Increasing resistance and resilience of Mediterranean conifer forests: the experience of Spain and France and their implications for management

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Increasing resistance and resilience of Mediterranean conifer forests: the experience of Spain and France and their implications for management.

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Abstract

Management strategies, using thinning combined or not combined with underplanting, have been tested in experimental forests of Spain and southern France to promote growth, recruitment and increase their resilience.
In dry and fire-prone areas of southern Spain and France, *Pinus halepensis* forests were thinned at different levels and hardwood species were introduced under pine canopy and in opened areas. Thinning activities increased light, modified microclimate and soil moisture availability. Growth was improved in all sites but survival showed a more contrasted response. In mountainous areas, thinning treatments applied on *Abies alba* forests of southern France and *Pinus nigra* forests of central Spain were tested. Thinned silver fir stands showed higher tree growth than the control stands. In black pine forests, maximal seedling emergence was found for high basal area values whereas survival and growth were the highest for lower values.
Despite strong site differences, thinning to a basal area around 15-20 m^2/ha appeared to be a good compromise to promote growth of the residual stand and recruitment. In fire-prone areas, thinning, alone or combined thinning with the introduction of resprouting hardwood species, is an efficient technique but has to be adapted to site conditions and species under focus. Finally, we discussed usual thinning limitations and options of remediation in the light of the new opportunity opened by the increasing demand in forest biomass.

Keywords: thinning, stand management, recruitment, resprouting species, growth

Introduction

Climate change projections in the Mediterranean region tend to indicate longer drought periods, heat waves, more severe fire regime, more frequent pest outbreaks (Lindner *et al.* 2010) putting at risk numerous ecosystem services (Schorer *et al.* 2005). Moreover, forest productivity is susceptible to be reduced while increase rates of mortality could be observed (Spittlehouse 2005). This uncertainty in the future of forest development and production is reinforced by an increasing demand in wood products, more specifically in wood biomass as a substitute to fossil fuel.
To respond to these apparently contradictory constraints, managers will be challenged to develop adaptation strategies. A possible option of managements is to promote forest resilience: forests can not only accommodate to climate change and related disturbances but are able to return toward a prior

condition either naturally or with management assistance (Stephens *et al.* 2010). This is a good option for Mediterranean forests in the drier regions and submitted to increasing fire risk. Another option is to manage forest ecosystems so that they are better able to withstand the impacts of climate change (*e.g.* drought periods, insect attacks) or to anticipate undesired effects of climate change.
In this paper we explore how modifications of reduction of tree density through thinning practices may represent a proactive management option to promote resistance or resilience of forest systems and also to satisfy demand in wood products or biomass. We focus on Mediterranean monospecific conifer forests which cover huge areas and developed either naturally (like in southern France) or from an afforestation effort (central and southern Spain for instance). Based on field experiments established in contrasted site conditions and for different pine species, we more particularly addressed the following questions:

-What is the impact of reduced tree density on residual stand growth and recruitment in conifer forests (*Pinus nigra* and *Abies alba)* developed in mountainous areas?

-Is thinning followed by planting of resprouting hardwood species a valuable technique to promote resilience in *Pinus halepensis* forests in dry and fire-prone areas?

Methodology

Sites description and experiments

Five experimental sites were installed in adult monospecific conifer forests: three in dry and fire-prone areas (St Mitre, Ayora and Palencia) and two in mountainous and more temperate areas (Cuenca and Comefroide, Fig. 1).

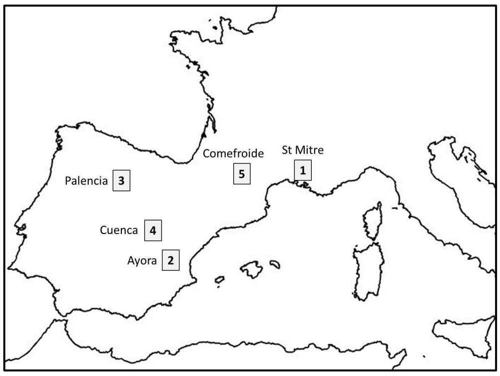

Fig.1. Location of the five experimental sites.

In sites of St Mitre (SE France), Ayora (SE Spain) and Palencia (NE Spain), the objective was to study the influence of Aleppo pine overstorey cover on seedlings establishment and development.
In St Mitre and Ayora, stands were thinned at two levels or left uncut leading to 3 basal area treatments: high (no thinning, G=32 m^2/ha), medium (G=12-19 m^2/ha) or low (G=8-10 m^2/ha). Each treatment included 3 plots (625-900 m^2) in which 6 different hardwood species were underplanted (Fig. 2A) or sown in 2007-2010 (minimum 15 seedlings/plot). All plots were fenced to prevent any damage by wild animals. On the contrary, in Palencia direct acorn seeding was tested under heavy wildlife acorn predation (rodents and wild boar). Acorns were introduced beneath pine stands thinned at 20m^2/ha or in open conditions using 3 protection treatments: no protection (control), protection of the seed against rodents using a simple wire 20cm×20cm mesh plate (Prévosto *et al.* 2015) and, protection of the seed and the seedling against rodents and large herbivores and wild boards using a specifically designed wire mesh cylinder (Reque and Martin 2015, see Fig. 2B). The experimental treatments were replicated in a split-plot design across six units (blocks). Each of the six units contained 45 sowing points (15 for each treatment).

In Cuenca (Central Spain) and Comefroide (SE France) the objective was to analyse the influence of thinning on natural recruitment and growth of the residual stand (Fig. 2C,D). In Cuenca, 9 representative forest stands of about 0.5 ha were evenly distributed in the 3 following basal area treatments: low (15-20 m^2/ha), medium (25-30 m^2/ha) and, high (35-40 m^2/ha). A permanent plot of 7m×10m was set up in each forest stand and fenced to prevent any damages by wild animals. In each plot, six 3m×3m subplots were divided in order to have three replicates for two soil treatments: scalping (organic matter removed using a hoe from 1-2 cm of mineral soil) and control (no treatment). Each subplot was sown using *Pinus nigra* seeds collected during the natural seed-dispersion period of Spanish black pine in the Cuenca Mountains (Del Cerro *et al.* 2009). In Comefroide, thinning treatments were applied to mature silver fir forest located at the southern range of the species area distribution and endangered by climate change. Two mature stands of 1ha size were selected respectively on moderate slope or flat conditions. In each stand, two thinning treatments were applied on half of the area: reduction of the basal area from 40 m^2/ha to 20 m²/ha and (N= 400 to 200 stems/ha) or control (stand left uncut). Measurements concerned health status and radial growth of objective trees, global stand growth, undergrowth and natural regeneration development.

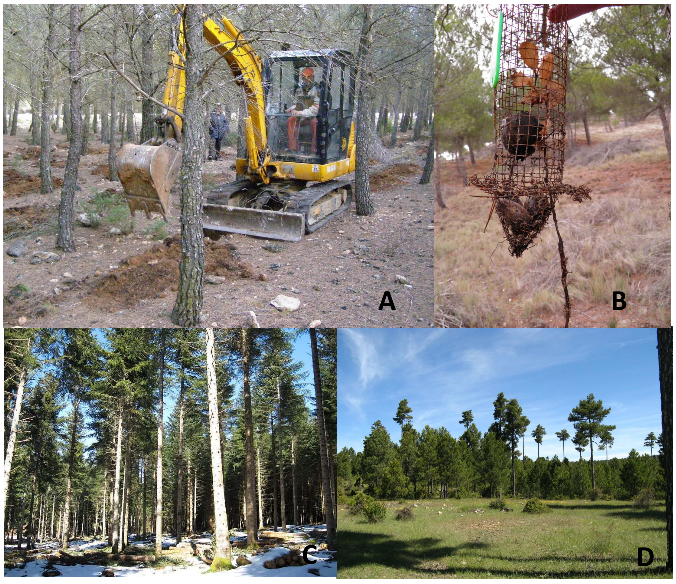

Fig.2 View of the sites and treatments A) Site preparation for planting in Aleppo pine stands in Ayora, B) Seed protector against herbivores and wild boar in Palencia, C) Silver fir stand after heavy thinning in Comefroide, D) Natural regeneration of Black pine stand before the final cutting (shelterwood system) in Cuenca Mountains.

Measurements and data analysis

In St Mitre and Ayora, seedlings survival and growth were measured yearly up to 2013. Relative growth rates in diameter and height were produced. Light transmittance was measured at both sites using PAR sensors placed beneath canopy in each plot and in open conditions. Soil moisture at 30 cm was measured throughout a growing season using TDR probes. Air temperature and air humidity were also monitored using 3-10 sensors per treatment and used to compute vapor pressure deficit (VPD). ANOVA were used to compare effects of treatments in each site on growth and microclimatic factors and log-rank test was used for survival.

In Palencia, the number of living seedlings and seedling height was censused yearly at the beginning and end of each growing season (2011-2013). Oak survival was defined as the number of established seedlings that survived the second drought period (summer 2012). Seed predator attacks were assessed monthly during the first year. General linear model procedures were used to test for differences in survival rate and height according to sowing and seed protection conditions.

In Cuenca, seed emergence, seedling survival and initial seedling growth were monitored from June-2006 to December-2009. Changes in seed emergence and seedling survival among basal area and soil treatments were tested using a repeated measurement analysis. For the analyses of initial seedling growth, we used multifactor analysis of variance (ANOVA) since seedling measurements were made on one occasion, at the end of the experiment (December 2009). In Comefroide, the monitoring of health status, including rate of leaf deficit, and individual stem circumference were measured on a sample of dominant trees, while global stand growth was evaluated through full inventories. Phytovolume and composition of the competing vegetation were measured, out of five plots of 4 m² each. Fir seedlings were also counted and measured on these plots. Data were collected at the installation of the experiment, one year later and then expected to be collected every two years for a minimum period of eight years.

Results

<u>Thinning and hardwood species introduction in fire-prone areas</u>

In St Mitre and Ayora, light transmittance increased significantly from the dense cover of uncut stands to the light cover of the heavily thinned stands at both sites (Fig. 3A). Maximum daily temperature and VPD also increased with basal area reduction, especially under summer hot conditions (data not shown). In contrast, change in soil moisture during the dry summer season was only significantly higher in the low basal area treatment at Ayora site (Fig. 3B).

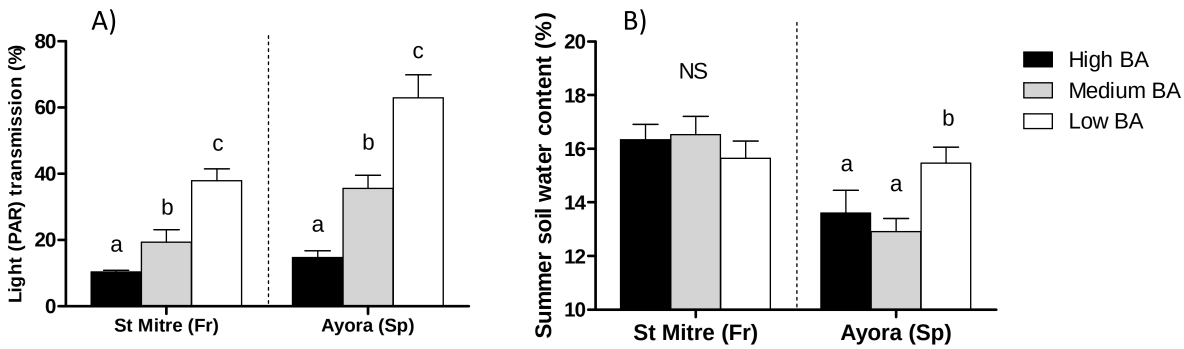

Fig. 3. St Mitre and Ayora sites, changes according to basal area treatments (high, medium or low) in: A) light transmission (mean + SE) and, B) mean soil water content in summer (mean + SE). Different letters indicate significant differences among treatments (Tukey test).

Survival and relative growth rate in base stem diameter are shown for the common 3 species planted at both sites. Survival of *Quercus ilex* and *Arbutus unedo* showed a contrasted pattern (Fig. 4A): survival was reduced in the dense stands at St Mitre but increased at Ayora whereas *Fraxinus ornus* survival was high and unaffected by the treatments. In contrast, relative growth rate in diameter was always enhanced by basal area reduction at both sites and for all species (Fig. 4B).

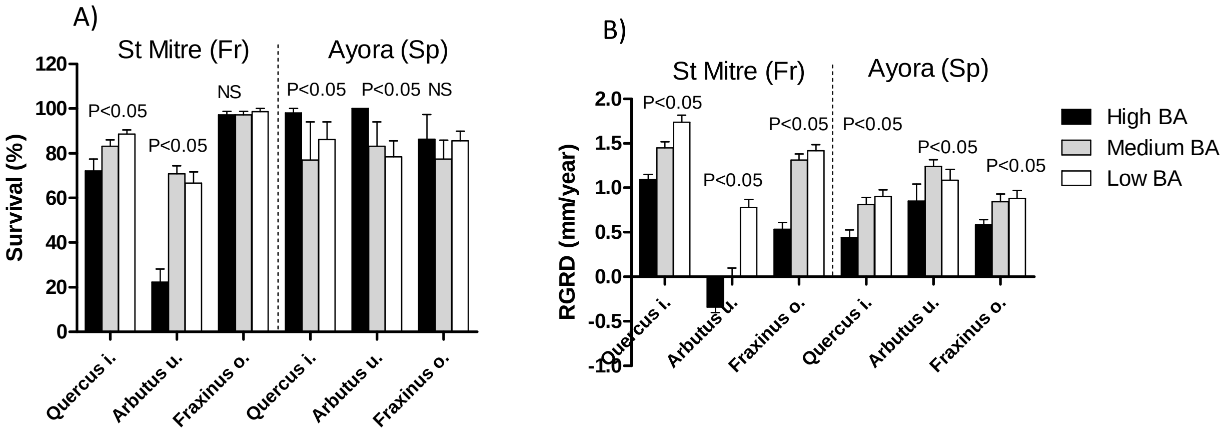

Fig. 4. St Mitre and Ayora sites. A) Survival rates according to the treatments (mean + SE) and B) Relative Growth Rate in Diameter (mean + SE) according to the treatments. Significant differences among treatments are indicated for each species at each site (NS= not significant).

In Palencia, two years after direct seeding, protected acorns reached a 77% establishment rate in underplanting and a 32% in open light. The effect of predators on acorns sown without protection (control) or protected with the wire mesh plate was severe, reaching 100% losses during the first winter after sowing under thinned forest canopy. Germination extended during the whole month of June (8 months after sowing). Oak survival was affected by protection treatment as well as by the interaction between sowing conditions and protection treatment (Fig. 5A). Protected seedlings underplanted in forest conditions (basal area of 20 m^2/ha) showed the best growth results and a 100% survival rate during the second growth period (Fig. 5B). By contrast, 56% of the one-year seedlings established in open light conditions perished during the same period.

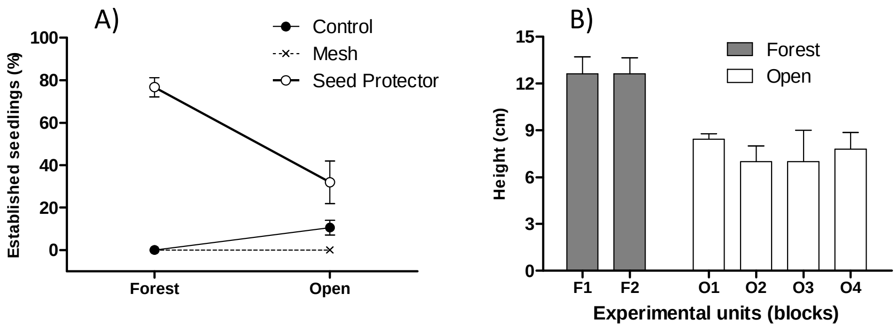

Fig. 5. Site of Palencia. A) Survival 22 months after direct seeding (mean ± SE) according to sowing conditions (forest or open conditions) and seed protection treatments. B) Height growth (mean ± SE) of 22-month-old direct seeded holm oak seedlings planted in six units (blocks) and protected with the P4 seed protector (see Fig. 2B).

<u>Influence of thinning on recruitment and growth in mountainous areas</u>

In Cuenca, Spanish black pine seed emergence was higher in medium and high basal area treatments and in scalped soil treatment than in the undisturbed control plots (Fig. 6A). In contrast, higher seedling survival percentage was obtained in lower basal area treatments in combination with scalping (Fig. 6B). Seedling dimensions were higher in low basal area treatments and the influence of soil treatment was found not significant (Fig. 7).

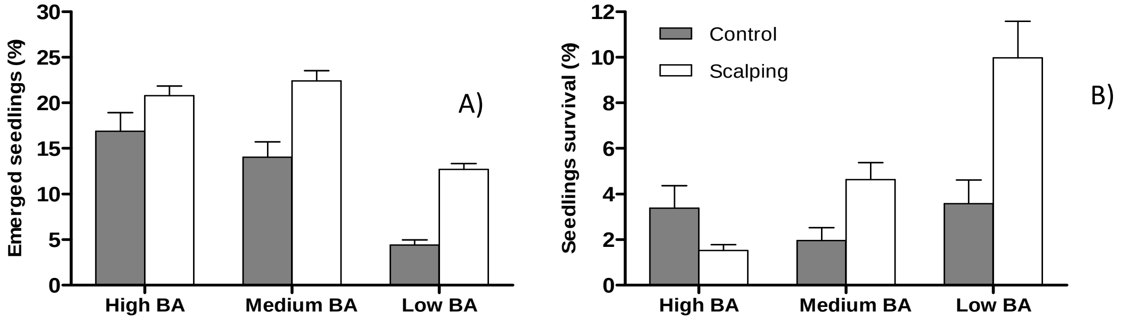

Figure 6. A) Seedling emergence (mean ± SE) and B) seedlings survival (mean ± SE) at the end of the experiment (December 2009). Values are calculated for each basal area interval (High: 35-40 m^2/ha, Medium: 25-30 m^2/ha, Low: 15-20 m^2/ha) and soil preparation treatment (Scalping and Control).

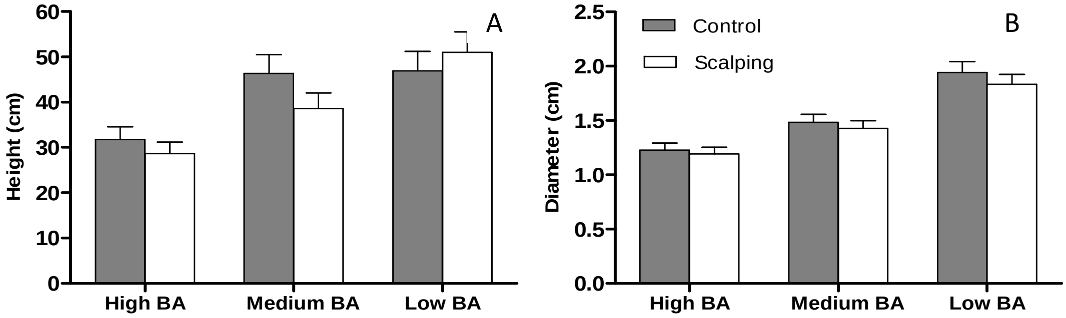

Fig. 7. Seedling dimensions: A) seedling height (mean ± SE) and B) stem basal diameter (mean ± SE). Values are calculated for each basal area interval (High BA: 35-40 m^2/ha, Medium BA: 25-30 m^2/ha, Low BA: 15-20 m^2/ha) and soil preparation treatment (Scalping and Control) at the end of the experiment (December 2009).

In Comefroide, the health status of the monitored silver fir trees has hardly changed after one year. Leaf deficit has slightly increased in both treatments, but this change was not significant. As expected, the radial growth of the remaining trees was higher in the heavy thinning treatment due to reduced competition. Undergrowth vegetation gradually restored in the heavy thinning modality after having been reduced during timber harvesting. Fir seedlings were more numerous in the control parcel but were slightly higher in the heavy thinning treatment. However, these differences were not significant and monitoring over a longer time scale is needed.

Discussion

Our work comprises various management experiences applied in different monospecific conifer forests of the Mediterranean area. Despite differences in dominant species and site conditions, some common silvicultural lessons can be shared from our results. Considering density management, in all our study sites, low to intermediate crown covers appear to be appropriate in order to increase forest stability and resilience. A surprising common value of 15-20 m^2/ha of basal area has been found as an optimum compromise between residual tree growth and regeneration achievement. In all the cases, the response of the residual stand growth to thinning was positive after this treatment.

However, regeneration establishment and survival varied between sites, differing in species composition and abundance, soil and climatic conditions. Open canopies were always beneficial to seedling growth whereas no common pattern could be found concerning seedling survival. While in the driest sites (Ayora and Palencia), seedling survival was positively related to increasing crown cover, in the more temperate sites (Cuenca and St Mitre), shaded conditions prevailing under closed canopies had negative effects. Distinct heat stress, evaporative demand, interspecific competition and contrasted behaviour in specie's autoecology may explain such differences. In fact, conflicting effects on survival and growth have been frequently documented in Mediterranean conditions (*e.g.* Marañón *et al.* 2004, Gómez-Aparicio *et al.* 2008).

Mediterranean forestry presents special characteristics related to climate, productivity, human uses and risks that limit the adoption of the common silvicultural guidelines defined for temperate forests. Our results allow us to recommend moderate to heavy thinning as a strategic conservation treatment in order to increase forest resilience and release light-limitation for seedlings growth in dense stands. In a classical temperate climate silvicultural approach, the goal of a thinning is to concentrate the site´s productivity in a reduced number of selected trees that will close canopy in a short number of years at the time a yield is harvested. An overall Hart spacing index ($S_{\%}$) between 20 to 25% is commonly recommended. In our Mediterranean conditions, and in order to increase stand resilience, we propose intermediate pine densities about 15-20m^2/ha ($S_{\%}$» 25) to boost natural recruitment and residual stand stability. Optimal conditions for seedling survival are site-specific and seem to be influenced by a trade-off between light availability and summer abiotic conditions. It is noteworthy that thinning alone sometimes does not allow a sufficient recruitment and that site treatments (*e.g.* scalping in this study) have to be achieved (Lucas-Borja *et al.* 2012, Prévosto *et al.* 2012). In sites where natural broadleaved seed supply is absent or limited, underplanting natural resprouting hardwoods appears as a viable site adapted strategy for stand´s resilience enhancement. Hardwood sowing under canopy achieves similar results with containerized planting but adapted protection is absolutely necessary due to the increasing predation exerted by herbivores and wild boars.

Carrying out thinning in Mediterranean forests have traditionally been limited due to low timber value and reduced yields. Our recommendation of intermediate post-thinning residual densities implies moderate to heavy thinning intensities that permit to achieve attractive volumes in the promissory biomass market where no specific technological timber quality is demanded. The increasing demand for renewable energetic resources opens new unknown silvicultural opportunities in Mediterranean forestry. Our experiences have been carried out in areas with limited damages due to wind storms and mostly on calcareous soils. On superficial or compact soils the risk of windthrow associated with heavy thinning has to be assessed. The resulting open canopy can promote the natural establishment of hardwood species but also of heliophilous shrubs that can lead to dangerous fuel models with horizontal and vertical fuel continuity. On the other hand, the achievement of a more diverse forest structure and species composition promotes forest resilience in dry and fire-prone areas.

Conclusions

Active management in Mediterranean conifer forests is necessary to curb the undesirable effects of climate change and to respond to increasing demand in wood products. Heavy to moderate thinning, with a residual basal area of 15-20 m^2/ha, represents a potentially beneficial compromise to promote forest resilience and resistance. In fire-prone areas, thinning can be combined with introduction of hardwood resprouting species and native species growing in similar ecological conditions should be preferentially selected. In all conditions, thinning enhances growth and natural recruitment although site treatments are sometimes necessary.

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