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Understory fuel load and structure eight to nine years after prescribed burning in Mediterranean pine forests

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ABSTRACT

Prescribed burning is being widely used in fire-prone forests to modify stand structure, reduce risks of severe wildfire, and increase ecosystem resilience to natural disturbances. This study focuses on changes to understory cover, phytovolume, and species richness eight to nine years after underburning, by comparing the understory structure of burned and paired unburned (100 m^2) plots in eight Mediterranean pine stand locations (Catalonia, Spain). Taking into account the assumptions of the space-for-time substitution in our study design, phytovolume was significantly lower in burned plots compared to the unburned plots. These differences varied, however, across localities, ranging from negligible changes to a reduction of more than 90%. Differences attributable to management were greater in forest plots with higher overstory cover, which was assessed by hemispherical photograph analysis. This result suggests that the lack of light availability may limit the reestablishment of understory in managed dense stands. Crown Fire Initiation and Spread (CFIS) simulations indicated that these changes in understory structure would only decrease the behavior of a potential wildfire when occurring in low or moderate weather conditions. In both burned and unburned plots, woody obligate resprouters represented more than 60% of the total cover, while facultative resprouters or obligate seeders accounted for less than 20%. No differences were detected in the richness of resprouter, seeder, graminoid or legume functional groups between burned and unburned plots. Our results support the application of prescribed fires to reduce surface fuels in the studied forest types, and the hypothesis that fuel load reduction is most effective in a forest with a closed overstory.

1. Introduction

The occurrence and impact of wildfires is increasing due to environmental, climate and social changes, which are leading to longer dry periods and higher fuel loads (Piñol et al., 1998). In addition, contemporary land use trends promote biomass accumulation and landscape-level continuity of highly flammable fuel types, thus favoring large and severe fires (Vega-García and Chuvieco, 2006). To reduce wildfire intensity and severity, forest management agencies have shifted emphasis from fire suppression to the proactive treatment of forest stands. Prescribed burning (PB) is the planned use of fire under defined environmental conditions to achieve precise and clearly-defined management objectives (Wade and Lunsford, 1989), and is taught through a professional training system in Europe (Colaco and Molina, 2010). Despite the relative low importance of fuel in comparison with weather as a driving force of wildfire behavior under extreme fire danger conditions (Bessie and Johnson, 1995; Bradstock et al., 1998), understory PB aims to reduce fire hazard by decreasing fuel loads (Pyne et al., 1996), but also by disrupting the horizontal and vertical continuity of the fuel complex to modify fire behavior and potentially decrease the fire's severity (Agee and Skinner, 2005).

Reducing fuel load under a threshold level without impacting ecosystem functions is the main goal of PB as a tool for wildfire hazard reduction. Increasing the longevity of fuel treatment is a key management objective, defining the management strategy and the appropriateness of burning as a tool. As expected, understory cover and height decrease just after burning, but they may either re-establish to near pretreatment levels within a few growing seasons, or remain lower for several years (Fernandes and Botelho, 2003 and references here-in). Thus, the assessment of the recovery of fuel loads several years after burning is key to evaluate the effectiveness of the management. Considering that underburning is typically a low intensity fire and that Mediterranean plant species recover rapidly after fire, we hypothesized that

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understory fuel load eight to nine years after PB will be similar to that before management.

Disparities in the recovery timing after PB depend, among other factors, on specific management characteristics (i.e. fire intensity, season), understory composition, and the success of each individual plant to survive and compete in the new micro-environment. Understanding the responses of plant species to disturbance is relevant for the comprehension of long-term vegetation dynamics and undesired ecosystem impacts, as well as for defining appropriate management options. The plant richness of Mediterranean forest understories is high, possessing a wide range of traits that operate after different levels of perturbation to reestablish each species and better compete for the acquisition of resources. Many plant species are able to resprout after disturbance (resprouters), while others rely on the recruitment from seeds (seeders) (Keeley and Zedler, 1978; Trabaud, 1987). In addition, a third group, facultative resprouters, may persist after fire by both resprouting and seed recruitment. These different functional groups may respond differently to burning management, resulting in an increase of one group in respect to others. Resprouters' and seeders' adaptation to disturbance can lead to different resource allocation and growth. Although it has been suggested that seeders maximize their growth after disturbance in comparison with resprouters, results are not consistent (Knox and Clarke, 2005; Chew and Bonser, 2009). Resprouting species may nearly recover their pre-fire size within a few years following PB, if fire had not affected below-ground organs (Bellingham and Sparrow, 2000). The recruitment of seeder species may depend on the seed longevity within the seedbank, the effects of burning on the buried seeds and the availability of light and water after emergence (Tyler, 1995; Knox and Clarke, 2006). Since resprouting seems to be advantageous following fire because it allows for quick occupation of space in comparison with the recruitment of seeders (Bond and Midgley, 2001), we hypothesized that the relative cover of resprouting species will increase in respect to seeders after burning.

In the NE Iberian Peninsula (Catalonia, Spain), resprouters and seeders are both present in fire-prone landscapes, but resprouting constitutes the dominant mechanism of post-fire regeneration in forests (Lloret et al., 2005). Intraspecific variability in resprouting is related to the pre-disturbance state of individuals (e.g. non-structural carbohydrates and nutrient levels) and the post-fire capacity to acquire resources (Moreira et al., 2012). Although water and soil nutrients usually control primary productivity in Mediterranean ecosystems, the growth of resprouting plants may be less sensitive to these resources due to their favorable root:shoot ratio and reduced competition after fire (Midgley, 1996). In contrast, low light availability has been suggested to explain the low resprouting vigor of different shrub species individuals (Gracia and Retana, 2004; Quevedo et al., 2007) or the low understory plant cover in ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) forest 30 years after PB (Scudieri et al., 2010). Therefore, we hypothesized that the reestablishment of understory fuel load will be limited by the density of overstory cover, as a proxy for the understory light availability.

Several computer models have been developed for estimating the potential for crown fires at forest stand scale, and can be used to compare potential effectiveness of fuel treatments (Scott, 1999; Finney, 2004; Alexander et al., 2006). Examining the structure and composition of vegetation after PB, together with modeling the behavior of potential wildfires may contribute to understanding the effectiveness of using PB as a management tool in reducing fuel hazard, define management timing and assess the effort required to reach the targeted objective.

Much of the current knowledge on the effects of PB on Mediterranean forest understory comes from wildfires or short-term post-fire studies. Hence, the main goal of this study was to quantify the effects of PB on the structure and composition of Mediterranean pine forests' understory, eight to nine years after management. As far as we know, long-term experimental designs specifically aimed to test the effects of burning on fuel load do not exist for our region. Hence, this study is based on comparing contemporary spatial differences between burned and paired unburned stands as a surrogate for the effects of fire treatment in the burned plots, eight to nine years after management in eight Mediterranean pine forests.

2. Material and methods

2.1. Experimental design

This study is based on the comparison of prescribed burned and paired unburned plots. The experimental design minimized the confounding effects of climate, topography or soil type between both burned and unburned stands, but is subject to the assumptions inherent to the space-for-time substitution (Picket, 1989). Hence, it assumes that the contemporary differences between burned and paired unburned plots, if they exist, are only due to the burning treatment and that other factors (e.g. abiotic characteristics, historic management and disturbances) are the same between paired plots. To minimize the effect of these assumptions on our results, stands were carefully selected to ensure burned and unburned plots were as similar as possible.

2.2. Site selection

PB in Catalonia (Spain) is carried out by the Forest Actions Support Group (GRAF) of the Autonomous Government (Generalitat de Catalunya). GRAF has compiled a database documenting all PBs that have been conducted from 1998 to date. The database includes information about fire characteristics (burn data, times of initiation and termination, ignition pattern, burned area), the assigned human resources, a burned-area perimeter map, and photographs taken in selected points. From the 233 underburn dataset performed between 1998 and 2011, we pre-selected 12 forest stands, treated with fire between the years 2003 and 2004, and not re-burned after. Site pre-selection was done after checking for potential paired unburned stands with the same slope, aspect and historic land-use as in the burned stand. Using historic series of georeferenced aerial photographs (http://www.icc.cat/vissir3/), we confirmed that selected sites have been forested since at least 1956, with no apparent differences in management or changes in land-use between burned and paired unburned stands since then. In addition, we checked for the absence of wildfires using historical wildfire database. Definitive stand selection was done after a field visit: sites showing traces of clear-cutting or mechanical management after burning were discarded.

Eight sites were finally selected (Table 1). In the managed stands, fire was ignited by hand and burned with backing fires (i.e., downhill or downwind) under fuels with moderate moisture content, from late winter to early spring between 2003 and 2004. Woody understory was not thinned before burning. Field sampling was done in 2011, at the peak of the growing season (May–July), eight or nine years after the treatment.

2.3. Study sites

The study sites are located in the NE Iberian Peninsula, at 0.7–1.7°E and 41.0–42.2°N, between 260 m and 1010 m a.s.l. (Table 1, Fig. 1). The climate is typically Mediterranean with dry summers and wet winters in three sites and Submediterranean, as defined