Quality site and silvicultural treatments influence in *Pinus halepensis* Mill. regenerated post-fire[1]

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Abstract

Aleppo pine trees are not only the most dominant evergreens in the Mediterranean basin and eastern Spain but also the most susceptible to forest fires. The growth, reproductive dynamics, and health status of these trees after a fire seem to be related to the foliar nutrient concentration, which in turn, might be the result of a complex interaction between soil nutrients and the effective availability caused by the climate, water, site, density, and silvicultural treatment effects. Thinning has proved to be an efficient practice to improve the growth in young post-fire forest stands.

This study examines the effects of several silvicultural treatments on Pinus halepensis Mill. growth and reproductive capability at two different sites in SE Spain, each of which has a different quality site (dry and semiarid ombroclimates). For the purpose of the study, monitored plots (10x15 m.) employed two thinning intensities (1600 and 800 trees ha $^{-1)}$ and pruning at both stations; also, untreated areas have been considered where control plots were delimited. Silvicultural treatments were applied five and ten years into the post-fire regeneration. The temporal-scaled treatments included: control plots, five-year treated plots, ten-year treated plots, and five- and ten-year consecutive treatments in plot.

Results show a significant influence from thinning and quality site on growth parameters and cone production, germination percentages, and advanced progression of the reproductive phase. Therefore, intensive thinning is advised (800 trees ha $^{-1)}$ to improve health status and stimulate the reproductive phase. Furthermore, the canopy seed bank stored in thinned plots was high enough to ensure post-fire persistence.

Key words: *Aleppo pine, post-fire, reproductive dynamics, serotiny, thinning.*

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Introduction

Fire is considered as one of the major ecological factors in the Mediterranean Basin. In the Mediterranean environment, Aleppo pine's marked drought resistance is especially important and the provenances from less xeric sites displayed the strategy typical of drought tolerant species. *P. halepensis* is a Mediterranean serotinous wind-dispersed tree, which strategies are based on sexual reproduction and seed development and the post-fire regeneration depends totally upon its canopy-stored seed bank.

Large amount of studies about Aleppo pine showed that growth, reproductive dynamics and health status of these trees after fire seem to be related to the foliar nutrient concentration, the climate, water availability, site, density and silvicultural treatment (Gonzalez-Ochoa and others, 2004; Verkaik and Espelta, 2006). Early flowering is necessary for successful post-fire colonization, according to several studies and it is proved that early silviculture treatments (to get lower densities) accelerate flowering and cone production, also a higher serotiny rank so are promoting to increase the seed storage canopy bank (De las Heras and others, 2004, 2007) since soil seed bank is negligible (Daskalakou and Thanos, 1996; Ferrandis and others, 2004)

The significance of *P. halepensis* forests and the increase of the number of fires and burnt surface in Spain, make necessary to design an appropriate forest management during the early stages of the pine regeneration. In the present study, effects on different silviculture treatments carried out 5 and 10 years after great fires, on the reproduction of 11 years old pine stands are given in order to give an adequate tool for foresters.

Material and methods

Study Site

This study examines the effect of several silvicultural treatments on *Pinus halepensis* Mill. growth and reproductive capability at two different localities in SE Spain. The first locality is Yeste (YES), affected by a great fire in August 1994 (14,000 ha burned) and it is set in the dry ombroclimate. The other locality is Calasparra (CAL), also affected by other great fire (30,000 ha) occurred in August 1994, and it is set in a semiarid ombroclimate. Five years after the fires, 21 permanent plots (10 m x 15 m) were set in each locality, in places with a high and dense pine regeneration (>15.000 ind/m2) and ecologically homogeneous(Corona and others,1998).

In July 1999, the experimental plots were set in each study site in order to conduct different silvicultural treatments (t: thinning to a density of 800 trees ha $^{-1}$; T: thinning up to 1,600 trees ha $^{-1}$; P: pruning (up to the half of the tree size); T+P a combination of pruning plus thinning up to 1,600 trees ha $^{-1}$). After five years (autumn 2004), silvicultural treatments were carried out again to get 3 situations: a)plots treated in 1999, b) plots treated in 2004(T´(control to 1600 trees ha^{-1}), t´(control to 800 trees Ha^{-1})) and c) plots treated consecutively in 1999 and 2004(T+t´+p´: first thinning to 1600 trees Ha^{-1} and second thinning to 800 trees Ha^{-1} and T+p´ :prune in T plots).

Local tree density (D_{FINAL}) was estimated for each plot by counting the total number of trees. Tree height (H) and trunk diameter at 20-30 cm height from base (D) were recorded for each sampled tree. All female strobili (cones younger than one year old) were counted in each selected pine. Brown or mature (cones are two to three years old), grey or serotinous (was four years old or older) and opened cones were tagged and counted (Moya and others, in press).

A soil sample to record number of sound seeds in soil was carried out for every plot in both localities. Four sub-samples (2,5 cm depth) was conforming each soil simple. Subsamples were got digging 10 cm^2 and carrying it in bags to laboratory. Soil samples were sieved and carefully inspected for pine seeds. To avoid mistakes, seed were scrutinized in white light to insure species (Daskalakou and Thanos, 1996). Seeds was dissected and observed to classificate them in sound or unsound seeds (checking healthy embryo tissues). Number of sounds seeds was recorded.

Six mature serotinous cones were collected from trees outside the experimental plot. Once in the laboratory, the volume of each cone was measured by immersing cones in water in a test tube (accuracy 0.01 mm^3). Sample cones were kept in boiling water for one minute and then left in a heater at 45ºC for 48 hours in order to open them. Seeds were manually extracted and counted for each cone.

The percentage of sound and unsound seeds was calculated by cutting 50 seeds per cone and viability was calculated applying the Tetrazolium method to the sound seeds. Four replicates of 25 seeds each were randomly selected for each cone type (mature and serotinous) and placed in petri dishes. The seeds were continuously watered to maintain the required humidity level. The germinators were kept in a germination chamber at a constant temperature of 20 ±0.5 ºC with a 14-h photoperiod. Germination (seeds with a geotropic radicle longer than 2 mm) was recorded every 2-3 days for 35 days. A record was kept of germinated seeds and these were removed.

Aerial seed bank density was defined as the number of viable seeds per hectare. The number of seeds per cone was defined as the average number of sound seeds contained in each cone and was calculated by multiplying the average number of seeds per cone and the percentage of sound seeds (Goubitz, 2004).

Statistical Analysis

For all statistical analyses, data were transformed using the log or √arcsine transformation to meet the assumptions of normality and homoscedasticity. Tables and figures present untransformed data and standard error of the mean (±SE). A One-Way ANOVA was used to test differences. Fisher´s Least Significant Difference (LSD) procedure was used to compare mean values. Influential variables for study characteristics and cone parameters were analysed by stepwise multiple regression. All statistical analyses were conducted using a critical p-value ≤ 0.05.

Results

Growth parameters considered in the study were diameter and height of trees (Table 1). Higher results were obtained in YES (values ranged from 147,51 to 229,77 cm), the best site quality, than CAL (ranging values from 108,96 to 131,50 cm). Comparing results obtained in each locality lowest values in control plots were found for both parameters.

In YES, we found that intensive thinning carried out in a five years old stand was significantly higher than others silvicultural parameters as much tree height (229,77±27,00 cm) as tree diameter (7,56±0,39 cm). Also intensive thinning plus prune plots in ten years old stands showed higher tree height and high tree diameters.

For CAL locality intensive thinning in ten years old stand showed higher height and diameter (131,50±21,27 and 2,35±0,46 cm, respectively). Also combined treatments, soft thinning at five years old and final density to 800 tree ha^{-1} plus prune in ten years old stands, produced higher significant diameter group and high tree height.

Table 1— *Growth measurements. YES: Yeste; CAL: Calasparra. Treatment acronyms are detailed above. $D_{FINAL:}$ tree density (tree ha^{-1}); D: averaged diameter (cm); H: averaged height(cm).Small letters indicates significant different groups, obtained by LSD method, p<0,05.*

		YES		CAL	
TREATMENT	**$D_{FINAL:}$**	**H**	**D**	**H**	**D**
C	>10000	$147,51±4,33^{d}$	$3,47±0,20^{d}$	$108,96±9,35^{c}$	$1,64±0,11^{c}$
T	1600	$165,49±5,13^{c}$	$4,66±0,15^{c}$	$117,01±7,16^{b}$	$2,54±0,10^{a}$
T+P	1600	$173,35±14,31^{c}$	$4,89±0,74^{c}$	$105,33±3,93^{c}$	$2,09±0,04^{b}$
T+p´	1600	$209,28±18,30^{a}$	$5,77±0,34^{b}$	$116,56±9,03^{b}$	$2,66±0,22^{a}$
T´	1600	$188,08±18,70^{b}$	$4,76±0,54^{c}$	$122,02±7,96^{b}$	$2,32±0,37^{a}$
T´+p´	1600	$183,07±2,27^{b}$	$4,21±0,14^{c}$	$105,26±5,54^{c}$	$1,85±0,07^{b}$
T+t´+p´	800	$208,97±11,89^{a}$	$6,03±0,33^{b}$	$118,69±9,26^{b}$	$2,53±0,03^{a}$
t´	800	$185,73±7,00^{b}$	$3,76±0,13^{c}$	$131,50±21,27^{a}$	$2,35±0,46^{a}$
t´+p´	800	$221,92±10,25^{a}$	$5,80±0,34^{b}$		
t	800	$229,77±27,00^{a}$	$7,56±0,39^{a}$		

Seed bank was estimated in the studied localities (Figure 1). Thinning intensity was taken into account to calculate soil seed bank. No significant differences were found and the number of sound seeds (seed plot^{-1}) was very low in each taken sample. Silvicultural treatments were increasing soil seed bank but finally it was negligible.

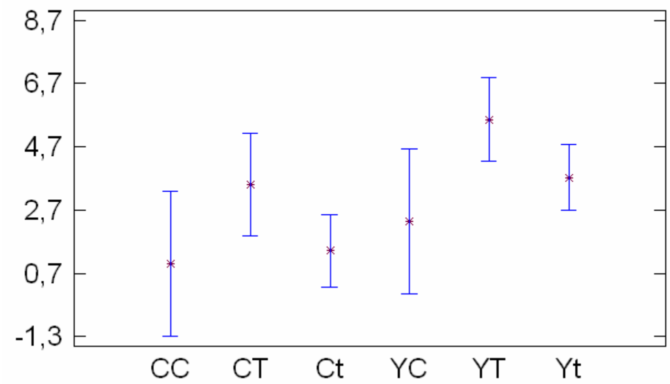

Figure 1—Soil seed bank accumulated in both localities, values was averaged by thinning intensity. Values are mean number of seeds m^{-2}. No significant differences were found.

Also canopy stored seed bank was recorded (Figure 2) and seeds from serotinous cones were annotated to asses influence in the total canopy seed bank of the current year(seed contained in mature and serotinous cones). Averaged number of stored seed per ha showed significant differences for localities. In higher site quality number of retained seeds was higher. In CAL locality, no significant differences were found for silvicutural treatments although, high intensity thinning carried out at ten years old and soft intensity plus recent prune were quantitative higher (22437 and 30632 seed ha^{-1} respectively). High intensity thinning carried out at ten years old and soft intensity plus recent prune was significantly the highest values in YES (262985 and 161487 seed ha^{-1} respectively). Other treatments were also significantly higher than control (without thinning).

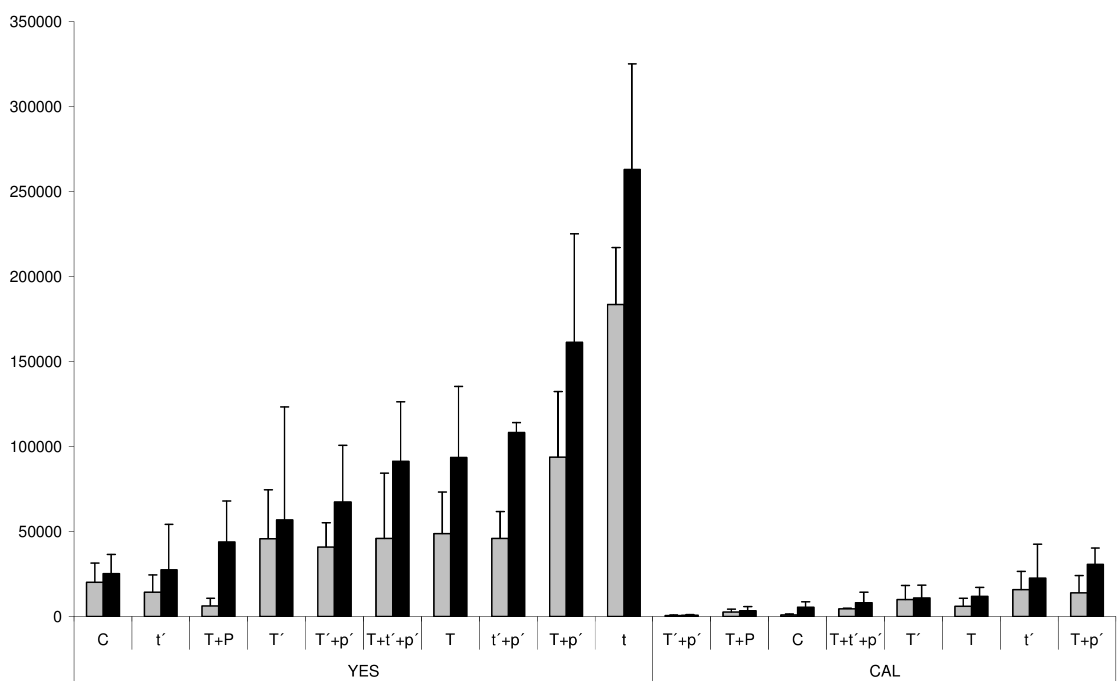

Figure 2—Canopy seed bank accumulated in both localities. Grey bars: seed enclosed in serotinous cones; Black bars: canopy seed bank storage in current year; Mean values was averaged by thinning intensity (seed ha^{-1}).

Discussion

The best quality site (YES) promotes a higher height and diameter growth without treatments. Considering silvicultural treatments is important to notice how density values were influencing the studied parameters. The results were showing a higher height and diameter growth for the thinned plots. This result was more important in the five years treated plots. This is due to the intraespecific competence decreasing what induce to a higher light exposition and higher water and nutrients availability. The increase for the ten years treated plots is lower due to the short term from treatments to measurements (De las Heras and others, 2004, Lopez-Serrano and others, 2006).

In general, seed germination reached lower values in Calasparra than in Yeste, although no significant differences were recorded among treatments. Ungerminated seeds viability did not present significant differences among treatments in Calasparra and showed lower percentage values than in Yeste (data not showed). It is known that isolated trees have and good resources availability (especially water and N) promotes early flowering and higher number and healthy cone production (Gonzalez-Ochoa and others, 2004). Those parameters could be obtained decreasing density throughout thinning (De las Heras and others, 204, 2006; Lopez-Serrano and others, 2005).

Soil seed bank was negligible for both sites meanwhile canopy seed bank was, in general, too high to insure natural regeneration (Thanos&Daskalakou, 2000; Tapias and others, 2001). In Yeste a high amount of viable seed was recorded for the canopy seed bank especially in control and thinned plots to 800 trees ha^{-1} .

In conclusion, Mediterranean areas where Pinus halepensis Mill. is not close to the tolerance limit, for natural regenerated post-fire young stands is advisable to carry out silvicultural treatments, thinning, to promote early flowering and improve growth, cone production and obtain a canopy storage seed bank to insure natural regeneration post-fire, whenever the optimal weather conditions required be held. For areas that were close to lower tolerance limit is necessary to study other parameters as biodiversity, soil loss risk, etc.

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