Book Section:

Calviño-Cancela, María, Chas-Amil, Maria Luisa and Touza, Julia M. orcid.org/0000-0001-8170-1789 (2014) Assessment of fire risk in relation to land cover in WUI areas. In: Viegas, Domingos Xavier, (ed.) Advances in forest fire research. Imprensa da Universidade de Coimbra , pp. 657-664.

https://doi.org/10.14195/978-989-26-0884-6

Assessment of fire risk in relation to land cover in WUI areas

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Abstract

Areas where urban and wildland intermingle, known as wildland-urban interface (WUI), are increasing worldwide over the last decades (Theobald and Romme 2007; Montiel and Herrero 2010). These WUI areas are of particular concern in forest fire risk management because the presence of housing developments in contact with forestlands increases the likelihood of a fire starting as a consequence of human activities. In Spain, for example, there is increasing evidence that the wildland-urban interface constitutes a highly risk prone area (Herrero et al. 2012; Chas-Amil et al. 2013). Given the recognised role of land cover distribution in fire risk (Bajocco and Ricotta 2008; Oliveira et al. 2013), this paper evaluates recent fire activity across different land cover categories, and the causes and motivations, comparing WUI and non-WUI areas. Fire data were collected in Galicia, Spain, where fires are mostly due to deliberately-caused ignitions. We show that arsonist are more likely to ignited a fire in WUI areas than in non-WUI; and the same seems to be true for fires ignited by agricultural activities. Moreover, land cover types only have a significant impact on the patterns of fire occurrence in WUI areas.

Keywords: fire hazard, land-use cover, wildland-urban interface, intentional-caused fires, Galicia, Spain.

1. Introduction

Fire is a natural process in many ecosystems, with an important role in shaping species adaptations and landscapes (Bond and Keeley 2005). However, human activities have altered fire regimes in areas such as southern Europe, increasing fire frequency, especially of large fires (Moreno et al.1998). In Spain, for instance, more than 90% of wildfires are caused by human activities, according to official statistics (MAGRAMA, 2010). Therefore, areas where wildland and human developments intermingles, known as wildland-urban interface (WUI), are especially vulnerable to the risk of fire ignitions (Chas-Amil et al 2013; Lampin-Maillet et. al. 2010; Syphard et al. 2007). In addition, the presence of population living close to forestlands increases the likelihood of severe consequences in properties and land-use activities and may also pose serious threats to lives.

The fire risk (or ignition risk) is the chance of a fire starting as determined by the incidence of causative agents (FAO 1986; NWCG 2006). A good understanding of the patterns and causes of fire ignition is essential for effective fire prevention (Finney 2005). Land use and land cover (LULC) have been recognized as a major determining factor of fire risk (Bajocco and Ricotta 2008; Moreira et al. 2009; Carmo et al. 2011; Xystrakis and Koutsias, 2013) and, in contrast with other factors such as weather and topography, it can be subject to active policy management, which makes the analysis of fire risks associated with LULC types especially interesting for fire prevention policies. In addition, it can provide useful information for local residents, as these are often not aware of the fire risk associated with their behaviour. The type of LULC determines fuel load and characteristics (e.g. flammability and moisture content; Saura-Mas et al. 2010; Ganteaume et al. 2009) and is associated with human activities with contrasting levels of fire risk (e.g. use of fire as a management tool for agricultural waste disposal in farmlands or for pasture renewal in rangelands; Vélez 2002; Ganteaume et al. 2013). Moreover, socio-economic factors may lead to land-use conflicts that can trigger intentionally-caused fires (e.g. urbanization pressure or unemployment; Prestemon et al. 2012; Romero-Calcerrada et al. 2010).

In this paper, we analyse the level of fire risk at different land covers and the causes and motivations of fires, comparing WUI and non-WUI areas. We analyze whether different land cover types are equally fire-prone, i.e. fires occur in direct proportion to the availability of those land cover types in the landscape, or otherwise some land cover types burn more or less frequently than expected given their abundance. We contribute to the previous literature on fire ignition selectivity towards different land cover types by comparing WUI and non-WUI areas, in order to determine whether the contrasting socio-economic contexts in these types of areas have a significant impact on the patterns of fire occurrence and its causes.

2. Materials and methods

2.1. Study area

The study was carried out in Galicia (NW of Iberian Peninsula). Its ancient mountains, with an average altitude of 508 meters, characterize the territory. Climate is rather humid and because of Galicia's meridional latitude, it can be quite warm in some areas. Galicia is the most important forestry region in Spain (Manuel and Gil 2002), with c. 70% of the land being forested. More than half of the forested area is covered by tree plantations of *Pinus pinaster* and *Eucalyptus globulus*, in pure and mixed stands. Depopulation and farming abandonment has led to an increase of forested land, as in many other rural areas in Europe, particularly the expansion of eucalypt plantations, resulting in important changes in the regional landscape, mainly in rural lowland areas (Marey-Pérez et al., 2006; Cramer and Hobbs, 2007). Native forests dominated by *Quercus robur*, which occupied large areas in the past, have now been reduced to small, isolated patches (Ramil-Rego et al., 1998; Teixido et al., 2010). Based on Chas-Amil et al. (2013), the interface between urban and forested areas (WUI) totals 2,442 km^2 in Galicia, which represents 8.3% of the region, with many WUI areas located along the Atlantic coast and in the southwest of Galicia. A significant proportion (79%) of the WUI areas are classified as non-forested areas, while the forested land in WUI is mainly characterized by a high level of fragmentation. On the other hand, forestlands dominate non-WUI areas, covering nearly three-quarters of these areas. Compact forestlands with little fragmentation cover more than half of the territory outside the interface (56%), while highly fragmented forestland covers 14%.

With an annual average of more than 4,000 forest fires and 30,000 ha burned between 2006 and 2009, Galicia is the region of Spain with the highest frequency of fires; more than 30% of forest fires in Spain each year are located in this region, even though it represents only 6% of the Spanish territory. In addition, most fires are human-caused (99%), mainly associated with intentional behaviour (80%) (Chas-Amil et al. 2010).

2.2. Fire and land cover data and analyses

We defined wildland-urban interface (WUI) as the intersection of the forest area and/or forest influence areas (up to 400 m from forestland) with the buffer of 50 m around buildings, where bush clearing is compulsory by law (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). The identification and mapping of WUI en Galicia was obtained from Chas-Amil et al. (2013).

A database of the daily forest fire ignition points for the period from January 1, 2006 to December 31, 2011 was employed for this study. These fire ignition data were obtained from the Rural Affairs Department of the Regional Government (Xunta de Galicia), and the Spanish Ministry of Agriculture, Food and Environment (MAGRAMA). Forest fire reports list general information on burned areas, date and estimated time of ignition, the geographic coordinates of the ignition point, causes and motivations, and the fire-fighting measures applied. A fire is included in the official database only if it fully or partially affects forest and other woodland areas. The coordinates of the ignition points for all fires in the database were evaluated and corrected if errors were detected. We refined the coordinates by using maps of administrative boundaries (parishes, municipalities, population entities) at a scale of 1:25000, a raster topographic map 1:25000, and Landsat TM images. All computations were performed with ArcGIS® 9.3.1 by ESRI and Geomedia Professional 6.0 by Intergraph.

We then combined the WUI layer and the geographic coordinates of the ignition points to randomly select a total of 600 wildfires (100 per year), 300 in WUI areas and 300 in non-WUI areas, together with all their characteristics included in the wildfire database. Fire causes were grouped in 4 classes: deliberate, negligence, unknown, others (natural causes and accidents that are not considered negligence). For deliberated fires, the motivation behind the fires is also included in fire reports, and was grouped in the following categories: farmers (fires caused by farmers for clearing shrubland areas), rangers (burning of shrublands for pasture renewal), arsonists, vandals, chasing wildlife away (e.g. wolfs or wild boars), others or unknown motivations. Note that causes are, in most cases, presumed by the technical staff in the field, and only in c. 10% are confirmed caused.

The land cover type of all these locations was identified, using information from the Fourth National Forest Inventory (IFN4), which was developed in Galicia in 2008-2009. The IFN4 has been based on the cartography of the Forest Map of Spain at 1:25.000 (MFE25) carried out on aerial orthophotos of the PNOA of the National Geographic Institute that are divided in homogeneous polygons of 0.5 to 2 ha in size (depending on the cover type) and are classified according to a hierarchic classification with a total of 63. We re-grouped these categories according to our research interest into the following categories: broadleaved forests (broadleaved natural forest, as differing from tree plantations, dominated by native broadleaved trees, mostly *Quercus robur* and *Quercus pyrenaica*; plantations of broadleaved trees such as *Castanea sativa* or *Betula pendula* has been included also in this category), tree plantations (pure or mixed stands dominated by *Eucalyptus globulus*, *Pinus pinaster*, *Pinus radiata* and *Pinus sylvestris*), shrublands (dominated by shrubs, with no tree cover), farmland (used for crops and pastures for livestock), and artificial (areas devoted to urban or industrial developments and infrastructures).

In order to determine fire selectivity for different land cover, the frequency of different land covers between ignition points and a random null model, was investigated using Maximum Likelihood Ratio tests (G test, Sokal and Rohlf 1995). For this, we selected a total of 200 random points (100 in WUI and 100 in non-WUI areas) and determined their cover type. Significant differences indicate that fires would not occur randomly in the landscape, with different proportion of ignition points and available land-cover types. We also estimated the selection ratio (w_i) for a given cover class, an index estimated as $w_i = U_i/A_i$, where U_i is the proportion of the ignition points belonging to cover class i and A_i is the proportion of available area belonging to that cover class i (Manly et al. 1993). A cover type with a percentage of ignition points proportionate to its availability has a value $w_i = 1$, a class with a percentage of ignition points exceeding that expected by chance (i.e. selected positively by fire, thus more fire-prone than expected by random) had a value $w_i > 1$, whereas a cover type with a less than expected proportion ignition points (i.e. avoided by a fire, less fire-prone than expected by random), has a value $w_i < 1$ (e.g. Moreira et al. 2001; Nunes et al. 2005).

3. Results

3.1. Wildfire causes

Most wildfires in Galicia were considered deliberate for the period 2006-2011. Differences between WUI and non-WUI in regard to causes of wildfires were marginally significant (G=13.5, 3 d.f., p<0.05), with a higher number of fires due to negligence in WUI areas (1.9 times more than in non-WUI areas) (Fig. 1).

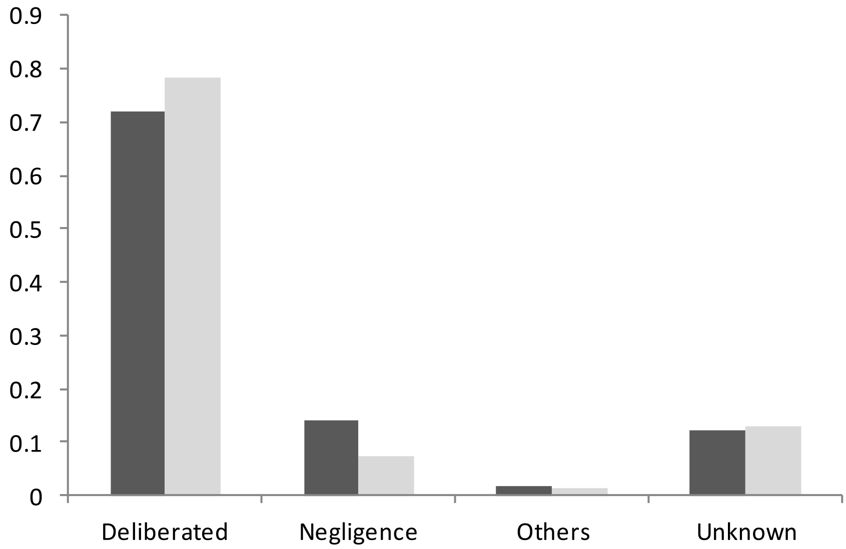

Figure 1 – Relative frequencies of wildfire causes in WUI (dark gray) and non-WUI areas (light gray).

Motivations behind deliberate fires differed markedly between WUI and non-WUI areas (G=58.0, 5 d.f., p < 0.05), especially in regard to fires caused to chase wildlife away, which were more than 15 times more frequent in non-WUI than in WUI areas (Fig. 2). Fires caused by ranchers were also somewhat more frequent in non-WUI than in WUI areas (1.6 and 1.3 times more), whereas those caused by arsonist and farmers showed the opposite pattern (1.6 and 1.2 times more frequent in WUI than in non-WUI areas).

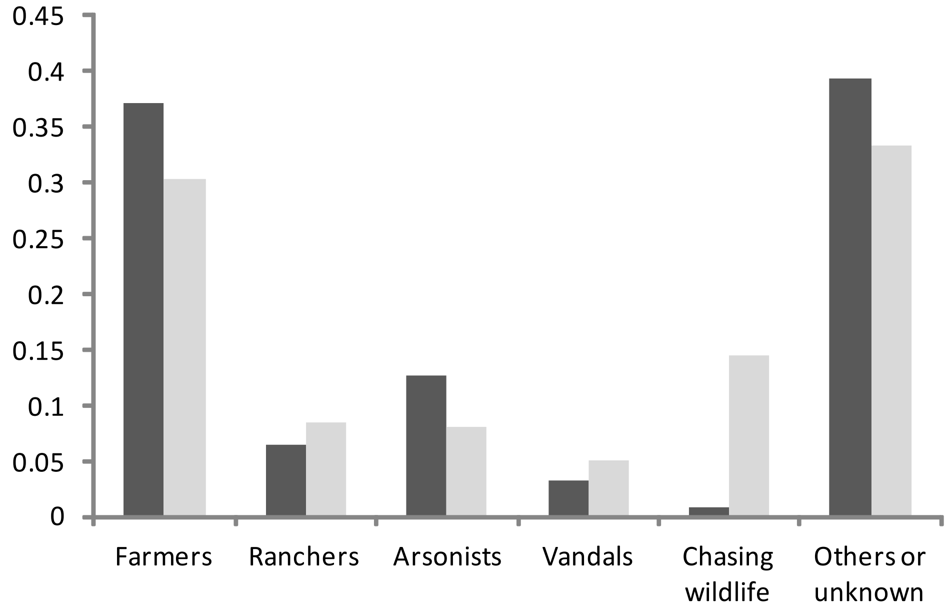

Figure 2 – Relative frequencies of motivations behind deliberated wildfire in WUI (dark gray) and non-WUI areas (light gray).

In non-WUI areas, causes of wildfires had similar frequencies among land cover types. However, in WUI areas, the frequency of fire causes in farmlands and plantations differed from the general pattern (pooling together all cover types). In farmlands, deliberated fires and those caused by negligence were the most frequent (87%), but fires caused by negligence were 1.8 times more frequent than expected by the general pattern, whereas deliberated fires were 13% less frequent than expected. In plantations, deliberated fires were the most frequent (72%), similarly as for all cover types pooled, whereas fires caused by negligence were 25% less frequent than expected.

3.2. Patterns of cover types and wildfire distribution

The coverage of land uses differed between WUI and non-WUI areas, with more land devoted to farms in WUI than in non-WUI (77% vs. 22%) and less to shrublands (3% vs. 26%), plantations (13% vs. 37%), and broadleaves forests (7% vs. 10%).

Table 1: Estimated selection ratio index in WUI and non-WUI in the study area.

Land cover types	**Area (%) with respect to total**	**Ignition points (%) of those randomly selected**	w_i

WUI			
Artificial	6	12.8	2.14
Farmland	70	51.0	0.73
Shrublands	3	3.7	1.24
Tree plantations	13	25.3	1.95
Broadleaved forests	7	5.4	0.77
Others	1	1.7	1.7
			G = 21.63*
Non-WUI			
Artificial	5	1.3	0.27
Farmland	22	27.4	1.25
Shrublands	26	29.1	1.12
Tree plantations	37	29.1	0.79
Broadleaved forests	10	12.0	1.20
Others	0	1.0	-
			$G = 5.60^{ns}$

* Significance at 5%.

The proportion of fire ignitions in land cover types differs between WUI and non-WUI areas (G = 108.2, 5 d.f., p<0.001), with more frequent fires at shrublands and broadleaved forests in non-WUI areas compared to WUI areas (with fires being 7.8, 2.2 times more frequent in non-WUI than in WUI areas, respectively). However, ignitions are less frequent in artificial areas and farmlands in non-WUI compared with WUI areas (with fires being 9.8 and 1.9 times more frequent in WUI than non-WUI areas). The proportion of fires ignited at tree plantations is similar in WUI and non-WUI areas (25.3% vs. 29.1% respectively).

In WUI areas, the location of wildfire starting points in relation to land cover types differ from that expected by random (Table 1), with artificial areas and tree plantations being positively selected (2.14 and 1.95 more wildfires than expected according to a random distribution), as well as shrublands, in a lesser degree (1.24 times more fires than expected). On the other hand, farmlands and broadleaved forests had fewer fires than expected by random (27% and 23% less wildfires than expected by random; Table 1). In non-WUI areas, the distribution of wildfires did not differ significantly from a random distribution among land cover types (Table 1).

4. Discussion and conclusions

The great majority of fires are linked to deliberate-caused fires, both in WUI and non-WUI areas, as expected. Looking at the apparent motivations behind deliberated fires, most of them seem to be caused by activities that use fire as a managing tool. Those caused by arsonists or vandals are however less frequent. Farmers and rangers seem to cause most deliberated fires, farmers using fire mostly for clearing and rangers for pasture renewal. In addition, fires related to chasing animals away to avoid damage to crops and livestock may be also cause by farmers or rangers. It is interesting to note the different incidence of negligence and deliberate fires between WUI and non-WUI areas. Outside WUI areas, where the danger of fires due to negligence related to human-activities is lower, there was a higher incidence of deliberate fires, an especially of those related to extensive farming practices. Thus, fires caused to chase animals away or for pastures renewal for livestock were more frequent here than in WUI areas. The higher incidence of negligence in WUI areas might be related to a higher intensity of human activities, for instance related to crop cultivation. Interestingly, in farmlands in WUI areas the incidence of negligence was much higher than in other cover types, this negligence being mostly related to agricultural waste disposal.

Selectivity patterns of fire for particular cover classes were only apparent in WUI areas. Here, the high fire-proneness of artificial areas might be related to a higher human activity concentrated in these areas, which favors human-related fires, either deliberated or due to negligence or accidents. Regarding plantations, the other cover class positively selected by fire, their higher fire-proneness contrasts with the negative selection showed for broadleaved forests (see also Moreira et al. 2009, Moreno et al. 2011). This might be related to a higher flammability of plantations, which increases the chances for a fire to actually start after a deliberate attempt or a negligent conduct. *Eucalyptus globulus* and *Pinus pinaster* litter is highly flammable (Ganteaume et al. 2009), and they can grow more biomass of understory vegetation, which also is dominated by highly flammable species such as Ulex spp. and grasses (Ganteaume et al. 2009, Calviño-Cancela et al. 2012). This is especially true in the case of *Eucalyptus globulus* plantations with very low-management, which are very common in Galicia due to rural depopulation and land abandonment (Marey-Pérez et al., 2006, Robak, 2008; Díaz-Balteiro et al., 2009). Broadleaved forests, on the contrary, are more humid and less biomass in the understory (although with higher diversity; Calviño-Cancela et al. 2012). The expansion of plantations in many parts of Galicia, especially those of *Eucalyptus globulus* (MAGRAMA 2011), at the expense of broadleaved forests (Marey-Pérez et al., 2006) may have contributed to increased fire hazard in this region.

5. Acknowledgments

This research was funded in part by Ministerio de Economía y Competitividad (Project ECO2012-39098-C06- 05). The Spanish Ministry of Agriculture, Food and Environment (MAGRAMA), and the Rural Affairs Department (Xunta de Galicia) provided the wildfire database.

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