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Application of a geographical assessment method for the characterization of wildland–urban interfaces in the context of wildfire prevention: A case study in western Madrid

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A B S T R A C T

The increasing occurrence of fires in areas where wildlands and urban structures meet (wildland–urban interface areas, WUIs) is currently of great concern to policy makers in Euro-Mediterranean countries. A better understanding of these areas is crucial for efficient fire management. This paper presents a method to map and characterize WUIs from the perspective of fire risk using a case study in the Madrid Region of Spain. The internal structure of interface areas, and also the features of the landscapes in which they are located, were analyzed. Spatial analyses of pooled data, including fuel, topography, housing structure, past fires and key driving forces were based on Geographic Information Systems. This procedure enabled the identification of seven representative *WUI Situations* within the 14,800 ha of WUI in the area. The results revealed the variability of WUIs, suggesting that wildfire prevention needs to be adapted to the different types of WUIs. The characterization of such situations may be a useful tool to achieve this goal.

Introduction

According to the EFFIS database, an average of 70,000 fires occur in Europe every year, destroying more than half a million hectares of forest. Fire activity and fire effects are concentrated in the Mediterranean region, where 70% of these fires occur and are responsible for 85% of the total burned area in Europe (EEA, 2010). In this context, the obvious ecological damage and destruction of forests is not the only concern; the increasing problem of wildfires reaching populated areas is also a major issue. The 43 casualties in the 2003 and 2005 fire seasons in Portugal, and the 78 casualties in the 2007 fire season in Greece, illustrate the magnitude of the problem (Viegas, Ribeiro, Viegas, Pita, & Rossa, 2009).

People who live in wildland areas thus represent serious problems for fire risk management in both hazardous and vulnerable areas. First, fire ignition sources increase the probability of wildfires starting near urban structures; 90% of fires in the Mediterranean region are caused by humans (Vélez, 2009). Second, populated wildlands are areas where fires can have disastrous social and economic consequences (Jappiot, Gonzalez-Olabarria, Lampin-Maillet, & Borgniet, 2009; Syphard, Radeloff, Keeley, Hawbaker, Clayton, & Stewart, 2007; Vilar, Martín, & Martínez, 2008).

A wildland–urban interface (WUI) is the area where buildings and other human development meet or intermingle with undeveloped wildlands (Radeloff et al., 2005; USDA and USDI, 2001). Macie and Hermansen (2003) noted that the term *wildland–urban interface* is subject to many interpretations under different perspectives; nevertheless, it is now used almost exclusively in the context of wildland fire (Stewart, Radeloff, Hammer, & Hawbaker, 2007).

In Europe, the WUI concept was directly imported from the United States. However, the American wildfire interface problem differs from that in the Euro-Mediterranean region, where wildfires affecting communities are not necessarily related to forest structures only, but also to other woody lands and even to agricultural land uses (Montiel & Herrero, 2010). Consequently, the concept of WUI often applies to the area where urban areas meet and interact with rural lands (Vince, Duryea, Macie, & Hermansen, 2005; FUME Project). The present study takes into account the specificity of European landscapes, where agriculture is a major landscape creator and component.

Major international research efforts have been undertaken since governments, the scientific community and the general public have become aware of the WUI as a fire prone scenario. Many attempts

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to map WUI areas have been made at different scales, resulting in local, regional or national maps, depending on the goal of the study. Small scales usually provide information on the concurrence of vegetation and urban land uses (Kamp & Sampson, 2002; Radeloff et al., 2005; Theobald & Romme, 2007). The use of time periods of different duration has also led to the identification of general spatial–temporal trends for large areas, such as countries (Zhang, He, & Yang, 2008). At larger and more precise scales, a more accurate delineation of the WUI can be obtained at the local scale, and even for the area surrounding a home. Information about the elemental characteristics that comprise the WUI also can be obtained to assess the potential fire risk to neighboring built-up areas (Lampin-Maillet, Jappiot, et al., 2010; MARM, ref 2009; Marzano, Camia, & Bovio, 2008).

In the geography of risk, a change in scale is very important. A risk area is characterized by its components and interactions with its environment. Only a multi-level assessment can provide a complete picture of the problem (Calvo, 2001). In addition, with respect to the risk of forest fire, a consecutive zoom can clarify and complete information concerning the main processes at play in the territory, especially those related to population and urban dynamics (Antrop, 2004; Wade, Wickham, Zaccarelli, & Riitters, 2009). In the present study, we used a multi-scale approach to analyze WUIs from the perspective of fire management. We used three different scales: a regional scale corresponding to the western sector of Madrid; a local scale for individual WUIs; and the scale of one settlement to analyze some representative examples. There are interactions and overlaps between scales, which may influence WUI characterization, because WUI components and processes interact at different levels.

Conceptually, WUI is the conjunction of housing and wildland vegetation, and descriptions of WUI are usually based on two main criteria: human presence and vegetation. The spatial arrangement of buildings influences WUI configuration and hence the exposure of buildings to the fire front or even the probability of fire occurrence. As a result, many studies of WUIs start with the categorization of structures (Caballero & Beltrán, 2004; Lampin, Jappiot, Long, Morge, & Ferrier, 2008). In addition, according to Weise and Wotton (2010), fire initiation and spread are determined by vegetation characteristics, the flammability of each species (Díaz-Delgado, Lloret, & Pons, 2004; Haight, Cleland, Hammer, Radeloff, & Rupp, 2004), the vertical structure of the vegetation (Agee & Skinner, 2005; Koetz, Morsdorf, Van Der Linden, Curt, & Allgöwer, 2008) and the spatial distribution of forest fuels (González, Palahí, & Pukkala, 2005; Safford, Schmidt, & Carlson, 2009; Weir, Johnson, & Miyanishi, 2000). Specifically, there is a correlation between the patterns of fuel continuity and fire risk; in this context, landscape metrics have proven very useful to measure the aggregation of vegetation (He, Dezonia, & Mladenoff, 2000; Viedma, Angeler, & Moreno, 2009). Thus, the spatial configuration of the WUI influences fire risk and should therefore guide wildfire management in the development of both fire prevention and extinction strategies (Badia, Serra, & Modugno, 2011; Galiana, Herrero, & Solana, 2007).

The present paper incorporates these theories and includes buildings/structures with fuel horizontal continuity in WUI characterization. However, the territorial context also plays an important role in evaluating fire risk at the WUI. According to Zipperer (2005), *context* refers to the location of WUIs in the landscape and the area in its vicinity. Thus, not only internal morphology but also the surroundings will determine the method to assess WUIs in the context of wildfire risk management. Landscape character assessment has been shown to be the best tool for this purpose (Galiana-Martin, Herrero, & Solana, 2011).

Landscape patterns and fire disturbance regimes are assumed to interact with each other (Moreno, Viedma, Zavala, & Luna, 2011). The influence of the landscape on wildfire occurrence and spread has been empirically confirmed in certain regions (Lloret, Calvo, Pons, & Díaz-Delgado, 2002; Mermoz, Kitzberger, & Veblen, 2005). However, the landscape influences not only the spatial arrangement of land cover and land uses but also the driving forces behind spatial changes; indeed, urbanization processes often follow existing landscape structures (Antrop, 2004; Burgüi, Hersperger, & Schneeberger, 2004). A landscape approach accounts for the spatial connectedness of physical, ecological and social components, which are crucial to understanding wildfire risk in WUI areas (Moreira et al., 2011).

This study goes further; our aim was to design a method to perform the integrated assessment of WUI areas focusing on aspects that may require different management strategies. The method is based on the following hypothesis: in general terms, the presence of a WUI increases fire risk (Martinez, Vega-Garcia, & Chuvieco, 2009; Vilar et al., 2008). Although we accept this statement, we consider that fire risk does not depend only on the existence of these interface areas. We hypothesize that fire risk depends largely on the type of WUI and the characteristics of the territorial context in which the WUI is located. On the national scale, Herrero (2011) identified major differences in the distribution of and changes in WUIs as a function of the driving forces of land use change and regional physical characteristics. Here, we expect that, using a local scale, it is also possible to recognize the variability of WUIs based on the forest and urban components and on the driving forces at play. The confirmation of these hypotheses could help adapt fire management strategies to the specific needs and characteristics of each WUI.

We chose a sector in western Madrid as a study area to achieve the following objectives: (i) obtain a cartographic delineation of WUI areas to study their distribution at a local scale; (ii) classify the mapped WUI areas according to their urban and forest components; (iii) evaluate the incidence of fire in different types of WUI areas; and (iv) characterize WUIs as fire prone scenarios from a regional geographic point of view, focusing on territories and interactions between urban and rural processes and their environment.

Study area

The study area (Fig. 1) is located in the western sector of Madrid (central Spain). It covers 74,878 ha in grids 508 and 533 of the National Topographic Map (1:25.000; 40°50′00″ N, 3°51′15″ W; 40°30′00″ N, 4°11′15″ W). It includes part of the Guadarrama Mountain Range, which runs from the south-west to the north-east with maximum altitudes of more than 2000 m. The pediment, or ramp system, starts approximately 800–1000 m above sea level, with smooth slopes and isolated hills. This physiographical unit occupies most of the area up to the Tajo river basin fault in the eastern part of the study area (Nicolás, 2001).

The climate in the study area is Mediterranean with a long, hot, dry season in summer. However, its location far inland and its orography can slightly modify the typical characteristics of a Mediterranean regime toward less rainfall and higher thermal amplitudes (Castillo, Horcajo, & Casado, 2011). The typical vegetation can survive extreme temperatures and long periods of drought. *Pinus pinaster*, *Pinus sylvestris*, *Pinus pinea* and *Quercus ilex* are the dominant forest species in the area. According to the regional forest plan (2007), this area comprises some of the most forested areas in the Madrid Region (approximately 80–85%), while agricultural land use is limited.