Ecological Modelling 228 (2012) 106–111

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Modelling the phenological niche of large fires with remotely sensed NDVI profiles

Antonella De Angelis[a], Sofia Bajocco[b], Carlo Ricotta[a,*]

[a] Department of Environmental Biology, University of Rome 'La Sapienza', Piazzale Aldo Moro 5, 00185 Rome, Italy
[b] National Council for Research in Agriculture, Unit of Climatology and Meteorology Applied to Agriculture (CRA-CMA), Via del Caravita 7a, 00186 Rome, Italy

ARTICLE INFO

Article history:
Received 26 October 2011
Received in revised form
30 December 2011
Accepted 2 January 2012
Available online 27 January 2012

Keywords:
Environmental niche factor analysis (ENFA)
Fire ignition
Fire risk
Modis
Phenological metrics

ABSTRACT

Although the area burned by single wildfires may range over many orders of magnitude, only a handful papers has explored the factors that contribute to drive fire ignitions into large burns. While in southern Europe most fire ignitions are of human origin, fire propagation is mostly influenced by weather conditions, topography and fuel type. In this framework, the phenological status of vegetation represents the primary driver influencing fuel availability and moisture content. Therefore, any investigation on fire behavior requires the capability of capturing spatio-temporal changes in coarse-scale vegetation phenology that are descriptive of changes in fuel conditions. The aim of this study is thus to apply a habitat suitability modelling tool originally developed in wildlife science for reconstructing the phenological niche of the ignition points of wildfires from remotely-sensed multitemporal NDVI profiles in Sardinia (Italy) in the period of 2000–2008. Overall, our findings indicate that wildfires occur preferentially in remotely-sensed phenological conditions that considerably differ from the mean phenological conditions in Sardinia. When compared to the entire set of ignition points (irrespective of the resulting fire size), ignitions resulting in burned areas larger than 20 ha are preferentially associated to a longer and later fire season showing also marked preference for higher fuel loads.

1. Introduction

Fire risk (the chance of a fire starting as determined by the presence and activity of any causative agent, also defined 'ignition risk') is an essential element in assessing fire danger (FAO, 1986; Hardy, 2005; NWCG, 2006). For instance, the ability to understand and predict the patterns of fire ignition and to detect areas of high ignition risk is essential for managers aiming at improving the effectiveness of fire prevention, detection and fire-fighting resource allocation (Conedera et al., 2011; Moreira et al., 2011).

In southern Europe, where most fires are of human origin (EC, 2008), the spatial patterns of fire ignitions are mostly influenced by variables related to human pressure (Cardille et al., 2001; Cardille and Ventura, 2001; Nunes et al., 2005; Genton et al., 2006; Catry et al., 2009; Conedera et al., 2011). However, not all fire ignitions result in burned areas of similar size (Moreira et al., 2010). While the number of ignitions is usually connected with social, economic and cultural drivers, fire size is mainly controlled by factors such as topography, weather conditions, fuel types, fire intensity, time lag until detection and intervention, and efficiency of the fire-fighting activities (Bajocco and Ricotta, 2008; Moreira et al., 2010). Therefore, across the territory, the areas that experience the highest frequency of ignitions usually differ from those where larger fires occur (Bajocco and Ricotta, 2008).

Unfortunately, although large events contribute most to the ecological and economic impact of fires, only few studies have analyzed the factors that contribute to drive ignitions into large burns. While Preisler et al. (2004) found that in Oregon (USA) the probability of an ignition turning into a large fire (>40 ha) is mainly determined by weather conditions and vegetation type, Bajocco and Ricotta (2008) and Pezzatti et al. (2009) emphasized the influence of land cover on fire size in Sardinia (Italy) and Ticino (Switzerland), respectively. For Portugal, Moreira et al. (2010) found that larger fires are inversely related to population density, and are more likely to occur in shrublands and forests and farther away from roads.

From a biological viewpoint, in the Mediterranean Basin, the strong bioclimatic control on wildfires is testified, on one hand, by the close relationship between climatic conditions and the spatial distribution of vegetation types and their associated fuel characteristics (Bajocco et al., 2010a). On the other hand, climate *per se* affects fire ignition and propagation through its influence on fuel moisture content (Rothermel, 1983), such that high correlation between wildfires and the seasonal timing of the vegetation

* Corresponding author. Tel.: +39 06 4991 2504.
E-mail address: carlo.ricotta@uniroma1.it (C. Ricotta).

0304-3800/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolmodel.2012.01.003

Fig. 1. Location of the study area.

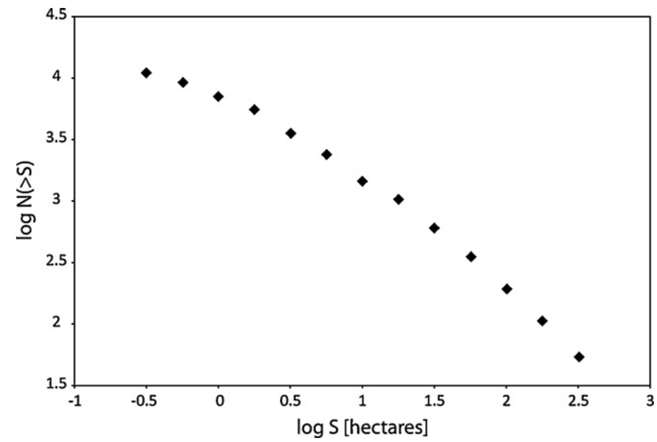

Fig. 2. Cumulative frequency–area distribution in Sardinia in the 2000–2008 period. The number of fires $N(>S)$ with size greater than S is plotted as a function of S in a double-log space.

is usually observed with the highest concentration of events during the dry and hot summer months (Bajocco and Ricotta, 2008; Moreira et al., 2011). Accordingly, as vegetation phenological status represents the primary driver influencing fuel availability and moisture content, any investigation on fire behavior over large areas requires the capability of capturing spatio-temporal changes in vegetation phenology that are descriptive of changes in fuel conditions (Bajocco et al., 2010b).

Remotely sensed observations derived by sensors like MODIS meet these requirements since they provide comprehensive spatial coverage at reasonable temporal resolution to update fuel conditions in an operational manner. Combined with modelling tools remotely sensed imagery offers the best approach for large-scale, spatially contiguous measurements of vegetation phenology and fuel conditions (Elmore and Asner, 2005) and can be effectively used to estimate fire behavior (Lozano et al., 2007; Schneider et al., 2008; Bajocco et al., 2010b; Chuvieco et al., 2010). The purpose of this paper is thus to apply a habitat suitability modelling approach for reconstructing the phenological niche of the ignition points of large fires from data on the remotely-sensed vegetation seasonal dynamics in Sardinia (Italy), a typical Mediterranean region characterized by high fire frequency and variable vegetation composition.

2. Study area

Sardinia covers roughly 24,000 km^2 and is located in the Mediterranean Sea between 38°51′N and 41°15′N latitude and between 8°8′E and 9°50′E longitude (Fig. 1). The island is characterized by a complex physical geography and high heterogeneity in geological and morphological features. The highest elevation is 1834 m; average elevation is 338 m. Climate is typically Mediterranean; average annual rainfall range from less than 500 mm in the coastal areas to 900 mm in the inner mountainous regions. Mean annual temperature ranges from 11 °C to 17 °C. In the coastal areas land cover is dominated by sclerophyllous shrubs, thermomediterranean *Quercus ilex* forests, and agricultural lands that cover about 45% of Sardinia. Most urban areas are located along the coast. In the interior areas, forest stands combined with pastures and shrublands prevail. The principal forest formations include meso-mediterranean *Q. ilex* and *Quercus suber* forests. At higher elevations the sclerophyllous oak forests merge with deciduous forests of *Quercus congesta* and *Quercus ichnusae*.

3. Data

Information on the remotely sensed dynamics of the vegetation of Sardinia was obtained from the standard 16-day MODIS 250 m NDVI product. We acquired twenty-three NDVI maximum value composites per year from 2000 to 2008, resulting in a total of 207 MODIS images.

The coordinates of all fire ignitions for the same time interval were obtained from the Regional Forest Service. During this period, 24,360 events are registered, resulting in an average of 2707 forest fires per year. In Sardinia, fire is strongly seasonal; more than 95% of fires occur between May and October with a peak of fires in July.

From the fire database we also extracted the location of the ignition points of all 974 fires ≥20 ha that occurred in the study area during 2000–2008 (i.e. roughly the upper 4% of the fire size frequency distribution). Fire size was obtained from a visual estimate of the burned area made in the field by experienced fire-fighting professionals. Although the selected threshold of 20 ha is approximately one order of magnitude lower than the size usually adopted in southern Europe for defining a large fire (see Moreira et al., 2011 and references therein), this size represents a good compromise between a reasonably large burned surface and a reasonably large number of events for statistical analysis. In addition, while representing only a small fraction of total fire occurrence, as the cumulative fire size distribution in Sardinia in the 2000–2008 period is adequately described by a power-law over many orders of magnitude (Ricotta et al., 2001; Malamud et al., 2005), the fires ≥20 ha account for 74% of the total burned area (Fig. 2).

4. Methods

For each image pixel we derived a mean annual NDVI profile calculated averaging all NDVI values for each 16-day composite over the period 2000–2008. From the mean NDVI profiles of each pixel we next extracted nine fire-related phenological metrics linked to key events in the remotely-sensed seasonal dynamics of Mediterranean vegetation, like timing, duration and intensity of the summer dry season (Fig. 3). These metrics can