Landscape and Urban Planning 158 (2017) 129–138

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

The ignition index based on flammability of vegetation improves planning in the wildland-urban interface: A case study in Southern Spain

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HIGHLIGHTS

- The best method of mitigating the likelihood of homes is to decrease the flammability of the surrounding areas.
- Spatio-temporal flammability data improves planning in the wildland urban interface.
- Ignition index could be evaluated using field flammability data, mainly in wildland urban interface.
- Some species should be considered fire-wise species for landscaping use in the wildland-urban interface.
- Improving the quality of ignition cartography is a high priority for efficient allocation of limited economic resources.

ARTICLE INFO

Article history:
Received 5 March 2016
Received in revised form
30 September 2016
Accepted 1 November 2016

Keywords:
Flammability
Ignition fire risk
Intermix vegetation
Ornamental vegetation
Ignition probability

ABSTRACT

Forest fires in the wildland urban interface (WUI) are a widespread and growing problem due to changes in land use and climate. The impacts of WUI fire depend on the exposure of homes to dense vegetation (both natural and ornamental), as well as fire intensity, which is determined by meteorological, topographical, and vegetation conditions. In this study, our goal was to identify the ignition index in one risky Mediterranean WUI based on the potential flammability of the main intermix species at the particle level. The flammability of 18 species (natural and ornamental) commonly found in southern Spain was analyzed at the particle level. Flammability experiments ranked the flammability of the different species from moderately flammable to extremely flammable. Flaming duration (a variable related to fire suppression difficulty) and the ignition coefficient of the surrounding vegetation helped to complete the ignition risk for each vegetation aggregation. *Thuja orientalis* and *Ligustrum vulgare* showed the greatest individual potential to mitigate fire spread, and are recommended for planting and use as landscaping hedges in the Mediterranean WUI. We concluded that this methodological procedure is a useful tool for prioritization and budget allocation of fire risk reduction treatments. Furthermore, the development of technical guidelines for public urban landscaping as well as landscaping on private residences is required to adequately address and mitigate fire impacts both on homes and the surrounding landscapes.

1. Introduction

Wildfires have become a mounting threat to Mediterranean landscapes in southern Spain, and people living in areas affected by wildfires have become increasingly concerned about the risk of wildfire (Andalusia Government, 2013). Changes in socio-economics, land use, and climate are the major contributing factors in the increase in large wildfires because of their role in promoting large accumulations of available fuel to burn (Cardil, Molina, & Kobziar, 2014; Rodríguez y Silva & Molina, 2012). Although recently there has been more money invested in resources and training for fire agencies, the number of small fires has not decreased and the number of large fires has drastically increased in southern Spain due to biomass accumulation (WWF, 2015).

Landscapes are composed of a cluster of interacting land areas (Finney, 2001), including agricultural and forest areas, as well as urban areas. The zone of contact between human infrastructure and wildland vegetation, known as the wildland urban interface (WUI), has increased worldwide over the last few decades and has a direct relationship with the risk of forest fires (Chas-Amil, Touza, & García-Martínez, 2013). Wildfires that impact settlements are becoming increasingly frequent because of the increasing

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http://dx.doi.org/10.1016/j.landurbplan.2016.11.003

number of houses and infrastructures located within and adjacent to areas prone to wildfires (Marzano, Camia, & Bovio, 2008). Fire can spread easily through the ornamental trees and hedges present in housing developments. Consequently, forest fires have emerged as a civil emergency concern due to the risk to human lives and residential properties in the WUI (Cohen, 2008). However, urban planning rarely takes fire vulnerability into account and housing development in the WUI is frequently unregulated (Madrigal, Ruíz, Planelles, & Hernando, 2013). The identification of high vulnerability fire areas in relation to the complex interaction of meteorological conditions, vegetation, and topography is the key to developing specific preventive measures that improve the legal, preventive, and suppression aspects of wildfire management (Montiel & Herrero, 2010, Madrigal et al., 2013). The responsibility for preventive measures and other fire defense techniques must be shared and coordinated between land managers and homeowners (Butsic, Syphard, Keekey, & Bar-Massada, 2017; Caballero, 2008).

Remote sensing and GIS are fundamental in WUI characterization. There are different methodological approaches in order to assess the hazard and vulnerability of WUI which is based on landscape analysis, on the use of Geographic Information Systems (GIS) techniques and remote sensing (Galiana, Herrero, & Solana, 2011; Mercer & Zipperer, 2012). A new approach has characterized hazardous fuels at the scale of individual structures by integrating aerial photography, airborne laser scanning and cadastral datasets into a hazard assessment framework (Skowronski et al., 2016). WUI characterization should consider vegetation and housing density and the degree of clustering of both components (Price & Bradstock, 2014). Therefore, WUI can be mapped using the WUImap® tool implemented by ArcGIS software (Lampin-Maillet et al., 2010; Madrigal et al., 2013). Other approaches have provided indications of settlement vulnerability based on the relationship between landscape metrics and fire risk using Fragstats software (McGarigal & Marks, 1995; Marzano et al., 2008). Additionally, a risk matrix and a summarize wildfire risk were created based on the population density and burn probability (Haas, Calkin, & Thompson, 2013).

The identification and evaluation of WUI fuels should be basis for improvement of treatment prioritization and budget allocation (Mell, Manzello, Maranghides, Butry, & Rehm, 2010). Flammability characterization is an effort to address these gaps in understanding by providing physical explanations for the relation between species and fire behaviour (White & Zippere, 2010). In this sense, our focus is given to the ignition index (Rodríguez y Silva, González-Cabán, & Molina, 2014) which indicates the capability of accumulated fine fuels to ignite given a heat source, showing the predisposition of fuels to accept heat and start combustion. This index employs an integral approach to modelling vegetation flammability which depends on the probability of ignition (USDA Forest Service, 2004), the ignition coefficient (Rodríguez y Silva et al., 2014), and species flammability. While the probability of ignition and the ignition coefficient can be easily assessed, plant flammability has been widely studied in the laboratory using several methods (Dimitrakopoulos & Papaioannou, 2001; Elvira & Hernando, 1989; Ganteaume, Jappiot, & Lampin, 2012; Hernando, 2009). However, the results obtained by the different vegetation flammability assessment methods depend on the scale considered (Etlinger & Beall, 2004; Ganteaume & Jappiot, 2014). In this sense, the assessment of flammability in the laboratory is limited by the scale of experimentation because plant exposure to heat is frequently not comparable to wildfire conditions (Fernandes & Cruz, 2012). However, field experiments in WUI are often limited by safety constraints and landscape impacts. In spite of these limitations, the classification of fuels surrounding homes is an essential component of fire hazard assessments (Dimitrakopoulos & Papaioannou, 2001; Herrero, Jappiot, Bouillon, & Long-Fournel, 2012; Madrigal et al., 2013; Massada, Stewart, Hammerc, Mockrin, & Radeloff, 2013; White & Zippere, 2010).

The understanding of fire behavior provided by ignition index in and around WUI gives invaluable insights into the factors affecting flammability in different environments. The presence of higher accumulations of vegetation around houses, both natural and ornamental, is one of the main causes of house ignition (Etlinger & Beall 2004). The most efficient way to mitigate the damage to homes caused by fire in WUI areas is to decrease the amount of flammable fuels surrounding the homes (Ager, Vaillant, & Finney, 2010; Calviño-Cancela, Chas-Amil, García-Martínez, & Touza, 2016). Knowledge of how species differ in their flammability characteristics is needed to develop more efficiency treatments for landscaping homes in the WUI (White & Zippere, 2010). Therefore, less flammable species are recommended as ornamental plants (Ganteaume & Jappiot, 2014; Monroe, Long, & Marynowski, 2003). Vegetation components in the dooryard, such as hedges, ornamental bushes, and trees, affect fire behavior and, as a consequence, fire ignition, propagation, and heat release near the building (Caballero, 2008). WUI homeowners are advised to annually reduce or eliminate highly flammable vegetation and use less flammable species as replacements.

The aim of this study was to identify the ignition index in one risky Mediterranean WUI based on the potential flammability of the main intermix species at the particle level. This index calculates the fuel availability to ignite and propagate through plants as affected by meteorological conditions (ignition probability), the characteristics of fuel model (ignition coefficient) and the species flammability. While the probability of ignition was estimated based on summer conditions in the study area, the ignition coefficient was obtained by field sampling. Flammability identification could become an essential tool for the removal of vegetation and the development of a vegetation maintenance schedule for homeowners to mitigate fire spread and the ecological and socioeconomic impacts of fire.

2. Material and methods

2.1. Study area

The study area is located in Andalusia Region in southern Spain (Fig. 1). A continental Mediterranean climate characterizes the area with daytime summer temperatures above 40 °C that are conducive to fire ignition and propagation, and, consequently, a higher risk of fire occurrence. Fire statistics from the Córdoba Province show an average of 13.4 forest fires per year (2001–2012) in the study area, which burn 11.54% of the total burned area in the Province.

The WUI in the study area covers 30,000 ha including three local administrative departments and 39 settlements. Although field studies have shown that the extent of WUI in the study area has remained steady between 1990 and 2014, there are more houses within the same area. In some cases, there are now many houses where before there was only one house. Now, modern houses are built with more fire vulnerable materials than older, traditional buildings. This urban phenomenon has become a real problem for policy makers and decision makers. According to the Andalusia experience, WUI fires have shown that the capacity of road networks collapse during fire events, preventing or severely delaying firefighting equipment access to the area. During a fire, social alarm causes traffic jams because everyone tries to use the existing, narrow escape routes.

Settlements present differences in total area, housing density, and spatial distribution (isolated, dispersed, and compacted distribution). As a consequence, vegetation composition and structure also vary greatly between the settlements. Settlements were clas-