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Research article

Mapping wildfire vulnerability in Mediterranean Europe. Testing a stepwise approach for operational purposes

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ABSTRACT

Vulnerability assessment is a vital component of wildfire management. This research focused on the development of a framework to measure and map vulnerability levels in several areas within Mediterranean Europe, where wildfires are a major concern. The framework followed a stepwise approach to evaluate its main components, expressed by exposure, sensitivity and coping capacity. Data on population density, fuel types, protected areas location, roads infrastructure and surveillance activities, among others, were integrated to create composite indices, representing each component and articulated in multiple dimensions. Maps were created for several test areas, in northwest Portugal, southwest Sardinia in Italy and northeast Corsica in France, with the contribution of local participants from civil protection institutions and forest services. Results showed the influence of fuel sensitivity levels, population distribution and protected areas coverage for the overall vulnerability classes. Reasonable levels of accuracy were found on the maps provided through the validation procedure, with an overall match above 72% for the several sites.

The systematic and flexible approach applied allowed for adjustments to local circumstances with regards to data availability and fire management procedures, without compromising its consistency and with substantial operational capabilities. The results obtained and the positive feedback of end-users encourage its further application, as a means to improve wildfire management strategies at multiple levels with the latest scientific outputs.

1. Introduction

Wildland fires are recurrent events in southern Europe and a major cause of land degradation in this region (Pausas et al., 2008; Rodrigues et al., 2013; San-Miguel-Ayanz et al., 2013; Turco et al., 2016). Particular physical and human circumstances contribute to this high incidence of wildfires. In fact, the Mediterranean climatic conditions, with the temporal coincidence of the driest with the hottest season, and the predominance of Mediterranean-type vegetation, result in fire-prone landscapes (Ganteaume et al., 2013; Moreira et al., 2011; Roberts et al., 2001; Urbieta et al., 2015). Moreover, the coexistence of urban settlements, infrastructure networks and vegetated areas in a complex and intimately interconnected patchwork increase fire hazard. This is exacerbated by the recent changes in demographic patterns and land use, combined with the diminished control on traditional practices involving fire as an instrument for land management (Badia et al., 2011; Gomes, 2006; Lampin-Maillet et al., 2011; Moreira et al., 2011; Nunes et al., 2016; Pausas et al., 2008; Ruiz-Mirazo et al., 2012; San-Miguel-Ayanz et al., 2012a). Fire activity in this region is

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also likely to intensify due to climate change, aggravating its impacts on the environment and society (Amatulli et al., 2009; Amraoui et al., 2013; Carvalho et al., 2011; Giannakopoulos et al., 2009; Kovats et al., 2014; Moreno, 2009; Moriondo et al., 2006).

In this context, evaluating the impacts of wildfire occurrence and developing approaches to prevent potential damages are critical for fire management. Vulnerability assessment provides particular tools to analyse the potential for loss and has received growing attention at the international level (Cutter, 2015; UNISDR, 2015). Previous efforts have been made to define logical and consistent vulnerability assessment approaches; some studies focused specifically on the ecological dimension of wildfires (Aretano et al., 2015; Duguy et al., 2012; Ibarra et al., 2007), whereas others were centred around socio-economic aspects (Rodríguez et al., 2013; Román et al., 2013). Holistic frameworks have also been tested, attempting to integrate the wide range of potential impacts and interactions of wildfires (Birkmann et al., 2013; Chuvieco et al., 2014; Ortega et al., 2012; Tedim et al., 2013). These studies presented valuable alternatives to implement systematic approaches for evaluating vulnerability, however some challenges persist. The lack of data for all the variables integrated, in a suitable scale and format, and their consistent aggregation in meaningful indicators, are relevant issues (Birkmann et al., 2013; Chuvieco et al., 2014; Kuhlicke et al., 2011). Other main challenge regards the need to transfer the scientific knowledge resulting from these complex approaches into technical and operational procedures, required in other sectors linked to wildfire management.

1.1. Background and objectives

The research here presented tried to respond to these challenges. The main purpose was to develop a structured approach for vulnerability assessment of wildfires, based on recent scientific outcomes and implemented for operational purposes, applicable within the geographical context of Mediterranean Europe.

This study was integrated into the framework of an European research project (*PREFER — Space-based Information Support for Prevention and Recovery of Forest Fires Emergency in the Mediterranean area, G. A. nr. 312931*), dedicated to the development of a service infrastructure for the provision of EO-based (Earth Observation) cartographic products related to fire management activities in the Southern European countries most affected by wildfires, namely France, Greece, Italy, Portugal and Spain (EC, 2015; Turco et al., 2016). Vulnerability assessment was part of the range of services provided, together with fuel mapping, daily and seasonal hazard maps and burned areas mapping at very high-resolution, among others. Institutions working on wildfire management of the participating countries, specifically Civil Protection Departments, Forest Services, Fire Brigades and regional Environmental Agencies, were involved as stakeholders during the several phases of the project, to ensure the operational application of the outputs developed (Laneve et al., 2014; Oliveira et al., 2017a).

Following the outcomes of previous studies and the specific goals of the PREFER project, this research was steered by three main objectives:

i) the identification of common components and variables in multi-hazard vulnerability assessments that are suitable for wildland fire research;
ii) the delivery of cartographic products that represent wildfire vulnerability and its multiple spatial interactions;
iii) the development of products adjusted to the needs of end-users and with practical implementation, to contribute to decision-making processes from an operational perspective.

The methodological procedure implemented and the results obtained for different test sites are presented. The advantages and limitations of this approach, the main challenges for its operational use and the implications for further application in other areas, are discussed.

2. Materials and methods

2.1. Study area

The vulnerability framework was designed to be implemented in any area within the 5 Southern European countries most affected by wildfires (Fig. 1). Within this region, several sites were selected to test the framework developed, based on the following criteria: i) the characteristics of the area with regards to fire occurrence; ii) the availability of suitable data; iii) the possibility of obtaining feedback from potential users, stakeholders of the project, in relation to the outputs provided with the framework. The sites selected were the Minho region, in northwest Portugal, and the southwest of Sardinia, in Italy. Additionally, to evaluate the replicability of this framework, the procedure was applied to another site in Northeast Corsica, in France (Fig. 1).

Minho region, Portugal (Fig. 1, 1). Minho is one of the most fire-affected regions in Portugal, with over 3.000 fire events and about 17.000 ha of burned area annually in recent years. This region occupies 4.700 km^2 and is composed of 24 municipalities. The eastern side of the region is occupied by the protected area of Peneda-Gerês, recognized at the international level.

SW Sardinia (Fig. 1, 2). This test site was located in the Southwestern part of Sardinia island, covering about 3000 km^2. It comprised the whole province of Carbonia-Iglesias and part of the Cagliari and Medio-Campidano provinces. Forest fires represent the main source of risk for this area. It hosts the protected area of Monte Arcosu Forest, one of the biggest holm oak forests of the Mediterranean region.

NE Corsica (Fig. 1, 3) — The island of Corsica occupies an area of 8.680 km^2 and is composed of 2 departments: Corse-du-Sud (SW) and Haute-Corse (NE), the test site being located in the latter. On average, more than 500 fires burn over 1000 ha per year throughout the region. The inner part of the island, predominantly rural and intersecting both regions, is classified as a Regional Natural Park.

2.2. The wildfire vulnerability framework

The methodological approach was designed to accommodate specific adjustments required for an operational application, associated with fire management procedures already in place in the participating countries. This was enabled by integrating the feedback of stakeholders and potential users in the development of the service infrastructure from the beginning, and by delivering outputs which complied with a harmonized set of technical requirements defined in view of users' needs and suitable scientific options based on recent research.

The vulnerability framework developed followed a comprehensive approach and inherited its main structure from recent scientific studies (e.g. Birkmann et al., 2013; Chuvieco et al., 2014, 2010; Turner et al., 2003). It analyses the assets, or values-at-risk, that can be affected by a wildfire, integrating variables that reflect different dimensions: social (population), physical (buildings and road infrastructure) and environmental (fuels/vegetation and protected areas). In addition, institutional resources which affect the coping capacity of communities were included, such as surveillance and fuel management activities.

The vulnerability assessment framework integrated three main