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Regenerating mature Aleppo pine stands in fire-free conditions: Site preparation treatments matter

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ABSTRACT

Aleppo pine is the most widespread pine species around the Mediterranean Basin. Its post-fire recruitment has been studied in depth, but regeneration of mature stands in fire-free conditions has received considerably less attention. This study examines the impact of different site preparation treatments on pine recruitment using three experimental mature stands along a gradient of site fertility in southeastern France. The stands were partially felled and subjected to the following treatments replicated four times on each site: mechanical chopping (all sites), chopping followed by single soil scarification (all sites) or double scarification (2 sites), controlled fire of low intensity (2 sites) or of high intensity (1 site) and control (all sites). In addition, the influence of slash, either left on the soil or removed before treatments, was tested for the single scarification treatment on two of the sites. Pine regeneration was counted and soil cover conditions described at different time intervals: 1–6 years after the end of the treatments for two sites and 1–16 years for one site. Seedling dimensions were determined during the last count. Mean seedling densities after 6–9 years (0.57–1.06 pines/m^2) were comparable to those found in post-fire conditions, although with a narrower range. Pine density was negligible in the control, while chopping followed by a single soil scarification emerged as the most favourable treatment tested in the three sites on seedling density (0.74–1.54 pines/m^2 after 6–9 years) and seedling growth. For this treatment, the amount of slash had a contrasting influence on pine density according to site conditions. Double scarification did not affect pine density. Controlled high intensity fire, due to slash presence, was very favourable for pine regeneration (2.35 pines/m^2), although this treatment was only tested at one site. Lastly, we found low pine densities in the chopping and low-intensity controlled fire treatments (0.20–0.56 pines/m^2). Variation in herb cover was a major factor influencing pine recruitment. This study emphasises the need for adapted site preparation treatments to regenerate mature pine stands in southern Europe.

1. Introduction

Plant recruitment is a key phase in plant population and community dynamics (Nathan and Ne'eman, 2004), particularly in forest ecosystems, and foresters have devoted much effort to obtaining natural regeneration in ageing stands. However, regeneration of mature stands is challenging in the Mediterranean forests due essentially to limitations of seed and seedling establishment (e.g. Acácio et al., 2007; Mendoza et al., 2009; Smit et al., 2009), driven mainly by abiotic constraints such as drought (Castro et al., 2004), but also by high pressure from herbivores (Baraza et al., 2006) and sometimes inappropriate management techniques (Pulido et al., 2001).

In this study we examined the influence of different types of silvicultural treatments on Aleppo pine (*Pinus halepensis*) recruitment in various environmental conditions. *P. halepensis* (subsp. *halepensis* and *brutia*) is the most widespread coniferous species in the Mediterranean area, covering some 6.8 million hectares in the Mediterranean Basin (Barbéro et al., 1998). This pine exhibits a dual life history strategy characterised by its efficiency in exploiting new establishment opportunities generated by various disturbances in the absence or in the presence of fire (Ne'eman et al., 2004). Its capacity to colonise disturbed sites in fire-free conditions is illustrated by the fast expansion of this species after land abandonment in southern France – from 135,000 to 250,000 ha in less than five decades – and its ability to invade unburned disturbed areas in the southern hemisphere (Richardson, 2000). After a fire, recruitment of Aleppo pine, like other post-fire regenerating serotinous pines, is generally profuse though variable (Pausas et al.,

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2004a) and has been studied in depth (e.g. Trabaud et al., 1985, Daskalakou and Thanos, 1996, Arianoutsou and Ne'eman, 2000). In contrast, in the absence of fire, seedlings rarely establish beneath pine canopy and various explanations have been suggested such as light limitation, seed predation, needle layer effect (Arianoutsou and Ne'eman, 2000; Nathan and Ne'eman, 2004). Some studies performed on *Pinus pinaster*, another European Mediterranean pine with similar ecological traits, also showed the importance of percentage of litter cover on natural regeneration (Rodríguez-García et al., 2010) as well as the influence of coarse woody debris on post-fire recruitment (Castro et al., 2011). As no clear single key factor has been put forward to explain lack of regeneration of Aleppo pine in fire-free conditions, recruitment has been depicted as fairly unpredictable (Nathan and Ne'eman, 2004). In the course of succession in mesic or sub-humid areas, Aleppo pine is progressively replaced by hardwood species, mostly oaks such as *Quercus ilex* and *Quercus pubescens*, leading first to mixed stands and then to pure oak stands (Barbéro et al., 1998; Zavala et al., 2000). Therefore, in the absence of external disturbances, elimination of the Aleppo pine is likely to occur over the long term. However, maintaining Aleppo pine, in pure or mixed stands, is of importance for forest managers for both economic and ecological reasons. In productive areas with low fire risk, managers can target forest production by favouring pines, whereas in more fire-prone landscapes, pines and hardwood species (especially oaks) can be combined to take advantage of the faster growth of pines and the high resprouting capacity of oaks for fire resilience (Pausas et al., 2004b).

Like other pine species, regeneration of Aleppo pine is challenging in fire-free conditions and previous studies in natural coniferous mature stands of the temperate and boreal zones have shown that successful recruitment, early growth and survival can be strongly influenced by soil preparation and ground vegetation control treatments (e.g. see reviews by Balandier et al., 2006 and Wiensczyk et al., 2011). However, experiments testing impacts of such treatments in coniferous Mediterranean stands are scant (Prévosto and Ripert, 2008), even though silvicultural treatments may gain importance in the future for ensuring regeneration under climatic changes (Scarascia-Mugnozza et al., 2000; Spiecker, 2003).

In a previous field experiment, we showed that adapted site preparation treatments could have positive effects on pine regeneration over a short period after treatment application (Prévosto and Ripert, 2008). In this study, we sought to determine whether these first results held over a longer period of observation, and how variations in soil and climatic site conditions could influence seedling establishment, by integrating the results of two other field experimental sites. More specifically, our objectives were (i) to determine the impacts of vegetation and soil treatments on pine regeneration including emergence, survival and growth and (ii) to explain how these treatments determined soil cover conditions, which in turn influence pine recruitment.

2. Materials and methods

2.1. Site description

Three experimental sites located in southern France (Fig. 1) were selected along a gradient of soil fertility. The first and least productive site (Barbentane) is located on a gentle north-facing slope (altitude 105 m) and has a meso-Mediterranean climate characterised by a dry, hot summer. Mean annual rainfall, computed over the period 1961–1996, is 673 mm and the mean annual temperature is 14 °C (Table 1). Soils are shallow calcareous, 10–20 cm deep, with a heavy stone load. The vegetation is dominated by a mature 90–100-year-old Aleppo pine forest (dominant height 12 m) with a weakly developed shrub layer composed of *Buxus sempervirens*, *Quercus ilex* and *Quercus coccifera*. *Brachypodium retusum* is the most abundant species in the herbaceous layer.

The second site (Saint-Cannat, altitude 245 m) lays on a flat area with a climate comparable to that of the first site: mean rainfall 620 mm and mean temperature 13.3 °C. Soils are also calcareous but deeper (30 cm) than in the first site and the limestone bedrock is more fractured. These features, plus the fact that the area had been cultivated in the past, give a higher soil fertility than in Barbentane. The vegetation is composed of a 60–90-year-old Aleppo pine tree layer (dominant height 15 m), a developed shrub layer dominated by *Q. coccifera* and secondarily by *Ulex parviflorus* and *Phillyrea angustifolia* and a sparse herbaceous layer.

The third site (Vaison-la-Romaine, hereafter Vaison, altitude 300 m) is located on a gentle northeast-facing slope further north than the two previous sites. The climate is wetter (mean rainfall 761 mm) and colder (mean temperature 12.3 °C). Soils are also deeper (30–50 cm), the bedrock being composed of a micritic limestone. A mature 70–90-year-old Aleppo pine stand (dominant height 16 m) forms the upper tree layer, the subcanopy layer was well developed and dominated by *Q. pubescens* and *Q. ilex*, and the herbaceous layer was composed mainly of *Brachypodium phoenicoides*.

2.2. Treatments and experimental design

The three sites were all partially felled (regeneration cut) before treatment application during winter 2004–2005 for Barbentane, winter 2002–2003 for Vaison and winter 1990–1991 for Saint-Cannat (Table 1). The basal areas remaining after the cuts were respectively 12, 10 and 9.5 m^2/ha for Barbentane, Saint-Cannat and Vaison. Timber was removed in all sites, but logging slash, mainly composed of tree canopy branches, were either left on the ground (noted hereafter _S1) or removed (noted _S0) depending on sites and treatments (see below).

2.2.1. Barbentane

Treatments were applied during winter and early spring 2005. A complete description of all the treatments applied in this site is available in Prévosto and Ripert (2008). We recall below the main characteristics of the seven treatments used in this study. They consisted in (Table 2):

(i) Ground vegetation chopping: this mechanical treatment reduces all branches, shrubs and wood pieces up to 15 cm to small fragments; it was performed in the presence of slash (CHOP_S1).
(ii) Chopping followed by scarification of the soil in one direction in the presence of slash (SCA_S1).
(iii) Chopping followed by scarification of the soil in one direction with slash removed beforehand (SCA1_S0).
(iv) Chopping followed by scarification in two perpendicular directions with slash left (SCA2_S1).
(v) Controlled intense fire in the presence of slash, leaving only ashes on the soil (FIRE_S1).
(vi) Controlled fire of low intensity without slash, ground vegetation and litter being only partially burned (FIRE_S0).
(vii) Control: no treatment applied (CONT).

Treatments were applied on 200 m^2 plots and replicated four times using four 2800 m^2 blocks (one block included all the treatments).