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Postfire regeneration dynamics in a Mediterranean type ecosystem in Sithonia, northern Greece: ten years after the fire

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ABSTRACT: Postfire regeneration dynamics was studied in an open *Pinus halepensis* woodland, in Sithonia northern Greece. During ten years after fire, data collected included plant species composition, density, height and biomass. Analysis by the Sorenson's similarity index was used to estimate changes in floristic composition, while structural data (species height, biomass and density) were used to estimate the differences of the current status from the previous one. The findings showed that the regeneration took place immediately after fire, mainly by resprouting species while the obligated seeders appeared later (after autumn) in the same year. However, ten years after the fire the ecosystem is dominated by the maquis species that existed prefire and it seems that the process of regeneration is towards to reform the previous ecosystem. The number of *Pinus halepensis* seedlings is relative low but it seems adequate to secure the presence of the species in the future ecosystem at least in the same proportion as it was before the fire.

1 INTRODUCTION

Postfire vegetation dynamics has been investigated in many cases throughout the areas where the wildfires are a common phenomenon (Arianoutsou 1999). However, many studies have been carried out along the Mediterranean basin since, in this region, fire is an important ecological factor (Naveh 1991, Arianoutsou and Ne'eman 2000) that in many cases determines the type of the existing vegetation (Trabaud 1987). Data collected concern different ecosystems and they generally focus on Mediterranean pines, maquis, phryganic ecosystems etc. (Papanastasis 1978, Papio 1984, Thanos and Marcou 1991, Tsitsoni 1991, Zagas 1994, Ne'eman et al. 1995, Daskalakou and Thanos 1996, Hatzistathis et al. 1996, Tsitsoni 1997, Ganatsas et al. 1998, Eshel et al. 2000). The studies are usually materialized during the early postfire years (one to three years) and in some cases they last until 10 to 12 years after the fire (Calvo et al. 2002). This is due to the fact than in most cases the great changes in ecosystem composition and structure appear during these years while at the age of 10 to 12 years the ecosystems usually return to the previous state (see Trabaud 1994 for a review). However, based on the available data the general conclusions can be summarized (Trabaud 1994, Kazanis and Arianoutsou in press): i) in most cases there is no actual succession but an autosuccesion process ii) the establishment of the previous communities is a rapid phenomenon iii) the abundance of herbaceous species is quite remarkable during the first years in the burned areas, iv) the majority of the species that gain dominance during the re-establishment of the mature vegetation are present in the first few years after fire and v) as burned communities age, returning to a state similar to that of unburned systems, structure becomes more and more complex,

with numerous layers. Herbaceous layers predominating during the early stages gradually decrease and they are replaced by shrub and tree layers.

The aim of the study was the analysis of the postfire regeneration dynamics in an open *Pinus halepensis* woodland during ten years after the fire. Monitoring was focused on plant species composition, density, height and biomass and the progress of regeneration was compared to the previous ecosystem status. Data analysis was used to estimate changes in floristic composition and structure of the postfire ecosystems.

2 MATERIAL AND METHODS

2.1. *Study area*

The study was carried out in the Sithonia peninsula at Chalkidiki, northern Greece. The region consists of low and hilly elevations (average altitude 80-100 m asl). Geologically, the area belongs to the Axios zone and Circum Rhodope zone. The parent rock materials are mainly igneous and crystalline-schists and only a small part are of sedimentary formations, such as limestone with tertiary and quaternary depositions (Mountrakis 1985). The vegetation of the area belongs to the Mediterranean vegetation zone *Quercetalia ilicis* and particularly to the association Oleo-lentiscetum. The climate is characterized as Mediterranean type (Csa) according to Koeppen classification. The annual amount of rainfall is 420 mm and the dry period has an average duration of 5-6 months, lasting from April to September (data from the meteorological station in Ag. Mamas for the period 1988-1997). The ecosystem studied was pre-fire dominated by a scattered overstory of *Pinus halepensis* and a dense shrub story of maquis species. The fire took place at the beginning of the summer 1994 (6 of June 1994). The area had repeatedly been burnt prior to that while the previous fire had occurred 45 years before as was proved by the age of the Aleppo pine trees (as the tree ring measurements showed).

2.2. *Data sampling and analysis*

For the estimation of the early postfire regeneration process ten plots of 10 m^2 were established just after the fire. The monitoring took place every fifteen days throughout the growth period when the fire occurred (summer 1994) until the mid of November. In each plot all the stems of all plant species and their height were recorded. In order to estimate the later regeneration dynamics twenty plots were selected at each monitoring year, one, two and ten years after the fire (in fact, the last measurement took place after ten growth periods and 9.5 years after the fire, in late autumn of the year 2003). The plot size was of 2mX2m, in the last recording, and for comparison reason, ten plots of 4mX4m were selected in the adjacent unburned stands. In each plot, all the plant species, their height and diameter at ground level were recorded, the above ground biomass per species and totally was computed as follows: all the stems were cut at the ground level, all the parts of each species were gathered in a different plastic bag and the bags were transported to the laboratory. For practical reasons in the last recording and for biomass estimation of the prefire status, only representative samples of plant material were selected and transported to the laboratory. All the samples were oven-dried in 72 ^{0}C for 48 hours and then their dry weight was calculated. Finally, for the estimation of *Pinus halepensis* natural regeneration twenty permanent plots of 10mX10m were installed and the number of seedlings, their height, diameter at ground level and crown dimensions were recorded in each recording year. The annual increment of above ground biomass for the third to tenth recording year was calculated dividing the corresponding total biomass by the years since the last fire (Cannellas and San Miguel Ayanz 2000). Floristic similarities between the current postfire status and the prefire status were evaluated by Sorenson index (*Cs*) as $Cs = 2a/(b+c)$, where a is the number of common species between two ecosystems, and b and c the number of species in each of the two ecosystems assessed (Magguran 1988). Density, height and biomass were used to evaluate structural changes. Statistical analysis was performed using the SPSS pack-

age. Differences on species height and biomass were assessed by t-test ($P<0.05$). Nomenclature follows Flora Europea (Tutin et al. 1980).

3 RESULTS

3.1. *Changes in community composition*

The establishment of new postfire plant community began early, twenty days after the fire, by the recruitment of the species regenerating vegetatively (Table 1). *Quercus coccifera* was the first species appeared, followed by the species *Pistacia lentiscus Phillyrea latifolia*, *Olea europea* var. *sylvestris, Arbutus unedo, Arbutus andrachne* and *Erica manipuliflora*. All species existing before fire having resprouting ability regenerated during the same summer when fire occurred. During this early phase the absence of species regenerating from seeds was remarkable. These species appeared later, after the mid of November, practically not contributing to the community composition during the early postfire phase (except for an individual of *Carex* sp. that was recorded only in one plot). Thus, after the mid of November many species regenerating from seeds colonized the burnt area (Table 2). These were mainly the *Cistus* species (*C. monspeliensis, C. creticus* and *C. salvifolius*), *Pinus halepensis* and many herbaceous species. However, during this period resprouters were the dominant community components. As regard to the density of *Pinus halepensis* natural postfire regeneration, this was found 0.15 seedlings per m^2 one year after the fire (Table 3), the maximum and the minimum number of seedling were 0.38 and 0.01 seedlings per m^2 respectively. However, after the second year the naturally regenerated *Pinus halepensis* seedlings slightly increased (0.16 per m^2).

Table 1. Early species recruitment through resprouting (fire event on 5th of June, 1994).

Species	Time of recruitment	Days after the fire	Max height at the end of the 1st growth period (cm)
Quercus coccifera	25 June	20	122
Pistacia lentiscus	7 July	32	52
Phillyrea latifolia	7 July	32	55
Olea europea var. *sylvestris*	7 July	32	47
Arbutus unedo	7 July	32	80
Arbutus andrachne	7 July	32	76
Callicotome villosa	5 August	32	18
Asparagus acutifolius	5 August	61	15
Spartium junceum	20 August	76	74
Lonicera implexa	6 September	93	27
Erica manipuliflora	6 September	93	12
Anthyllis hermaniae	6 September	93	5
Ruscus aculeatus	Mid of November	142	4

Table 2. Community composition before fire, one, two and ten years after the fire.

Species	Prefire	Postfire			
		5 months	1 year	2 years	10 years
Resprouting species					
Quercus coccifera	√	√	√	√	√
Pistacia lentiscus	√	√	√	√	√
Phillyrea latifolia	√	√	√	√	√
Olea europea var.*sylvestris*	√	√	√	√	√
Arbutus unedo	√	√	√	√	√
Arbutus adrachne	√	√	√	√	√
Callicotome villosa	√	√	√	√	√
Asparagus acutifolius	√	√	√	√	√
Spartium junceum	√	√	√	√	√
Lonicera implexa	√	√	√	√	√
Erica manipuliflora	√	√	√	√	√
Anthyllis hermaniae	√	√	√	√	√
Ruscus aculeatus	√	√	√	√	√
Seeding Species					
Pinus halepensis	√		√	√	√
Cistus creticus	√		√	√	√
C. salviifolius	√		√	√	√
C. monspeliensis	√		√	√	√
Osyris alba	√		√	√	√
Juniperus oxucedrus	√				
Colutea arborescens	√				
Rubia peregrine	√				
Dorycnium hirsutum	√		√	√	√
Teucrium divaricatum	√			√	√
Fumana thymifolia	√		√	√	√
Convolvulus althaeoides	√		√	√	√
Carex flacca	√	√	√	√	√
Conyza canadensis			√		
Trifolium arvense			√		
Muscari negeletum			√	√	
Scorpinus muricatus			√		
Teline monspessulanum	√		√		√
Festuca sp.	√		√	√	√
Piptatherum coerulescens				√	√
Lactuca serriola				√	√
Erigeron canadensis				√	
Senesio sp.				√	
Chondrilla juncea				√	
Desmazeria rigita				√	
Lolium perenne				√	√
Filago gallica				√	
Scleropoa rigida				√	√
Crocus sp.					√

Table 3. Natural regeneration of *Pinus halepensis* during ten years after the fire, in Sithonia, Chalkidiki (northern Greece). Values are means and standard error of means (in parenthesis).

Regeneration of	Years after the fire		
Pinus halepensis	1	2	10
Individuals per hectare	1500 (80.3)	1665 (88.4)	2780 (99.1)
Mean height in cm	5.61 (0.02)	18.19 (0.03)	194.0(0.10)
Mean collar diameter in cm	0.14 (0.01)	0.26 (0.01)	4.2 (0.12)
Crown Dmax in cm	*	8.5	93.2
-//- Dmin in cm	*	7.0	90.4

*not recorded

Ten years after the fire the floristic elements of the postfire ecosystem tend to be the same as they were before the fire. The Sorensen similarity index (Cs) between post and prefire communities was found 86.2, that means a great percentage of the species are the same in the post and prefire ecosystems. Both ecosystems are characterized by the great dominance of the woody shrub species, the total number of plant species recorded in the plots was 28 and 30 respectively. The dominant shrub story in both cases is composed by the evergreen broadleaf shrubs *Quercus coccifera*, *Pistacia lentiscus*, *Phillyrea latifolia*, *Olea europaea* var. *sylvestris*, *Erica manipuliflora*, *Arbutus unedo*, *A. andrachne*. and some seasonal dimorphic subshrubs *Anthyllis hermanniae*, *Cistus creticus*, *C. salviifolius*, *C. monspeliensis* and *Callicotome villosa*. The number of species regenerating from seeds was 17 species, many of them woody species like *Pinus halepensis* and *Cistus* spp. The contribution of *Pinus halepensis* in ecosystem composition, in terms of individual density, increased to 0.28 per m^2. Species that present at the prefire ecosystem and absent in the new community are very few such as *Juniperus oxycedrus* (a late successional species which its regeneration faces difficulties) and the species *Rubia peregrina* and *Colutea arborescens*.

3.2. *Changes in community structure*

During the early postfire phase the density and the height of the species increased rapidly (Fig. 1 and Table 1). The total number of sprouts reached 18.1 per m^2 at the beginning of November while the maximum height reached over one meter. *Quercus coccifera* is the species with the overall highest resprouting ability with a mean number of sprouts 6.6 per m^2, and maximum height 122 cm at the end of the growth period. The stem density increased and ten years after fire reached 38.3 stems per m^2. At this age the plant community is characterized by a high contribution of *Cistus* species, 17.0 stems per m^2 (44.4%). It can be mentioned that *Cistus* contribution in the composition of the prefire ecosystem was only 1.4 stems per m^2. However, ten years after the fire the ecosystem is characterized by the dominance of the woody shrub species. The shrub story covers almost all the area, not allowing herb species to survive. The species *Quercus coccifera, Pistacia lentiscus* and *Phillyrea latifolia* exhibit the greater height forming a vertical layer over 70 cm, while *Cistus* species, *Anthyllis hermanniae* and some other less abundant species form a second layer bellow this height. *Pinus halepensis* in this age started to show a differentiation in height from the shrubs, but this is not so evident, since the tree story has not yet been created. The saplings had significantly greater height from the shrubs (Table 3 and 4), but the greater shrub individuals compete the saplings of *Pinus halepensis*, for example the maximum height of *Quercus coccifera* was 2.4 m. However, this comprises a significant difference in structure between the postfire and prefire ecosystem. Before fire, the community structure was dominated by the large scattered *P. halepensis* trees, which besides their low number (ca. 50-80 trees per hectare), they dominated the ecosystem due to their large dimensions (mean height 13.2 m and mean diameter 32.6 cm). Ten years after the fire the contribution of *Pinus halepensis* in ecosystem composition, in terms of individual density, was much greater. However, its contribution to ecosystem structural characteristics was low due to the relative low dimensions. The average height and diameter of the dominant woody species did differ statistically between the pre- and postfire status (Table 4). Generally, the dimensions of the shrubs in the postfire ecosystem were lower than that of the same species before the fire.

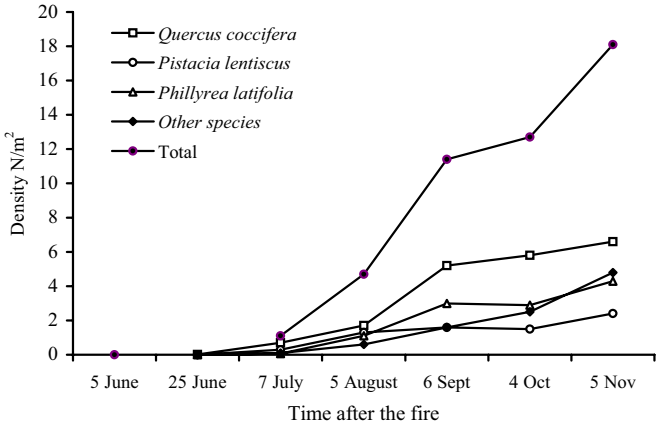

Figure 1. Species density in the young regenerating plant community.

3.3. *Biomass accumulation*

The above ground biomass accumulation was rapid and reached 1,696 kg.ha^{-1} one year after fire (Fig. 2). The species *Quercus coccifera* is by far the dominant species in biomass accumulation with 995.2 kg.ha^{-1} (percentage 58.7% of the total biomass). Apart from this species, *Phillyrea latifolia* and *Pistacia lentiscus* contribute to a high percentage to total biomass. The former with 278.5 kg.ha^{-1} (percentage 16.4%) and the latter with 206.9 kg.ha^{-1} (percentage 12.2%). Biomass of the species regenerating vegetatively was by far higher than that of the seeders (1,612 and 83.7 kg per ha respectively) (percentage 95.1% and 4.9%). Two years after the fire plant community exhibited similar productivity to that of the first year. The biomass production during the second year was 1,640 kg.ha^{-1}, and the total amount of biomass reached 3,336 kg.ha^{1}. Resprouters were the dominant ecosystem components with a high percentage of biomass accumulation 2,748 kg.ha^{-1} (82.4%) while the seeders increased their participation from 83.7 kg per ha (4.9%) in the first postfire year to 588 kg per ha (17.6%), two years after fire. It is worth to point out that the biomass contribution of *Cistus* sp. increased in the second year and reached to 468.4 kg.ha^{-1} (14.03% contrary to 3.93% in the first year). Ten years after fire the total above ground biomass was 11,452.8 kg.ha^{-1} (ranged from 8,808.3 to 16,964.9 kg.ha^{-1}), and it was significantly lower than the shrub biomass of the prefire ecosystem, which was found 25,144 kg.ha^{-1} (ranged from 20,098 to 32,443 kg.ha^{-1}). The mean annual biomass accumulation for the period 3 to 10 years after fire was 1,014.6 kg.ha^{-1}. *Quercus coccifera* was the main component of the shrub biomass in post and prefire ecosystem, with mean percentages 43.7% and 61.2% respectively. *Cistus* species increased their biomass during the postfire regeneration process reaching to a high contribution (24.9%) ten years after fire. However, their biomass in the prefire ecosystem was low (170.4 kg.ha^{-1}).

Table 4. Characteristics of the dominant plant species, before fire and ten years after. The values are means and standard error of the mean. Values of H and D of the same species followed by a different letter are significantly different.

Species	Before the fire			Ten years after the fire		
	Density stems/m^2	H cm	D mm	Density stems/ m^2	H cm	D mm
Resprouters						
Quercus coccifera	13.3	90.0(0.10)a	11.5(0.78)a	8.5	84.2(0.04)b	9.5(0.64)b
Pistacia lentiscus	2.0	147.4(0.05)a	15.3(0.53)a	2.3	80.8(0.04)b	10.6(0.77)b
Phillyrea latifolia	1.6	146.8(0.03)a	21.8(0.59)a	0.2	77.3(0.05)b	10.0(0.79)b
Olea europea var. *sylvestris*	*			0.2	110.0(0.02)	13.8(0.12)
Arbutus unedo	0.6	237.1(0.03)	12.4(0.31)	*		
Arbutus andrachne	*			*		
Callicotome villosa	*			0.4	62.1(0.09)	5.0(0.93)
Asparagus acutifolius	0.7	60.2(0.02)a	1.5(0.08)ns	0.6	22.4(0.06)b	1.8(0.09)ns
Spartium junceum	0.7	62.4(0.06)a	2.7(0.09)ns	0.2	53.9(0.09)b	2.6(0.05)ns
Lonicera implexa	0.5	64.4(0.03)a	3.1(0.13)ns	1.6	56.9(0.03)b	2.8(0.11)ns
Erica manipuliflora	0.7	116.8(0.09)a	12.9(0.29)a	0.7	57.1(0.07)b	4.2(1.14)b
Anthyllis hermaniae	*			3.5	63.8(0.03)	4.8(0.25)
Ruscus aculeatus	1.1	33.1(0.04)ns	1.7(0.05)ns	0.2	29.3(0.06)ns	1.5(0.04)ns
Seeders						
Pinus halepensis	0.006	1320(41.9)a	326.0(6.0)a	0.28	194.0(0.22)b	4.2(0.12)b
Cistus creticus	0.6	59.0(0.03)ns	4.2(0.41)ns	7.0	62.3(0.02)ns	4.3(0.18)ns
C. salviifolius	0.6	63.4(0.08)ns	4.4(0.23)ns	7.9	66.4(0.03)ns	4.4(0.12)ns
C. monspeliensis	0.2	50.3(0.07)ns	3.9(0.29)ns	2.1	49.6(0.04)ns	3.8(0.21)ns
Osyris alba	0.7	85.9(0.06)	4.8(0.12)	*		
Juniperus oxucedrus	0.1	53.0(0.12)	4.4(0.16)	-		
Colutea arborescens	0.3	135.8(0.04)	10.3(0.57)	-		
Rubia peregrina	0.1	17.0(0.07)	1.0(0.08)	-		
Other species	1.1			2.6		
Total	24.9			38.3		

* species recorded but they were scarcely found within the plots.

4 DISCUSSION

The findings showed that the regeneration took place immediately after fire, mainly by resprouting species while the obligated seeders appeared later (after the autumn). Thirteen resprouting species appeared during the summer when the fire occurred. These species existed before the fire and remained as the dominant structural elements ten years later. The species *Quercus coccifera* showed the higher resprouting ability appearing just twenty days after the fire. The number of herbaceous species was high during the first postfire years, as recorded in other studies (Perez and Moreno 1998, Kazanis and Arianoutsou 1996, Kazanis and Arianoutsou in press), while later their contribution to community composition and especially to structure is limited. However, ten years after the fire the ecosystem composition tend to be the same as they were before the fire, the ecosystem is dominated by the maquis species that existed prefire and it seems that the process of regeneration is towards to reform the previous ecosystem. The dominant shrub story is composed by the evergreen broadleaf shrubs *Quercus coccifera*, *Pistacia lentiscus*, *Phillyrea latifolia*, *Olea europaea* var. *sylvestris*, *Erica manipuliflora*, *Arbutus unedo*, *A. andrachne* and some seasonal dimorphic subshrubs *Anthyllis hermanniae*, *Cistus creticus*, *C. salviifolius*, *C. monspeliensis* and *Callicotome vil-*

*losa.*This composition is closely similar to that of the vegetation existed before fire. A significant difference is the contribution of *P. halepensis* to ecosystem structure. Before the fire, the large scattered *P. halepensis* trees that formed the tree layer structurally dominated the plant community. Ten years after the fire the contribution of *P. halepensis* in ecosystem composition, is low in terms of density, is low (naturally regenerated *P. halepensis* saplings were 0.28 per m^2 versus 38.3 stems per m^2 total density) as well as their structural participation. The saplings had greater height from the shrub species but the tree story has not been created yet. This resulted in a relative low vertical structure, contrary to the two-story structure existed before the fire. However, this is temporary since the number of *P. halepensis* saplings are adequate to secure the presence of the species in the future ecosystem in the same proportion and probably higher than it was before the fire (ten years after the fire the naturally regenerated *P. halepensis* saplings were 2780 per hectare while before the fire the tree density was ca. 50-80 trees per hectare). Shrub biomass accumulation was rapid during the first years and continued until the age of 10 years, reaching 11,452.8 kg per hectare. However, at this age the biomass is characterized by the high contribution of *Cistus* species (24.9%).

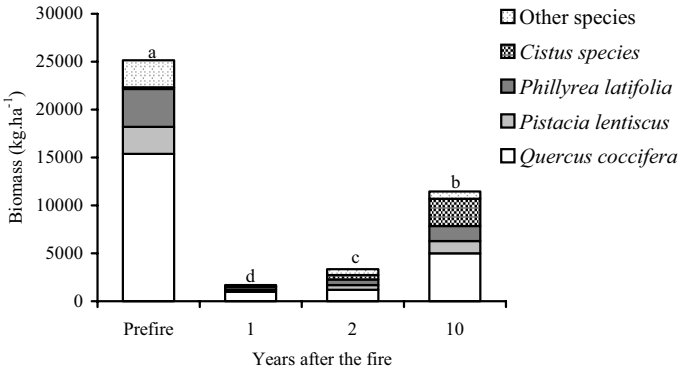

Figure 2. Above ground biomass accumulation during 10 years after the fire, in comparison to the prefire status. Bars indicated by different letters are statistically different.

5 CONCLUSION

The findings of the study support the general conclusions about postfire regeneration process synthesized by Trabaud (1994), and recently reported by Kazanis and Arianoutsou (in press) for southern Greece. These concussions are valid in our case with only slight modifications. Thus, the establishment of the previous community is a rapid phenomenon and the species that gain dominance during the early regeneration process are the dominant community elements during the first 10 years after fire. Consequently, it seems that there is no actual succession but an autosuccesion process (if no fire occurs), as in other cases reported. In case that another fire event occurs, the findings of the study indicate that the next postfire situation will be characterized by the lack of *Pinus halepensis* seedlings (which can result in a secondary succession), since a very low cone production was observed (even though specific measurements have not been made). The rest dominant species are able to regenerate either by resproutings (*Quercus cocifera, Pistacia lentiscus, Phillyrea latifolia*) or from seeds (*Cistus* species).

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