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# Characterizing Alpine pyrogeography from fire statistics

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ABSTRACT

In this paper, we describe current fire characteristics in the Alpine region using a ten-year forest fire record at the third and lowest resolution of the European Classification of Territorial Units for Statistics (NUTS3). To this purpose, we performed hierarchical clustering based on the Bray-Curtis dissimilarity index on five pyrogeographic metrics. This resulted in three main geographically well-distinguished clusters (Southern, Northern, and Maritime Alps) and two small groups of outliers. From a geographic point of view, we found a clear differentiation between the high fire density on the southern slope of the Alps and the substantially lower proportion of burnt areas registered in the north. The most relevant climatic (e.g., frequency and length of drought periods), environmental (e.g., vegetation types, mean elevation and predominant orientation of valleys), and socio-economic (e.g., population density and educational level) drivers for the described clusters of fire characteristics were also identified. The proposed pyrogeographic characterisation may represent an important baseline for detecting future shifts in fire occurrence or anomalous fire seasons.

## 1. Introduction

Since its domestication by humans, fire on Earth depends on both climatic and ecological factors, as well as the cultural use of fire (Fernandes, 2013; Pyne, 1997). Humans may influence fire activity directly through setting and controlling fires, but also indirectly by modifying the flammability of landscapes through management, and, more recently, anthropogenically induced climate change (Bowman et al., 2011). As a consequence, resulting fire activity reflects not only the natural fire environment (fire proneness based on climate and vegetation) but also the way mankind perceives and relates to the landscape (Coughlan & Petty, 2012). Furthermore, factors affecting fire occurrence may act at different scales resulting in complex spatially-correlated patterns in fire regimes (Boulanger et al., 2013).

The best way to illustrate such multi-scaled spatio-temporal interactions between fire and the environment is to select suitable recurring fire characteristics and dimensions, so that homogeneous pyroregions may be distinguished within defined space-time windows (Bradstock, Gill, & Williams, 2012; Falk & Swetnam, 2003; Krebs, Pezzatti, Mazzoleni, Talbot, & Conedera, 2010; Morgan, Hardy, Swetnam, Rollins, & Long, 2001). Different quantitative and qualitative approaches exist for defining such pyroregions at different temporal and spatial scales (see Moreno & Chuvieco, 2013 for a short review). A large body of literature has been published reporting on global, continental, and regional-level, as well as past, present, and future pyrogeography, including related driving factors (e.g., Archibald, Lehmann, Gomez-Dans, & Bradstock, 2013; Bowman, O'Brien, & Goldammer, 2013; Pausas & Paula, 2012).

The very steep environmental gradient combined with the considerable diversity in legislation and management approaches make the

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Alpine region a particularly challenging case study for determining subareas with homogeneous fire characteristics. Unfortunately, obtaining consistent forest fire data in a politically and administratively fragmented area such as the Alpine region is a very demanding task. As a result, data has been published in the past for specific regions (e.g., Arpaci, Malowerschnig, Sass, & Vacik, 2014; Fréjaville & Curt, 2015; Pedrolli, 1984; Pezzatti, Zumbrunnen, Burgi, Ambrosetti, & Conedera, 2013; Stefanì, 1989; Vacik et al., 2011) or for particular fire characteristics (Conedera, Cesti, Pezzatti, Zumbrunnen, & Spinedi, 2006; Reineking, Weibel, Conedera, & Bugmann, 2010; Wastl et al., 2013), but to date no synthesis exists on present pyrogeography for the whole European Alpine region (see also Valese, Conedera, Held, & Ascoli, 2014).

Within the framework of the two Alpine Space Interreg projects MANFRED (www.manfredproject.eu) and ALPFFIRS (www.alpffirs.eu), it was possible, for the first time, to create a decennial (2000–2009) Alpine forest fire database compiling records and statistics from national and local forest services and fire brigades. Based on these efforts, the aim of this paper is to define the current main homogeneous pryroregions in the Alpine space, and to discuss their possible socio-economic, environmental, and climatic drivers.

## 2. Study area

The geographical extent of the Alpine region can be identified in different ways based on different purposes. For example, boundaries may be defined based on the Alpine Convention (www.alpconv.org) for developing regional policies, the European Alpine Space Programme (www.alpine-space.eu) which sets the context of European funded projects, or the Greater Alpine Region (Auer et al., 2007) for defining regional climatology. In our study, we consider the Alpine area as defined by the Alpine Convention. In practical terms, we retained all three levels used in the European Nomenclature of Units for Territorial Statistics classification system (NUTS, hereafter referred to as NUTS3) included in or cross-bordering the limits of the Alpine Convention Region (Fig. 1). NUTS refers to the hierarchical system used to divide up the economic territory of the European Union for the collection, development, and harmonization of socio-economic analyses of each region. The three categories include major socio-economic regions at the highest level (NUTS1), basic regions for the application of regional policies (NUTS2) and small regions (< 800,000 inhabitants) for specific diagnoses (NUTS3) (http://ec.europa.eu/eurostat/web/nuts/). The study area so defined includes 82 NUTS3 for a total area of 249,184 km$^2$.

From a climatic point of view, the Alpine area is part of the transition at the continental scale from "temperate westerly" to "Mediterranean subtropical" climate as defined by Auer et al. (2007) when referring to the Greater Alpine Region. As highlighted by the authors, the climate within the Greater Alpine Region can be used to identify a northern sector, comprising most of Germany, Austria, and northern Switzerland, and a southern sector, including Italy, France, Slovenia, part of Austria (Carinthia), and part of Switzerland (Canton Ticino and minor parts of the Cantons Valais and Grisons) (Fig. 1). In the northern sector, the precipitation series show a distinct maximum during the warm season (Fig. 2, meteorological station of Garmisch-Partenkirchen), whereas in the southern sector, autumn precipitation exceeds that of the summer season (Fig. 2, Embrun, Brescia, and Auronzo). The southern sector is warmer and more affected by dry katabatic fall winds (foehn), especially on the western side (Piemonte, Aosta Valley and Lombardia; Fig. 2, Brescia). In the lake region across the Swiss-Italian border, the special case of the Insubric climate is characterized by sub-tropical-like climatic conditions (Fig. 2, Locarno Monti) whereas the French part of the study area is strongly influenced by the Mediterranean climate (Fig. 2, Embrun). Further distinctions regarding Alpine climatology emerge when considering distance from the sea (continentality) and elevation (altitude gradient). Auer et al. (2007) identify an inner Alpine sector characterized by internal valleys at high elevation which are much drier than on the northern side of the Alps (Fig. 2, Umhausen), even if the seasonal distribution of precipitation is similar.

Finally, a great number of forest and vegetation types are found in the Alps as a consequence of the heterogeneous climatic and topographic patterns, ranging from pseudo-Mediterranean and Mediterranean forests (near seas and lakes, as well as in the foothills) to boreal-like conifer stands at higher elevation. In contrast, in the low to medium range, temperate broadleaved forests dominate (EEA 2007). The spatial distribution of environmental features and especially the continuous change from favorable to adverse fire propagation conditions such as slope orientation (south/north), steepness (cliff *vs.* valley vegetation), abundance of conifers *vs.* broadleaved species, and accessibility (managed *vs.* unmanaged forests) lead to highly variable characteristics in terms of fire ignition and behavior.

## 3. Material and methods

### 3.1. Forest fire data

Within the framework of the ALPFFIRS and MANFRED European funded Alpine Space projects, it was possible, for the first time, to collect a high-resolution ten-year dataset of forest fires for the entire Alpine area of France, Italy, Switzerland, Germany, Austria, and Slovenia. All fire records contained information on location (municipality), date of ignition, and total burnt area. Information on ignition sources was not available in all cases, preventing us from using fire cause as a discriminating fire metric. The original dataset consisted of 19,072 forest fires that occurred between 2000 and 2009 in the 82 NUTS3 regions of the study area. The number of fires and burnt area varied greatly among NUTS3 regions ranging from 17 to 2906 events and from 1 to 29,865 ha burnt area, respectively. For statistical reasons, we discarded NUTS3 regions with highly incomplete data series, e.g., with fire data series of fewer than five years or fewer than two events per year on average. This led to the exclusion of 18 NUTS3 regions from further analysis. The final dataset consisted of 17,862 forest fires belonging to 64 NUTS3 regions distributed from France to Slovenia (Fig. 1 and Table 1). At the country level, German forest fire data did not go beyond 2005 and had to be discarded.

We are aware that fire statistics data spanning ten years is rather short for defining fire regimes. Unfortunately, fire records covering most of the study area were available for the period 2000–2009 only. Here, the term fire regime refers to NUTS3 fire characteristics under the current (2000–2009) fire regime.

### 3.2. Fire regime metrics

Fire metrics were defined in order to take fire density (relative average frequency and burnt area) and phenology (seasonal periodicity) into account. Specifically, we calculated four density-related and three phenology-related metrics (see Table 2).

The two density-related metrics (i.e., number of fires and burnt area per square kilometer of combustible area and year) aim at describing susceptibility to ignition and fire spread (i.e., the number of fires and burnt area per combustible area). In addition, we considered the average size of a fire at the NUTS3 level.

Phenological metrics were derived from previous studies dealing with fire seasonality in specific Alpine regions (Cesti & Cerise, 1992; Pezzatti et al., 2013; Vacik et al., 2011; Zumbrunnen, Bugmann, Conedera, & Burgi, 2009). In particular, we defined two phenological metrics describing the share of fire frequency and burnt area in the non-growing season (from the beginning of December to the end of April, hereafter referred to as winter fires) and during the vegetative period (May to November, hereafter, summer fires). In order to limit the influence of single large fires, we created two additional metrics by log-