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Short-term effects of prescribed burning on litterfall biomass in mixed stands of *Pinus nigra* and *Pinus pinaster* and pure stands of *Pinus nigra* in the Cuenca Mountains (Central-Eastern Spain)

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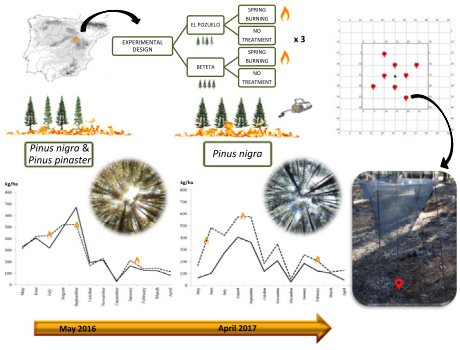
HIGHLIGHTS

- Short-term effects of low-intensity prescribed burns on litterfall biomass were studied.
- There is an increase of needle fall 3–4 months immediately after burning.
- One year after burning, there are no differences on litterfall biomass between burned and unburned plots (control).
- Burning could reduce production of inflorescences.
- Low intensity prescribed burning did not produce changes in LAI (Leaf Area Index).

GRAPHICAL ABSTRACT



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ABSTRACT

Fire severity, defined as the magnitude of fire effects in an ecosystem, is a key factor to consider in planning management strategies for protecting forests against fire. Although prescribed burning has been used as a fuel reduction tool in forest ecosystems, it is quite limited in the Mediterranean region. Furthermore, little is known about how tree crowns are affected by prescribed underburning aimed at reducing fire severity in conifer stands. As part of an ongoing study to assess the effects of prescribed burning on the tree canopy, litterfall is currently being monitored in a network of experimental plots located in mixed (*Pinus nigra* and *Pinus pinaster*) and pure (*P. nigra*) conifer stands in the Cuenca Mountains (Castilla La Mancha, Spain). A total of 12 study plots (30 m × 30 m) were established in a completely randomized experimental design to determine the effect of burning, with 2 treatments: no burning (control) and burning (i.e. with three replicate plots for each treatment and site). Burning was conducted in May 2016. In each plot, 8 litterfall collectors were installed at regular intervals, according to international protocols (ICP Forests), and all biomass falling into the collectors is being monitored monthly. The specific objective of this study is to assess how prescribed burning affects the rate of generation of foliar and non-foliar litterfall biomass due to the fire. In addition, the Leaf Area Index was estimated before burning and one year later to verify possible changes in the structure of the stands. This information could be used to help minimize the negative impacts of prescribed underburning on litterfall. To our knowledge, this study represents the first attempt to evaluate the effect of prescribed burning on litterfall biomass in Europe.

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1. Introduction

Forest fires represent one of the main types of disturbance in ecosystems in many parts of the world. Indeed, along with climate, fire is considered the main causal agent of vegetation changes, acting as a "global herbivore" (Bond and Keeley, 2005). Increased numbers of fires have been reported in some countries in Mediterranean Europe, including Spain (San-Miguel-Ayanz et al., 2012; Rodrigues et al., 2013). Nonetheless, huge spatial and temporal variability in fire frequency trends have been suggested, especially in Spain, where increasing and decreasing trends have been detected depending on the analysis period and scale considered (Turco et al., 2016). Fire regimes are related to climate and environmental changes (Pausas and Keeley, 2009) and are also dependent on human activity (Salis et al., 2013; Archibald et al., 2013). High-intensity fires threaten important ecological and social functions of pine species and their economic value (Pausas et al., 2008). The negative impact of forest fires on forests and their associated functions is expected to increase in the future as model predictions indicate increased frequency, intensity and severity of forest fires due to land-use change and climate change (Flannigan et al., 2009).

The importance of intensifying preventive measures is highlighted in order to minimize the forest fire risk, which is mainly due to the conditions of horizontal and vertical continuity and a high fuel load in forest stands in the Iberian Peninsula. Use of prescribed burning as a fuel management tool facilitates fire suppression efforts by reducing the intensity and size of wildfires and the damage that they cause (Fernandes and Botelho, 2003). However, the use of prescribed fire may alter the structural and functional conditions of the ecosystem. Such alterations can affect the tree crowns, especially under intense burning processes, which can have repercussions in changes in the patterns and regimes of the litterfall biomass.

For the implementation of prescribed fire as a management tool, it is essential to know the processes that determine the dynamics of forest ecosystems. One of these processes is the nutrient cycle, i.e. the flow of organic and inorganic matter through the ecosystem components. The main route of transfer of these nutrients to forest soil generally occurs via litterfall (leaves, buds, flowers, fruits, barks, twigs, etc.) (Bray and Gorham, 1964; Vitousek et al., 1995; Berg and Meentemeyer, 2001), although the volume of fine roots may play a more important role (Vogt et al., 1986). The balance between biomass production and decomposition controls the amount of carbon available in the soil and, therefore, site productivity. In Mediterranean forest ecosystems, the role of litter decomposition in nutrient cycling becomes even more important when considering the degradation of forest vegetation and soils by wildfire, long destructive cultivation and overgrazing (Kavvadias et al., 2001). Several studies have examined how litterfall is associated with climatic and site variables, such as those relating litterfall to climatic characteristics (Kouki and Hokkanen, 1992) and humidity (Hennessey et al., 1992). Furthermore, on a European scale, shedding of pine needles can also be related with relatively good precision to latitude (Berg et al., 1993, 1999), amplitude of the senescence period and nitrogen redisplacement (Del Arco et al., 1991), forest production (Bray and Gorham, 1964; Albrektson, 1988; Bellot et al., 1992) and soil fertility (Hernández et al., 1992). Scarce information has been reported regarding the effect of silviculture treatments (Roig et al., 2005) and the same happens with information regarding the effects of prescribed burning treatments on litterfall biomass.

Leaf Area Index (LAI) is another factor strongly related to forest productivity and stand structure (Innes et al., 2005). Accurate estimation of LAI is fundamental to understand the functioning of ecosystem processes, including rainfall, radiation and CO_2 interception, as well as quantification of ecosystem productivity (Montes et al., 2007), a factor closely associated with litterfall. Although several studies report little change in physiology, growth or stand structure after a low severity prescribed burning (e.g. Valor et al., 2015; Battipaglia et al., 2016), the impact of this treatment via direct effects on the canopy (heat from the flames) and possible stress by cambium heating (which could reduce LAI) are uncertain.

Pure stands of *Pinus nigra* Arn. ssp. salzmannii (Spanish black pine) and mixed stands of *Pinus pinaster* Ait. (Maritime pine) and *Pinus nigra* Arn. ssp. salzmannii have been chosen. Spanish black pine is one of the most widely distributed species in Central and Eastern Spain and Southeast France. The convention for Conservation of European Wildlife and Natural Habitats (European Union, 1996) has classified stands of this species as "habitat of European interest" (Lucas-Borja et al., 2016). Spanish black pine has disappeared from some regions, mainly as a result of wildfires or interspecific competition (mostly with *Pinus pinaster*) (Barbero et al., 1998). Spanish black pine is a Mediterranean tree species that is resistant to low intensity surface fires due to the thick bark characteristic of the species (Fulé et al., 2008; Touchan et al., 2012; Pausas, 2015). However, recurrent large wildfires are threatening the permanence of *P. nigra* forests in some Mediterranean areas as a result of the almost total lack of capacity of this non-serotinous pine to regenerate after fire (Espelta et al., 2003; Ordóñez et al., 2005; Fernandes et al., 2008; Christopoulou et al., 2013; Lucas-Borja et al., 2017). In addition, the species releases its seeds early in the year, at the beginning of spring, and therefore no seed bank is maintained after summer wildfires (Ordóñez et al., 2005). According to Lucas-Borja et al. (2016), little is known about the impact of prescribed burning on the natural regeneration of Spanish black pine. On the other hand, maritime pine is a conifer from the Western Mediterranean basin that covers >1,200,000 ha of land in Spain as a dominant species, under different elevation, climate and soil conditions, resulting in a high level of genetic variation (Alía et al., 1996). Important reforestation projects carried out during the 20th century, motivated by different factors, led to the wide expansion of this species. Fire is an important threat to maritime pine, but also plays a crucial role in the perpetuation of natural stands (Fernandes and Rigolot, 2007; Cruz and Fernandes, 2008). Some provenances of this species have a thick bark (that allows survival of the trees after low-intensity fire) and also produce serotinous cones (Fernandes and Rigolot, 2007). The provenance under study (from the Cuenca Mountains) does not produce serotinous cones (Alía et al., 1996). In Spain, the total area occupied by maritime pine that was burned between 1974 and 2010 was 674,055 ha, representing 31% of the total burned forest area. The area of Spanish black pine burned in the same period represents 4% of the total (Vázquez De La Cueva, 2016).

Several authors have reported higher stability of mixed species stands than of monocultures (e.g. Schütz et al., 2006; Felton et al., 2010). However, others argue that damage to mixed stands will only be reduced in the same proportion of the stable species (Lupke and Spellmann, 1997). Exploration of the resilience of pure and mixed stands to perturbations such as prescribed burning is therefore essential to establish recommendations for management and fire prevention strategies for these stands.

To our knowledge no previous studies have evaluated the effect of prescribed burning on litterfall biomass. This study is a first attempt to compare litterfall patterns in pure stands of *P. nigra* and mixed stands of *P. nigra* and *P. pinaster* in the short term, after prescribed burning, and one year after the disturbance. The hypothesis proposed in this study is that low-intensity prescribed burning in pure stands of *Pinus nigra* and mixed stands of *Pinus nigra* and *Pinus pinaster* does not affect crown trees, to corroborate this hypothesis the specific aims of this study were as follows: (1) to analyze the effect of prescribed burning on the quantity, patterns and fractions of the litterfall in pure *P. nigra* and mixed *P. nigra* and *P. pinaster* stands in the Cuenca Mountains; (2). to compare changes in LAI one year after treatment.

This study is part of a more comprehensive research study on the impacts of prescribed underburning, in which other treatment (autumn burning) and effects (soil, vegetation, tree heating of trunks and growing) are being investigated.

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