

LANDSCAPE-BASED FIRE SCENARIOS AND FIRE TYPES IN THE AYLLÓN MASSIF (CENTRAL MOUNTAIN RANGE, SPAIN), 19TH AND 20TH CENTURIES

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ABSTRACT. Wildfires have been a major landscape disturbance factor throughout history in inland mountain areas of Spain. This paper aims to understand the interaction of fire regimes and landscape dynamics during the last two centuries within a socio-spatial context. The study area selected for this historical and spatial analysis is the Ayllón massif, in the Central Mountain Range. The theoretical background used to identify the driving forces of fire regime changes over the 19th and 20th centuries in this mountain area includes landscape-based fire scenarios and fire-type concepts. Both concepts have been addressed in recent studies from a spatial planning and fire management approach in an attempt to understand current fire landscapes and wildfire risk. However, this is the first time that these concepts have been applied to show that both spatial and temporal scales are crucial for an understanding of the current wildfire panorama, and that fire history related to landscape dynamics is fundamental in socio-spatial differences in fire regimes.

Four variables (fire history, land use, population and settlement system, and forest management) were assessed to define historical landscape-based fire scenarios, and three fire feature variables (fire extent, fire cause, and spatial distribution pattern) were considered to define historical fire-types. We found that the non-linear evolution of fire regimes during the 19th and 20th centuries was determined by fire-type changes according to landscape dynamics. Moreover, population and forest management have been the main driving forces of fire regime tipping points or pyrotransitions. This study validates the hypothesis that fire regime changes are the result of the interaction of fire history and landscape dynamics.

Escenarios territoriales del fuego e incendios-tipo en el macizo de Ayllón (Sistema Central, España), siglos XIX y XX

RESUMEN. Los incendios forestales han sido históricamente uno de los principales factores de transformación del paisaje en las regiones montañosas del interior de España. El objetivo de este artículo es explicar la interacción que se ha establecido a lo largo de los últimos dos siglos entre el régimen de incendios y las dinámicas del paisaje, en su contexto territorial. El área de estudio seleccionada para llevar a cabo este estudio ha sido el Macizo de Ayllón, en el Sistema Central. Los escenarios territoriales del fuego y los incendios-tipo son los dos conceptos básicos del marco teórico empleado para identificar las fuerzas motrices de los cambios del régimen de incendios acontecidos durante los siglos XIX y XX en esta región montañosa. Ambos conceptos han sido recientemente manejados en la investigación sobre ordenación del territorio y gestión del fuego para explicar los paisajes y el riesgo de incendios. Sin embargo, es la primera vez que se aplican para demostrar la influencia de las escalas espacial y temporal en la definición del problema de los incendios forestales y para poner de manifiesto que la dialéctica histórica fuego-paisaje es fundamental para comprender las diferencias socio-espaciales del régimen de incendios en la actualidad. La valoración histórica de los escenarios territoriales del fuego se

ha apoyado en el análisis de cuatro variables (historia del fuego, uso del suelo, población y sistema de poblamiento, y gestión forestal), y para la identificación de los incendios-tipo históricos se han manejado tres de sus principales características (superficie quemada, causa del siniestro y distribución espacial de los incendios). El resultado obtenido ha mostrado una evolución discontinua del régimen de incendios a lo largo de los siglos XIX y XX, como consecuencia de los cambios acontecidos en los incendios-tipo en relación con las dinámicas del paisaje. Además, la población y la gestión forestal han sido las principales fuerzas motrices de los puntos de ruptura en el régimen de incendios, denominados pirotransiciones. En definitiva, esta investigación ha permitido validar la hipótesis de trabajo que atribuía los cambios del régimen de incendios a la interacción de la historia del fuego y las dinámicas del paisaje.

Key words: fire regime, historical wildfires, land use, Spain, pyrogeography.

Palabras clave: régimen de incendios, incendios históricos, uso del suelo, España, pirogeografía.

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1. Introduction

Humans and fire have evolved with each other, and in their regular interaction fire has become a risk factor for human society (Pyne, 1997; Scott, 2018). Mediterranean-type climate landscapes are highly fire-prone (Keeley *et al.*, 2012; Pausas *et al.*, 2008). Especially from the 1980s onwards, fire risk has become a complex and challenging topic for policy-makers, land managers and operational systems (European Commission, 2017; San-Miguel-Ayanz *et al.*, 2017; Turco *et al.*, 2016). New planning and prevention approaches have been introduced into the research agenda, aimed at predicting fire behavior, thus providing basic information for its control and management (Cissel *et al.*, 1999; Coughlan *et al.*, 2012, 2013; Duane *et al.*, 2015; O'Connor *et al.*, 2011; Silva *et al.*, 2010). These new fire management approaches include concepts such as fire-type and landscape-based fire scenarios (Black *et al.*, 2005; Castellnou *et al.*, 2010, 2009; Costa *et al.*, 2011; LaCroix *et al.*, 2006; Murphy *et al.*, 2013; Pérez *et al.*, 1998), formulated in pyrogeography, which attempts to examine the human-fire relationship from an holistic perspective (Bowman, 2015; Keeley *et al.*, 2011; Roos *et al.*, 2014).

The fire-type concept refers to fire spread patterns depending on the fuel load, landscape structures and synoptic weather conditions (Acebrón, 2017; Costa *et al.*, 2011). On the other hand, landscape-based fire scenarios refer to the contextual factors of a fire regime, i.e. the environmental, socioeconomic and policy drivers of wildfire ignition and propagation on different spatial and temporal scales. In fact, fire scenarios are multiscale land-type planning units for a fire regime with different applications at national, regional, and local scales. Previous studies have addressed landscape-based fire scenarios in Spain at a national scale (Montiel-Molina *et al.*, 2016) and a regional scale (Costa *et al.*, 2011). Nevertheless, the local scale has not attracted the attention of many researchers, despite proof of its importance when examining the relationship between fire regime and landscape dynamics (Beilin *et al.*, 2015; Wilbanks *et al.*, 1999). Moreover, the vast majority of recent studies have focused on a recent time scale context (since 1968, when fire data statistics started), regardless of the fact that fire and landscape history are relevant to the current fire risk (Smith *et al.*, 2016) and that a longer perspective is needed to characterize fire regime changes. Even though no specific data on fire behavior is available before the statistical period (which makes it difficult to apply the fire-type method), fires recorded pre-1968 do share two common features: extent and fire cause (Montiel-Molina, 2013), applicable to the definition of the historical fire-type concept.

The concepts of both landscape-based fire scenario and of fire-type therefore provide a theoretical basis to explain the dynamic character of the fire regime, through spatial and temporal dimensions (Keeley *et al.*, 2012). Fire regime changes can be either linear or progressive, or non-linear based on tipping points, i.e. pyrotransitions, which in Mediterranean landscapes are closely related to anthropic aspects (Tedim *et al.*, 2014). In general, fire regimes are linked to the environmental, socioeconomic and political contextual systems, which differ from place to place. When there is a balance between the contextual systems, the fire regime is expected to display linear progress. However, when there is an imbalance between these influencing systems, or a change in one of them, the fire regime changes abruptly, triggering a pyrotransition (Bowman *et al.*, 2011). In this context, the concepts of fire scenario and fire-type enable the identification of pyrotransitions and an understanding of the fire regime dynamics (Krebs *et al.*, 2010). The reconstruction of fire regimes, at a local scale and from a historical perspective, should consider some key components such as fire history, and others related to an understanding of the driving forces of fire behavior, such as land use, population and settlement system, and forest management. Recent studies have approached Spanish fire history before statistical data was available, from century time scales and based on geo-historical sources analysis (Araque, 1999; Lloret *et al.*, 2001; Montiel-Molina, 2013), to millennial time scales through palynological and paleoecological methods (Abel-Schaad *et al.*, 2013; Franco-Múgica *et al.*, 2001; Gil García, 1992; Ruiz Zapata *et al.*, 1996; Vera *et al.*, 1984). Other studies confirm the connection between land use changes, fire behavior and landscape structure (Viedma *et al.*, 2006). However, because long historical land use data series are unavailable, most studies of land use changes are restricted to the second half of the 20th century (Gallardo *et al.*, 2016; Martínez-Vega *et al.*, 2017; Viedma *et al.*, 2015).

This paper connects landscape-based fire scenario (LFS) and fire-type (FT) concepts from a long-term perspective (19th and 20th centuries) at a local scale in the Ayllón massif, well-known for its particular historical dynamics related to fire (Montiel-Molina, 2013). We believe that the fire regime in Ayllón Massif is non-linear, with three pyrotransitions: (1) at the end of the 19th century; (2) in the 1970s; and (3) in the mid-1980s, facilitated by a breakdown in the balance of contextual factors. This led us to formulate our hypothesis, which proposes that the fire regime changed according to the fire scenarios, fire history and fire types, and that tracing the history of these key values will allow us to describe the fire regimes that existed in each phase between pyrotransitions. This paper attempts to answer the question of what driving forces were responsible for fire regime pyrotransitions throughout the 19th and 20th centuries in the Ayllón Massif.

2. Material and Methods

2.1. Study area

This case study was carried out in the Ayllón Massif, which covers 1,400 km² in the eastern part of the Central Mountain Range natural region in the Iberian Peninsula, between the provinces of Guadalajara, Segovia and Madrid (Castel, 1873; Mata Olmo *et al.*, 2004). Slopes are steep, and altitudes range from 700 to 2,272 m a.s.l. The climate is predominantly sub-Mediterranean with mean annual temperature around 8°C and mean annual precipitation from 800 mm to over 1,500 mm (FAO Climate data). The vegetation is very diverse, given its significant climatic variety. The most important species are *Pinus sylvestris*, *Quercus pyrenaica*, *Quercus coccifera*, *Fagus sylvatica*, and *Nardus stricta* (high mountain pastures) (Mecha-López, 2004). Two headwaters (Jarama and Sorbe) in the Tagus River water catchment area are located in the Guadalajara area of the massif, where the predominant lithology is metamorphic (black slate and gneiss), sedimentary (clay slate), and igneous (granite) (Blázquez-Díaz, 1987). The Ayllón massif is a protected National Park (Natura 2000 Network, “Sierra Norte de Guadalajara” Natural Park, since 2011), Special Protection Area for birds, and Special Conservation Area. Most of this forest area is publicly owned and is regulated and protected as Forest for Public Use. These forest areas were common land until the end of the 19th century.

Two case study areas were selected and delimited using micro-watershed units within the Ayllón massif: (1) Sorbe and (2) Jarama (Fig.1). Both case studies consist of four micro-watersheds and cover a total area ranging from 8000 to 10,000 ha. The Jarama case study area is in the heart of the

massif and covers the municipal districts of Campillo de Ranas and El Cardoso de la Sierra. The Sorbe area covers three municipal districts on the eastern side of the massif (Cantalojas, Galve de Sorbe and La Huerce) plus two districts in the heart of the massif (Majaelrayo, and Valverde de los Arroyos). All these municipal areas were considered as the spatial reference for data collection, processing and analysis.

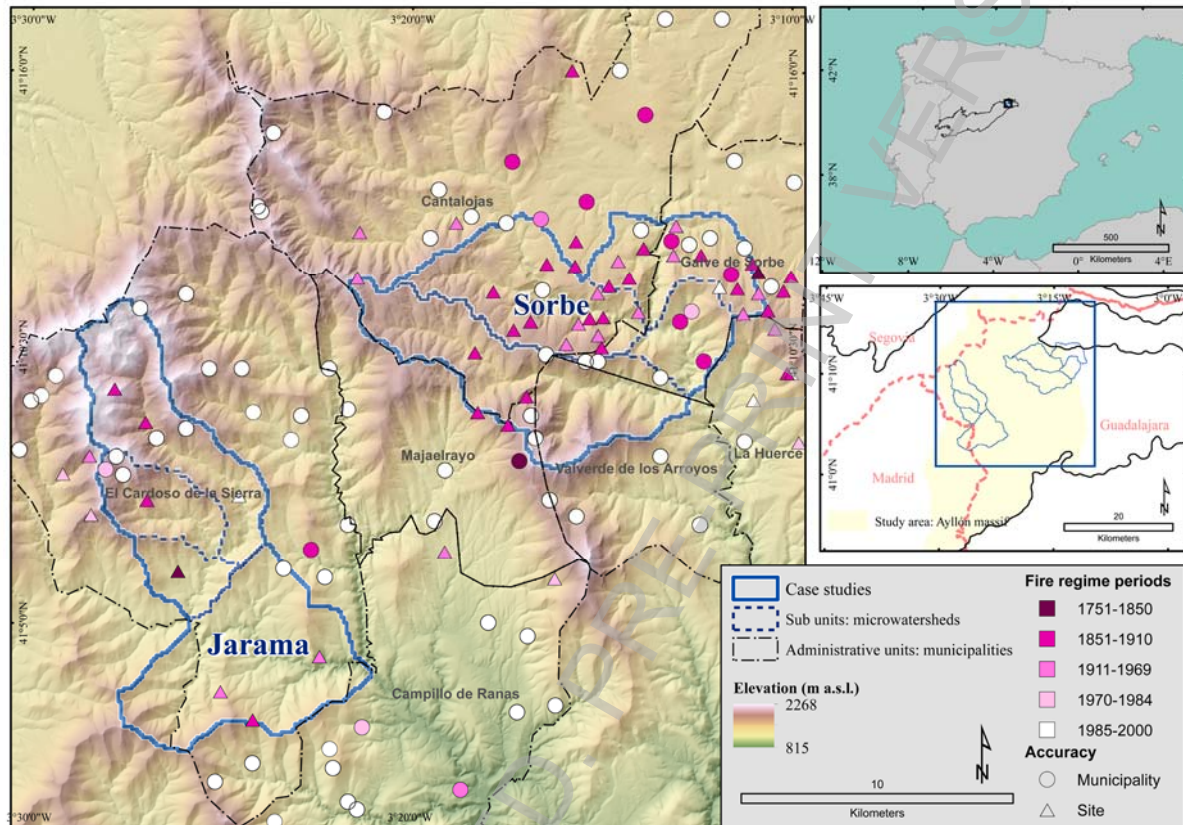


Figure 1. Study area, case studies and spatio-temporal distribution of fire occurrence.

The study area is characterized by marked human influence through natural resource management of timber, charcoal and firewood supplies, and because of the extensive afforestation campaigns in the 19th and 20th centuries (Fernández-Muñoz, 2002; López-Gómez, 1974). Logging, grazing and hunting were historically the main activities in this forest area, with the origin of some settlements related to hunting practices (e.g. El Cardoso de la Sierra) or to livestock (with constructions known as *tainas* in e.g. Valverde de los Arroyos and Majaelrayo). Nowadays, the cultural landscape of the Ayllón is severely depopulated or with an aging population, where tourism has become the main economic resource for the isolated villages (Agnoletti *et al.*, 2015).

2.2. Data: sources and variables

The characterization of landscape-based fire scenarios is based here on four main spatial components: (i) land use; (ii) population and settlement systems; (iii) forest management; (iv) fire history. These spatial components are analyzed in a historical and dynamic approach, according to the availability of sources and our focus on the processes (Table 1).

Table 1. Sources and data used for each variable.

Variables	Sources	Data				
		Name	Dates	Format	Scale	Retrieved from
Land use	Geohistorical and cartographic	Planimetric map collection	1895-1897	Raster	1:25,000	Instituto Geográfico Nacional
		Ortophoto	1956-1957	Raster	1:32,000	Map Services of the Gobierno Regional de Castilla-La Mancha
	Geospatial	Corine Land Cover Map 2000	1999-2001	Vector	1:100,000	Copernicus Land Monitoring Service
Population and settlement systems	Statistical	Population Census	1864-2001	Average interval 10 years	Municipal	Instituto Nacional de Estadística
		<i>Nomenclator</i> Municipal Registry	1858-2000	Average interval 10 years	Municipal	Instituto Nacional de Estadística
	Statistical	Agriculture Census	1999		Municipal	Instituto Nacional de Estadística
Forest management	Historical Documentary	Minutes of Municipal council meetings, Auctions papers and others	1750-1990	Paper	Municipal	Municipal Archives
Fire history	Based on historical documentary sources	Fire history Database (FHD)	Pre-1980s	Access	Central Mountain System	Forest, Geography, Policy and Socioeconomics Research Group, Complutense University
	Statistical	Statistical Fire Database (EGIF)	From 1968	Access	Spain	Spanish Ministry of Agriculture

- (i) Land use changes were considered in order to understand the fuel structure from the late 19th century to the year 2000. The main sources and data used for this assessment were geohistorical cartographic sources (Planimetric map collection 1895-1897, in raster format, scale 1:25,000, available from the Instituto Geográfico Nacional (IGN); Ortophoto 1956-1957, in raster format, scale 1:32,000, provided by the Map Services of the Gobierno Regional de Castilla-La Mancha) and geospatial data sources (Corine Land Cover Map 2000, 1999-2001, in vector format, scale 1:100,000 with minimum cartographic unit 25 ha, available from Copernicus Land Monitoring Service).
- (ii) Population and settlement systems were assessed to describe the human influence on the landscape. This was done through the following statistical data sources: Population Census 1864-2001, average interval 10 years, at municipal level for all 7 municipal districts covered by the case studies (available from Instituto Nacional de Estadística (INE)); and *Nomenclator* Municipal Registry 1858-2000, average interval 10 years, at municipal level for all 7 municipal districts (also available from INE).
- (iii) The forest management component was considered to evaluate the socioeconomic value of land management and the influence of rural activities on fuel control in the case study area, using official statistical data (Agriculture Census 1999 at municipal level) and municipal historical documentary data sources.
- (iv) The fire history was evaluated using the same resources as those used for analyzing historical fire types, based on three fire variables (fire extent, fire cause, and spatial distribution pattern, including the Fire History Database (FHD) and statistical fire database (*Estadística General de Incendios Forestales*, EGIF). Both are Access databases sharing

data to define each fire event (date, geo-location accuracy, extent, cause, etc.), but each one refers to a different period and is based on different information sources. The FHD, created by the Forest Geography, Policy and Socioeconomics Research Group in the Complutense University of Madrid, refers to the pre-1980s and is based on documentary sources (administrative documents, judicial and police sources and the press) obtained from different types of archives (historical archives, forest services and municipal archives and historical libraries). We gathered 101 historical fire records from 1768 to 1982 in the Ayllón massif study area, including 15 records for the Jarama and 46 records for the Sorbe area. All these historical fire records were geo-referenced with different levels of accuracy (from municipal boundaries to specific sites or plots) depending on the precision of the historical source. The EGIF is the official fire dataset provided by the Spanish Ministry of Agriculture since 1968 with increasing data accuracy over time (Vélez Muñoz, 2009). We used this statistical information to update the FHD until 1982, and then considered the EGIF for a second analytical period from 1983 to 2000, which includes 323 fire records (67 records for the Jarama and 56 records for the Sorbe case study).

2.3. Methods and techniques

Spatial and historical methods were used to integrate and analyze very diverse data series. Territorial and fire dynamics were investigated in a systemic approach, using ArcGIS for Desktop 10.3 to process the data (including photo interpretation), and qualitative analysis and basic statistical analysis techniques (Microsoft Excel 2013) for data integration. These methods were applied to process selected components to define fire scenarios (land use, population and settlement system, and forest management) and the variables considered to define fire types (fire extent, fire cause, and fire distribution pattern).

We used two spatial analysis scales: a landscape or intermediate scale (1:25,000) for the whole Ayllón massif study area (Smith *et al.*, 2016); and a local scale (1:10,000) to approach the Jarama and Sorbe case studies (Beilin *et al.*, 2015). For the temporal scale, we used a long-term analysis (19th and 20th centuries) to identify the tipping-points of fire regime change and the related driving factors.

3. Results and Discussion

3.1. Fire history and fire-types

Reconstructing fire history from geo-historical documentary sources shows that fire has been an ever-present feature since at least the late 18th century in the Ayllón massif, and particularly in the Jarama and Sorbe watersheds. 101 fire records from 1768 to 1982 were obtained for this mountain area, often related to rural activities where fire was a common land management tool (Table 2). This was why there are so many pre-1880 fire records, of small forest fires reflected in the printed press, judicial and police sources because of their social and economic impact. This human impact at a local scale explains why some wildfires are recorded in several documentary sources despite the relatively small area burned.

Table 2. Number of fire records for each period and fire database

	FHD (1768-1982)	EGIF (1983-2000)
Ayllón massif	101	323
Jarama case study	15	67
Sorbe case study	46	56

*FHD: Fire History Database; EGIF: Statistical Fire Database

The first large wildfire was recorded on August 15, 1891 in the public forests in Riaza (Segovia) with three simultaneous ignitions, burning 119 ha. Other large wildfires were recorded in 1954, 1970, 1978 and 1983. Since 1991 – when three large wildfires were recorded – this type of fire situation, the increasing number of ignitions and the variability of fire behavior have defined the present fire regime of uncertainty in the Ayllón massif.

According to the fire history of this massif, three shifts or *pyrotransitions* have been identified in the fire regime dynamics in the 19th and 20th centuries (Fig. 2). These fire regime shifts occurred especially (i) in the late 19th century/early 20th century, with increased fire occurrence; (ii) in the 1970s, when a few fires caused a large burnt area; (iii) in the 1980s, when fire occurrence increased again, leading to a new uncertainty scenario. In short, from the late 19th century until the year 2000, there was a shift in the Ayllón from a situation where fire was used as a management tool in everyday rural activities to one where the fire risk is unexpected and uncontrolled.

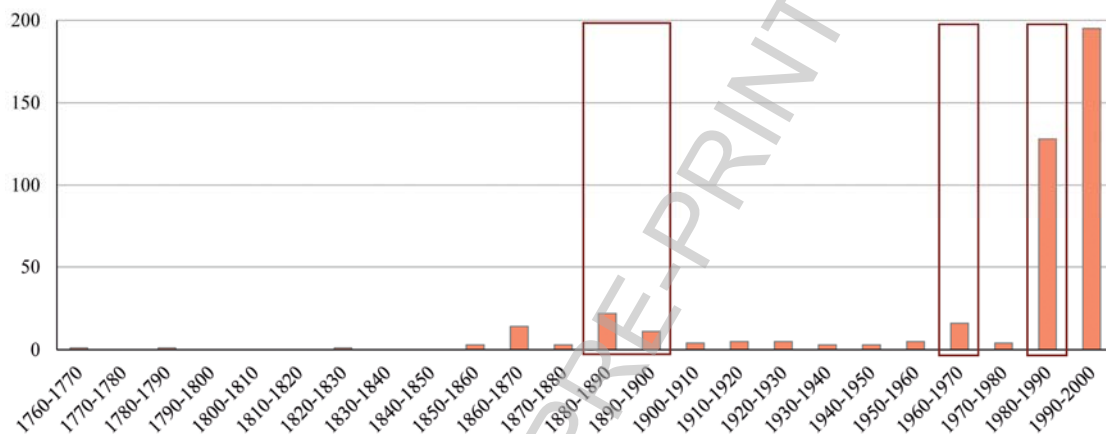


Figure 2. Number of fires recorded in the Ayllón massif and tipping-points (or *pyrotransitions*) of the fire regime dynamics (rectangles).

The drivers leading to the present fire regime have historical roots at the local level. In fact, significant differences were found between the two local case studies. The Jarama area was historically less affected by wildfires than the Sorbe watershed, although the opposite was true during the statistical period (see Table 2 and Fig. 3a). Nevertheless, the evolution of the burnt area has been different in both areas and is greater in Sorbe than in Jarama since 1984 (Fig. 3b).

Table 3. Population and settlement system dynamics.

Case study	Population density of the settlement system (Inhab/km ²)			
	Jarama		Sorbe	
	1900	2000	1900	2000
Small villages	2,37	0,34	6,84	1,54
Scattered populated areas	0,08	0,09	0,01	0,01

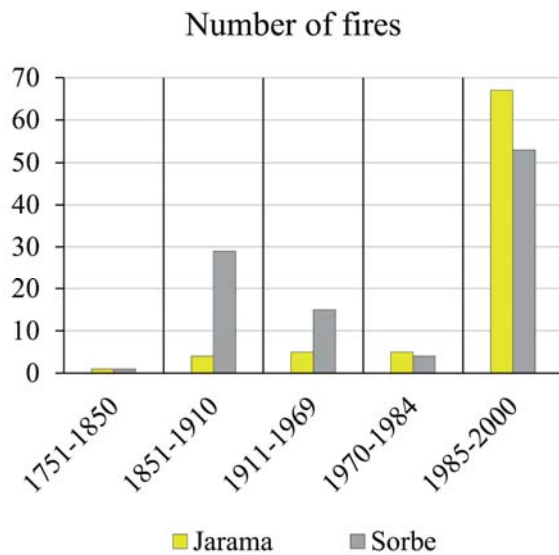


Figure 3a. Occurrence of fires in Jarama and Sorbe.

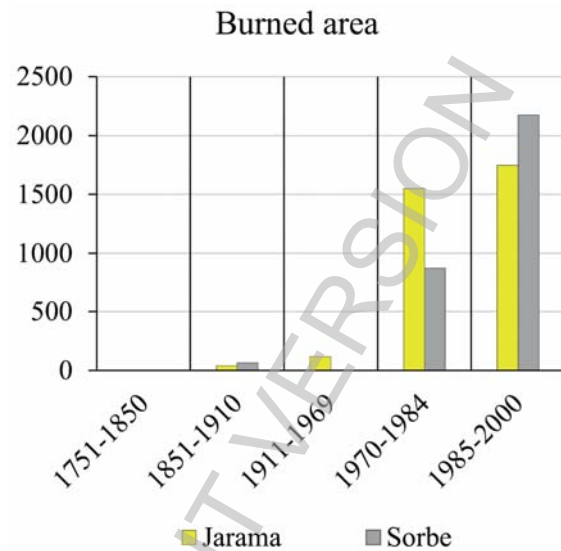


Figure 3b. Extent of fires in Jarama and Sorbe.

Historical fire types were analyzed during the five periods identified according to the three pyrotransitions mentioned above and the tipping-point recognized by the mid-19th century resulting from the socioeconomic effects of Forest Administration regulations in the context of Liberalism. Thus, fire types have been characterized in each period according to their main features, i.e. fire size, fire cause, and spatial distribution pattern. Fire size is classified as follows: (i) *very small fire*, < 1 ha; (ii) *small fire*, 1-15 ha; (iii) *medium size fire*, 15-100 ha; (iv) *large fire*, 100-500 ha; (v) *very large fire*, > 500 ha. These numerical thresholds were established from a thorough analysis of historical events, considering that a small historical fire usually represents an accident, i.e. loss of control in the use of fire, and is extinguished by efficient community-based suppression systems. In contrast, what are usually called large historical fires in the documentary sources are normally larger than 100 ha and demonstrate the inefficiency of local suppression systems.

On a local scale, the first very large wildfire (>500 ha) is recorded in the 1970s in the Jarama watershed, and ten years later in Sorbe (Fig. 4). In both cases, the ignition trends and burnt areas, and the occurrence of very large wildfires, suggest that the last pyrotransition is marked by a large wildfire episode resulting from the destabilization of the entire socio-spatial system. This destabilization occurred later – although with more abrupt effects – in the Sorbe watershed as a result of landscape dynamics related to the fire use practices maintained until the second pyrotransition in the 1970s. However, very large wildfires remain exceptional events in the Ayllón massif due to the rural character of the landscape and the socio-economic dynamics. Currently, small and very small fires are the main sizes observed in this mountain area.

For the direct causes of fire, four major ignition groups have been identified in the Ayllón massif: (i) *burning for pasture renewal/agriculture/forest activities*, (ii) *intentional/arson*, (iii) *natural/lightning*, and (iv) *negligence/accidental/other*. It was found that for this variable, the two case studies were historically fairly similar (Fig. 5). Despite the limitations of the historical documentary sources, the available data show that burning for pasture renewal/agriculture/forest activities and negligence/accidental/other were the two main causal factors of fire in the Ayllón massif until 1984. Since then, intentional/arson fires are the most prevalent, particularly in the Jarama watershed, due to the breakdown of the traditional land management system and the introduction of new lifestyles which increased fires from arson in the late 20th century. Also notable is the high proportion of fires from natural causes here at the eastern end of the Central Mountain Range (Vélez Muñoz, 2009).

For the spatial location pattern, historical fires were geo-referenced according to the information recorded at two levels of accuracy: (a) municipality, and (b) plot/site. The municipal level includes historical fire records where documentary sources do not provide information about the precise ignition site, and pre-2000 statistical records without geographic coordinates. Plot/site refers to historical fire records with spatial information about the fire ignition and the statistical records since

2000 with geographic coordinates. Despite these constraints, the space-time analysis of the location of historical fires at local level obtains a concentrated pattern of fire records over time in Sorbe, meaning a fire resilient landscape (San-Miguel-Ayanz *et al.*, 2017) in comparison with the relatively random pattern and fire deficit in Jarama (Fig. 1).

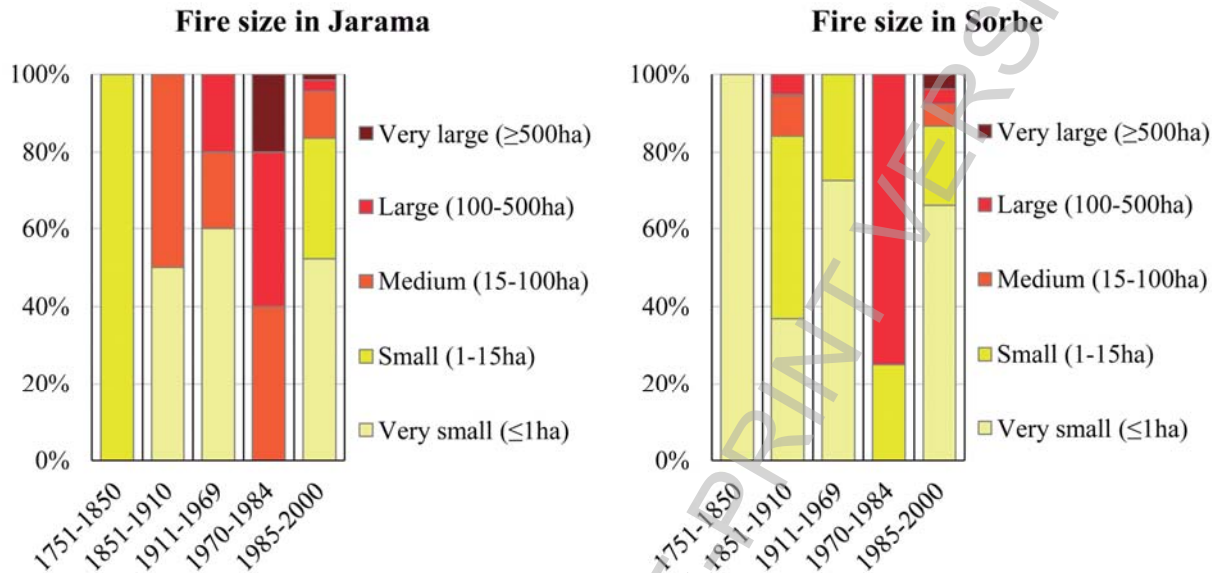


Figure 4. Fire size in Jarama and Sorbe.

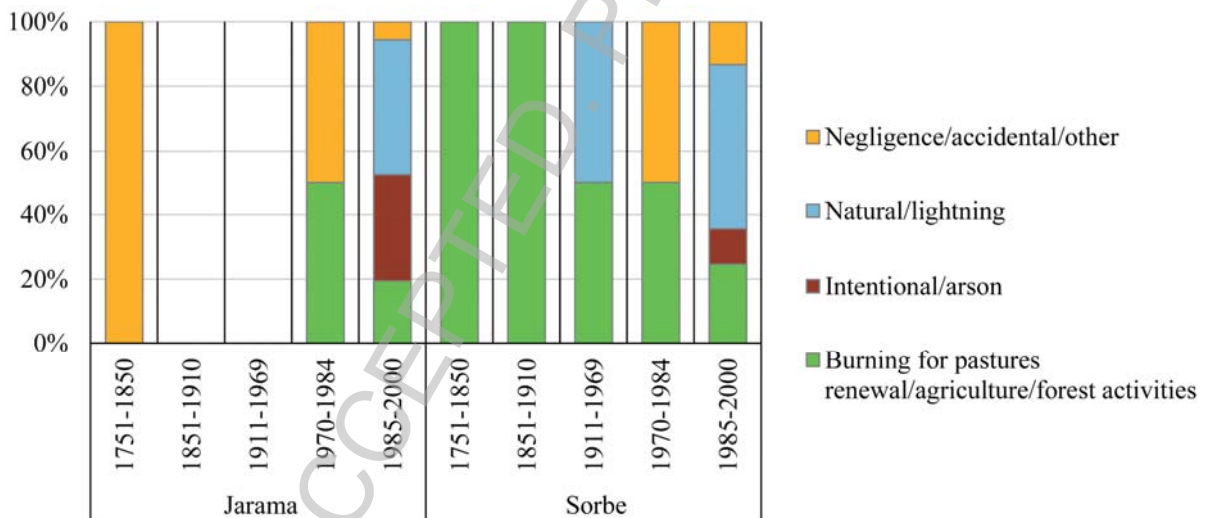


Figure 5. Fire causes in Jarama and Sorbe.

3.2. Population dynamics and settlement system

The cultural landscape of the Ayllón massif is linked to the demographic dynamics, population lifestyle and rural practices. This mountain area located in the Spanish central region of Castilla benefitted only barely from the legislative progress in civil affairs during the period of the Second Republic, which just brought about a slower rate of population decline since the first census (1877) in contrast with the general positive trend in the country as a whole (Fig. 6). The social and cultural stagnation lasted until the 1960s during the Franco dictatorship (Ussel, 1990). Then, the economic development and cultural changes in Spain linked to the industrialization process and urban growth led to the rural exodus and abandoning of agrarian activities in mountain areas in the interior (Jerez *et al.*, 2004). This is particularly evident in Sorbe and Jarama, where the decline in population and rural

activities continued until the recovery in the 1980s in Jarama and in the 1990s in Sorbe, due to official local development policies co-funded by the European Union (Montiel-Molina, 2003).

As a result of this long secular decline in the Ayllón massif (from 20,539 inhabitants in 1877 to 15,154 in 2001), the population density in 2001 was lower than four inhabitants per km², which is considered by FAO as a severe under-population problem. In fact, the Ayllón massif is one of the mountain areas in central Spain included in the European high-risk fire scenarios of disadvantaged rural areas (Montiel *et al.*, 2010).

The settlement system presents the traditional structure of depopulated rural areas, with very low population density, even in the existing small villages (fewer in Sorbe than in Jarama) with population of less than 160 inhabitants. The population of these villages decreased significantly during the 20th century, although the population density of the sparsely populated areas had slightly increased in both Sorbe and Jarama (Table 3). Agricultural and pasture land normally surround each village, while infrastructures, public services and other facilities are minimal because of the low population density, accentuating the features of this disadvantaged rural mountain area.

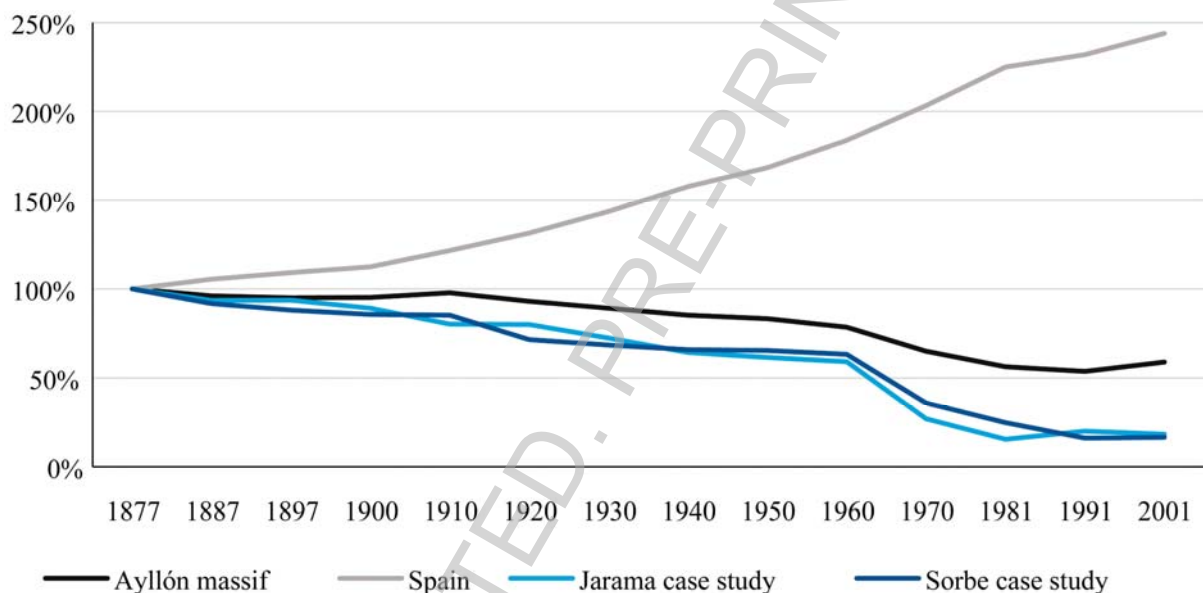


Figure 6. Relative demographic evolution of Spain, Ayllón massif, Jarama and Sorbe case studies.

3.3. Land use changes

The present forested landscape characterizing both Sorbe and Jarama is the result of similar land-use dynamics throughout the 20th century, re-shaping the very different cultural landscape in each watershed at the end of the 19th century. Although shrublands were the predominant land-use in both areas 1895-1897, Jarama had a significant agricultural area, mainly in the central and southern sectors, while Sorbe was entirely woodland. However, by 1999-2001 both Sorbe and Jarama had a very similar forested landscape, with approx. 58% forest, 5% pasture and the remaining area shrubland (Fig. 7).

Forest land use had increased considerably in the Ayllon Massif by the end of the 20th century. However, the dynamics of the land use change were completely different in the first and in the second half of the century. In the first fifty years a growing trend to forest regression and general maintaining of other land uses can be observed in both Jarama and Sorbe, while the most striking trend since the 1950s is the general forest progression. With these contrasting dynamics, the formerly diverse landscape structures have become increasingly uniform and unstable, particularly in Jarama (Fig. 8).

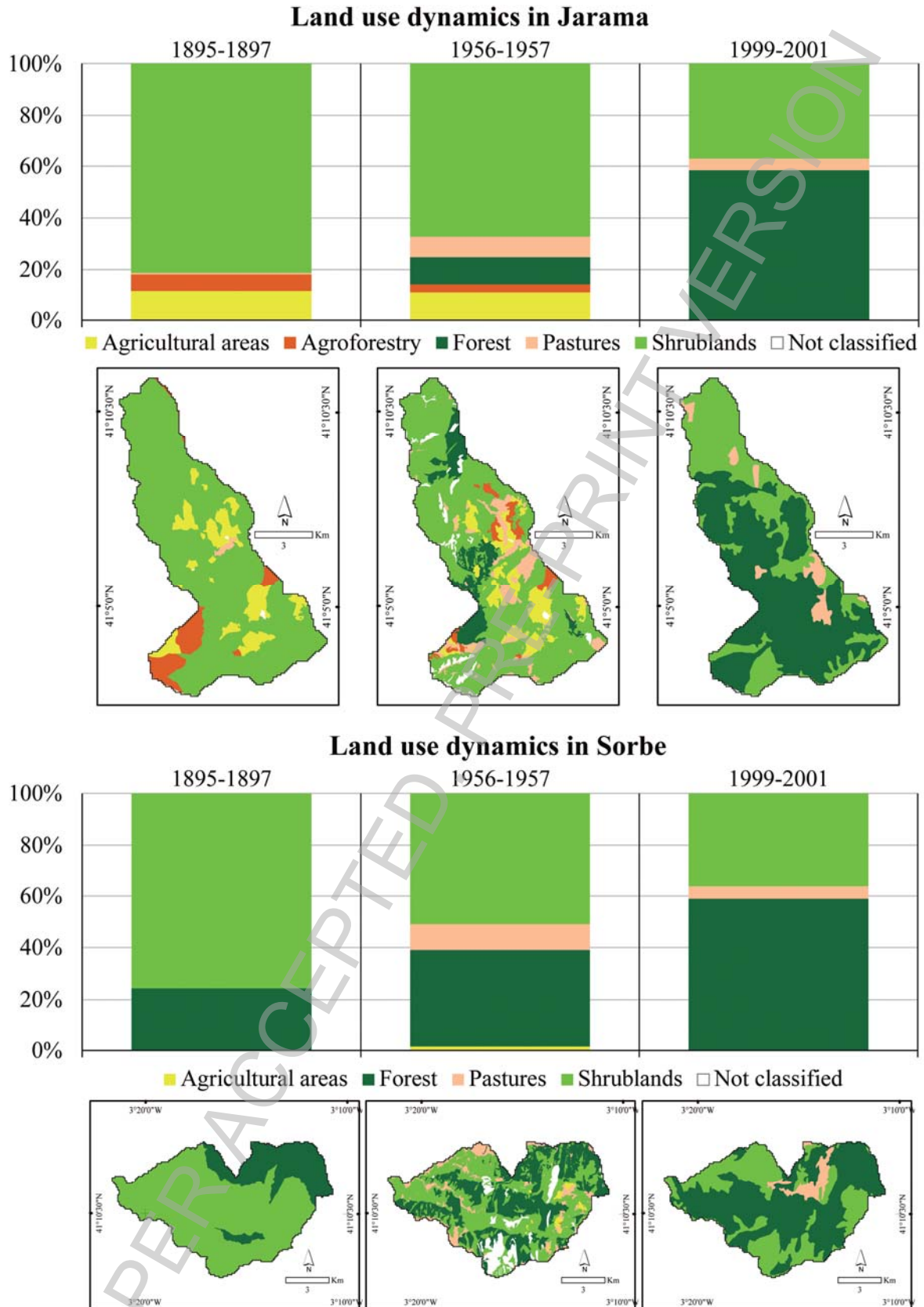


Figure 7. Land use dynamics in Sorbe through the 19th and 20th centuries (1895-1897, 1956-1957 and 1999-2001) in Jarama and in Sorbe case studies.

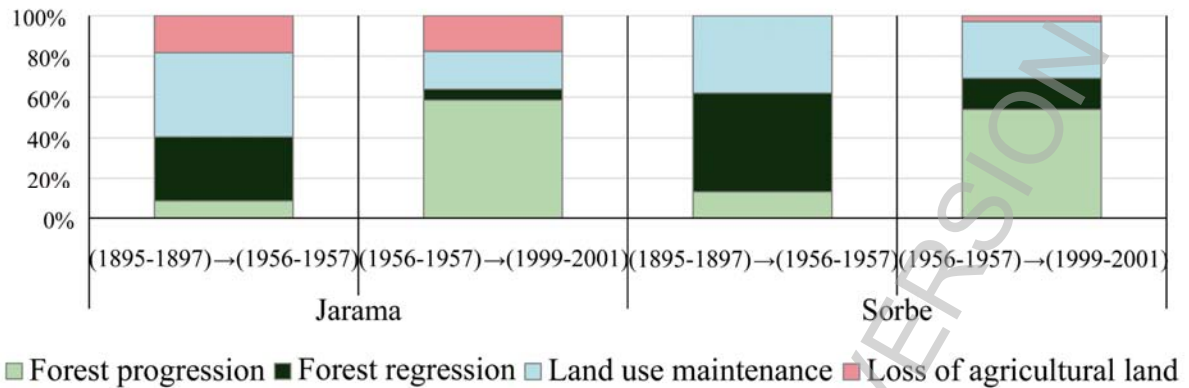


Figure 8. Land use changes in Sorbe and in Jarama in (1895-1897) – (1956-1957) and (1956-1957) – (1999-2001).

The main factors influencing these contrasting dynamics of land use change and the related landscape uniformity and instability are the official policies of expropriation (19th century) and reforestation (20th century) (Fernández-Muñoz, 2002; Fernández-Muñoz *et al.*, 2000). The Common Agricultural Policy (CAP) Reform measures have also contributed to recent forest progression through afforestation programs (Vadell *et al.*, 2016). In addition, the abandonment of rural mountain areas in inland Spain in the 1960s resulted in the loss of traditional land management practices and the generally uncontrolled progression of woodland (Stellmes *et al.*, 2013; Tolón Becerra *et al.*, 2007).

3.4. Forest resources management and regulation

Historically, forest management played a major role in the socioeconomic organization of rural areas in the Ayllón massif. The large number of local regulations and related permits, and reports on illegal activities, are a good indicator of the critical value of forest resources for the subsistence economy in both Jarama and Sorbe. Timber and firewood extraction were the main forest products in both areas, while communal grazing was also a widespread forest management practice, mainly with transhumance from Extremadura and Andalucía (Blanco, 1993; Comíns *et al.*, 2011) (Fig. 9).

Grazing was a widespread forest management practice in the rural areas of the Central Mountain Range, and livestock density remained relatively stable in the Ayllón massif until the mid-20th century (López-Gómez, 1974). However, certain variations can be seen at the local scale. In Sorbe, livestock density increased during the period 1911-1970, mainly due to an open-range livestock grazing trend in the 1930s and 40s for meat production. Then, in the 1970s, the traditionally predominant sheep and goats almost disappeared, in contrast with a sustained or even increased trend to cattle rearing in Jarama (Fig. 10).

Reports on illegal forest uses mostly relate to grazing activities since 1911 and refer to conflicts between local inhabitants because of a shortage of pastureland. The subsequent period (1970-1984) highlights that conflictive situation further, largely due to the implementation of EU afforestation programs. We suggest that grazing activities in the Ayllón massif retained their social non-economic value, but because they were not organized on a consensual basis, they generated regulatory problems and illegal grazing activities. The last period (1985-1990) evidences some degree of chaos, since the number of reports on illegal forest uses other than logging and grazing increased sharply. On the other hand, most illegal logging conflicts seem to have been solved in the Ayllón massif in this last period analyzed (Fig. 9).

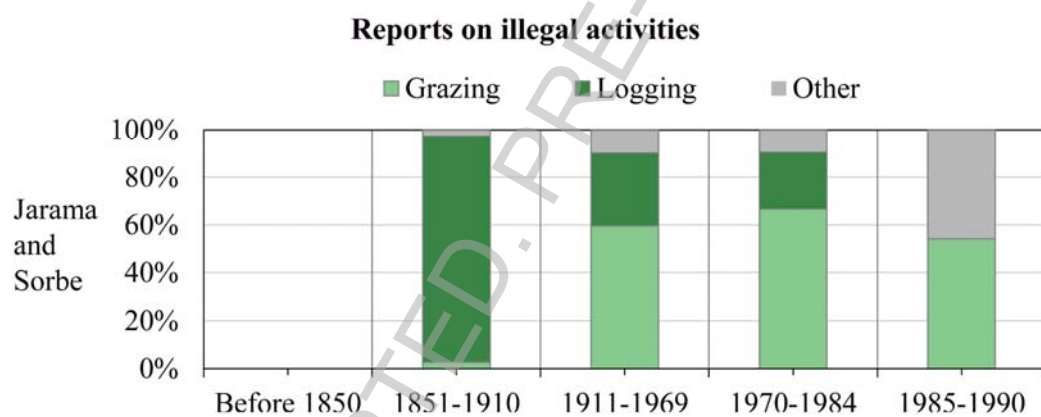
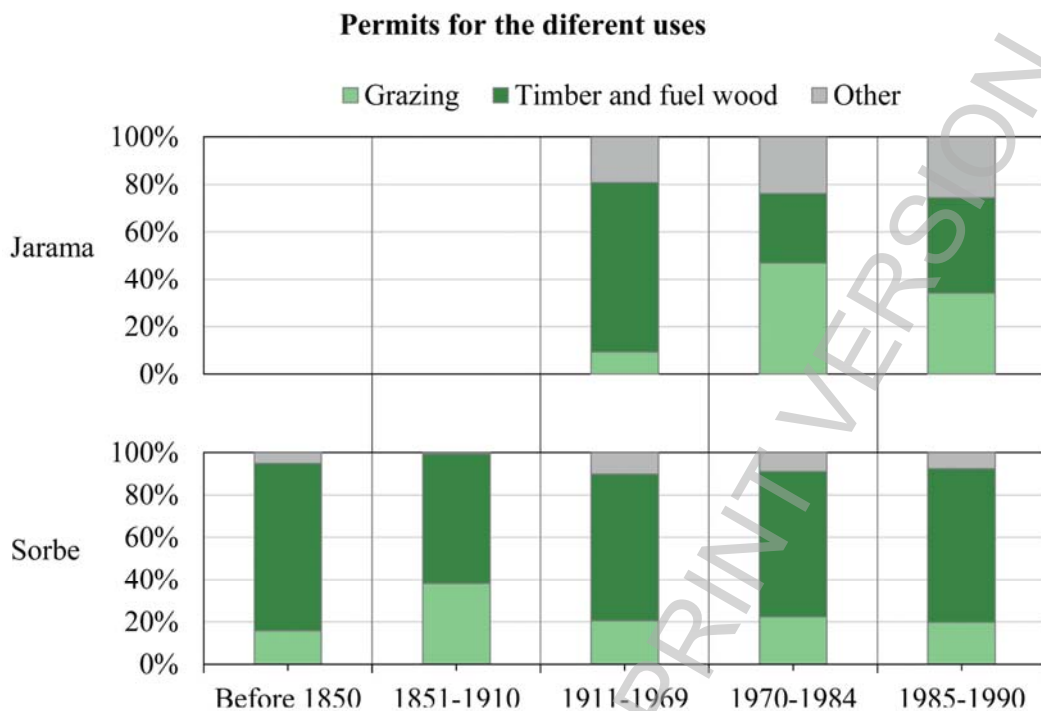


Figure 9. Social indicators of forest resources management until 1990.

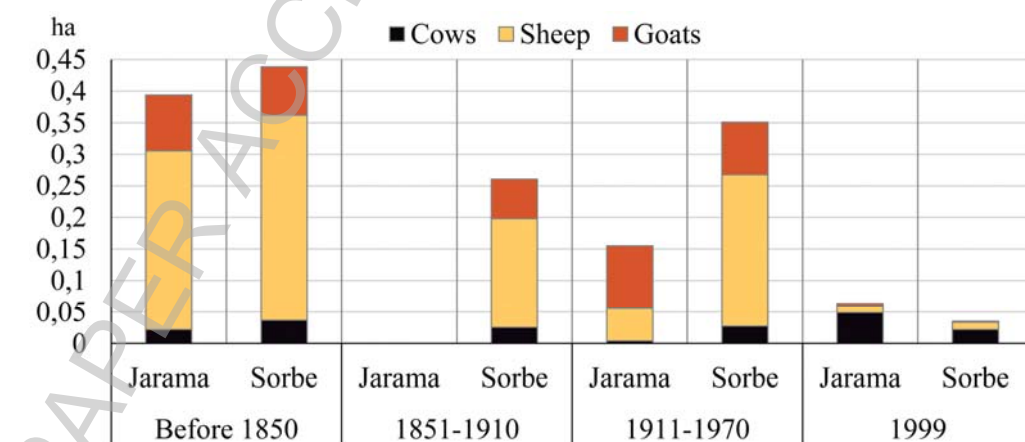


Figure 10. Average livestock density (number of livestock per hectare) in Sorbe and Jarama.

Other contextual factors of local conflicts related to forest resource management are the consequences of the expropriation process in the 19th century. The subsequent municipal management system and legal protection of forest for public use led to many different systems of community-based management regulations in Sorbe and Jarama (Montejano, 1988), originating an increasing number of reports of illegal uses of the forest (Fig. 9). In fact, the province of Guadalajara is one of the areas which best represents the expropriation process in the latter half of the 16th century, leading at that time to the start of the demographic decline, livestock recession, deforestation, and the socio-spatial reorganization of agricultural areas. Nevertheless, these privatization processes of forestland were not significant in the Sorbe and Jarama rural areas (Gómez-Mendoza, 1967). On the contrary, new land management regulations introduced by the Forest Administration in the second half of the 19th century, and hydrological and forestry policies in the 20th century, disrupted the land ownership structure and socio-spatial systems in the area.

Following the mid-20th century transition of rural society, the forest resource management system was not adapted to the new socioeconomic situation (Paniagua *et al.*, 2001). The trend to an aging population and decreasing active population continued, despite the new opportunities emerging from local development policies (Delgado Viñas, 2015; Pascual, 2006). Furthermore, this mountain area lost its importance as the main supplier of forest products to Madrid and further isolated itself by accentuating traditional economic rural activities and forest uses, mainly in Sorbe (Hernando *et al.*, 2016).

3.5. Shaping the landscape-based fire scenarios

Both the fire regime and territorial dynamics have changed throughout the history of the Ayllón massif, which explains the presence of different fire risk situations and territorial fire scenarios. As multiscale land-type planning units, the current landscape-based fire scenarios at the national scale are the *massifs and forestry ranges of the Central Mountain Range* and *mountain massifs and ranges, southwestern peneplains*, characterized by scarcely-populated, predominantly forested areas with high/medium propagation capacity and low agricultural presence (Montiel-Molina *et al.*, 2016). At the regional scale, the Sorbe and Jarama watersheds are both within the forestland use scenarios of first and second wildfire generations. The first wildfire generation scenarios refer to long perimeters and high propagation velocity fire behavior due to the continuity of the forest mass as a result of agricultural abandonment. The second wildfire generation scenarios imply complex, high intensity wildfires with high propagation velocity because of increased fuel load from the abandoning over time of farmland and traditional forest management (Costa *et al.*, 2011; Montiel-Molina *et al.*, 2018).

The Ayllón massif is a mountainous area in the interior of the Iberian Peninsula characterized by its isolation from the main road networks, reduced croplands and scarce population dependent on small-scale domestic agriculture and livestock activities, mainly open-range beef cattle rearing (Allende *et al.*, 2014; Paniagua *et al.*, 2001). However, fire risk is more dependent on socio-ecological conditions at the local scale, than on the socio-spatial character at the regional scale. Our data shows that the Jarama watershed comprises the most underpopulated municipality of the Ayllón massif and it is characterized historically by a lower occurrence of wildfires. On the other hand, the Sorbe area is less suitable for agriculture, with more forest resources and a higher impact of historical wildfires.

The four variables selected to define the historical landscape-based fire scenarios – fire history, land use, population and settlement system, and forest management – can be qualitatively ranked in order of importance for the shaping of current fire scenarios. The two most influential variables are land use and forest resources management and regulation. The other two variables – population and settlement, and fire history – play a secondary supporting role, enhancing the dynamics generated by the two leading variables. We argue that no single fire scenario can be defined for each local case study since there is insufficient data available on historical fire behavior, but instead the dynamics of each variable can be reconstructed to analyze their interactions (Table 4).

Table 4. Fire scenarios variables.

Variables and case studies		End of the 19 th century	> 70s 20 th century	> 80s 20 th century	2000
Fire history	Pyrotransitions				
	Jarama and Sorbe		Increase on the number of fires	Increase on burned area	Increase on the nr of fires Uncertainty
Land use	Jarama and Sorbe		Forest regression		Forest progression
Population and settlement	Jarama		Decrease on population	80s: Increase on population	Decrease on population
	Sorbe		Decrease on population		90s: Increase on population
Forest management	Jarama		Livestock amount decrease and changes on composition		
			Main forest resource exploitation: Timber and fuel wood Social conflict situation for forest resources		Illegal logging conflict solved
	Sorbe	Livestock amount decrease	40s: Livestock amount increase	Livestock amount decrease	
Fire types	Size		Jarama case study: Occurs first very large fire	Sorbe case study: Occurs first very large fire	
	Cause		Main fire cause: Burning for pastures		Main fire cause: various
	Distribution pattern		Jarama case study: Random Sorbe case study: Concentrated		

In short, we have identified three different spatial-temporal fire scenarios in the Ayllón massif since the late 19th century:

1. The socio-ecological context in the period between the two pyrotransitions identified (from the end of the 19th century to the 1970s), characterized by overall forest regression dynamics, decreasing population and livestock density, and increasing fire occurrence. This was a still a relatively stable fire scenario, because despite the increasing number of fires and conflicts related to the grazing practices in communal areas, the main causes of wildfires were still connected with traditional rural activities in Sorbe and in Jarama.
2. The contextual factors of wildfires from the second to the third pyrotransition (1980s) linked to major land use change that led to widespread forest progression and a significant increase in the burnt area. In this fire scenario, the agricultural character of the Jarama area was lost, the equilibrium of the socio-ecological system was disrupted, and the first very large fire was recorded. Forest and shrublands spread while the management of forest resources was abandoned. In addition, changes in population structure seem to have altered the socio-ecological system, especially in Jarama where depopulation was even more pronounced. Moreover, the processes of agricultural industrialization, rural exodus, land abandonment, change in traditional rural practices, and energy transition from the use of biomass to fossil fuels, caused landscape homogenization, generally favoring wildfire occurrence in the last decades of the 20th century.
3. From the third pyrotransition onwards, the occurrence of fire events increased sharply in a context of growing uncertainty. The causes of fires changed as a result of the shifting social system, and the socio-ecological equilibrium of Sorbe was lost, ten years later than Jarama. Local conflicts related to grazing activities and lack of governance mechanisms for conflict resolution led to a scenario of very high fire risk, depending on extreme meteorological situations in the Ayllón massif (Pausas *et al.*, 2012; San-Miguel-Ayanz *et al.*, 2017).

5. Conclusions

The interactions between landscape dynamics and fire regime do not display linear progressions in time or space in the Ayllón massif. The rural fire culture, prevalent for centuries, meant that fire was commonly used as a land management tool in this rural context (i.e. frequent but controlled use of fire for the maintenance of pastureland). At historical moments of socio-ecological crisis and system instability (e.g. the establishment of the forest administration in the 19th century or the rural abandonment in the 20th century), the frequency of fire occurrence and the burnt area increased. In the Ayllón massif, the influence of the socio-ecological system on the fire regime was evidenced through the pyrotransitions identified in the late 19th century, in the 1970s, and in the mid-1980s.

Reconstruction of the fire history and analysis of key socio-spatial variables of landscape dynamics in the 19th and 20th centuries have enabled us to describe the space-time context of wildfires at a local scale and to demonstrate the influence of historical landscape dynamics as the driving forces of the present fire scenarios in Sorbe and Jarama.

The main driving forces shifting fire regimes and shaping fire scenarios in the Ayllón massif during the 19th and 20th centuries were forest resource management and land use changes. These same drivers and processes took place in all Mediterranean countries to different degrees (Millington *et al.*, 2007), and were significantly shaped by human societies throughout history, closely related to fire use practices, particularly for agriculture and grazing purposes (Keeley *et al.*, 2012; Mazzoleni *et al.*, 2004; Silva *et al.*, 2010). This means that in all Mediterranean countries the same set of socio-spatial variables considered in our study are drivers of landscape change, and the spatial differences of fire types are mainly related to contrasting timelines and to specific local conditions (Beilin *et al.*, 2015). Thus, the strong connection between past socio-ecological dynamics and current landscape structures is a convincing argument in favor of the major role of history in our understanding of current scenarios and fire regimes (Smith *et al.*, 2016).

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