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Fire severity and pine regeneration in the Eastern Iberian Peninsula

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ABSTRACT: We asked to what extent post-fire regeneration of *Pinus halepensis* (Aleppo pine) woodlands is related to fire severity. To answer this question we studied the regeneration of pine woodlands after a wildfire in Canabes, in the eastern Iberian Peninsula. We defined two fire severity classes based on the degree of consumption of the pine canopy: low (canopy retaining >20% of green leaves) and high (canopy with >80% of the leaves consumed). The results suggested that there is no clear relationship between seedling density and fire severity; however, seedling growth (shoot biomass and root biomass) was higher in the high severity class. Analysis of foliar nutrients suggested a tendency towards higher soil nutrient availability (especially P) during the first post-fire year in the high fire severity plots. Mortality of resprouting species was higher in the high severity class. We hypothesise that the results of higher growth in high fire severity plots can be explained by soil processes: Sites in the high fire severity class may have sustained higher fire intensities, which are related to higher soil organic matter mineralisation and, thus, to higher post-fire soil fertility. This higher fertility would produce higher survival and growth. The fact that plots with different canopy damage seem to show different soil nutrient dynamics and different resprouting failure suggests that fire severity at the canopy level may be related to fire intensity at the ground level.

1 INTRODUCTION

The regeneration of *Pinus halepensis* woodlands after fire has been studied elsewhere (e.g., Trabaud *et al.* 1985, Moravec 1990, Daskalakou & Thanos 1997, Ne'eman 1997, Herranz *et al.* 1997, Tsitsoni 1997, Pausas *et al.* 1999). However, due to fuel heterogeneity and to topography, wind and microclimatic changes during a fire, both the intensity and the severity of fires are quite variable throughout the landscape and produce heterogeneous post-fire environments. Thus, fires contain areas with different fire intensities and different fire severity, usually in a complex mosaic. Despite the importance of fire in the Mediterranean Basin, the different post-fire regeneration of patches (regeneration variability) with different degrees of consumption has not yet been addressed.

The present study aims to address to what extent the regeneration of *Pinus halepensis,* a dominant species in the eastern Iberian Peninsula, is related to a simple qualitative measure of fire severity.

In the present work, we classify fire severity according to the degree of consumption of the canopy after a crown fire. This measure of fire severity, which is related to flame height, provides information on fire severity at the canopy level. To what extent fire severity at canopy level is related to fire severity at ground level remain unknown. However, we can hypothesise that post-fire *P. halepensis* regeneration may be related to fire severity (as defined above) because: a) *P. halepensis* has serotinous cones and fire at canopy level may control seed release and mortality; b) different canopy consumption may create different post-fire litter inputs from the scorched canopy; and c) different fire severities may produce different changes in soil nutrient availability.

2 METHODS

2.1 *Study area*

The study was carried out on Ferradura Mountain (200-500 m a.s.l.; UTM 31TYK54), in the municipality of Cabanes (Plana Alta, Castelló, Spain), in the Eastern Iberian Peninsula (Fig. 1). The climate is typically thermo-mediterranean, with a mean annual temperature of about 16ºC and a total rainfall of 486 mm (Cabanes Meteorological Station, 291 m a.s.l.; 1989-1990) and 540 mm (Vilafamés Meteorological Station, 295 m a.s.l.; 1973-1990). The predominant bedrock type on the slopes is carbonated marl from the Cretaceous; the upper part of the mountain is dominated by hard limestone. As in many other areas in Spain (Pausas & Vallejo 1999), most of the slopes were terraced during ancient times and then abandoned during industrialization. Current vegetation on these slopes consists of *Pinus halepensis* (Aleppo pine) woodlands with an understorey composed of numerous shrubs (*Erica multiflora*, *Pistacia lentiscus*, *Rhamnus alaternus*, *R. lycioides*, *Lonicera implexa, Anthyllis cytisoides, Rubia peregrina, Asparagus acutifolius, Smilax aspera, Daphne gnidium, Globularia alypum, Ulex parviflorus, Chamaerops humilis, Juniperus oxycedrus, Rosmarinus officinalis*). The herb layer is dominated by the perennial grass *Brachypodium retusum*. At the upper part of the mountain (on limestone), the dominant vegetation is a *Quercus coccifera* garrigue.

The whole area (ca. 900 ha) was burnt by a crown wildfire in April 1999, leaving a mosaic of pine woodland patches with different degrees of consumption. The area had previously been affected by another wildfire in 1979, from which many trees had survived (low severity fire). Thus, before the 1999 fire, the pine population consisted of a ca. 20-year-old regeneration population plus a previous population of older trees.

Figure 1. Situation of the study area (Ferradura Mountain, Cabanes).

2.2 *Sampling*

After the 1999 fire, three different fire severity classes were differentiated according to pine canopy damage: low, moderate and high (see Table 1 for detailed definition). For the present work, only the low and high fire severity classes (the most contrasted) were studied.

Table 1. Fire severity classes judged from *Pinus halepensis* canopy damage; description and post-fire mortality of the pines. In all three classes, the forest floor litter layer was consumed.

Fire severity classes	Description	Post-fire mortality
Low	Light fire; canopy trees retain > 20% of green leaves (top of the canopy). Trees remain mainly green after the fire.	No
Moderate	Most leaves (>80%) of canopy trees are scorched (dead) but not consumed. Green leaves may occur at the top (< 5%), and some leaves at the bottom may be consumed (< 5%). Trees are mainly brown (retained scorched leaves) after the fire.	Yes
High	Severe fire; canopy trees with > 80% of the leaves consumed and the rest (if any) scorched (top). No green leaves left.	Yes

Four permanent plots for each fire severity class were selected on Ferradura Mountain. Each of these rectangular plots was situated on a flat area of an old terrace. Plot size ranged from 81.5 to 145 m^2 (mean = 109 m^2) depending on the site constrictions (continuity of canopy, size and shape of the terrace, homogeneity of conditions). Diameter at breast height was measured in all the stand trees of each plot and in all the adjacent trees whose projected canopy area fell within the plot. The proportion of projected canopy area that fell within the plot was also recorded. Seedling emergence was sampled in December 1999 (8 months after fire) and survival and growth in September 2001 (29 months after fire). From the seedlings present during the first sampling, 10 growing in the high-severity class and 10 growing in the low-severity class were collected (above- and below-ground) in the second sampling (2.5 year-old seedlings). The number of burnt resprouting shrubs that failed to resprout one year post-fire was also quantified in each plot.

2.3 *Analysis*

Seedling density and mortality were calculated for each plot. Basal area of pre-fire trees was computed to include the individual trees adjacent to the plot weighted by the proportion of the canopy area covering the plot (i.e., weighted basal area). Collected seedlings were separated in different fractions (roots, stems, needles), and needles were separated in 3 cohorts (I: the oldest, III: the youngest). All fractions were oven-dried (60^{o}C until constant weight) and weighed. Needles of the seedlings were mixed to obtain one composite sampled per plot and per needle cohort, and then the needles were milled and their nutrients (N, P) analyzed. Total N was analyzed by elemental auto-analyser (Carlo Erba 1500). Total P was obtained by acid wet digestion with an HNO3:HClO4 (2:1) mixture and determined by optic ICP (Induced Coupled Plasma) (Jones & Case 1990). To help the interpretation of nutrient responses, vector analysis of foliar nutrients (Haase & Rose 1995) was used by assuming the low severity plots as reference plots. With vector it is possible to compare the relative changes in nutrient concentration in relation to changes in nutrient contents between two treatments (in our case, low *versus* high fire severity).

3 RESULTS

The two sets of plots related to the two fire severity classes showed different adult pine density; however, the weighted basal area (that is, considering adjacent trees, which are potential seed source) was similar for the two fire severity classes, ensuring that the plots were comparable (Table 2).

Table 2. Summary of the results (standard deviations in brackets) found in plots under low and high fire severity classes.

	Low	High
Pre-fire tree density (trees/ha)	212 (158)	504 (147)
Pre-fire weighted basal area (m^2/ha)	21.60 (8.21)	21.83 (6.99)
Seedling density (m^{-2}) 8 months post-fire	0.66 (0.25)	0.33 (0.13)
Seedling density (m^{-2}) 29 months post-fire	0.35 (0.20)	0.30 (0.10)
Total seedling biomass (gr) 29 months post-fire	0.82 (0.76)	3.85 (2.25)
Foliar N concentration (%) in needles of cohort I	1.07 (0.16)	1.08 (0.11)
Foliar P concentration (mg/g) in needles of cohort I	0.519 (0.17)	0.690 (0.22)

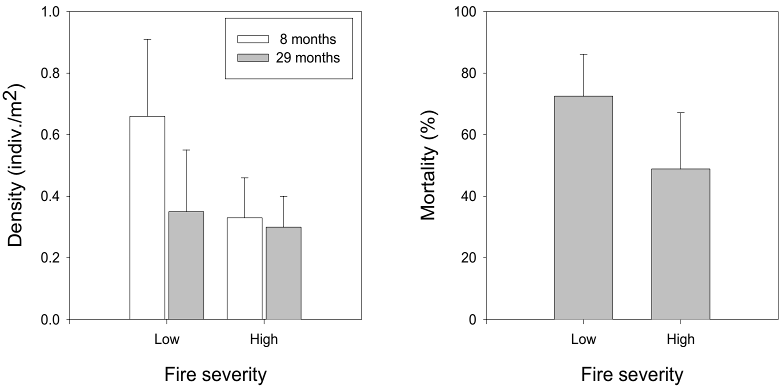

Figure 2. Seedling density (individuals/m^2) 8 and 29 months after fire (left) and mortality (%) of the seedlings tagged 8 months after the fire (right), under the low and the high fire severity classes.

The first post-fire seed germination was observed in autumn 1999, which corresponds to the period with the first important rainfalls after the fire. From the total number of individuals tagged on the first sampling date throughout the whole study site (489 individuals), 182 (37%) survived after 2.5 years. In the first sampling (8 months after fire), seedling density ranged from 0.1 to 1.43 (mean = 0.45) individuals/m^2 (Fig. 2), and showed higher density in the low fire severity class (although the variability was large). Considering both emergence and mortality, seedling density ranged from 0.01 to 0.52 (mean = 0.27) at 2.5 years after fire and did not show any difference between severity classes (Fig. 2a). Looking at the mortality 2.5 years post-fire of the seedlings tagged in the first sampling (8 months post-fire), it is clear that high fire severity plots showed the most stable seedling density with time (Fig. 2, left), due to the lower mortality (Fig. 2, right).

Two-and-a-half years after the fire, seedlings in the high fire severity class were significantly bigger than those in the low fire severity class, that is, biomass values (both the above- and below-ground fractions) were higher for the high than for the low severity class (Fig. 3). Root:shoot ratio did not show any difference between severity classes.

Vector analysis of foliar nitrogen (Fig. 4, left) showed an increase in relative N contents (by needle biomass unit, expressed in relative terms) without changes in concentration, when comparing seedlings at low fire severity versus seedlings at high severity (for any of the needle cohorts). These results suggest that N was not limiting during the post-fire growth. However, P concentration together with P contents tended to increase in the needles of cohort I (oldest) in the high severity class (Fig. 4, right). These changes, combined with an increment in needle weight, suggest that during the first post-fire year there was a tendency towards more P availability in the high fire severity plots than in the low fire severity ones. In the same sense, foliar (cohort I) N concentration did not show any difference between severity classes (Fig. 5) but there was a tendency towards higher P concentration in the needles at high fire severity (Fig. 5). Mortality of resprouters was clearly higher in the high fire severity plots (Fig. 6).

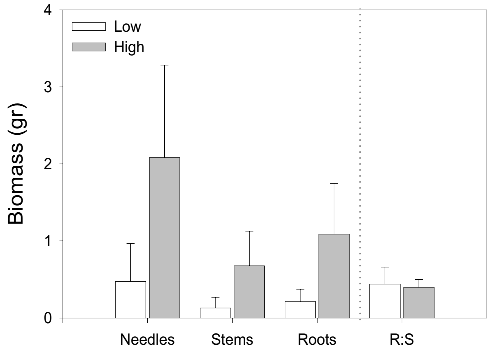

Figure 3. Biomass of the different fractions (leaves, stems and roots) and the root:shoot ratio for 29 month-old seedlings growing in low and high fire severity plots.

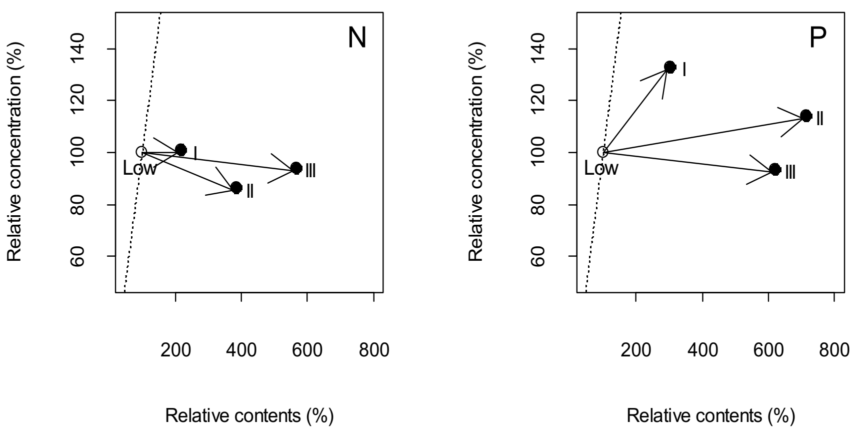

Figure 4. Vector analysis (relative concentration in relation to relative contents) for phosphorus and nitrogen, for 3 cohorts (I, II, III) of needles. Reference plots (x=y=100; open circle) are those with low fire severity. Dotted line is the 1:1 line (proportional increase of concentration and content).

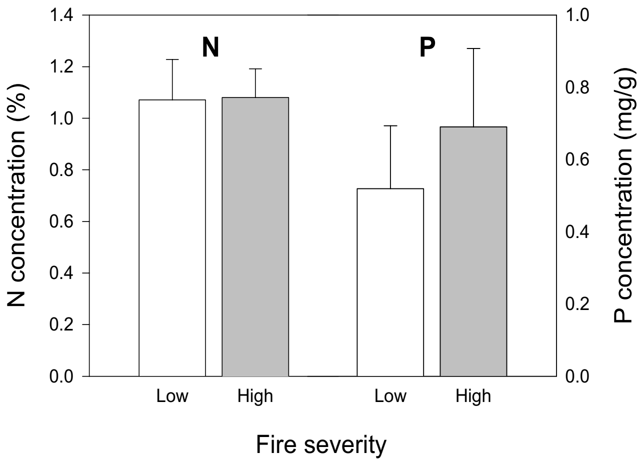

Figure 5. Phosphorus (mg/g) and nitrogen (%) concentration in the first cohort of needles (i.e., first post-fire year needles) growing under low and high fire severity.

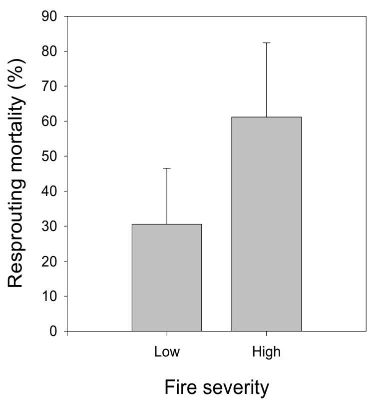

Figure 6. Proportion of resprouting shrubs that failed to resprout on low and on high fire severity plots.

4 DISCUSSION

Initial pine seedling densities tended to be higher in the low severity fire; however, seedling mortality was lower in the high fire severity class. Thus, the final (2.5 year) seedling densities were not related to fire severity. In most plots, seedling density values were low compared with those found on most sites from Greece and the Near East (Tsitsoni 1997, Ne'eman *et al.* 1992, Eshel *et al.*

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2000), but they were similar to those found in south-eastern Spain (Herranz *et al.* 1997). Seedling growth was clearly higher on the high severity plots, and the root:shoot ratio was maintained constant. It is interesting to note the constant resource allocation to roots and shoots even when the growth and biomass values were very different.

Foliar nutrient analysis suggests that the higher growth of seedlings could be explained by the higher soil nutrient, especially P, availability in the high fire severity plots during the first post-fire year. Although soil data on nutrient availability were not available, the foliar analysis of the needles that grew during the first post-fire year (cohort I) integrates the possible soil nutritional status of the soil at that time. Serrasolsas & Vallejo (1999) studied post-fire soil nutrient dynamics in a *Quercus ilex* community of the eastern Iberian Peninsula and showed an increase in soil available phosphorus and nitrogen during the first post-fire year. Romanyà et al. (2001) also showed higher soil nutrients in plots with higher fire severity (higher soil heating by an experimental fire) in Mediterranean old fields, although in their case they only studied soil mineral N. However, other studies found a decrease in N mineralization in burned vs. control plots (Ojima et al. 1994). The increase or decrease in N availability after fire is not easily related to fire severity because the higher the severity the higher the N losses by volatilisation, but also the N mineralisation by heating the top soil. In the case that mineral N was higher in the high severity plots, vector analysis indicates that the seedlings were not nitrogen deficient. In fact, the needle N concentration found in our seedlings (ca. 1.1 %, Table 2) is not very different from the N concentration observed in pine seedlings growing in nursery conditions (1.1-1.7 %, Valdecantos 2001), while our values of total P (ca. 0.5-0.7 mg/g, Table 2) are much lower than those found in nursery seedlings (3.1-3.5 mg/g, Valdecantos 2001). Furthermore, in our area, forest soils on marls are typically more deficient in P than in N (Valdecantos 2001).

In conclusion, in our study area, post-fire *Pinus halepensis* regeneration seems to be controlled more by the changes in soil fertility than by the direct effect of fire on the canopy. In the short term (ca. 2.5 years after fire), better regeneration is found at high fire severity because of the increased post-fire soil P concentration. However, the implications for the long term are yet unknown, and further investigations are needed in this context.

The fact that plots with different canopy damage seem to show different soil nutrient dynamics and different resprouting failure suggests that fire severity at the canopy level may be related to fire intensity at the ground level. Different canopy damages were produced by different flame heights, which are related to the understorey fuel load. Thus, high fuel loads may produce high fire intensity to the soil and stumps and also tall flames. This also suggests that post-fire regeneration could be related to pre-fire vegetation variability (e.g. variability of fuel loads).

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