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Wildfire frequency varies with the size and shape of fuel types in southeastern France: Implications for environmental management

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ABSTRACT

Characterizing time intervals between successive fires in the recent history is of main interest for fire hazard prevention and sustainable environmental management as it indicates what the typical fire return interval for each type of ecosystem is. We tested the extent to which fire return intervals (FRIs) depend on fuel type and age, and we compared FRI values between two fire-prone areas of south-eastern France (Provence). These areas had similar weather and roughly similar fuel types but fuels occurred in patches with different sizes and shapes in the landscape. We built a fire database (1960–2010) and we fitted Weibull distributions of FRI in order to compute the probability density function and the hazard of burning. Our results indicate maximal probability of burning again for shrublands (garrigues and maquis), and minimal values for mixed broadleaf-conifer forests and broadleaved forests. Most fuel types of Provence showed no effect of fuel age on the probability of burning again. Only the unmanaged maquis showed a linear increase of fire hazard in time due to a rapid postfire fuel build up. Rather long fire-free intervals and low age-dependency for most forest fuels of Provence suggest that reducing their biomass may not be sufficient to reduce fire risk. In contrast, the flammable shrublands have rather short fire return intervals and represent a high fire hazard for the whole study area. The two areas had statistically significant difference of fire return intervals for a same fuel type (e.g. 18–22 years for shrublands, 20–24 years for pine forests, and 24–27 years for oak forests). This suggested that size, shape and connectivity of fuels play a major role in the probability of burning again and should be taken into account for fire management. The present policy of fire prevention puts efforts into public information and prevention, and preferential management of fuels at risk in the vicinity of roads and wildland–urban interfaces where fires occur preferentially. However, fire suppression may also take advantage of favouring low-flammable fuels with low age-dependency on strategic places in the landscape.

1. Introduction

South-eastern part of France (so-called Provence) is a fire hotspot with ca. 35,000 fires burned during the 1973–2006 period and 8500 ha burned annually on average (JRC-EFFIS, 2006). Provence belongs to the biodiversity hotspot of the Mediterranean basin (Myers et al., 2000) and has a wide range of Mediterranean type ecosystems (MTEs) with shrublands, forests, and grasslands. Literature has long stated that fire is a key disturbance in such MTEs, which has a major impact on Humans, ecosystems, and landscapes (Moreno and Oechel, 1994; Pausas et al., 2008; Keeley et al., 2012). Previous studies in Provence have indicated that fire is an essential element in the vegetation dynamics, thus shaping the landscape mosaic (Curt et al., 2011; Schaffhauser et al., 2011). In Provence as in many MTEs of southern Europe, abandonment of former agricultural practices, afforestation policy and the increase of population were major drivers of fire risk during the past decades (in Moreira et al., 2011). Shrublands have expanded in the past decades because of the abandonment of former agropastoral management, and they sometimes constitute large tracts with high fire hazard (Curt et al., 2011; Schaffhauser et al., 2011). Extensive afforestation with conifer forests (mainly *Pinus halepensis* and *Pinus pinaster*) and their spontaneous expansion from planting (Barbéro et al., 2000) have strongly increased the fuel biomass and the connectivity of fuels on landscape scale. Thus, pine forests have been claimed to increase fire hazard in Provence, because they favoured intense crown fires (see Fernandes and Rigolot, 2007). Mixed pine–oak forests have a reputation for being highly flammable because of the vertical connectivity between the different species (see in Pausas et al., 2008). Only oak forests are considered to be low flammable and

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resilient due to a good resprouting ability (Pausas et al., 2008; Curt et al., 2009). Urban sprawl and the strong increase of population (Moreira et al., 2011) have favoured the development of road corridors and wildland–urban interfaces (i.e. the area where houses and the wildland vegetation coincide) where vegetation is generally extensively managed, with possible incidence on fire risk. The Provence area includes two neighbouring fire-prone areas with the same climate and roughly similar fuel types but with different size, shape and connectivity of fuels across the landscape: the Aix-Marseille area and the Maures massif. This configuration provided a unique opportunity to investigate if fire frequency was similar for a given fuel type but different patch size and connectivity. This has implications for management, because if fire frequency is similar for a certain fuel type in both areas then similar management should be applied.

In this context, it is crucial for sustainable management to characterize the fire frequency specific to each type of ecosystem (hereafter referred to as ‘fuel types’, i.e. identifiable associations of fuel elements of distinctive species that will cause a predictable fire behaviour; Pyne et al., 1996). It is noteworthy that although the Provence area is a fire hotspot, no georeferenced fire database existed yet. This prevented any accurate fire frequency analysis whereas it existed in neighbouring countries such as Spain (e.g. Diaz-Delgado and Pons, 2001) or Portugal (e.g. Oliveira et al., 2011). This may explain why controversy still persists among land managers in Provence about the role of fuel age and the typical fire return interval for the most common fuel types. Literature stated that characterizing the past fire regime, i.e. spatial pattern, frequency, intensity and seasonality of fires prevailing in an area (Gill, 1975; Pyne et al., 1996) is necessary to assess fire risk and the ecosystem vulnerability. Fire frequency is a main feature of fire regime which is notably characterized by fire intervals, i.e. time in years between two successive fires in a designated area. First, this key component has major implications for fire risk assessment since it is important to predict the mean fire return interval or the probability of a new fire after having burned (Moritz et al., 2009). Secondly, fire intervals control in part the survival and regeneration of many species (Pausas et al., 2008) and thus the dynamics and sustainability of wildland and forests. As a consequence, the characterization of fire return intervals (FRIs) has been increasingly used to guide forest management, to prevent fires by fuel treatment (Keeley et al., 1999; Fernandes and Botelho, 2003), to mimic the natural disturbance regime in order to maintain biodiversity (Martin and Sapsis, 1992; Burrows, 2008), or to limit the risk of species extinction in fire-prone ecosystems (Allen et al., 2002). It has been proved that fires at inappropriate time intervals may change the quality of habitats (Burrows, 2008) or lead to the extinction of interval-sensitive species (Eugenio et al., 2006; Pausas, 2006; Russell-Smith et al., 2010).

The distribution of FRI in a landscape results from the recurrence and the patterning of fires which in turn results from a complex stochastic process of ignition, spread, and regrowth dynamics (Moritz et al., 2009). Interactions between ignitions sources, weather, topography and land cover explain why some locations burn more often than others in a landscape (Mermoz et al., 2005; Moreira et al., 2011). In many MTEs, ignition is man-induced (Moreira et al., 2011) then favoured by weather. As a result, most points of ignition aggregate in road corridors (Curt and Delcros, 2010) or wildland–urban interfaces (Lampin-Maillet et al., 2010) and fuel types located in the vicinity of these areas are likely to burn more frequently than others. FRI should also strongly depend on factors controlling fire spread within the landscape, including physiography and fuels. In French or Spanish MTEs it has been proved that fire recurrence is higher on certain topographic positions (e.g. south facing slopes and crests; Mouillot et al., 2003; Vazquez and Moreno, 2001) due to a combination of factors linked to ignition, topoclimate, and fuels (Moreira et al., 2011). Fuels can play a major role in variations of FRI as certain fuel types or land covers are especially flammable because of their composition, biomass, structure, and moisture. Higher fire selectivity for shrublands rather than for forests and agricultural lands has been stated in many MTEs (see in Moreira et al., 2011). Some fuel management practices such as forest thinning, planting or shrub-clearing would also affect the probability to burn (or to reburn) and to propagate fire because they modify the biomass and spatial arrangement of fuel. As FRI expresses the probability of reburning within a certain time period, it also depends upon the ability of a fuel to recover after fire or to shift to another fuel type (Moritz et al., 2009). Some fuel types exhibit rapid postfire fuel build-up whereas others can stay for a long time with fuel load insufficient to carry a new fire (‘fuel limitation’ stage). A feedback exists between fuels and fire (i.e. fuels produce fires and, in turn, are affected by fires), and a typical FRI is expected to settle down for a certain duration in a certain landscape (Turner, 1989).

In the study we assessed the fire return intervals for two fire-prone areas in Provence, based on an original georeferenced fire database from 1960 to 2010 including all fires larger than ca. 3 ha. First, we tried to find out what the typical FRI for each fuel type was. This knowledge is crucial to guide the type of management to apply to ensure the ecosystem sustainability. For that purpose we computed the FRI for each fuel type and area using both censored and uncensored data. Censored data take only into account fire intervals between two fire dates known precisely while uncensored include all data. Then, we tested the hypothesis that FRI could differ from one area to the other for a same fuel type (and a similar climate) due to a difference of size, shape and connectivity of fuels. For that purpose we compared FRI for a same fuel type in the two areas. Our final objective was to advise what type of fuel management could be applied to the main fuel types existing in Provence.

2. Materials and methods

2.1. Study areas

We selected two study areas within the Provence fire hotspot since it enabled us to compare FRI with similar climate and fuel types but with different size, shape and connectivity of fuels across the landscape. The Aix-Marseille area (called below AIXM; central point: 43° 20N, 5° 23E; area 510,593 ha) has ecosystems on limestone-derived soils dominated by *P. halepensis*, *Quercus ilex* and *Quercus pubescens*, and *Quercus coccifera* shrublands (Appendix 1A). The Maures massif (called below MAUR; central point 43.3° N, 6.3° E; area 145,686 ha) is made of a gneissic substratum and has siliceous soils. Its ecosystems are dominated by *P. pinaster*, *Quercus suber* (with *Q. pubescens* and *Q. ilex*), and *Erica-Cistus* shrublands (Appendix 1B). Fuels are roughly similar in these two areas with the exception of mixed forests (Appendices 1A and B; Fig. 3).

Conversely, the two areas exhibit a high contrast of size, shape and connectivity of fuels in the landscape. The Maures massif is dominated by wildland with sparse cork oak woodlands intermingled with large extents of flammable *Erica-Cistus* maquis (Fig. 1B). In contrast, the Aix-Marseille area is a matrix of fragmented and interspersed pine and oaks forests, with small patches of *Q. coccifera* garrigue. In addition, wildland and forests are almost absent in the western part of AIXM (Fig. 1A) which is dominated by agriculture, industries, and salt pans. The two areas are close to each other and have the same climate making them conducive to frequent and intense summer fires (JRC-EFFIS, 2006). Both areas had roughly similar fuel types including shrublands, pine forests, oak forests, and mixed pine–oak forests. Shrublands are fire-prone ecosystems