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# Post-fire plant diversity and abundance in pine and eucalypt stands in Portugal: Effects of biogeography, topography, forest type and post-fire management

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ABSTRACT

This study concerned the mid-term regeneration of the woody understory vegetation of pure and mixed stands of *Pinus pinaster* Ait. and *Eucalyptus globulus* Labill. in northern and central Portugal following wildfires in 2005 and 2006. Pine and eucalypt stands are the most widespread and most fire-prone forest types in Portugal. The main aim was to investigate the importance of biogeography, topography, forest type and post-fire management operations in explaining the patterns in shrub diversity (species richness) and abundance (cover). To this end, 284 study sites in four distinct biogeographic regions were sampled 5 to 7 years following the last wildfire. At each site, the presence and cover of individual shrub species were estimated using 4 sub-plot of approximately 10 $m^2$ each. The entire data set was analyzed by means of GLM using a total of seven explanatory variables: biogeographic region, forest type, three types post-fire management operations (soil tillage, tree harvesting, and shrub clearance), and two topographic variables (slope angle and elevation). The GLM analysis was also done for the individual biogeographic regions.

Biogeographic region and slope steepness were key factors explaining shrub species richness, albeit the role of slope angle was possibly linked to the intensity of past land use.

Biogeographic region equally played a significant role in explaining the cover of all shrubs together as well as of the shrubs of Leguminosae and Cistaceae. All three types of post-fire management operations appeared to hamper the recovery of resprouters and Leguminosae, whereas just tree harvesting and shrub clearance (but not soil tillage) negatively affected the cover of seeder species. These impacts of post-fire management operations had a noticeable region-specific component, being more relevant in the less productive biogeographic regions.

Also the role of forest type depended strongly on biogeographic region. It was only significant in the South Mediterranean region, where pine plantations had a higher total shrub cover as well as higher covers of seeders and Cistaceae. Possibly, however, this significant role of forest type could be due to the lower incidence of shrub clearance in the pine stands.



## 1. Introduction

Forests are of the utmost importance for mankind as they provide a vast number of ecosystem services such as regulation of water fluxes, protection against soil (fertility) losses and conservation of plant and animal biodiversity (EuropeanComission, 2010). According to the insurance hypothesis (Bengtsson et al., 2000; Folke et al., 1996), the present and future ecosystem services provided by forests (and other ecosystems) depend heavily on their biodiversity as their biodiversity is fundamental to an ecosystem's resistance and resilience against disturbances. A large number of plant species is considered essential for the continued provision of services by ecosystems, even if these species appear to be partially redundant in terms of ecosystem functioning (Isbell et al., 2011). Ecosystem resilience is of particular relevance for fire-prone forests such as the planted pine and eucalypt forests studied here, including because fire frequency in Portugal is not expected to reduce substantially in the near future (Fernandes et al., 2013; Moreira et al., 2011). The understory vegetation of western Iberian eucalypt and pine stands deserve special mention for their key role in the ecosystem service of water flux regulation

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and erosion protection, especially during the early stages of the so-called window-of-disturbance (e.g. Fernandez et al., 2011; Prats et al., 2012, 2013) and with important implications for long-term land-use sustainability (e.g. Grigal, 2000). Conservation of present and future biodiversity is also relevant from an economic point of view, as biodiversity constitutes an important aspect in forest certification schemes such as FSC (Forest Stewardship Council) and, thus, in valorization of forest products.

A variety of factors is likely to affect the cover and floristic composition of the understory vegetation in burned forest plantations. Biogeographic regions, which encompass climatic, edaphic and topographic conditions, constitute limits to the distribution ranges of native species (e.g. Abella and Covington, 2006; Lobo et al., 2001). Also topographic factors have often been pointed out as key variables in explaining floristic patterns, albeit not in a consistent manner. For example, Pausas (1994) found that woody species richness was negatively correlated with elevation in high-elevation mountain ranges, while Lobo et al. (2001) found the opposite for the Iberian Peninsula. In the case of forests, the species richness of the understory has been associated to the predominant tree species of the overstory (Suckling et al., 2001). However, it is often unclear if the role of forest type is due to direct or indirect effects, resulting for example from competition by the tree species, alterations in abiotic conditions (e.g. pine needle cast) or differences in forestry practices (Cavard et al., 2011; Macdonald and Kurulok, 2007). Management operations carried out following wildfires can be a major driver in the regeneration of the understory vegetation from the direct fire effects, both in terms of its cover and its species diversity (Vallejo and Alloza, 2012). A wide range of management operations have been applied in recently burnt areas, ranging from tree harvesting, to soil tillage in preparation of new plantations, to restauration actions such as seeding. All such operations can be expected to affect vegetation persistence and/or (re-)colonization following wildfires (Hartley, 2002).

Forests in Portugal, like in other parts of southern Europe, have changed profoundly over the past few decades, especially due the widespread planting of commercial tree species such as *Pinus pinaster* Ait. (for wood production) and eucalypt and, in particular, *Eucalyptus globulus* Labill. (for paper pulp production). At present, planted forests dominated by maritime pine and/or eucalypt constitute approximately 50% of the forested area in Portugal (ICNF, 2013). Since the tree layer of these planted forests is composed of just one or two species, the understory vegetation largely determines these forests' plant species diversity. Bengtsson et al. (2000) considered the understory vegetation of mono-specific plantations as the best indicator of their overall biodiversity and, thereby, of their sustainability. An important drawback of pure and mixed stands of pine and eucalypt is their elevated flammability (Fernandes, 2009; Silva et al., 2009). To reduce their intrinsic fire hazard, pine and eucalypt plantations are typically subjected at regular intervals to reductions of the standing biomass of the understory vegetation, traditionally by grazing and shrub collection for livestock bedding and presently by mechanical shrub clearance and increasingly prescribed burning (e.g. Oliveira, 1999). These fuel management operations, however, can be expected to interfere with the biodiversity of the understory and, thus, with the principles of sustainable management.

The present study is a follow-up of Moreira et al. (2013), which concerned the native and exotic tree species in pure and mixed stands of maritime pine and eucalypt that had burnt 5–7 years earlier and which showed that biogeographic region and post-fire management operations were the most important factors explaining native tree species diversity. This study, on the other hand, concerned the mid-term post-fire regeneration of the woody understory vegetation. The specific objectives of this study were: (i) to describe the patterns in shrub species richness as well as in their total cover and in the cover of the two main plant functional groups (in terms of fire adaptation strategy) and of the most common families; (ii) to explain these patterns in terms of potential explanatory variables related to biogeographic region, topography, forest type and post-fire management operations.

## 2. Materials and methods

### 2.1. Study areas and study sites

Within northern and central Portugal, twenty study areas were selected that according to the Portuguese digital atlas of burnt areas had burnt in 2005 or 2006. The selection of these areas furthermore involved the following criteria: (i) the presence of sufficient numbers of mono-specific and/or mixed stands of eucalypt and maritime pine; (ii) the size of the burnt area (which ranged from 137 to 10,924 ha); (iii) accessibility. The number of pure and mixed eucalypt and pine stands was estimated using the data of the 5th National Forest Inventory (NFI) of 2005–2006 (ICNF, 2013). From the NFI grid points within each area that corresponded to pure and mixed eucalypt and pine stands, up to 30 were selected in a random stratified manner such that the study sites were equally divided over the three forest types as possible. The final selection of the study sites involved a field check in terms of accessibility, indications for the occurrence of a fire in 2005/2006 and the occurrence of a change in forest type following the NFI of 2005–2006, as further detailed in Moreira et al. (2013) and Águas et al. (2014). Sites that were recently planted or sites where the spontaneous vegetation was eliminated by recent forestry operations were not included in this study.

### 2.2. Field sampling

A total of 284 study sites were sampled between the winter of 2010 and the late spring of 2012, by which time the sites had burnt for the last time between 5 and 7 years earlier. At each site, a sampling plot was laid out that consisted of a circular buffer with a radius of 6.78 m (Fig. 1), using as center the coordinates of the respective NFI grid point. For this study, sampling itself was carried out in four sub-plots with a radius of 1.78 m, whose center was located at 5 m distance from the center of the plot in the four cardinal directions (N, E, S, W). Within each sub-plot, the woody species making part of the understory (further referred to as

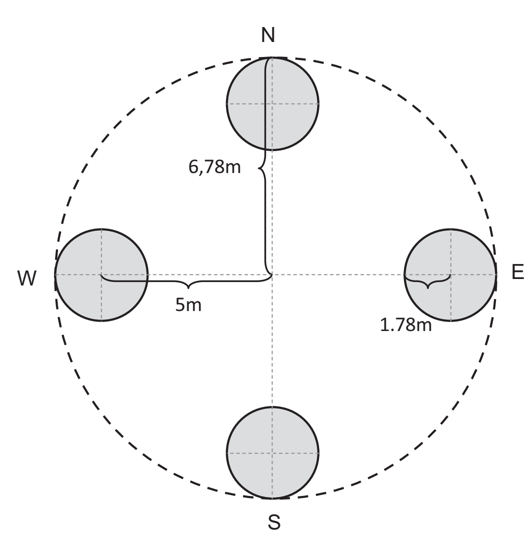


**Fig. 1.** Schematic view of a sampling plot and its four sub-plots.