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Spatial and temporal patterns of fire and climate change in the eastern Iberian Peninsula (Mediterranean Basin)

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ABSTRACT: Fire is a dominant ecological factor in Mediterranean ecosystems, and changes in the fire regime can have important consequences for the stability of our landscapes. In this framework we asked what is the temporal and spatial pattern of number of fires and area burned in the eastern Iberian Peninsula during the last decades. Because in the study area most fires occur in summer, and summer weather conditions are key factors for fire, we also asked what is the temporal and spatial pattern of summer rainfall and summer temperature. To answer these questions we analysed the meteorological data from 350 stations covering the eastern Iberian Peninsula (1950-2000), and the fire records for the same area (1968-2001). The results suggested a slight tendency towards decreasing summer rainfall and a clear pattern of increasing summer temperatures during the last decades. They also show that the meteorological stations in warmer places tended to show a higher rate of summer temperature increase. The analysis of fire records suggested a clear increase in the annual number of fires although the area burned did not show a clear trend but rather 2 peaks. Spatial analysis of the fires suggests that most fires are small, but most of the area burned is due to very few large fires, and that fires often overlap (fire recurrence) in such a way that 15% of the wildland area had burned at least twice in the last 23 years, and that the average fire interval in the recurrently burnt area is 8 years.

1 INTRODUCTION

Summer drought and summer fires are two characteristics of Mediterranean ecosystems. Although Mediterranean vegetation is able to cope with fire (Hanes 1977, Trabaud 1987, Pausas 1999a, Pausas et al. 2004a), changes in the area burned and the consequent changes in fire recurrence (and inter-fire periods) can have consequences at landscape level. Thus, understanding spatial and temporal patterns in the fire regime and their relation to climate is a key factor for predicting future Mediterranean vegetation scenarios (Pausas 1999a).

In Mediterranean ecosystems, changes in climate and consequent changes in fire hazard have been studied by Piñol et al. (1998) on the basis of one meteorological station, by relating climate and potential fire hazard through fire hazard climatic-based indices. In the present work we use a regional approach, based on 350 meteorological stations located in the eastern Iberian Peninsula and on the area burnt in the same region. Spatially-explicit fire statistics were computed for better characterizing the fire regime.

2 METHODS

The study area corresponds roughly to the political boundaries of the region of Valencia (Fig. 1), in the Eastern Iberian Peninsula (the Mediterranean coast). It comprises 2325508 ha, of which ca. 52% is forest land. The climate of the area is typically Mediterranean with mild winters and warm and dry summers.

Climatic data from 350 meteorological stations (1950-2000) all over the study area were obtained from the National Meteorological Service (see Fig. 1 for location). Data for annual fire occurrence and annual area burned were obtained from the Regional Government of Valencia for the period 1968 – 2000 (see also Pausas and Vallejo 1999, Pausas et al. 1999). Spatially explicit fire data were obtained by digitizing fire limit maps for the period 1978 – 2001 for the central area of the study region (Valencia Province; 1076560 ha, of which ca. 53% is forest land; Fig. 1c). Fire limits were then incorporated in a GIS for further analysis.

Spatial dependence of climatic trends (slopes of the regression between climatic variables and years) was analyzed using Moran's autocorrelation index.

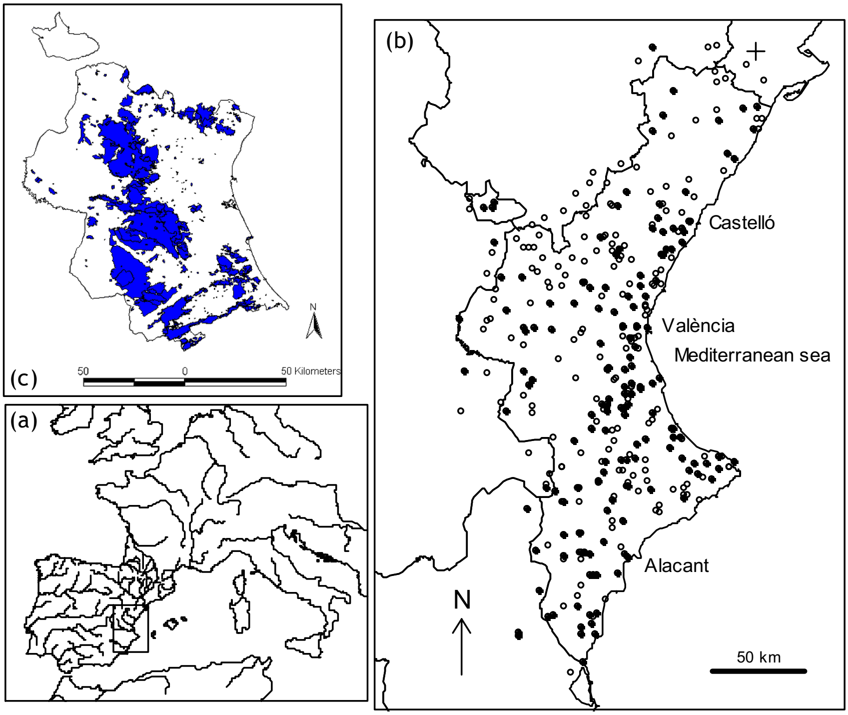

Figure 1. Location of the study area (a), location of the meteorological stations (b) with precipitation and temperature data (closed symbols) and those with precipitation only (open symbols), and Valencia province (c, the central part of the Valencia region) with the area affected by fire during the period 1978-2001 (shaded area).

3 RESULTS

3.1 *Temporal pattern of fires*

The number of fires has increased notably in the study area during the last three decades (Fig, 2a). On average, the annual increase in fires is ca. 16 per year. The annual area burned during the last three decades shows a large inter-annual variability (Fig. 2b), with two clear peaks in 1978/79 (ca. 80000 ha each year) and 1994 (140000 ha in a single year). On average, the annual area burnt was ca. 21000 ha (1.7% of the wildland area), and the fire cycle for the whole wildland area (the temporal extent of the fire history data divided by the proportion of area burnt) was about 60 years. The central part of the study areas (Valencia Province; 60% of the wildland area of the whole study area) is the area with most fires, with an annual area burnt of about 17000 ha (3% of the wildland area) and a fire cycle of ca. 34 years. Most fires (42%) and most area (ca. 80%) burnt during July and August, with some (24% in number and 13% in area) during September and October.

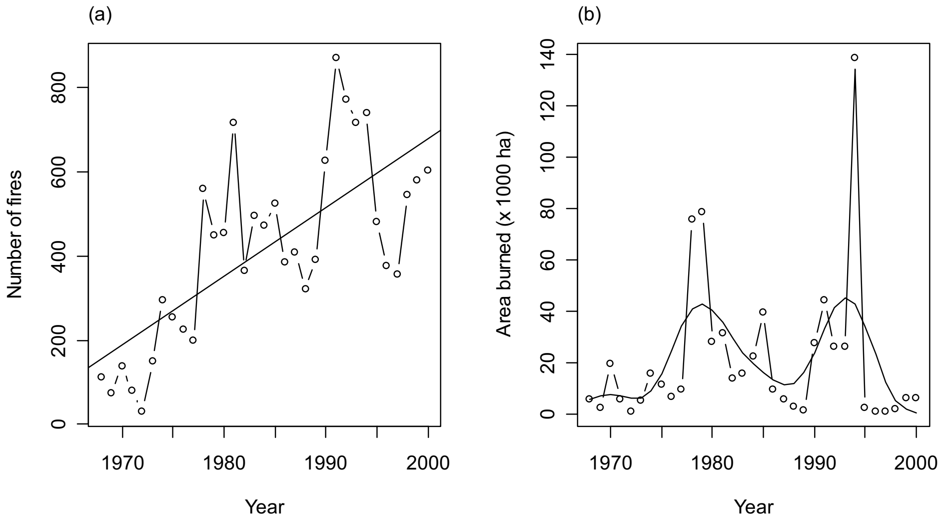

Figure 2. Annual number of fires (a, $F = 32.95$, $p < 0.0001$) and annual burned area (b, smooth line) in the Eastern Iberian Peninsula during the last three decades (see also Pausas 2004).

3.2 *Spatial pattern of fires*

Fires that occurred between 1978 and 2001 (in the Valencia Province) showed large size variation, ranging from very small fires up to 38000 ha (median = 2145 ha). Most fires (82%) were small (<200 ha) but most of the area burnt (59%) occurred in a few (3%) large fires (>1600 ha; Fig. 3a). The top 10% of these large fires accounted for 82% of the area burnt. During this period, fires overlap in space. The current landscape (year 2001) shows unburned patches and patches recurrently burned up to 5 times in the last 23 years (years in which spatially-explicit information was available). About 55% of the forest landscape did not burn during this period, ca 30% burned once only, 14% burned twice, and very small areas burnt 3 or more times (Fig. 3b). The fire return interval ranged from 2 to 22 years, with a median of 8 years. About 11% of the forest land has suffered recurrent fires with fire intervals shorter than 15 years (in the last 23 years).

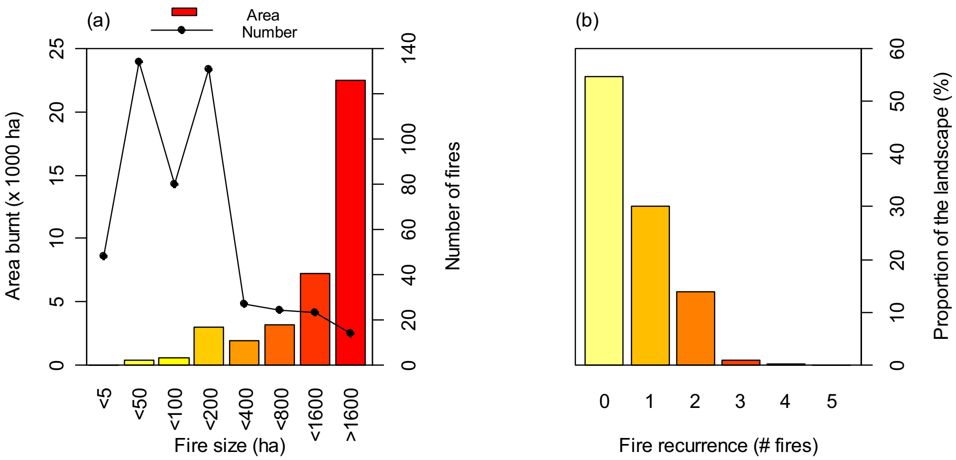

Figure 3. Area burnt (a, colored boxes) and number of fires (a, line) by fire size classes, and proportion of the landscape with different fire recurrences (b) in the Valencia Province.

3.3 *Temporal pattern of climate change*

Summer rainfall tended to decrease (Fig. 4a), but the decreasing pattern was not statistically significant ($p = 0.08$) due to the large interannual variability. At the local scale, 70% of the stations showed a tendency to decreasing summer rainfall, although most of them were not statistically significant.

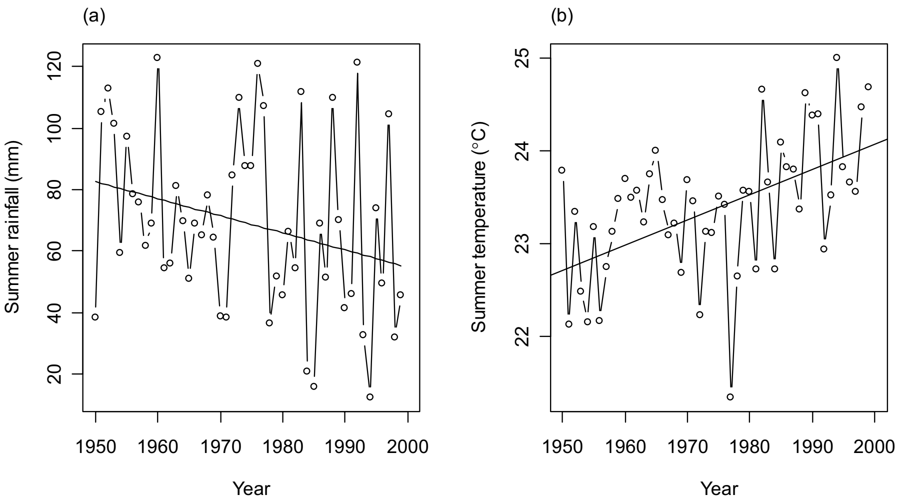

Figure 4. Changes in summer rainfall (a) and in mean summer temperature (b) during the last five decades (Pausas 2004). Changes for rainfall are not statistically significant and the line represents smoothing function; changes in summer temperature are statistically significant ($R^2 = 0.50$; summer: $F = 13.9$, $p<0.001$, $R^2 = 0.22$).

Summer temperature increased significantly with time ($F = 13.9$, $p<0.001$, $R^2 = 0.22$; Fig. 4b). On average, the increase in summer temperature was 0.27 °C per decade respectively. At the local scale, a tendency to increase was observed in 73% of the stations; the increase was statistically significant for 40% of the total stations.

3.4 *Spatial pattern of climate changes*

Meteorological stations showing increases or decreases in summer rainfall and temperature are distributed over all the study area (Fig. 5). No significant spatial autocorrelation of the climatic changes (measured as the slopes of the regression between these climatic variables and time) was detected (Moran's I indices were not significant). However, there was a positive relationship between long-term mean summer temperature and the slope of the temporal change in summer temperature ($F=12.83$ $p= 0.00046$, $df= 1, 152$), suggesting that meteorological stations in warmer places tended to show a higher rate of summer temperature change.

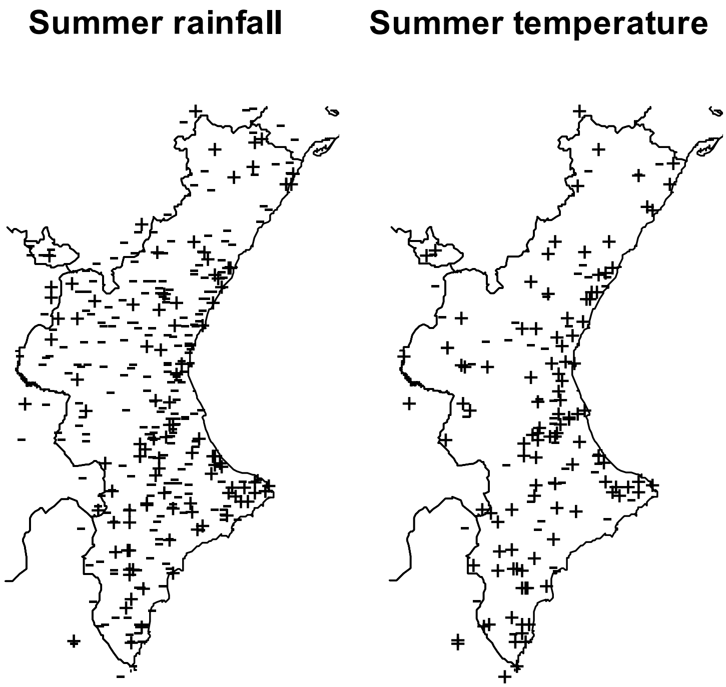

Figure 5. Trends of increase (+) and decrease (-) in summer rainfall (left) and summer temperature (right) in the study area during the last decades.

4 DISCUSSION

During the last decades, the number of fires has grown markedly (Fig. 2). In the same period, the surface area affected by fire did not show a clear tendency for the last three decades, but rather a strong inter-annual variability. The longer-term (historical) data, although less accurate, suggest that both the number of fires and the area burned increased greatly during the late 70s (Pausas 2004). Fire return intervals in the study area are relatively short (median = 8 years) compared to the mature age of the dominant tree in the study area (ca. 10-15), the non-sprouting *Pinus halepensis*. Thus, restoration actions may be needed for regenerating forested landscapes (Pausas et al. 2004b).

Average summer rainfall has tended to decrease over the last 50 years, with an average regional decrease of about 5.2 mm per decade. However, the high annual variability in summer rainfall makes this possible trend almost imperceptible (and non-significant) at both local and regional scales. Furthermore, summer temperatures (and consequently, potential evapotranspiration) have clearly increased during the study period. This increase in temperature together with a tendency to decreasing rainfall suggest that summers are becoming warmer every year. Meteorological stations in warmer places (with higher average long-term summer temperatures) tended to show higher rates of increase in summer temperature. Nevertheless, the sudden increase in fire occurrence and area burned during the mid 1970s cannot be explained by climatic parameters alone, and socioeconomic causes need also to be considered (Vélez 1993, Pausas 1999b, 2004, Pausas and Vallejo 1999). If the current climatic trends (Fig. 4) remain constant, fuel conditions in summer will become drier each year and, as a consequence, the risk of large burned areas will increase. This increase in fire may reduce return fire intervals at local scale, which may limit the regeneration of late-maturing non-resprouting species and thus threaten biodiversity.

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