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Incidence and recurrence of large forest fires in mainland Portugal

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Abstract Fires are an important land use tool, a growing global hazard, and a factor involved in landscape processes with feedbacks on land degradation, especially in the Southwestern Mediterranean Europe, where the importance of fires in shaping ecological processes has long been recognized. As fires become recurrent, their intensity and dimension have increased and they have taken on catastrophic proportions, losing their role as catalysts of ecosystem renewal. Fires, and especially large forest fires (LFF), are the main drivers of land degradation in forest areas in Mediterranean sub-humid regions and are likely to increase as a result of climate and other global changes. The study area consists of the whole of mainland Portugal, which for the purpose of civil protection, is divided into 18 districts. The data used, including physical and demographic characteristics, change in land use and land cover, and economic structures are provided mainly by the Institute for the Conservation of Nature and Forests in statistical format and in shapefile format. Throughout the years, LFF in Portugal have become increasingly important. Although LFF in mainland Portugal represent a small fraction of the total occurrences (0.8 %), in accordance with the trends of the Mediterranean Basin, they are responsible for a large percentage of burned areas (>70 %). With the use of the GIS software, we were able to use the available information to generate a map of forest fire recurrences and, with the purpose of detecting homogeneous groups between the districts of mainland Portugal, a cluster analysis was applied. Using a multiple regression analysis, we present the LFF and their recurrence in mainland Portugal at the district level, demonstrating their regional incidence and the similarity between districts.

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1 Introduction

The Southwestern Mediterranean region has an intimate and long relationship with fires. In
fact, fires have been an important element in forestry, agriculture, and pastoralism and have
played an important role in shaping landscape patterns of high ecological and cultural
diversity (Goldammer et al. 2007). However, the substantial increase in forest fires in the
Mediterranean (Moreno et al. 1998; Ferreira et al. 2009; Lloret et al. 2009; Pausas et al.
2008; Shakesby 2011) has created a serious problem.

At the turn of the twentieth century, there was evidence of temperatures increasing and
precipitation decreasing and, as predicted, this trend contributed to greater fire activity
(Carvalho et al. 2008; Costa et al. 2007; Santos et al. 2002; Bento-Gonçalves et al.
2011, 2013). Even though climate change can be an important fire regime driver (Piñol
et al. 1998; Pausas 2004), socio-economic factors (e.g. depopulation, ageing rural popu-
lace, and forest and agricultural policies) and land use changes (e.g. agricultural aban-
donment, expansion of wildland–urban interfaces, expansion of highly flammable species
such as *Pinus pinaster* and *Eucalyptus globulus*, homogenization of the landscape) (Pausas
2004) are much more important. The renewed growth of woody vegetation in cleared
landscapes (i.e. revegetation) (Collins et al. 2015), as well as the success in suppressing
small and medium size fires, is producing landscapes with higher flammability and more
fuel loads which contribute to larger and more severe forest fires (Pausas and Vallejo 1999;
Moreno et al. 1998).

Forest fires are a phenomenon with one of the highest environmental impacts in the
Iberian Peninsula, and they are thought by many researchers to significantly contribute to
land degradation and the desertification of large areas (Moreno et al. 1998; Trabaud 2002;
Ferreira et al. 2008; Pausas et al. 2008; Lloret et al. 2009; Mataix-Solera et al. 2011).

Frequent and more intense fires reduce the vegetation cover and biomass of an area,
affecting the productive soil layer which exposes the soil to meteorological agents,
physical and chemical soil impoverishment, change in the composition of species and
vegetation structure, and the increase in fast-growing invader species (Cerdà 1998; Certini
2005; DeBano et al. 2005; Doerr and Shakesby 2009; Ferreira et al. 2010; Giovannini
1994; González-Pérez et al. 2004; Trabaud 2002; Brown and Smith 2000). These effects
have significant implications on the decline of biodiversity, soil erosion, general produc-
tivity of the landscape, and, therefore, on the land degradation of the affected areas (De-
bano et al. 1998; Bento-Gonçalves et al. 2012).

The already degraded areas, in turn, become more likely to be affected by fires, espe-
cially in the Mediterranean region. This is due to the fact that these areas are characterized
essentially by herbaceous plant and shrubs which are extremely susceptible to fire because
of their low moisture content and flammable fuel load (Catry et al. 2010). Furthermore,
degraded areas are located in both semi-natural areas, in agricultural lands and in the
wildland–urban interfaces, where high human concentrations determines a higher proba-
bility of ignition sources and, hence, of fire occurrence (Piñol et al. 1998; Syphard et al.
2007; Cardille et al. 2001; Mercer and Prestemon 2005; Catry et al. 2009; Vieira et al.

2009). We are, therefore, facing a vicious cycle in which further soil degradation implies the occurrence of more and larger fires, consequently involving further soil degradation.

Historically, forest fires are one of the most important agents of land use and cover change in Portugal (Rego 1992; Pereira and Santos 2003; Nunes and Coelho 2007; Nunes 2012). However, throughout the years, we have verified a new reality in Portugal regarding large forest fires (LFF), which are considered, in this work, as any fire which covers an area of more than 100 ha. These have become increasingly important and one of the most significant sources of the degradation of an important part of Portuguese forests and soils.

Until very recently, the ICNF (Instituto de Conservação da Natureza e das Florestas-Institute of Nature and Forestry Conservation) defined, for statistical purposes, LFF as any fire which covered an area of more than 100 ha. Currently, the official definition is 500 ha which was established by the Parliamentary Resolution no. 35/2013 of 19th March (D.R. no. 55, Series I). In this study, we will perform the analysis based in the first areal definition of LFF, in order to be consistent with the statistical data used and to be comparable with other studies on this subject (Ferreira-Leite et al. 2010; Nunes et al. 2005; Oliveras et al. 2005; Pereira and Santos 2003).

In Portugal, the evolution of the forest cover has followed a pattern which is shared by all the Mediterranean countries: the destruction of original forestland through frequent fires in order to make way for grazing grounds, the use of the best soils for cereal culture, and the use of wood as fuel and construction material (Andrada e Silva 1815; Ferreira Borges 1908; Rego 2001). However, the phenomenon described is not that of a contemporary perspective of forest fires, but that of the slash-and-burn policy carried out by societies to make way for their activities or for their protection.

In fact, until the 1970s, fires were not a crucial problem for Portuguese forests. However, after that decade, there was an increase in the accumulation of fuel materials in the forests, as a result of the decrease in sheep grazing and the clearing of the land for animal bedding brought about by the rural exodus which started in the 1950s. This situation reflected the socio-economic changes taking place in the southern European countries, particularly in the Mediterranean region at this time (Vélez 1993; Moreno et al. 1998; Rego 2001; Bento-Gonçalves et al. 2010).

The changes in the traditional use of land and life style of the rural populations, especially in mountain areas, entailed an increase in the large number of abandoned farmlands. On the one hand, this led to the encroachment of vegetation and the increase in the fuel materials accumulated in traditional forest areas (Rego 1992; García-Ruiz et al. 1996; Roxo et al. 1996; Bento-Gonçalves et al. 2009). On the other hand, it led to the consequent increase in areas used as forest land. Many of these rural areas became liable to the occurrence of devastating fires as a result of the high quantities of biomass accumulated over the years, which could fuel catastrophic fires during the summer months (Beverly and Martell 2005; Keeley and Rundel 2005).

Fire data, made available by the Institute for the Conservation of Nature and Forests (Instituto de Conservação da Natureza e das Florestas-ICNF) since the 1980s, reveal that in prior decades fires in mainland Portugal had never reached 10,000 ha of burned area in a single occurrence. The first occurrence of these fires affected the municipalities of Vila de Rei and Ferreira do Zêzere (Castelo Branco and Santarém districts, respectively) (Lourenço 1986) in 1986 and subsequently the municipalities of Arganil, Oliveira do Hospital, and Pampilhosa da Serra (Coimbra district) in 1987 (Lourenço 1988). We can claim that as early as 1987 a new era of forest fires began in Portugal (Ferreira-Leite et al. 2013a, b).

In addition, the recurrence of fires became frequent, changing significantly the existing fire regimes.

In this context, this paper aims to (1) show the importance of LFF and (2) their recurrence in mainland Portugal over the past 33 years, namely at the national and regional (district) levels, and (3) the similarity between districts (i.e. physical and demographic
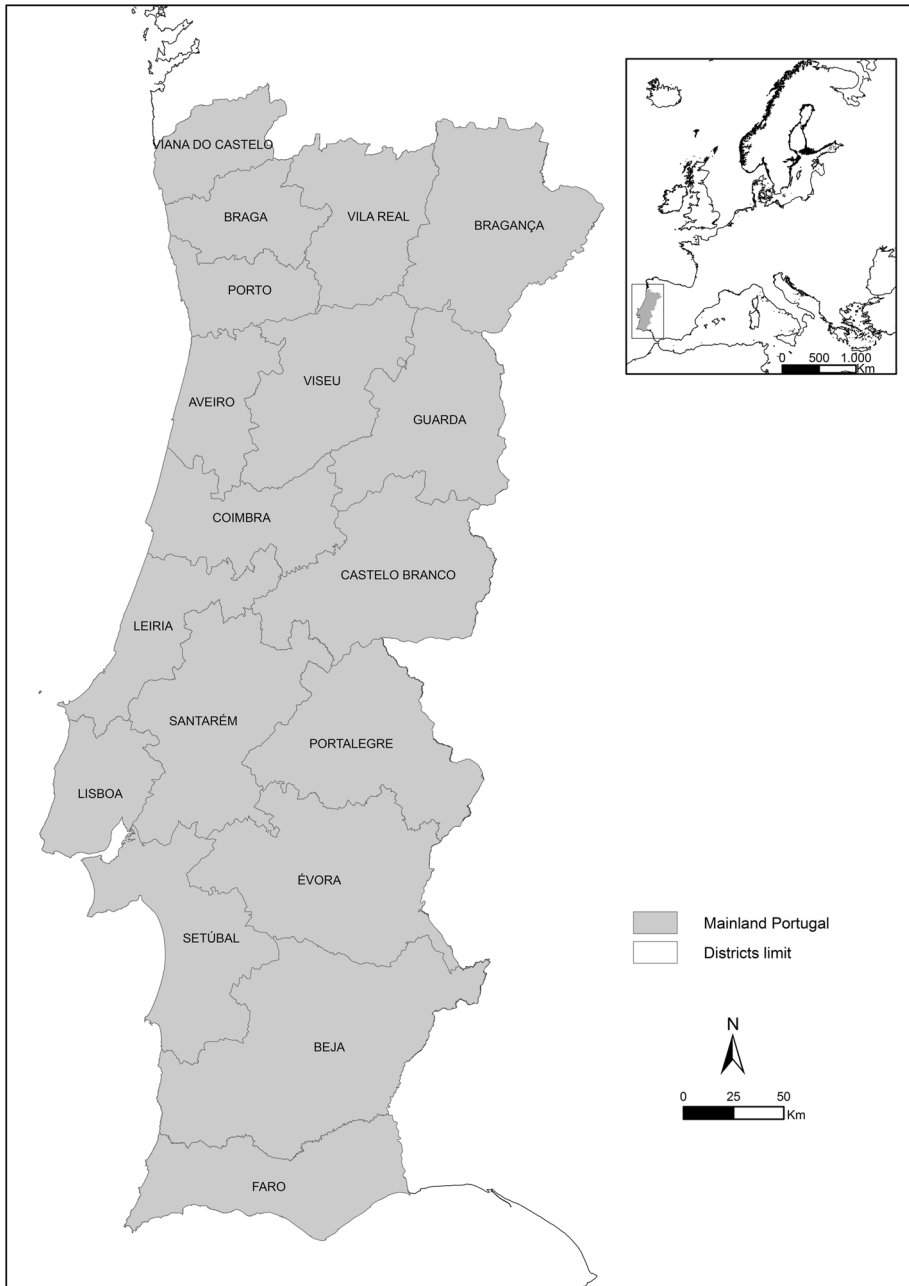

Fig. 1 Location of mainland Portugal and identification of Portuguese districts (administrative regions)

characteristics, changes in land use and land cover, and economic structures) using explanatory variables.

2 Materials and methods

2.1 Study area

The study area consists of the whole of mainland Portugal, which has a surface area of 89.073 km^2 and is located in the most western part of continental Europe (i.e. in the Iberian Peninsula).

Mainland Portugal, for purposes of civil protection, is divided into 18 districts (Fig. 1), and the total population of the country is about 10 million, the majority of which is concentrated in the coastal areas. More than 60 % of the population lives in the suburban area of the two major cities: Lisbon and Porto. On the other hand, the less densely populated areas are located in the inland districts, especially in the mountainous and more forested areas.

Portugal's climate features a warm and dry summer, with rainfall concentrated in the autumn and winter. The rainfall distribution is mainly influenced by altitude and the proximity to the Atlantic Ocean. The northern and central mountains provide a natural division between the north and the south. In the north, 95 % of the area is above 400 m, while in the south, 62 % of the area is below 200 m (Ribeiro 1955). The average annual precipitation varies between around 3500 mm in the north-western mountains and 500 mm in the south-eastern areas of the country. For the average annual temperature, this pattern is reversed with the highest values registered in the southern region and the lowest in the north-eastern region. Despite these differences, all the districts have a significantly long dry season. The dry season lasts between 2 and 4/5 months and increases from north to south and from the coastal to inland regions. Therefore, according to the Köppen climate classification, Portugal has a Mediterranean climate, with a *Csb* in the north and centre and *Csa* in the south (Nunes 2012).

In terms of land use, the agricultural areas and wildlands are the most representative classes of land use in Portugal. More precisely, according to the Corine land cover (2000), wildland areas represent more than one-third of the total continental land area.
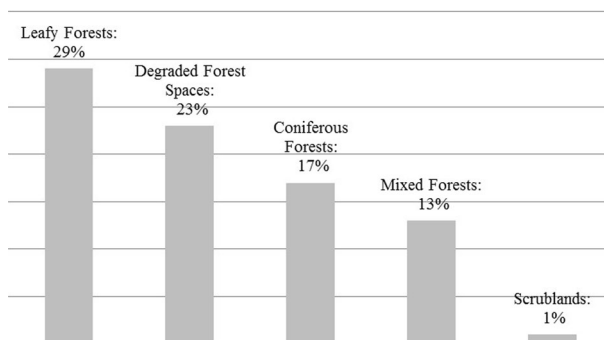
Fig. 2 Wildlands in mainland Portugal (CLC 2000)

With regard to wildlands, we can verify that they are constituted mainly by leafy forests spaces (29 %) and degraded forest spaces (23 %), and other coniferous forest and mixed woodlands and forests (Fig. 2).

The national forest is dominated by the maritime pine, eucalyptus, and cork oaks which together represented over 70 % of the national forest spaces in 1995. Of these three species, only the oak has gained more area in the latest survey (+23.9 thousand hectares), while the maritime pine has lost 265.5 thousand hectares. While more discreet, the reduction in eucalyptus trees resulted in less 25.4 thousand hectares since 1995 (Table 1).

Accordingly, in the last couple of decades, we have witnessed a significant transformation of the land cover in which the structure and organisation the national territory in continuous and dense mono-specific forest settlements, associated with the lack of spatial planning, promoted a homogenisation of the territory. In addition, the small dimension and fragmentation of the property structure—typical of the majority of the forest lands in Portugal—hamper forest planning and management. Consequently, it creates great difficulties for landowners to profit from their lands and additional incentives for them to abandon them.

Adding to these problems is the coexistence of a plethora of different interests—e.g. cattle grazing, herding, and hunting—which favour the occurrence of forest fires.

These factors, associated with the incorrect management of forest spaces, have long hindered the protection of forests against fires and contributed to accentuate the devaluation of the social, economic, and environmental utility of the forest and areas with woodland aptitude. Thus, these elements have contributed and keep contributing to the increase in combustion load in the forests.

2.2 Data

The statistical and spatial data used in this study were produced by the Institute for the Conservation of Nature and Forests (Instituto de Conservação da Natureza e das Florestas-ICNF) and are freely available on their website (http://www.icnf.pt/portal/florestas/dfci/inc). Forest fire occurrence and burnt areas are surveyed by civil protection teams (GNR-SEPNA and GTF) in the field and validated by remote sensing technologies (Ferreira-Leite et al. 2012).

The statistical information includes the place of occurrence, the burnt area for each fire, the land use of the affected areas, and the probable cause. The data set considered for this study ranges from 1981 to 2010 and was only selected for forest fires with burnt areas over 100 ha.

Spatial data consist in a set of shapefile files, representing the burned areas and the date and place of occurrence, as well as the probable cause. Spatial data are only available since 1990.

Table 1 Areas according to species, in thousands of hectares, of the three most representative forest species in Portugal *Source*: IFN95/05

	1995/8	2005/6	Variação
Maritime pine	976.1	710.6	−265.5
Eucalyptus	672.1	646.7	−25.4
Cork oak	712.8	736.7	+23.9

Information regarding the climatological normals for the period 1971–2000 was obtained from the Portuguese Meteorological Institute, whilst the statistical variables were compiled from the census statistics. Other spatial variables, such as land use, were acquired from digital maps provided by national authorities.

2.3 Methodology

The analysis of the recurrence of LFF was conducted based on statistical and also spatial data. The ICNF releases the national mapping of burnt areas in shapefile format since 1991 for use in geographic information systems (GIS). This enables the mapping the burned areas by size, allowing for the geographical analysis of the problem of LFF in our country at different scales. In order to achieve our goal, we have mapped the LFF ($\geq$100 ha) that occurred between 1991 and 2013 in the Portuguese mainland (at the district level). The cartographic information provided by ICNF (2014) was subsequently manipulated and analysed with GIS software specifically ESRI's ArcGis 10.2.

With the use of the GIS software, we were able to use the available information to generate a map of forest fire recurrences by implementing a modelling process (Ferreira-Leite et al. 2011). Accordingly, with ArcGis 10.2, the information relating to the occurrences of fires had to be organized by individual "layers" corresponding to the year of their incidence. Next, the aforementioned information was converted to raster format and was codified according to the existence or not of burned scorched areas—e.g. "0" for non-

Table 2 Explanatory variables

Physical and human characteristics	Source
TI, topographic roughness index	Portuguese Environmental Agency
MAP, mean annual precipitation, 1971–2000 (in mm)	Portuguese Institute of Sea and Atmosphere
MAT, mean annual temperature, 1971–2000 (in °C)	
TP, total population, 2011	Statistics Portugal
PV, population variation, 1960–2011 (in %)	
RP, percentage of rural population, 2011 (in %)	
AI, ageing index, 2011	
Land use/cover change and economic activities	
ALsro, agricultural land (in %), 1970	SROA
FLsro, forest land (in %), 1970	
ULsro, uncultivated land, 1970	
AL, agricultural land (in %), 2006	Corine land cover/AEP
FL, forest land (in %), 2006	
UL, uncultivated land, 2006	
AAV, agricultural area variation (in %), 1970–2006	SROA versus Corine land cover
FAV, forest area variation (in %), 1970–2006	
UAV, uncultivated area variation (in %), 1970–2006	
TSL, total small livestock (sheep and goats), 2009	Statistics Portugal
SLV, small livestock variation (in %), 1955–2009	
PS, plot size (in hectares), 2009	

SROA Service of Agrarian Recognition and Management (1970), *AEP* Portuguese Environmental Agency

scorched areas and "1" for the areas scorched by fires. After the raster data were converted, it was combined into a final raster output which summarized all of the previous information. Subsequently, it was then possible to create a legend that reveals the patterns of wildfire recurrence—i.e. "0" (non-scorched areas), "1" (areas scorched once), "2" (areas scorched twice), "3" (areas scorched three times), "4" (areas scorched four times), and "5" (areas scorched five times). The final result allows us to visualize the scorched areas and the pattern of recurrence throughout the years.

The Ward's method of hierarchical clustering was applied and conducted using Statistical Package for Social Sciences software (IBM SPSS statistics, Version 19).

With the aim of understanding the factors that influence the incidence and recurrence of LFF, explanatory variables were compiled, including physical and demographic characteristics, changes in land use and land cover, and the economic structure at the district level (Table 2). All the variables, dependent and explanatory, were normalized in order to give them the same relative importance. The z-score calculation [z-score = (value−mean)/SD] was used.

Taking all the variables into account, stepwise multiple regression analyses were performed using the SPSS 19.0 statistical package. Stepwise multiple regression is basically a search method that is centred essentially on identifying and classifying the explanatory variable(s) that actually have a strong relationship with the explanatory variable(s). This analytical tool involves the addition of one variable at a time to the regression equation, and variations are selected for addition to the model based on their partial correlation with the dependent variable(s) (Jimoh 2008; Nunes 2012). As some of the variables denote elevated co-variability values and some of them were not relevant in the explanation, the stepwise multiple regressions determine which variables to keep and which to remove. All the variables listed in Table 2 were considered in the statistical analysis but were only accepted if they met the 0.05 significance level.

3 Results and discussion

3.1 Framework of LLF in mainland Portugal

Based on fire statistics for the decade 1981–1990 (ICNF 2014), LFF represented 1.6 % of the total number of occurrences recorded during that period. This was the most significant value in the last three decades—in the periods 1991–2000, 2001–2010, and in the last 3 years, the value was only 0.7 %. Nevertheless, there was an effective increase of over

Table 3 Occurrences and LFF (≥100 ha) in mainland Portugal by decade (1981–2013)

Decade	Occurrences		Large forest fires				
	Number (n°)	Burned area (ha)	(n°)	(%)	Burned area by LFF (ha)	Burned area by LFF (%)	Average area burned by LFF
1981–1990	82,205	955,140	1280	1.6	703,764	73.7	550
1991–2000	245,858	1,043,302	1620	0.7	704,075	67.5	435
2001–2010	254,023	1,844,127	1733	0.7	1,165,981	63.2	673
2011–2013	67,060	335,734	481	0.7	241,565	72.0	502

Table 4 Annual percentage of LFF, by class size and annual percentage of the area consumed by LFF, grouped by class size of the fires (1981–2013)

	[100–500[ha		[500–1000[ha		[1000–5000[ha		[5000–10,000[		≥10,000 ha	
	Number of fires	Burned area	Number of fires	Burned area	Number of fires	Burned area	Number of fires	Burned area	Number of fires	Burned area
1981	80.6	10.9	11.2	38.1	6.7	43.7	1.5	7.3	0.0	0.0
1982	84.0	39.4	9.3	25.9	6.7	34.7	0.0	0.0	0.0	0.0
1983	70.7	21.5	12.1	13.2	15.5	48.8	1.7	16.5	0.0	0.0
1984	92.6	70.7	5.6	17.7	1.9	11.6	0.0	0.0	0.0	0.0
1985	75.4	37.1	14.8	22.7	9.4	34.8	0.4	5.4	0.0	0.0
1986	68.7	24.7	19.8	24.7	10.7	36.6	0.0	0.0	0.8	14.0
1987	72.2	30.3	18.5	25.0	7.4	21.8	1.9	22.9	0.0	0.0
1988	82.8	50.7	13.8	36.3	3.4	13.0	0.0	0.0	0.0	0.0
1989	74.9	32.8	12.0	19.2	12.6	40.3	0.6	7.6	0.0	0.0
1990	75.7	30.4	12.1	16.7	11.2	39.9	1.0	13.0	0.0	0.0
1991	61.5	17.7	14.0	11.6	23.0	58.7	1.5	12.0	0.0	0.0
1992	84.4	38.6	3.9	5.1	10.4	34.7	1.3	21.6	0.0	0.0
1993	78.9	38.6	14.5	24.2	6.6	37.2	0.0	0.0	0.0	0.0
1994	89.2	69.3	8.2	19.8	2.5	10.9	0.0	0.0	0.0	0.0
1995	79.6	40.9	12.0	20.1	8.0	34.5	0.4	4.4	0.0	0.0
1996	86.2	60.7	11.3	26.9	2.5	12.4	0.0	0.0	0.0	0.0
1997	94.6	81.5	5.4	18.5	0.0	0.0	0.0	0.0	0.0	0.0
1998	69.3	33.8	22.8	35.1	7.9	31.1	0.0	0.0	0.0	0.0
1999	75.4	38.5	16.7	29.1	7.9	32.4	0.0	0.0	0.0	0.0
2000	82.3	43.2	11.3	19.5	6.4	37.3	0.0	0.0	0.0	0.0
2001	80.6	40.5	7.4	13.5	12.0	46.0	0.0	0.0	0.0	0.0
2002	79.1	42.3	13.0	22.8	7.9	34.8	0.0	0.0	0.0	0.0
2003	53.4	7.7	14.6	6.7	24.5	36.0	4.0	18.0	3.6	31.5
2004	68.5	24.7	17.3	20.1	13.1	34.7	0.6	7.9	0.6	12.6

Table 4 continued

	[100–500[ha		[500–1000[ha		[1000–5000[ha		[5000–10,000[		≥10,000 ha	
	Number of fires	Burned area	Number of fires	Burned area	Number of fires	Burned area	Number of fires	Burned area	Number of fires	Burned area
2005	67.5	23.3	18.0	18.7	13.0	41.8	1.2	12.2	0.2	4.1
2006	80.3	42.0	14.2	23.5	4.7	24.4	0.8	10.1	0.0	0.0
2007	83.3	44.8	11.1	21.2	5.6	34.0	0.0	0.0	0.0	0.0
2008	88.9	73.3	11.1	26.7	0.0	0.0	0.0	0.0	0.0	0.0
2009	82.7	44.3	10.5	20.1	6.0	21.6	0.8	14.0	0.0	0.0
2010	72.6	28.1	14.0	18.0	12.9	48.9	0.5	5.0	0.0	0.0
2011	83.6	54.4	11.5	23.5	4.9	22.1	0.0	0.0	0.0	0.0
2012	81.8	32.3	10.5	14.2	7.0	26.1	0.0	0.0	0.7	27.4
2013	74.1	28.5	13.9	17.7	11.1	37.2	0.5	5.5	0.5	11.1
Average	**75.6**	**28.9**	**13.5**	**19.3**	**9.9**	**36.8**	**0.7**	**8.1**	**0.3**	**6.9**

27 % when comparing the second decade to the first and over 35 % LFF when compared to the decade 1981–1990. In the last 3 years, we have verified an increase in LFF of about 7 % with regard to the total areas registered during the same period (2011–2013).
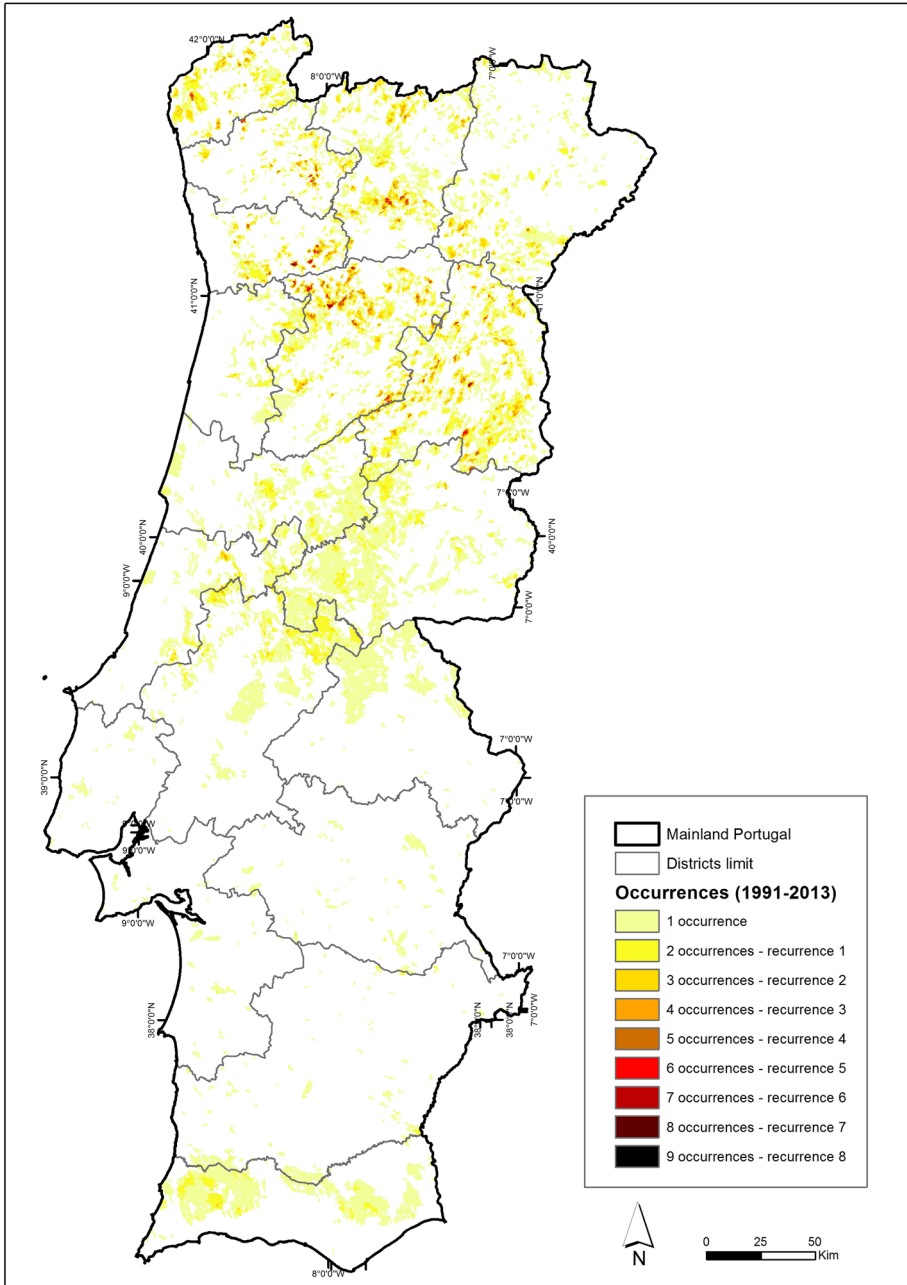

Fig. 3 Maximum recurrence degree of LFF at the district level in Portugal (1991–2013)

Therefore, we have verified a substantial increase in LFF in Portugal. This resulted only from an increase from the first to the second and third decades, with apparent continuity of the increase in the last 3 years under analysis (Table 3).

Nevertheless, if there was a significant increase in the number of LFF during the analysed period, in terms of burned areas, the growth was even more considerable having almost doubled from the first to the third decade (over 65.7 %). However, regarding the percentage of burned areas by LFF, the decade 2001–2010 was not the most representative decade, despite having registered 63.2 %. In fact, the values reported in the first decade analysed (1981–1990) were the most significant, reaching 73.7 % of burned area in LFF (Table 2). It is thus confirmed that, in general, the LFF represent a small fraction of the total number of occurrences but are responsible for the overwhelming majority of the total burned area.

Another aspect that should be noted is the fact that the largest LFF occurred in the last decade (2001–2010). Even though this period did not register the largest percentage of LFF (0.7 %), it did reveal the greatest amount of burned area (1,165,981 ha). This means that each LFF in this decade burned, on average, more area than the fires of the previous decades (with an average burned area of 673 ha) (Table 3).

By breaking down the information on LFF, we can verify that the most frequent fires burned areas between 100 and 500 ha. On average, these fires represent 75.6 % of the LFF and were responsible for 28.9 % of the average LFF burned areas during this period. With regard to fires over 500 ha, we should highlight those that consumed areas between 1000 and 5000 ha. These fires represent 9.9 % of the total and were, on average, responsible for 36.8 % of the burned areas. The LFF over 5000 ha only represent 1 % of the total LFF and were responsible for 15 % of the area burned by LFF (Table 4).

3.2 Regional incidence and recurrence of LFF: similarity between districts

By analysing the data from ICNF (ICNF, 2015), we have identified the maximum recurrence degree of LFF (LFF that occurred more than once in the same area) at the district level in Portugal (Fig. 3).

At the national level, there were 9 LFF occurrences in areas previously burnt by LFF. Accordingly, there was a maximum of 8 reoccurrences during this period. However, the areas of the LFF do not totally overlap since as reoccurrences increase the burnt areas decrease.

In a total area of 8,907,339.9 ha, 1,592,591 ha have been scorched by a LFF at least once (17.8 % of the total area). Of these areas, 408,929.38 ha have been scorched more than on one occasion. Therefore, 25.67 % of the scorched areas in mainland Portugal reveal at least one recurrence, while 5.17 % (82,416.06 ha) of the areas have been scorched three times (recurrence 2), and 2.39 % (38,231.93 ha) have been scorched at least four times. Records show that 6.61 ha revealed an eighth recurrence (nine occurrences of LFF).

As a result, 1,592,591 ha, corresponding to 17.88 % of the total area of mainland Portugal, have recorded at least one LFF between 1991 and 2013. This area compromises about half the Portuguese forest space, which corresponds to 35.4 % of the national area.

The majority of the burnt areas related to LFF were located in the northern region of Portugal, with the exception of the Faro district in the south. Historically, the district of Guarda was the area most seriously affected by LFF, followed by Viseu, Vila Real, and Castelo Branco. These four districts accounted for around 50 % of the global burned area

by LFF. Conversely, Beja, Évora, Lisboa, and Setubal recorded the lowest values of burnt area by LFF (Fig. 4).

The district of Guarda emerges again with highest areas burned twice, about 21.5 % of the total, followed by Viseu (15.8 %), and Vila Real (11.6 %). These three districts account for almost half of the areas burned twice and 60 % of the burnt areas three times, during the study period. However, when the spatial incidence of the areas burned four or more times was analysed, two districts—Guarda and Viseu—were responsible for more than half (around 57 %) of the total recorded in mainland Portugal.

3.3 Main factors associated with LFF and their recurrence in Portugal

In order to determine which explanatory variables (physical, land use and land cover, and sociodemographic variables) had the most influence on the incidence of LFF and its recurrence (dependent variables) at the district level, multiple regression analysis were carried out. The regional variation in total burnt area as a consequence of LFF, estimated from stepwise multiple regression models, included four variables which explained more than 90 % of the variance observed (Table 5).

The proportion of uncultivated land (UL) was the most important factor affecting burnt areas in Portugal, explaining *per se* around 50 % of the variability observed. In fact, uncultivated land that is covered mostly by shrubs, grass, and other light vegetation seems to be the land cover most prone to fires. These tend to result from agricultural abandonment as a consequence of demographic changes (the population exodus from rural areas to coastal cities and European countries, associated with the ageing population), since the last half of the twentieth century. Several studies have confirmed that shrubs are one of the land cover types most affected by fire (Nunes et al. 2005; Sebastián-López et al. 2008; Catry et al. 2009; Moreira et al. 2009; Bajocco and Ricotta 2008; Nunes 2012; Carmo et al. 2011; Ganteaume and Jappiot 2013).

This point can be explained by the lower priority given to fire fighting in shrub lands (on the assumption that they are the least valuable land cover) (Carmo et al. 2011; Moreira et al. 2011) or because shrubs are very frequently the land cover type in steeper slopes where the rate of fire dissemination is higher.
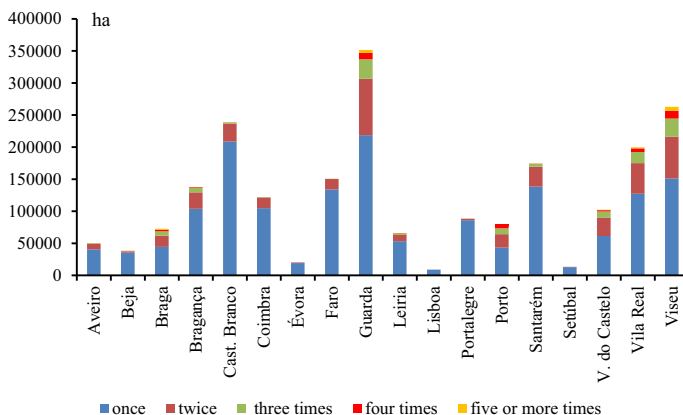

Fig. 4 Spatial distribution of burnt areas, from one to five or more times, at the district level

Table 5 Stepwise multiple regressions results—total of burnt area

	Model	R	Explained variance (%)	Std. error of the estimate	Multiple regression equation
TBLFF	1	0.687	47.2	0.7490	$DI = 0.6512 + 0.687_{UL}$
	2	0.894	79.9	0.4777	$DI = 0.0533 + 1.062_{UL} + 0.683_{FLsro}$
	3	0.922	85.1	0.4257	$DI = 0.3521 + 1.256_{UL} + 0.969_{FLsro} -0.333_{MAP}$
	4	0.953	90.9	0.3452	$DI = 0.3456 + 1.109_{UL} + 0.740_{FLsro} -0.450_{MAP} -0.377_{SLV}$

Dependent variable: total of area burnt by large forest fires

Model 1—predictors in the model: constant; UL, uncultivated land (2006)

Model 2—predictors in the model: constant; UL, uncultivated land (2006); and FLsro, forest land, according to SROA (1970)

Model 3—predictors in the model: constant; UL, uncultivated land (2006), FLsro, forest land, according to SROA (1970); and MAP, mean annual precipitation (1970–2000)

Model 4—predictors in the model: constant; UL, uncultivated land (2006), FLsro, forest land, according to SROA (1970); MAP, mean annual precipitation (1970–2000); and SLV, small livestock variation (1955–2009)

The multiple regression equation for this variable also included the forest area registered in middle of the last century according to the SROA statistics, meaning that the regions which historically recorded the highest areas of forest, mainly composed by highly flammable species (*P. pinaster*), were also the most affected by large fires. This variable accounted for an additional 30 % of the variance. Although fire is often vital to maintain pine status in ecosystems, it is also a major hazard in plantations and the most significant threat to Pinus forests in the Mediterranean Basin (Barbéro et al. 1998; Fernandes and Rigolot 2007). Shakesby et al. (1996) also consider that afforestation focused on highly inflammable species, mainly pines (predominantly *P. pinaster*) and eucalyptus (*E.*

Table 6 Stepwise multiple regressions results—burnt areas once

	Model	R	Explained variance (%)	Std. error of the estimate	Multiple regression equation
BAO	1	0.584	34.1	0.8370	$BAO = -0.059 - 0.584_{PS}$
	2	0.818	66.9	0.6121	$BAO = -0.000 - 0.731_{PS} - 0.592_{TP}$
	3	0.869	75.5	0.5458	$BAO = -0.000 -0.884_{PS} -0.461_{TP} -0.369_{AAV}$
	4	0.909	82.5	0.4777	$BAO = -0.000 -0.790_{PS} -0.526_{TP} -0.552_{AAV} -0.386_{VAF}$

Dependent variable: burnt areas once (BAO)

Model 1—predictors in the model: constant; PS, plot size, 1999

Model 2—predictors in the model: constant; PS, plot size, 1999; and TP, total population (2011)

Model 3—predictors in the model: constant; PS, plot size, 1999; TP, total population (2011); and AAV, agricultural area variation (1970–2006)

Model 4—predictors in the model: constant; PS, plot size, 1999; TP, total population (2011); AAV, agricultural area variation (1970–2006); and VAF, forest area variation (1970–2006)

globulus), also favours the proliferation of forest fires. Once fires break out under highly dangerous conditions, they spread more easily and cannot be stopped.

A positive association between LFF and average annual precipitation and a negative relationship with small livestock variation, between 1955 and 2009, were also suggested by the multiple regression analysis. However, these variables only explain 10 % of the observed variance.

Stepwise multiple regression equations were also formulated for the areas burnt once, twice, three, and four or more times (Tables 6, 7, 8, 9, respectively). With regard to the areas burnt once, multiple regression suggested negative relationships with all of the variables integrated in the model, which explained 82.5 % the spatial variance. Plot size and total population were the most important factors in explaining the variance (66.9 %) in the percentage of the district areas burnt once over the last decades. For the areas burnt twice, three variables explain 87 % of the observed variance. Regression analysis suggested a strong negative relationship between the mean annual temperature and the percentage of areas affected twice by fire (R: 0.800). The stepwise multiple regression models

Table 7 Stepwise Multiple Regressions results—burnt areas twice

	Model	R	Explained variance (%)	Std. error of the estimate	Multiple regression equation
BAT	1	0.800	64.0	0.6187	$BAT = -0.000 - 0.800_{MAT}$
	2	0.865	74.9	0.5334	$BAT = -0.000 - 0.6030AM_{AT} + 0.385_{UL}$
	3	0.931	86.6	0.4032	$BAT = -0.000 - 0.242_{MAT} + 0.872_{UL} + 0.552_{FLsro}$

Dependent variable: burnt areas twice (BAT)

Model 1—predictors in the model: constant; MAT, mean annual temperature

Model 2—predictors in the model: constant; MAT, mean annual temperature; and UL, uncultivated land (2006)

Model 3—predictors in the model: constant; MAT, mean annual temperature; UL, uncultivated land (2006); and FLsro, forest land, according to SROA (1970)

Table 8 Stepwise multiple regressions results—burnt areas three times

	Model	R	Explained variance (%)	Std. error of the estimate	Multiple regression equation
BATt	1	0.810	65.9	0.634	$BATt = -0.000 - 0.810_{MAT}$

Dependent variable: burnt areas three times (BATt)

Model 1—predictors in the model: constant; MAT, mean annual temperature

Table 9 Stepwise multiple regressions results—burnt areas four or more times

	Model	R	Explained variance (%)	Std. error of the estimate	Multiple regression equation
BAFt	1	0.709	50.2	0.471	$BAFt = -0.000 - 0.709_{MAT}$

Dependent variable: burnt area four or more times (BAFt)

Model 1—predictors in the model: constant; MAT, mean annual temperature

also highlighted two other variables as being capable of explaining the percentage of the district area burnt twice over the last decades: the uncultivated land and the presence of forests in the past, which account for an additional 22.6 % of the observed variance.

When the regional variability in average area burnt three and four or more times (Tables 8, 9), a single variable emerged as a key factor, namely the mean annual temperature, which accounted for more than 65 and 50 % of the observed variance, respectively. Both situations denote a negative relationship, suggesting that the greatest pressures from fire occur in regions with lower annual temperatures. In mainland Portugal, the mean annual temperature showed strong negative inter-correlations with average annual precipitation (R: -0.705, p value <0.001) and the topographic roughness index (R: -0.830, p value <0.000), indicating the existence of significant relationships between these factors. In fact, it is in the humid and sub-humid regions (that record the lowest annual temperatures and highest rainfall) which produce more quantities of biomass and where the grasses and shrubs regenerate more quickly after the fires. Some areas are also characterized by a greater pressure from agriculture and grazing or by an intense land abandonment that triggered very significant changes in the landscape by promoting the spread of natural vegetation. The increase in combustible biomass leads farmers and, in particular, shepherds to start fires in order to control the spread of shrubs and facilitate the regeneration of forage (De la Riva and Pérez-Cabello 2005). Shepherds often do what fire management organizations do not do in terms of using fire to reduce fuel (Xanthopoulos et al. 2006). This practice appears to be most common in the humid and sub-humid regions of the central and northern Portugal.

4 Conclusion

Although forest fires have always existed in Portugal, they were infrequent. The truth is that the social and economic transformations that have taken place in Portuguese society since the second half of the twentieth century have profoundly altered the habits and traditions of the population. The relationship between the small villages and the forests, which used to be a very close, stable, and interconnected, slowly disappeared and paved the way for the occurrence of extensive forest fires.

The reality of the LFF in Portugal went through different stages in terms of their extent. As of the 1970s, LFF became rather common, but it was only after the 1980s that they reached areas over 10,000 ha. Over the following decade (the 1990s), there was an increase in the LFF, and so, within the last 10 years, we have verified two LFF covering an area of over 20,000 ha, demonstrating that there is an increase in the individual area of the larger LFF.

Spatially, the fire incidence and recurrence interval differ markedly between districts. Guarda, Viseu, Vila Real, and Castelo Branco were the districts most affected by wildfires and with the largest burnt areas. However, Guarda and Viseu concentrated more than a half of the areas burnt three, four, or more times. The highest incidence and recurrence of fires were significantly related to land cover and climate. As the climate cannot be controlled, the management options for reducing burnt areas must address the root causes of fires associated with human and land use factors which influence the management of shrubland fuels, agricultural areas, and forests. Thus, living with recurrent wildfires also requires a change of paradigm based on the implementation of suppression policies that have not been properly accompanied by vegetation management, silviculture, and integrated landscape-level forest management.

This information is vitally important in supporting environmental and civil protection policies, designing appropriate prevention measures, and allocating firefighting resources more effectively.

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