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Natural regeneration of *Pinus pinaster* and *Eucalyptus globulus* from plantation into adjacent natural habitats

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ABSTRACT

The tree species used in planted forests are highly productive and have an important role in countries economy but the expansion of these trees into habitats outside plantations is a concern for managers and conservationists. Among the most planted forest species worldwide, we can find eucalypts and pines species. Understanding spatial patterns and the factors that influence these species colonization is crucial to increase the knowledge about expansion capability of these species and may help managers to improve and prioritize eventual control plans. Our study aimed to identify the recruitment spatial patterns of *Pinus pinaster* (native species) and *Eucalyptus globulus* (exotic species) into habitats surrounding plantations in Portugal (native forests, grasslands and shrublands) and to determine the factors that influence recruitment. This was done by looking at the recruitment success in several habitats near plantations, using a spatial gradient of distance to plantations edge. We observed as expected that the recruitment of *P. pinaster* and *E. globulus* decreased exponentially from the plantation edge. However, the higher *P. pinaster* seedling recruitment in this study (*P. pinaster*: 247 seedlings/ha; *E. globulus*: 22 seedlings/ha), the smallest decline in seedlings density with distance from plantation boundary (*P. pinaster* = −0.036 seedlings/m vs *E. globulus* = −0.048 seedlings/m), and the longer distance of seedling establishment, demonstrate clearly that *P. pinaster* is more successful colonizing the habitats near plantations than *E. globulus*. Nevertheless *E. globulus* can growth seedlings within the planted stands suggesting that the species is becoming naturalized. However, localized recruitment (92% of the total seedlings recorded were located less than 15 m from the plantation edge) and lower levels of establishment of *E. globulus* from managed plantations, suggested that this species did not demonstrate an invasive behavior. However, future research in abandoned eucalyptus plantation is needed to understand the role of plantation management and age as barriers to *E. globulus* colonization. Results from our survey revealed the suitability of all habitat types studied for *P. pinaster* natural regeneration, although their recruitment was more limited in forest habitat type. Forest and grassland were very resistant to *E. globulus* establishment. The two species recruitment was also influenced by different factors, with *P. pinaster* being independent of climatic variables, while *E. globulus* was affected by temperature seasonality and recruitment was found to be higher in areas with lower seasonal differences.

1. Introduction

During the last decades the increasing world demand for forest products (such as timber, fuel and paper) and the needs to restore large degraded areas has led to a global increase in planted forest area (Dodet and Collet, 2012; FAO, 2010). In many countries, plantation forestry consist mostly on a few fast-growing species, mainly eucalyptus and pines (Richardson, 1998). Once planted, these fast-growing species can spread to nearby natural and semi-natural ecosystems by seed regeneration. Regeneration from seeds involves many stages in the life cycle of plants, with seed and seedling stages recognized as the most important for their success (Houle, 1996). However, the success of regeneration and establishment of a new species is context specific and depends on both characteristics of the new species itself and of the host community and on the interaction between the two (Rejmanek et al., 2005). Thus, the ability of introduced species to recruit, the capacity of a species to reach suitable regeneration sites (which depends on the number of seeds produced and on the dispersal ability), and

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the susceptibility of the environment (or its opposite, ecological resistance) to the establishment of these new individuals are crucial for the recruitment success (Lonsdale, 1999). Davis et al. (2000) suggests that the susceptibility of a receiving community can change in function of competitive and facilitative interactions, nutrient availability, or disturbance and can be quantified as the probability of establishment per arriving propagule of the new individual. Thus, understanding the spatial pattern of establishment of new individuals (recruitment) of introduced forestry species is an important prerequisite to manage their colonization into natural habitats.

Among the most planted forest species worldwide, we can find Eucalyptus and Pinus species. In northern and central of continental Portugal, most forest area is due to the plantation of two species, *Eucalyptus globulus* Labill. (Tasmanian blue gum) and *Pinus pinaster* Aiton (maritime pine) (ICNF, 2013). *P. pinaster* is a species from western Mediterranean Basin that covers over four million hectares and has great economic and ecological importance in this region (Ribeiro et al., 2001). *P. pinaster* was used in Portugal since the 19th century in large scale reforestation, which lead to its expansion clearly beyond their natural distribution (Aguiar et al., 2007). Actually, this species is the main forest tree species for timber production in Portugal (Garcia-Gonzalo et al., 2011), representing 23% of its forest cover (ICNF, 2013). Still, given the importance of *P. pinaster* in south western Europe there are surprisingly few studies of its regeneration in the Mediterranean (Juez et al., 2014; Rodríguez-García et al., 2011, 2010, 2007). Because of its commercial importance and easy acclimation, maritime pine has been planted also in temperate regions outside its natural range. In fact, pine expansion is recognized as a global phenomenon (Richardson and Rejmánek, 2004). Outside its natural range, maritime pine and several other pines are counted among the most invasive plant species, mainly in the southern hemisphere (Richardson and Rejmánek, 2011, 2004; Richardson, 1998). Should, however, native pine expansion from plantations be seen as a part of the natural dynamics of the ecosystem? Or, although it occurs within its natural range, as a process caused by human activities with some negative consequences (i.e. invasion)? There is no consensus to this complex question (Valéry et al., 2009, 2008; Wilson et al., 2009). In this sense, studies from pine natural range, especially those related to recruitment process can be very important for developing colonization models (increasing the insights from the native and introduced ranges on the distribution of pines) (Richardson and Bond, 1991).

E. globulus, native from Australia, is the most important pulpwood species planted in the Iberian Peninsula (Potts et al., 2004). This species has a significant economic role in this region (Potts et al., 2004) and is now the most widespread tree species in Portuguese mainland, representing 26% of its forest cover (ICNF, 2013). This species was introduced in the middle of the 19th century and since the middle of 20th century the development of the pulp and paper industries originated the expansion of *E. globulus* plantation in the country (Alves et al., 2007). But, as other widely planted species such as acacias and pines, there are concerns about the *E. globulus* natural regeneration from seeds. However, quantification of tree establishment has rarely been implemented for eucalyptus (Callaham et al., 2013; da Silva et al., 2011), and very few deal with *E. globulus* (Calviño-Cancela and Rubido-Bará, 2013; Catry et al., 2015; Larcombe et al., 2013). The invasion risk of *E. globulus* was assessed in several publications based on the Australian Weed Risk Assessment (Daehler et al., 2004; Gassó et al., 2009; Gordon et al., 2012; Marchante et al., 2014). Weed risk assessments (WRA) are mainly based on species biological traits and expert knowledge (Pheloung et al., 1999), and rarely based on field quantitative information (distribution of the species in the introduced range). Given the extend of *E. globulus* plantation (high propagule pressure), their fast growth, the production of very large quantities of seeds, and in light of their diverse adaptations for dealing with disturbance (such as fire), the invasion risk of this species was classified as "High" (based on the Australian WRA) in Spain (Gassó et al., 2009), in Portugal (Marchante et al., 2014), in the USA (Gordon et al., 2012), in Hawaii and other Pacific Islands (Daehler et al., 2004). Indeed, Rejmánek and Richardson (2013) showed that *E. globulus* was reported as invasive in seven of the fifty geographical regions considered by these authors: North, Central and South America, Europe, New Zealand, Pacific Islands and Indian Oceans Islands. Namely, *E. globulus* was reported as invasive in Europe based on Marchante et al. (2014) field guide (where *E. globulus* is classified as a major invader in Portugal based on Australian WRA) (Rejmánek and Richardson, 2013). On the other hand, *Eucalyptus* have been reported as species with a low invasive risk based on field quantitative studies (Callaham et al., 2013; da Silva et al., 2011; Larcombe et al., 2013; Lorentz and Minogue, 2015). Recently, Catry et al. (2015) studied *E. globulus* natural establishment along roadside transects adjacent to eucalypt plantations distributed throughout continental Portugal. They found that *E. globulus* density was mainly affected by precipitation, reaching the highest values at around 1500 mm of annual precipitation and the lowest values below 800 mm and above 2400 mm (Catry et al., 2015). In addition, *E. globulus* establishment was also more abundant in areas with lower thermal amplitudes and seemed to be favoured in areas with certain soil types (Cambisols and Podzols) (Catry et al., 2015). However, roadsides adjacent to eucalypt plantations are areas with particular characteristics, such as high human-caused disturbance, becoming difficult to generalize to other habitat types. We still have an information gap about recruitment spatial pattern and the factors that influence this species colonization from plantations into different natural habitats. Whereas a lot is known of the invasion ecology of pines (e.g. summarized in Richardson, 2006), very little is known about crucial aspects (such as seed dispersal, and the role of fire and mycorrhiza) that determine the limited range of eucalypts natural regeneration (Rejmánek and Richardson, 2011).

In the light of this, and in order to provide guidelines for better managing plantations and its surrounding natural and semi-natural habitats, the main goal of our study was to identify the recruitment spatial patterns of *P. pinaster* and *E. globulus* into habitats surrounding the plantations, and to determine the factors influencing that recruitment. More specifically we asked: (i) how is the seedling recruitment in relation to distance from the parent (plantation)?; (ii) which are the most important factors related with plantation characteristics, habitat type and climatic conditions influencing their recruitment spatial pattern and (iii) how do these variables affect each species recruitment spatial pattern? This was done by looking at recruitment success in several habitats near plantations, using a gradient of distance to plantation's edge.

2. Methods

2.1. Study species

Despite *Pinus pinaster* being a Portuguese native species it was included in this study because, as *Eucalyptus globulus*, this species is highly represented in Portugal mainland and, as a cultivated tree, its current distribution in Portugal is mainly a result of human activity. In Portugal, *E. globulus* plantations are mostly intensive managed through a coppice system (10–12 year rotations) and their wood is mainly used for pulp production (Soares et al., 2007). The main limiting climatic factors to *E. globulus* growth in Portugal are water availability and low temperatures (mainly occurrence of temperatures below 0 °C) (Almeida et al., 1994;