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Research article

Improving fire season definition by optimized temporal modelling of daily human-caused ignitions

S. Costafreda-Aumedes [a, *], C. Vega-Garcia [b, c], C. Comas [d]

[a] Department of Agri-food Production and Environmental Sciences, University of Florence, Piazzale delle Cascine 18, 50144, Florence, Italy
[b] Department of Agriculture and Forest Engineering, University of Lleida, Alcalde Rovira Roure 191, 25198, Lleida, Spain
[c] Forest Sciences Centre of Catalonia, Ctra. Sant Llorenç de Morunys km 2, 25280, Solsona, Spain
[d] Department of Mathematics, University of Lleida, Agrotecnio Center, Avinguda Estudi General 4, 25001, Lleida, Spain

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A B S T R A C T

Wildfire suppression management is usually based on fast control of all ignitions, especially in highly populated countries with pervasive values-at-risk. To minimize values-at-risk loss by improving response time of suppression resources it is necessary to anticipate ignitions, which are mainly caused by people. Previous studies have found that human-ignition patterns change spatially and temporally depending on socio-economic activities, hence, the deployment of suppression resources along the year should consider these patterns. However, full suppression capacity is operational only within legally established fire seasons, driven by past events and budgets, which limits response capacity and increases damages out of them. The aim of this study was to assess the temporal definition of fire seasons from the perspective of human-ignition patterns for the case study of Spain, where people cause over 95% of fires. Humans engage in activities that use fire as a tool in certain periods within a year, and in locations linked to specific spatial factors. Geographic variables (population, infrastructures, physiography and land uses) were used as explanatory variables for human-ignition patterns. The changing influence of these geographic variables on occurrence along the year was analysed with day-by-day logistic regression models. Daily models were built for all the municipal units in the two climatic regions in Spain (Atlantic and Mediterranean Spain) from 2002 to 2014, and similar models were grouped within continuous periods, designated as ignition-based seasons. We found three ignition-based seasons in the Mediterranean region and five in the Atlantic zones, not coincidental with calendar seasons, but with a high degree of agreement with current legally designated operational fire seasons. Our results suggest that an additional late-winter-early-spring fire season in the Mediterranean area and the extension of this same season in the Atlantic zone should be re-considered for operational purposes in the future.

1. Introduction

The protection of lives and properties is always a priority for fire and civil protection agencies, so wildfire suppression strategies applied in fire-affected countries with high values-at-risk have been based on fast and aggressive attack of all ignition points in the territory, everywhere and under all weather conditions (Paveglio et al., 2010). Total control of fires with a rapid response, even under specific time constraints, was the paradigm leading to the early development of detection and suppression systems (Bradshaw et al., 1983; Kilgore, 2007). Resource optimization needs soon steered fire managers to modulate the number of available suppression resources along the year, increasing during high fire occurrence periods designated as “fire seasons”. According to the definition by Merrill and Alexander (1987) and FAO (2005), a fire season is the “period(s) of the year during which wildland fires are likely to occur, spread and affect resource values sufficient to warrant organized fire management activities”. As designated fire seasons have legal and budgetary implications for resources allocation and temporal hiring opportunities, dates are officially published by fire agencies. They tend to be stable over the years (i.e. in Andalusia, Spain, from 1st June-15th October, in Italy from 15th June – 30th September, in France from 15th June to 15th September).

However, firefighting organizations recognize intra and inter-

* Corresponding author.
E-mail address: sergi.costafredaaumedes@unifi.it (S. Costafreda-Aumedes).

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annual variability in the wildfire drivers that determine the fire season: weather, fuel availability and ignition patterns (Moritz et al., 2005). They often have to modify their preparedness levels outside the fire season, in response to spatiotemporal changes in drivers like heat waves or drought. To reduce uncertainty and improvisation in fire operations, relevant fire drivers need to be better understood. This is especially true in regions exposed to altered fire regimes like the Mediterranean region (Moreira et al., 2011), with increasing chances of more damaging fire seasons due to both socioeconomic and climatic changes (Rodrigues et al., 2013). There are evidences that fire season length and burnable areas affected by long fire seasons have significantly increased in all continents except Australia since 1979 (Jolly et al., 2015). According to these authors, European Mediterranean forests have experienced a lengthening of 12–19 days in fire season length from 1979 to 2013, and inter-annual variations are significantly related to inter-annual burned area variations in all Southern European countries.

In this context, daily models of fire occurrence likelihood encompassing a wide range of wildfire factors were built since the 50's with the purpose of predicting ignitions, developing early warning systems and optimizing deployment, pre-attack planning and suppression actions (Crosby, 1954; Dlamini, 2010; Martell et al., 1987). Most of these daily models analysed human-caused fires (HCFs) since more than 90% of the wildfires worldwide are linked, directly or indirectly, to socio-economic activities (FAO, 2007; Ganteaume et al., 2013), and especially in the human-dominated Mediterranean landscapes (Catry et al., 2009; Ganteaume et al., 2013; Rodrigues et al., 2016; Vasconcelos et al., 2001). For a review of fire occurrence models see Costafreda-Aumedes et al. (2017).

However, most of the daily models published relied on factors with high temporal variability related to weather or environmental conditions that cause downward changes in fuel moisture, increasing the probability of ignition and general fire danger (Alonso-Betanzos et al., 2003; Bedia et al., 2014). Because geographic or spatial variables linked to human settlements, and activities potentially leading to fire starts, had low inherent variability or were updated every few years (i.e. vegetation or road maps), most authors excluded them from their daily models, regardless of their potential useful contribution for their relation to ignition agents (Ruffault and Mouillot, 2017). Moreover, recent studies have demonstrated that the influence of physiography, vegetation and human presence on HCF occurrence varies spatially and temporally in relation to the causative agent through the year; spatially, arson and intentional fires tend to occur in steep slopes and close to urban areas (Vasconcelos et al., 2001) whilst negligence and accidental fires tend to occur in moderate slopes and close to roads (Juan et al., 2012; Serra et al., 2013). Agriculture-related fires tend to occur in low-population rural regions (Vasconcelos et al., 2001) with smooth relief (González-Olabarria et al., 2015) and pastoral- and forestry-related fires mainly occur in mountain areas (González-Olabarria et al., 2015; Zhang et al., 2010).

From a temporal perspective, Gonzalez-Olabarria et al. (2015) observed that accidental fires from smokers, power lines, engines and campfires occur mainly in summer in Spain, while cropland-, pastures- and forestry-related fires tend to occur in late winter and early spring. Both Curt et al. (2016) and Duane et al. (2015) found that intentional and accidental fires in France tend to occur in summer while negligence fires related to pastoralism and vegetation management in agricultural and forestry operations occur more often from autumn to winter-spring. On the contrary, HCFs are linked to stubble burnings all year round in Germany, Bulgaria and Slovakia (Duane et al., 2015).

Therefore, spatial variables linked to specific fire ignition causes may alter their relevance as predictors of general HCF occurrence along the year. These variables may even show opposite trends in different seasons (i.e. slope), which would demand seasonal models of daily fire occurrence for operational purposes, ultimately depending on causality. Unfortunately, reliable classifications of specific causes are available (Camia et al., 2013; FAO, 2007), but the cause of fires is not always known with certainty (i.e. lack of incriminating evidence or fire events derived from remote sensing data). The usual practice in modelling is adding all causes in a database for analysis, due to the need to aggregate a large enough number of fire observations for study. Consequently, HCFs modelling frameworks should incorporate spatial or geographic variables as input to models, but in order for this integration to be optimal, their periods of relevance along the year need to be identified. A fact preventing this temporal identification in the past has been that fire occurrence models are either calculated with lumped yearly data or for a predetermined fire season (i.e. Haines et al., 1970; Leuenberger et al., 2018; Vasconcelos et al., 2001; Vilar et al., 2010).

We intentionally excluded weather factors from our study, to focus on human-ignition-related spatial variables. Human behavior can be modified by education, enforcement or prevention actions, hence our focus on ignitions. We have also excluded fire propagation-related factors because usually propagation is modelled separately, driven by environmental factors and modifiable only by forest/vegetation management at the landscape level (Alcasena et al., 2017).

The changing relevance of spatial or geographic variables, considered proxies for socioeconomic activities creating human-ignition patterns, was analysed within HFC daily fire occurrence models organized by day-of-year for the study case of Spain, a South European Mediterranean region. We aimed to test and improve fire season(s) definition by identifying optimal spatial predictors by day-of-year in municipal prediction units, and grouping similar occurrence models within continuous periods. These significant periods for human ignition within a year could be compared to calendar seasons (widely used to organize human activities) and operational fire season(s). This comparison would provide a temporal human risk frame for potential future interactions between wildfire drivers under extended fire weather seasons that could recommend a re-assessment of operational fire seasons in Spain.

2. Materials and methods

2.1. Study area

Our study area (Fig. 1) covers Peninsular Spain and the Balearic Islands (497,121 km^2), stratified in two climatic zones, Mediterranean and Atlantic (Moreno et al., 1990). Different fire regimes are present in these two climatic zones, which are analysed and described in Verdú et al. (2012). Central, East, South Peninsular Spain and the Balearic Islands have a Mediterranean climate (covering the 83.6% of the study area). The Mediterranean region has temperate and rainy winters (avg. mean temperatures and rainfall round 4–9 °C and 100 mm, respectively), and dry and hot summers (avg. mean temperatures and rainfall round 20–25 °C and 25–50 mm, respectively), and the Central peninsula has the highest annual thermal ranges (20 °C). The northern third (16.4% of the study area) is characterized by an Atlantic climate. The Atlantic region has abundant rainfall (>800 mm) and the annual thermal amplitude is low in the coastal region (9-11 °C) but increases in the mainland hilly regions (12–15 °C). The combination of climatic and topographic variability and a pervasive human presence over millennia in both regions results in an uneven distribution of