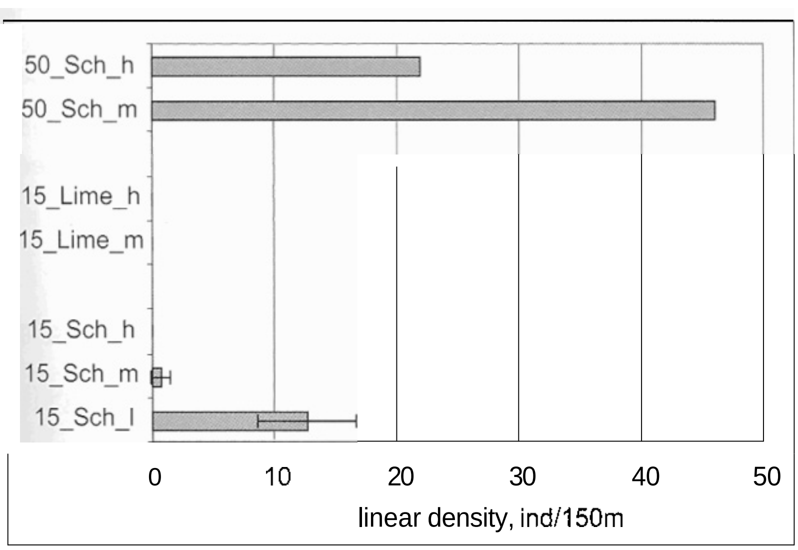

Fig. 8. Mean pine linear density, 22 months after fire for the different groups of communities of Sounion N.P.

Summarizing thefindingsfrom the Sounion N. P. fire event, poor regeneration is the case throughout the twice-burned area, but it is deteriorated under the combination of certain factors (limestone high slope, schist low slope). On the other hand, pine resilience is enhanced in plain areas, near unburned, mature trees.

Conclusions

In both regions the tendency seems to be towards the formation of shrublands instead of woodlands due to the very low regeneration capacity of pine species. Low regeneration of some key-plant groups (such as *Brachypodium* spp., Cistus spp. and annual legumes) results in low values of vegetation cover and increased levels of erosion risk. No species or group of species was found to be present only in cases of poor regeneration and, accordingly, no indicator taxon or group (sensu Noss [37]) can be proposed. Key-species or functional groups can play the role of indicators of poor regeneration through their over or under-representation in thevegetation.

OVERALL DISCUSSION AND CONCLUSIONS

Resilience, an important ecosystem function, was initially described as the system capacity to absorb the effects of disturbance and to maintain its structure [38]. Later, Westman [39] has broadened the concept by not only emphasizing on the final outcome but also on the processes and pathways that act towards the return ofthesystem to its pre-disturbancesituation.

According to Westman 's concept, resilience is a multi-dimensional function. This is the reason why resilience evaluation depends on the person who performs it [36]. For a soil scientist, for example, the key function is vegetation cover, since it is of primary importance for preventing soil erosion, whereas an ornithologist will be more interested in the shrubs and trees to re-build their pre-fire architecture, so as to present a variety of nesting and feeding habitat alternatives to avifauna. For the vegetation scientist, any attempt to study and evaluate the resilience of ecosystems implies either the existence of a sequence of different species dominance and replacement (typical secondary succession), or of a sequence of change in species relative abundance along the "autosuccessional " model [40]. The later is the case for mediterranean-type shrublands and forests. Therefore, the resilience potential of any mediterranean-type plant community is evident even from the first post-fire years.

The reported low pine regeneration together with the underdevelopment of vegetation within the first post-fire years of vulnerable pine patches in both Spain and Greece is a strong indication towards the 'non-resilience' of these patches. The dominant causes of their inability to regenerate and absorb the consequences of fire were rather different between the studied regions, a fact related to the different abiotic and historical characteristics of each region. However, by combining the main characteristics of the vulnerable areas per region with early data on vegetation dynamics, we are now at the position of producing vulnerability maps, i.e. maps that will indicate patches of high vulnerability to fire under the scenario of a future fire event [41, 42]. Furthermore, by applying the overall knowledge and experience on vegetation dynamics, the temporal pattern of the different vegetation patches across the landscape can be predicted and modeled [43].

The high degree of heterogeneity on the causes and outcomes of vulnerability to fire between different regions highlights the need for more such comparative studies throughout the Mediterranean Basin.

ACKNOWLEDGEMENTS

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