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Fuzzy definition of Rural Urban Interface: An application based on land use change scenarios in Portugal

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ABSTRACT

Land cover dynamics influence the spatio-temporal evolution of the Rural-Urban Interface (RUI). This represents the most prone area for human-caused forest fires ignitions in Mediterranean countries. Traditionally, RUI mapping is based on the measurement of the distances among specific land covers. This methodology suffers from the definition of pre-established fixed parameters. To avoid this arbitrariness, a new procedure based on Multilayer Perceptron and Fuzzy Set Theory is introduced in this paper. This allows to develop continuous non-categorical maps expressing the possibility of being part of this interface. Thus, an innovative way for assessing the uncertainty in identifying RUI is presented. The proposed methodology has been applied to the case study of Portugal, elaborating a future scenario for the RUI. The results show how the framework proposed in this paper is able to correctly identify the areas belonging to this interface, providing useful information for forest fires -prevention policies.

1. Introduction

Wildland-Urban Interface (WUI) was first defined as the area “where humans and their development meet or intermix with wildland fuels” (USDI - US Department Of The Interior and USDA - US Department Of Agriculture, 2001). Lately, compounded by climate changes, urban growth and the fragmentation of rural areas, WUI became the central focus of wildland fire policy (Stewart et al., 2007).

Several approaches have been proposed by the scientific community to map the WUI (Bar-Massada et al., 2013; Conedera et al., 2015; Herrero-Corral et al., 2012; Lampin-Maillet et al., 2010; Radeloff et al., 2005). These are prevalently GIS based, where the boundaries of the WUI area are defined through a fixed-distance buffer around buildings and overlapping the wild vegetation/forest. This assumption relies on the observation that human presence, associated to factors such as the population and buildings density or the proximity to roads or single houses, positively affects the probability of forest fires occurrences. Therefore, the spatial extent of WUI is determined by anthropogenic variables, wild vegetation and the buffer value.

Such WUI maps are useful support tools for fire managers, but suffer the definition of fixed parameters and a pre-established buffer's width. It was pointed out that maps relying on the same broad definitions and input data can result in hugely different WUI classifications due to differences in the analytical methods used to produce them (Stewart et al., 2009). Moreover, even when similar conceptual models, data sources, parameters and metrics are applied, details of the implementation can lead to different estimates of the WUI's extent (Platt, 2010). Nevertheless, all these methods are appropriate and necessary to give precise indication for fire protection and prevention, provided that their limitations are made explicit, as well as the purpose for which such maps were developed, the quality of the data and the method of analysis.

WUI is not a static concept; to the contrary, it dynamically changes in space and in time, driven by different anthropogenic and environmental factors. For instance, the abandonment of remote rural areas and the consequent urbanization processes favours the expansion of the WUI and enhances the probability that forest fires reach houses and infrastructures (Theobald and Romme, 2007; Viedma et al., 2015; Zhang et al., 2008). Deforestation and afforestation are other factors affecting the WUI dynamics.

Land use and land cover changes (LULCC) are closely related to

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the delimitation of an interface area between urban and rural/wildland surfaces, where human-caused forest fires are more likely to occur, and represent a main hazard for people, houses and infrastructures. In the last few decades LULCC in European Mediterranean countries have been marked by the progressive abandonment of rural areas under the pressure of urbanization and the expansion of costal tourist centers (Alados et al., 2004). As a consequence, rural activities, such as low-intensity agriculture and grazing practices, were progressively discarded leading to the intensification of forest covers and scrubland vegetation, especially in remote and poor accessible areas (Antrop, 2004; Millington et al., 2007; Poyatos et al., 2003). Urbanization is a very complex and dynamic process that involves natural and the rural lands: these are progressively converted into urban and industrial areas, driven by physical conditions (e.g. topography) and the accessibility to the area (e.g. road network) (Antrop, 2000; Kim et al., 2017). Specifically in Portugal, that in terms of burned area and number of forest fires is among the first three countries in Europe (Moreira et al., 2001; Nunes et al., 2005; Oliveira et al., 2017), the abandonment of rural lands in marginal areas and the coastal urbanization characterized the landscapes changes since 1980 (Diogo and Koomen, 2012; Nunes et al., 2016; Van Doorn and Bakker, 2007).

In this context, the notion of WUI has to be redefined, taking into account the related rural-urban process and the changes of the landscape. Therefore, the broader concept of Rural–Urban Interface (RUI) is more appropriate. RUI has been identified by recent studies as the most fire prone area in Mediterranean countries (Badia-Perpinyá and Pallares-Barbera, 2006; Catry et al., 2009; Moreira et al., 2009). LULCC and RUI have a strong mutual influence: on the one hand, each vegetated land cover type has a specific fire proneness (Pereira et al., 2014; Oliveira et al., 2014); on the other hand, fire affects the landscape pattern and dynamics by changing the vegetation structure and soil processes (Pausas et al., 2008; Viedma, 2008). This suggests the opportunity of investigating the spatio-temporal changes of the RUI and make prevision about its future evolution by analysing and modelling LULCC.

Land use science is an extremely investigated field (Foley et al., 2005; Kalnay and Cai, 2003; Ramankutty and Coomes, 2016). In the last decades, particular attention was paid to LULCC and broad ranges of models have been developed for research and management purposes. These include tools to analyse and quantify changes incurred between two or more periods and can incorporate sophisticated models to predict land use/land cover future scenarios (Martellozzo et al., 2018). Several of these last LULCC models have been designed to facilitate decision-making processes in the field of landscape protection, natural hazards and disaster risk management, urban growth regulation (Foley et al., 2011; Amato et al., 2015, 2016; Muñoz-Rojas et al., 2015; Di Palma et al., 2016; Nunes de Oliveira et al., 2017; Young, 2017). Routines and software developed to predict LULCC and future scenario implement models that can broadly be classified as based on deductive or inductive approaches (Overmars et al., 2007a, 2007b). The latter are based on past land use/land cover (LULC) in a raster format (i.e. pixel units) to estimate the change transition potential, and apply mathematical/statistical functions including explanatory spatial variables to predict future scenarios. Inductive models are commonly used in land change science, in which emphasis is placed on fitting parameters to observations. In contrast, deductive approaches (including agent-based models) simulate the interactions among a set of so-called agents (e.g. land use, householders, farmers, etc.) to analyse their effects on the system as a whole, attaining deeper knowledge of the process. These models, focusing on actors' behaviours, are more popular among economists and decision makers (d'Aquino et al., 2002; Parker et al., 2003; Robinson et al., 2007).

This paper proposes an innovative approach to define the RUI avoiding the definition of rigid boundaries and eliminating their dependence on predefined parameters, such as the buffer width around the concerned land cover classes. A spatio-temporal analysis of RUI has been performed here, based on LULCC model, which allowed to define future scenario maps. These represent a useful support tool for the development of effective fire prevention policies. The methodology has been applied to the case study of Portugal (Western Europe), an area particularly affected by fires.

2. Materials and methods

In this study we introduce a spatially explicit inductive approach to analyse spatio-temporal changes of the RUI and to simulate future scenarios based on the evolution and prediction of the RUI in Portugal from 1990 up to 2030. Among the existing implemented approaches, we selected the Land Change Modeler (LCM™, also available as an ArcGIS® extension); it includes a supervised neural network model, namely Multilayer Perceptron (MLP) trained by backpropagation, to produce probability maps allowing to elaborate future scenarios. This approach fits well when the process under study is non-linear, as it is the case for simulating urban growth and rural development. Moreover, compared with other models/software, LCM provides an higher accuracy of simulations when using MLP (Eastman et al., 2005).

2.1. Study area

Portugal is located in the south-western Europe. It covers the western coast of the Iberian Peninsula for about 200 km (Fig. 1). Mainland has surface of 89,000 km^2 with an altitude range from sea level to about 2000 m in the north central region. Continental Portugal has a temperate climate characterized by wet and mild winters and dry summers, warm in the northern area and hot in the southern. This typical Mediterranean type of climate suffers from the influence of the Atlantic Ocean that bathes its western and southern coasts (Instituto Português do Mar e da Atmosfera, 2018). The country is split by the Tagus River in two parts of approximately the same size, but characterized by a different topography and sub-climatic conditions. In the northern area prevails a mountainous landscape interspaced with river valleys, with an annual average temperature ranging from 8 °C to 12 °C. The southern part is characterized by rolling plains with an average annual temperature of about 17 °C. Vegetation grows in the spring season, while it experiences hydric and thermical stress during the summer months, when most fire occurrences are reported. In agreement with the climate and the local topography, forests are predominant in the northern half of the country, while in the southern area prevail agricultural lands and scrub types of vegetation in the south coast(EEA, 1994) Urban areas are mostly located in the north-western part of the country; here there are the two metropolitan areas of Porto and Lisbon. In the southern part only the Algarve coastal region, which has its administrative centre in the city of Faro, is densely populated.

Fire events in Portugal display a regime strongly related to climate and weather conditions, resulting in about 90% of burned areas concentrated in the summer season (June to September). Many studies report that in the Iberian Peninsula, weather and climate are responsible for about two-thirds of variability of the total annual burned area (Pereira et al., 2013, 2005; Trigo et al., 2016). As regards to the distribution in space and in time of forest fires and burned area in the last decades, the northern Portuguese area is much more affected than the southern: namely, in the period 1990–2013, 25,322 fires were registered in the first, compared with 1951 in the second (considering only burned areas > 5 ha) (Tonini et al., 2017b). Density maps derived from this