Forest Ecology and Management 409 (2018) 826–834

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Fire increases *Eucalyptus globulus* seedling recruitment in forested habitats: Effects of litter, shade and burnt soil on seedling emergence and survival

María Calviño-Cancela[a,*], Paula Lorenzo[b], Luís González[c]

[a] Department of Ecology and Animal Biology, Faculty of Biology, University of Vigo, 36310 Vigo, Spain
[b] Centre for Functional Ecology (CFE), Department of Life Sciences, University of Coimbra, 3000-456 Coimbra, Portugal
[c] Department of Plant Biology and Soil Science, Faculty of Biology, University of Vigo, 36310 Vigo, Spain

ARTICLE INFO

Keywords:
Alien trees
Biological invasions
Forest fires
Germination
Plantation forestry

ABSTRACT

Plantations of alien tree species may pose environmental risks associated to their spontaneous spread in areas of introduction. *Eucalyptus globulus* Labill. is one of the most used species in forestry and has been reported as invasive in many areas around the world. Fire has been suggested to enhance *E. globulus* recruitment but no study to date has compared burnt vs. unburnt sites for seedling emergence and survival, and little is known about the mechanisms that could favour recruitment after fire. A better understanding of the effect of fire on the invasive potential of *E. globulus* is essential for improved management of this species in the areas of introduction. In this study, we analyse the effect of fire on the emergence and establishment of *E. globulus* seedlings in the field, in the most common habitats adjacent to plantations in NW Spain, and explore the underlying mechanisms that could explain the patterns observed by means of greenhouse experiments. Fire enhanced seedling recruitment in the forested habitats studied, due to a positive effect on both seedling emergence and survival. Seedling emergence was 42.5 and 7.0 times higher in burnt vs. unburnt sites in native forests and pine plantations, respectively. Final seedling establishment was 2% in burnt vs. nil in unburnt native forests, and 2.5 times higher in burnt vs. unburnt pine plantations. In shrublands, however, final seedling establishment was similar in burnt and unburnt sites. The positive effect in forested habitats seems to be mainly related to the destruction of litter, which played an important role as a physical barrier to seedling emergence, and to the increase in light availability, which has a positive effect on seedling survival and can result from litter consumption or the burning/scorching of the canopies. Our results demonstrate that fire can increase the invasion risk posed by *E. globulus* to the native vegetation next to plantations, especially in native oak forests, which had been shown to be rather resistant to *E. globulus* seedling establishment in the absence of fire. This increased seedling recruitment in burnt areas together with the high fire-proneness of eucalypts could lead to positive feedbacks that may favour eucalypt expansion, further increasing the vulnerability of the native vegetation to colonization by this alien tree.

1. Introduction

Plantation forestry around the world is mostly dependent on a limited number of fast-growing species, often alien to most of the areas where they are planted. Plantations of alien trees may pose environmental risks associated to their spontaneous spread in areas of introduction (Richardson, 1998; van Wilgen and Richardson, 2012; Brundu and Richardson, 2016). *Eucalyptus* (Myrtaceae) is one of the most used genus in forestry and has been widely planted around the world, mainly for production of timber and pulp for the paper industry, and as a source of biomass for energy production (FAO, 2010; Eufrade et al., 2016). The rapid growth of some eucalypts, their high fecundity, frugality and tolerance to a wide range of environmental conditions make them especially suitable for the forestry industry, but these traits also increase their invasive potential (Turnbull, 1999; Boyd, 1996; Richardson and Rejmánek, 2011). Among them, *Eucalyptus globulus* Labill. (Tasmanian blue gum; native from South-Eastern Australia), is one of the most widespread, and has been reported as invasive in southern Europe, North and South America, the Pacific Islands, and New Zealand (Sanz-Elorza et al., 2001; Richardson and Rejmánek, 2011). In addition, several weed risk assessments give high scores to this species, identifying it as a species implying a high environmental risk both for the likelihood of invasion and for its socioeconomic and ecological impacts (Daehler et al., 2004; Buddenhagen et al., 2009; Gassó et al., 2010; Gordon et al., 2012). The first plantations of the species in Spain (in Galicia, NW Spain) were probably back in the 1850s

* Corresponding author.
E-mail addresses: maria@uvigo.es (M. Calviño-Cancela), paulalorenzo@uc.pt (P. Lorenzo), luis@uvigo.es (L. González).

https://doi.org/10.1016/j.foreco.2017.12.018
Received 25 September 2017; Received in revised form 7 December 2017; Accepted 11 December 2017

(Silva-Pando and Pino-Pérez, 2016) although its massive planting for pulpwood production only started after the mid-20th century. In NW Spain, *E. globulus* plantations have been shown to harbour less biodiversity that native forests or pine plantations (see Calviño-Cancela et al., 2012, 2013; Calviño-Cancela, 2013), they have higher risk of fire than native forests (Calviño-Cancela et al., 2016, 2017) and show very low rates of litter decomposition, with litter inhibiting soil microbial activity, leading to a drastic impoverishment of N in soils (Castro-Díez et al., 2012).

E. globulus seedling recruitment occurs naturally in plantations and adjacent natural habitats with no fire, being higher in shrublands, followed by pine plantations, with less recruitment in native broadleaved deciduous oak forests (Calviño-Cancela and Rubido-Bará, 2013 in NW Spain). In the absence of fire, seeds are mainly dispersed within the fruits (capsules; with an average of 12 seeds per capsule in the study area), which can be released all year round, but mainly during autumn and winter (Calviño-Cancela and Rubido-Bará, 2013). Once in the ground, capsule desiccation leads to the opening of capsule valves and to seed release. Seeds germinate readily in lab conditions and show no dormancy (> 95% germination; Calviño-Cancela, unpublished data). Following fires, *E. globulus* resprouts intensively from epicormic buds, and some studies point also to post-fire increased seedling recruitment (Larcombe et al., 2013; Águas et al., 2014). However, no study to date has compared the *E. globulus* recruitment process in burnt vs. unburnt sites, and little is known about the mechanisms that could favour recruitment after fire. In many species, fire stimulates the release of seeds stored in the canopy (Lamont et al., 1991; Tapias et al., 2001; Pausas et al., 2004), which increases seed availability in the soil. This has been shown for *E. globulus*, and seems to be mediated by branch desiccation, which leads to capsule desiccation and, with it, to a slow release of seeds that can last for a month or longer (Santos et al., 2015). Since fires usually occur in summer, this delay leads to seeds being released in more favourable conditions, usually in the rainy season, in an empty and fertile seedbed that can enhance establishment (Gill, 1981; Stoneman, 1994). Fire can also have a positive effect on seed germination, which can be mediated by heat, smoke or ash (Moreira et al., 2010; Nelson et al., 2012). In *E. globulus*, either ash, smoke nor heat have a stimulating effect on seed germination (Reyes and Casal, 2001; Arán et al., 2013; Silva et al., 2016) and heat has been shown to have a detrimental effect (Arán et al., 2013). A low tolerance of seeds to high temperatures is a common pattern among resprouters (Paula and Pausas, 2008), but the woody capsules of *E. globulus* protect the enclosed seeds during fires (Gill, 1981). Another effect of fire related to recruitment is the amelioration of the environmental conditions for seedling establishment, by increasing light availability with the destruction of vegetation and litter, or by increasing nutrients in ashbeds (Chambers and Attiwill, 1994; Tyler, 1995). Light is an important environmental factor in the regulation of seed germination and early seedling establishment, especially in small-seeded species (Baskin and Baskin, 1998; Kyereh et al., 1999; Seo et al., 2009). *E. globulus* seems to be tolerant to a wide range of light intensities, and recruits better under moderate shade (González-Muñoz et al., 2011). The presence of plant litter can drastically reduce the light intensity reaching the seeds, and can also affect recruitment in many other ways. Since fire is a very important agent of litter destruction it can have important implications for subsequent seedling emergence, survival and growth. For instance, litter can create a physical barrier that obstructs seedling emergence and growth, especially for small-seeded species (Facelli and Pickett, 1991; Dzwonko and Gawronski, 2002; Moles and Westoby 2004). It forms also an isolating layer that reduces temperature fluctuations (Donath and Eckstein, 2010) and retains soil moisture, which affects both seed germination and seedling establishment, by preventing desiccation and facilitating seed imbibition and seedling growth (Facelli and Pickett, 1991; Murphy et al., 2004). It may increase soil nutrients through decomposition (Brearley et al., 2003) and can be a source of phytotoxic substances, produced by leaching or litter decomposition, with effects on both germination and seedling growth (González et al., 1995; Chu et al, 2014; Aguilera et al., 2015). Litter may also have indirect impacts, by affecting biotic interactions, e.g. by providing a more favourable environment for herbivores or fungal pathogens (García-Guzmán and Benítez-Malvido, 2003). Fire can thus indirectly affect seedling emergence and growth through litter destruction.

Galicia (NW Spain) is the region of Spain with the highest concentration of eucalypts and the highest incidence of wildfires (Barreiro and Hermosilla, 2013), which makes it especially relevant for the study of eucalypt recruitment after fire. Despite Galicia represents only 6% of the Spanish territory, it has more than 60% of the total coverage of eucalypt plantations in the country (Aspapel, 1988) and more than 40% of the wildfires (decade 2001–2010; MAGRAMA, 2012). Galicia is also the most important forestry region in Spain (Manuel and Gil, 2002), with c. 70% of the land being forested. *Eucalyptus globulus* has been intensively cultivated, mostly for the production of pulp for the paper industry (Riesco, 2004). Eucalypt plantations cover c. 288,000 ha in pure stands and 146,000 ha in mixed stands and have multiplied its cover by c. 10 times over the last 30 years (MARM, 2011), both by intentional planting and natural spread (Manuel and Gil, 2002). This expansion has taken place mostly in lowland areas near the coast, causing important changes in the regional landscape in rural areas (Marey-Pérez et al., 2006).

In this study, we analyse the effect of fire on the emergence and establishment of *E. globulus* seedlings in NW Spain (Galicia). We tested in the field whether *E. globulus* seedling emergence is enhanced in burnt sites compared to unburnt areas and whether this effect differs among habitats of potential colonization (i.e. the most common habitats adjacent to plantations in NW Spain: oak forests, pine plantations and shrublands dominated by *Ulex* spp. and *Erica* spp.). We used also greenhouse experiments in order to explore the underlying mechanisms that could explain the patterns observed, by using a combination of treatments to disentangle the main factors involved. We hypothesize that increased seedling recruitment after fire could be the result of litter destruction, which may have a detrimental effect on recruitment, mediated either by its effect as a physical barrier for seedling emergence, for the shade it provides or the leachates it produces. A better understanding of the effect of fire on the invasive potential of *E. globulus* is essential for improved management of this species in the areas of introduction.

2. Methods

2.1. Study area

Field work was carried out in NW Spain (Galicia), in an area that suffered a big fire of c. 1,800 ha in late August 2013 (41°59′25″N 8°48′10″W), which burnt different types of vegetation including *Pinus pinaster* Aiton plantations, *E. globulus* plantations, native oak forest patches dominated by *Quercus robur* L. and Atlantic shrublands dominated by *Ulex europaeus* L., *Cytisus scoparius* (L.) Link and *Erica* spp. The climate in the study area is oceanic (Cfb following the updated Köppen-Geiger classification; Kottek et al., 2006). Average daily temperatures in the study period (September 2013 – February 2014) ranged from 19.1 °C (September) to 7.3 °C (February), with maximum daily temperatures ranging from 30.2 °C (September) to 11.9 °C (February) and minimum daily temperatures ranging from 10.1 °C (September) to 1.7 (December), with no frosting days. Precipitation ranged from 93.3 L/m^2 in November to a maximum of 305.3 L/m^2 in January, with an average of 204 L/m^2 per month (Meteogalicia, Castro Vicaludo - Oia weather station, http://www.meteogalicia.es).

2.2. Field sampling

We tested for differences in seedling emergence and survival between burnt and unburnt sites in 3 types of habitats, the most common