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Post-Fire Regeneration in *P. halepensis* Mill. Adult Forests of the Gargano Promontory (Puglia, Italy)

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Abstract: *We report the results of a post-fire regeneration study concerning an adult Aleppo pine forest, destroyed by fire during summer 2007. The area was subsequently hit by a violent downpour that caused flooding, leading to soil erosion and depletion of the post-fire soil seed bank. Post-fire regeneration of pine in promptly cleared areas was compared with areas where the clearance of the burnt plants was carried out after about eighteen months, in compliance both with regulations governing protected areas according to Italian Law no. 394 of 6 December 1991 and with the area being designated a Site of Community Importance (SCI), in accordance with the European Commission Habitats Directive 92/43/EEC. The surveys in question covered a period of about four years.*

Keyword: *P.halepensis Mill.,Mediterranean ecosystem, forest fire, forest management, post-fire regeneration.*

1. Preliminary Remarks and Aim of the Work

The role of fire as an ecological factor for numerous forest ecosystems, including those of the Mediterranean area, is widely acknowledged (Kozlowski and Ahlgren 1974, Naveh 1975, Pons and Thinon 1987, Pyne 1995, Pausas and Vallejo 1999). Several experimental surveys carried out in the last 30 years have concerned the effects of forest fires on Aleppo pine (*Pinus halepensis* Mill.) forests in the Mediterranean area (Trabaud et al. 1985, Moravec 1990, Saracino et al. 1993, Martínez-Sánchez et al. 1995, Ne'eman et al. 1995, Martínez-Sánchez et al. 1996, Herranz et al. 1997). The Aleppo pine is known to be a species which necessarily reproduces by seed dispersal (Trabaud 1987): in the event of a fire the opening of the cones and release of a large quantity of seed leads, in most cases, to prompt and abundant regeneration. Pine seed germination occurs between the beginning of autumn and late winter, which in most environments with a Mediterranean climate represents the rainy period, often associated with mild temperatures conducive to germination. The presence of serotinous cones in the canopy is another feature of the Aleppo pine which must be considered a fire-adaptive trait (Daskalakou and Thanos 1996). Each tree produces both serotinous and non-serotinous cones: the former remain closed for several years after maturation and open thanks to the heat of fire, or under the action of warm dry winds which are not at all uncommon in the Mediterranean area (Nathan et al. 1999, Nathan and Ne'eman 2000). Thus the canopy seed bank of the fire-damaged stand is increased in the post-fire phases (Goubits et al. 2003).

Research has highlighted the results of different options of silvicultural management concerning natural post-fire regeneration (Ne'eman et al. 1993, Saracino and Leone 1993, Martínez-Sánchez et al. 1999, Leone et al. 2000, De las Heras et al. 2002, De las Heras et al. 2004). Indeed, the post-fire regeneration of Aleppo pine can undergo strong quantitative variations both on a regional and local scale, leading even to temporary disappearance of pinewoods in numerous areas of the Mediterranean basin (Tsitsoni 1997, Pausas et al. 2004). In such cases, the forest manager has to take measures both to identify ways to ensure that pine seedlings take root and become established, and identify possible areas where the low intensity of regeneration could require direct additional interventions (sowing or plantations) in the subsequent phases of environmental restoration.

In light of the above considerations, post-fire restoration represents a widely discussed issue both in Italy and abroad. The Italian regulations governing the sector, given a history of widespread illegal building, aim to penalise speculative action on fire-damaged forests and pastures and prevent

wildfires from being profitable activities (according to Art.10, Law no. 353 of 21 November 2000). For this specific case, it is important to underline that the first paragraph of the above-mentioned law bans "….. for five years, on the above-cited stands, activities of reforestation and environmental engineering supported with public funds, except under specific authorization given by the Minister for the Environment, for natural protected state areas, or by the competent region, in other cases, for documented situations of hydrological degradation and in situations where an intervention for the protection of certain environmental and landscape values is urgent. It also bans pasturage and hunting for ten years, only for the stands of the fire-damaged wooded areas". These are important regulations to protect the woods themselves, meriting some reflection. Traditionally, in numerous areas of the Mediterranean basin, one of the very first post-fire operations carried out to re-establish damaged pinewoods regards the cutting down and removal of the plants, totally or severely fire-damaged, whose justification lies in the following reasons:

i. dragging the logs on the ground, when the burnt wood is hauled out, facilitates the germination of pine seedlings, since it enhances contact between the seeds which survived the fire and the soil;
ii. the removal of the dead plants greatly reduces the proliferation risk of xylophagous insects, which could attack the surviving plants (as actually occurred, in the case of this study, with *Tomicus piniperda* L.) or negatively affect the survival of the future pinewood.

However, some studies carried out on the matter have shown that the removal of the dead plants would have a negative effect on the establishment and survival of the pine seedlings, since:

i. leaving the dead plants standing would bring about the release of a further quantity of seed, which would supplement seed dispersal which normally occurs due to heat;
ii. even in the event of total destruction of the needles constituting the foliage, the trunks and the branches would perform a shading action, albeit slight, thereby reducing insolation and hence mortality of the seedlings during summer (Ne'eman et al. 1993, Saracino and Leone 1993).

These are two different options (cutting down and removing the plants whose vitality is compromised by the fire, or leaving the plants where they are and postponing the operation to some future date) which often create ideological conflict both among academics and technical staff called upon to express opinions about feasible interventions to restore fire-damaged pinewoods.

A third option could be to cut down the burnt trees and leave the single prunings, or brushwood and logs, which could well serve a multiple function: release of additional quantities of seeds, provision of seedling shade, and soil protection against runoff caused by heavy rains, especially in steeply sloping areas (Moreira et al. 2011). This would also avoid damage to regeneration after the felling and extraction of dead trees.

This research reports the results of the survey carried out in an area of the Gargano Promontory in south-eastern Italy (Municipality of Peschici, Puglia, 41°57′ lat. N, 16°1′ long. E, Fig. 1), devastated by a wildfire in July 2007. In particular, we describe the results achieved in terms of natural regeneration by adopting different silvicultural options.

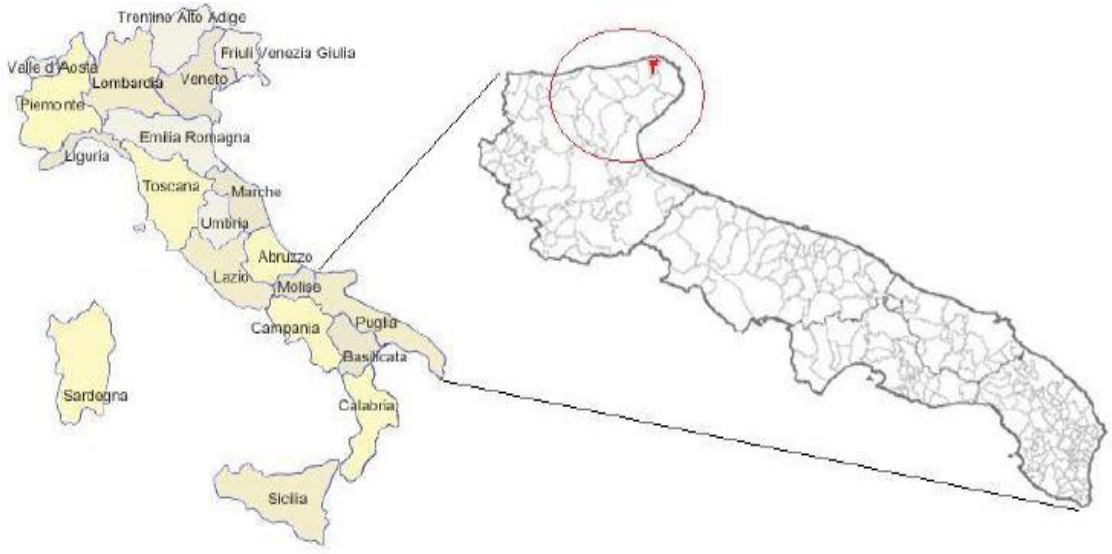

Fig 1. *In the circle the Gargano promontory; in red the territory of Peschici (Puglia, southern Italy)*

2. THE CASE STUDY

According to the Official Gazette no. 85 of the Puglia Regional Authority published on 28/08/1998 in the period 1974-1994 in the territory of Peschici about 23 forest fires on average were recorded every year. Throughout the province of Foggia, Peschici comes second (after Vieste, with about 32 fires every year) in terms of wildfire frequency. The average area damaged per fire in the above-mentioned period was 13.25 hectares. The statistical data (Leone and Lovreglio 2003) show that huge wildfires have occurred in the Gargano Promontory for at least several decades, especially in the territories of Peschici and Vieste.

The above data should be considered in connection with the expansion of pinewoods in the Gargano, located mostly along the coastline and in the immediate hinterland from Vico del Gargano to Mattinata and Monte Sant'Angelo and which, according to Agostini (1964), amounted to nearly 7,150 ha, while according to Mastelloni (1980) it amounted to 8,070 ha subdivided into 39 nuclei. Barbone (1988) reports a completely different pinewood area (about 14,800 ha) which includes approximately 2,300 ha of plantations and forest restoration carried out after the occurrence of wildfires. The period of greatest impact of the phenomenon of forest fires, typical of Mediterranean areas, coincides with the hottest and driest months. In descending order of impact, August is the most severe (37.78%), followed by July (34.11%), September (13.19%) and June (8.66%).

On July 24, 2007 an enormous wildfire swept through the area of Peschici, one of the most beautiful in the Gargano Promontory and a popular tourist destination. The fire, exacerbated by a prolonged drought, by high temperatures (the temperature recorded at 10 am was close to 40 °C), and above all by the exceptional wind speed that day (about 20 m per second), caused the destruction of hundreds of hectares of pinewoods (pure stands or mainly of *Pinus halepensis* Mill.) and of Mediterranean maquis. The images obtained with the multi-spectral sensor Modis placed on the satellite Aqua clearly show that:

i. in the Gargano Promontory, and in the regions of Molise and Abruzzo there were several contemporaneous fires which created difficulties for the authorities in charge of monitoring and extinguishing fires (red hot-spot in the IR image of Fig. 2);

ii. the seriousness of the phenomena which occurred in the Gargano was undoubtedly exacerbated by the wind speed, as shown by the columns of smoke driven towards the Adriatic sea (Fig. 3).

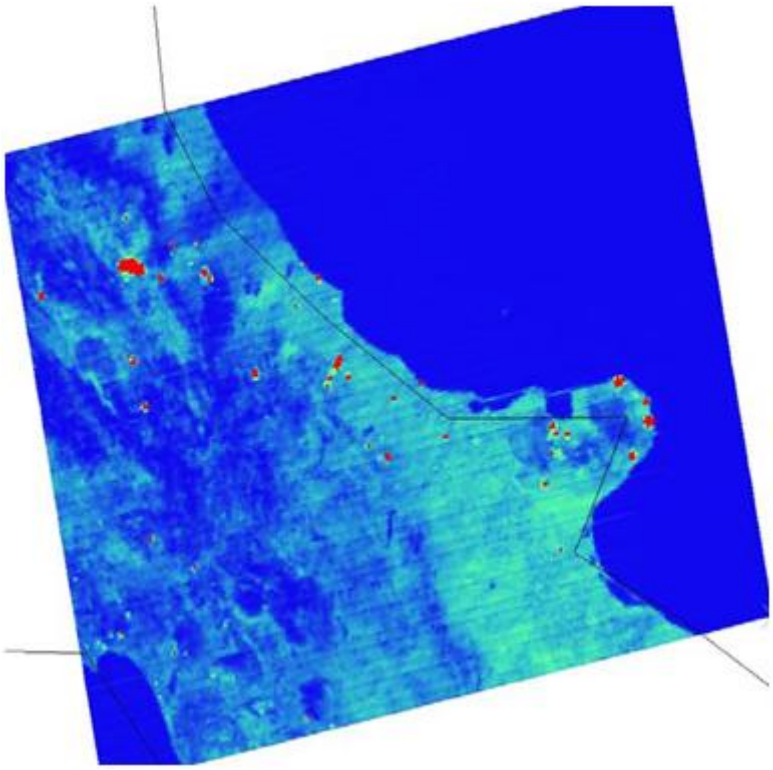

Fig 2. *Satellite image in the field of the thermal infrared (IR) detected at 12.05 UTM by the multi-spectral sensor Modis placed on board of the polar NASA satellite Aqua (source MARSEC)*

Fig 3. *Satellite image in TrueColor detected at 12.05 UTM by the multi-spectral sensor Modis placed on board of the polar NASA satellite Aqua (source MARSEC)*

The main problems to tackle immediately after the disaster concerned both the management of the burnt topsoil, and the hydrological protection of the areas damaged by the fire. Subsequent to an ordinance by the Mayor of Peschici issued immediately after the fire, a strip of 20m between the provincial road SP 52 and other municipal roads was clear-felled and logged out for reasons of public safety. Unfortunately, no preventive intervention was undertaken for soil protection from erosive agents, whose effects considerably aggravate the direct consequences of the fire, due to the severe and often permanent change in the physical, chemical, mineralogical and biological characteristics of the pedogenetic substrate (González-Pérez et al. 2004, Certini 2005). On 22 October 2007 a storm of exceptional intensity hit the area already devastated by the fire. The rain, particularly heavy and brief (240.4 mm recorded at the weather station in Vico del Gargano), caused flooding and landslides.

Therefore, it is quite likely that in this case the pine seeds were washed away together with the soil layer. It is also likely that the seeds had fallen abundantly from the adult pinewood after the fire, representing the precondition for efficient and natural reconstitution of the pinewood stand.

All this resulted in conditions for an experimental study on natural pinewood regeneration in the following two different situations:

1) areas where the dead plants were promptly cut down and cleared;
2) areas where the plants were cleared starting from 9-10 months after the fire and ending about 24 months after this event.

After commenting on the different management options for fire-damaged land, we report the main results in terms of their effects on the natural regeneration.

3. MATERIALS AND METHODS

The research was carried out in fire-damaged natural pinewoods in the area of Peschici. On the basis of the data and the descriptions in two Forestry Management Plans carried out in the area partially affected by the fire, it can be inferred that the stands were coetaneous, mostly in the medium-high age group. The area has frequent rocky outcrops along the ridges, and thick soils in valleys with many broadleaved trees, especially holm oak, manna ash and other thermophilic species typical of the vegetation belt (La Marca 2004a, La Marca 2004b).

The wood volume of the stands, concerning the trees of diameter greater than 8 cm, ranged between 100 and 170 m^3 per hectare. In the above pinewoods, surveys were carried out in February 2009 and February 2010 on the natural regeneration established after fires.

During the first survey (February 2009), post-fire pine regeneration was measured in 18 transects identified so as to represent, in the adjoining areas, the different situations as regards exposure, slope and post-fire treatment:

- treatment A: areas where the burnt pine trees had been promptly cut down and removed immediately after suffering fire damage (August 2007);
- treatment B: areas situated in the same exposures where the burnt pine trees had not been cut.

The transects, each 10 m^2 (20 m long, 0.5 m wide) and identified systematically, were spaced 15m apart, while the distance between transects situated in the two different treatments was 20m. All the transects were perpendicular to the slope, and they were made permanent by the means of hardened steel stakes fixed in the ground. The areas where the transects were made were not in fact barred to pasture. In each transect, the position of every single seedling, the vegetative state (dead or living) and its height were recorded. The position of the seedling was considered important in order to evaluate possible time dynamics, in terms of mortality and/or appearance of new seedlings.

Both in the areas where the plants had been removed and in those where no intervention had been carried out, the natural vegetation established after the fire was generally made up of species typical of the Mediterranean maquis: lentisk, phillyrea, rosemary, myrtle, euphorbia, cistus (*salvifolia* and *monspeliensis*), and various grass species. Tree species, besides pine seedlings, included shoots originating from coppices of pre-existing broadleaved trees, mainly holm oak, manna ash and oleaster (wild olive). The surveys in the transects were repeated after a year (February 2010). In 2010 the heights of the pine seedlings were also measured in order to calculate the Regeneration Index (IR) *sensu* Magini (1967).

4. RESULTS

Table 1. shows the results of the surveys carried out in 2009 and 2010 in the 18 transects, the number of dead plants being compared in relation to slope, exposure and the type of forest management practised (treatments A and B). Tab. 2 shows the experimental values of the Regeneration Index of Magini (1967), measured in 2010.

Table 1. *2009-2010 P. halepensis seedlings (number per square meter) observed in the three study areas.*

				Survey 2009							Survey 2010								
				Thesis A			Thesis B			Total	Thesis A				Thesis B				Total
Area	Transect	Aspect	Slope	Live	Dead	Total	Live	Dead	Total	A+B	Live	Dead	Born	Total	Live	Dead	Born	Total	A+B
1	1	N-E	<5%	17.1	0.7	17.8	0.5		0.5	18.3	14.6	2.5		17.1	0.5			0.5	17.6
1	2	N-E	<5%	0.7		0.7				0.7	0.1	0.6		0.7					0.7
1	3	N-E	<5%	2.4	0.2	2.6	0.3		0.3	2.9	1.8	0.6		2.4		0.3		0.3	2.7
Total area 1				20.2	0.9	21.1	0.8		0.8	21.9	16.5	3.7		20.2	0.5	0.3		0.8	21.0
Average area 1				6.7	0.3	7.0	0.3		0.3	7.3	5.5	1.2		6.7	0.2	0.1		0.3	7.0
2	1	W	5-20%	10.4	0.1	10.5				10.5	8.9	1.5		10.4					10.4
2	2	W	5-20%	1.0	0.3	1.3				1.3	0.9	0.1		1.0					1.0
2	3	W	5-20%	0.8		0.8	2.2	0.2	2.4	3.2	0.6	0.2		0.8	1.0	1.2		2.2	3.0
Total area 2				12.2	0.4	12.6	2.2	0.2	2.4	15.0	10.4	1.8		12.2	1.0	1.2		2.2	14.4
Average area 2				4.1	0.1	4.2	0.7	0.1	0.8	5.0	3.5	0.6		4.1	0.3	0.4		0.7	4.8
3	1	S	>20%	1.0		1.0	2.3		2.3	3.3	0.8	0.2		1.0	1.5	0.8		2.3	3.3
3	2	S	>20%	2.5		2.5	3.2	0.1	3.3	5.8	1.3	1.2	0.1	2.6	1.9	1.3		3.2	5.8
3	3	S	>20%	3.3	0.2	3.5	2.1		2.1	5.6	3.0	0.3	0.1	3.4	1.1	1.0		2.1	5.5
Total area 3				6.8	0.2	7.0	7.6	0.1	7.7	14.7	5.1	1.7	0.2	7.0	4.5	3.1		7.6	14.6
Average area 3				2.3	0.1	2.3	2.5	0.0	2.6	4.9	1.7	0.6	0.1	2.3	1.5	1.0		2.5	4.9

Table 2. *Values of Regeneration Index (RI) measured in 2010.*

Replicate(???)	Thesis A			Thesis B		
	live pines ($n*m^2$)	average height (cm)	RI	live pines ($n*m^2$)	average height (cm)	RI
1	17.1	41.2	705.0	0.5	39.2	19.6
1	0.7	32.8	22.9			
1	2.4	46.6	111.9	0.3	35.3	10.6
2	10.4	28.7	298.8			
2	1.0	39.5	39.5			
2	0.8	29.5	23.6	2.2	38.7	85.1
3	1.0	37.5	37.5	2.3	40.0	92.1
3	2.5	30.0	75.1	3.2	36.5	116.7
3	3.3	31.5	104.0	2.1	34.5	72.3

5. DISCUSSION AND CONCLUSIONS

From the analysis of Tab. 1 what emerged overall is that natural regeneration, regardless of treatment, was generally scant with respect to the data in the literature on this area for mature pinewoods of Aleppo pine after a wildfire. In the case examined herein, the natural regeneration, two years after the fire (February 2010), reached around 43,500 plants per hectare in treatment A and about 11,700 plants per hectare in treatment B. It therefore follows that the regeneration is more abundant in the areas promptly cut (treatment A) with respect to those cut late (treatment B) both in zone 1 and in zone 2, with an average number of plants per zone equivalent to 6.73 per m² and 4.07 per m² in treatment A against an average number of plants per zone of 0.27 per m² and 0.73 per m² in treatment B. In zone 3, instead, the data concerning regeneration, the lowest of those examined, do not show appreciable differences in the areas with a different management, with an average 2.27 seedlings per m² in treatment A and 2.53 in treatment B.

It must also be pointed out that in spring 2009, that is, one vegetative season after the fire, of all the seedlings (living and dead) in the 18 transects examined, 78.8% were found in the transects subject to treatment A and only 21.1% in the transects which represented treatment B (Tab. 1). The mortality recorded in the period of observation (2009-2010) was constantly greater in treatment B than in treatment A: on average in the three zones examined, about 18% in treatment A *vs* about 43% in B.

Contrary to what would be expected, leaving the dead plants standing (treatment B) did not favour the sprouting of new seedlings, while new seedlings, albeit not in large numbers, were detected in the areas where the plants had been cut down and removed (treatment A) (Tab. 1).

The results of the studies showed that in the areas where the burnt arboreal vegetation was promptly removed (August 2007) regeneration of the pine was more successful than in the areas logged out late in all of the three examined zones. Our findings appear to show that in the zones promptly cleared of the burnt plants, the success of regeneration increases probably due to the soil exposed by wood hauling operations and the increase in the quantity of seed on the ground due to the greater presence of tiny loppings and strobilus which inevitably stay on the ground after use.

In the transects examined both in 2009 and 2010 the Analysis of Variance (ANOVA) did not highlight any statistically significant differences between the treatments and the surveyed zones: the observed values of F are lower than the critical values of F determined from tables. This is the reason why it is not possible to claim the existence of statistically significant differences, both between zones and at an interaction level. Also as regards Magini's Regeneration Index (RI), no statistically significant differences between the examined zones are reported.

In connection with the general scarcity of regeneration observed above, it must be noted that the whole area of Peschici was affected by flooding which occurred at the end of October 2007 and caused considerable slope erosion, with significant soil volume (and we also believe seed) transport. On the other hand, it is known that, in the case of forest fires, hydrological protection is compromised the first time because the elements (the plants) which afford soil protection are directly affected; the second time because the fire negatively affects the soil structure making the substrate more erodible by surface run-off.

All in all, it would appear that the zone in question has undergone events that have resulted in substantial randomness in terms of the intensity and the distribution of pine regeneration, linked above all to:

i. the abiotic variables at the several sites involved in the phenomenon (exposure, slope, soil depth, outcropping, presence, or otherwise, of surface irregularities, including coppices, etc.) which could have affected surface flows during the flood. Investigations are under way to establish the existence of probable correlations between the presence or absence of regeneration and soil micro-morphology;

ii. rainfall phenomena (and to the total omission of post-fire hydrological protection measures) which in October 2007 involved the study area, whose intensity negatively affected the regeneration density, since it washed away the soil and, most probably, also the seed which it contained.

A further consideration, which would incline towards immediate intervention through cutting down and removing burnt plants (compared to non-intervention) comes from the fact that, if postponed, clearing the plants will inevitably compromise the regeneration established in the meantime.

On the basis of our experience in this field and findings reported elsewhere (Pausas et al. 2004, Padovano 2008) it would be better, where slope and topography may result in soil being washed away together with the seed contained therein, to leave logs after being cut down, placing them in a position perpendicular to the slope so that they perform a primitive but efficient hydrological protection function. By the same token, leaving the loppings *in situ* would have a positive effect on soil protection, on protecting seedlings from grazing cattle, at least in the early phases, and ultimately on regeneration intensity.

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