

# Post-fire management and recovery of a pine forest in Greece

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The effects of management after fire in *Pinus halepensis* forests were assessed in northern Greece. Seeding, logging and building of log barriers were applied in burned sites and compared to a control site. Two years after treatment application, 70–80% of the ground in all sites was covered with vegetation. Seeding with herbaceous plants did not increase plant cover. Logging and building of log barriers negatively affected herbaceous species but increased woody species. During the first spring after fire, the highest numbers of *P. halepensis* seedlings were observed in the control site and the lowest number in the logged site. Logging and log barrier building had a negative effect on pine regeneration compared to control and seeding treatments. Woody plant composition was similar in control and seeding sites, with dominance of *P. halepensis* and *Cistus* species. A different pattern was observed in the logging and log-barrier sites with a low number of seeders and a high number of resprouter species.

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Wildfires often occur in Mediterranean forests that usually recover through natural regeneration (Trabaud 1994, Ne'eman 1997, Pausas et al. 1999, Leone et al. 2000). Among pines, *Pinus halepensis* Mill. is the species that has better adapted to regenerate after fire (Thanos et al. 1996, Tsitsoni 1997, Tsitsoni and Karagiannakidou 2000, Pausas et al. 2003).

After fire, soils are vulnerable to accelerated rates of soil erosion and can yield large but often variable amounts of sediment (DeBano et al. 1998). Post-fire rehabilitation treatments can be important in minimizing damage to soil, water and plant resources (Vallejo et al. 2000). Rehabilitation methods such as grass seeding, logging, building of branch barriers and mulching have been widely used, although little information is available (Robichaud et al. 2000). However, restoration activities such as tree felling (to create terraces with dead trees) and planting trees can be harmful if these actions are not implemented at the right time (Ubeda et al. 2006).

Although the effects of fire on Mediterranean pine ecosystems are well documented, few studies have focused on post-fire management activities and their effects on ecosystem recovery (Ne'eman et al. 1995, Zagas et al. 2004, Spanos et al. 2005, Raftoyannis and Spanos 2005, Spanos et al. 2010). In this study, we assessed the effects of post-fire management practices on *P. halepensis* forest recovery in northern Greece.

## Material and methods

The study area was located in the Kassandra peninsula, almost 100 km south of Thessaloniki, Greece (39°57'92"N, 23°33'13"E). *Pinus halepensis* forms uneven-aged stands at a density of 320 trees ha<sup>-1</sup>, with a canopy height at 16 m, mean diameter at breast height 21 cm, wood volume 120 m<sup>3</sup> ha<sup>-1</sup> and annual wood growth of 6.5 m<sup>3</sup> ha<sup>-1</sup>. The climate is Mediterranean with 550 mm mean annual rain-

fall and 16.5°C mean annual air temperature. Rainfall is irregular, distributed mainly in spring and autumn, and the dry season lasts from May to September.

On 22 and 23 August 2006, a high-intensity crown fire burned more than 7000 ha of *P. halepensis* forest. Four months after the fire, four permanent plots 0.5 ha each (100 × 50 m) were established on a slope (30%) in the burned area. In the first plot (control), no action was taken. The second plot was sown with a mix of equal quantities of *Dactyloctenium aegyptium* L., *Lolium rigidum* Guard. and *Phalaris tuberosa* L. var. *aquatica* seeds (seeding). In the third plot, all burned trees were logged and removed from the site using animal traction (logging). In the fourth plot, all burned trees were logged and log barriers were constructed along contour lines with a distance of 5 m between them (barriers). Soil sampling revealed no significant differences between the plots in pH (mean value = 7.1), phosphorous content (mean value = 3.2 mg per 100 g) and organic matter content (mean value = 1.3%). As replicated plots were not available for the treatments, the extrapolation of results should be considered with precaution.

Groundcover, pine regeneration and woody plant cover were monitored on April 2007, October 2007, April 2008

and October 2008. In each plot, six permanent rectangular plots (20 × 3 m) were established along contour lines. Ground cover was characterized every 10 cm along the two longer plot borders, using a metal pin vertical to the ground. Five cover categories were used: stones, bare soil, plant debris, herbaceous plants and woody plants. On the same dates and inside the strip plots, we recorded the number of viable pine seedlings and estimated the percentage of plant cover for each woody plant species.

Differences between treatments were tested with analysis of variance (ANOVA) and means were compared with Tukey's multiple comparison test. Percent data did not satisfy ANOVA assumptions and they were arcsine transformed prior to statistical analysis, but actual percentages are given in the tables. All tests for significance were conducted at the  $p \leq 0.05$  level.

## Results

Eight months after fire, significantly higher rates of exposed soil were found in logged and log-barrier plots (Table 1). Regeneration of herbaceous species seemed to be

Table 1. Percentage of ground cover in each treatment. Means within the same ground cover type and date of observation, followed by the same letter are not significantly different at  $p \leq 0.05$  ( $n = 12$ ).

Date	Treatment	Ground cover (%)				
		Stones	Bare soil	Plant debris	Herbaceous plants	Woody plants
Apr 2007	Control	4 <sup>a</sup>	22 <sup>a</sup>	3 <sup>a</sup>	67 <sup>c</sup>	4 <sup>a</sup>
	Seeding	2 <sup>a</sup>	16 <sup>a</sup>	3 <sup>a</sup>	68 <sup>c</sup>	11 <sup>b</sup>
	Logging	7 <sup>b</sup>	44 <sup>c</sup>	14 <sup>b</sup>	17 <sup>a</sup>	18 <sup>b</sup>
	Barriers	1 <sup>a</sup>	32 <sup>b</sup>	16 <sup>b</sup>	33 <sup>b</sup>	17 <sup>b</sup>
Oct 2007	Control	1 <sup>a</sup>	12 <sup>a</sup>	1 <sup>a</sup>	72 <sup>d</sup>	15 <sup>a</sup>
	Seeding	3 <sup>a</sup>	14 <sup>a</sup>	3 <sup>a</sup>	62 <sup>c</sup>	18 <sup>a</sup>
	Logging	7 <sup>b</sup>	28 <sup>b</sup>	11 <sup>b</sup>	20 <sup>a</sup>	35 <sup>b</sup>
	Barriers	1 <sup>a</sup>	17 <sup>a</sup>	13 <sup>b</sup>	37 <sup>b</sup>	32 <sup>b</sup>
Apr 2008	Control	3 <sup>a</sup>	10 <sup>a</sup>	2 <sup>a</sup>	65 <sup>c</sup>	11 <sup>a</sup>
	Seeding	2 <sup>a</sup>	8 <sup>a</sup>	7 <sup>b</sup>	59 <sup>c</sup>	25 <sup>b</sup>
	Logging	5 <sup>b</sup>	16 <sup>b</sup>	11 <sup>c</sup>	36 <sup>a</sup>	32 <sup>bc</sup>
	Barriers	1 <sup>a</sup>	8 <sup>a</sup>	9 <sup>b</sup>	43 <sup>b</sup>	39 <sup>c</sup>
Oct 2008	Control	3 <sup>a</sup>	11 <sup>a</sup>	5 <sup>a</sup>	52 <sup>c</sup>	30 <sup>a</sup>
	Seeding	2 <sup>a</sup>	13 <sup>a</sup>	13 <sup>c</sup>	41 <sup>b</sup>	32 <sup>a</sup>
	Logging	5 <sup>b</sup>	12 <sup>a</sup>	8 <sup>b</sup>	36 <sup>a</sup>	39 <sup>b</sup>
	Barriers	1 <sup>a</sup>	12 <sup>a</sup>	10 <sup>b</sup>	34 <sup>a</sup>	43 <sup>b</sup>

inhibited by logging and the building of log barriers. On the other hand, woody plant regeneration was better in all manipulated plots compared to control plots. In October 2007, the percentage of ground covered by woody plants almost doubled compared to April previous year, and this change was particularly evident in the logged and log-barrier sites. At the same time, significantly higher rates of bare soil were still evident in the logged plot. In April 2008, a further reduction on the percentage of bare soil was recorded, mainly in the logged and log-barrier sites. In October 2008, 70–80% of the ground in all treatments was covered by plants and the percentage of exposed soil was similar in all treatments. Seeding with herbaceous plants did not increase vegetation cover. Logging and building of log barriers seemed to negatively affect herbaceous species, but increased the regeneration of woody species.

During the first spring after the fire, the highest number of *P. halepensis* seedlings was observed in the control plot and the lowest number in the logged plot (Table 2). A high rate of seedling mortality during summer time almost halved the number of viable seedlings in October 2007. Additional germination of pine seeds increased the number of seedlings by April 2008, and the highest seedling density was observed again in the control plot. By October 2008, the number of pine seedlings increased in all treatments. Logging and log barrier building had a negative effect on pine regeneration compared to control and seeding treatments.

In April 2007, *P. halepensis* was the dominant woody species, followed by *Asparagus acutifolius* L. in control, seeding and barrier treatments. The logged site was dominated by *Smilax aspera* L. (Fig. 1). *Cistus monspeliensis* L., *Cistus salvifolius* L. and *Cistus incanus* L., were the dominant woody species in 2008 although *Pistacia lentiscus* L., *Phillyrea latifolia* L., *Quercus coccifera* L. and *Spartium junceum* L. were present in most treatments. In October 2008, woody plant composition was similar in control and seeding sites, with a dominance of *P. halepensis* and *Cistus* species. A different pattern was observed in the logging and log barrier plots which showed lower numbers of *P. halepensis* and *Cistus* species, but higher numbers of *P. latifolia*, *P. lentiscus* and *S. aspera* individuals.

## Discussion

In our study, post-fire treatments did not significantly affect ground cover or species composition. Logging and the building of barriers with logs negatively affected herbaceous species, but increased the regeneration of woody species, while seeding with herbaceous plants did not increase overall cover. Reports from similar studies show that post-fire logging increase sediment transfer (Helvey et al. 1985), but logging residues can protect the disturbed soils from rainfall impact and reduce soil loss up to 95% (Shakesby et al. 1996). The main reason could be the use of ground-based logging equipment which can cause disturbance and soil compaction (Beschta et al. 2004) and reduce plant growth on trails (Smith and Wass 1980). The building of log and branch barriers had no positive effect on ground cover as shown elsewhere (Raftoyannis and Spanos 2005).

Post-fire management can therefore affect plant regeneration, and thus, alter plant community structure. In our site, control and seeding treatments were dominated by seeders while the logging and log-barrier treatments were dominated by resprouters. Resprouting species seem to be more resistant to post-fire activities as has also been observed by Stuart et al. (1993). Post-fire logging can encourage colonization of several native ruderal species (Abrahamson 1984, Greenberg et al. 1994). Cutting down burned trees, removing twigs or leaving them in the burned area had only a marginal influence on total species richness or cover of resprouting species (Ne'eman et al. 1995). Removal of burned *Pinus pinaster* trees, one year after fire, had a minimal effect on vegetation structure, and only legumes increased in logged sites (Perez and Moreno 1998).

In our study area *P. halepensis* is the dominant tree species and its regeneration success after fire is crucial for ecosystem health and recovery (Tsitsoni 1997). Two years after the Cassandra fire, the highest number of *P. halepensis* seedlings was observed in the control plot, followed by the seeding treatment, while logging and log-barrier building had a negative effect on pine regeneration. These negative effects has also been reported elsewhere (Ne'eman et

Table 2. Mean number of *P. halepensis* seedlings per square meter in each treatment. Means within the same date of observation, followed by the same letter are not significantly different at  $p \leq 0.05$  ( $n = 6$ ).

Date	Treatment			
	Control	Seeding	Logging	Barriers
Apr 2007	7.3 <sup>c</sup>	4.7 <sup>b</sup>	1.2 <sup>a</sup>	3.3 <sup>b</sup>
Oct 2007	2.1 <sup>b</sup>	2.3 <sup>b</sup>	0.5 <sup>a</sup>	1.5 <sup>a</sup>
Apr 2008	3.2 <sup>b</sup>	2.3 <sup>a</sup>	1.2 <sup>a</sup>	2.3 <sup>a</sup>
Oct 2008	3.8 <sup>b</sup>	3.0 <sup>b</sup>	1.5 <sup>a</sup>	2.4 <sup>a</sup>

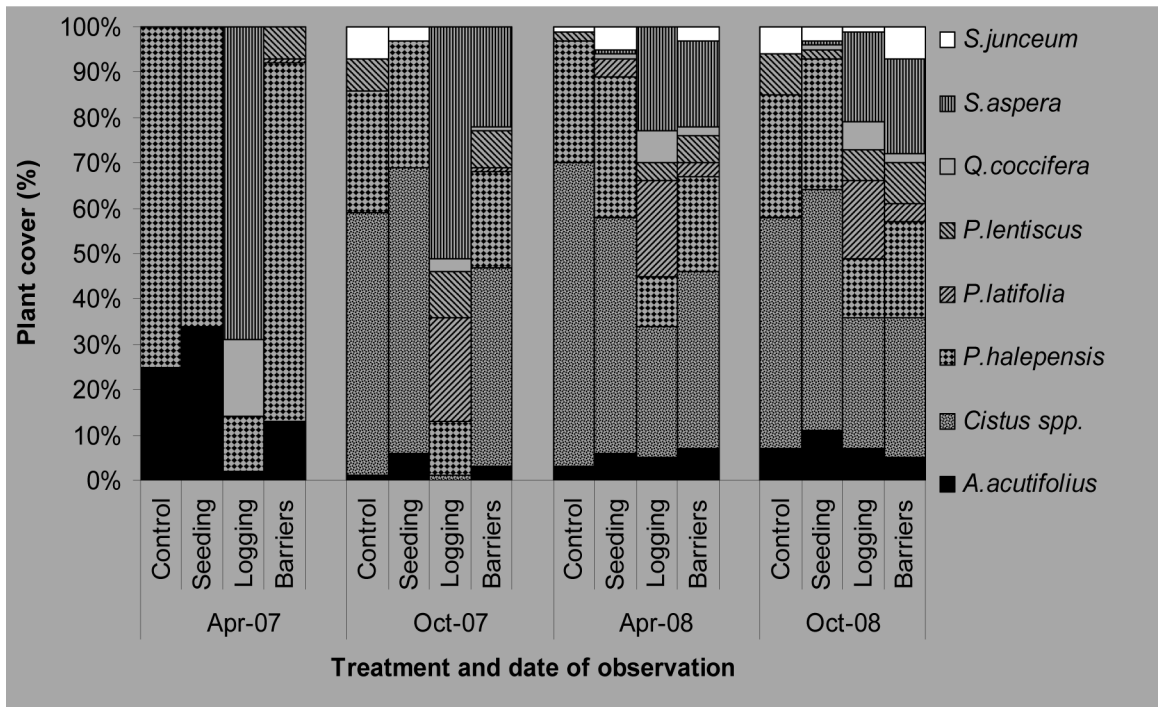


Figure 1. Percentage of ground cover by woody species.

al. 1993, Saracino and Leone 1993, Spanos et al. 2005) although in a similar study, removal of burned trees had no effect on pine recruitment (Ne'eman 1997). Martínez-Sánchez et al. (1999) concluded that traditional wood removal practices do not threaten natural post-fire *P. halepensis* re-establishment if initial seedling density is large enough. The timing of felling after fire has a significant effect on seedling survival, and in our case, logging occurred at the start of seedling emergence. Should logging have occurred after seedling emergence, a high number of seedlings could have been killed, thus threatening post-fire recovery. It is therefore advisable that logging after fire is carried out well before seedling emergence.

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