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Forest fire spatial pattern analysis in Galicia (NW Spain)

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ABSTRACT

Knowledge of fire behaviour is of key importance in forest management. In the present study, we analysed the spatial structure of forest fire with spatial point pattern analysis and inference techniques recently developed in the Spatstat package of R. Wildfires have been the primary threat to Galician forests in recent years. The district of Fonsagrada-Ancares is one of the most seriously affected by fire in the region and, therefore, the central focus of the study. Our main goal was to determine the spatial distribution of ignition points to model and predict fire occurrence. These data are of great value in establishing enhanced fire prevention and fire fighting plans. We found that the spatial distribution of wildfires is not random and that fire occurrence may depend on ownership conflicts. We also found positive interaction between small and large fires and spatial independence between wildfires in consecutive years.

1. Introduction

A wildfire is any uncontrolled fire in combustible vegetation in the countryside or in a forestry area. At landscape level, wildfire ignition and spread result from a complex interaction among ignition sources, weather, topography and land cover (e.g. Mermoz et al., 2005; Moreira et al., 2011). The four major natural causes of wildfire ignition are lightning, volcanic eruption, sparks from rock falls, and spontaneous combustion (National Interagency Fire Centre, 2011). However, many wildfires are attributed to human sources (Pyne et al., 1996).

In southern Europe (France, Greece, Italy, Portugal and Spain), the fight against fire is one of the most serious issues faced by environmental managers (Badia-Perpinya and Pallares-Barbera, 2006). In the last thirty years, an average of 49,838 forest fires have burned approximately 0.5 million hectares of forests and other rural lands each year (San Miguel-Ayanz et al., 2012).

Lately, there has been an increase in the number of intentionally caused wildfires (arson) (Catry et al., 2009; Chuvieco et al., 2010; González-Olabarria et al., 2011; Juan et al., 2012; Romero-Calcerrada et al., 2008). Different causes of arson have been considered such as the increase of forest area (Badia et al., 2003; Catry et al., 2009); new agrarian landscape patterns (Amatulli et al., 2007; Catry et al., 2009; Corcoran et al., 2007; Fernandes, 2009; Kalabokidis et al., 2007; Martínez et al., 2009; Moreira et al., 2009, 2011; Verde and Zêzere, 2010); traditional agrarian landscape patterns (Vázquez and Moreno, 1998, 2001); agricultural abandonment (Acosta et al., 2005; Aranzabal et al., 2008; Falcucci et al., 2007); the expansion of shrubland surface (Bajocco and Ricotta, 2008; Díaz-Delgado et al., 2004; González et al., 2006; González and Pukkala, 2007; Koutsias et al., 2009; Moreira et al., 2009; Mouillot et al., 2005; Nunes et al., 2005; Sebastian-Lopez et al., 2008); socioeconomic changes (Arianoutsou, 2001; Badia-Perpinya and Pallares-Barbera, 2006; Cardille et al., 2001; Curt and Delcros, 2010; Loboda and Csizar, 2007; Martínez et al., 2009; Romero-Calcerrada et al., 2010; Vasconcelos et al., 2001; Vilar et al., 2010; Wittenberg and Malkinson, 2009; Zea-Bermudez et al., 2009) and changes in rent distribution and higher unemployment levels (González-Olabarria et al., 2011).

Different approaches have been considered to solve the difficulties of modelling human-caused fire ignition in Europe with a spatially explicit approach. Some studies have attempted to predict the probability of fire occurrence using logistic models (Cardille et al., 2001; Catry et al., 2009; Chuvieco et al., 2010; Martínez

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et al., 2008, 2009; Vasconcelos et al., 2001; Wittenberg and Malkinson, 2009); artificial neural networks (Vasconcelos et al., 2001; Vilar del Hoyo et al., 2007); weights of evidence (Amatulli et al., 2007; Romero-Calcerrada et al., 2008, 2010); multivariate statistics (Kalabokidis et al., 2007); generalized linear regression (Wood and Augustin, 2002), generalized Pareto distribution (Zea-Bermudez et al., 2009), fuzzy logic (Loboda and Csizar, 2007), Bayesian models (Verde and Zêzere, 2010); Poisson models (Benavet-Corai et al., 2007; Mandallaz and Ye, 1997; Wotton et al., 2003); generalized additive models (Vilar et al., 2010); kernel density (Amatulli et al., 2007; de la Riva et al., 2004); Monte Carlo simulations (Conedera et al., 2011) and Comaps (Corcoran et al., 2007).

In this study, we focused on the application of spatial point processes, specifically Poisson processes, to assess forest fire behaviour. Keetch and Byram (1968) first introduced Poisson models in fire ecology to estimate an expected number of fires. Mandallaz and Ye (1997) also used a Poisson model to explore the relationships between diverse European dryness indices and other meteorological variables, with the number of fires. Dickson et al. (2006) used the weights-of-evidence (WOE) model, a Bayesian predictive method, to quantify the probability of fire occurrence by the use of superimposed maps. Quintanilha and Ho (2006) carried out a longitudinal study in which data were fitted to a negative binomial function.

A wildfire dataset can be seen as a realization of a spatio-temporal stochastic process (Mateu et al., 2006). It comprises the spatial, longitudinal and latitudinal coordinates of the ignition point, in addition to other variables for each fire: magnitude, type of land burned, cause of fire and time of ignition. This type of process typically reveals dependence between spatial positions and temporal instants, as well as interdependence between them. Genton et al. (2006), Yang et al. (2007) and Hering et al. (2009) applied first and second order analyses of spatial point patterns to study the spatial structure of forest fires in Florida and Missouri.

The aim of the present study is to assess forest fire occurrence in an area of interest using statistical methods developed for spatial point processes. The study focuses on the spatial framework, and the dataset is considered a marked spatial point process (Ripley, 1987; Cressie, 1993; Illian et al., 2008), considering the temporal information (year of fire) as a discrete mark.

In Section 2.1 we describe the study area, the criteria for choosing it and its specific features, and the wildfire database. The spatial point processes analysis techniques applied to study the wildfire dataset are introduced in Section 2.2. Results of the analysis of wildfires are presented in Section 3. Finally, in Section 4 we discuss the results and outline future lines of investigation.

2. Material and methods

2.1. Study area and wildfire database

In the case of Galicia (northwest of Spain) (Fig. 1) the forest area, 2,060,453 ha, accounts for 69% of the region. It has a high potential for forest productivity (Marey-Pérez and Rodríguez-Vicente, 2008). In the year 2010, it reached 6,868,500 m^3, which represents 50% of Spanish timber production and about 4.5% of that in the European Union (FEARMAGA, 2011). Galicia is characterized by the presence of small forest owners (Rodríguez-Vicente and Marey-Pérez, 2008, 2010), agricultural exploitations (Álvarez-López et al., 2008; Riveiro-Valiño et al., 2008, 2009) and a mosaic of cropped and livestock farmed and forested land (Díaz-Varela et al., 2009). During the four last decades there has been an increase in the process of afforestation in different agricultural areas and in the abandonment of rural activities (Marey-Pérez et al., 2006), together with a sharp decrease in population in rural areas (Marey-Pérez et al., 2012).

Forests have been managed primarily by individual private owners. Over 96.6% of forestlands in Galicia are privately held and about 63.7% of forestland is managed by 672,618 individual private

Fig. 1. Fonsagrada-Ancares district location in the province of Lugo, Galicia (NW Spain).