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Does large fire activity vary within the French Mediterranean area?

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Introduction

In the French Mediterranean, large fires have significant socio-economic and environmental impacts. The previous works dealing with fires in the French Mediterranean were based on gridded fire data commencing from the mid-1970s (e.g., Ruffault *et al.*, 2016; Fréjaville and Curt, 2017; Ganteaume and Guerra, 2018; Lahaye *et al.*, 2018). Working with longer time-series of georeferenced fires (extending back to 1958) would allow examining both spatial and temporal distributions of large fires (>100 ha) across the French Mediterranean. The objectives of this work were (i) to identify the locations associated with large fire recurrence and to quantify the spatial extent of the region with reburns, (ii) to establish the mean fire extent and the fire return level as well as the LF causes along a longitudinal transect spanning the study area (identifying possible roles of climate conditions and fuel continuity in shaping this longitudinal gradient), and (iii) building on previous research, to re-estimate trends in large fires across the region taking advantage of a fire record spanning almost six decades.

Material and Methods

Study area

The study area (total surface area of 11 157 km^2) is one of the most fire-prone region of SE France in terms of fire frequency (i.e. number of fires) and burned area (Ganteaume and Jappiot, 2013; Ganteaume and Guerra, 2018). The western part is characterized by an extensive WUI where the ignitions are the most frequent (47% of the total ignitions occurred in the WUI) (Ganteaume and Long-Fournel, 2015). Most large fires occur in summer but their cause is often unknown and when it is known, these large fires are mainly due to arson (Ganteaume and Guerra, 2018). The study area can be divided into two parts located on a West-East gradient of the Mediterranean that share most characteristics albeit the amount of annual precipitation and forested massif size increase eastwards contrary to WUI area.

Fire data

A long-term geo-referenced fire perimeter database (1958-2017) derived from aerial photography and remote sensing and compiled by the Office National des Forêts (ONF) and Directions Départementales des Territoires et de la Mer was used to analyze both spatial and temporal distributions of large fires (LF; ≥100 ha). These LF represented only 28% of the total number of

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fires ≥1 ha (N=1277) but accounted for 94% of the total burned area. Large fire causes were analyzed according to the regional fire database Prométhée that has recorded fires since 1973.

Climate and Land Cover Data

We computed the daily Fire Weather Index (FWI) from the Canadian Forest Fire Weather Index system using daily surface meteorological variables at a 8-km spatial resolution from the quality-controlled SAFRAN dataset providing maximum temperature, minimum relative humidity, precipitation and wind speed over France from 1959-2017.
We extracted fuel cover data from the "BD Forêt 2014" of the National Geographic Institute and regridded the data onto 8-km spatial grid.

Results

The region was impacted in some locations up to 6 times by recurrent LF (Fig. 1) and 21% of the total area burned by LF occurred on a surface that previously burned in the past, with potential impact on forest resilience. Results also showed that there was a strong spatial variation of LF according to the time-since-fire, with clusters of recent LF along the coast (where the recurrence was the highest) and more ancient LF in the central and northern part of the eastern area where the tourist pressure is lower. In contrast, LF were homogeneously distributed in the West, regardless of their age.

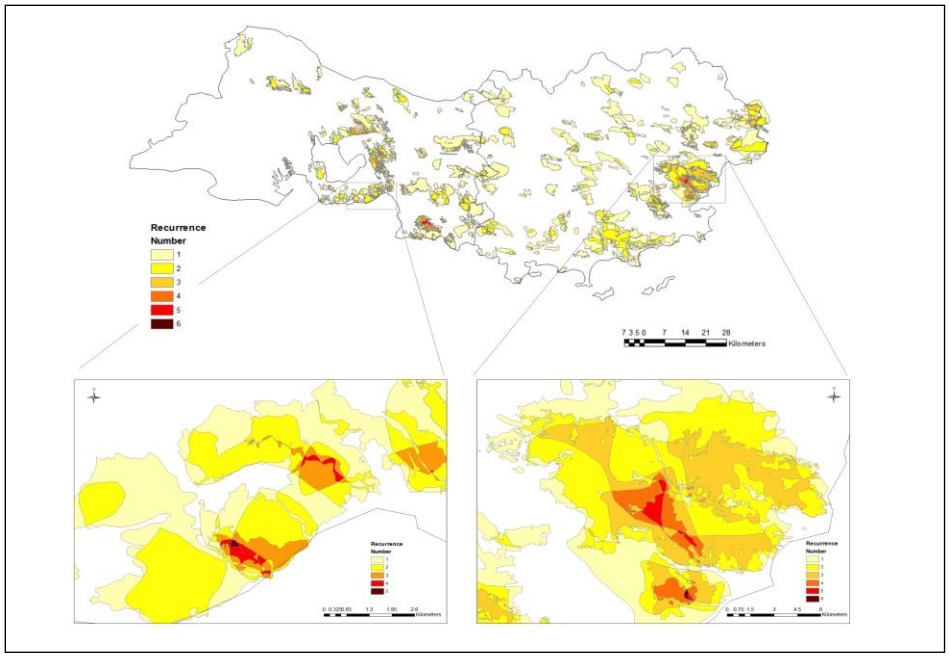

Figure 1: Fire recurrence on the 1961-2017 and 1958-2016 period in the western and eastern areas, respectively.

We found contrasting patterns between the East and the West of the study area, the former experiencing fewer LF but of a larger extent compared to the latter, with an average time of occurrence between LF exceeding 4,000 ha <7 years mostly in the eastern coastal area and >50

years in the West. This longitudinal gradient in LF return level contrasts with what we would expect from mean fire weather conditions strongly decreasing eastwards during the fire season but is consistent with larger fuel cover in the East, highlighting the strong role of fuel continuity in fire spread (Fig. 2). This longitudinal gradient is likely due to the variation in landscape fragmentation. Indeed, the western area presents a mosaic of wildlands interspersed with agricultural areas and WUI, LF being thereby concentrated in natural spaces less extended than in the eastern part where large forested massifs mostly located on the coast allowed fire spread. By contrast, LF were more frequent in the West where population density, the proportion of WUI, and infrastructures (railroads and roads) are the highest

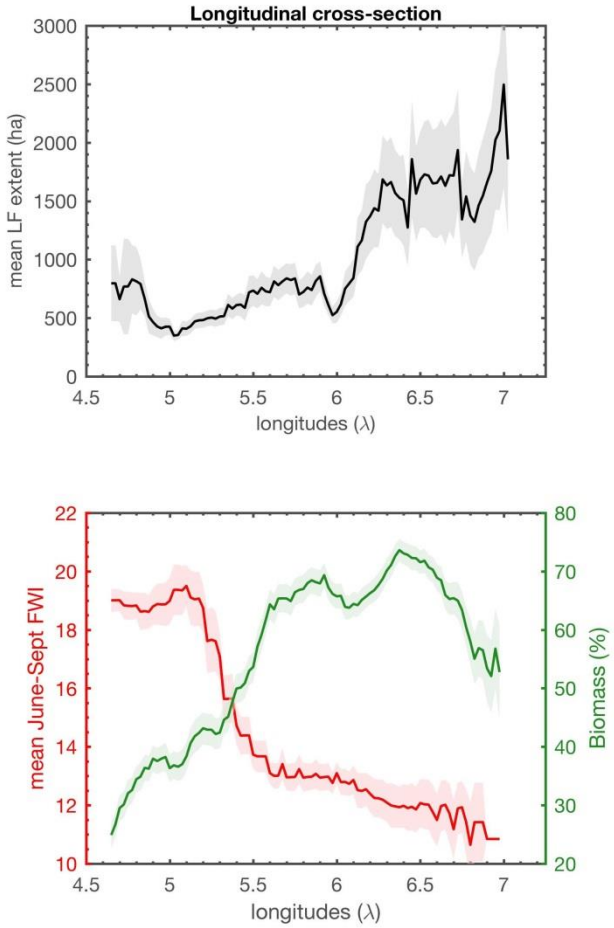

Figure 2: Top) Longitudinal cross-section of mean LF extent computed over 30-km sliding windows. The 95% confidence intervals were estimated using a bootstrapping approach. Bottom) Same as top panel but for mean June-September FWI (in red) and the percent of biomass (in green).

The shapes of LF which were more elongated in the wind direction in the western part support the results of Ruffault *et al.* (2018) pinpointing that the main wind-driven large fires that had occurred in 2016 were located in the western part while the main heat-driven large fires that occurred in 2003 were located in the East of the area.

An abrupt decline in LF was evident across the eastern part in the early 1990s, mostly due to a change in fire management policy thereby contributing to the weakening of the climate-fire relationship. However, despites large means allocated to fire suppression, large fire outbreak is still possible in the French Mediterranean (such as in 2003 or 2016), as specific weather conditions can overwhelm fire suppression efforts (Fernandes *et al.*, 2016; Lahaye *et al.*, 2018).

Regarding the causes of LF, the proportion of unknown cause was high throughout the region, varying from 74% to 77% from the West to the East. It is worth noting that the knowledge of smaller fires (<100 ha) was also bad (73 to 75% of unknown cause). In contrast to the western area, this bad knowledge of LF causes has worsened since 1997 (82% between 1997 and 2017). In the entire region, arson (but with undetermined motives) was the most frequent cause of LF (40 to 43% from West to the East), followed by negligence during forestry works (14%) in the East and by negligence during agricultural works, negligence with glowing objects and vehicles (10% each) in the West (Fig. 3). The occurrence of LF due to arson did not vary during the period studied while LF due to forestry and agricultural works as well as most LF due negligence with glowing objects occurred only before 1997 contrary to LF due to vehicles.

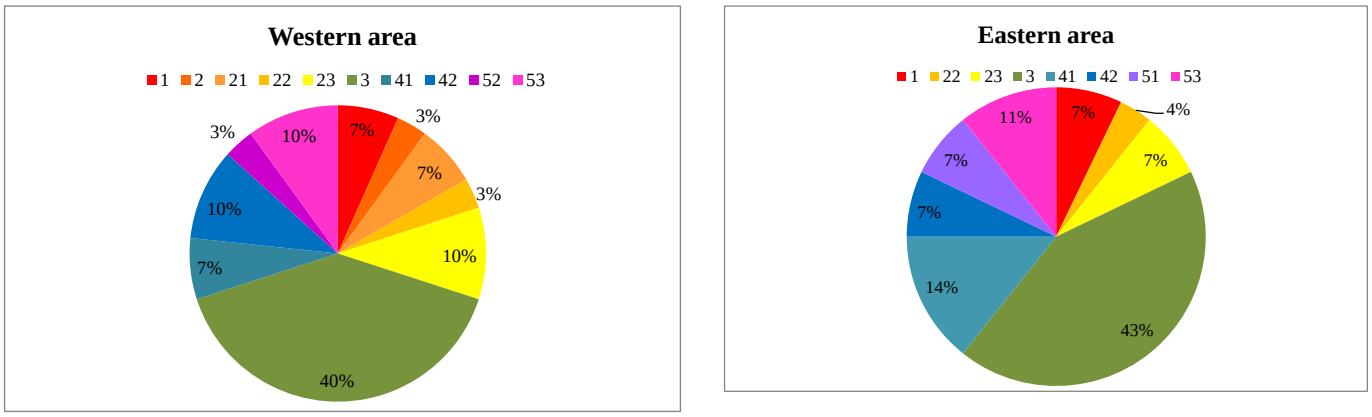

Figure 3: Proportion of LF causes in the western and eastern areas

Conclusion

Improving our understanding of large fire activity is of upmost importance to fire prevention and management to mitigate their impacts. Here, we presented a comprehensive analysis of spatial and temporal patterns of LF in the French Mediterranean. To our knowledge, the fire database compiled and analyzed in this framework provides for the first time a detailed description of LF recorded on geo-referenced long time series.

A better knowledge of LF drivers and causes is necessary to strengthen fire prevention by providing valuable information on priority areas where LF are more likely to occur and by better targeting the origins of these deleterious fires.

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