Science of the Total Environment 624 (2018) 424–437

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Negligent and intentional fires in Portugal: Spatial distribution characterization

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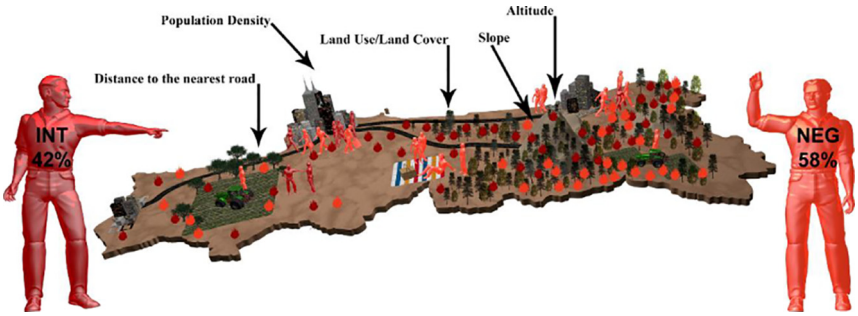
HIGHLIGHTS

- Average fire size is much higher for intentional than for negligent fires.
- Incidence of negligent and intentional fires has different distribution patterns.
- Higher drivers' influence for intentional fires, burnt area and in the south region
- Human's drivers and altitude are the most important for fire ignitions.
- Negligent (intentional) fires burn more forest and agricultural (human) areas.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 September 2017
Received in revised form 30 November 2017
Accepted 2 December 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Human fire
Negligent fire
Intentional fire
Spatial patterns
Portugal

ABSTRACT

In the European context, Portugal is the country with the highest number of wildfires and the second with more burnt area. The vast majority of these events are of human origin, whether caused by accident, negligence or arson, reason why it is particularly important to know the regime of these wildfires for forest and wildfire management activities. The study focuses on the most recent years of 2001–2014, when wildfire ignition's coordinates are known, and aims to identify and characterize the wildfire incidence spatial patterns of variability as well as their main drivers. After grouping wildfires with human cause into negligent and intentional, we studied their spatial distribution in terms of normalized number of wildfires (NNF) and burnt area (NBA) in the five Nomenclature of Territorial Units for Statistics II regions of mainland Portugal. Results disclose an uneven spatial distribution of the fire incidence, characterized by a south-north gradient, much higher values in *Norte* region and more evident for intentional than for negligent wildfires. Human and biophysical drivers strongly influence NNF and NBA, at regional and national scales. Distribution patterns at regional scale, for negligent and intentional wildfires are quite different from entire mainland and all wildfires. Drivers' influence is higher for intentional than for negligent wildfires, for southern than for northern regions and for NBA than for NNF. The leading drivers of NNF are distance to roads (*d*) population density (*pd*) and altitude (*h*) while of NBA are *h*, *d*, slope and *pd*, and this influence is higher for intentional than for negligent wildfires.

Abbreviations: NF, Number of fires; BA, Burnt area; TNF, Total number of fires; TBA, Total burnt area; CLC, CORINE Land Cover 2006; NUTS, Nomenclature of Territorial Units for Statistics; *AML*, *Área Metropolitana de Lisboa*; *h*, Altitude; DEM, Digital elevation model; *s*, Slope; *pd*, Population density; INE, Portuguese National Statistics Institute; *d*, Distance to the nearest road; PRFD, Portuguese Rural Fire Dataset; ICNF, Portuguese Institute for the Conservation of Nature and Forests; RA, NUTS II region area; RNF, Relative number fires; RBA, Relative burnt area; CA, Class' area of each variable in each NUTS II region; NNF, Normalized number fires; NBA, Normalized burnt area.

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https://doi.org/10.1016/j.scitotenv.2017.12.013
0048-9697/

1. Introduction

In the last decades, Europe registered a high number of fires (hereafter, NF) and burnt area (hereafter, BA) with different spatial and temporal trends as the result of human-driven fuel transformations and climate change (Fernandes, 2013; Pereira et al., 2013, 2014; San-Miguel-Ayanz et al., 2016; Vilar et al., 2016). The society and the scientific community regard this phenomenon as a natural ecological factor and, at least in some cases, a natural/human disaster (Nunes et al., 2016; Vilar et al., 2016). Despite its smaller land area in comparison with other Mediterranean countries, Portugal is the European country with the highest total NF (hereafter, TNF) and the second largest total BA (hereafter, TBA) (San-Miguel-Ayanz et al., 2016).

The distribution of fire incidence (NF and BA) is one of the characteristics of the fire regime and, in Portugal, presents a high spatial-temporal variability. Weather and climate variability are the main drivers of the temporal distribution. The Mediterranean type of climate of mainland Portugal broadly controls the fire incidence's temporal and spatial variability. This type of climate favours the emergence and growth of vegetation during the wet and humid season as well as water and thermal stress during the dry season, which helps to understand the vast majority of NF and BA occur during the noticeable summer fire season (Amraoui et al., 2015; Pereira et al., 2005; Trigo et al., 2016). The occurrence of extreme weather (e.g., heat waves) and climate variability events (e.g., drought), which also tend to be more frequent and intense during the summer fire season, are main contributors to this sharp seasonal character of the fire incidence in Portugal (Parente et al., 2016; Pereira et al., 2014, 2005; Trigo et al., 2006).

The different subtype of climate in northern and southern Portugal also helps to understand why most of NF and BA is located at north of the Tagus river (Parente et al., 2016; Tonini et al., 2017). However, spatial distribution of fire ignitions and BAs is also highly dependent of other human and biophysical drivers such as demographic, socioeconomic, topographic and land use/land cover factors. In fact, previous studies suggested that a few number of landscape and anthropogenic variables could play an important role on fire risk mapping and the spatial patterns of fire incidence (Botequim et al., 2017; Fernandes et al., 2016; Oliveira et al., 2012; Vasconcelos et al., 2001; Verde and Zêzere, 2010). On this respect, Curt et al. (2016) modelled the spatial patterns of fire regime's features in southern France, using anthropogenic and environmental drivers, and found that socioeconomic factors partially control the fire regime, influencing the timing, spatial distribution and potential size of fires. In Portugal, Catry et al. (2007) studied the distribution of fire ignitions between 2001 and 2005 in relation to topographic and socio-economic variables, and concluded that most of the fire ignitions were intentionally caused and concentrated in the most populated municipalities of the north and centre littoral areas. Nunes et al. (2016) analysed the wildfires' geographical incidence and temporal trends in Portugal at a municipal level, and found that topography, population density, land cover and livestock are significant drivers of both ignition density and BA. Recent studies identified and characterized the role of variables such as altitude, slope and land cover in the fire incidence and to justify the existence, location and size of space-time clusters of fires in Portugal (Parente et al., 2016; Parente and Pereira, 2016; Tonini et al., 2017). Understanding the role of these human and biophysical drivers on the spatial patterns of fire incidence will be of fundamental importance to support forest and fire management as well as the implementation of legislation relating to human activities that may cause fires (Curt et al., 2016; Martínez et al., 2009; Moreira et al., 2010; Nunes et al., 2016).

Irrespective of whether a favourable set of conditions for the occurrence and propagation may be present, a wildfire needs a source of ignition to start, which in turn, is dependent on human activities. In fact, on a global scale, humans cause most of the wildfires, except in the boreal areas of North America and Eurasia, where a significant number of natural wildfires occurs and are responsible for a large part of the TBA (Le Page et al., 2015; Rowe and Scotter, 1973; Stocks et al., 2002; Veraverbeke et al., 2017). In Mediterranean-type ecosystems, wildfires are mostly caused (intentionally or negligently) by human activities which vary spatially and temporally in ways that could affect their size and destructiveness (Curt et al., 2016; Ganteaume et al., 2013; Pereira et al., 2017; Syphard and Keeley, 2015). According to the Portuguese Rural Fire Database (Pereira et al., 2011), currently available for the 1980–2014 period, although the limited confidence in the statistics for the first few years, only 32.8% of the TNF in Portugal have known cause, namely 0.6% caused by lightning, 23.1% by negligence and 76.4% intentionally. Even though most of the fires in Portugal are negligent or intentional, there are still a number of unanswered research questions, namely: The spatial distributions of negligent and intentional wildfires are equal or different? Do negligent and intentional wildfires have the same drivers? Do these factors have the same influence on the two types of wildfire? Are there regional differences in the influence of the drivers on the incidence of negligent and intentional wildfire? Therefore, main objectives of this study, in order to answer the previous questions, are to assess: (i) the spatial distribution of negligent and intentional wildfires; (ii) the influence of human and landscape drivers on the incidence of negligent and intentional wildfires; and, (iii) eventual regional differences in the spatial distribution and role of the drivers. We believe that it is of paramount importance to deepen our knowledge on the regime of negligent and intentional wildfires at regional level since they represent the vast majority of wildfires in the Portugal and are those that cause the greatest impacts and most catastrophic consequences. In addition, negligent wildfires will be those for which campaigns of sensitization and prevention as well as other fire management activities can be more efficient while risk management and monitoring of possible arsonist activities may be more effective.

2. Materials and methods

2.1. Study area

Continental Portugal is geographically located between Spain and the Atlantic Ocean, just at a few hundred kilometres of North Africa with a mainland area of about 90,000 km^2. The altitude is very heterogeneous within the mainland (Fig. 1a), ranging from the sea level in the western and southern coast to about 2 km of the highest point (*Serra da Estrela*) located in the central region (Fig. 1a). Naturally, altitude (value and location) determine the spatial features of slope (Fig. 1b). The Tagus River divide the country into two regions of approximately the same area but with different topography and two sub types of temperate (group C) climate. In accordance with Köppen-Geiger's climate classification (Kottek et al., 2006; Peel et al., 2007; Rubel and Kottek, 2010), the two subtypes of Mediterranean climate in Portugal are: Csb (dry and warm summer) in the north part of the country; and, Csa (dry and hot summer) in the south (Fig. 1c). Consequently, and in accordance with CORINE Land Cover 2006 (hereafter, CLC), these regions present two different predominant vegetation types, namely: Forests (22%) and Scrub and/or herbaceous vegetation associations (30%) in the north region; and, Heterogeneous agricultural areas (27%) and Forests (24%) in the south region.

In 1986, the Portuguese Government adopted the common standard for all member states of the European Commission, designated by the Nomenclature of Territorial Units for Statistics (hereafter, NUTS). The NUTS classification is a single, coherent and hierarchical system for dividing the territory of the European Union for the purpose of collecting, development and standardising a set of common regional statistical rules and procedures (CM, 1986). The NUTS regions were created by the Eurostat group in 1970, and consists of 3 levels of territorial units aggregation whose specific settings in each Member State depends on