Effects of fire on high altitude coniferous forests of Greece

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Abstract
Fire used to be a rather rare and localised disturbance for high altitude coniferous forests in Greece. However, during the last decade an increasing number of fire events are recorded across landscapes covered by such forests, a possible result of the global climate change. For Greece, *Abies cephalonica* Loudon (Greek fir) and *Pinus nigra* J.F Arnold (black pine) form the most affected forest types of this group. Both species have not been evolved under the selective force of fire and thus do not have any active post-fire regeneration mode. In summer 2007, 7 large fires burned approximately 70% of the total burned area of 270.000 ha. At least in two cases, fire burned over extended mountainous ridges, affecting both dry Mediterranean and high altitude forest ecosystems. In the case of Mount Parnitha, 2,180 ha of fir forest have been burned, whereas in the case of Mount Taygetos, 4,500 ha of Greek fir and Black pine have been affected. In both cases, permanent transects have been established during the 2nd post-fire year, so as to monitor plant community composition and seedling emergence of both tree species. In all cases, plant communities recovered rapidly and the number of plant taxa found within the burned areas was much higher than that found within the neighboring unburned patches, with annual herbs being the richest growth form. Compositae was the richest family in terms of species number, and consisted of taxa bearing reproductive units of remarkable ability for long distance dispersal. Nevertheless, in the case of burned fir forests the second richest family was that of Leguminosae, a family with typical seeding species, the germination of which is greatly promoted by fire. A relatively high number of black pine seedlings was recorded, most of which located within a zone of 30 meters from unburned patches, while fir showed almost no regeneration. It is concluded that besides successful regeneration of most understorey plant taxa the recovery of the dominant tree

population will be a slow process, especially for *Abies*, while the importance of unburned patches shouldn't be underestimated. The differences in colonization potential of the two tree species may allow black pine to colonize sites previously dominated by firs in case the two species used to co-exist.

Keywords:
Climate change, *Pinus nigra*, *Abies cephalonica*, natural regeneration, vegetation dynamics

1. Introduction

Fire forms a major ecological factor in many biomes of the world (Rundel, 1981; Pausas and Keeley, 2009). Fire incidents in the Mediterranean Basin are very common and a high frequency of fires has extended back into the past. Evidence of man-induced fires can be identified in the Iron Age, 2600 years B.C., when shepherds and farmers used to set fires in order to exploit the burned area for pasture and cultivation (Papanastasis et al., 2010). Recurrent wildfires have acted as an integral part of the Mediterranean climate ecosystems evolutionary history, having shaped their adaptive traits (Naveh, 1975; Trabaud, 1994; Arianoutsou, 1988; Pausas and Keeley, 2009). Under normal fire regime, plant species regeneration is feasible and community recovery is a process based on pre-fire floristic composition (Kazanis and Arianoutsou, 1994; Moreno and Oechel, 1994; Oliveira and Fernandes, 2009). Much of the discussion on changing forest fire regimes has been oriented towards land use changes history which has largely occurred since late 80's in most of the Mediterranean countries (e.g. Arianoutsou, 2001; Moreira et al., 2001; Arianoutsou et al., 2002). However, increased concern is raised recently on issues related to the potential impact that climate change may have on fire regime (Piñol et al., 1998; Pausas, 2004; Arianoutsou, 2007). Evidence for this comes from fires that are nowadays spreading over higher altitudes and northern latitudes. In these environments forest ecosystems are not resilient to fire, as they have not been evolutionary exposed to its frequent action (Ordoñez et al., 2006; Arianoutsou et al., 2008). The year 2007 will be regarded as a landmark for the environmental history of modern Greece, when more than 270,000 ha have been affected by fire, with most of 70% of the burned area corresponded to 7 only fire events (megafires) (JRC, 2007). In several cases, both McE and high altitude forest ecosystems were burned. Among the most affected forest types were those of the Greek endemic *Abies cephalonica* Loudon (Greek fir) and those of *Pinus nigra* J.F Arnold (Black pine) (Arianoutsou et al., 2009a, 2009b). Both tree species are vulnerable to fire as they do not produce serotinous cones and do not maintain a seed bank when summer wildfires occur (Habrouk et al., 1999; Ordoñez et al., 2005; Politi et al., 2007). Therefore, their natural post-fire recovery is limited, and is strongly dependent on long-distance seed dispersal from neighboring unburned individuals or patches (Retana et al, 2002; Ordoñez and Retana, 2004; Arianoutsou et al., 2009a, 2009b). The aim of this work is to study the effects of fire on these forest ecosystems with emphasis on the potential role of the remaining unburned patches in their recovery process.

2. Materials and methods

2.1 Study areas

The most typical examples of high altitude coniferous forests burned in the summer of 2007 are found on two mountainous areas of Greece (Fig. 1), both included in the Natura 2000 "network of sites for the conservation of species and its habitats" (Directive 92/43/EEC). The first site is 'Mount Parnitha', the highest (1,413 m) and most extended mountain of Attica, in central Greece, being a National Park since 1961. The core zone of the National Park comprises the highest peaks of Parnitha, an area of c. 3,800 ha, 90% of which was covered with the endemic *Abies cephalonica* (Greek fir) forest till 2007. The altitudinal zone of the area in question is between 900 to 1,400 m.a.s.l. and the climate is characterized by cool summers (usually air temperature does not exceed 18°C) and winter temperatures frequently near 0°C. The buffer zone of the periphery is mostly covered by *Pinus halepensis* forest and stretches down to the foothills of the mountain (Amorgianiotis, 1997). Climatic conditions in this zone are characterized by cool summers (usually air temperature does not exceed 18°C) and winter temperatures frequently near 0°C. Snow is also frequent in the fir forest. One of the largest fires in the history of the Park took place in June 2007 and burned a great part (2,180 ha) of the strictly protected area and almost 50% of the *Abies cephalonica* forest. The second site is 'Mount Taygetos', the highest (2,407m) and most extended mountain range of Peloponnese prefecture in Southern Greece. Taygetos is characterized by an appealing variety of ecosystems and a diverse flora and fauna. Forest ecosystems of the mountain are dominated by *A. cephalonica* and *P. nigra.* Coniferous forests cover an altitudinal zone between 800 and 1.600-1.700 meters. The climatic conditions of the zone in question resemble those of Mount Parnitha, with the only difference that annual precipitation at Taygetos can exceed 1,000 mm per year. In summer 2007, an area of 11,300 ha was burned, of which approximately 4,500 ha correspond to coniferous forests. It is worth mentioning that the populations of both tree species meet the southernmost edge of their natural geographic distribution on Mount Taygetos, while *Pinus nigra* forests is a priority habitat type including in the Annex I of the Directive 92/43/EC (9530*-(Sub)-Mediterranean pine forests with endemic black pines). In both cases, fire did not burn the area in a homogeneous way, probably because of the dissected landscape physiography, the prevailing meteorological conditions and the tactics applied during the suppression phase. As a result, several unburned patches of various sizes have remained inside the burned area.

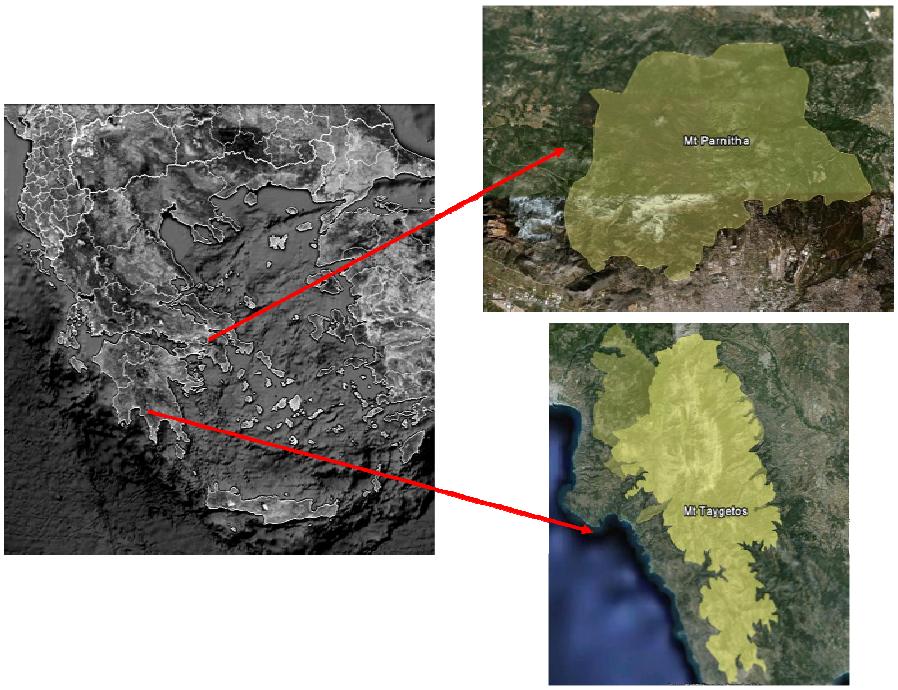

Figure 1. Geographical location of the two study regions.

2.2 Field Sampling

The study was conducted during the 2nd post-fire year. In each study area, four study sites have been selected for sampling. Three 100-m-long permanent transects were established in each of the burned study sites, stretching to an equal length within the unburned patch, whenever possible. A minimum distance of 50 meters was secured between transects. Seedling and sapling densities of *A. cephalonica* and *P. nigra* were measured in strips of 100 m^2 alternatively positioned along transects within the burned area. Plant community species composition was twice (autumn and spring) recorded across transects. Each taxon was ascribed to a regeneration mode (seeder/resprouter), while its life and growth form were also recorded.

3. Results

Total number of plant taxa recorded in the burned areas varied significantly among the two ecosystem types. However, differences were also observed within the same ecosystem type (fir forest) between the two studied areas. The highest plant species richness has been recorded in the burned areas of Mount Parnitha *A. cephalonica* communities, where 104 plant taxa have been collected. Burned fir plant communities of Mount Taygetos consisted of 84 taxa, while in burned *Pinus nigra* stands only 63 taxa have been collected.

As shown in Fig.2, the family with the highest number of taxa in both systems of Mount Taygetos was that of Compositae, while at Mount Parnitha it ranked first together with Leguminosae. The latter is the family with the highest plant taxa number. However, if the number of individuals per family is taken into account, individuals of leguminous species are the most abundant (data not shown). Gramineae also is a family that presents high abundance of its individuals (data not shown). It is noteworthy that some families are

represented only in one site, such as the Cistaceae, appearing only in Mount Parnitha, the Polygonaceae in *Pinus nigra* forests of Taygetos or the Orchidaceae in the fir forests of Mount Taygetos. In all cases, annual herbs dominated the growth form spectra of the burned communities (Fig. 3). Nevertheless, the 'annual herb' dominance was more apparent at Mount Parnitha sites. Shrubs are present in all three ecosystem types, with a highest percentage in *Pinus nigra* forests. No tree species has been recorded in the recovering burned community of Mount Parnitha, since *A. cephalonica* depends on seed dispersal from adjacent unburned stands for its establishment. On the contrary, 2 seedlings of *A. cephalonica* have been found in one of the *Abies* study sites at Mount Taygetos, in a distance of 9 m from the edge of the unburned patch. The most important, is the fact that, in the same area, *Pinus nigra* seedlings were present as well. As far as the *P. nigra* study sites are concerned, several seedlings have been recorded along transects, 90% of which was found at a distance limit between 0 - 30 m from the edge of the unburned patches. Other tree species recorded at the burned sites, were the obligate resprouters *Crataegus monogyna*, *Castanea sativa* and *Quercus ilex*. Within the unburned clusters of *Abies cephalonica* several shrub species such as *Juniperus oxycedrus* were present. These species did not regenerate in the burned areas. *Pinus nigra* was presenting natural regeneration from seeds that had been dispersed from mature individuals remaining in the unburned patches. It is important to mention that many shrub or tree species present in the unburned pine forest, such as *Castanea sativa*, *Erica arborea,* and *Rosa canina* have successfully regenerated and were present in the burned areas. Therophytes dominate among the life forms (Fig. 4), with the highest appearance in Mount Parnitha's burned fir forest. Hemicryptophytes are also appearing in high numbers. A notable high participation of geophytes in the community composition of both cases of burned *A. cephalonica* stands was recorded, with resprouting species of the Liliaceae and Orchidaceae families among others. Still, It should be noted that in the context of this work, not only species forming permanent seed banks are characterized as 'seeders' but also species whose seeds have arrived on the burned soil though long distance dispersal (e.g. members of the Compositae and Gramineae families). Apparently, this is the case of both *A. cephalonica* and *P. nigra*.

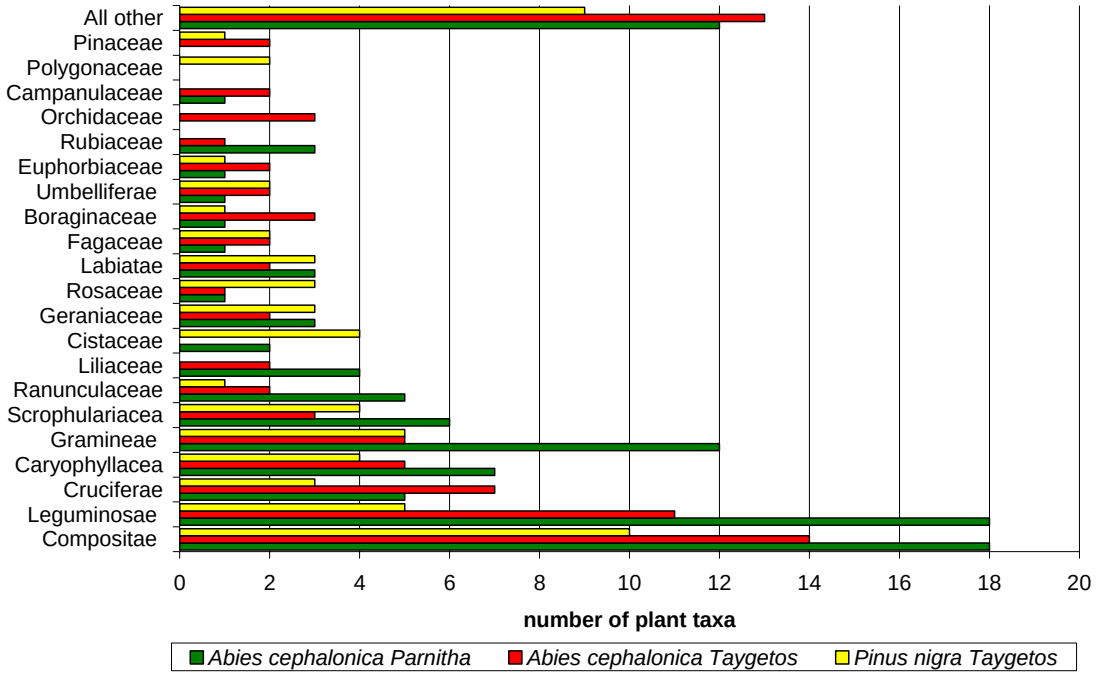

Figure 2. Plant taxa per family in each study area

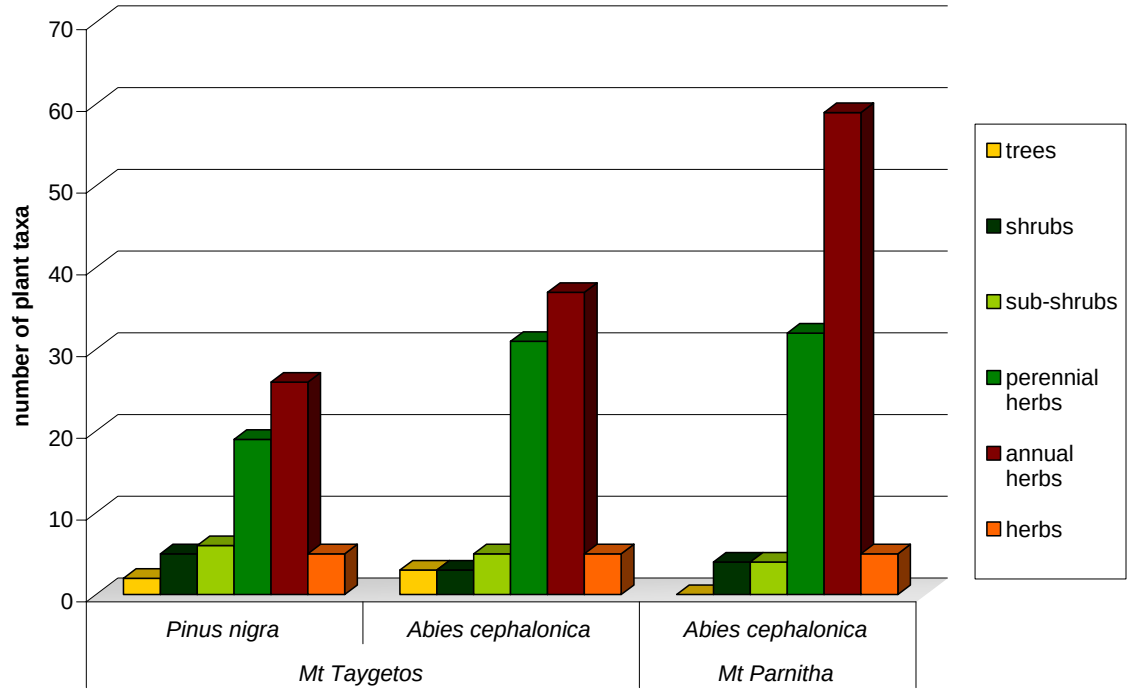

Figure 3. Growth form spectra of the plant taxa identified in the studied forest ecosystems: trees, shrubs, sub-shrubs, perennial herbs, annual herbs, herbs. (herbs: herbaceous taxa that haven't yet been identified).

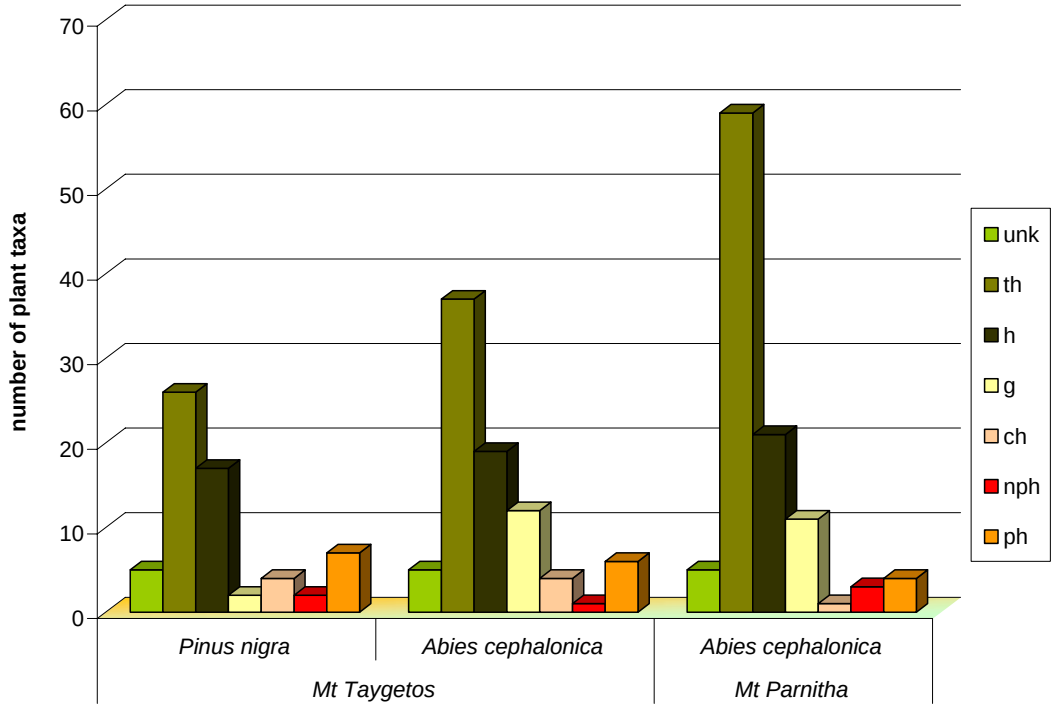

Figure 4. Life form spectra of plant taxa identified in the study forest ecosystems, according to Raunkiaer's classification (ph: phanerophytes, nph: nanophanerophytes, ch: chamaephytes, h: hemicryptophytes, g: geophytes, th: therophytes, unk: unknown, i.e. taxa that haven't yet been identified).

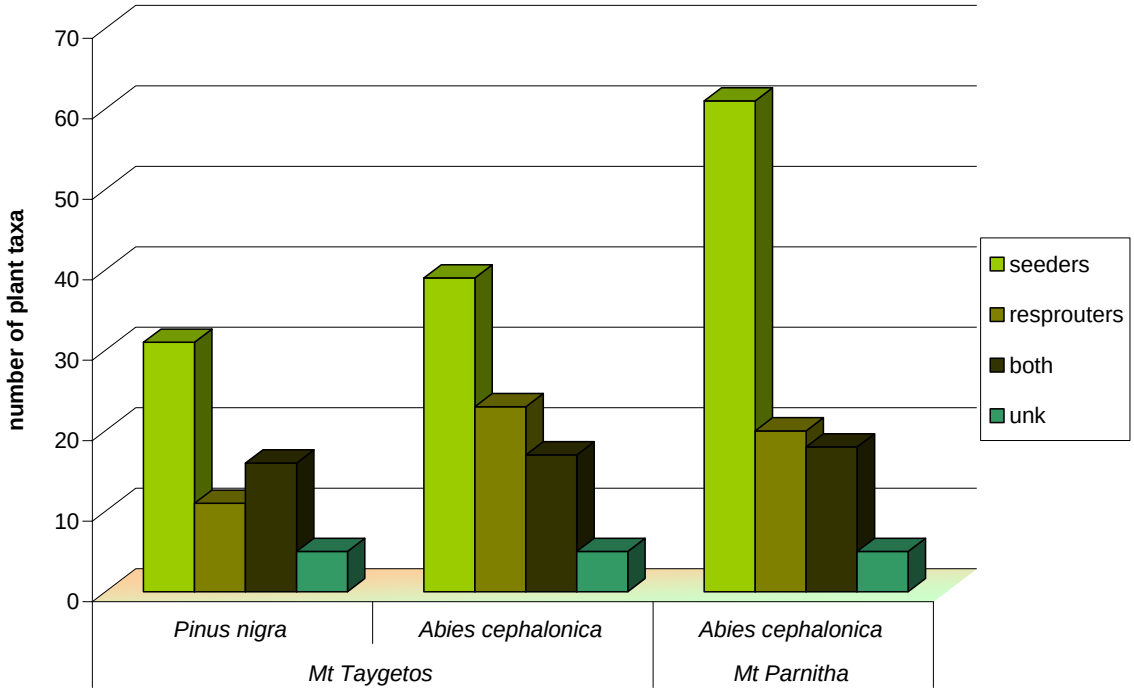

Figure 5. Number of plant taxa classified according to their regeneration mode (both: species showing both mechanisms) in each of the study sites (unk = unknown: i.e. taxa that haven't yet been identified).

4. Discussion

Both coniferous species studied, neither resprout nor they have serotinous cones; thus they are sensitive to crown fire. At the same time, both are anemochorous and therefore share the potential to colonize burned areas from the unburned patches through seed dispersal (Ordoñez et al., 2005; 2006; Christopoulou et al., 2008; Arianoutsou et al., 2009a). Nevertheless, only *Pinus nigra* presented a certain number of young pine individuals, 90% of which was found at a distance between 0 - 30 m away from the edge of the unburned patches. Still, few seedlings and saplings were found up to a distance of 95 m, a fact that can be attributed both to anemochorous seed dispersal and to secondary dispersal by mammals- especially rodents-, birds and ants (Lanner, 1998; Ordoñez, 2004). Most of the seedlings and saplings of *Pinus nigra* were found in the understory or next to *Pteridium aquilinum*, a fire-adapted species that regenerates strongly through resprouting (Hofmann et al., 1998; Moretti et al., 2002). Seedling survival has been found to be the highest in the understory of large resprouting individuals, suggesting that these large shrubs can have strong facilitative effects on *Pinus nigra* seedlings (Ordoñez, 2004), as it has been also suggested for the establishment of *Pinus halepensis* seedlings (Konstantinidis et al., 2006). Therefore, even though the post fire recovery of Black pine population is strongly dependent on the number and spatial availability of unburned patches (Trabaud and Campant, 1991; Retana et al., 2002; Ordóñez et al., 2006). some areas and under specific microhabitat characteristics, its regeneration is better (Gracia et al., 2002; Retana et al., 2002; Ordóñez et al., 2006; Arianoutsou et al., 2009b). No young individuals of *Abies cephalonica* was recorded in Mount Parnitha, whereas only two (2) were recorded at Mount Taygetos study sites, 9 m away from the unburned patch. Particularly interesting is the fact that in Mount Taygetos within *Abies cephalonica* burned stands, saplings of *Pinus nigra*

have been observed, even though the distance from the unburned patch is much greater than that of *A. cephalonica*. These preliminary results show that in burned areas where stands of the two species are found in relatively small distance, black pine could potentially invade sites previously dominated by fir. The lack of active natural regeneration observed in the Greek fir may become worst over the long tem given the masting behavior of *A. cephalonica* (Politi et al., 2009). A considerable number of species appeared across the burned coniferous stands studied. Most of the species were annuals, which are absent from the understory layer of the unburned forests (unpublished data). Similar observations have been reported for *Pinus nigra* Arn. subsp. *pallasiana* burned forests in Central Anatolia (Ocac et al., 2007). The highest number of plant taxa was recorded in the burned sites of Mount Parnitha's *A. cephalonica,* while within the unburned *Abies* forest the understory vegetation is relatively poor (unpublished data). As it is already mentioned, important shrub species of the unburned fir understory were practically absent from the burned areas as they failed to reprout or germinate. *Juniperus oxycedrus,* the main shrub species of this understory, is a typical example as it has been also previously reported for other ecosystem types (Kazanis and Arianoutsou, 2004; Pausas et al., 2008). However, fir forests of Mount Taygetos, presenting different plant species composition in their understory, do have certain shrubs and trees that regenerate after fire, such as *Euphorbia myrsinites, Dorycnium hirsutum, Quercus coccifera, Phillyrea latifolia* and *Crataegus monogyna*.

Differences in the vegetation composition and plant family spectrum between the two sites of *A. cephalonica* highlight the importance of habitat characteristics and disturbance regime and history as a factor that should be taken into consideration, similarly to what has been reported for dry Mediterranean coniferous forests (Kazanis and Arianoutsou, 2004). In all cases, species regenerating through resprouting and seed germination have been enlisted. The vast majority of the recorded species have been classified as 'seeders'. Seeders form the richest (and most abundant) functional group of plants after fire in the case of most McE (e.g. Trabaud, 1994; Kazanis and Arianoutsou, 1996), where there are plenty of data on species life traits in relation to fire (e.g. Paula et al., 2009), permitting the distinction of seeders sensu stricto (i.e. species whose seed germination is enhanced by fire) and seeders sensu lato, including species whose seeds do not survive fire and depend on long distance seed dispersal for establishment (i.e. colonizers) (Kazanis and Arianoutsou, 2004). In this topic, more research is needed to cover the biota of high altitude coniferous forests and their characteristics. For the time being, many seeders seem to colonize burned areas, through seed dispersal. Nineteen (19) colonizers have been found in *Pinus nigra* study area, whereas in *Abies cephalonica* the same number was twenty-three (23) for Mount Taygetos and thirty-two (32) for Mount Parnitha. All colonizers are either annual or perennial herbs. It should be mentioned that as colonizers are also been characterized the two dominant tree species, due to the anemochorous dispersal they exhibit. Most of the species which have been characterized as colonizers belong to the families of Compositae and Gramineae.

5 Conclusion

Our research has shown that most understorey plant taxa of the studied coniferous forest ecosystems present satisfactory regeneration after fire. Furthermore, an enrichment of the local flora has been recorded, particularly due to the establishment of annual herbaceous taxa. Furthermore, an enrichment of the local flora has been recorded, particularly due to

the establishment of annual herbaceous taxa. In some cases fire can be considered as a disturbance that changes community structure by favoring colonizing species capable of forming permanent seed banks.

Considerable differences have been noted in the post-fire behavior of the two tree species. Both species do not have an active post-fire regeneration mode. Still, *A. cephalonica* showed almost null regeneration, whereas most *P. nigra* seedlings appeared within a zone of 30 meters from the unburned stand. In general, recovery of the tree population is expected to be a very slow process especially for the Greek fir. The recovery of Black pine population is expected to be quite localized and strongly dependent on the existence of the remaining unburned patches, their numbers and their spatial availability despite the fact that in some areas and microhabitat characteristics, regeneration is better. The difference in the colonization capacity among the two tree species allows the prediction that in burned areas where stands of both species are found in relatively small distance from one another, black pine may colonize sites previously dominated by fir.

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