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Beneficial effect of pine thinning in mixed plantations through changes in the understory functional composition

Alice Nunes[a,b,*], Graça Oliveira[a], M. Salomé Cabral[c], Cristina Branquinho[a], Otília Correia[a]

[a] Centro de Biologia Ambiental, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, C2, 1749-016 Lisboa, Portugal
[b] Departamento de Biologia e CESAM, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[c] Centro de Estatística e Aplicações, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, C6, 1749-016 Lisboa, Portugal

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ABSTRACT

Areas dominated by *Pinus halepensis* in the Mediterranean Basin largely result from its plantation as a restoration tool and often exhibit low diversity and resilience. Given their extent and importance, increasing efforts are being made to overcome these limitations, mainly through management practices such as pine thinning. However, studies on the effects of thinning are few, rely mainly on species diversity, and often lead to contradictory results. Further clarification is needed, particularly regarding species functional traits, as they are the key drivers of ecosystem functioning and resilience, two primary targets of restoration projects.

We performed a 35% pine thinning to decrease competition and improve the functioning of an ecosystem dominated by pines, at a restored quarry site in the southwest of the Iberian Peninsula. A functional approach was used for the first time to monitor the thinning effect in mixed plantations of *P. halepensis* and late-successional Mediterranean shrubs under a dry sub-humid climate. The effects of thinning on the understory plant diversity, functional composition and woody species growth were monitored for two years.

While no changes were detected in species richness and diversity, thinning promoted key functional traits, increasing the density of groups with N-fixing ability, semi-deciduous drought strategy and therophyte life-form, mostly with anemochorous and barochorous dispersal. In the medium term, these changes are expected to contribute to improve nutrient cycling, ecosystem resilience to drought and fire, and biotic fluxes, which are important early limitations to plant establishment and functional recovery at the quarry site. Basal growth of planted evergreen sclerophylls increased, indicating a competitive relief. A moderate intensity pine thinning was useful to alleviate competition and improve ecosystem function in mixed stands with different pine densities and sizes.

Our findings reinforce the benefits of a functional approach to monitor the effect of management practices on ecosystems, and may help researchers and managers to convert *P. halepensis* dominated areas into more diverse and resilient ecosystems, particularly in Mediterranean areas.

1. Introduction

Restoration of highly degraded areas in the Mediterranean Basin has been largely performed with *Pinus halepensis* Mill. (Aleppo pine) monocultures since the 19th century, due to its drought-tolerance features, its capacity to thrive in a wide range of soil conditions, and its ability to regenerate under post-fire conditions (Ne'eman et al., 1995; Pausas et al., 2004; Fuentes et al., 2010). It was planted as a pioneer species and was expected to have a facilitative effect on late-successional hardwoods and to gradually generate a diverse ecosystem (Pausas et al., 2004; Osem et al., 2009). However, there is increasing evidence that *P. halepensis* plantations support low species diversity, promote pest outbreaks and are susceptible to short fire-intervals (Bellot et al., 2004; Maestre and Cortina, 2004), which may increase according to climate change predictions. In addition, in Mediterranean

* Corresponding author at: Centro de Biologia Ambiental, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, Edifício C2, 5° Piso, Sala 2.5.14, 1749-016 Lisboa, Portugal. Tel.: +351 217500000; fax: +351 217500048.
E-mail addresses: alicemnunes@gmail.com (A. Nunes), g.oliveira@fc.ul.pt (G. Oliveira), mscabral@fc.ul.pt (M.S. Cabral), cmbranquinho@fc.ul.pt (C. Branquinho), odgato@fc.ul.pt (O. Correia).

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semiarid areas some evidences were found of a negative effect on later-successional species and of failure to improve ecosystem functioning (Bellot et al., 2004; Maestre et al., 2004; Goberna et al., 2007). Therefore, management of *P. halepensis* dominated areas became one of the major environmental challenges to researchers and managers in Mediterranean areas, which look for ways to convert them into more diverse and resilient ecosystems.

One of the restoration strategies claimed to promote diverse and resilient ecosystems in degraded areas is to implement mixed plantations of late-successional shrubs together with pioneer fast-growing species, such as pines (Pausas et al., 2004; Piñeiro et al., 2013). Initially, the former would benefit from the presence of pines through microclimate amelioration at the regeneration stage and also through perch effects for dispersion (González-Moreno et al., 2011). However, at later stages, pines may reduce shrub survival and growth through competition for water, nutrients and light (Bellot et al., 2004; Maestre et al., 2004), especially if in high densities, e.g. above 1600 pines/ha, easily achievable after wildfires (Daskalakou and Thanos, 2010). In addition, the introduction of species with higher resource requirements (i.e. fast-growing conifers and late-successional shrubs) in areas with extremely limited resources may lead to uncertain outcomes. In the medium term, it may create a system with: (i) high competition and possibly slow growth rates and mortality due to exhaustion of limited resources (e.g. Prévosto et al., 2012); (ii) low nutrient recycling due to low litter decomposability of late-successional shrubs with sclerophyllous leaves which tend to immobilize nutrients (Arianoutsou and Radea, 2000; Dias et al., 2013); (iii) hindered incoming of spontaneous species, which may be important to "hierarchically rebuild" ecosystem's functioning and promote biotic fluxes, due to canopy closure. These impediments may culminate in an auto-limited system, stuck in a steady state which was not the initial goal.

Management practices are needed to redirect such systems. Nonetheless, the effects of silvicultural treatments (e.g. clearcutting, thinning, pruning) on biodiversity, ecosystem functioning and successional trajectories lack specific scientific studies, particularly in pine plantations in Mediterranean areas (but see Torras and Saura, 2008). Pine thinning has been considered a potentially useful tool to redirect pine plantations toward lower densities where facilitation mechanisms predominate, as in the case of oak regeneration (Gómez-Aparicio et al., 2009). However, few studies assess the effect of *P. halepensis* plantations' management on biodiversity in dry sub-humid areas and most of them deal with young pines, after the burning of mature stands (De Las Heras et al., 2004; Moya et al., 2009; Prévosto et al., 2011). Moreover, they report contradictory effects of management practices on the biodiversity of young post-fire regenerated communities: while De Las Heras et al. (2004) found an increase in annual herbs' cover and no effect on understory richness and diversity two years after pine thinning, others reported an increase in shrub species richness (Moya et al., 2009). Due to the relevance of *P. halepensis* dominated areas in the Mediterranean Basin, the actual effects of such practices must be clarified.

Monitoring of restoration and management actions traditionally relies on measures of species diversity (richness, abundance), despite the fact that their influence on ecosystem processes depends on species traits. A functional trait approach is thus more informative and advisable, since traits are the key mechanism through which diversity affects ecosystem functioning, influencing short-term resource dynamics and long-term ecosystem stability and resilience (Díaz and Cabido, 2001; Cadotte et al., 2011).

Our aim was to test pine thinning as a management tool to decrease competition and improve functioning of a restored ecosystem dominated by *P. halepensis*, using a functional approach. The study was performed in a post-exploited quarry where *P. halepensis* and several late-successional Mediterranean shrubs had been planted to restore it. To our knowledge, it is the first time this issue is addressed in mixed plantations under a dry sub-humid climate. We studied the understory diversity, functional composition and growth of woody species for two years after thinning. We hypothesized that pine thinning, by alleviating competition for water, light and nutrients, (i) would increase understory diversity, change functional composition and enhance woody species growth and (ii) that those effects would be better captured by a functional approach in addition to conventional diversity measures.

2. Materials and methods

2.1. Study area

The study was performed in a revegetated area of a limestone quarry, located in Arrábida Natural Park (38°29′48″ N, 8°56′24″ W), a small chain of limestone outcrops with 500 m maximum elevation, 50 km south of Lisbon, Portugal. The climate is Mediterranean dry sub-humid, with an average yearly temperature of 16.4 °C and 650 mm of precipitation. Vegetation surrounding the quarry is a well-preserved Mediterranean maquis, dominated by evergreen sclerophylls and semi-deciduous shrubs.

The usual environmental constraints imposed on vegetation by the Mediterranean climate (e.g. summer drought, inter-annual rainfall variability) are enhanced at the quarry by the extent of barren surfaces (which increase local thermal amplitudes and erosion) and by the lack of soil (marl spoils are used as substrate).

Quarry excavation of the hill face was conducted from top to bottom, resulting in a stair-like sequence of narrow terraces with approximately 20 m of height (Supplementary Fig. S1). When the exploitation of each terrace ceased, it was revegetated within the following 3 years, to reduce the visual impact. A substrate layer (<1 m depth) with high clay and stone contents was placed on the bare rock. Plantation was carried out in autumn-winter, using plants from a local nursery, and no further planting was performed on those terraces. Local species – *Arbutus unedo* L., *Ceratonia siliqua* L., *Juniperus phoenicea* L., *Myrtus communis* L., *Olea europaea* L. var. *sylvestris* (Miller) Lehr., *Phillyrea angustifolia* L., *Phillyrea latifolia* L., *Pistacia lentiscus* L., *Quercus coccifera* L., *Quercus faginea* Lam. and occasionally *Rosmarinus officinalis* L. – as well as fast-growing species less common in the surrounding areas – *Pinus halepensis* Miller, *Retama monosperma* (L.) Boiss.; occasionally *Pinus pinea* L. and *Spartium junceum* L. – were used. By the time of this study, pines had become dominant in the terraces and the understory was composed mainly of planted evergreen sclerophylls, some spontaneous shrubs (e.g. *Cistus albidus* L. and *Cistus salviifolius* L.) and herbaceous species (e.g. *Anagallis monelli* L. and *Bituminaria bituminosa* (L.) C.H. Stirt) recruited from the surrounding natural shrubland community. Soil organic matter was about 2.1% and soil total N 0.05% (0–10 cm depth). Photosynthetic photon flux density (PPFD) under pine shadow was reduced by more than 80% (224 $\mu mol\ m^{-2}\ s^{-1}$) when compared to values in the sun (1619 $\mu mol\ m^{-2}\ s^{-1}$) (average of five consecutive days recorded in July with an Onset Hobo data logger, Massachusetts, USA).

Air temperature and precipitation were recorded during the study period (from 2002 to 2004) by a micrometeorological station located in one of the studied terraces (P2, see next section). The wettest year was 2003 (997 mm) and 2004 was the driest (548 mm). Mean maximum air temperatures of the hottest month ranged from 29 °C (2002) to 32 °C (2003); in the coldest months, minimum temperatures were 7–8 °C in all years.