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Ranking the importance of Wildfires' human drivers through a multi-model regression approach

Leone D. Mancini[a,*], Piermaria Corona[b], Luca Salvati[b]

[a] Department for Innovation in Biological, Agro-food and Forest systems (DIBAF), University of Tuscia, via S. Camillo de Lellis snc, I-01100 Viterbo, Italy
[b] Consiglio per la Ricerca in agricoltura e l'analisi dell'Economia Agraria (CREA), Research Centre for Forestry and Wood, viale Santa Margherita 80, I-52100 Arezzo, Italy

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ABSTRACT

Wildfires are a major ecological disturbance in Mediterranean environments, and affect together natural resources, ecosystem services and human activities. The impact of socioeconomic forces on wildfire regimes is generally less investigated than the effects of biophysical drivers. Being grounded on a multi-model regression analysis of socioeconomic and territorial indicators, the present study identifies relevant factors influencing local-scale wildfires' regimes in Italy. An economically-disadvantaged context with persistent unemployment, rural poverty, social inequalities and population aging proved to be associated to more frequent fire events. Additionally, our analysis points out that occurrence, average size and density of wildfires reflect different correlation profiles with the local-scale socioeconomic context. Along with the socioeconomic profile of local communities, the empirical outcomes of our study show the importance of landscape structure, land-use and cropping systems in local-scale fire regimes. The empirical results of this study justify a multidimensional analysis of relevant socioeconomic dimensions in fire risk assessment and contribute to an informed approach to wildfire management. Moreover, our study provides basic knowledge advancing research on fire prevention, and informing spatial planning and developmental policies aimed at increasing preparedness to large fires.

1. Introduction

Wildfires are considered a major ecological disturbance in Mediterranean-type environments, and affect natural resources (e.g. soil, vegetation, biodiversity) and ecosystem services (e.g. biomass production, carbon sequestration, freshwater provision), impacting negatively economic activities such as agriculture, tourism, transportation and housing. The estimated causes of wildfires in European Mediterranean countries are anthropogenic in > 90% of recorded cases (Leone et al., 2009; Vélez, 2009; Ganteaume et al., 2013; Ager et al., 2014). Furthermore, human activity may have a relevant impact on different fire dimensions (occurrence over time, spatial concentration, size of burned area), e.g. altering vegetation composition and structure that influence (directly or indirectly) fuel load (Moreira et al., 2011; Tedim et al., 2015; Vilar et al., 2016).

Since the second half of the 20th century, transformations of rural systems in southern Europe have enhanced land-use conflicts, resulting in an increased wildfire risk under specific socioeconomic contexts (San-Miguel-Ayanz et al., 2013). Together with climate change (Dimitrakopoulos et al., 2011), depopulation of marginal and economically-disadvantaged areas, decline of traditional use of grazing and firewood, reduction of forests as a raw material producer, a rising recreational use of forests and a progressive expansion of wildland-urban interfaces, have been identified as processes leading to increased frequency and severity of wildfires (Montiel and Herrero, 2010; Ganteaume and Jappiot, 2013; Zitti et al., 2015; Curt et al., 2016; Nunes et al., 2016).

While climate variability is a relatively well-known factor shaping wildfire risk, earlier studies have stressed that the impact of socioeconomic forces on wildfire regimes is relatively less investigated (and probably more complex) than the synergic impact of biophysical drivers (e.g. Millington et al., 2009; Salvati and Ranalli, 2015; Fernandes, 2016). Accordingly, a better knowledge of the main anthropogenic factors influencing spatial patterns of wildfires is a crucial step to improve effectiveness of fire prevention, detection and fighting strategies (Ganteaume et al., 2013; Fernandes et al., 2014; Salvati and Ferrara, 2014).

Earlier studies have identified relevant anthropogenic factors that affect wildfire distribution and intensity in Mediterranean Europe including land-use (Koutsias et al., 2010; Carmo et al., 2011; Moreno et al., 2011; Verdu et al., 2012; Barros and Pereira, 2014; Oliveira et al., 2014a), landscape structure and functions (Costafreda-Aumedes et al.,

* Corresponding author.
E-mail address: leone.mancini@unitus.it (L.D. Mancini).

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2013; Madrigal et al., 2013; Martin-Martin et al., 2013; Salvati and Ferrara, 2014; Barbati et al., 2015; Gallardo et al., 2016; Salvati and Ranalli, 2015), basic characteristics of agricultural systems (Kalabokidis et al., 2007; Koutsias et al., 2010; Oliveira et al., 2014b; Rodrigues et al., 2014; Álvarez-Díaz et al., 2015), population distribution and density (Martínez-Fernandez et al., 2013; Mourão and Martinho, 2014; Rodrigues et al., 2014; Álvarez-Díaz et al., 2015; González-Olabarria et al., 2015), infrastructure and place accessibility (e.g. Romero-Calcerrada et al., 2010; Costa et al., 2011; Moreno et al., 2011; Padilla and Vega-García, 2011; Vilar Del Hoyo et al., 2011; Rodrigues et al., 2014). While earlier research has demonstrated the importance of specific socioeconomic drivers shaping local-scale fire regimes (Biasi et al., 2015; Ferrara et al., 2016; Costafreda-Aumedes et al., 2018), relatively few studies have focused on the joint influence of multiple anthropogenic factors on wildfires (e.g. Amatulli et al., 2006; Romero-Calcerrada et al., 2008; Sebastian-López et al., 2008; Martínez et al., 2009; Moreira et al., 2010; Marques et al., 2011; Nunes, 2012; Oliveira et al., 2012; Ortega et al., 2012; Ganteaume and Jappiot, 2013; Martínez-Fernandez et al., 2013). In these regards, Michetti and Pinar (2013) and Costafreda-Aumedes et al. (2018) have investigated the influence of multiple anthropogenic factors on fire frequency and size at regional scale using statistical and econometric approaches, including a panel data strategy.

By assuming a latent relationship between local communities and natural environments (Bovio and Camia, 1997; Moreira et al., 2001; Tomao et al., 2017; Masini et al., 2018), we hypothesize that multiple anthropogenic factors impact differently local-scale wildfires' regimes according to distinct territorial conditions and spatially-heterogeneous characteristics of local communities (e.g. Ferrara et al., 2017; Pili et al., 2017; Duvernoy et al., 2018). In other words, wildfires' regimes are supposed to be significantly affected by the intimate characteristics of complex socio-ecological systems, as defined by Redman et al. (2004) and Kelly et al. (2015). Based on these premises, the present study aims at identifying (and ranking the importance of) relevant anthropogenic forces influencing long-term wildfire regimes in Italy at a spatially-detailed geographical scale. An improved understanding of the latent relationship between socioeconomic local contexts and ecological disturbance regimes, such as wildfires, clarifies the role of basic factors affecting occurrence, density and average size of wildfires. This approach is intended to provide valuable information to fire risk assessment, contributing to more effective strategies for prevention and firefighting and enhancing preparedness with distinctive respect to large fires.

2. Methodology

2.1. Study area

We studied a large part of the Italian peninsula, a territory particularly prone to wildfire (CFS 2014) and with evident socioeconomic and biophysical disparities (Salvati and Carlucci, 2011; Recanatesi et al., 2016; Salvati et al., 2017). Climate regimes are relatively different in northern and southern Italy, with higher temperatures and lower precipitations along the latitudinal gradient. Being characterized by a steep topography, regional climate regimes in Italy were also influenced by elevation, with humid or sub-humid regimes being frequently observed in mountain districts along the Alps and the Apennines (Salvati et al., 2008). To a great extent, soils, vegetation and landscapes followed the latitudinal and elevation gradients, with remarkable variability due to local water availability, land protection, and heterogeneous human pressure (Ferrara et al., 2014). Although Italy is a polarized country with wealthier districts most frequent in northern regions and disadvantaged areas concentrated in southern regions, income, wealth, unemployment and socio-demographic conditions are molded by multiple local-scale factors, including urbanization, accessibility, land productivity and natural amenities promoting tourism development (Salvati and Carlucci, 2011).

A total of 1,100,000 ha of forest land have been burnt over the last 20 years in Italy. On average, 11,000 fires were recorded annually, burning nearly 50,000 ha of forest land. Similarly to other Mediterranean countries, the large majority of wildfires in Italy was below 1 ha. The largest wildfires were concentrated in central and southern Italy, possibly as a consequence of multiple interacting factors such as dry or semi-arid climate, fuel accumulation and land abandonment (CFS 2014). In northern Italy, wildfires have occurred preferentially in the first quarter of the year (from January to March), a time period when herbaceous vegetation is dry due to low temperatures and winter drought, becoming especially prone to ignition. Conversely, wildfire occurrence in central and southern Italy was the highest in the third quarter of the year (from July to September). Future scenarios of climate change in Italy are expected to produce a significant increase in extreme events, posing a relevant challenge for prevention and suppression measures that are increasingly required to adapt to the distinct fire regimes typically observed in northern and southern Italy (Michetti and Pinar, 2013).

2.2. Data and variables

The National Forest Service (Corpo Forestale dello Stato, CFS) and the Forest Services of autonomous Regions collect and disseminate geo-referenced wildfires data in Italy. Vector geo-datasets of burnt areas (forest and non-forest natural areas including shrubland and macchia vegetation), recorded by ground-based GPS surveys, were made available for a time period spanning from 2007 to 2014. This dataset covers 17 of the 20 EU-NUTS2 level administrative units of Italy (i.e. Sardinia, Sicily and all the administrative regions with ordinary legislation status), totaling 95% of the area burnt over the whole country (Mancini et al., 2017). The dataset adopted in this study was used to assess spatial patterns of wildfires at the geographical scale of municipalities. To determine the burnt area for each municipality, a zonal statistic procedure was run in a Geographic Information System environment by overlay of two vector layers: (i) the map of burnt area illustrated above and (ii) a map representing the boundaries of Italian municipalities provided by Italian National Statistical Institute (ISTAT).

We tried to balance sample size in order to compare a similar number of municipalities with (or without) fire events that satisfy a specific fire size threshold. In these regards, four binary variables were calculated for 7467 Italian municipalities with the aim to classify each elementary spatial unit on the base of the occurrence of at least (i) one wildfire during the study period (irrespective of its size), or (ii) one small fire (i.e. a fire smaller than the median size of wildfires recorded over the study area during 2007–2014: 2.95 ha), (iii) one medium-to-large fire (> 50 ha) or (iv) one large fire (> 100 ha) over the study period. Size threshold for large fires was coherent with earlier studies (e.g. Moreno et al., 2011; Ganteaume and Jappiot, 2013; Tedim et al., 2015). Medium-large fire size threshold was adopted in this study according to what was proposed by EFFIS monitoring system developed by European Joint Research Centre, Ispra (http://effis.jrc.ec.europa.eu/). For municipalities (n = 3831) where at least one wildfire (irrespective of its size) was recorded over the study period, two additional variables were calculated based on the database illustrated above: (i) average burnt area per fire (ha) and (ii) fire density (number of events/km^2). Prior to analysis, these variables were log-transformed with the aim to normalize the statistical distribution of non-normal variables, improving parameters' estimates and overall model's performances (Salvati and Zitti, 2005).

A total of 39 variables supposed to influence (directly or indirectly) local-scale wildfire regimes (Table 1), were derived from official data sources at municipal scale and were classified under different research domains (landscape and land-use, agriculture, income and wealth, population, education, job market). Selection of candidate variables quantifying anthropogenic factors associated to wildfire occurrence was