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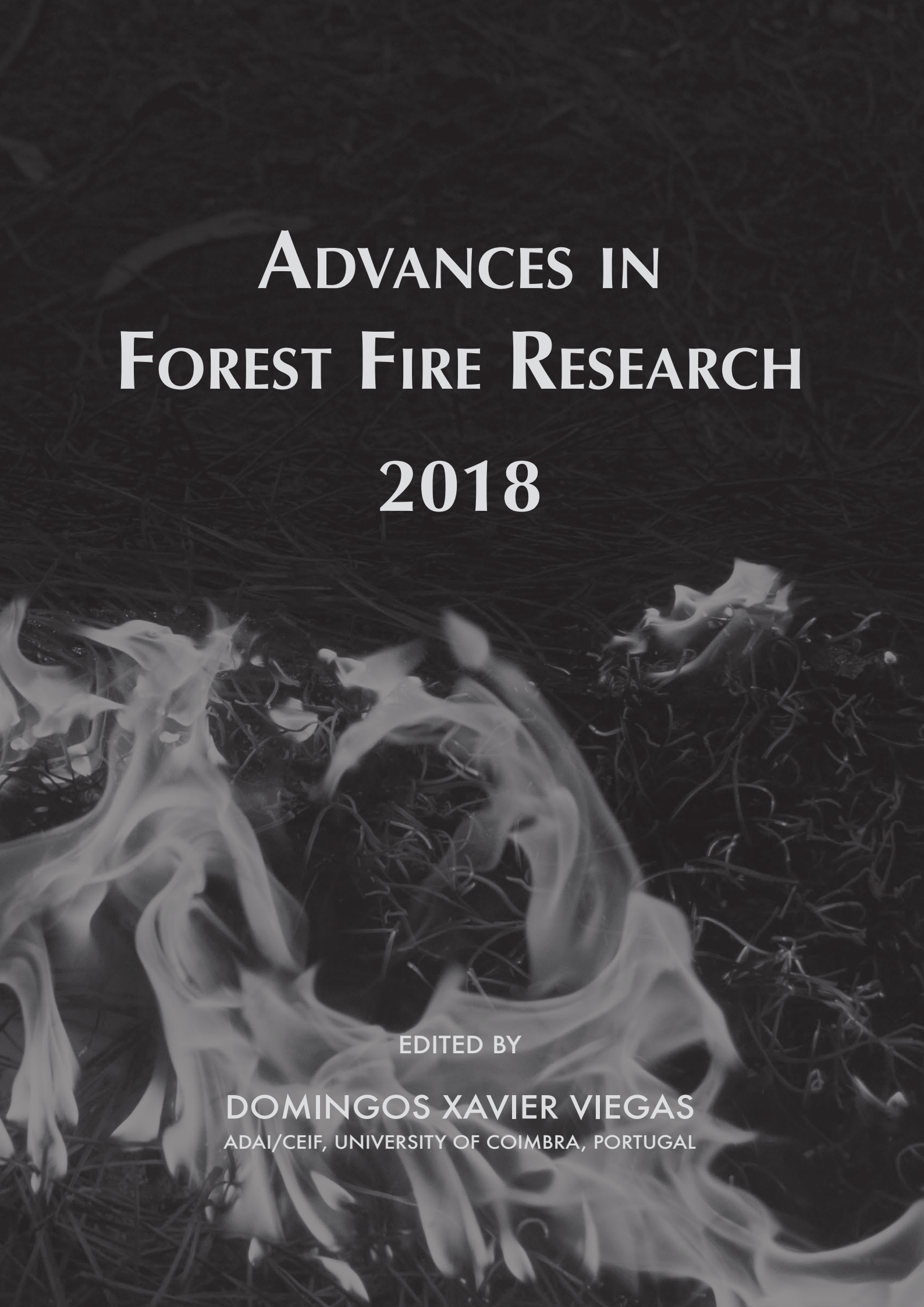

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Climatic conditions and fire regime affect vegetation recovery after large wildfires in Pinus forest ecosystems

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Abstract

Fire is one of the most important disturbance processes in *Pinus* forest ecosystems in the Mediterranean Basin. These ecosystems differ markedly in their response to this disturbance. They rely on climatic conditions in the area, fire regime and biological traits of the vegetation. Thus, understanding the influence of climatic conditions and fire characteristics in shaping postfire vegetation recovery will help to identify the most appropiate post-fire management strategies.

During recent decades, wildfire ocurrence in fire-prone ecosysems in the Mediterranean Basin has increased because of changes in land use, increased fuel load and continuity in the landscape. Moreover, these socio-ecological changes are related to the increase in burn severity and the surface affected. These large wildfires usually result in high heterogenous spatial mosaics with different degrees of severity and recurrence, which clearly influence vegetation regeneration capacity. However, fire regime characteristics not only affect vegetation regeneration after wildfire but also climatic conditions and their functional traits. Many authors recognise that in situations of high recurrence, resprouter species have an advantage over seeders.

To determine how vegetation regeneration in a *Pinus* fire-prone ecosystem may be related to climatic gradients, fire regime characteristics and plant traits, we selected three large wildfires that occurred in the Iberian Peninsula during 2012 and 2013: the Carnota wildfire in Atlantic climate conditions (Galicia), the Sierra del Teleno wildfire in transition climatic conditions (León) and the Cortes de Pallás wildfire in Mediterranean climatic conditions (Valencia). In each study area, a burn severity map of two levels (low and high) was obtained from a classification (threshold) of a Landsat-based differenced Normalized Burn Ratio image. Moreover, in each fire scar we evaluated recurrence in the last 20 years and differentiated two recurrence situations: low (1 wildfire) and high (2 or more wildfires). As a result, four scenarios were differentiated: low recurrence-low severity, low recurrence-high severity, high recurrence- low severity and high recurrence-high severity.

In each scenario, a proportional number of 2 m x 2 m plots were established. In each plot, we sampled the visual cover percentage of all plant taxa in 4 subplots of 1 m^2 three years after the wildfire. Mean cover values of *Pinus* saplings and resprouter and seeder shrubs were differentiated and compared among fire regime scenarios and climatic conditions. We observed diferences in the regeneration patterns in the three study sites, with more similarity between the Transition and Mediterranean ones. The common pattern of regeneration among the three climatic conditions has a significant negative effect on *Pinus* recruitment and cover in scenarios of high recurrence with low and high severity. At the same time, the resprouter shrubs species were favored by high recurrence.

Keywords: climatic gradients**,** *Pinus* forest, post-fire regeneration, vegetation functional traits, wildfire recurrence, wildfire severity

1. Introduction

Fire is a major and frequent disturbance in forest ecosystems, especially in Mediterranean Basin countries (Hosseini *et al*. 2018), where it shapes plant communities and landscapes. During recent decades, the natural fire regime has been affected by several factors, mainly by changes in land use, increased fuel load and continuity, global warming, changes in forest policies and an increase in invasive plant species (Pausas and Keeley 2014). Therefore, the main changes in the Mediterranean Basin in fire regimes characteristics include an increase in the number of fires (San-Miguel-Ayanz *et al*. 2016; Fernandez-García *et al*. 2018) and also in burn severity and the surface affected (González-de Vega *et al*. 2018). These large wildfires usually result in high heterogenous spatial mosaics with different degrees of severity and recurrence, which clearly influence vegetation regeneration capacity. However, fire regime characteristics not only affect vegetation regeneration after wildfire but also climatic conditions and their functional traits.

Fire affects all plants in burned ecosystems, but its effects strongly depend on the functional traits of the species, which determine their responses to disturbances, and reflect the mechanisms underlying these responses (Lavorel *et al*. 1997). Hence, changes in the abundance of plants with different functional traits could be used to assess the effects of fire. In addition, species sharing similar traits are expected to show similar responses after fire (Pausas 1999). For instance, many authors recognise that in situations of high recurrence, resprouter species have an advantage over seeders (Diez Delgado and Pons 2001; Calvo *et al*. 2012). However, in scenarios of high severity fires, there is not a common pattern in the behaviour of the resprouter versus seeder species. The reason for this could be because it depends on the type of resprouting mechanism or on the ability to survive inside serotine cones or fruit and the soil seed bank.

In general, fire-prone ecosystems, such as Mediterranean *Pinus* forest, are characterized by good resilience of vegetation to fire throughout the two regeneration strategies: resprouters (buds in soil or protected by tissues) or obligate seeders (seeds buried in the soil bank or enclosed in aerial banks) (Calvo *et al*. 2003, 2008, 2012). In some cases, seed germination can be initiated or improved by heat, presence of burnt wood or ash as scarifying agents (Alvarez *et al*. 2005, 2007; Calvo *et al*. 2013, 2016). High temperatures can also facilitate the opening of serotinous cones or fruits to release seeds after a fire (Calvo *et al*. 2008).

Several studies have been carried out on the effects of fire on *Pinus pinaster* (Maritime pine) forests in the western Mediterranean Basin after one fire (Calvo *et al*. 2003, 2008, 2012, 2016). However, the importance of this study lies in the effects of wildfire in maritime pine forest under different scenarios of recurrence and severity of fire. This species is one of the best-adapted tree species to fire. It is an obligate seeder with a dual-life strategy, early reproduction and both serotinous and non-serotinous cones, with a high percentage of serotinity, mainly in the north-western populations of the Iberian Peninsula very frequently affected by fire (Tapias *et al*. 2001).

The objective of this research was to determine how vegetation regeneration in a *Pinus* fire-prone ecosystem may be related to climatic gradients, fire regime characteristics and plant traits. Our goal was to improve knowledge of fire recurrence and severity effects on vegetation regeneration as a support tool to be used in post-fire planning and decision making for the recovery of ecosystem services provided by these forest.

2. Materials and Methods

We selected three study sites along an Atlantic-Transition-Mediterranean climatic gradient within Spain (Figure 1). The Atlantic study site is located in La Coruña Province (Carnota), within the perimeter of a large forest fire that occurred in September 2013, which burned 2,523 ha mostly covered by *Pinus pinaster* forest. The soils are acidic. The annual average rainfall is 1655 mm and the average

annual temperature is 13 °C, and there were no drought months during the summer. The Transition site (Sierra del Teleno) is a mega-fire that occurred in August 2012 located in the Southwest of León Province (Spain). The burned surface was 11,602 ha, predominantly covered by a *Pinus pinaster* forest. The mean annual rainfall is/was? 640 mm and average annual temperature 10 °C, presenting two months of summer drought. The Mediterranean site is a megafire in June 2012 in the West of Valencia province (Cortes de Pallás) that burned 29,752 ha. The surface affected by the fire was represented by reforestation stands of *Pinus pinaster* and *Pinus halepensis.* The soils are basic. Annual average rainfall is 582 mm and average annual temperature 16 ºC, with three months of summer drought (Ninyerola *et al*. 2005).

In each study area, a burn severity map of two levels (low and high) was obtained from a classification (threshold) of a Landsat-based differenced Normalized Burn Ratio image (Fernandez-García *et al*. 2018). Moreover, in each fire scar we evaluated recurrence in the last 20 years and differentiated two recurrence situations: low (1 wildfire) and high (2 or more wildfires). As a result, four scenarios were differentiated: low recurrence-low severity, low recurrence-high severity, high recurrence- low severity and high recurrence-high severity (Fig. 1).

A set of 120 plots of 2x2 m were randomly established in each study site. These plots were proportionally distributed among the four scenarios. In each plot, we sampled the visual cover percentage of all plant taxa in 4 subplots of 1 m^2 three years after the wildfire. Mean cover values of *Pinus* saplings, resprouter and seeder shrubs, and herbaceous species were differentiated and compared among fire regime scenarios and climatic conditions.

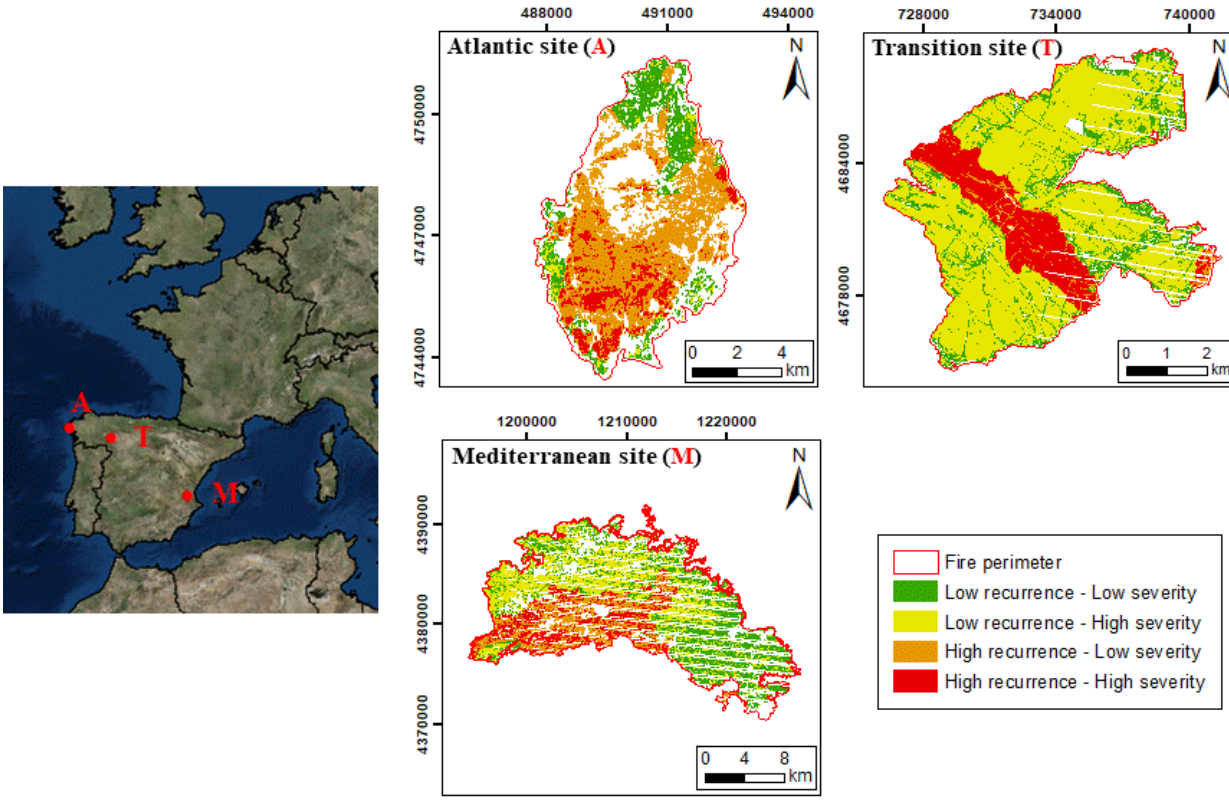

Figure 1 - Location of the three study sites in Spain across an Atlantic (A)-Transition (T)-Mediterranean (M) climatic gradient. Fire perimeter and four scenarios of recurrence (low= one fire in the last 20 years, high= more than one fire in the last 20 years) and severity (low and high)

A Principal Component Analysis (PCA) was carried out to distinguish the effects of study sites and recurrence-severity scenarios in the vegetation response (Pine saplings cover, resprouter shrubs cover, seeder shrubs cover and herbs cover).

Principle Component Analysis (PCA), which included all the studied variables (Pine saplings cover, resprouter shrubs cover, seeder shrubs cover and herbs cover), were performed for the comparison among the three study sites (Atlantic-Transition-Mediterranean) and in each site to identify the behaviour of each recurrence-severity scenario.

All data analyses were carried out with R (R Core Team, 2016), using the vegan package (Oksanen *et al*. 2016).

3. Results

In the analysis of the ordination of the three study areas together in relation to the plant functional traits we observed a clear differentiation (Fig. 2) between the Atlantic site, characterized by the dominance of herbaceous cover and resprouter woody cover, mainly dominated by *Ulex europaeus* and *Rubus* sp., and the other two study sites. Both the Transition and Mediterranean sites were more similar in terms of vegetation functional traits, which were characterised by the abundance of seeder shrub species and the highest cover of pine seedlings.

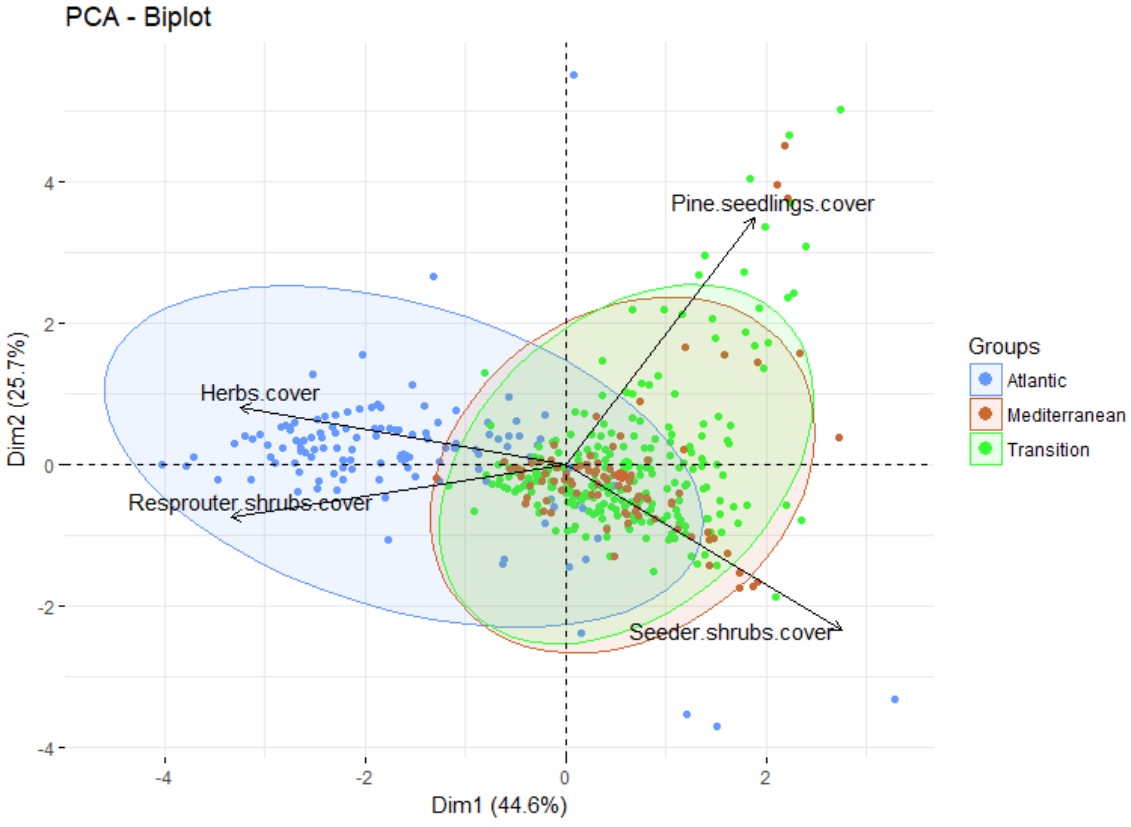

Figure 2 - PCA biplot showing relationships between recurrence-severity scenarios in the three study sites (Atlantic- blue dots, Transition- green dots and Mediterranean- brown dots) and vegetation functional traits (Herbaceous cover, Resprouter shrubs cover, Seeder shrub cover and Pinus seedlings cover).

There is no clear effect of the different fire regime attributes in the abundance of the different plant functional traits after fire in the Atlantic site (Fig. 3). We observed that in the scenario of high recurrence and high severity herbs cover predominated, under high recurrence and low severity there was higher cover of shrubs species, both resprouters (*Ulex europaeus*) and seeders (*Halimium lasianthum*, *Erica cinerea* and *Erica ciliaris*) .Pine seedlings were abundant in environments of low recurrence and low severity.

However, in the Transition site, recurrence represents the main fire regime attribute that affected vegetation regeneration. Under the scenario of high recurrence, more than two fires in 20 years, resprouter woody species, such as *Erica australis* and *Pterospartum tridentatum* showed better adaptation to regeneration. Whereas, in scenarios of low recurrence, *Pinus pinaster* seedlings have a better opportunity to germinate.

In the Mediterranean site there was a common pattern of vegetation traits regeneration behaviour, with clear dominance of resprouters in a high recurrence scenario, regardless of severity. *Quercus coccifera* is the resprouter species with highest abundance. However, in scenarios of low recurrence, there was a clear effect of fire severity. So, low severity favoured the increase in the cover of *Pinus halepensis* and *Pinus pinaster* seedlings, while high severity positively affected the dominance of shrub seeder species such us *Ulex parviflorus*.

4. Discussion

A better understanding of the ecological role of fire regime attributes in the regeneration of ecosystems is a matter of importance, given the evident increase in both the number and severity of wildfires in the Mediterranean Basin (Moreno and Chuvieco 2013). The field study revealed marked differences in the type of plant functional traits regeneration in relation to fire regime attributes and climatic conditions. In general, areas with wetter climatic conditions, such as the Atlantic site, show faster regeneration of the resprouter and seeder shrubs and herbaceous species than much drier climate areas, such as the Transition and Mediterranean study sites. This is in accordance with findings obtained by other authors (Arnan *et al*. 2007; Acácio *et al*. 2009).

Vegetation from fire-prone ecosystems is fire-adapted, and is therefore highly resilient, meaning that almost all perennial species can recover after a fire (Calvo *et al*. 2008), though, they could be constrained by the fire regime attributes. Post-fire vegetation cover depends not only on the number of fires, but also on the time interval between them and severity. Some authors have indicated that the time since the last fire has a stronger effect than the number of fires, provided the former is sufficiently long to allow some vegetation to recover (Espelta *et al*. 2008; Fernandes and Rigolot 2007).

The results of the current study indicated that the fire recurrence has a greater impact on the regeneration of the different plant functional traits than fire severity. Many authors have observed that high recurrence and short intervals between successive fire events may lead to substantial changes in vegetation (Tessler *et al*. 2014, 2016). In general, the impact of recurrent fires on vegetation composition produce an increase in the dominance of resprouter shrubs (Delitti *et al*. 2005; Schaffhauser *et al*. 2011, 2012). So, resprouters can regenerate efficiently up to a certain fire recurrence threshold. In the case of the Transition site, *Erica australis* is one of the most favoured resprouters by fire recurrence. The buds of this species, *Erica australis*, are found in the lignotuber (Calvo *et al*. 2002). The presence of a lignotuber gives a great advantage in their response to recurrent fires (Moreno *et al*. 1999). The presence of this type of storage mechanism is probably associated with recurring perturbations that eliminate all the aboveground biomass. Another shrub species with great ability to resprout in the Transition site is *Pterospartum tridentatum*, mainly from the bank of shoots situated in the root (Tárrega *et al*. 1992). This species undergoes a process of progressive ageing of the aerial biomass, only the outer edge of each branch remaining green. Therefore, recurring perturbations favour rejuvenation (Calvo *et al*. 2002). However, a decrease in pine tree cover was documented after high

recurrence in the three study sites. A fire regime of low recurrence allows the pines to reach reproductive age (Reyes and Casal 2002).

Lloret *et al*. (2003) pointed out that high fire recurrence produced an increase in grasses, and a decrease in abundance of *Quercus*, and disappearance of *Pinus*. In the same way, Tessler *et al*. (2014) showed that a higher number of fires led to a decrease in *P. halepensis* density in Israel. A similar tendency was found by Herman (2009) and Santana *et al*. (2010) in studies carried out in Spain.

In the current study, the effects of burn severity were only observed in the low recurrence scenario, where low severity favoured the increase in *Pinus halepensis* cover and *Pinus pinaster* seedlings, while high severity increased the cover of seeder species, such us *Ulex parviflorus*, in the Mediterranean site. The last species are characterised by hard coat seeds, which allow them to resist the high temperature reached under high severity fires (Santana *et al*. 2012). Similarly, the position of these seeds in the soil seed bank is another factor that controls their ability to germinate after fire. Baeza *et al*. (2002) in prescribed fires carried out in the south of Spain, observed that *Ulex parviflorus* showed the highest percentage of germination when situated 3 cm deep, which seems to evidence that very intense temperature pulses in the first centimeters of soil profile could produce seed death, while at deeper situation (3 cm) stimulate seed germination. This seed dormancy-breaking behavior would guarantee their capacity to regenerate in areas affected by high severity fire (Baeza *et al*. 2002).

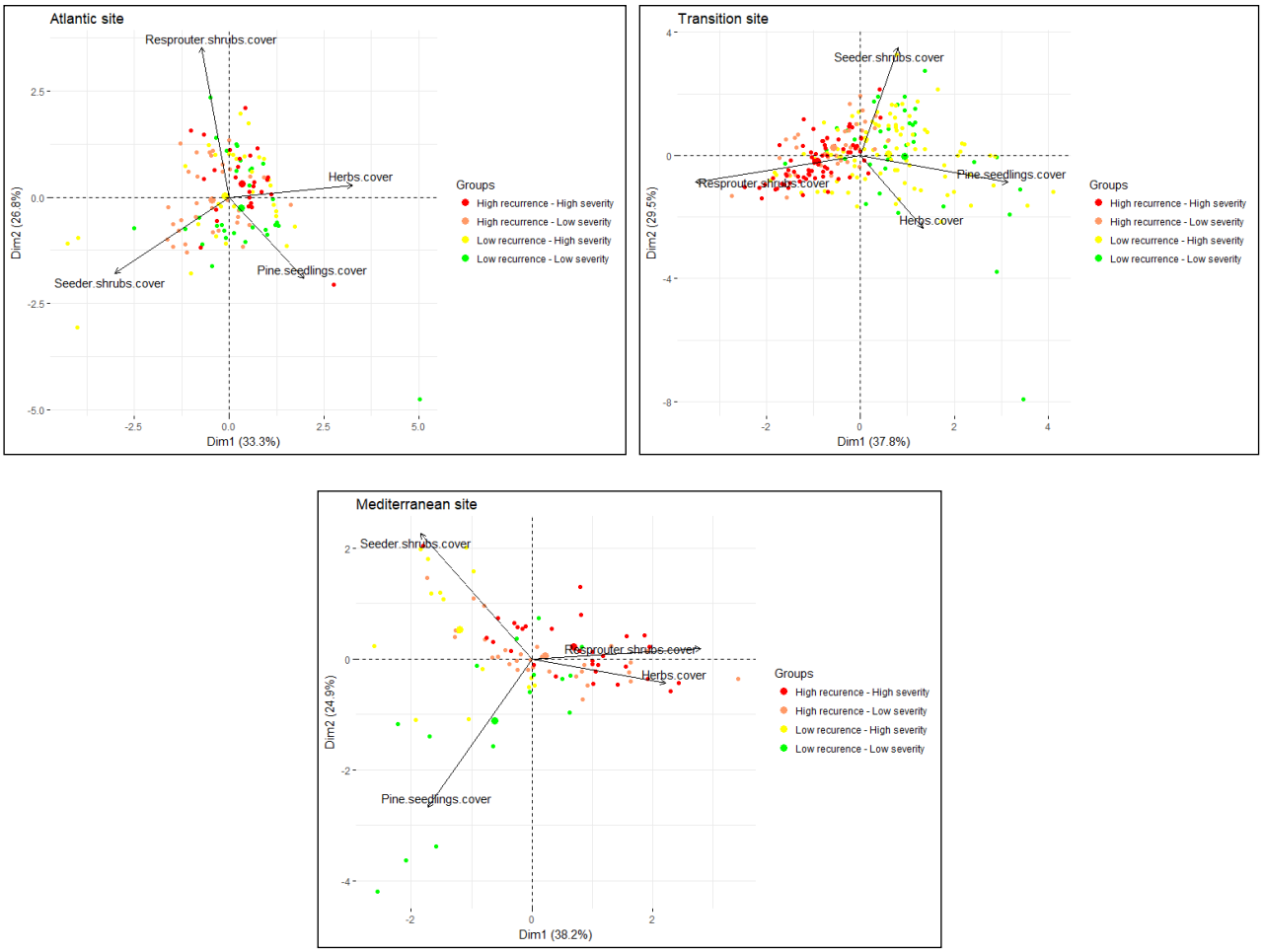

Figure 3 - PCA biplot showing relationships between recurrence-severity scenarios (high recurrence and high severity (red dots); high recurrence and low severity (orange dots), low recurrence and high severity (yellow dots) and low recurrence and low severity (green dots)) and vegetation functional traits (Herbaceous cover, Resprouter shrubs cover, Seeder shrub cover and Pinus seedlings cover) in each of the three study sites (Atlantic, Transition and Mediterranean).

Adaptive strategies developed by plants that have evolved in Mediterranean climates provide resilience to regenerate after fire during a short-term period. However, it is important to acquire knowledge about the ecological effects of fire severity and recurrence to apply proper adaptive forest management in changing scenarios in which a fire regime is not natural. According to the results obtained in this study, we conclude that the regeneration of the different plant functional traits after wildfire depends on the climate in the study area, with greater vegetation regeneration speed under wetter climatic conditions.

Among the fire regime attributes, apparently fire recurrence showed more impact on the vegetation regeneration with a clear dominance of resprouter species and a decrease in the cover of pine seedlings. The main effect of severity was observed in the Mediterranean study site and with low recurrence, where seeder species and pine seedlings were favored.

5. Acknowledgements

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