Forest Ecology and Management 293 (2013) 132–139

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Dendrochronology-based fire history of *Pinus nigra* forests in Mount Taygetos, Southern Greece

Anastasia Christopoulou [a], Peter Z. Fulé [b], Pavlos Andriopoulos [a], Dimitris Sarris [a], Margarita Arianoutsou [a,*]

[a] Department of Ecology and Systematics, Faculty of Biology, University of Athens, Panepistimiopolis 15784, Greece
[b] School of Forestry, Northern Arizona University, PO Box 15018, Flagstaff, AZ 86011, USA

ARTICLE INFO

Article history:
Received 31 July 2012
Received in revised form 21 December 2012
Accepted 24 December 2012

Keywords:
Fire regime
Pinus nigra
Black pine
Dendrochronology
Mediterranean

ABSTRACT

In the past few decades there is an increasing trend of both fire activity and area burned in many regions of the world. Moreover, there is a worldwide concern regarding the increasing presence of crown fires in forest types that were historically prone to surface fires. Among the recently affected mountainous forest ecosystems are those of *Pinus nigra*, an ecologically and economically important species that is widely distributed around the Mediterranean Basin. Mount Taygetos, a mountainous landscape in Peloponnese, Greece, that was severely burned in 2007, was selected to carry out the first landscape-scale fire history reconstruction in *P. nigra* of the eastern Mediterranean. The aims of the study were to investigate whether fire-regime attributes can be reconstructed from fire-scarred trees and also to examine the consistency of fire occurrence and spatial extent through time within the area selected. Partial cross-sections were sampled within the perimeters of the more recent known large fires in the region, those of 2007 and 1998. The overall mean fire interval between 1845 and 2007 was 4.9 years, while for the larger fires this time window was 16.2 years. Even at the individual-sample scale, with the sample mean fire interval equaling 29.5 years, the fire frequency still falls within the range of the "predictable stand-thinning fire" regime. The majority of fire scars recorded were dated to the warm and dry season of summer to fall. During the last 165 years of fire reconstruction, neither fire frequency nor percentage of trees scarred by fires varied significantly. Nevertheless, the size of the area burned as well as the type of fire seem to have changed, with the 2007 event being the most extended crown fire encountered so far. Our study has provided additional evidence that *P. nigra* is indeed a fire-resistant tree species provided that it is exposed to surface fires, even if they are recurrently occurring. Shifts from this pattern may lead to local extirpation of the species, as in the case of severe and extended crown fires.

1. Introduction

Fire regimes have been shown to vary over space and time at many scales (Baisan and Swetnam, 1990; Skinner et al., 2008, 2009). Many factors are considered to influence fire activity in a region, including weather conditions, fuel characteristics, fire management activities, land use changes and climatic change (Dimitrakopoulos et al., 2011). Inspecting fire-scarred trees dated with dendrochronological techniques is a widely used method that can provide reliable quantitative information of fire-regime evidence at multiple scales (Baisan and Swetnam, 1990; Brown et al., 1999; Brown and Wu, 2005). A fire scar is a result of partial cambial death at the base of a tree caused from heating and recorded in tree-ring series (Gutsell and Johnson, 1996; Brown and Wu, 2005). Once the tree cambium is injured by fire or mechanical damage, it is often more susceptible to additional fire scarring (Brown and Smith, 2000). Trees with open injuries, susceptible to further scarring, are useful as recorders of fire history (Van Horne and Fulé, 2006). Fire scars are normally formed on mature trees, with thick bark, that are adapted to survive surface fires. Numerous data on fire history and reconstruction through fire-scars are available from North and South America (Falk et al., 2011), but few European sites have been studied (Niklasson et al., 2010). Fire history in the Eastern Mediterranean region remains poorly developed, with only one study from the region (Touchan et al., 2012).

In Mediterranean climate ecosystems, fire acts as an important disturbance triggering vegetation change and many plant species possess specific traits to cope with fire (Bond et al., 2005; Pausas and Keeley, 2009). Nevertheless, both the number of fires and the area burned are increasing considerably (Piñol et al., 1998; Ordóñez et al., 2005; Miller et al., 2012). Moreover, there is a worldwide concern regarding the increasing presence of crown fires in forest types that were historically prone to surface fires (Ordóñez et al., 2005; Fernandes et al., 2008; Keeley, 2012). Among the recently affected

* Corresponding author.
E-mail address: marianou@biol.uoa.gr (M. Arianoutsou).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2012.12.048

mountainous forest ecosystems are those of *Pinus nigra* J.F Arnold (Black pine) which represent a European priority habitat type included in Annex I of the Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.

P. nigra does not produce serotinous cones and does not maintain a seed bank (Habrouk et al., 1999; Ordoñez et al., 2005), so its regeneration after severe crown fires is almost nil (Trabaud and Campant, 1991; Retana et al., 2002; Ordóñez et al., 2004; Ordóñez, 2004; Pausas et al., 2008). In such cases its natural post-fire recovery depends almost exclusively on long-distance seed dispersal from neighboring unburned patches or sparse individuals of the species (Retana et al., 2002; Ordoñez and Retana, 2004; Ordóñez et al., 2005, 2006; Arianoutsou et al., 2010). While vulnerable to crown fires, mature trees of *P. nigra* can withstand surface fires due to their thick bark and the fact that they grow tall with few branches in the lower bole (Tapias et al., 2001, 2004; Pausas et al., 2008). Black pine trees can live for many centuries (Tapias et al., 2004) and they have been widely used in dendrochronological studies (Strumia et al., 1997). The dates of fire scars in old living *P. nigra* trees in Spain provide evidence of a fire regime of low intensity surface fires (Fulé et al., 2008). Evidence of recurring surface fires was recently reported for *P. nigra* forests in the Valia Kalda mountain range in northern Greece (Touchan et al., 2012).

The aim of the current study is to reconstruct at landscape-scale the fire history in *P. nigra* forests of the Taygetos mountain range of Southern Greece, a region heavily affected by recent fires, especially in 2007 when Greece experienced the most severe wildfires in its modern history. We used fire-scarred trees and data records from the local Forest Service to address the following questions: (1) Could fire-regime attributes be reconstructed from fire-scarred trees? and (2) Are fire occurrence and spatial extent consistent through time?

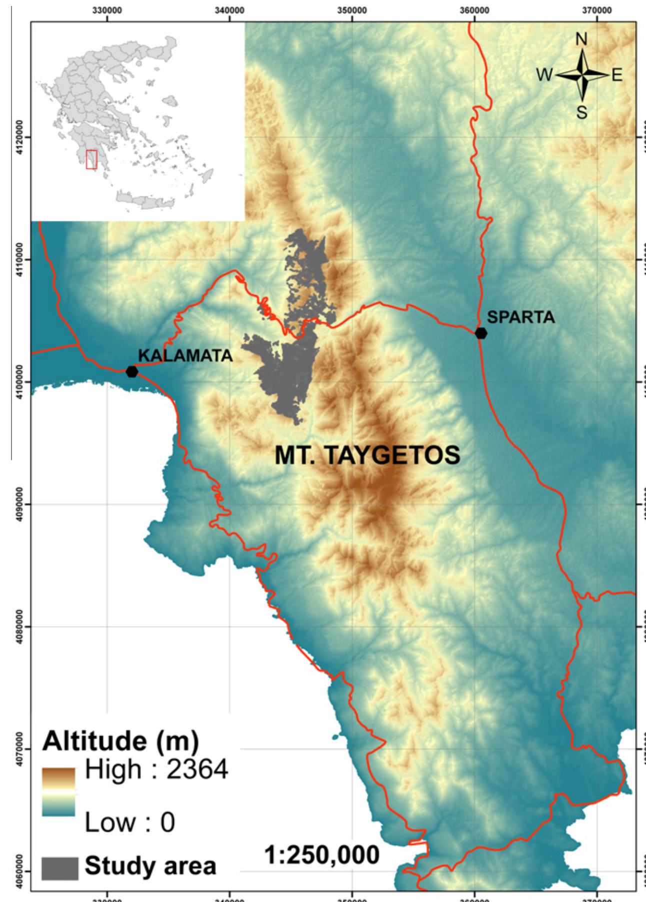

Fig. 1. Location of Mt. Taygetos, Southern Greece. Topography map based on the 30 m ASTER GDEM. Main roads and capitals are also presented. Coordinates in meters are according to the GGRS87/Greek Grid.

2. Materials and methods

2.1. Study area

Mount Taygetos (Fig. 1) is the highest (2407 m) and longest mountain range of Peloponnese in Southern Greece. Coniferous forests cover an altitudinal zone between 800 and 1600–1700 m and are dominated by *P. nigra* J.F Arnold and *Abies cephalonica* Loudon (Greek fir). The main geological substrates are limestone and schist. Climatic conditions vary among the different vegetation zones of the mountain range, while only few meteorological stations exist in the forest zone. A meteorological station situated near the study area (Touristiko Taygetou), at an elevation of 1310 m, reported mean annual temperature of 10.2 °C and annual precipitation of 1082 mm, for the period 2007–2011. Black pine dominate the drier aspects and lower elevations of the mountain range, covering an area of 2451 ha, while firs are found on mesic northern aspects and higher elevations, covering an area of 4502 ha. Mixed conifers correspond to 1918 ha.

Approximately 20% (1930 ha) of the total area covered by *P. nigra* and mixed *P. nigra*–*A. cephalonica* forests was burned in the 2007 fire, as calculated from a fire map based on satellite data with very fine spatial resolution and the 2004 Forest Service's vegetation map (Christopoulou et al., 2010). Of those 1930 ha of Black pine forest 340 ha had previously burned in a fire in 1998. Additional data for fires occurred between 1977 and 2010 were obtained from the Local Forest Service (Table 1).

2.2. Field methods

Partial cross-sections were collected from fire-scarred *P. nigra* trees throughout the study area. Since 2007 and 1998 represent the two most extended fire events in the mountain range on record (see Table 1), sampling took place within the perimeters of these two fire events, in order to detect whether past fire events had burned areas of equivalent size. The fire of 1998 burned the northern part of the study area, while in 2007 both the northern and the southern parts were burned. We aggregated sampling points into two groups, according to their location in the northern (points named TN_i) or southern part (points named TS_i), using as a landmark the Kalamata–Sparti highway, which crosses the study area.

The sampling was designed to maximize the completeness of fire occurrence dates over as long a time period as possible. Forest stands distributed across the study area were checked, even at remote areas using forest roads and hiking for access. Fire-scarred specimens, (live trees, logs, snags and stumps) were carefully observed and examined to contain fire scars. Samples were collected from specimens with the greatest numbers of well-preserved fire scars distributed as broadly as possible across the study site (Van Horne and Fulé, 2006; Skinner et al., 2008). However, sampling was limited to areas with adequate road access, so samples were not evenly distributed across the study area. In addition, in several areas it was not possible to find trees with fire-scar records owing to the relatively young ages of trees (Swetnam and Baisan, 1996; van Horne and Fulé, 2006; Farris et al., 2010). Cross-sections were cut with a chain saw. In the case of standing trees, living or dead, small partial cross-sections were cut. This technique causes minimal harm to living trees (Heyerdahl and Mckay, 2001, 2008).

The main limitation on fire-scar sampling was that past management and land-use practices had eliminated the majority of

Table 1
Fire events within the limits of Black pine forest in Northern Taygetos according to fire data records from the local Forest Service of Kalamata during the last 33 years (1977–2010). Areas refer to sites designated as “reforestable” by the Forest Service.

Fire years	Number of fire events	Total burned area (ha)	Burned area in Black pine forests (ha)
1977	5	659.1	176.0
1981	2	109.4	11.0
1982	1	31.7	3.3
1987	2	77.4	8.3
1989	1	140.0	37.8
1993	1	1.9	0.3
1998	1	3599.0	851.4
2007	3	8807.6	1885.4

old trees that could retain fire information. The total number of individual trees sampled was 62 (31 for both parts: northern and southern): 25 samples were collected from living trees, 23 from snags, 16 from cut stumps and two from logs.

The elevation of sampling points varied between 1125 and 1588 m (mean 1361 m). The mean slope was 47% and varied from 9% to 75%. Samples were collected from all aspects. The understory vegetation varied from site to site, mostly consisting of *Pteridium aquilinum*. In lower elevations trees and shrubs such as *Castanea sativa*, *Erica manipuliflora*, *Cistus creticus* and *Genista acanthoclada* were also present.

2.3. Laboratory methods

All samples were air-dried, glued to mounting boards, and cut to a flat surface in a wood shop. Final surfacing was done with a belt sander using a series of progressively finer abrasive grits (to 1200 grit for the samples with the most compressed tree rings). Surfaces were polished until cells were clearly visible under magnification. The width of each annual ring on the cross-sections was measured to the nearest 0.001 mm.

Samples were cross-dated with a local tree-ring chronology (Kuniholm and Groneman, 2012) obtained from the International Tree-ring Data Bank (http://www.ncdc.noaa.gov/paleo/treering.html). All specimens were visually cross-dated when possible, using visual recognition of tree-ring patterns and lists of marker years (those with narrow rings) (Yamaguchi, 1991).The COFECHA software was used with the tree-ring measurements to check the quality of dating and to assist in dating trees that could not be dated visually (Grissino-Mayer, 2001a).

The season of fire occurrence was estimated based on the relative position of fire injuries within each annual ring (Baisan and Swetnam, 1990), noted as EE (early earlywood), ME (middle earlywood), LE (late earlywood), LW (latewood), D (dormant or ring boundary) or U (undetermined).

After dating the fire events, we compared the reconstructed fire history with fire records from the local Forest Service. We also estimated fire area burning using methods described in Farris et al. (2010).

2.4. Data analysis

The FHX2 software (Grissino-Mayer, 2001b) was used for analyzing the fire scar data. We analyzed fire interval data in two categories, including all fire years within the study area, as well as “major” fire years, estimated by filtering only years in which $\geqslant$25% of the recording samples were scarred. Recording samples are those with open injuries, susceptible to further scarring. The $\geqslant$25% level has been reported most widely in the literature to represent larger fires that will have scarred more trees than smaller ones (Swetnam and Baisan, 1996; Van Horne and Fulé, 2006; Fulé et al., 2009; Farris et al., 2010).

The mean fire interval (MFI) is the average number of years between fire dates in a composite fire chronology and has been widely used to describe fire frequency (Brown et al., 1999). MFI was calculated for the entire study area as well as for its northern and southern parts. We were not able to further subdivide the area because sample size declined substantially with every subdivision. MFI along with its bootstrapped 95% confidence intervals were estimated using R software (R Development Core Team, 2012). The Weibull median probability interval (WMPI) was calculated in FHX2 software (Grissino-Mayer, 2001b). The WMPI is the fire interval associated with the 50% exceedance probability of a modeled Weibull distribution of all fire intervals from a fire chronology and it is a better estimate of central tendency in skewed distributions which are typical of fire interval distributions (Grissino-Mayer, 1999). The MFI and WMPI will be similar if fire intervals are distributed normally, but, in general, fire interval data are positively skewed since there is no upper bound on intervals while 1 year is the lowest possible interval (Brown et al., 1999).

We also explored our data for spatial differences in fire occurrence between the northern and southern part of the study area. To detect possible temporal changes of the fire regime, the years of analysis were separated into two discrete, non-overlapping periods: from 1845 until the end of the Second World War in Greece (1945), (period 1845–1945), which represents a period with important human presence and an augmented number of battles in the mountain range, especially during the Second World War (Antonakakis, 2006), and the more recent years (1946–2010), which represents the onset of the modern history of Greece, with the gradual appearance and establishment of the Forest Services as well as land-use changes associated with land abandonment and afforestation of former agricultural land (Koutsias et al., 2012a). The MFI and WMPI were estimated for the spatial and the temporal disaggregation of the study area using both all fire events and the 25%-scarred filter. The Mann–Whitney test was conducted to check for differences in the temporal pattern of percentage area burned using the STATISTICA software (Statsoft Inc., v7).

For the events representing “major” fires, their estimated extent was delineated in space through a proximity analysis and the areas of *P. nigra* forests affected by each “major” fire event were mapped. In more detail, every single active recorder tree for these years was assigned either as “burned” or “not burned” status, according to the tree-rings’ analysis. Space between the recorder trees was assigned into two categories (burned – not burned) with the use of Thiessen polygons, based on the assumption that the presence of a fire event at an non-sampled location is predicted best by the presence of this fire event at the nearest data point of reference. Thiessen polygons were selected in this study because they allow drawing a defined fire extent, useful in quantitative analysis, while they require the least amount of parameterization and subjective user input (Farris et al., 2010).

3. Results

3.1. Fire records

We were able to cross-date samples derived from 54 trees (87%), which were equally distributed in the northern and southern parts of the study area (27 trees per site) and identify their fire dates. The period covered by the fire-scarred samples was 290 years (1721–2010). Within this period a total of 173 fire scars, representing 38 fire years were detected. The oldest confirmed fire date was 1801, while 1823 and 1830 represented the first fire dates recorded on more than one sample. Fire interval analyses were conducted in the period considered to have adequate sample depth, at least 10% of the total number of trees and a minimum of six recording sample trees. This period was 1845–2010 (165 years) (Fig. 2).

Comparing data obtained from the analysis of fire scars with the fire incidents recorded by the Forest Service, it was evident that the three largest fire events of the last 33 years that burned >100 ha (1977, 1998 and 2007) were correctly identified.

3.2. Fire season

Seasonality of scarring could be determined on 64% of the fire scars. The majority of fire scars occurred during the period from summer to fall, with 97% being formed in latewood, late earlywood or while tree-ring growth was dormant. The most common seasonal position was latewood (69%). The Forest Service data information regarding seasonality is insufficient in terms of their quality and quantity. Nevertheless, 60% of the fire records are reported for late summer season (July–August).

3.3. Fire interval analysis

During the 165-year period (1845–2010), 34 fires occurred within the total area covered with Black pine forests of our study site (3370 ha) and fire intervals ranged from 1 to 12 years. Based on the 25% filter analysis, 11 events represent major fires, with fire intervals ranging from 1 to 31 years. Mean fire interval per-tree was equal to 29.5 years, ranging from 8 to 103 years.

3.4. Fire occurrence and extent

Considering the percentage of scarred trees per fire year, the two latest fires (2007 and 1998) constituted the largest fire events, since they scarred 80% and 50%, respectively, of the available recorders. The spatial configuration of the scarred recorders and the fire extents that their relative location implies (Fig. 3) confirm the magnitude of the 2007 as the greatest fire event recorded in the study area (burned 84% of the recorded study area).

The two largest fires of the 19th century were that of the year 1845, affecting 50% of the recorders, and of the year 1860, recorded in 44% of the recorders (Table 3). However, both these fires were recorded in neighboring trees. Based on Thiessen polygons analysis, the year 1879 represents the most extended fire event of the 19th century, due to the fact that the recorders were most widely distributed in space (Fig. 3). Fires that occurred in the years of 1944 and 1945 can also be considered as large, but it is very likely to be associated with the augmented number of battles that took place in the mountain range during the Second World War.

3.5. Spatial and temporal patterns

No significant differences were detected between the northern and southern parts of the study area in terms of fire intervals or percentage scarred as far as it concerns the 165-year period (1845–2010). Fire chronologies of the areas were statistically independent (i.e., not synchronous) both for all fires and for the 25% filter. Only three fires have burned simultaneously in the two areas: in 1879, 1945 and 2007 (Fig. 3 and Table 3).

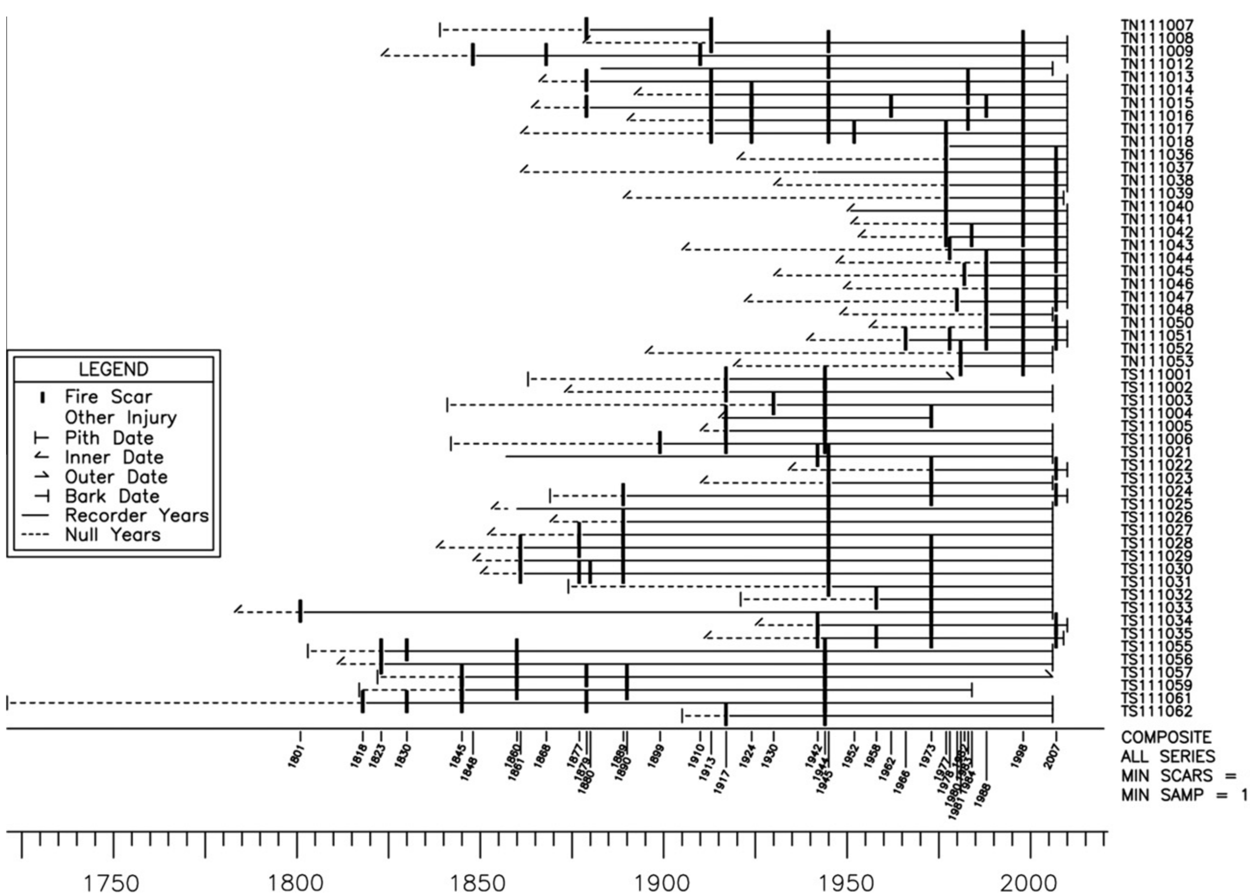

Fig. 2. Fire history chart for the study area. Filled vertical bars are fire dates. Solid horizontal lines indicate recording periods; dashed horizontal lines are non-recording periods (e.g., before formation of first scar). Samples were separated in two groups with their number representing N for North and S for South.

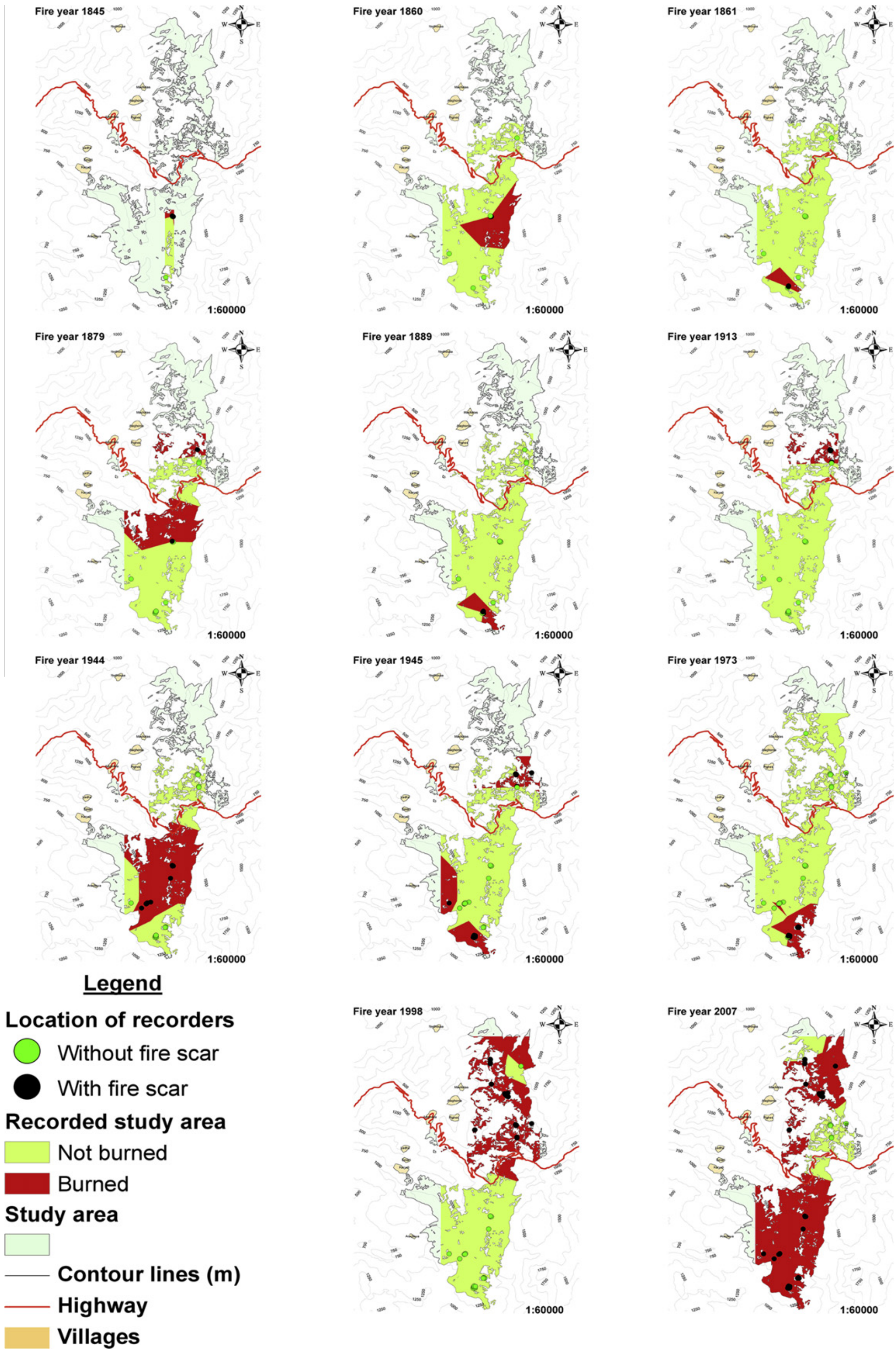

Fig. 3. Delineation of the areas burned by the major fire events from 1845 to 2007 in *Pinus nigra* forests of Mt. Taygetos (study area) as derived by fire-scar analysis. Burned areas (in red) were considered areas proximal to the scarred Black pine individuals (black dots) and were delineated with the use of Thiessen polygons. Topography (contour lines every 250 m) and the existing human constructions (villages and the main asphalt road) are also presented. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Comparing the two time periods of analysis, from 1845 until the Second World War (1845–1945) and the more recent years (1946–2010), no significant differences were detected either for all fires or for the 25%-scarred filter in terms of mean fire interval or percentage of trees scarred. By performing the same analysis for the northern and southern parts of the study area, estimates of MFI for all fires were found to be significantly different in the more recent period (1946–2010), with a higher MFI in the southern part (Table 2). During the most recent 34 years, several small fire events (eight fire years) were recorded in the northern part, as well as the 1998 large fire. On the contrary, the southern part had not been burned since 1973 with a 34-year fire-free interval from 1973 to 2007.

The average percent of study area burned per fire year was 25%. With the exception of 1 year in the 19th century, 1879, fire years that exceeded the average value of study area burned are 1944–1998–2007, with the greater being 2007. The trend of increasing percent of burned area noted since 1944 (Table 3) was found to be statistically significant (Mann–Whitney $U = 4.0$, $p = 0.045$).

4. Discussion

The results of this study add to the limited published data (Fulé et al., 2008; Touchan et al., 2012) on fire history reconstruction through fire-scars in the Mediterranean Europe. A previous study of fire history in Black pine forests from Spain (Fulé et al., 2008) reported 57 years as the longest fire-free interval, while 11 fire dates were recorded in 172 years. The study by Touchan et al. (2012) in Northern Greece had only eight fire-scarred samples from a 4-ha *P. nigra* stand, a sample size probably insufficient to estimate fire interval statistics with confidence. However, their study documented the occurrence of surface fires for over seven centuries. Our data covered 165 years with a total of 34 fire events. The overall mean fire interval for the 3370 ha covered with Black pine at Mount Taygetos was 4.9 years, while 16.2 years was the mean fire interval for the larger fires (25%-scarred filter). The mean fire interval estimated per tree was equal to 29.5 years. The range of mean fire intervals recorded allow us to rank them in the category of "predictable stand-thinning fire" regime. This category was suggested by Keeley and Zedler (1998) as comprising ecosystems that are characterized by increased biomass production and frequent presence of low intensity ground fire, which can sometimes be converted into local crown fires.

Numerous data on fire history and reconstruction through fire-scars are available, mostly from North and South America (Falk et al., 2011). Among the most thoroughly studied species is *Pinus ponderosa* (e.g. Fulé et al., 1997; Brown et al., 1999; Van Horne and Fulé, 2006), which has several characteristics similar to the Black pine. For instance, like Black pine, mature ponderosa pine trees are well adapted to survive surface fires, due to their thick bark and high crown (Brown and Wu, 2005). The historical fire regime of all fires at Mount Taygetos with a fire return interval ranging from approximately 5–16 years is similar, though somewhat longer, to those found for ponderosa pine forests on landscapes of similar size (3.7 years, Fulé et al., 1997; 1–10 years, Brown et al., 1999; 2.2 years, Farris et al., 2010).

The majority of fire scars recorded on the Black pines of Mount Taygetos was in the driest period of the year, from summer to fall, as has been reported for other areas with Mediterranean climate (Stephens et al., 2003). Our results are in agreement with those of Touchan et al. (2012) who found that almost all fires in an old Black pine forest in Northern Greece occurred during the period of active tree growth, forming mid-earlywood to latewood scars that represent fires occurring during the period from mid-summer to early fall. At the national level, fires occurring from July to September accounted for 85% of the total burned area (Tsagari et al., 2011). The intra-ring position of fire scars found is similar throughout the period 1801 to 2010, a fact that leads us to assume that fire season has not changed during the last 210 years, with most of the fires occurring during the summer xerothermic period and especially in the late summer.

Neither fire frequency nor percentage of trees scarred by fires varied significantly within the period of analysis. This result may

Table 2
Fire frequency estimations for Mount Taygetos. Two estimates of mean fire interval are presented; one for the entire study area and one for its' Northern and Southern part during the 165 years-period (1845–2010) and for two discrete, non-overlapping periods: 1845–1945 and 1946–2010. MFI and its 95% confidence interval were estimated using bootstrap resampling. A Weibull estimate of the median probability interval (WMPI) along with its standard deviation is also given. Sample size (n) is 54 fire-scarred trees for the entire study area ($n = 27$ for Northern and $n = 27$ for Southern part).

Area	Period	No. of intervals	MFI boot[a]	Bootstrap confidence intervals		WMPI (±SD)[b]
				Lower bound	Upper bound	
No filter						
All study area	1845–2010	33	4.9	3.7	6.1	4.1 ± 3.7
Northern part		18	8.4	5.0	12.3	5.9 ± 8.2
Southern part		16	10.1	6.1	14.6	7.2 ± 9.7
All study area	1845–1945	18	5.6	3.8	7.3	4.6 ± 4.1
Northern part		6	8.4	9.0	23.8	14.9 ± 9.2
Southern part		13	7.7	4.2	11.1	5.5 ± 7.4
All study area	1946–2010	14	4.1	2.7	5.7	3.5 ± 3.0
Northern part		12	4.8	2.7	6.9	3.7 ± 4.1
Southern part		2	20.7	13.0	34.0	20.1 ± 9.3
25% Filter						
All study area	1845–2010	10	16.2	9.9	22.4	13.0 ± 12.4
Northern part		4	32.0	15.3	47.8	30.4 ± 15.6
Southern part		8	20.3	9.3	32.8	13.7 ± 20.9
All study area	1845–1945	7	14.3	6.7	21.9	10.4 ± 13.3
Northern part		2	33.0	31.0	34.9	33.2 ± 1.1
Southern part		6	16.7	4.8	33.2	9.5 ± 20.8
All study area	1946–2010	2	20.7	9.1	32.2	20.5 ± 7.8
Northern part		1	31.0	9.0	53.0	25.7 ± 23.2
Southern part		1	31.0	25.1	36.9	31.4 ± 3.1

[a] Mean fire interval using bootstrap resampling.
[b] Weibull median (50% exceedance) probability interval in years and standard deviation.

Table 3
Eleven largest fires in terms of percentage of scarring during the 165 year analysis period (1845–2010). Sample size $n = 54$ fire-scarred trees.

Year	Total scars	Recorder trees	Percent scarred	Fire interval	Percent of area burned[a]
1845	3	6	50		12
1860	4	9	44	15	21
1861	3	12	25	1	5
1879	5	16	31	18	32
1889	6	19	32	10	7
1913	7	24	29	24	6
1944	12	32	38	31	58
1945	17	35	49	1	23
1973	12	38	32	28	10
1998	25	50	50	25	36
2007	40	50	80	9	84

[a] Represents percent of area burned within the borders of each fire event recorded area according to Thiessen polygons analysis.

seem surprising compared to other regions of the world that have shown a reduction in fire occurrence in the 20th century, mainly due to climatic changes and secondly to land-use changes and fire suppression efforts (Morgan et al., 2008; Girardin et al., 2012). However, in the Euro-Mediterranean countries, wildfires have been occurring at an increasing rate since the early 1970s (Pausas and Fernández-Muñoz, 2012; Koutsias et al., 2012b). Especially in mountainous areas, agricultural land abandonment, decline of pastoral activities and abandonment of traditional practices of exploitation of timber and wood resources are considered important contributors of increased fire hazard (Körner et al., 2005; Moreira et al., 2011; Koutsias et al., 2012). Fire suppression policies and improvement of firefighting capabilities have reduced the total number of fires. However, they have not been able to lower the occurrence of large fires in the Mediterranean forests, a fact probably due to the increased fuel accumulation that has originated from land use changes further aggravated by extended drought and warmer periods recently occurring (Pausas and Fernández-Muñoz, 2012). As a result, during the last decades, the area burned has increased considerably in Greece, like in other Euro-Mediterranean countries (Díaz-Delgado et al., 2004; Moreira et al., 2011). This seems to be the case for Mount Taygetos as well, with the latest fires of 1998 and 2007 being the most widespread incidents recorded during the 165 years of the current fire history reconstruction.

Reconstructing representative fire histories from fire scars requires an understanding of how fire-scar sampling networks record fire years (Farris et al., 2010). Large fires have a high probability of being detected by a fire-scar network, in contrast to small fires that are more numerous but burn little cumulative area. The 25%-scarred filtered composites have been used to represent the fires that are likely to have been more widespread within the study site, consistent with numerous studies (Fulé et al., 1997, 2009; Stephens et al., 2003; van Horne and Fulé, 2006; Farris et al., 2010). However, none of the 9 larger fires prior to 1998 affected an equivalent number of trees as the two latest fires. Specifically, the fire of 2007 appears to be the most extended one, essentially covering the entire study area. The severity of recent fires cannot be compared to previous fire events due to the lack of old-photos that show what these forests looked like. Nevertheless, the extended forest area covered with Black pine forests as well as the presence of mixed forests with *A. cephalonica*, which like the majority of *Abies* species (Furyaev et al., 1983; Ali et al., 2008; Whitlock et al., 2008) is not adapted to fire, lead us to the assumption that in the past there were no stand-replacing fires within the Mountain range.

In conclusion, the fire regime in the Black pine forest of Mount Taygetos seems to present a consistent pattern of fairly regular surface fires, mostly burning in late summer. In contrast to many forests with fire-tolerater pines (Keeley, 2012) in North America and Europe, where a long period of fire exclusion is believed to have contributed to recent increase in wildfire size and severity (e.g., Cocke et al., 2005; Hurteau et al., 2011; Keeley, 2012), Mount Taygetos continued to experience frequent fires through the 20th century. The longest fire-free gap detected in the southern part of the study area lasted 34 years and it started from 1973 to 2007. This fact in association with abandonment of traditional forest management practises as well as afforestation of former agricultural land occurred in Mount Taygetos as reported in many mountainous regions of the Mediterranean Basin (Pausas and Fernández-Muñoz, 2012; Koutsias et al., 2012b), seem to have lead to an increasing fuel accumulation that could be related to the fact that 2007 burned mostly as a crown fire.

Our study has provided additional evidence that *P. nigra* is indeed a fire-resistant tree species provided that it is exposed to surface fires, even if they are recurrently occurring. Shifts from this pattern may lead to local extirpation of the species, as in the case of severe and extended crown fires. To assist integrated forest management further research into fuel management, as well as and potential effects from changes in climate, is needed to clarify the factors leading to increasingly large and severe wildfires, in a region that is expected to be severely impacted by climatic change (IPCC, 2007; Giorgi and Lionello, 2008).

Acknowledgments

This research was financed by the European project FUME (Grant agreement no. 7243888). Part of the laboratory analysis has been conducted in the NAU School of Forestry in Flagstaff with financial support from the Ecological Restoration Institute, Northern Arizona University. The authors would like to express their thanks to the three anonymous reviewers for their valuable comments on an earlier version of the manuscript. Dr. Nikos Fyllas has helped with statistical analysis in R. The authors thank the staff of the Forest Service of Kalamata who helped in field work and provided available fire records. Additional thanks to George Seintis for assistance in samples preparation.

References

Ali, A.A., Asselin, H., Larouche, A.C., Bergeron, Y., Carcaillet, C., Richard, P.J.H., 2008. Changes in fire regime explain the Holocene rise and fall of *Abies balsamea* in the coniferous forests of western Québec, Canada. The Holocene 18 (5), 693–703.

Antonakakis, N.Ch., 2006. National Resistance of EAM-ELAS in Taygetos and Parnon 1941–1944, Alfeios Editions, Athens, (in Greek), 244pp.

Arianoutsou, M., Christopoulou, A., Kazanis, D., Tountas, Th., Ganou, E., Bazos, I., Kokkoris, I., 2010. Effects of fire on high altitude coniferous forests of Greece. In: Viegas D.X. (Ed.), Proceedings of the VI International Conference on Forest Fire Research, Electronic Edition.

Baisan, C.H., Swetnam, T.W., 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, USA. Can. J. For. Res. 20, 1559–1569.

Bond, W.J., Woodward, F.I., Midgley, G.F., 2005. The global distribution of ecosystems in a world without fire. New Phytol. 165, 525–538.

Brown, J.K., Smith, J.K., 2000. Wildland fire in ecosystems: effects of fire on flora. In: Gen. Tech. Rep. RMRS-GTR-42, vol. 2. USDA Forest Services, Rocky Mountain Research Station, Ogden, 257 pp.

Brown, M., Wu, R., 2005. Climate and disturbance forcing of episodic tree recruitment in a Southwestern Ponderosa pine landscape. Ecology 86, 3030–3038.

Brown, P.M., Kaufmann, M.R., Shepperd, W.D., 1999. Long-term, landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. Landsc. Ecol. 14, 513–532.

Christopoulou, A., Andriopoulos, P., Pleniou, M., Koutsias, N., Arianoutsou, M., 2010. Effects of 2007 fire on Black pine forests (*Pinus nigra* JF Arnold) of Mt. Taygetos; spatial assessment of the availability of unburned patches. In: Book of Abstracts of the 5th Conference of the Hellenic Ecological Society: "Ecological Processes in space and time". Page 208 (in Greek).

Cocke, A.E., Fulé, P.Z., Crouse, J.E., 2005. Forest change on a steep mountain gradient after extended fire exclusion: San Francisco Peaks, Arizona, USA. J. Appl. Ecol. 42, 814–823.

Díaz-Delgado, R., Lloret, F., Pons, X., 2004. Spatial patterns of fire occurrence in Catalonia, NE, Spain. Landsc. Ecol. 19, 731–745.

Dimitrakopoulos, A.P., Vlahou, M., Anagnostopoulou, Ch.G., Mitsopoulos, I.D., 2011. Impact of drought on wildland fires in Greece. Implications of climatic change? Clim. Change 109, 331–347.

Falk, D.A., Heyerdahl, E.K., Brown, P.M., Farris, C., Fulé, P.Z., McKenzie, D., Swetnam, T.W., Taylor, A.H., van Horne, M.L., 2011. Multiscale controls of historical forest fire regimes: new insights from fire-scar networks. Front Ecol. Environ. 9, 446–454.

Farris, C.A., Baisan, C.H., Falk, D.A., Yool, S.R., Swetnam, T.W., 2010. Spatial and temporal corroboration of a fire-scar based history in a frequently burned ponderosa pine forest. Ecol. Appl. 20, 1598–1614.

Fernandes, P.M., Vega, J.A., Jiménez, E., Rigolot, E., 2008. Fire resistance of European pines. For. Ecol. Manage. 256, 246–255.

Fulé, P.Z., Covington, W.W., Moore, M.M., 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecol. Appl. 7, 895–908.

Fulé, P.Z., Ribas, M., Gutiérrez, E., Vallejo, R., Kaye, M.W., 2008. Forest structure and fire history in an old *Pinus nigra* forest eastern Spain. For. Ecol. Manage. 255, 1234–1242.

Fulé, P.Z., Korb, J.E., Wu, R., 2009. Changes in forest structure of a mixed conifer forest, southwestern Colorado, USA. For. Ecol. Manage. 258, 1200–1210.

Furyaev, V.V., Wein, R.W., MacLean, D.A., 1983. Fire influences in *Abies*-dominated forests. In: Wein, R.W., MacLean, D.A. (Eds.). The Role of Fire in Northern Circumpolar Ecosystems. SCOPE, pp. 221–234.

Giorgi, F., Lionello, P., 2008. Climate change projections for the Mediterranean region. Glob. Planet Change 63, 90–104.

Girardin, M.P., Ali, A.A., Carcaillet, C., Gauthier, S., Hély, C., Le Goff, H., Terrier, A., Bergeron, Y., 2012. Fire in managed forests of eastern Canada: risks and options. For. Ecol. Manage.. http://dx.doi.org/10.1016/j.foreco.2012.07.00.

Grissino-Mayer, H.D., 1999. Modeling fire interval data from the American Southwest with the Weibull distribution. Int. J. Wildland Fire 9 (1), 37–50.

Grissino-Mayer, H.D., 2001a. Evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA. Tree-Ring Res. 57, 205–221.

Grissino-Mayer, H.D., 2001b. FHX2-software for analyzing temporal and spatial patterns in fire regimes from tree rings. Tree-Ring Res. 57, 115–124.

Gutsell, S.L., Johnson, E.A., 1996. How fire scars are formed: coupling a disturbance process to its ecological effect. Can. J. For. Res. 26, 166–174.

Habrouk, A., Retana, J., Espelta, J.M., 1999. Role of heat tolerance and cone protection of seeds in the response of three pine species to wildfires. Plant Ecol. 145, 91–99.

Heyerdahl, E.K., Mckay, S.J., 2001. Condition of live fire-scarred ponderosa pine trees 6 years after removing partial cross sections. Tree-Ring Res. 57, 131–139.

Heyerdahl, E.K., Mckay, S.J., 2008. Condition of live fire-scarred ponderosa pine trees 11 years after removing partial cross sections. Tree-Ring Res. 6, 61–64.

Hurteau, M.D., Stoddard, M.T., Fulé, P.Z., 2011. The carbon costs of mitigating high-severity wildfire in southwestern ponderosa pine. Glob. Change Biol. 17, 1516–1521.

IPCC, 2007. Climate change 2007: synthesis report. In: Core Writing Team, Pachauri, R.K., Reisinger, A. (Eds.). Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 104 p.

Keeley, J.E., 2012. Ecology and evolution of pine life histories. Ann. Forest Sci. 69, 445–453.

Keeley, J.E., Zedler, P.H., 1998. Evolution of life histories in *Pinus*. In: Richardson, D.M. (Ed.), Ecology and Biogeography of *Pinus*. Cambridge University Press, Cambridge, UK, pp. 219–250.

Körner, Ch., Sarris, D., Christodoulakis, D., 2005. Long-term increase in climatic dryness in the East-Mediterranean as evidenced for the island of Samos. Reg. Environ. Change 5, 27–36.

Koutsias, N., Arianoutsou, M., Kallimanis, A.S., Mallinis, G., Halley, J.M., Dimopoulos, P., 2012a. Where did the fires burn in Peloponnisos, Greece the summer of 2007? Evidence for a synergy of fuel and weather. Agr. For. Met. 156, 41–53.

Koutsias, N., Xanthopoulos, G., Founda, D., Xystrakis, F., Nioti, F., Pleniou, M., Mallinis, G., Arianoutsou, M., 2012b. On the relationships between forest fires and weather conditions in Greece from long-term national observations (1894–2010). Int. J. Wildland Fire. http://dx.doi.org/10.1071/WF12003.

Kuniholm, P.I., Groneman, C., 2012. International Tree-ring Data Bank. <http://www.ncdc.noaa.gov/paleo/treering.html>.

Miller, J.D., Skinner, C.N., Safford, H.D., Knapp, E.E., Ramirez, C.M., 2012. Trends and causes of severity, size, and number of fires in Northwestern California, USA. Ecol. Appl. 22, 184–203.

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbati, A., Corona, P., Vaz, P., Xanthopoulos, G., Mouillot, F., Bilgili, E., 2011. Landscape–wildfire interactions in southern Europe: implications for landscape management. J. Environ. Manage. 92, 2389–2402.

Morgan, P., Heyerdahl, E.K., Gibson, C.E., 2008. Multi-season climate synchronized forest fires throughout the 20th century, Northern Rockies, USA. Ecology 89, 717–728.

Niklasson, M., Zin, E., Zielonka, T., Feijen, M., Korczyk, A., Churski, M., Samojlik, T., Jedrzejewska, B., Gutowski, J., Brzeziecki, B., 2010. A 350-year tree-ring fire record from Białowieza Primeval Forest, Poland: implications for Central European lowland fire history. J. Ecol. 98, 1319–1329.

Ordóñez, J.L., 2004. Análisis y modelización del reclutamiento de *Pinus nigra* en zonas afectadas por grandes incendios, Tesis Doctoral. CREAF, Universitat Autònoma de Barcelona.

Ordóñez, J.L., Retana, J., 2004. Early reduction of post-fire recruitment of *Pinus nigra* by post-dispersal seed predation in different time-since-fire habitats. Ecography 27, 449–458.

Ordóñez, J.L., Franco, S., Retana, J., 2004. Limitation of the recruitment of *Pinus nigra* in a gradient of post-fire environmental conditions. Ecoscience 11, 296–304.

Ordóñez, J.L., Retana, J., Espelta, J.M., 2005. Effects of tree size, crown damage, and tree location on post-fire survival and cone production of *Pinus nigra* trees. For. Ecol. Manage. 206, 109–117.

Ordóñez, J.L., Molowny-Horas, R., Retana, J., 2006. A model of the recruitment of *Pinus nigra* from unburned edges after large wildfires. Ecol. Model. 197, 405–417.

Pausas, J.G., Fernández-Muñoz, S., 2012. Fire regime changes in the Western Mediterranean Basin: from fuel-limited to drought-driven fire regime. Clim. Change 110, 215–226.

Pausas, J.G., Keeley, J.E., 2009. A burning story: the role of fire in the history of life. BioScience 59, 593–601.

Pausas, J.G., Llovet, J., Rodrigo, A., Vallejo, R., 2008. Are wildfires a disaster in the Mediterranean basin? –a review. Int. J. Wildland Fire 17, 713–723.

Piñol, J., Terradas, J., Lloret, F., 1998. Climate warming, wildfire hazard and wildfire occurrence in coastal eastern Spain. Clim. Change 38, 345–357.

R Development Core Team, 2012. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. <http://www.R-project.org/>.

Retana, J., Espelta, J.M., Habrouk, A., Ordóñez, J.L., de Solà-Morales, F., 2002. Regeneration patterns of three Mediterranean pines and forest changes after a large wildfire in Northeastern Spain. Ecoscience 9, 89–97.

Skinner, C.N., Burk, J.H., Barbour, M.G., Franco-Vizcaíno, E., Stephens, S.L., 2008. Influences of climate on fire regimes in montane forests of north-western Mexico. J. Biogeogr. 35, 1436–1451.

Skinner, C.N., Abbott, C.S., Fry, D.L., Stephens, S.L., Taylor, A.H., Trouet, V., 2009. Human and climatic influences on fire occurrence in California's North Coast Range, USA. Fire Ecol. 5, 73–99.

Stephens, S.L., Skinner, C.N., Gill, S.J., 2003. A dendrochronology based fire history of Jeffrey pine-mixed conifer forests in the Sierra San Pedro Martir, Mexico. Can. J. Forest Res. 33, 1090–1101.

Strumia, G., Wimmer, R., Grabner, M., 1997. Dendroclimatic sensitivity of *Pinus nigra* Arnold in Austria. Dendrochronologia 15, 129–137.

Swetnam, T., Baisan, C., 1996. Historical fire regime patterns in the southwestern United States since AD 1700. In: Allen, C.D. (Ed.) Fire Effects in Southwestern Forest: Proceedings of the 2nd La Mesa Fire Symposium, pp. 11–32. USDA Forest Service, Rocky Mountain Research Station, General Technical, Report RM-GTR-286.

Tapias, R., Gil, L., Fuentes-Utrilla, P., Pardos, J.A., 2001. Canopy seed banks in Mediterranean pines of southeastern Spain: a comparison between *Pinus halepensis* Mill, *P. pinaster* Ait, *P. nigra* Arn., and *P. pinea* L.. J. Ecol. 89, 629–638.

Tapias, R., Climent, J., Pardos, J.A., Gil, L., 2004. Life histories of Mediterranean pines. Plant Ecol. 171, 53–68.

Touchan, R., Baisan, Ch., Mitsopoulos, I.D., Dimitrakopoulos, A.P., 2012. Fire history in European black pine (*Pinus nigra* Arn.) forests of the Valia Kalda, Pindus mountains, Greece. Tree-Ring Res. 68, 45–50.

Trabaud, L., Campant, C., 1991. Difficulté de recolonisation naturelle du Pin de Saizmann *Pinus nigra* Arn. ssp. *salzmannii* (Dunal) Franco après incendie. Biol. Conserv. 58, 329–343.

Tsagari, C., Karetsos, G., Proutsos, N., 2011. Forest fires in Greece, 1983–2008. In: WWF-Hellas and NAGREF – Institute of Mediterranean Forest Ecosystems and Forest Products Technology. 122 p., Electronic Edition, (in Greek).

van Horne, M.L., Fulé, P.Z., 2006. Comparing methods of reconstructing fire history using fire scars in a southwestern United States ponderosa pine forest. Can. J. For. Res. 36, 855–867.

Whitlock, C., Marlon, J., Briles, C., Brunelle, A., Long, C., Bartlein, P., 2008. Long-term relations among fire, fuel, and climate in the north-western US based on lake-sediment studies. Int. J. Wildland Fire 17, 72–83.

Yamaguchi, D.K., 1991. A simple method for cross-dating increment cores from living trees. Can. J. For. Res. 21, 414–416.