

Short communication. Recruitment and early growth of *Pinus pinaster* seedlings over five years after a wildfire in NW Spain

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Abstract

Aim of study: The main aim of this study was to analyse the post-fire recruitment and growth of *Pinus pinaster* seedlings during the first five years after wildfire and also to analyse the effects of climatic conditions on the survival of *P. pinaster* seedlings

Area of study: The study area was located in a *P. pinaster* stand in León province (NW Spain) burned in 1998.

Material and methods: Three sites in the burned area were selected. In each site three permanent transects of 20 m × 1 m were placed. In each transect, twenty 1 m² sampling units were marked and the number and height of each pine seedlings was recorded at 7, 8, 9, 10, 11, 12 months and 2, 3, 4 and 5 years after the wildfire. The soil of study area is Cambisol.

Mean results: Mean *Pinus* regeneration densities varied between 33.2 seedlings/m² after 7 months and 6 seedlings/m² five years after wildfire. In this *P. pinaster* stand, maximum mortality appeared during the summer months in the first year of regeneration. There was a significant increase in seedling height associated with a decrease in density.

Research highlights: The post-fire recruitment is considered enough to ensure good natural *Pinus pinaster* forest regeneration. In the short term post-fire management strategy in this type of forest could be the remaining branches with cones of burned trees that allow the dissemination of the seeds during the first few years after fire and ensure natural regeneration.

Key words: fire effects; natural regeneration; León province (NW Spain); seedlings density; growth and survival.

Introduction

The population of *Pinus pinaster* Ait. in the Sierra de Teleno (NW Spain) is characterised by high frequency lightning fires (>1 fire 100 km⁻² year⁻¹) (Gil *et al.*, 1991, Tapias *et al.*, 2004). Thus fire recurrence, in addition to factors such as climate and site quality, has affected the characteristics of the population in the Sierra de Teleno, such as the fact that 97% of the *Pinus* trees are serotinous and produce a large number of mostly serotinous cones (Gil *et al.*, 1991).

Since *P. pinaster* is a seeder species and has fixed serotinity in this population (Tapias *et al.*, 2004), its regeneration relies on the recruitment of a post-fire cohort of seedlings. It produces an abundant yearly seed crop, part of which is held in serotinous cones, thus constituting a cumulative canopy seed bank, as

occurs in other types of Mediterranean pine species (de las Heras *et al.*, 2002). Post-fire regeneration of *P. pinaster* depends mainly on the canopy seed bank (Calvo *et al.*, 2008). Seed germination and seedling recruitment occur in the resource-rich environment generated by fire (Luis-Calabuig *et al.*, 2002; Rego *et al.*, 1991). In general, post-fire seed germination takes place almost exclusively during the first post-fire stages, as in the case of *P. halepensis* (Arianoutsou and Ne'eman, 2000). Seedling mortality has been reported in the first post-fire year (Thanos *et al.*, 1996) or at some locations during the second year (Ne'eman, 1997).

Seedling establishment, growth and mortality have been described widely for *P. halepensis* over much of its range (De la Heras *et al.*, 2002; Herranz *et al.*, 1997; Thanos *et al.*, 1996); however, studies of *P. pinaster* recruitment are still limited (Calvo *et al.*, 2003; Gallegos *et al.*, 2003; Rego *et al.*, 1991). Therefore, it is necessary to extend knowledge about the post-fire

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regeneration and recruitment of *Pinus* seedlings, as well as the possible influence of climatic conditions on the regeneration process, since these factors will provide an ecological basis for defining a suitable management strategy.

The main goal of this study is to analyse the post-fire recruitment and growth of *P. pinaster* seedlings during the first five years after fire in a population with adaptations to recurrent fires. Similarly, we try to define the influence of climatic conditions on the survival of *P. pinaster* seedlings.

Material and methods

Study area

The study area is located in a *P. pinaster* stand in the Sierra del Teleno, León province (NW Spain), at an elevation of 1,100 m. In this area, 3,000 ha were burned by a wildfire in September 1998. The vegetation present in the area before the fire was dominated by 60-85 year old *Pinus pinaster* trees, with a density of 500-900 trees/ha.

The climate is Mediterranean with 2-3 months dryness in summer and annual precipitation of 650 to 900 mm (Ministerio de Agricultura, 1980). Mean annual temperature is 10.3°C and the soil is Cambisol (Junta de Castilla y León, 1987).

We selected three sites in the burned area: S1, S2 and S3. All of them were situated at a gentle slope (< 10%) and showed homogeneity in tree characteristics. Site 1 (S1) was north-facing (42° 16' 16" N; 6° 11' 52" W); site S2 was S-W facing (42° 15' 30" N; 6° 11' 24" W) and site S3 was N-W facing (42° 15' 10" N; 6° 11' 03" W).

Sampling data

In each study site three permanent transects of 20 m × 1 m were placed perpendicular to the slope. The burned pines remained in the sites during the study period. In each transect, twenty 1 m² sampling units were marked and the number and height of each pine seedlings was recorded at 7, 8, 9, 10, 11, 12 months and 2, 3, 4 and 5 years after the wildfire.

Statistical analysis

A two-way repeated measures analysis of variance was carried out to compare changes in the density and

height of *Pinus* seedlings in different sites (S1, S2 and S3) over time, using time as the repeated measure. The Tukey test was used to assess whether differences were significant ($p = 0.05$). The David *et al.* (1954) test was used to check normality and the Cochran (1941) test was used to check homoscedasticity. The Kolmogorov-Smirnov test was used to check the normality.

Correlations between the densities of *P. pinaster*, precipitation (mm) and aridity index of Martonne were tested. We also evaluated the correlations between the densities and the mean seedling height. Correlation was calculated by Pearson coefficients.

Results

Pinus pinaster highest seedlings densities (Fig. 1) were recorded during 7th month at sites S1 and S3 and during the 8th month at S2. There was great heterogeneity in seedling densities among the three sites with significant differences ($F_{2,78} = 33.10$, $p < 0.01$) among them during the initial years of regeneration. In general, mean regeneration densities varied between 33.2 seedlings/m² after 7 months and 6 seedlings/m² five years after wildfire.

Analysis of seedling dynamics in each site through time (Fig. 1) showed a significant decrease ($F_{9,552} = 220.0$; $p < 0.01$) in S1 from the 7th month (76.3 seedling/m²) to the 10th month (17.4 seedling/m²). However, from this month onward, there were no significant temporal differences, reaching 9 seedlings/m² during the 5th year. The site S2, with the lowest seedling density, presented a less marked decrease during the initial months of regeneration, reaching 4.68 seedlings/m² at 5th year. In S3, changes in seedling density behaviour were similar to S1 and a significant decrease ($F_{9,552} = 37.97$; $p < 0.01$) was observed from the 7th month (17.2 seedlings /m²) until the 9th (8 seedlings/m²). No significant changes were subsequently observed at this site. In general, at sites with the highest *Pinus* seedling density (S1 and S3) two important decrease points were observed, one between the 7th and 8th months and a second during the summer months: July, August and September (months 10, 11 and 12, respectively) in the first post-fire year.

Positive correlation was observed between precipitation, aridity of Martonne and the total density of *P. pinaster* seedlings, although these were not significant in any of the study sites.

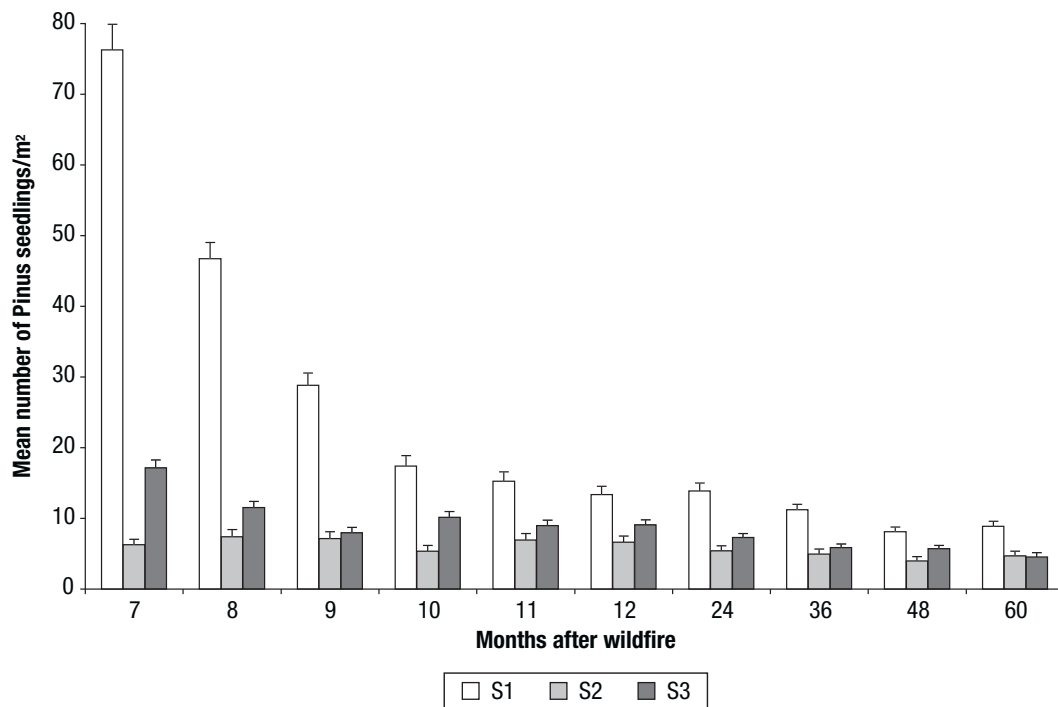


Figure 1. Mean number of *Pinus* seedlings/m² and standard error in the three study sites (S1, S2, S3) through time.

Table 1. Mean height (cm) of *Pinus* seedlings, standard error and range (minimum-maximum) of height values in the three study sites (S1, S2, S3) through time. Different letters indicate significant differences in each study site through time

Months after wildfire	Study sites								
	S1			S2			S3		
	X	SE	Range (cm)	X	SE	Range (cm)	X	SE	Range (cm)
7	1.92 a	0.03	0.5-4	1.29 a	0.04	0.5-3	1.89 a	0.04	0.5-4
8	4.58 a	0.04	2.0-8.0	3.18 a	0.14	1-5	3.74 ab	0.04	1-7
9	4.24 ab	0.07	2.0-8.0	4.00 a	0.05	2-6.5	4.68 ab	0.08	2-10
10	5.41 b	0.10	2.0-10.0	4.77 a	0.12	2-9	6.48 ab	0.12	2.5-15
11	6.21 b	0.17	2.0-16.0	5.64 a	0.21	2-18	8.69 b	0.19	2-19
12	6.62 b	0.19	1.5-18	5.45 a	0.2	2-13.5	9.13 b	0.21	1.5-22
24	10.97 c	0.4	2-35	12.17 b	0.61	2-40	21.32 c	1.02	3-60.5
36	23.23 d	0.8	3-66	25.08 c	1.59	5-69	38.99 d	1.84	5-94
48	34.57 e	1.22	3-87	32.35 d	1.6	3-87	48.42 e	2.40	3-120
60	45.79 f	1.67	4-113	40.76 e	2.23	5-103	65.06 f	4.18	14-132

Mean seedling height showed (Table 1) a significant increase in time (5 years) at the three study sites, S1 (from 1.92 to 45.79 cm) ($F_{9,495} = 469.7$; $p < 0.01$); S2 ($F_{9,495} = 145.2$; $p < 0.01$) (from 1.29 to 40.76 cm) and S3 ($F_{9,495} = 279.9$; $p < 0.01$) from 1.89 to 65.06 cm. However, the increase was more pronounced from

24 months after fire. Site S3 showed the greatest height (65.06 cm) 5 years after fire. The correlation analysis between mean number of *Pinus* seedlings and mean seedling height showed a significant negative correlation in S1 ($r = -0.28$, $p < 0.05$), S2 ($r = -0.10$, $p < 0.05$) and S3 ($r = -0.13$, $p < 0.05$). The site with

low *Pinus* density (S3= 4.53 seedlings/m²) during the fifth year (Fig. 1) showed the tallest saplings (65.06 cm) (Table 1).

Discussion

The high density of seedlings after fire shows that there was good natural regeneration of *P. pinaster* in the study area. The density of seedlings is higher than those reported by other authors (Gallegos *et al.*, 2003) in studies carried out in a *P. pinaster* forest in the south of Spain. The large proportion of serotinous cones in Sierra del Teleno's population (Tapias *et al.*, 2004) that allowed good seeds protection against fire could explain these differences.

First post-fire establishment of *Pinus pinaster* in the study sites occurred 7 months after fire in the rich-resource environment generated by the fire passage. This early seedling establishment may be related to the great dissemination power of pines and its heliophily (Thanos *et al.*, 1996). In general, the great seedling recruitment occurs during the first post-fire years, although we observed sporadic emergence of seedlings until the fifth year, similar to the results found by Herranz *et al.* (1997). These new seedlings may come mainly from adhering serotinous cones on the burned trees that were present in the study zone.

The results obtained showed great heterogeneity in the regeneration process among study sites (S1 and S3 greater than S2) regardless of being located at the same elevation and slope. These differences could be explained by the different exposure of sites S1 (North), S3 (North-West) and S2 (South-West). Some authors (Gracia *et al.*, 2002) explain that the number of *Pinus* in north- or northwest-facing areas was higher than in west-facing areas.

These differences among sites were also found in the analysis of the seedlings density dynamics after fire. A significant decrease was observed in zones S1 and S3 (sites with a higher seedling density) from the 7th to the 10th regeneration month. The main cause of pine seedling mortality was the harsh meteorological conditions, particularly summer drought as has been found by other authors (Madrigal *et al.*, 2005; Thanos *et al.*, 1996; Trabaud *et al.*, 1997). In this sense, in our study sites the precipitation in the summer (64.7 mm) and also the average annual precipitation in the first post-fire year (354.7 mm) were extremely low (an approximate reduction of 75%) in comparison with the

mean annual precipitation (718.48 mm) for the area in the following years.

Seedling height increments were more pronounced from the 2nd year after the fire and showed inter-site variability. So five years after fire the S3 site showed the tallest saplings with significant negative correlation between density and height. Some authors have related the enhanced growth of pine seedlings to soil characteristics (Ne'eman, 1997; Pausas *et al.*, 2003). In our study the soils at site S3 showed the highest quantity of nitrogen and organic matter (Calvo *et al.*, 2008).

In conclusion, in the study area seedling density was high enough to ensure natural regeneration of *P. pinaster* forest. The sites with higher densities (S1 and S3) showed greater seedling mortality during the first post-fire summer. However, site S2, with lower densities, showed less pronounced changes. During the first two years great recruitment of new seedlings was observed from cones which were opened but not killed by heat, and which remained on trees and were able to shed seeds during this time. No significant correlations were found between *Pinus* seedling densities and environmental factors (precipitation, and aridity index). The site with low *Pinus* density (S3) during the fifth year after fire showed the tallest saplings.

In the short term post-fire management strategy in this type of *Pinus pinaster* forest could be the remaining branches with cones of burned trees that allow the dissemination of the seeds during the first few years after fire, and ensure natural regeneration. In medium term, probably thinning of this type of forest would be a good management treatment to improve seedlings growth and to reduce fuel accumulation.

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