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Using Monte Carlo simulations to estimate relative fire ignition danger in a low-to-medium fire-prone region

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ABSTRACT

A comprehensive assessment of fire ignition danger is nowadays a basic step towards the prioritization of fire management measures. In this study we propose performing a fire selectivity analysis using Monte Carlo simulations to statistically estimate the relative fire ignition danger in a low-to-intermediate fire-prone region such as Canton Ticino, Switzerland. We define fire ignition danger as the likelihood that at a given place a fire will be ignited. For each 25 m × 25 m pixel of the study area, landscape characteristics that may be related to the probability of fire ignition such as vegetation type, elevation, aspect, slope, urban–forest interface were first split into 9–12 categories. The selectivity of each category with respect to fire ignition was then statistically tested by means of Monte Carlo simulations. Finally, we proposed two different approaches for calculating the ignition danger index: cumulating the scores of the Monte Carlo simulations to a final index or producing synthetic scores by performing a principal component analysis of the Monte Carlo results. The validation of the resulting fire danger indices highlights the suitability of both proposed approaches. The PCA-option allows a slightly better discrimination between ignition and non-ignition points and may be of more general application.

1. Introduction

In last few decades, advances in fire ecology and the strong evidence of the unsuitability of a systematic fire suppression led most fire managers to a shift away from a fire control approach (i.e. concentration of the main effort on suppressing ongoing wildfires) towards a more comprehensive approach, where fire prevention, pre-suppression and suppression strategies as well as knowledge of local fire history and ecology are fully integrated in landscape management (Fries et al., 1997; Swetnam et al., 1999; Bengtsson et al., 2000; Bergeron et al., 2002; Castellnou et al., 2002; Vélez and Merida, 2002; Silva et al., 2010). Modern fire management strategies should, however, consider not only the complex interactions between past natural and anthropogenic forces, but also the present evolution of landscape structures (e.g. wildland–urban interface, WUI, Lampin-Maillet et al., 2010), forest ecosystem services (protection, economic and recreational) and the changing environmental conditions (climate change, pollution, invading alien species, etc.) that may cause unforeseen and unprecedented post-fire ecosystem reaction patterns (Alexandrian, 2002; Flannigan et al., 2000, 2005; Trabaud, 2002; Whitlock et al., 2003).

A basic step towards achieving management goals and minimizing intervention costs is to conduct a comprehensive and quantitative assessment of fire danger and fire risk. Different methodological approaches have been developed in recent times for assessing fire danger and risk (see EUFIRELAB, 2003, 2004; Amatulli et al., 2006; Catry et al., 2009 for a review on strengthens, gaps and drawbacks of the main existing methods) and for the prioritization of fire management measures (Alexandrian, 2002; Finney, 2005; Reynolds and Hessburg, 2005; Hessburg et al., 2007). Unfortunately in some regions where forest and wildfires are not very frequent or where they just start to become a problem as a consequence of the global change (Krawchuk et al., 2009), statistical data on fire frequency and distribution may be lacking or may be too scarce for allowing a statistical approach such as multiple linear regressions or logistic regressions. This may be the case for instance in the Alps (Schumacher and Bugmann, 2006), in selected areas of central Europe such as Germany (Neff and Scheid, 2003; Thonicke and Cramer, 2006) and the French Vosges (Neff et al., 2004), of the Balkans (Albania, former Yugoslav Republic of Macedonia), of the Maghreb (Neff et al., 2007) among others.

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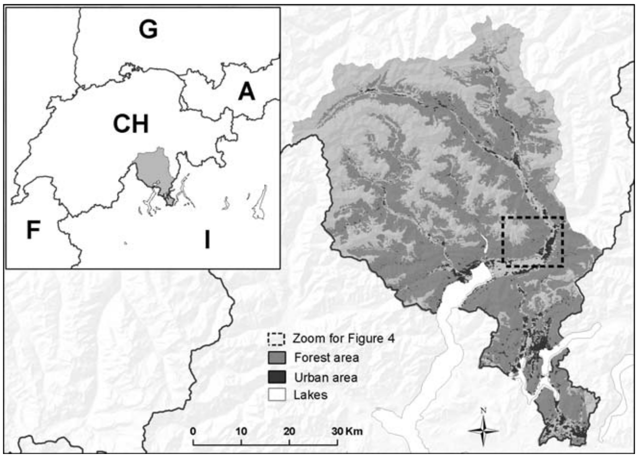

Fig. 1. The study area of the Canton Ticino. The inset refers to Fig. 4.

In this study we test the suitability of using Monte Carlo simulations to statistically estimate the fire selectivity of single landscape characteristics in a low-to-intermediate fire-prone region such as Canton Ticino, Switzerland. We then propose two different approaches for implementing the Monte Carlo results into a relative fire ignition danger index.

2. Material and methods

2.1. Defining the fire ignition danger

Fire management terminology has been constantly evolving and is not uniformly used in all countries and in all fire contexts. Hardy (2005) notes how the terms we use to characterize resource management, particularly fire management, appear to have become less concise over time, and provides examples of numerous inconsistencies in the use of most fire management terms. There are linguistic and cultural aspects behind this problem, partially due to different languages and partially due to the fact that fire is a complex phenomenon involving very different kind of people, e.g. fire fighters, foresters, ecologic lobbying groups, environmental NGOs, land owners, and scientists. These may not share the same vocabulary (Bachmann and Allgöwer, 1999).

A short review of the existing definitions of the terms "fire danger", "fire risk", and "fire hazard" shows that there are currently various definitions, interpretations, and implementations of such concepts in fire management (Hardy, 2005; EUFIRELAB, 2004). In this paper we define "fire ignition danger" as the likelihood that at a given place a fire will be ignited ("fire risk" according to FAO, 1986).

According to EUFIRELAB (2004) the most appropriate time scale for assessing such ignition danger is the long-term (10 years or more). Considering such a time span allows referring to almost static variables that is fire-relevant parameters that do not change along the period of reference. In this paper we therefore refer our estimates of "fire ignition danger" to structural and locational factors (e.g. topography, forest cover) that do not change or only change very slowly over time. This approach enables to describe the long-term relative fire ignition danger within the study area avoiding an explicit use of meteorological data, whose spatial and seasonal distribution is assumed to be similarly recurrent during the study period. This corresponds in practice to the assessment of the internal climatic gradient of an average fire season for which the mean ignition danger can be calculated using the historical fire data.

2.2. Study area

The Canton of Ticino is located on the southern slope of the Alps. It has a total area of 2812 km^2, with 320,000 inhabitants and represents the southernmost of the 26 Swiss Cantons, bordering on Italy (Fig. 1). Like the whole southern slope of the Alps, the area is characterized by a marked altitudinal gradient (from 200 to 340 m a.s.l.) and quite a heterogeneous geology, dominated by siliceous rocks originated in connection with the tectonics of the Alps. Depending on the elevation and the geographical location, the mean annual precipitation ranges from 1600 to 2600 mm, and the mean annual temperature from 3 to 12 °C. The high quantity of summer rain (800–1200 mm in the period June–September) contrasts with the low level of summer precipitation in the Mediterranean climate just south of Ticino. The climate is also characterized by dry and mild winters with some days (40 days a year on average) having strong gusts of a katabatic (descending) dry wind from the North (Foehn), which causes drops in the relative humidity to values as low as 20%. In summer long periods without rain or even of drought may alternate with thunderstorms and short, heavy spells of precipitation (Spinedi and Isotta, 2004).

Forest cover of the area is high (on average 50.5%). The forest vegetation is dominated at low elevations (up to 900–1100 m a.s.l.) by the chestnut tree (*Castanea sativa*), which was first cultivated (and probably first introduced) in the area by the Romans (Conedera et al., 2004). Chestnut forests are anthropogenic monocultures occasionally interrupted by the presence of other broadleaved species, such as *Tilia cordata*, *Quercus petraea*, *Quercus pubescens*, *Alnus glutinosa*, *Prunus avium*, *Acer* spp., or *Fraxinus* spp. At medium elevations (900–1400 m a.s.l.), the forests mostly consist of pure stands of *Fagus sylvatica*, followed by coniferous forests (*Picea abies* and, at higher elevations, *Larix decidua*). On the south-facing slopes the beech belt is sometimes completely missing. The presence of *Abies alba* has been reduced to small patches on north-facing slopes in the central part of the area, and pine forests are confined to very particular sites: *Pinus sylvestris* on dry south-facing slopes, and *Pinus cembra* on the most continental areas of the upper regions (Ceschi, 2006).

2.3. Forest fire data

Fire data have been collected in Ticino by the forest service since 1900. Although data recording has changed with time, some basic information such as the date, time, and cause of ignition, fire duration, area burnt, fire type, and forest type have been collected for the whole period. Thus it has been possible to organize the fire data in a relational database (Pezzatti et al., 2005). In addition, since 1969 geo-referenced perimeters of the burnt area exist for most forest fires.

Up to 2007, 5658 events are registered in the database, resulting in a long-term average of 52.4 forest fires per year. Since 1900, however, the general trend in forest fire frequency and burnt area has varied greatly with respect to this average value (Fig. 2). According to Conedera et al. (2004) and Conedera and Pezzatti (2005) a significant shift in burnt area took place starting in 1980s as a result from a major fire brigades reorganisation (1978) and from the start of systematic use of helicopters for both transport of the fire fighters and aerial fire fighting. Concerning the fire frequency, a relevant drop in anthropogenic induced fire ignitions without a correspondent change in the precipitation regime took place in 1990 as a consequence of two preventative legal acts (Conedera et al., 2004): the prohibition of burning garden debris in the open (Cantonal decree approved on October 21, 1987, but operational with the corresponding penalties since January 1, 1989) and the prohibition against fire works and celebration fires on the Swiss National Day of August 1st in case of high fire ignition danger (Cantonal