Forest Ecology and Management 397 (2017) 10–17

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Interacting effects of topography, vegetation, human activities and wildland-urban interfaces on wildfire ignition risk

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ARTICLE INFO

Article history:
Received 9 February 2017
Received in revised form 20 April 2017
Accepted 22 April 2017
Available online 29 April 2017

Keywords:
Wildfire ignition risk
Galicia
Forest fires
Human-related causes
Topography
Spain
WUI

ABSTRACT

Effective fire prevention requires a better understanding of the patterns and causes of fire ignition. In this study, we focus on the interacting factors known to influence fire ignition risk, such as the type of vegetation, topographical features and the wildland-urban interface (WUI; i.e. where urban development meet or intermingle with wildland). We also analyze the human activities and motivations related to fires and whether they differ depending on the type of vegetation and the location within/outside WUI. There were significant interactions between topography, type of vegetation and location within/outside WUI. The risk of ignition was in general higher at lower elevations, and this tendency was more marked in forested land covers (all plantations and open woodlands), with the noticeable exception of native forests. North-facing sites had lower fire ignition risk outside the WUI, especially in native forests, while southern aspects showed higher fire ignition risk, especially in open shrublands. However, this effect of the aspect was only significant outside WUI areas. In relation to causes, there were also interactions between human activities/motivations related to fires, the type of vegetation and the location within/outside WUI. All forestry plantations appeared clustered in relation to fire causes, especially in the WUI, with high incidence of deliberately caused fires related to violent or mentally ill people and rekindle fires. In contrast, native forests, despite structural similarities with forestry plantations, showed more similarity with agricultural areas and open woodlands in relation to fire causes. In shrublands, there was a relatively high incidence of fires related to ranching, especially outside the WUI. This pattern of interactions depicts a complex scenario in relation to fire ignition risk and prompts to the importance of taking this complexity into account in order to adjust fire management measures for improved effectiveness.

1. Introduction

Fire is an important agent of change in natural ecosystems that has driven species adaptations and shaped landscapes over millions of years. As a consequence of human activities, current fire regimes have changed dramatically in many areas compared to natural regimes, causing impacts in both natural ecosystems as well as in the human society (Bowman et al., 2011). For the need to better understand fire patterns and improve fire prevention measures, there is an increasing interest on fire causes and risks. Fires occur as a consequence of both natural and human causes, with weather, topography, type of vegetation or proximity to human settlements being decisive factors in determining the likelihood of fire occurrence (e.g., Moreira et al., 2011).

The type of vegetation, as a land use/land cover (LULC) type, has been shown to be especially relevant for fire ignition risk (e.g., Bajocco and Ricotta, 2008; Carmo et al., 2011; Cumming, 2001; Nunes et al., 2005). Vegetation types differ in fuel loads and flammability as well as on fuel continuity, as determined by the structure of vegetation (Saura-Mas et al., 2010). For instance, in NW Spain, native forests and agricultural areas have the lowest fire ignition risk, whereas shrublands and mixed forestry plantations have the highest ignition risk (Calviño-Cancela et al., 2016).

Abbreviations: WUI, wildland-urban interface; LULC, land use/land cover; Agr, agriculture areas; OpShr, open shrublands; Shr, shrublands; OpWd, open woodlands; AtlF, Atlantic forests; PiP, pine plantations; EuP, Eucalypt plantations; MxAtl, mixed Atlantic forests; MxEuPiP, ixed plantations of pines and eucalypts; MxPiP, mixed pine plantations; MxEuP, mixed eucalypt plantations.

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http://dx.doi.org/10.1016/j.foreco.2017.04.033
0378-1127/

Knowledge on the fire ignition risk associated to different vegetation types can inform landscape management policy decisions, which can promote vegetation types with lower fire ignition risk.

LULCs have been shown to interact with other factors such as the proximity of human settlements (Calviño-Cancela et al., 2016). In relation to this, wildland-urban interfaces (WUIs) have been defined as areas where urban development meet or intermingle with wildland, and this interfaces are of special concern for fire risk management since fires are usually more frequent in these areas and the danger to human lives and properties can be higher there (e.g., Cohen, 2000). The only study, to our knowledge, addressing this interaction between LULC and the WUI revealed that the fire ignition risk associated to different LULC does differ between WUI and non-WUI areas, with forestry plantations showing the highest increase in the likelihood of fire occurrence in WUI compared to non-WUI areas (Calviño-Cancela et al., 2016). Topography can also interact with LULC to modify fire risk, since it affects the distribution of vegetation (e.g., agriculture fields are usually located in flat, low areas, while forest and plantations usually occupy steeper areas, less suitable for agriculture) and some abiotic factors such as temperature and moisture content of fuels (e.g., in North versus South facing slopes).

In addition to these elements, nowadays the human factor is essential to understand the patterns of fire risk. Human activities have altered fire regimes worldwide, modifying fire frequency, intensity, and size of wildfires (Bowman et al., 2011). Human-related causes, whether intentional or by accident, are the most frequent causes of fires (FAO, 2007). In addition, certain human uses or activities are specifically associated to particular LULCs, being important drivers of fire risk in those LULCs. Common examples are agricultural burnings in farmlands or the periodical burnings in shrublands and grasslands to control woody encroachment and promote growth of new shoots, grasses and forbs for grazing (Ganteaume et al., 2013; Vélez, 2002; Webb, 1998). Similarly, socioeconomic factors, such as fragmentation of holdings, that limits the profit owners obtain from forestry products, urbanisation pressure, rural land abandonment or conflicts associated to forests' multiple uses have been shown to increase the probability of fire (e.g., Chas-Amil et al., 2015; Romero-Calcerrada et al., 2010; Yang et al., 2007). Moreover, since population density, human behavior and activities differ markedly between WUI and non-WUI areas, human-related factors are expected to modify the fire ignition risk associated to LULCs and topographical features depending on their location within or outside WUIs areas. Topography can also affect the risk of fire related to human causes, since human accessibility and activities can be markedly determined by topography (e.g., high and abrupt areas are less accessible).

In this study, we assess the fire ignition risk focusing on the interacting effects of LULC types, the WUI and topographical features. We also analyze the underlying causes related to fire occurrence, focusing on human activities and motivations, and how this is affected by location within or outside the WUI in different LULC types.

2. Materials and methods

2.1. Study area

This study was carried out in Galicia (NW of the Iberian Peninsula; Fig. 1), the most important forestry region in Spain (Manuel and Gil, 2002), where c. 70% of the land is forested, mainly covered by tree plantations of *Pinus pinaster* and *Eucalyptus globulus*, in pure and mixed stands. Native forests dominated by *Quercus robur* have higher species diversity and more distinctive communities than tree plantations (Calviño-Cancela et al., 2012a, 2012b; Calviño-Cancela, 2013), but are reduced to small, isolated patches (Díaz-Maroto and Vila-Lameiro, 2008; Teixido et al., 2010). Eucalyptus plantations have expanded notably in the last decades, both by intentional planting and natural spread (Aguas et al., 2014; Calviño-Cancela and Rubido-Bará, 2013; MAGRAMA, 2011). The frequency of wildfires is especially high in the study area: more than 30% of forest fires in Spain each year occur in this region, mainly associated with intentional behavior (75%) (MAGRAMA, 2012).

2.2. Data

A database of 26,838 wildfire reports for the period January 1st, 2006 to December 31st, 2011 obtained from the Spanish Forest Fire Statistics (EGIF) was used in this study, which includes the coordinates of each ignition point (see Calviño-Cancela et al. (2016) for details). Fire causes and motivations given in fire reports were grouped in 12 categories focusing, for deliberate and negligent fires, on human activities and behaviors to which the fire ignition was related: agriculture and vegetation management (including agricultural burnings and fires related to verge maintenance), ranching (fires related to pasture regeneration), forestry management, hunting, recreation, waste management (rubbish burning), profit gaining, conflicts, mentally ill or violent people, accidents, natural (lighting) and rekindle (Table 1). Fires caused by "other negligences", "other deliberate causes" and with "unknown causes" were excluded from the study, due to the lack of definition of these categories, as they may include very different causes.

For each fire ignition point we determined the land use/land cover type (LULC), its topographic features (slope, elevation, and aspect) and the location inside or outside of the WUI. We determined the LULC type using information from the Fourth National Forest Inventory (IFN4, MAGRAMA, 2011; see Calviño-Cancela et al. (2016) for further details). Areas with no or very scarce vegetation (e.g., water bodies, beaches, or artificial surfaces such as industrial or urban areas) were excluded, as well as the less frequent LULCs (grasslands, Mediterranean forests and Acacia woods), due to the low number of fires in WUI in these categories. WUI was defined as the area within a 50 m radius around buildings at a distance of up to 400 m from wildland vegetation (Law 3/2007 of April 9, 2007, addressing the issues of wildfire prevention and suppression, as modified by Law 7/2012 of June 28, 2012 of Galician Forestry). The mapping of WUIs in Galicia was obtained from Chas-Amil et al. (2013).

Topographic variables were calculated using the Spatial Analyst extension to ArcGIS® 10.2.2 by ESRI to derive the slope, elevation and aspect, based on a 10 m spatial resolution digital elevation model (DEM, 1:5000 scale), developed by SITGA (Galician Territorial Information System). The slope was defined as a percentage and elevation in meters. Aspect was defined as the compass direction that the slope faces: N (315–360° and 0–45°), E (45–135°), S (135–225°) or W (225–315°) direction.

2.3. Data analyses

In order to compare the patterns of distribution of ignition points with a random model, we selected 26,838 random locations in the region and characterized them in regard to WUI, LULCs and topography, as done for ignition points. To select random points we used the module Random Points Generation of Hawth's Analysis Tools, in ArcGIS. Then, we obtained 100 samples with 5000 locations each, out of the 26,838 fire ignition and random points, using a Montecarlo method (bootstrapping; random resampling with replacement; Efron, 1982; Manly, 1998).

In relation to topography, we tested whether there were differences in elevation between ignition and random points,