CHANGES IN FIRE AND CLIMATE 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 I asked firstly, what is the trend in fire number and area burned in the eastern Iberian Peninsula, and then, to what extent is the inter-annual variability of fires determined by climatic factors. To answer these questions I analysed the meteorological data (temperature and precipitation) from 350 stations covering the eastern Iberian Peninsula (1950–2000), and the fire records for the same area (historical data, 1874–1968, and data from recent decades, 1968–2000). The results suggested a slight tendency towards decreasing summer rainfall and a clear pattern of increasing annual and summer temperatures (on average, annual temperatures increased 0.35 °C per decade from 1950 to 2000). The analysis of fire records suggested a clear increase in the annual number of fires and area burned during the last century; however, in the last three decades the number of fires also increased but the area burned did not show a clear trend. For this period the inter-annual variability in area burned was significantly related to the summer rainfall, that is, in wet summers the area burned was lower that in dry summers. Furthermore, summer rainfall was significantly cross-correlated with summer area burned for a time-lag of 2 years, suggesting that high rainfall may increase fuel loads that burn 2 years later.

1. Introduction

Mediterranean ecosystems are often characterised by the occurrence of wildfires and summer droughts. Although Mediterranean vegetation is able to cope with fire (Hanes, 1977; Trabaud, 987, 1991; Pausas,1999a), changes in the area burned and the consequent changes in fire recurrence (and inter-fire periods) can have consequences at landscape level. For example, high fire recurrence may prevent seeders from replenishing seed banks (Zedler et al., 1983), may deplete resprouters bud banks (Canadell and López-Soria, 1998), and/or may favour certain species with invasive characteristics (D'Antonio and Vitousek, 1992; Vilà et al., 2001; Lloret et al., 2003). Thus, understanding changes in the fire regime and their relation to climate is a key factor for predicting future Mediterranean vegetation scenarios (Pausas, 1999a).

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* Dedicated to D. Peñarrocha (València, 1964–2002).

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Fire occurrence is determined by different factors, including human factors; however, my general hypothesis here is that some of the variability in the area burned should be, to some extent, related to climatic factors (Chandler et al., 1983; Clark, 1990), while fire ignitions should be more related to human factors and lightning. In Mediterranean ecosystems, changes in climate and consequent changes in fire hazard have been studied by Piñol et al. (1998). Their study was based mainly on one meteorological station, and they related climate and potential fire hazard by computing fire hazard climatic-based indices. In the present study, I take a further step by using a regional approach based on a large number of meteorological stations (350) that characterise the regional climate, and I analyse real data on fire-occurrence and area burned for the same region (eastern Iberian Peninsula) to study to what extent the two parameters (climate and fire) are related.

I first ask what the trend is in fire number and area burned during the last decades, and then, to what extent the inter-annual fire variability is determined by climatic factors. My aim is not to make an accurate climatic analysis for all meteorological stations, but rather to emphasise the general climatic trends at the same regional scale as the fire information and to analyse the variability in these trends at that scale.

2. Methods

2.1. STUDY AREA

The study area corresponds roughly to the political boundaries of the region of Valencia (Figure 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 (Pérez-Cueva, 1994) with mild winters and warm and dry summers. The area can be subdivided into two main distinctive bioclimatic zones by temperature: a thermo-Mediterranean zone right next to the coast (mean annual temperature: 17–19 °C; vegetative period: 12 months) and a meso-Mediterranean zone (inland area; mean annual temperature 13–17 °C; vegetative period: 9–11 months). Supra-Mediterranean areas (mean annual temperature: 8–13 °C) are less abundant further inland in the north-western mountains. The precipitation regime is mainly dry (annual precipitation from 350 to 600 mm) and subhumid (from 600 to 1000 mm) with some areas in the south showing lower precipitation (semiarid area, with <350 mm). The annual precipitation regime is strongly bimodal, with precipitation concentrated (>60%) in spring and autumn and with a dry summer (<20% of the annual precipitation).

Despite the spatial variability in climate, the entire study area faces eastwards, that is, towards the Mediterranean Sea, as there is a mountain chain at the west (inland). In fact, meso-meteorological processes during the fire seasons are dominated by east-west (up and downhill) movements of air masses (Millán et al.,

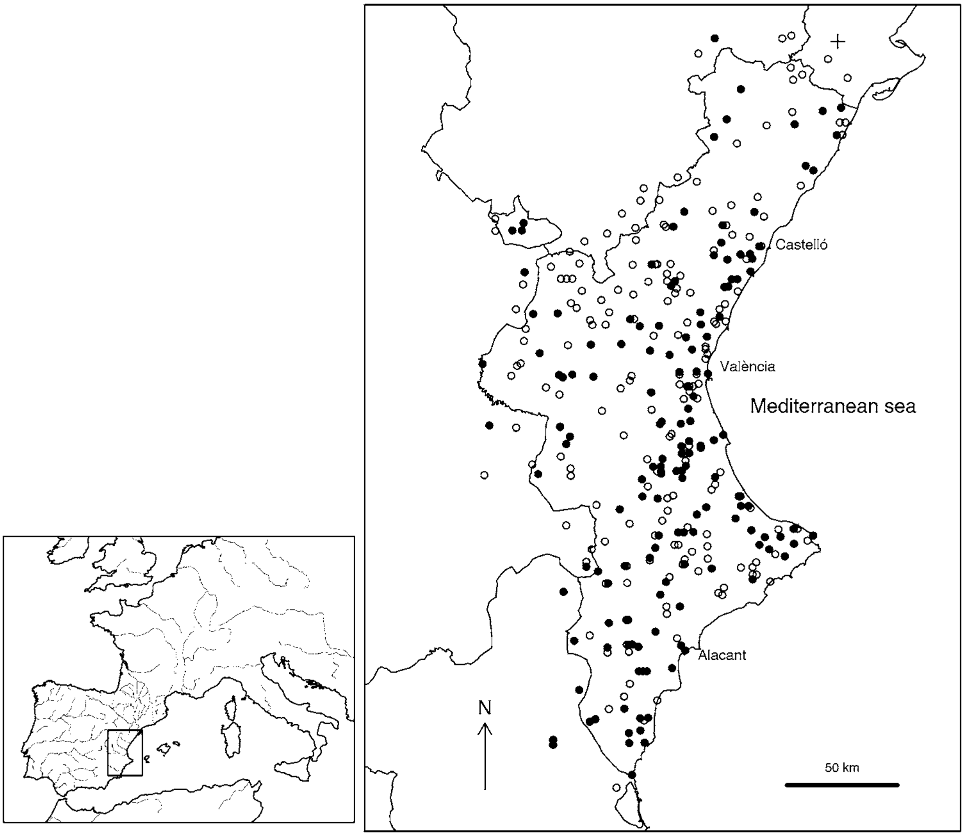

Figure 1. Location of the study area and location of the meteorological stations with precipitation and temperature data (closed symbols) and those with precipitation only (open symbols). The cross in the north area indicates the location of the meteorological station used by Piñol et al. (1998). Lines are political boundaries.

1998). The size and topographic structure of the study area imply that, in general, interannual climatic variability is very homogeneous throughout the study area; that is, although intra-regional variability can be observed (Estrela et al., 2000; de Luís et al., 2001), dry years are dry for the whole study area, and the same applies for wet years. In fact, preliminary analysis suggested that the correlation coefficients of rainfall data among 322 meteorological stations were positive in 99.5% and significantly positive ($p < 0.05$) in 80.6% of cases.

2.2. DATA SOURCES AND ANALYSIS

Accurate 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). Less precise data, tracing back to 1874, were obtained from Fernández Muñoz (1999) for the Valencia Province (central part of the study area; it comprises 46% of the total study area). After an exhaustive search in the old Forest Districts records and dossiers on fires, and of local magazines and newspapers, he was able to obtain the area burned for 73% of the total number of fires in the Valencia Province by decades. From these data I computed the mean annual area burned and annual number of fires by assuming the underestimation, that is, by increasing the burned area by 27%.

Climatic data from 350 meteorological stations (1950–2000) were obtained from the National Meteorological Service (see Figure 1 for location). These stations range from ca. sea level up to 1444 m a.s.l. (mean = 353, sd = 330). For each station and for each year with available data, we extracted: annual rainfall, mean annual temperature, summer (June, July and August) rainfall, mean summer temperature. For each climatic variable we only used the meteorological stations that had at least 10 years of records. All meteorological stations have rainfall data, but temperature data were only available for 154 (44%) stations. The climatic data used were the climatic data from each meteorological station (local-scale data) and the average of the climatic data from all the meteorological stations for each year (regional climatic data).

Fire information (annual area burned and annual number of fires) was related to the climatic conditions of the year by using the regional climatic data (average data for the study area). Regressions and the F-test were used to validate the significance of relationships. Because not all stations had data for the whole period, when climatic data were used by averaging different meteorological stations, the regressions were weighted by the number of stations that had data in each year. When no significant regression was obtained, a smoothing GAM function (Wood, 2000) is shown to visualise the trend.

Autocorrelation was analysed for the fire-related parameters (number of fires and annual area burned), and cross-correlation was analysed between fire parameters and climatic parameters. Both autocorrelation and cross-correlation were computed by using the time series package described in Venables and Ripley (1999).

3. Results

3.1. FIRE CHANGES

The number of fires has increased notably in the study area during the last three decades (Figure 2a). On average, the annual increase in fires is ca. 16 per year. The annual number of fires showed a significant autocorrelation for time lags shorter than 4 years (Figure 2b).

The annual area burned during the last three decades shows a large interannual variability (Figure 3a), with two clear peaks in 1978/79 (ca. 80000 ha each year) and 1994 (140000 ha in a single year). The temporal patterns show no significant autocorrelation (Figure 3b).

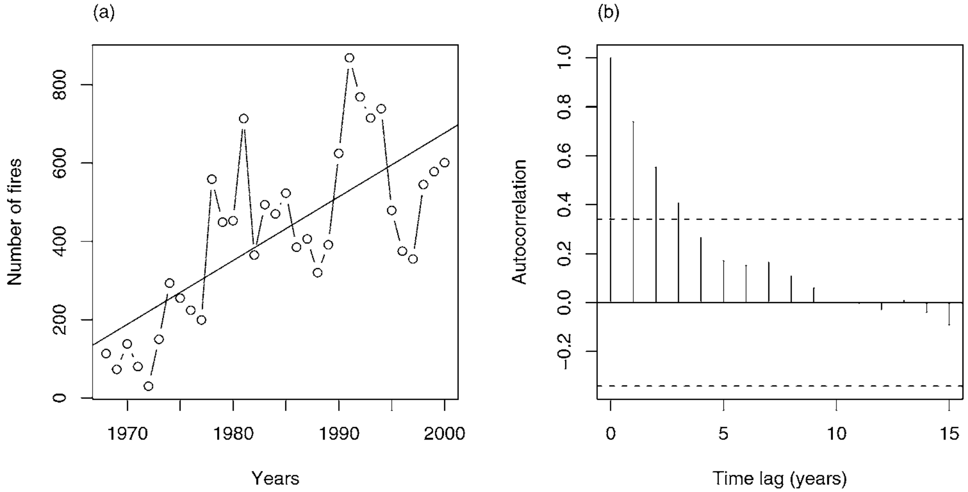

Figure 2. Annual number of fires in the Eastern Iberian Peninsula during the last three decades. (a) Changes with time ($F = 32.95$, $p < 0.0001$); (b) autocorrelation (dotted lines are the 95% confidence intervals).

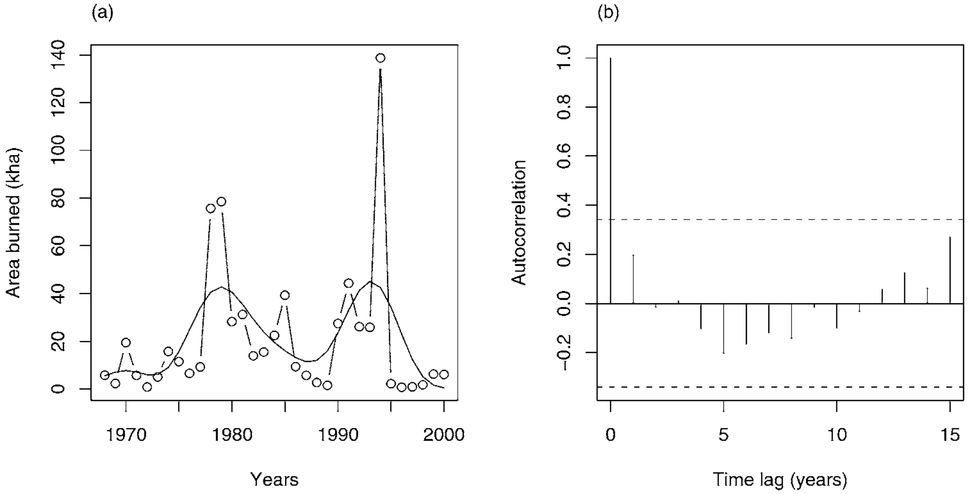

Figure 3. Annual burned area (1000 ha/year) in the Eastern Iberian Peninsula during the last three decades. (a) Changes with time, including a GAM smoothing line; (b) autocorrelation (dotted lines are the 95% confidence intervals).

Available historical data from 1874 for Valencia Province showed a strong increase in fire occurrence and area burned during the last century (Figure 4). However, the change was not continuous through time, but rather showed a sudden clear change in fire occurrence and area burned in the mid 1970s. The average annual number of fires and area burned during the period 1974–1998 was about 10 times higher than the values for the period 1874–1973.

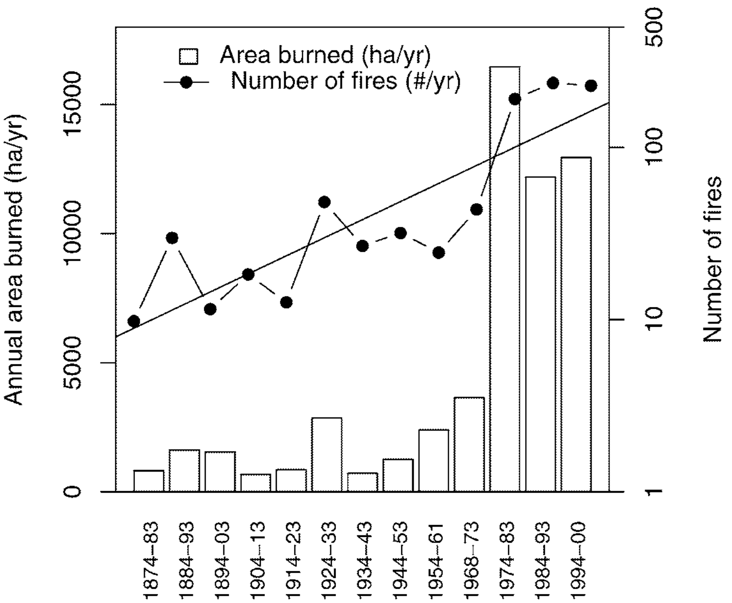

Figure 4. Average annual area burned (ha/year) and annual number of fires (log scale), from 1874 to 2000 by decades (except for three periods, 1954–61, 1968–73 and 1994–2000, in which information was available for the mentioned periods only). Elaborated from Fernández Muñoz (1999), Martínez Ruiz (1994) and Vélez (1996, 1997).

3.2. CLIMATIC DATA

On average (at the regional scale) total annual rainfall did not show a clear monotonic trend with time (Figure 5). Summer rainfall tended to decrease (Figure 5), 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 decrease summer rainfall, although most of them were not statistically significant (Table I). Neither total nor annual rainfall showed any significant autocorrelation pattern (not shown).

Annual temperature and summer temperature increased significantly with time (annual: $F = 47.8$, $p < 0.0001$, $R^2 = 0.50$; summer: $F = 13.9$, $p < 0.001$, $R^2 = 0.22$; Figure 5). On average, the increase in annual and summer temperature was 0.35 and 0.27 °C per decade respectively (Table I). At the local scale, a tendency to increase was observed in 72 and 73% of the stations; the increase was statistically significant for 47 and 40% of the total stations (respectively).

3.3. FIRE AND CLIMATE

The annual area burned was significantly related to regional annual rainfall ($F = 6.19$, $p = 0.019$) and more closely to summer rainfall ($F = 8.64$, $p = 0.006$; Figure 6a). In wet summers, the burned area tended to be small, while during dry

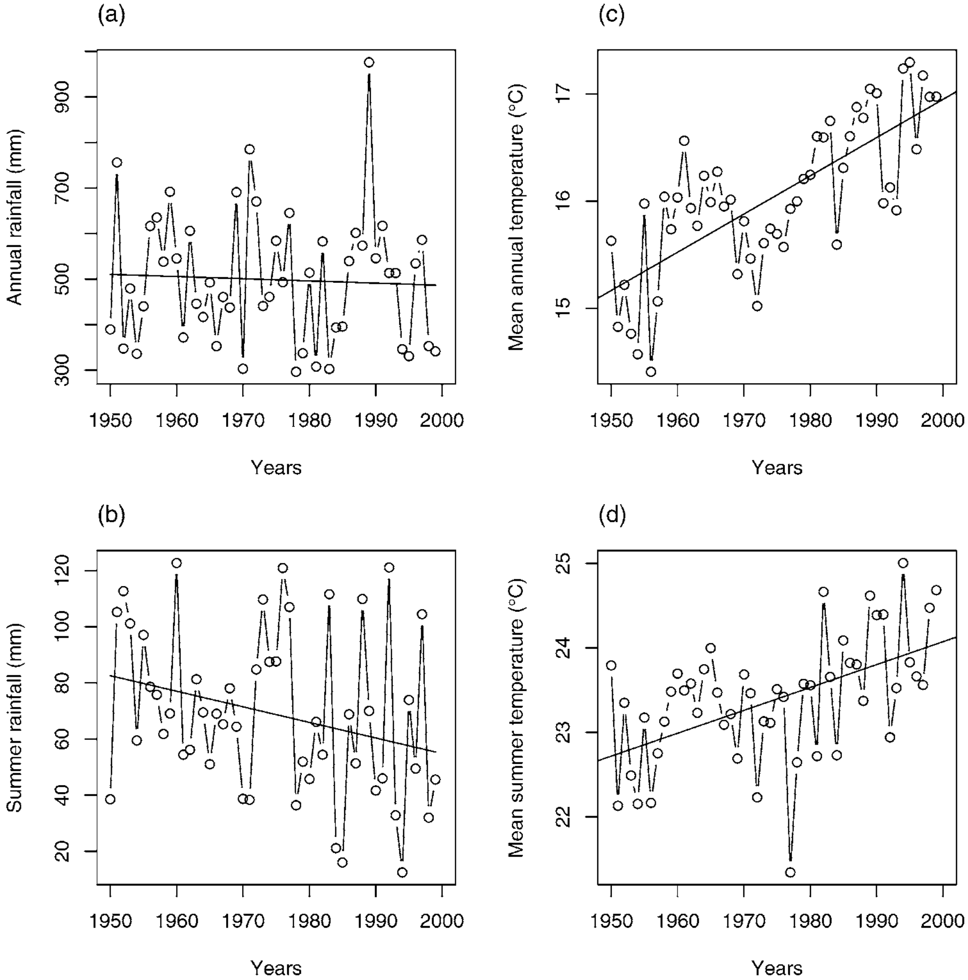

Figure 5. Changes in annual and summer rainfall (a and b) and in mean annual and summer temperature (c and d) during the last five decades. Changes for rainfall are not statistically significant and the line represents GAM smoothing function; changes in temperature are statistically significant (annual: $F = 47.8$, $p < 0.0001$, $R^2 = 0.50$; summer: $F = 13.9$, $p < 0.001$, $R^2 = 0.22$).

summers, the burned area could be either small or large. The relation remained significant even if we did not consider the year with the highest area burned (year 1994; area burned-summer rainfall: $F = 5.22$, $p = 0.029$). The number of fires also tended to decrease with summer rainfall although the relation was weaker ($F = 4.60$, $p = 0.04$).

The cross-correlation between annual area burned and summer rainfall show a significant negative cross-correlation at a time lag of 0 and a significant positive cross-correlation at a time lag of 2 (Figure 6b). This suggests, first, the simultaneous relation between low summer rainfall and high area burned and, second, a

Table I

Climatic and fire rate of change observed at regional scale (average change per decade of the parameters that show some trend; mean, standard deviation and *t*-test) and proportion of meteorological stations (local scale) with increasing and decreasing trend in the climatic parameters studied (in brackets the % of the total stations in which the trend is statistically significant at $p < 0.05$). *n*: number of Meteorological stations used in the analysis; *ns*: $p > 0.05$, ***: $p < 0.001$, ****: $p < 0.0001$

	n	Regional scale Average change per decade	*t*-test	Local scale % of stations	
				Decreasing	Increasing
Annual rainfall (mm)	322	No trend	–	57 (0)	42 (0)
Summer rainfall (mm)	350	–5.21 ± 3.00	*ns*	**70** (4.3)	30 (0)
Mean annual temperature (°C)	129	0.35 ± 0.05	****	27 (0)	**72** (47)
Summer temperature (°C)	154	0.27 ± 0.07	***	27 (0)	**73** (40)
Number of fires	–	163.1 ± 28.4	****	–	–
Area burned (ha)	–	No trend	–	–	–

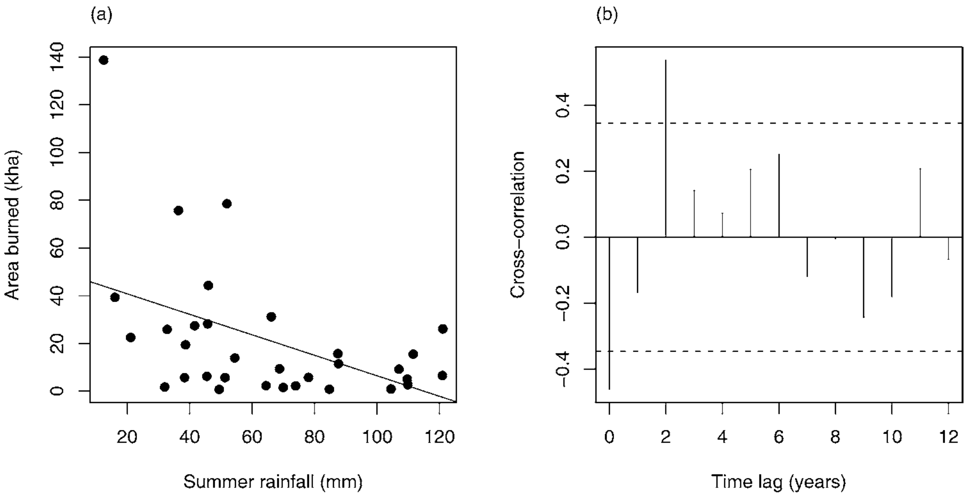

Figure 6. Relationship between annual area burned (1000 × ha) and summer rainfall (mm, computed as the mean of 350 meteorological stations distributed in the study area). (a) Regression analysis ($F = 8.6$, $p = 0.006$, $R^2 = 0.22$); (b) cross-correlation (dotted lines are the 95% confidence intervals) between area burned and summer rainfall.

positive relation between summer rainfall and area burned two years later. Consequently, the linear regression between area burned and summer rainfall in the second previous year was also highly significant ($F = 13.5$, $p < 0.001$).

4. Discussion

Despite the increase in fire prevention and suppression efforts during the last decades, the number of fires has continued to grow markedly. This process is seen in various parts of the European continent (Martínez-Ruiz, 1994; Martín et al., 1998; Moreno et al., 1998, UN, 1999; Figure 7) and the former Soviet Union (UN, 1999; Figure 7). Nevertheless, in the same period, the surface area affected by fire does not show a clear tendency for the last three decades, but rather a strong interannual 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 and Vallejo, 1999). The year with the highest fire impact ever recorded in the study area (and in the whole of Spain) was 1994, in which ca. 140000 ha burned in a few summer days (ca. 12% of the forest area). The previous peak (1978/79) burned 154000 ha in two consecutive fire seasons. The area burned does not show any autocorrelation (Figure 3b), that is, there is no correlation between the area burned in a year and the area burned in the following or previous years; however, there is a significant positive autocorrelation for the number of fires (Figure 2b). That is, a year with numerous fires is often followed by 2 or 3 years with a high number of fires, although the autocorrelation decreases with time (becoming insignificant by the fourth year).

During the last decades, fire detection in Spain has became very precise and all wildfires greater than 0.5 ha are detected and included in the annual database; thus, the statistics are quite robust. Nevertheless, uncertainty in the data from other areas (e.g., the former Soviet Union, Figure 7) may be quite high. As mentioned previously, the uncertainty of the historical fire records is also high; hence we have increased the number of fires and area burned to account for some missing information. The changes in fire regime are so strong, however, that even if we increased the fire data (occurrence or area burned) by an additional 25% or 50% (which would certainly be an overestimation), fire increase pattern would still be unambiguous (Figure 4).

Although there was no statistically significant linear trend, the smoothing function suggests that 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 rainfall makes this possible trend almost imperceptible at both local and regional scales. Amanatidis et al. (1993) also found a trend towards decreasing precipitation in Greece while Lebourgeois et al. (2001) observed a decrease in the number of rain days in France. Recently, Piervitali and Colacino (2003) showed a significant trend (–3.2 mm/year, 1951–1995) by integrating 69

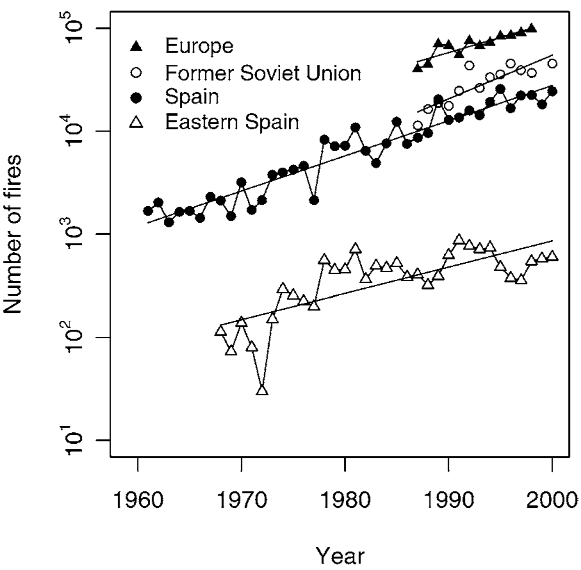

Figure 7. Comparison of the trends in the number of fires in eastern Spain, in the whole of Spain, in the whole of Europe and in the former Soviet Union during the last decades. Note the log scale of the y-axis. Data for Europe and former Soviet Union from UN (1999); data for Spain from Martínez-Ruiz (1994) and Vélez (1996, 1997).

meteorological stations in different countries of the central-western Mediterranean basin.

Furthermore, temperatures have clearly increased during the study period. At the regional scale, the average increase is about 0.35 °C per decade, which is similar to the change observed in France (mean of 0.40 °C per decade, Lebourgeois et al., 2001). Piñol et al. (1998) also found an increase in the maximum temperatures (but not in the minimum temperatures) during the 20th century in Roquetes (Catalonia, north of our study area, Figure 1), and Esteban-Parra et al. (2003) reported increasing trends for annual and seasonal temperature (except for spring), for the whole of Spain. Even if we considered that rainfall had not changed in the last five decades, the changes in temperature suggest an increase in evapotranspiration and so drier conditions for plants. In summary, there is evidence that summers have become warmer and drier over the last five decades. These changes imply a decrease in fuel moisture and a consequent increase in fire hazard (Piñol et al., 1998), which may partially explain the increase in the number of fires and area burned observed in the study period. If the climatic conditions became drier, fuel loads may also decrease, although the impact of lower but drier fuel loads on the future fire regime needs further research.

Summer rainfall (which largely determines the fuel moisture during the fire season) is an important factor for determining the amount of area burned. During the last three decades, fires occurring in dry years tended to affect larger areas than fires in wet years (Figure 6a). Rainfall (summer and total) do not show any autocorrelation, and thus wet-dry cycles were not observed in the studied period. However, rainfall (both summer and total) is cross-correlated with area burned with some delay (2 years), suggesting that high rainfall may increase fuel loads that burn 2 years later. A positive relationship between fire and high humidity in prior years has also been reported for other ecosystems (e.g., Grau and Veblen, 2000). In our data, rainfall and area burned are interrelated and each of these variables shows large interannual variability and low autocorrelations and thus, very low predictability. However, the fact that they are cross-correlated suggests that chances of a high fire season can be predicted from the rainfall of the previous years (Figure 6b).

The data suggest that if the current climatic trends remain constant, fuel conditions in summer will become drier each year and, as a consequence, the risk of large burned areas will increase. Future climatic scenarios based on global circulation models (GCM) also predict warmer summers and drier conditions for the Mediterranean Basin (due to increase in temperature and evapotranspiration), although there is no clear agreement in the predictions of future precipitation (Houghton et al., 2001). Likewise, the IPCC report predicted a probably increase in the wildfire risk in Mediterranean ecosystems. Increasing fire danger under changing climatic conditions has been predicted in many other ecosystems (e.g., Stocks et al., 1998; Williams et al., 2001). However, to predict the future fire regime, other factors are also important and show effects in different directions, such as the continuously increasing urban-wildland interface (which will favour fire ignitions), fuel management and increased prevention and suppression efforts.

Nevertheless, the sudden increase in fire occurrence and area burned during the mid 1970s (Figures 2 and 4) cannot be explained by climatic parameters alone, and socioeconomic causes need also to be considered (Vélez, 1993; Pausas, 1999b; Pausas and Vallejo, 1999). In Spain, during the 1960s, industrial development involved depopulation of rural areas, decreases in grazing pressure and wood gathering, and increases in the urbanisation of rural areas (LeHouérou, 1993). For example, the proportion of Spanish Gross Value Added from agriculture and forestry in the study area was reduced from 28.5% in 1960 to 4.3% in 1987 (Generalitat Valenciana, 1985, 1991). These changes are also reflected in the proportion of people dedicated to the different socioeconomic sectors (Figure 8). These changes in traditional land-uses and lifestyles have implied the abandonment of large areas of farm-land, which has led to an increase in accumulated fuel of early successional species in large parts of the Mediterranean landscapes (e.g., Rego, 1992), with large connectivity between the fuel beds. This increase in large and continuous fuel beds, together with the increase in population in the wildland/urban interface (and thus in fire ignitions, e.g., Keeley et al., 1999) and the increase in temperatures, may explain the sudden rise in burned areas during the 70s.

The results support the initial general hypothesis that although fire ignitions may be determined by human factors, some of the variability in the annual burned area is explained by climatic parameters.

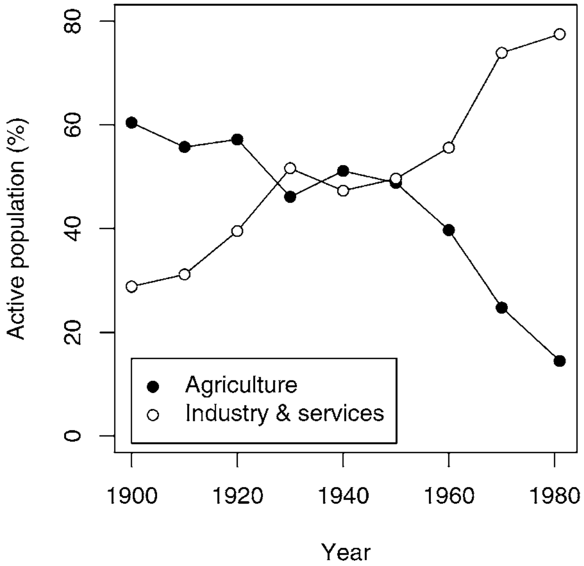

Figure 8. Changes in the proportion of the active population dedicated to agriculture and to industry and services, during the 20th century in Spain (elaborated from data in Paniagua 1992).

With the continuing tendency towards increasing the wildland-urban interface, land abandonment and summer drought, a rise in the fire hazard seems to be unavoidable. To what extent fuel and landscape management together with fire prevention and suppression can overcome this increasing fire hazard is yet to be shown, but strong emphasis on these policies is certainly required.

Acknowledgements

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