



Relationships Between Wildfires, Management Modalities of Community Areas, and Ownership Types in Pine Forests of Mainland Portugal

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Abstract

Investigations of factors influencing wildfire risks in Mediterranean forest areas have rarely considered the possible influence of the ownership type and management modalities in forest areas owned and/or managed by rural communities, referred to as baldios in Portugal. This study aimed to analyse the relationship between forest ownership types and the management modalities of community forests in the distribution of wildfires in *Pinus pinaster* areas of Portugal over the past 40 years. We carried out a comparative analysis of *P. pinaster* forests and wildfires considering three ownership types (community, private, and state forests) and four different management modalities of the community lands (by local communities or local authorities through independent management or in co-management with national Forest Services). The protection status of the pine forests was also considered. We also evaluated the possible influence of topographic variables—elevation, slope, and aspect—and their relationships with ownership types, management modalities, and protection status. To evaluate the trends and making use of the existing cartography, the study period (1975 to 2017) was subdivided into three time periods (1975–1989, 1990–2009, and 2010–2017). The results revealed significant differences in the annual percentage of burned areas in different among ownership types but no differences among protected and unprotected areas. Baldios showed the highest percentage of burned area relative to their total area, but some differences between the management modalities are apparent. Furthermore, the proportion of burned area increased over the study period, particularly with a very large area burned in 2017, possibly reflecting climatic changes and a decrease in management activities. This indicates that forest management should be strengthened, with special attention to fuel management. Fuel reduction could be improved through the development of new bioeconomic activities in community forests.

Keywords Baldios · Community-based forestry · *Pinus pinaster* · Fire risk · Fuel management

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Introduction

In the twentieth century, wildfires began to increase their impacts on ecosystems and societies even creating a sense of catastrophe (Moreira et al. 2010; Tedim et al. 2013). Every year, tens of thousands of fires burn hundreds of thousands of hectares of forests and other rural areas around the world (Rego et al. 2018; Ribeiro et al. 2020). Previous studies have shown that several Mediterranean ecosystems are resistant to fire, such as shrub and oak forests, but others, such as for example pine forests, are more sensitive (Pausas et al. 2008). This is the case of single-species maritime pine plantation forests, that occupied in 1990s about 50% of the forest area burned in Portugal (Pereira and Santos 2003).

In Portugal, the area of *Pinus pinaster* pure plantations increased as a result of policy changes in the nineteenth and twentieth centuries (Rego 2001; Fernandes and Rigolot 2007), along with European and global trends focusing on economic and environmental goals, mainly to reduce soil erosion in mountainous areas, caused by intensive farming and grazing (Le Maitre 1998; Germano 2000). Since the beginning of the twentieth century, public forestry policies in Portugal focused on the implementation of the Forest Regime¹ through the Afforestation Plan (1938–1968), which resulted in the afforestation of 420,000 ha, mainly with *P. pinaster*. The main goal of this programme was to stabilise dunes and mountainous areas with high soil erosion levels. Most of these unstable areas were located in community areas known as baldios (Devy-Vareta 2003). Before the implementation of this programme, the National Forest Services collected and organised information regarding land cover and soil degradation limits, amongst other data, in order to select priority areas to implement the Afforestation Plan, both in the State and the baldio areas (MA 1939). The afforestation and the outcomes of this plan became one of the most remarkable interventions in the Portuguese mountains, with the aim to reverse the extreme soil degradation resulting from deforestation, cereal cultivation, excessive grazing, and unbalanced fire-based pasture regeneration (Germano 2000).

Developed by the Forest Services and complying with the national forestry rules, afforestation under the Forest Regime drastically changed the traditional use of baldio areas. Earlier, they were used by commoners to provide pastures and agricultural fields, while the existing forests were used to harvest firewood (Fernandes et al. 2014). Moreover, pine forests were managed by resin collectors, who, along with their activities, took care of these areas and removed old and unproductive trees to use as fuel (Nunes 2012). The decrease and changes in agricultural activities, the replacement of wood by other energy sources (gas and electricity), and the rural exodus that caused the abandonment of baldios and rural areas in general are factors that led to the accumulation of biomass in the forests (Baptista 2010). Furthermore,

¹ The 'Forest Regime', whose history begins with the development of the first Forest Code in France in 1827, is a legal regime and can be defined as a set of special rules for the management, exploitation and enforcement of public and communal forests. It is a set of norms necessary not only to create, operate and preserve forest resources but also create and maintain forest cover, control the water regime, protect the floodplains, and decrease drylands or mountain soils erosion risks (Germano 2000).

the afforestation of baldios used *P. pinaster* pure stands—highly flammable with horizontal and vertical fuel continuity (Fernandes and Rigolot 2007; Nunes 2012). This situation associated to the lack of management and fire prevention plans along with neighbouring pasture burns eventually caused a considerable impact of wildfires in community forests.

To implement the Afforestation Plan, the Forest Services occupied and started to manage the baldio lands between the 1940s and the 1970s. The forest plantations covered 91% of the baldio lands (Rego 2001; Fernandes et al. 2014). After the Portuguese Democratic Revolution of 1974, the ownership and tenure rights of community lands were constitutionally recognised. These community areas were returned to their previous traditional owners, namely the rural communities. Currently, about 83% of the Portuguese forest is private. The State owns 3% of the forest area of the country, and community forests occupy approximately 12–15% of this area, under different management modalities (Feliciano et al. 2015). These lands represent a valuable heritage where important forestry activities take place (AFN 2010). However, land-use restrictions, resulting from the implementation of the Forest Regime, and later in the 1990s, the introduction of a national and European protected area network may have influenced the interests of rural communities toward these areas and, consequently, the management quality (Baptista 2010). Moreover, these areas experience frequent wildfires, occurring annually, which render forest management more difficult (Mateus and Fernandes 2014; Fernandes et al. 2014).

Since the second part of the twentieth century, fire frequency and burned area have been increasing in Portugal, causing by social, economic, and environmental losses and attracting more attention on both national and international levels (Moreira et al. 2001; FAO 2005; Nunes 2012; Fernandes et al. 2014). Thus, the interest in understanding changes in wildfire regimes is increasing.

To improve fire risk management and to preserve the integrity of ecosystems (Krebs et al. 2010), numerous studies have focused on factors influencing fire regime changes in recent decades. These factors include vegetation types (Pausas et al. 2008), topography, and weather conditions associated with climatic changes (Pausas and Fernández-Muñoz 2012; Bifulco et al. 2014), and human (in)activities (Bal et al. 2011; Moreno et al. 2014). Others have focused on fuel load and its continuity (Andrews and Butler 2006), political and legislative aspects (Montiel-Molina 2013) and socio-economic attributes (Marques et al. 2011; Mateus and Fernandes 2014).

In general, previous research has shown that all these influencing factors and effects combined have caused a large-scale increase in fire hazards, not only in Portugal but also in most of the Mediterranean regions (Pausas and Fernández-Muñoz 2012; San-Miguel-Ayán et al. 2013), mainly in mountainous areas, where most community lands are located. At national and international levels, the twentieth century was also marked by significant changes in the forest ownership structure, as well as the search for solutions in the field of biodiversity conservation and improved sustainable forest management (Weiss et al. 2019). However, thus far, few studies have investigated the impacts of such changes in different forest tenure regimes and particularly in community-based management areas.

Nowadays, community forests cover more than 10 million ha in 16 European countries (Živojinović et al. 2015). Community forests are defined in different ways

in different countries, but they are generally forested landscapes, located in mountainous regions and owned or managed by local communities, local authorities, or other collective stakeholders. Additionally, several of these areas have some type of conservation or protection status, recognised by central governments, which are often a source of conflict between authorities and owners (Young et al. 2005). In Portugal, understanding the effects of such measures on baldio forest management since they were returned to rural communities is crucial.

This study aimed to ascertain whether forest ownership types, management modalities of baldios, and protection status have influenced the distribution of wildfires in *P. pinaster* burned areas in the last four decades (1975–2017). This period started immediately after the change from a dictatorship to a democracy in 1974, instigating the return of the baldios to the rural communities, and ends in 2017, the most catastrophic year for wildfires in Portugal. The considerations of the protection status and the main topographic variables associated (elevation, slope, and aspect) were discussed. The trends over the global study period were analysed by the analysis of three different periods (1975–1989, 1990–2009, and 2010–2017).

Theoretical Framework

The analysis of forest ownership and management systems concerns one of the main social aspects of wildfire and requires a consistent theoretical foundation. On the basis of this premise, the study built upon the conceptual background of fire social sciences. In particular, we based the analysis on two theoretical frameworks: the *socio-ecological systems theory* and the *cognitive hierarchy theory*.

The *socio-ecological systems theory* focus on systems of people and nature, emphasising that humans must be seen as a part of, not apart from nature (Berkes and Folke 1998; Roepstorff et al. 2003; Rawluk et al. 2020) and is the most common approach to wildfire risk in the Mediterranean-climate ecosystems (San Miguel et al. 2017; Montiel-Molina et al. 2019). It is also the basis of the natural hazard paradigm in geography, which considers that ‘the source of disaster is rooted in the relationship between people and their environments’ (O’Brien et al. 2010). The *socio-ecological systems theory* is suitable to understand the complexity of socio-spatial structures and functions, which define the factors of ignition and fire propagation (Martínez et al. 2009; O’Connor et al. 2011).

The *cognitive hierarchy theory* is also a strong theoretical framework for social learning processes, providing a suitable basis for understanding social relationships in community-based forestry. This theory, which is a behavioural model that attempts to describe human thought processes via strategic games, allows the examination of the concepts underlying human activities, such as values, attitudes, and norms, and examines the relationships among them. Considering that the developments in fire policy, such as environmental politics, depend on the social construction of the fire problem (Hajer 2005), the social perception of fire risk and fire culture are critical components of understanding and enhancing support for specific management strategies (Czaja and Cottrell 2014). This theory is one of the bases of prevention programmes for reducing unwanted ignitions,

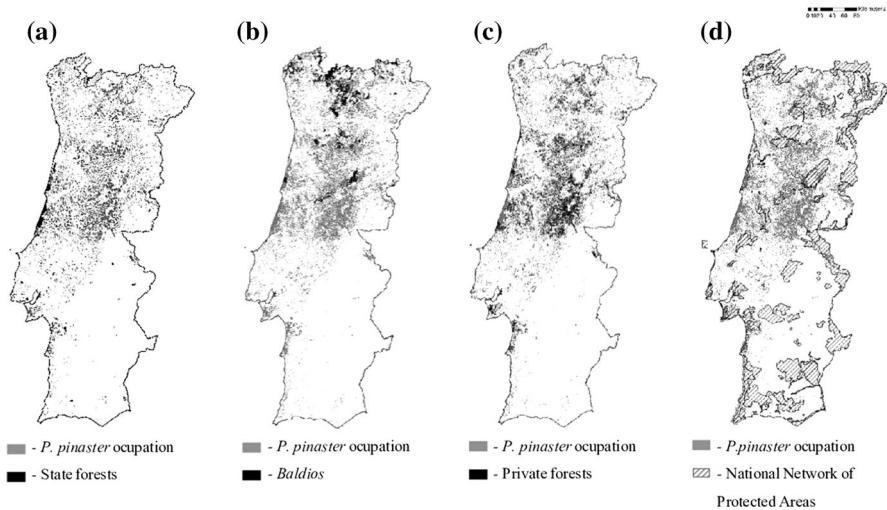


Fig. 1 *P. pinaster* forests in **a** baldios, **b** private areas, **c** state forests, and **d** areas included in the National Network of Protected Areas

including the promotion of good practices of fire use by the public and allowing to reduce the social vulnerability from wildfires.

Data and Methods

Study Areas

To achieve comparable results and to allow correct interpretations, the study focused on pure stands of *P. pinaster* (in which the specie occupies more than 75% of the total cover) in mainland Portugal, as this species has been historically present in the Portuguese territory in the community (baldios), private, and State areas. Both baldios and *P. pinaster* forests are mainly located in the north and the centre of Portugal (MA 1939; CNVTC 2010). Moreover, *P. pinaster* forests are present both inside and outside the National Network of Protected Areas (Fig. 1).

Most baldios have some type of protection or conservation status within their perimeters, such as the Natura 2000 sites and natural parks or reserves, which partly limits rural communities in their land-use choices. In this study, the system of Protected Areas (PA) considered included:

1. The national network of protected areas,
2. Classified areas that integrate the Natura 2000 network, and
3. Other protected landscapes under international commitments assumed by the Portuguese State.

Currently, at the national level, this system of Protected Areas occupies around 2.7 million ha, 8% of which is covered by *P. pinaster* stands. A large part of the baldios is also under protection status. The geographic information of the PA analysed in this study was retrieved from the Forest Services website (ICNF 2018a).

The use and occupation of soil by any forest species are not static in time or space, and the landscape reflects these dynamics (natural and anthropological). We considered the changes that took place in pine plantations in the past four decades. According to the periods previously defined, we considered the following maps:

1. 1970 National Forest Inventory Maps (IFN70), scanned and vectorized by the Centre for Applied Ecology of the School of Agriculture/University of Lisbon with the support of the General Directorate for Territory and based on data provided by the General Directorate of Forests,
2. Land Cover Map for 1990 (COS1990)², and
3. Land Cover Map for 2010 (COS2010) (see footnote 2).

The IFN70, COS1990, and COS2010 provide information on the land occupation type, cover percentage, and dominant and secondary species, in the case of forest cover, had a minimum mapping unit of 1 ha.

Information on elevation, slope and aspect were derived from a digital terrain model for mainland Portugal, with a resolution of 30 m (DTM, ESRI-PT 2009). The elevation map was subdivided into 20 classes, from 0 to 2000 m, with intervals of 100 m. The slope was categorised in six classes: five classes with intervals of 5° between 0° and 25°, and the last class with a slope above 25°. Lastly, the aspect map was classified into nine classes: flat, N, NE, E, SE, S, SW, W, and NW. To obtain information concerning the distribution frequencies of topographic variable classes, each of these three maps was intersected with the *P. pinaster* areas (extracted from the land use map COS2010) for the different forest ownership types, management modalities, and protection statuses.

Information on the annual national burned areas for the 1975–1989 period was provided by the School of Agriculture/University of Lisbon. Information on areas burned from 1990 to 2017 were obtained from the Forest Services website (ICNF 2018b).

Data on Ownership Types and Management Modalities of Baldios

The definition of the forest ownership perimeters was one of the main challenges during this study because of an incomplete land registry, which, among other factors, hampers the management of Portuguese forests. The land cadastral registration system, implemented between the 1930s and the 1990s, covered only 50% of the forest ownership (Beires et al. 2013), mainly in the south of Portugal.

² Both maps (2 and 3) are available on the website of the General Directorate for Territory (DGT 2018).

Table 1 Area of *Pinus pinaster*, 1970, 1990, and 2010. Sources: IFN1970, COS1990, and COS2010

Type of property	<i>Pinus pinaster</i> occupation (thousand hectares)		
	1970	1990	2010
Baldios	129.0	100.3	117.4
Private areas	1126.5	973.0	829.2
State areas	32.1	30.8	31.0
<i>Protection status</i>			
Protected areas	145.7 ^a	151.7	150.6
Non-protected areas	1141.9	952.3	833.9

^aOccupation of *P. pinaster* before the introduction of protective status

Table 2 Main baldio management modalities, based on the type of managers and the type of management type). Source: ICNF 2015

Management modalities	Type of management	
	Co-management with the forest services	Autonomous
<i>Type of managers</i>		
Communities	Modality 1	Modality 2
Local authorities	Modality 3	Modality 4

To obtain data regarding baldio perimeters, we used information from the Plans for the Use of Baldios (PUB). The development of PUBs started in 2006. Nowadays, baldio managers have developed and validated 664 PUBs with GIS maps, most of which are already approved by the Forest Services (currently the ICNF—Institute for Nature Conservation and Forests).

We considered the three main constitutionally recognised ownership types in the distribution of pure stands of *P. pinaster*: communal/baldios, private, and State ownerships. In this study, the shapefiles of the approved PUBs were used. These plans cover approximately 250,000 ha of community lands. We also used state forests GIS maps. As a result, on the IFN70, COS1990 and COS2010 it was possible to distinguish *P. pinaster* pure plantations, between baldios and State ownership. The remaining part represented a private pine stands.

The maps developed in this study, showed, for example, that in 2010, around 12% of the area covered by the *P. pinaster* forests was baldios, 85% was privately owned and only the remaining 3% belonged to the State. Moreover, around 15% of the *P. pinaster* forests were in protected areas. The evolution of the areas occupied by *P. pinaster* from 1970 to 2010 is shown in Table 1.

With respect to the management of baldios, four main modalities were considered in the study, on the basis of the type of managers (rural communities or local authorities) and their relationship with the Forest Services (co-management or autonomous management) (Table 2).

For the analysis of the different modalities of the management of baldios, we used a map compiled by the Forest Services in 2013 within the PUB areas, which

covered approximately 243,000 ha of baldios. Data on the 664 baldios units were subdivided into four groups (Table 2). Approximately 50% of these units were co-managed by rural communities with the Forest Services (modality 1), while autonomous management by communities accounted for 14% (modality 2). Local authorities (parish councils) in co-management with the Forest Services or in autonomous management (modalities 3 and 4, respectively) managed the remaining units, 29% e 21% respectively.

Also, the effect of the protection status was evaluated by the comparison of areas included in the Natura 2000 network or other types of protection (e.g. natural reserves) with areas outside these networks.

Some units showed conflicts/litigation related to a lack of agreement on their exact perimeters or associated to land appropriation problems. An analysis of the baldio area map in 2013 showed that conflict areas occupied 7% of the area. According to San-Miguel-Ayanz et al. (2013), fires in Galicia and northern Portugal (regions with a high concentration of baldios) have been associated with social conflicts that often arise from disputes over the use and exploitation of rural lands. According to Carmo et al. (2011), in Portugal, between 2001 and 2010, one-third of the fires with known causes were results of land use and vegetation management conflicts. Once again, an outdated and incomplete land cadastre complicated the situation. The new simplified register, described in Portuguese Law No. 78/2017, did not provide a baldio registration. In contrast, the Baldios Law No. 75/2017 provides a separate platform for the development of electronic registration for baldios, but its implementation is vaguely described. Because of these problems, the units with conflicts could not be included in the statistical comparisons among the main modalities.

During the GIS analysis, vector data format maps were processed and analysed using the ArcGIS® 10.6 software. For this, we built a GIS database with information on the topographical features of the *P. pinaster* distribution per ownership type, management modality, and protection status, as well as for burned areas between 1975 and 2017.

Data Analysis

At the temporal scale, the burned area of pure pine forests from the period of 1975–2017 at the national, mainland level was analysed on a per-year basis and aggregated into three periods (1975–1989, 1990–2009, and 2010–2017). This aggregation was in accordance with the updated dates in the land occupation maps IFN1970, COS1990, and COS2010; these periods were also in relation to important events in forest management. The first period coincided with the management of the baldios after they were returned to rural communities, which took place between 1975 and 1989. In the second period, from 1990 to 2009, the classification of natural habitats and protected areas was developed, and the network of protected areas was established, which might have resulted in economic and social conflicts and other changes. As a consequence of the mega-fires in 2003 and 2005, forest resource management plans began to develop on different scales, together with the National Fire Protection Plan of 2006.

The third period (2010–2017) encompasses two important events in the history of community forests: the elaboration of hundreds of PUBs and the legal framework for the creation and operation of teams of forest workers in state forests and community lands. This period also included mega-fires in 2017. We hypothesised that these factors subsequently influenced wildfire regimes in some forest areas.

On the spatial scale, the comparisons between the proportions of burned areas of the different classes had to consider the potential areas to burn. The establishment of an Annual Percentage Burned Area (APBA), which is the ratio between the area burned in a certain class and the total area of this class was used to quantify this trend.

We considered the APBA data for 43 years, subdivided into three periods and related to three different forest ownership types, four different management modalities for baldios, and two different protection statuses. This formed the basis for the statistical analyses.

Statistical Analyses

First, we considered the differences in the ownership types and the management modalities of baldios. As the baldios were also an ownership type, and to allow for easier comparisons, we subdivided the baldios according to their four management modalities. The combination resulted in six classes of type of ownership/management:

- Baldio forests—Modality 1
- Baldio forests—Modality 2
- Baldio forests—Modality 3
- Baldio forests—Modality 4
- Private forests
- State forests

We performed two-way analysis of variance (ANOVA) to evaluate the differences in APBA according to the six classes of type of ownership/management by using the years as the second source of variation. The analyses were performed with the SPSS statistical software. The significance level for p-values was set at <0.05 . For each ANOVA model with statistically significant results, we used Duncan's post hoc tests to assess individual differences. These analyses were performed for the entire study period (43 years; 1975–2017) and separately for the three periods considered.

Secondly, we performed similar analyses for the two classes of the protection status.

Results and Discussions

Topographic Context of *Pinus pinaster* in Different Classes

The distribution of *P. pinaster* according to different topographic variables and different classes can be observed in Fig. 2.

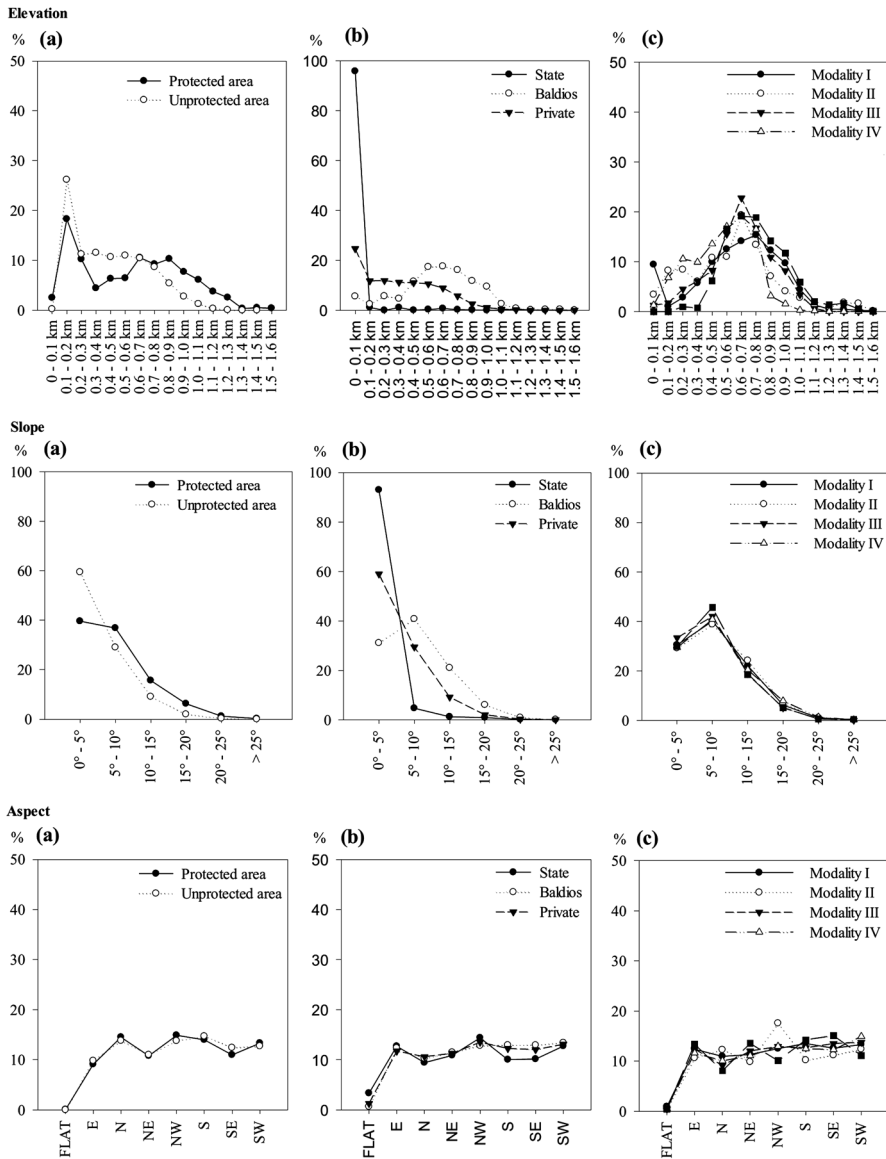


Fig. 2 Distribution of *P. pinaster* according to topographic variables (elevation, slope, and aspect) from top to bottom and different classes from left to right: **a** protected versus unprotected areas, **b** ownership types, and **c** baldios' management modalities

Figure 2 shows that pine forests in protected areas were at higher elevations and steeper slopes than pine forests in unprotected areas. For ownership types, it was clear that pine forests in the State ownership were at lower elevations with less slopes, whereas pine forests of baldios were at higher elevations with steeper slopes. Private pine forests were at intermediate elevations and slopes. It was clear that pine

forests in the different management modalities of baldios showed very similar distributions for elevation and slope. Aspect seemed to be very similar for all of the classes considered.

There was an obvious relationship between forest ownership types and their elevation and slope distributions. Moreover, the topographic factors were important and affected the dimension and severity of fires (Carmo et al. 2011). Because of this strong association, there was a possible confounding effect between these topographic variables and ownership types and therefore, it was not possible to assess in the comparisons of the APBA. The possible differences attributed to elevation by Marques et al. (2011) might also be attributed to ownership types, as possible differences attributed to ownership types might be explained by topographic variables. The ownership types were intrinsically associated with their topographic context.

Different Time Periods

Our analysis of the burned areas showed that the wildfire regime had changed significantly in Portugal over the past four decades. The annual burned area varied significantly from 1975 to 2017 (Fig. 3).

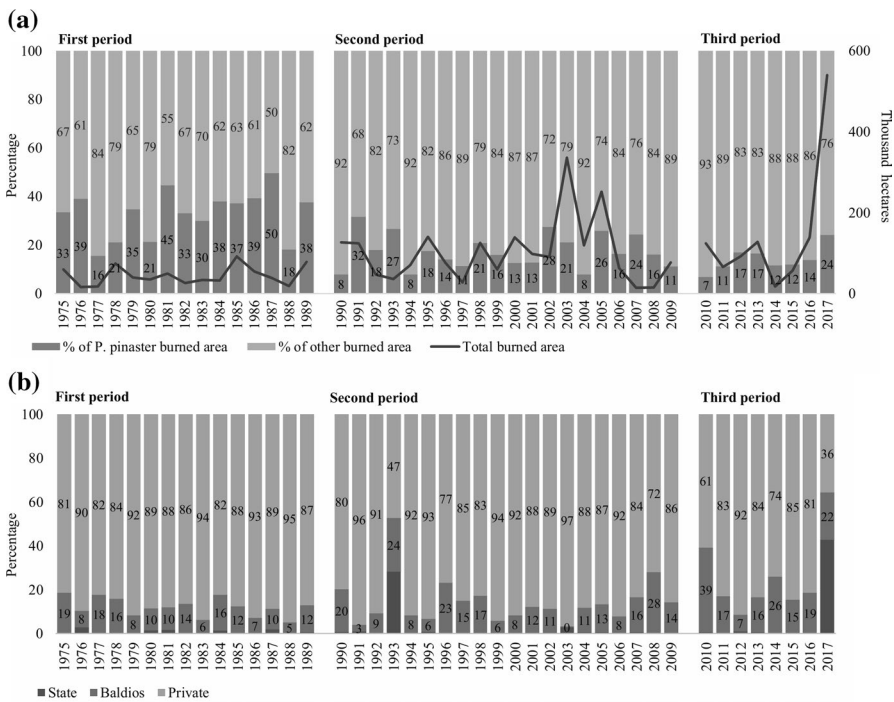


Fig. 3 a Total burned area between 1975 and 2017 at the national level and percentage in *P. pinaster* forests in total burned area. b Percentage of total burned area of *P. pinaster* by ownership types. Source: data from Forest Services ICNF, accessed in 2020

In the first period (1975–1989), although the baldios were returned to commoners after the revolutions of 1974, many local communities decided to manage their areas together with the Forest Services because of the lack of silvicultural knowledge. In some places, the tenure right of the baldios was given to local authorities (AFN 2010). Therefore, the Forest Services became the co-manager of hundreds of baldios, although a reduction of their technical staff occurred over the years, with impacts on the forest management quality in these areas.

The second period (1990–2009) began with important changes, as several important policies and institutions were developed. In the 1990s, the national PA system was created. Over time, it came to cover various types of ownership, including parts of the baldios. In 1996, the Forestry Policy Basic Law was enacted; it defines a set of tools needed to develop multi-level management plans from regional to local levels. In the subsequent years, additional laws were adopted, and all the forest owners had the obligation to develop these plans. However, the absence of a national land cadastre complicated its execution. The Forest Intervention Zones emerged in 2005, organising small-scale forest management. These helped to join several forest areas (irrespective of the ownership types) to be managed on larger spatial scales (Valente et al. 2013). Despite the changes, the areas burned increased, partly because of the mega-fires of 2003 and 2005 (Fig. 3a). The largest losses of pine plantations in 2003 occurred in the State and private areas (16%), whereas in 2005, they occurred most commonly in the baldios (20%). This influenced the creation of the National Fire Protection Plan in 2006, which included prevention guidelines for forest planning and management (AR 2015). The strong fire suppression policy, implemented in 2006, was temporarily successful but did not solve the wildfire problem (Moreira et al. 2011).

The third period (2010–2017) was extremely influenced by the year 2017, when mega-fires were responsible for close to half a million hectares of area burned (San-Miguel-Ayanz et al. 2013). In 2017, more than 100 human lives were lost, along with many houses, agricultural buildings, and farm animals. In terms of forest ownership, the largest loss in 2017 was observed in the State forest areas (54.7% of the total burned area). A report on the underlying reasons for the sizes of the 2017 fires (Guerreiro et al. 2017), indicated the lack of investment in fire prevention in all types of forest ownership over the past decades as one of the main reasons behind the tragedy. According to Colaço (2017), in the recent decades, the Portuguese Government has invested, on average, 2.7 times more for combatting wildfires as compared to prevention. Overall, fuel accumulation occurred (in quantity and continuity), suggesting that fuel management should become an integral part of forestry policy in the twentyfirst century (Marques et al. 2011; Fernandes et al. 2014), including the role that forests are expected to play in the future bio-economy (Verkerk et al. 2018). Note that post-fire management plans are very rarely developed and implemented, and some studies have shown that previously burned areas are more likely to re-burn than areas that have never burned (Moreira et al. 2011). This might also be a reason for the high burned areas in the third period.

In all of these periods, a significant percentage of the total burned areas was in the *P. pinaster* forests (45% in 1981, 50% in 1987, 28% in 2002, and 24% in 2017; Fig. 3a).

As for the distribution of burned areas in pine forests amongst the three main ownership types (Fig. 3b), it is, as expected, mainly located in private areas, where over 80% of pine forests are concentrated. However, in 1993 and 2017, *P. pinaster* burned areas were larger in State and baldio lands, when compared to private lands.

Influence of Protection Status

The analysis of the effect of the protection status on the annual percentage of burned area (APBA) showed that there were no significant differences ($F_{1,14}=0.088$, $p=0.768$) between the protected and the unprotected areas with the average values for APBA of 2.3% and 2.2%, respectively. These results were similar to those presented in AR (2015).

The same analysis was performed for the three periods considered. Here, it was clear that the third period had the highest percentage of burned area with more than 3% of the pine forests burned annually on average. However, again no significant differences were found between the protected and the unprotected areas in this period ($F_{1,7}=0.074$, $p=0.794$) nor in the previous period ($F_{1,19}=0.185$, $p=0.672$). Only in the first period, before the protection efforts, the percentage of pine forests burned in areas that would be protected was significantly ($F_{1,14}=6.641$, $p=0.022$) higher than in areas that were not considered for protection (APBA of 2.3% and 1.9%, respectively). Figure 4 presents a graphical illustration of this analysis.

From the analysis of these results, we concluded that if there was an effect of the protection status, it was only at the initial change in the protection status. In the two most recent periods, no significant differences were observed between the percentage pine forests burned annually in the protected or unprotected areas. In spite of the differences on various characteristics between protected and unprotected pine forests these results might indicate the ineffectiveness of the policies within the National System of Protected Areas in reducing the area burned in wildfires after the establishment of the system in the 1990s. Even if the main objective of the protection regime is not fire risk management, the percentage of pine forests that

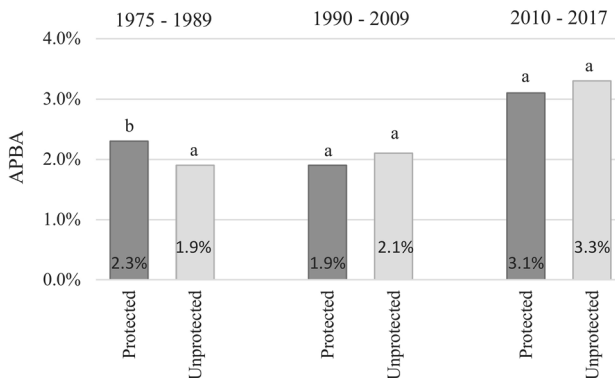


Fig. 4 Average annual percentage burned area (APBA) of *P. pinaster* of the areas under study in three different periods, according to protection status. In the different periods, values of APBA with the same letter above the bar indicate no significant differences ($p > 0.05$)

burn in wildfires is a critical factor to consider in the maintenance of the protected ecosystems.

According to the Institute of Nature Conservation (ICNF 2018c), annual fires might contribute considerably to the degradation of PA ecosystems, particularly in areas that are highly important in terms of nature conservation. The resilience of these ecosystems to fire dynamics is not sufficiently known. Since 1992, ‘Annual Reports on Wildfires in Protected Areas’ have been provided to produce a framework for risk reduction in PA. However, the effectiveness of such initiatives in reducing the wildfire effects on PA is unknown.

Influence of Ownership Types and Management Modalities in Baldios

As to ownership types and management modalities, an analysis between 1975 and 2017 indicated that the highest percentage of pine forests burned (APBA) was observed in the various modalities of baldios (3.4 to 5.0%), while the State and private forest areas revealed significantly ($F_{5,210}=3.695$, $p=0.003$) lower values (2.0% and 2.1%, respectively), as shown in Fig. 5.

The relationship between wildfires and land ownership is dynamic, as shown by several studies conducted in other European Mediterranean areas. For instance, changes introduced in 1968, by the law on communal forests in the north of Spain increased the number of conflicts in land ownership and land use, which in turn increased the number of wildfires (Marey-Pérez et al. 2010).

Because of the possible changes during the study period (1975–2017), it was possible to perform similar analyses independently for each of the three sub-periods considered (1975–1989, 1990–2009, and 2010–2017). The statistical results of the ANOVA tests indicated significant differences between the ownership types and the management modalities in baldios for the first period ($F_{5,70}=7.272$, $p<0.001$) and for the second period ($F_{5,95}=3.136$, $p=0.012$), but no significant differences were

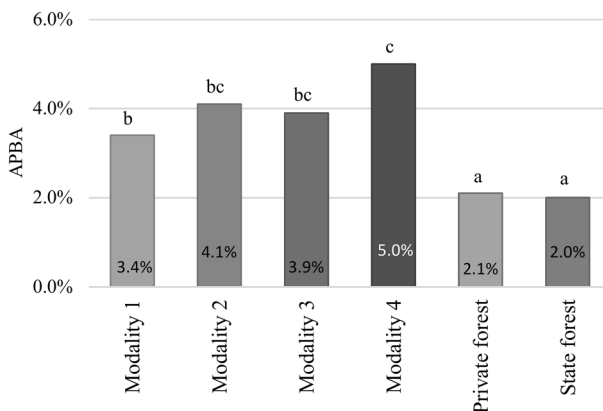


Fig. 5 Average annual percentage burned area (APBA) of *P. pinaster* forests from 1975 to 2017 in various management modalities of baldios and of private and State Portuguese forests. Values of APBA with the same letter above the bar are not significantly different ($p>0.05$) according to Duncan’s post hoc tests

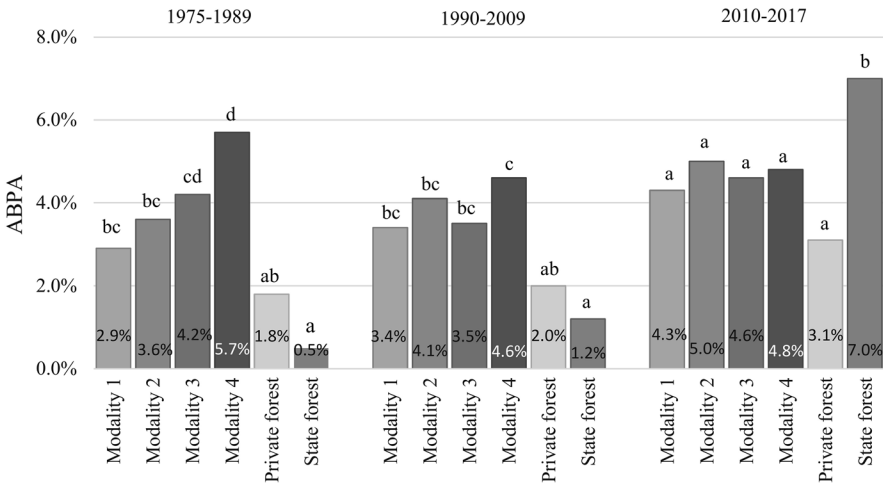


Fig. 6 Average annual percentage burned area (APBA) of *P. pinaster* forests of the areas under study in three periods. For each of the three periods, similar letters above the bar indicate no significant differences ($p > 0.05$) between the classes considered (management modalities of baldios and ownership types), according to Duncan's post hoc tests

found in the third period ($F_{5,35} = 0.268$, $p = 0.927$). A graphical illustration of the results observed in each of the three periods is presented in Fig. 6.

For each of the three periods, the reference used is the private pine forests, which always represented 85–90% of the total area of pine forests in Portugal (Table 1). In these private pine forests, the annual percentage burned area was around 2% in the first two periods and increased to more than 3% in the third period, mostly because of the catastrophic year of 2017.

State pine forests had, on average, a value of APBA similar to that of private pine forests (Fig. 5). However, the difference between the three time periods was very obvious (Fig. 6). State pine forests had the minimum APBA of all the classes in the first and the second periods (0.5% and 1.2%, respectively) and the maximum value in the third period (7.0%). The very low initial APBA value and its increase in the second period and particularly in the third period were probably related to the increasing problems in forest management by the Forest Services that lost qualified managers and other personnel, and overtime.

As for the baldios, their various management modalities always had APBA values higher than those in the private areas (Figs. 5 and 6). The highest APBA values in the first and the second periods for all the classes were observed in the case of modality 4 of the baldios (5.7% and 4.6%, respectively), corresponding to the autonomous management by local authorities. In contrast, among the management modalities of the baldios, it was modality 1, co-management by commoners with the Forest Services, that had the lowest APBA values. The differences among the modalities of baldios were considerably more obvious in the first period. In the last period, because of the large variability of the data and the smaller number of years analysed, no significant differences were found.

The higher values of APBA in the baldios than in the private pine forests has reasons that are subject to various interpretations. Some research studies (Andrews and Butler 2006; Fernandes and Rigolot 2007; Marques et al. 2011; Moreira et al. 2011; Fernandes et al. 2014) have pointed to the accumulation of biomass as one of the main factors behind the increased fire risk in Portuguese rural areas. However, we also agree with the results of Baptista (2010), who considered that this accumulation occurred first in the baldios. We also observed that the baldios were located at higher elevations and steeper slopes probably with less access and greater difficulty for fire-fighting. However, they also represented management units of larger size than private forests, which would be a comparative advantage. Various other contextual factors (social, economic, and environmental) might also influence this situation. In this study, the finding was that the pine forests of the baldios, with a given geographical context, burned proportionally more than the private pine forests.

The comparison between the management modalities of baldios was more straightforward, as all of them had a similar geographical context (Fig. 2).

The comparison of the modalities managed by rural communities (1 and 2) with the modalities managed by local authorities (3 and 4) revealed interesting aspects. In the first period, the modalities managed by commoners were considerably more favourable as those managed by the local authorities showed the highest APBA values. In the second and the third periods, the results were very similar between management by communities and that by local authorities, suggesting an increased interest of the local authorities in the management of the baldio forest areas after the first period. The management by local authorities, because of their state nature and the existence of annual budgets, had a greater investment capacity in forest management, even in areas with high fire risk levels (Gomes 2009). Communities from modalities 1 and 2 were in a more difficult position from this aspect. They invested less in forestry because of the high fire risk level and the lack of technical support in forest management (Skulska et al. 2020), as the support from the baldio associations was limited.

The comparison between modalities in co-management (1 and 3) and autonomous management (2 and 4) also revealed interesting results. In all cases, there was an observed tendency for the co-management modalities to have lower APBA values than the equivalent autonomous modalities (1 vs. 2 and 3 vs. 4). This indicated that co-management with the Forest Services had advantages in terms of fire management, but these advantages were considerably more apparent in the first period. According to Skulska et al. (2020) these differences might be attributed to the complexity of the management structure, the proactivity of baldio managers, and the bureaucracy associated with the modalities. In fact, the co-managers of modalities 1 and 3 (commoners and local authorities) emphasised the excessive bureaucracy and the recent lack of pro-activity by the Forest Services as a co-manager in the recent years.

Our results agreed with the findings of a qualitative assessment of the 40-year experience of community-based forestry in Portugal (Skulska et al. 2020), which showed a wildfire increase, in the recent decades, in all the modalities. These results pointed toward the need for using mixed and comparative approaches (qualitative and quantitative) in research focusing on community forest management.

Accumulated Biomass. What are the Solutions?

Currently, the Portuguese Government recognises the importance of forest fire prevention, focusing on biomass reduction, and highlights the importance of making these areas financially profitable to justify the costs related to fuels reduction (PG 2018).

A transition toward a bio-economy could offer opportunities to finance and operationalise long-term, landscape-scale management strategies (Verkerk et al. 2018) and to increase incomes and employment rates in rural areas (Carneiro and Ferreira 2012). Currently, new projects are being developed in the bioenergy field. In the short term, Portugal is planning the construction of biomass power stations. Considering the fire risk level in community lands, it is extremely important that when developing these stations, biomass from the baldios is considered an important primary fuel source. The implementation of these and other innovations in the field of bio-economy might help to solve the biomass problem at both the national (ICNF 2015) and the international levels (Verkerk et al. 2018). Additional studies are needed to implement this type of biomass reduction in baldio forest areas, as well as the search for other sustainable solutions.

Conclusions

The results of this study showed that, since the 1970s, amongst other important factors, ownership type and, consequently, management type, have been influencing the spatial and temporal distribution of burned areas in *P. pinaster* forests. Especially noticeable is the difference in the burned area distribution between the State and the community forest areas in the first period following the return of the baldios to rural communities. In turn, the implementation of a national protected areas system in the 1990s did not seem to affect the APBA in protected forest landscapes. Moreover, the effect of post-fire losses in ecosystems under a protection or conservation regime remains unknown.

After the baldios were returned to rural communities, in 1975, most of them chose to co-manage of these areas with the Forest Services, who previously managed these areas. In places with less active commoners, the management of baldios was turned over to local authorities. The Forest Services became co-managers of more than 70% of the community forest areas, although this did not prevent a decrease in their technical staff in the following years, with possible negative impacts on forest management. Autonomous management and co-management became increasingly similar with time.

In contrast, all the baldio management modalities had a higher percentage of burned areas in the *P. pinaster* forests than State or private lands. There seemed to be a common management problem in these lands. This was probably the result of the weak technical and financial investment in baldio forests, as well as a lack of sustainable forest management policies, irrespective of the management modalities. This points towards the importance of finding a way to increase the participation of both the Forest Services and local communities in the management of baldio

forests. Such participation should be primarily directed toward ensuring the sustainable management of these areas through biomass reduction and, at the same time, revenue increases.

Wildfires are often the result of tensions in land use issues at regional and local levels, particularly in the baldios and the protected areas, and an incomplete and outdated national land cadaster/register worsens this situation. The results of this study can help managers and politicians develop effective fire prevention policies. The solution to this problem requires the decentralisation of powers to the regional level and a coordinated long-term effort on the part of the government, based on reliable partnerships with local authorities and communities in joint forest landscape planning and management. Baldio managers should invest more in developing effective fire suppression forces, reducing ignitions through fire prevention education, and controlling forest access, particularly during severe fire weather periods. Reinvestment in forest areas is extremely important, as is the integration of rural communities in all forest management and fire prevention steps.

From a management perspective, landscape structure together with vegetation composition and fuel loads are the main variables that can be manipulated to affect fire behaviour. However, extreme weather conditions can cause mega-fires, and the development of such fires is not always determined by the landscape structure. Climate change scenarios indicate an increased risk of this type of event. Further works on multilevel research and active management on a collective basis (collaboration, associativism, and the creation of baldio forest intervention zones), along with the development of new economic activities (such as biomass power stations), can allow fire risk reduction projects to move forward, meeting local, national, and international goals.

As for the role of the State, it should be strengthened in terms of prevention and suppression of baldio wildfires. State forestry incentives should be directed to monitoring the implementation of territorial projects to reduce the load and continuity of biomass in forest landscapes and to increase the number of forestry technicians and teams of forest workers. It is essential to find flexible ways to promote collective projects, involving profitable and orderly forest areas. Such projects should take into consideration the initiatives of local managers.

Periodically updated fire protection plans are an important part of forest management plans, but the specificity of the management modalities of the baldios should always be considered.

With more information on the land register it will be possible to develop spatially explicit models that can consider the influence of other types of local variables, e.g. the topographic variables, the rural population, the road network, other types of land use, etc.

Because of the observed high fire risk in community pine forests, future studies in Portugal should pay specific attention to baldios. It also seems important to develop similar studies in other Mediterranean countries that share the same social and environmental history of development of Forest Regime in mountain community lands. The new challenges of these forests including the threat of wildfires and their new governance trends resulting from decentralization to municipal levels (e.g. France) or to local communities (e.g. in Galicia or northern Italy) need to be better understood.

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