

# Socioeconomic Factors Drive Fire-Regime Variability in the Mediterranean Basin

Brahim Chergui,<sup>1</sup> Soumia Fahd,<sup>1</sup> Xavier Santos,<sup>2</sup> and Juli G. Pausas<sup>3\*</sup> 

<sup>1</sup>Laboratoire Ecologie, Biodiversité et Environnement, Faculté des Sciences de Tétouan, Université Abdelmalek Essaâdi, El M'Hannech, BP 2121, Tétouan, Morocco; <sup>2</sup>CIBIO/InBIO (Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto), R. Padre Armando Quintas, 4485-661 Vairão, Portugal; <sup>3</sup>CIDE-CSIC, Campus IVIA, CV-315, Km 10.7, 46113 Montcada, Valencia, Spain

## ABSTRACT

In recent decades, fires in Mediterranean Europe have become larger and more frequent. This trend has been driven by socioeconomic changes that have generated rural depopulation and changes in traditional land use. Within the Mediterranean Basin, the most contrasting socioeconomic conditions are found by comparing southern European with North African countries, and thus our hypothesis is that this difference generates contrasting fire regimes between the two regions. Specifically, we predict that current fire regimes in Mediterranean Africa resemble past fire regimes in the Mediterranean Europe when rural activities dominated the landscape. To test our hypothesis, we compared fire statistics from the western Rif (northern Morocco, 1988–2015) and from Valencia (eastern Spain, 1880–2014). The results suggest that the Rif has a typical Mediterranean fire regime with fires occurring in the hot, dry summer season. However, fires are very small and the annual pro-

portion of burnt area is very low, compared to the current regime in Valencia (post-1970s). The current Rif fire size class distribution matches the fire regime in Valencia prior to the 1970s before the collapse of the rural population and when fires were fuel-limited. The shift in the recent decades in fire regime observed in different countries of the Mediterranean Europe (from small, fuel-limited fires to drought-driven fires) can be identified when moving from the southern to the northern rim of the basin. That is, most spatial and temporal variability in fire regimes of the Mediterranean Basin is driven by shifts in the amounts of fuel and continuity imposed by changes in socioeconomic drivers.

**Key words:** Western Mediterranean; Fire regime; Fire and climate; Fuel amount; Rural abandonment; Area burnt; Socioeconomic drivers; Land-use changes; Morocco; Spain.

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\*Corresponding author; e-mail: juli.g.pausas@uv.es; URL: <http://www.uv.es/jgpausas/>

## INTRODUCTION

The diversity of fire regimes, that is, the combinations of frequency, intensity, seasonality, and fire spread pattern, is one of the most important factors determining the structure of the landscape in many ecosystems (Bond and others 2005; Keeley and others 2012; Pausas and Ribeiro 2013). Fire regimes, however, can change. Historically, shifts in fire regimes were related mainly to changes in

atmospheric O<sub>2</sub> concentration, climate oscillation, and abrupt herbivore extinctions (McKenzie and others 2004; Gil and others 2009; Pausas and Keeley 2009, 2014). More recently, shifts in human activities have been interacting with climate to alter fire regimes (Marlon and others 2008; Bowman and others 2011). Human activities have changed ignition patterns (Keeley 2002; Keeley and others 2012), and anthropogenic climate changes have increased the conditions conducive to fire and thus modified fire frequency and fire seasonality (Piñol and others 1998; Kasischke and Turetsky 2006; Swetnam 1993; Westerling and others 2006; Pezzatti and others 2013). However, the most important human shifts in relation to fire are fuel amount and structure, and these are driven by land-use and land management changes (Covington and Moore 1994; Dubinin and others 2011; Pausas and Fernández-Muñoz 2012; Moreira and Russo 2007; Pausas and Keeley 2014).

The Mediterranean Basin (defined here as the region around the Mediterranean Sea with a Mediterranean-type climate) has an annual dry and warm period (summer) when intense crown fires are frequent (Pausas and Vallejo 1999; Pausas 2004; Keeley and others 2012). In such ecosystems, fire controls the age and structure of the vegetation, as well as the composition of species (Verdú and Pausas 2007), that is, vegetation depends not only on climate, but also on the fire regime (Traubaud 1996; Keeley and others 2012), and human activities have strongly modulated fire regimes across the Mediterranean Basin (Pausas and Vallejo 1999; Keeley and others 2012). The first evidence of fire-regime changes induced by humans in the Mediterranean Basin dates to the Neolithic (Naveh 1975). Since then, the Mediterranean has witnessed the evolution of many cultures, some with high population densities that have altered fire regimes in different directions (Keeley and others 2012). There is overwhelming evidence that the main driver for recent fire activity in Mediterranean Europe is associated with land-use changes and ultimately socioeconomic changes (Pausas 2004; Moreira and others 2011; Pausas and Paula 2012; Salis and others 2013). Rural depopulation and consequent land abandonment, together with reforestation projects, have caused an increase in the amount and connectivity of fuels, and this switched fire regimes from fuel-limited (during the dominance of rural lifestyles) to the current drought-driven fire regimes (that is, large fires driven by droughts; Pausas and Fernández-Muñoz 2012). However, because the socioeconomic levels are not homogeneous throughout the Mediter-

anean Basin (Zohry 2005), land use and fire regimes are expected to covary across the region. The most contrasting socioeconomic difference within the Mediterranean Basin lies between European and North African rim of the basin (Mairota and others 1998). Mediterranean Europe is strongly industrialized, and rural depopulation has increased the amount of landscape fuel and connectivity, whereas Mediterranean North Africa has a lower level of industrial activity and higher rural population densities. Agricultural activities, wood gathering, and especially overgrazing (mainly by goats and sheep) in many North African landscapes (Taiqui and Martin 1997) are drastically reducing fuel amounts and potentially influencing the fire regime. We therefore expect a strong spatial variability in fire regime within the biogeographic region of the Mediterranean Basin.

Unfortunately, little is known about fire regimes in North Africa, partially because of the paucity of fire statistics (but see Meddour-Sahar and others 2013b; Mharzi Alaoui and others 2015). Our hypothesis is that current fire regimes in Mediterranean Africa resemble past fire regimes in the Mediterranean Europe when rural activities dominated the landscape. If this is true, then we would have clues for predicting future fire regimes in North Africa, based on trends in southern Europe, and for understanding past fire regimes in Europe based on the current situation in North Africa. Specifically it would provide independent evidence for the role of socioeconomic factors in fire regime across the Mediterranean Basin ecosystems. Alternatively, similarity in current fire activity between the Mediterranean Europe and Mediterranean Africa would indicate that other factors such as climate were more important drivers of fire regimes than socioeconomic (and fuel) changes.

To test our hypothesis, we first studied the current fire regimes in the western Rif (northern Morocco in North Africa; hereafter, the Rif) and then we made a comparison with historical and current fire activity in the province of Valencia (Spain in southern Europe) where fire statistics are available from the end of the nineteenth century (Pausas and Fernández-Muñoz 2012). In Valencia, fire regimes shifted around the 1970s, and thus, we compared the fire regime of the Rif with the Valencia fire regime before the 1970s (when agriculture and livestock were the main economic activities in Spain), and after 1970s (when rural areas lost population as a consequence of the people moving to the secondary and tertiary sector) (Pausas and Fernández-Muñoz 2012). The Rif and Valencia lie in the same biogeographic region,

share climate and vegetation types (Mediterranean), but differ strongly in their socioeconomic dynamics, thus providing an excellent model to test the sensitivity of fire regimes to different socioeconomic frameworks.

## METHODS

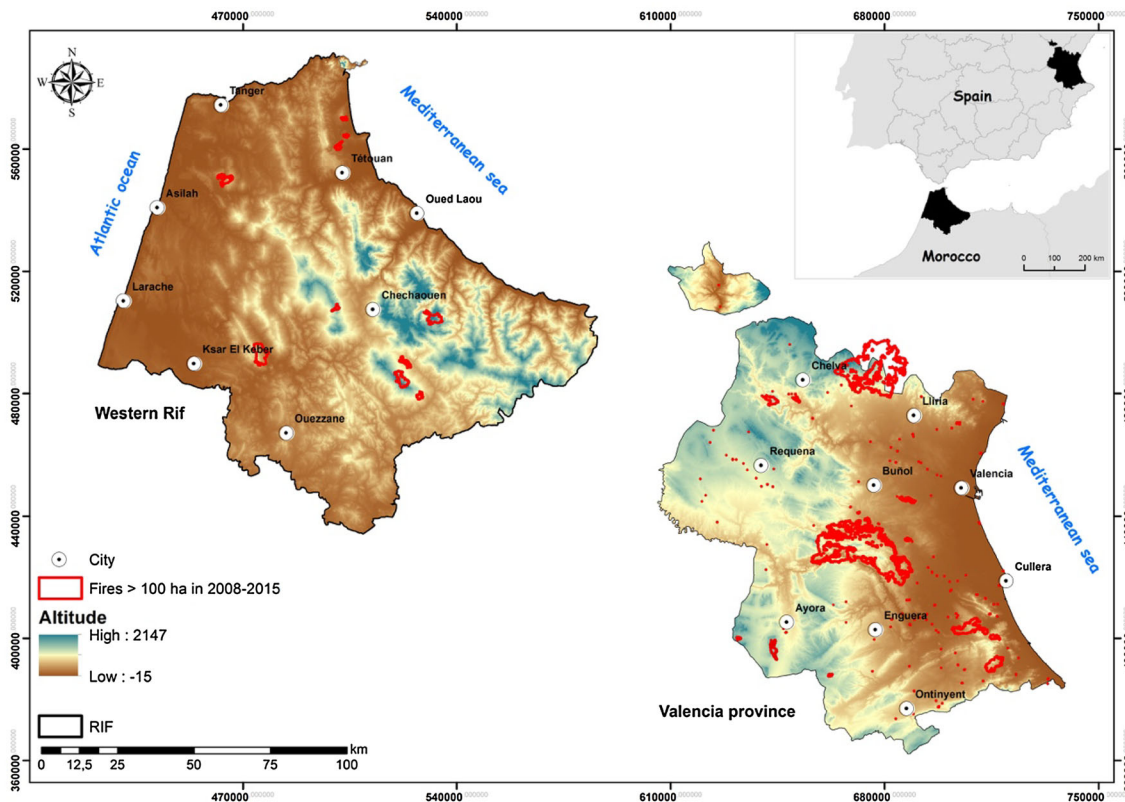
### Study Areas

The Rif stretches across part of northern Morocco, with the Atlantic Ocean to the west, the Mediterranean Sea to the east, and the Strait of Gibraltar to the north (Fig. 1). The climate is mainly Mediterranean (Table 1) with a mean annual temperature ranging from 15–19°C (Ajbilou 2001) and an annual rainfall that can reach 2000 mm (average values in Table 1). A clear altitudinal gradient in the Rif, from the coast and valleys to uplands (the maximum altitude is 2159 m at Jbel Lakraa), defines different bioclimatic zones (Quézel and Médail 2003): the thermo-Mediterranean zone (widespread, from 0 to 900 m; with temperature of the coldest month between 3 and 7°C), the meso-Mediterranean zone (between 900 and 1450 m; mean temperature of the coldest month between 0

and 3°C), the supra-Mediterranean zone (between 1450 and 1800 m; mean temperature of the coldest month between 0 and –3°C), and a small zone over 1800 m (mean temperature of the coldest month of the year –3 and –7°C).

The province of Valencia, in eastern Spain, is bordered by the Mediterranean Sea on the east (Figure 1). The climate is typically Mediterranean with mild winters and warm dry summers. A clear altitudinal gradient, from sea level to 1837 m (Pico Calderón), results in different bioclimatic zones: the thermo-Mediterranean zone (see above for the definition based on the temperature of the coldest month) along the coast, the meso-Mediterranean zone inland, and a small supra-Mediterranean area further inland in the north-western mountains. Most of the area is dry (annual precipitation from 350 to 600 mm) and sub-humid (from 600 to 1000 mm) (Table 1).

The population density of the two areas is similar (Table 1) but with sharply different in distribution. In the Rif, 37% of the population live in rural areas and small towns (Mikesell 1960; Taiqui and Martin 1997; Figure S1 in Supporting Information); forests are heavily exploited for timber and fuel by a dense



**Figure 1.** Location of the two study areas in the Rif and Valencia (*right top corner*), and their topography, with fires larger than 100 ha during the period 2008–2015.

**Table 1.** Summary of the Geographic, Climatic, and Socioeconomic Variables for the Two Study Areas.

	Western Rif	Valencia
<b>Geography</b>		
Latitude (range)	35.84/34.54	39.98/38.69
Longitude (range)	-5.58/-5.25	-1.13/-0.60
Size (km <sup>2</sup> )	12,650	10,763
Wildland area (%)	35	53
<b>Climate</b>		
Mean annual temperature ( <i>n</i> = stations)	18.44 ( <i>n</i> = 6)	16.2 ( <i>n</i> = 94)
Total annual precipitation ( <i>n</i> = stations)	639 ( <i>n</i> = 30)	532 ( <i>n</i> = 56)
Summer precipitation (%)	1.8	19
<b>Demography and socioeconomic</b>		
Total current population	3,157,075	2,566,474
Population density (inhabitants/ha)	2.50	2.38
Rural population (% , year)	44 (1994) 37 (2014)	50 (1950) 6.1 (2001)
Rural population density (inhab./ha)	0.92 (2014)	0.15 (2001)
Employment (%) by sector (primary, secondary and services) in 2013	44 22.5 33.5	3.5 22.9 73.6
Gross Domestic Product (%) by sector (primary, secondary and services) in 2013	12.2 34.1 53.7	2.1 27.8 70.1

Average values of climatic variables are based on a number of meteorological stations (in brackets). Sources for the socioeconomic data: [www.hcp.ma](http://www.hcp.ma), [www.pegv.gva.es](http://www.pegv.gva.es), Pausas and Fernández-Muñoz (2012).

rural population and are grazed by goats, cows, and sheep (with some 200,000 goats, 216,000 sheep, and 105,000 cows; Ajbilou 2001). In Valencia, the current rural population is 6.5% (2001) despite being 50% in 1950 and 70% in 1900 (Pausas and Fernández-Muñoz 2012); and currently, sheep, goats, and cows are rare and raised and fed mainly inside farms, with very little open grazing. This is reflected in the statistics by socioeconomic sector: most people in Valencia work in the service sectors, whereas most people in the Rif work in the primary sector (Table 1).

The vegetation of the two areas is dominated by Mediterranean evergreen forests and shrubland. In the Rif, cork oak (*Quercus suber*) forests and shrublands are the dominant formations, followed by holm oak (*Quercus ilex*) and maritime pine (*Pinus pinaster*) forests. Vegetation in Valencia is dominated by Aleppo pine (*Pinus halepensis*) with some holm oak woodlands, and a diversity of shrublands; cork oak and maritime pine are also present but uncommon.

### Forest Fire Database for the Western Rif

The Rif is the region with the highest fire incidence in Morocco (Schmuck and others 2012). To characterize the fire regime of the western Rif, we used two different data sets differing in data quality and

temporal window. (1) Information about the annual area burnt and number of fires from 1988 to 2015, taken from the *Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification* (hereafter the HCEFLCD), the *École Nationale Forestière d'Ingénieurs* (hereafter ENFI), and from Mharzi Alaoui and others (2015). (2) For the period 2008–2015, the available data are much more detailed and include the specific dates, coordinates of the ignition point, and size of all recorded fires (Figure S2). This data set was acquired from the HCEFLCD plus grey information from historic documents and reports, dossiers on fires, and local newspapers. Coordinates of all ignition points for the period 2008–2015 were intersected with four ecogeographical variables (mean annual rainfall, average maximum temperature, bioclimatic type, and land-use type) using GIS tools (ArcView version 10.0; ESRI, Redlands, CA, USA). Climatic variables (mean annual rainfall and average maximum temperature) were taken from the Climatology Resource for Agroclimatology (<https://power.larc.nasa.gov/cgi-bin/agro.cgi>), whereas the land-use distribution was determined from the National Forest Inventory. The initial land-use classification was reclassified into eight land-use classes as follows: natural forests (four types: *Quercus suber*, *Quercus rotundifolia*, *Pinus pinaster*, and other natural forests); shrublands;

**Table 2.** Summary of the Trends (Expressed as Slope of the Regression, with Their SE and *P* value) in Number of Fires, Area Burnt, and Climate for the Rif (1988–2015) and Valencia (post-70's).

X	Y	Western Rif	Valencia
Time	Area burnt	$-2.60 \pm 37.8$ (n.s.)	$+0.59 \pm 0.8$ (n.s.)
Time	Number of fires	$+3.33 \pm 1.4$ (0.026)	$+10.0 \pm 4.1$ (0.02)
Time	Annual P	$-7.17 \pm 5.7$ (n.s.)	$-0.56 \pm 4.4$ (n.s.)
Time	Summer P	$-0.33 \pm 0.3$ (n.s.)	$-0.52 \pm 0.3$ (n.s.)
Time	Annual T	$+0.07 \pm 0.01$ (<0.0001)	$+0.035 \pm 0.01$ (0.0007)
Time	Summer T	$+0.12 \pm 0.02$ (<0.0001)	$+0.05 \pm 0.02$ (0.01)
Annual P	Area burnt	$-2.43 \pm 1.2$ (0.05)	$-0.08 \pm 0.04$ (0.03)
Summer P	Area burnt	$-3.86 \pm 20.2$ (n.s.)	$-0.46 \pm 0.17$ (0.01)
Annual T	Area burnt	$+30.55 \pm 433$ (n.s.)	$-2.3 \pm 12.5$ (ns)

*Y* and *X* refer to the dependent and the independent variable of the regression. *P* precipitation; *T* temperature (mean maximum for Rif, and mean annual for Valencia). Valencia information from Pausas (2004); more details for the Rif in the Supplementary Material (S4–S7). n.s. indicates a non-significant slope.

coniferous plantations (especially *P. pinaster*); other monocultures; and non-forested land uses (agricultural fields and urbanized areas). Four bioclimatic types are represented in the study area, namely perhumid, humid, semi-humid, and semi-arid (Benabid 1982; Mharzi Alaoui and others 2015; Figure S2).

## Data Analyses

For the Rif, we first tested whether there was any trend in the fire history during the study period using annual fire data (burnt area and number of fires), and whether the temporal variability in annual fires was linked to climate variability (mean annual rainfall and average maximum temperature). We also tested the spatial distribution of fires in relation to the bioclimate and land-use types using the Chi-squared test with the expected frequencies under a null model (that is, the fire activity was similar in each bioclimate and land-use type).

For Valencia, we considered the number of fires and burnt area for the period 1880–2014 from an updated version (8 years added) of the fire data in Pausas and Fernández-Muñoz (2012). Because of a significant fire-regime shift during the 1970s, we split the Valencia data into two periods: 1880–1970 (pre-1970s; fuel-limited fire regime) and 1975–2014 (post-1970s; drought-driven fire regime). The comparison of fire regimes between the Rif and both periods in Valencia was conducted under the hypothesis that the Rif fire regime should resemble that of Valencia in the pre-1970s. Because detailed fire statistics for the Rif were available for only eight years, we also used eight years (randomly selected) for Valencia and for each period (pre- and post-1970s). This random selection was performed

20 times to estimate the variability of fire activity in Valencia. Differences between the Rif and Valencia were assessed by looking at whether the Rif data fall within the interval of variability of the Valencia data for each period.

## RESULTS

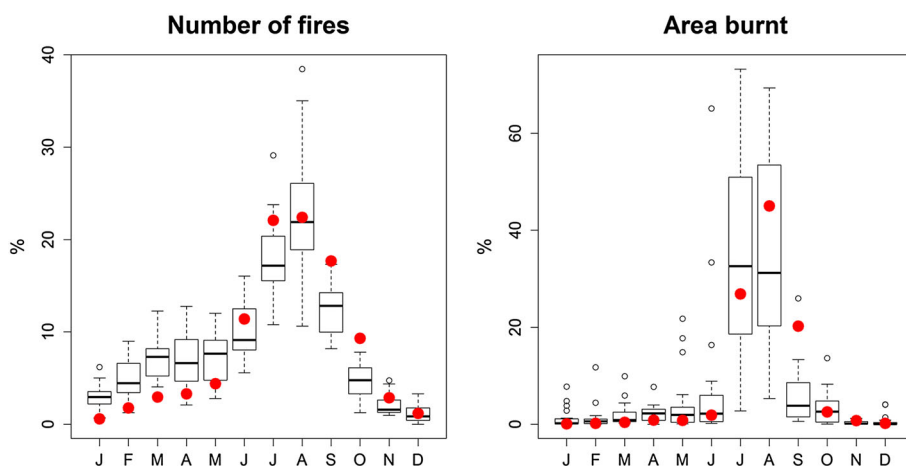
### Fire Regime in the Western Rif

During the period 1988–2015, 3803 fires burned a total of 41,641 ha (3.29% of the total area of the western Rif). On average, 136 fires burned 1487 ha yearly, although fire activity exhibited considerable yearly variation (Figure S3). The number of fires increased during the 1988–2015 period, whereas no temporal pattern was found with the total burnt area (Table 2, Figure S4). For the same period, the average maximum temperature significantly increased from around 22–24°C, and the annual rainfall tended to decrease, although the correlation was not significant due to the strong interannual variability (Table 2, Figure S4). Consequently, the number of annual fires recorded in the Rif increased with the average maximum temperature and decreased with annual rainfall (Table 2, Figure S5). The annual area burnt was not related to the average maximum temperature, but significantly diminished with the annual rainfall (Table 2, Figure S5).

During the period 2008–2015, 1182 fires burned approximately 7443 ha. This represents 0.6% of the total study area, or 1.9% of the vegetated area (including natural vegetation and monocultures). The number of fires was strongly biased towards small fires, with only one fire larger than 1000 ha (Sidi BouHaja, 1480 ha; Table 3). Most fires (73.6%) and most (94%) of the burnt area occurred during the hottest period, from June to

**Table 3.** Number of Fires and Area Burnt for Each Fire Size Class in the Western Rif for the Period 2008–2015.

Fire size class (ha)	Number of fires	% of fires	Area burnt (ha)	% of area burnt
0–1	833	70	244	3
1–10	287	24	894	12
10–100	49	4	1606	22
100–1000	12	1	3219	43
> 1000	1	0	1480	20

**Figure 2.** Monthly proportion of fires (*left*) and area burnt (*right*) in Valencia (*boxes*) and in the western Rif (*red symbol*). Boxes show the variability of 20 randomly chosen 8 years in Valencia (1880–2014), and symbols the 8 years of available data in the Rif (2008–2015).

September, and especially in July and August (Fig. 2; Figure S6).

Most of the burnt area during the period 2008–2015 belonged to only two land-use types (Table 4), namely natural forests of cork oak *Quercus suber* (39.9%) and coniferous plantations (45.9%). Both land-use types are among the commonest land-use types in the western Rif (Figure S7). Excluding the non-forested area, the proportion of burnt area significantly differed from the expectation based on the extension of each land-use type (Table 4) in such a way that coniferous plantations were burnt more frequently than expected by chance (highest residuals), followed by cork oak forest. Shrubland burned less than expected (lowest residuals, Table 4). Similarly, the burnt area differed among bioclimates, with perhumid and humid zones more burnt than expected by their areas (high residuals), and sub-humid zones less burnt than expected (low residuals, Table 4).

### Comparison with the Valencia Region

The seasonal distribution of fires was very similar between Rif and Valencia and concentrated in the hottest and driest period from July to September (Fig. 2). These two regions also showed a similar trend in annual climate changes: a significant in-

crease in the average annual temperature, and a slight decline in rainfall (but not significant due to the high interannual variability; Table 2). These figures suggest that the two regions share similar climate dynamics. In both regions, the burnt area was negatively related to precipitation, although this relation was especially weak in the Rif (Table 2).

Regarding the distribution of fire size classes, fire data on the Rif fall within the interval of variability of the pre-1970s in Valencia—but not within the range of the post-1970s fire regime (Fig. 3). Hence, the current fire regime in the Rif resembles that of Valencia in the period when fires were smaller and fuel-limited (prior to the 1970s).

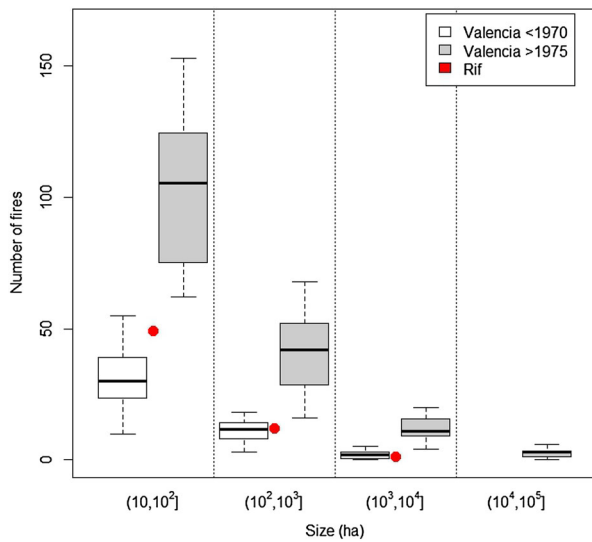
### DISCUSSION

Like other Mediterranean climate regions, the Rif is characterized by frequent fires concentrated in the hottest and driest period of the year. Moreover, the region shows a trend of rising temperatures and a weak tendency of diminishing in rainfall during the recent decades; this follows the climate patterns observed in other regions of the Mediterranean Basin (Pausas 2004; Mariotti and others 2008; Lelieveld and others 2012). The recent increase in the number of fires in the Rif (Figure S4) is also similar

**Table 4.** Total Extent and Area Burnt of Each Land-Use and Bioclimatic Type on the Western Rif for the Period 2008–2015.

Classes	Area		Number of fires	Area burnt		residuals
	ha	%		ha	%	
<b>Land-use types</b>						
<i>Pinus pinaster</i>	8200	0.7	9	21	0.26	−10.75
<i>Quercus suber</i>	114,670	9.2	195	2965	2.59	21.42
<i>Quercus rotundifolia</i>	24,200	1.9	42	396	1.64	2.61
Other natural forests	23,985	1.9	50	91	0.38	−17.33
Scrubland	163,524	13.2	155	418	0.26	−61.92
Coniferous plantations	49,124	4.0	565	3415	6.95	88.46
Other monocultures	14,462	1.2	87	92	0.64	−10.98
Non-forested	844,335	68.0	79	41	0.005	
<b>Bioclimatic type</b>						
Perhumid	150,301	7.3	203	1287	0.86	32.89
Humid	597,879	29.2	643	3638	0.61	37.29
Sub-humid	1,223,461	59.8	276	2141	0.17	−54.60
Semi-arid	74,360	3.6	60	377	0.51	6.59

For each type, the extent in hectares (ha) and the percentage (%) are included. Standardized residuals of the Chi-squared test for the distribution of area burnt in the different land uses ( $\chi^2 = 9958$ ,  $df = 6$ ,  $P < 0.0001$ ) and bioclimatic types ( $\chi^2 = 3227$ ,  $df = 3$ ,  $P < 0.0001$ ) are included.



**Figure 3.** Fire size distribution in Valencia, for the period 1880–1970 (white boxes) and for the period 1975–2014 (grey boxes), and in the western Rif (red symbols, 2008–2015). Boxes show the variability of 20 randomly chosen 8 years in Valencia for each period, and symbols (dots) show the 8 years of available data in the Rif. The cumulative form of this figure is shown in Figure S8.

to what is occurring elsewhere in the Mediterranean Basin (Pausas 2004; Gouveia and others 2016) and is likely to be driven by the growing human population (for example, from 150 to 215 inhabitants/Km<sup>2</sup> from 1994 to 2010 in the Chechouen valley; RGP 2005; Taiqui 2005). For

instance, new roads in the Rif are enabling access to remote areas where people burn forest areas to clear land for cannabis cultivation (Gatchui and others 2014). Despite the recent increase in the number of forest fires in the Rif (Table 2, Figure S3, S4), the annual burnt area in this region (on average, 0.210% of the forest land for 2008–2015; 0.336% for 1988–2015) is still low compared with climatically similar regions of the European rim of the basin (for example, González and Pukkala 2007; Mateus and Fernandes 2014; Koutsias and others 2012; San-Miguel-Ayanz and others 2013). In fact, fires in the Rif region are smaller than fires in Valencia (Mediterranean Europe; Fig. 3) and match better with the fire regime in European Mediterranean countries during the period in which the rural population was large (for example pre-1970s in Spain; Pausas and Fernández-Muñoz 2012). This suggests that fire regimes in the Rif are fuel-limited and climate is less relevant. Although the Rif has similar population density to some European regions, the socioeconomic trends and human spatial distribution is very different: in the Rif the population is highly rural with many livestock and fuel gathering activities (Taiqui 2005), rural landscapes in southern Europe have been dramatically depopulated in recent decades, and people have concentrated in cities and engaged in urban activities (Preiss and others 1997; Pinilla and others 2008; Pausas and Fernández-Muñoz 2012). This rural depopulation caused a shift in the fire

regime due to land abandonment and the greater amount and connectivity of fuel in the landscape (Pausas and Fernández-Muñoz 2012; Pausas 2004). Because the rural depopulation was so drastic that it has had consequences for the landscape, this demographic shift has been called it a *collapse* of the rural lifestyle (Pausas and Keeley 2014). Our results suggest that the fire-regime shift observed over time in the European rim (Pausas and Fernández-Muñoz 2012) mirrors the spatial variation now observed between the two rims of the Mediterranean Basin. This does not mean that fires in the Rif are independent of fuel, that is, different land covers have differing flammability, and when fires do occur in the Rif, they tend to be more concentrated in coniferous plantations and cork oak woodlands, and less in shrubland (which tends to be overgrazed). In Morocco, coniferous plantations are predominantly *Pinus pinaster* (Destremau 1974; Destremau and others 1976; Pastuszka and Sabay 1997), a highly flammable pine species (Shakesby and others 1996; Bremer and Farley 2010). Cork oak forests grow on poor soil and have a heathy flammable understory, which the locals tend let burn to transform the land for agriculture or grazing (including the expanding cannabis cultivation; Pastor-López and others 1997; Lara and others 2015). This is driving a severe reduction in these forests (for example, in the Ketama region the forested area shrunk from around 8000 ha in 1984 to only about 500 ha in 1990; Benabid 2000; Figure S9). Overgrazing and land transformation to production systems are no longer the dominant processes in Mediterranean Europe.

Overall, there is evidence that the current fire-regime differences between the Rif and Valencia are driven by contrasting socioeconomic conditions (that is, very different rural and urban population densities; Table 1). However, the two regions do not have identical climate, and thus, we cannot rule out that some differences are due to differing environmental conditions. For instance, the Rif is slightly more southerly (warmer) than Valencia and has less summer rainfall (which could limit fuel and fire size); however, the Rif has some Atlantic influence with wetter winters and higher annual rainfall than Valencia. Thus, it is not easy to predict the differences between Valencia and Rif in water availability for vegetation during the fire season. In addition, fires are biased towards relatively moister regions of the Rif (Table 4; Benabid 2000), suggesting that fire size is unlikely to be limited by aridity. That is, despite climate exerting some influence on the fire regimes (for example, a weak effect in the temporal variability; Figure S5),

the main driver limiting fire size and area burnt is fuel, and thus, current fire regimes are more fuel-limited than drought-driven.

On the basis of the experience from the European rim, we could attempt to predict fire-regime shifts for the southern rim (space-for-time substitution; Pickett 1989). Tourism is likely to expand in northern Africa, and the construction industry will grow along the coast (Belghazi 2014). This will have consequences for coastal biodiversity and will also encourage the human displacement from rural to coastal areas. Consequently, the rural lifestyle could collapse, as happened in European regions, with the consequent accumulation of fuels inland (increasing amount and continuity) and the abrupt rise of an era of megafires (Pausas and Fernández-Muñoz 2012; Tedim and others 2013; Gouveia and others 2016). We cannot easily make a forecast concerning when this will happen, as this process has occurred in many places but at different times depending of socioeconomic dynamics. For instance, the shift from fuel-limited to drought-driven fire regimes occurred in the 1970s in Spain (Pausas and Fernández-Muñoz 2012), in the 1980s in Greece (Stamou and others 2016), and in the 1990s in the former Soviet Union (Dubinin and others 2011). Rural population density in the Rif is currently of 0.92 inhab./ha, and a collapse can be estimated to occur before decreasing to 0.6 inhab./ha (Pausas and Fernández-Muñoz 2012). Thus, monitoring rural populations might provide an early warning as the fire-regime shift will follow a few years after the collapse of the rural population (Pausas and Fernández-Muñoz 2012). In fact, the depopulation of rural areas has already started in some North African regions such as in Algeria (driven by security problems), and in parallel, fuel and fire activity are now on the rise (Bessaoud 2006; Delenda 2012).

Overall, temporal and spatial variability in fire regimes across the Mediterranean Basin is strongly influenced by the human factor, which is determined by local socioeconomics (Bowman and others 2011; Pausas and Keeley 2014; Seijo and others 2017). This is because in highly populated regions such as the Mediterranean Basin, human activities directly affect ignition patterns, the amount and continuity of vegetation (fuels), and the fire suppression efforts (Vega-García and Chuvieco 2006; Loepfe and others 2010; Pausas and Paula 2012). Climate is also important, but especially when fuels are not limiting fires (for example, Pausas and Fernández-Muñoz 2012; Gouveia and others 2016). Current socioeconomic and climatic changes point to an increasing role for climate in



the future, as rural populations continue to fall in the Mediterranean Basin while climate warms. The strong dependence on fuels, however, also implies that management could potentially shape fire regimes.

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