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EFFECT OF THINNING AND POST-FIRE REGENERATION AGE ON GROWTH AND REPRODUCTIVE TRAITS OF *PINUS HALEPENSIS* FORESTS

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Abstract

Post-fire regeneration of Pinus halepensis forests usually results in high density stands, where thinning is recommended to prevent the occurrence of new fires and to ameliorate the forest structure. We studied the effects of thinning and the age of post-fire regeneration (10, 18 and 22 years) on the growth and main reproductive traits of Pinus halepensis trees. Thinning enhanced the growth of trees, the number of reproductive pines and the number of new cones produced per tree. However, thinning also increased the opening of some serotinous cones in the older stands (18 and 22 years). We conclude that thinning in these post-fire regenerated forests should be more strongly recommended to be conducted in younger stands (10 year-old, in our study), because thinning much shortens the non-reproductive period and largely increases the number of new cones produced, in totally serotinous individuals.

INTRODUCTION

Post-fire regeneration of Aleppo pine (*Pinus halepensis* Mill.) forests depends almost exclusively upon the presence of a canopy seed bank. After a fire event, massive liberation of seeds allows, in the absence of other co-occurring disturbances, a successful natural regeneration and the maintenance of the dominance of this species at the community level [13, 2]. However, a high post-fire density of seedlings may preclude tree growth and reproduction, while increasing the risk of new fire events. In case new fire events took place before the canopy seed bank has been developed, the maintenance of these Aleppo pine stands would be at risk [19, 1]. For that reason, density control (thinning) is strongly recommended both to lower the occurrence of new fires and to reduce between-tree competition, thus enhancing tree growth and reproduction [6]. The benefits of thinning in highly crowded post-fire regenerated forests have been emphasized in light of the increment of resource availability (e.g. water, N) [10, 12], Nevertheless, although the development of a canopy seed-bank is the only mechanism that can ensure the self-regeneration of these forests in case of a new fire, little attention has been paid to the effects that this practice may have in the reproductive traits [but see 7].

This study mainly aims to investigate the effects of thinning in the growth and development of the canopy seed bank of post-fire regenerated forests of *P. halepensis*. We have focused our interest in the effects of this management practice in tree growth, the onset of tree reproduction and the production of new cones, but also in the degree of serotiny. The reason for analyzing the effects of thinning in serotiny is because *P. halepensis* belongs to the group of weak or partial serotinous species [8]. Furthermore, we have analyzed the effects of thinning in forests with different regeneration ages because cone production may be affected by age but also because serotiny in *P. halepensis* has been described to vary as a function of tree age, resulting in a lower degree of serotiny in older trees [18]. Results obtained in this study may contribute to assess the impact that post-fire management practices may have in the development and retention of a canopy seed bank in obligate-seeding serotinous conifers.

MATERIAL AND METHODS

This study was carried out in the regions of Bages and Anoia (41º 45' to 42º 6' N; 1º 38' to 2º 1' E, 41º35' to 41º49' N, 1º32' to 1º46' E, Catalonia, NE Spain). This area includes three sites that were burned 22, 18 and 10 years prior to this study, being *P. halepensis* the dominant tree species before and after the fire event.

During the summer of 2003 six round plots of 10 m radius were randomly established in the three burned areas. In each plot, we randomly selected 20 pines and the following variables were measured:

basal diameter and the presence of cones. Cones were classified as new, immature, mature or serotinous [5]. Before applying the experimental treatment (thinning or control), we conducted a preliminary test to compare the number and viability of seeds contained in the mature cones of pines of the three different regeneration ages. To do this test, we randomly selected 6 mature cones outside the border of each experimental plot (18 mature cones per regeneration age class). Once in the laboratory, we measured the volume of each cone and the seeds contained were manually extracted after keeping the cones at 45ºC for 72 hours. Percentage of full seeds was calculated after cutting 30 seeds per cone. After this, we randomly selected four replicates of 25 seeds per regeneration age that were placed in Petri dishes. Seeds were immediately watered, and this was regularly repeated. We considered that a seed had germinated when its radicle could be clearly observed. The three regeneration ages did not differ in the volume of mature cones (ANOVA, F = 5.0, $p = 0.109$), the number of full seeds per cone (ANOVA, F = 2.1, $p = 0.137$) or the percentage of germination of seeds (ANOVA, F = 0.8, $p = 0.436$).

To evaluate the effect of thinning on the growth and reproduction of pines, half of the established plots were thinned during 2003. Thinning consisted in a drastically reduction of tree density, namely 95-99% of pines were logged to reach an approximate density of 1000 pines ha^{-1}. In 2004, all plots were revisited and the abovementioned structural and reproductive variables were measured again. Relative growth rate (RGR) in diameter (d) was calculated as RGR = $(d_{2004}\ d_{2003})/ d_{2003}$. To evaluate the effects of the regeneration age and the experimental treatment on the reproductive characteristics of the pines, we calculated the change in the number of reproductive pines and pines with open cones at the stand level, and the number of new cones and cones opened (mature or serotinous) per tree.

The effects of the regeneration age (F82, F86, F94), experimental treatment (control, thinning) and plot (nested within treatment) on the growth and reproductive characteristics of pines were analyzed by ANOVA models. In the analysis for the effects on the number of open cones we included the number of closed cones as a covariate.

RESULTS

Relative growth in diameter varied with the regeneration age of pines and with the experimental treatment applied (ANOVA, F = 42.9, $p = 0.001$). As shown in Figure 2, pines in the 10-year and 22-year thinned plots showed higher growth rates than those in the control (unthinned) treatment, while 18-year pines showed no differences.

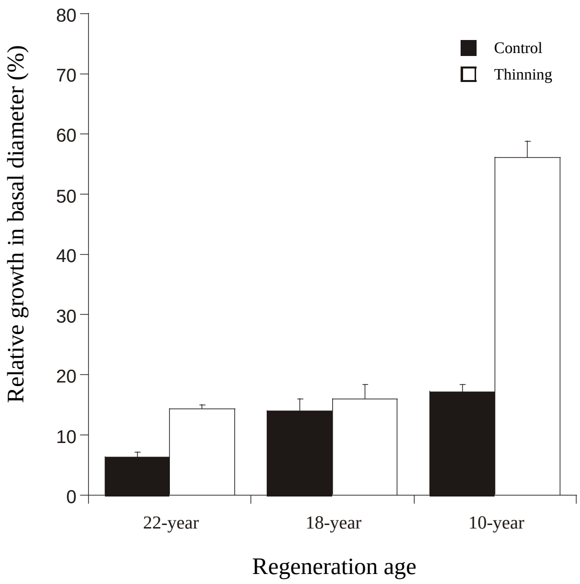

Fig. 1. Mean ±SE of the relative growth in diameter in thinned and un-thinned plots of three post-fire regeneration ages (22, 18 and 10-year).

Thinning increased the number of reproductive pines in all the regeneration ages studied (ANOVA, F = 10.3, $p = 0.0001$). During the experiment, the number of pines that produced new cones increased by 51% in the thinned stands and by 13 % in the control plots. Moreover, thinning increased the mean number of new cones produced per pine (ANOVA, F = 2.4, $p = 0.013$). Yet, the interaction of regeneration age and treatment indicated that this effect was much higher in the 10 and 22 year plots in comparison to the 18-year ones (Figure 2).

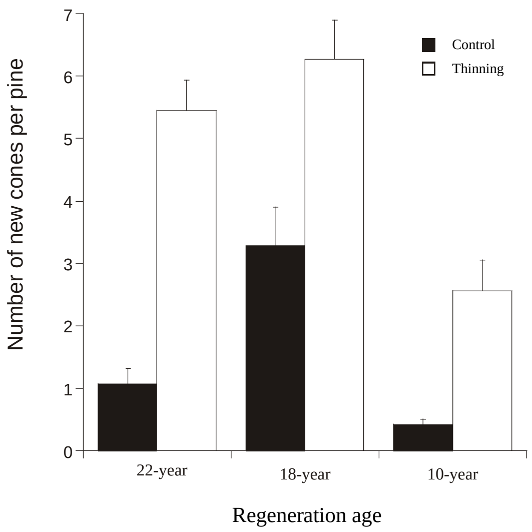

Fig. 2. Mean ±SE of the number of new cones per pine in thinned and un-thinned plots of three post-fire regeneration ages (22, 18 and 10-year).

During the experiment, the number of pines bearing open cones did not change in the control plots of all regeneration ages nor in the thinned plots of the youngest stands (10-year). In contrast, a significant increase (ANOVA, F = 7.9, $p = 0.0063$) was observed in the thinned stands of 18-year (6.7±4.0%) and 22-year (0.8±0.8%). Mean number of mature cones opened during the study period was neither affected by the regeneration age, the treatment, nor by the number of closed cones present in the tree. Conversely, the number of serotinous cones opened was positively related, although moderate, with the number of serotinous cones per tree (r^2=0.216 p>0.0001). Moreover, the number of serotinous cones opened increased significantly (ANOVA, F = 5.4, $p = 0.0043$) in the thinned plots (1.0 ± 0.2 cones pine $^{-1}$) in comparison to the control ones (0.6 ± 0.2 cones pine $^{-1}$)

DISCUSSION

Thinning strongly increased the growth in diameter of pines in the 10 and 22 year plots, the two forest areas with a higher initial density, while the effects were less clear in the 18 year forest. Reduction in tree density, through selective clear cutting, in young pine stands has been demonstrated to increase the availability of resources and thus enhance tree growth [4, 7].

Concerning tree reproduction, our results confirm the early production of an abundant crop of cones with viable seeds in *P. halepensis* at a very early post-fire regeneration age (10 years) [see also 18]. Moreover, these young regenerated forests have similar characteristics, in terms of number of seeds per cone and germination potential, to that of older stands (18 and 22 years).

In all regeneration ages, thinning increased the number of reproductive pines, and the number of new cones produced per pine (between two- and six-fold compared to control plots). This enhancement in tree reproduction after thinning has been suggested to be caused by a higher availability of resources (e.g. water, nutrients) and/or by the more direct exposition of tree crowns to light, and pollination [9, 3]. Moreover, the higher production of cones in thinned plots in comparison to the control ones can be expected to keep increasing in the mid term because of the larger number of reproductive pines present in the thinned plots but also due to the better growth of trees in this treatment [see also 17].

In the older forests (18 and 22 years) our results show that thinning may induce, to some extent, the opening of some serotinous cones. Cone opening in pines has been argued to be driven by a gradient of moisture between scales and the ambient air [14]. A greater presence of resin and other anatomical differences in the scales of serotinous cones [11] defers this process. In our case, the greater exposure of the crowns of residual trees in the thinned plots to higher light levels, temperature and changes in air humidity could promote the opening of some serotinous cones, suggesting that this process in *P. halepensis* cannot be necessarily mediated by extreme environmental conditions, but also by local environmental changes at tree level [14]. The number of serotinous cones opened increased significantly, but only moderately, with the number of such cones per tree. The weakness of this relationship stresses the large variability in the degree of serotiny exhibited by *P. halepensis* both at individual and population level [5, 16].

Seed release from serotinous cones in the thinned stands could be seen to have both positive and negative effects. On the one hand, opening of these cones in the absence of fire has been suggested to be a means to exploiting favourable environmental conditions for dispersal, providing new establishment opportunities, and resulting in the possible enlargement of the distribution area [15]. On the other hand, it must be noticed that seed release from serotinous cones could deplete the size of the canopy seed bank, having negative consequences in the case that a new fire event occurs. Nevertheless, the recorded high production of new cones in the thinned stands would, in a short term, largely compensate the number of serotinous cones opened, especially in the highly serotinous 10 year stands.

CONCLUSION

Our results show the benefits that thinning in dense post-fire regenerated *P. halepensis* forests can have in terms of growth and some crucial reproductive processes, namely: an increase in the number of reproductive pines and in the number of new cones produced per pine. Although we have recorded that thinning may induce the opening of some serotinous cones in pines of medium-aged stands, this process seems to be largely compensated by the important increase in the production of new cones in the same individuals. Notwithstanding this compensation, we conclude that thinning should be more strongly recommended to be conducted in the younger stands. On the one hand, thinning at this age is probably cheaper and more easily performed, with a much more reduced volume of residues to be destroyed [7]. On the other hand, our results show that, having this young stands (10 year) a similar seed potential germination and a higher degree of serotiny than older ones, thinning much shortens the non-reproductive period and largely increases the production of new cones.

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