Journal of Environmental Management 146 (2014) 373–382

Contents lists available at ScienceDirect

Journal of Environmental Management

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

The dynamics and drivers of fuel and fire in the Portuguese public forest

Paulo M. Fernandes [a, b, *], Carlos Loureiro [a, b], Nuno Guiomar [c], Gianni B. Pezzatti [d], Filipa T. Manso [e], Luís Lopes [b]

[a] Centre for the Research and Technology of Agro-Environmental and Biological Sciences, CITAB, University of Trás-os-Montes and Alto Douro, UTAD, Quinta de Prados, 5000-801 Vila Real, Portugal
[b] Departamento de Ciências Florestais e Arquitetura Paisagista, University of Trás-os-Montes and Alto Douro, UTAD, Quinta de Prados, 5000-801 Vila Real, Portugal
[c] ICAAM – Instituto de Ciências Agrárias e Ambientais Mediterrânicas, Departamento de Paisagem, Ambiente e Ordenamento, Universidade de Évora, Núcleo da Mitra, Apt. 94, 7002-554 Évora, Portugal
[d] WSL Swiss Federal Institute for Forest, Snow and Landscape Research, Research Group Insubric Ecosystems, Via Belsoggiorno 22, CH-6500 Bellinzona-Ravecchia, Switzerland
[e] Centro de Estudos Transdisciplinares para o Desenvolvimento (CETRAD), Universidade de Trás-os-Montes e Alto Douro, Apt. 1013, 5000-801, Portugal

ARTICLE INFO

Article history:
Received 11 January 2014
Received in revised form
29 April 2014
Accepted 23 July 2014
Available online

Keywords:
Fire regime
Global change
Fuel hazard
Fire modelling
Fire management
Mediterranean Basin

ABSTRACT

The assumption that increased wildfire incidence in the Mediterranean Basin during the last decades is an outcome of changes in land use warrants an objective analysis. In this study we examine how annual area burned (BA) in the Portuguese public forest varied in relation to environmental and human-influenced drivers during the 1943–2011 period. Fire behaviour models were used to describe fuel hazard considering biomass removal, cover type changes, area burned, post-disturbance fuel accumulation, forest age-classes distribution and fuel connectivity. Biomass removal decreased rapidly beyond the 1940s, which, along with afforestation, increased fuel hazard until the 1980s; a subsequent decline was caused by increased fire activity. Change point analysis indicates upward shifts in BA in 1952 and in 1973, both corresponding to six-fold increases. Fire weather (expressed by the 90th percentile of the Canadian FWI during summer) increased over the study period, accounting for 18 and 36% of log(BA) variation before 1974 and after 1973, respectively. Regression modelling indicates that BA responds positively to fire weather, fuel hazard and number of fires in descending order of importance; pre-summer and 2-year lagged precipitation respectively decrease and increase BA, but the effects are minor and non-significant when both variables are included in the model. Land use conflicts (expressed through more fires) played a role, but it was afforestation and agricultural abandonment that supported the fire regime shifts, explaining weather-drought as the current major driver of BA as well. We conclude that bottom-up factors, i.e. human-induced changes in landscape flammability and ignition density, can enhance or override the influence of weather-drought on the fire regime in Mediterranean humid regions. A more relevant role of fuel control in fire management policies and practices is warranted by our findings.

1. Introduction

The fire regime concept allows the description of fire incidence over time and is the basis to understand and communicate its environmental impacts (Krebs et al., 2010). Fire regime characterization is crucial for fire management, despite its dynamic nature and intrinsic variation in space and time. Humans affect the fire regime directly by initiating and suppressing fire, and indirectly by conditioning vegetation (fuel) through the type and intensity of land use. Anthropogenic fire regimes are then determined by the interplay between human population activities and fuels (Fulé et al., 2012; Guyette et al., 2002). Landscape patterns and dynamics influence fire regimes and post-fire responses, and such knowledge is relevant in landscape planning and management (Moreira et al., 2011).

* Corresponding author. Departamento de Ciências Florestais e Arquitetura Paisagista, University of Trás-os-Montes and Alto Douro, UTAD, Quinta de Prados, 5000-801 Vila Real, Portugal. Tel.: +351 259 350861; fax: +351 259 350480.
E-mail address: pfern@utad.pt (P.M. Fernandes).

http://dx.doi.org/10.1016/j.jenvman.2014.07.049
0301-4797/

Profound landscape changes took place during the second half of the 20th century in the Mediterranean Basin, mostly in relation to passive (vegetation succession after farmland and rangeland abandonment) or active (afforestation) processes that increased fuel loading, extent and connectivity of shrublands and woodlands (Fernandes, 2013; Loepfe et al., 2010; Moreira et al., 2011). Large-scale afforestation and reforestation with fast-growing pioneer conifers was a prominent feature of forest policies in the Mediterranean Basin, from Portugal to Turkey, with objectives of wood production and land restoration (Pausas et al., 2004). Forest plantations on Portuguese public land totalled 419,010 ha (85.5% of the total) from 1923 to 1995, of which 91.2% on communal land and 8.8% on coastal sand dunes (Carvalho and Morais, 1996; Rego, 2001); all south-western Europe countries experienced vigorous afforestation of common lands since the 1940s (Pinto-Correia and Vos, 2004).

Common lands were central to mountain agriculture in the multifunctional cultural landscapes of northern Portugal, as sources of pasture and shrub bedding for livestock and organic fertilization, fuel wood, charcoal and rye (Brouwer, 1993; Estêvão, 1983). Like elsewhere in southern Europe (Cussó et al., 2006; Pinto-Correia and Vos, 2004), livestock was the main integrator of agriculture and other land uses, crucial in the extraction, transference and deposition of nutrients (Aguiar et al., 2009; Estabrook, 1998, 2006). Shrub- and grass-covered common lands occupied the highest elevations and poorer soils and were extensively grazed, cut and frequently burned by small and low-severity fires (Aguiar et al., 2009; Seijo and Gray, 2012). Afforestation of common lands was imposed by the state forest service, in Portugal (Brouwer, 1993) as in Spain (Seijo and Gray, 2012). In Portugal the units of commons were aggregated in 'forest perimeters'. Local communities opposed afforestation because it implied grazing exclusion and conditioned other uses of biomass (Brouwer, 1995). Emigration of rural population was primarily an outcome of transition to an industrial society, but afforestation added to it, therefore accelerating the agricultural system disruption (Estêvão, 1983; Seijo and Gray, 2012). Most common land is currently co-managed with the forest service, following 1976 legislation that reinstated control by local communities. Anthropogenic fire has long been a regular and important factor of disturbance in Portuguese mountains (e.g., Connor et al., 2012), and mountain common lands currently comprise more than 60% of the Portuguese areas with a nature conservation status (Lopes et al., 2013). Afforestation of public land in Portugal was based on *Pinus pinaster* Aiton (maritime pine), which forms flammable stands that require extensive fuels treatment to avoid high-severity fire (Fernandes and Rigolot, 2007). Persistence of pre-industrial burning practices in the common lands and in their vicinity threatened the new stands (Seijo, 2005; Seijo and Gray, 2012). Accordingly, the forest service enforced fire exclusion and setup a fire suppression system (Quintanilha et al., 1965), but fuel management was not implemented until the 1980s when increased fire activity had become evident (Fernandes and Botelho, 2004; Silva, 1997).

Previous studies have characterized the last decades land-use changes in southern Europe and the concomitant increase in fire activity in the last half of the 20th century (Moreira et al., 2011). Temporal shifts and trends in burnt area have however occurred both upward and downward (Moreno et al., 2014; Pausas and Fernández-Muñoz, 2012; Pezzatti et al., 2013; Turco et al., 2013a). The relationships between land use changes in the Mediterranean and observed or potential fire activity have been approached through landscape structure metrics (Lloret et al., 2002; Loepfe et al., 2010; Martín-Martín et al., 2013; Vega-Garcia and Chuvieco, 2006), fuel accumulation rates (Rego, 1992) and fuel hazard scores assigned to land cover types (Millington, 2005; Moreira et al., 2001; Romero-Calcerrada and Perry, 2002; Viedma et al., 2009). Azevedo et al. (2011) went a step further and translated land use changes into fire potential by modelling fire intensity and fire growth in discrete moments in time (1958–2005) in a landscape of NE Portugal.

Fire-regime modifiers other than land use dynamics can be equally important, namely climatic change (Amatulli et al., 2013; Batllori et al., 2013; Bedia et al., 2014; Krawchuk et al., 2009). Interaction between climate and fuels produces a fire-regime gradient from fuel-limited, where fuel load and connectivity are too low for fire to spread, to moisture-limited, where fuel does not dry enough to support fire spread (Bradstock, 2010; Krawchuk and Moritz, 2011; Pausas and Ribeiro, 2013). Mediterranean-type ecosystems occupy an intermediate position in the precipitation gradient and it is unclear whether fuels or moisture prevail in determining the fire regime, introducing uncertainty regarding the direction and intensity of the response to climate change (Batllori et al., 2013). Empirical evidence on the dependency of burnt area on fuel structure and fuel moisture in the Mediterranean is restricted to Spain (Vázquez et al., 2002; Pausas and Fernández-Muñoz, 2012; Pausas and Paula, 2012). Further interactions and complexity result from active fire management, namely fire suppression (Brotons et al., 2013; Moreno et al., 2014; Pezzatti et al., 2013). Sound management of fire-prone Mediterranean landscapes, currently and in the future, requires deeper and more quantitative understanding of the relative importance of the various fire-regime drivers (Fernandes, 2013).

This study (1) assesses trends in fuel hazard in the Portuguese public forest from 1943 to 2011; (2) identifies points of change in the fire regime during this period as described by annual area burned; and (3) models annual burned area from environmental and human-influenced drivers to assess the relative strength of their influences. We hypothesize a gradual increase in fuel hazard due to the effects of afforestation and agriculture decline and

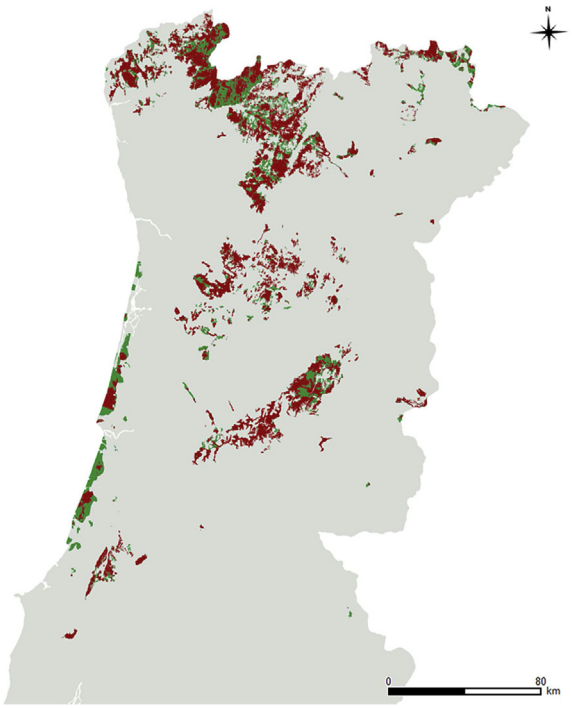

Fig. 1. Study area. Public forest land is displayed in red and green, respectively burnt at least once from 1975 to 2011 (67% of the burnable surface) and unburnt since 1975. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)