

Original Article

Fire history of *Pinus nigra* in Western Anatolia: A first dendrochronological study

Evrin A. Şahan^{a,*}, Nesibe Köse^b, Ünal Akkemik^b, H. Tuncay Güner^b, Çağatay Tavşanoğlu^c, Anıl Bahar^c, Valerie Trouet^d, H. Nüzhet Dalfes^a

^a Eurasia Institute of Earth Sciences, Istanbul Technical University, 34469, Istanbul, Turkey

^b Faculty of Forestry, Forest Botany Department, Istanbul University-Cerrahpaşa, Istanbul, Turkey

^c Division of Ecology, Department of Biology, Hacettepe University, Beytepe, 06800, Ankara, Turkey

^d Laboratory of Tree-Ring Research, University of Arizona, Tucson, USA

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ABSTRACT

Forests in the Mediterranean basin frequently experience fires due to both anthropogenic and natural causes. There are concerns that the fire season will prolong in the Mediterranean basin, the fire frequency will increase with ongoing climate change, moreover, the fire regimes will shift from surface fires to local crown fires. Here, we aim to improve our understanding of the fire regime components of black pine forests in Turkey by 1) reconstructing a high-resolution fire chronology based on tree rings, 2) revealing the seasonality of fires, 3) investigating the relationship between fire and climate, and 4) comparing our reconstruction results with documentary data from forest management units. We collected 62 fire-scarred trees from three sites in Kütahya and developed a 368 year-long (1652–2019) composite fire chronology using dendrochronological methods. We found that at two sites major fire years coincided with dry years. Two major fire years (1853 and 1879) were common to all sites and two additional fire years (1822 and 1894) were found at two sites. Our results show a sharp decline in fire frequency after the beginning of the 20th century at all sites that can be attributed to increased fire suppression efforts and forest management activities in the 20th century. Our results suggest that the spread of fires has been actively suppressed since the first forest protection law in Turkey. Yet, tree-ring based and documentary data corroboration shows that seasonality did not change over the past +350 years.

1. Introduction

Wildfire is a key factor in shaping ecological landscapes by affecting ecosystem processes, forest dynamics and structure, ecological functioning, and biodiversity (Bowman et al., 2009; Touchan et al., 2012; Piha et al., 2013; Pausas and Bond, 2020; Szymczak et al., 2020). Forest ecosystems in the Mediterranean Basin have been experiencing frequent fires of both anthropogenic and natural origins over the late Quaternary period (Carrión et al., 2003; Pausas et al., 2008). The severity and extent of fires in the Mediterranean basin vary on spatial and temporal scales (Pausas, 2004). Although the number of anthropogenic fires has increased significantly in recent decades (Turco et al., 2017), climatic factors are still the major determinants of the fire occurrence in the Mediterranean basin (Dube, 2009; Türkeş and Altan, 2012; Pausas and Ribeiro, 2013; Tatlı and Türkeş, 2014; Bekar and Tavşanoğlu, 2017). Due to climate change, an increase in temperatures, a decrease in

precipitation, and an increased drought risk are expected in the Mediterranean basin in the near future (FAO, 2018; IPCC, 2019). These future climatic conditions will affect the flammability of vegetation and an increase in the severity of fires is therefore also expected in Mediterranean forests (Turco et al., 2017; IPCC, 2019). At the global scale, the occurrence of severe forest fires will create feedback effects on climate change with the release of greenhouse gases (e.g., CO₂, CH₄, N₂O) and by increasing the surface albedo (IPCC, 2019). Increased fire risk also threatens the present occurrence and the future distribution of some non-fire-prone species by changing regional fire regimes (FAO, 2018).

In the Mediterranean basin, many woody plants have developed various strategies to survive or regenerate after fire. In some pine species (e.g., *Pinus halepensis* Mill., *Pinus brutia* Ten.), the presence of serotinous cones is an adaptation that allows the seeds in the cones to survive crown fires (Pausas et al., 2008; Hernández-Serrano et al., 2013). Other fire adaptations include the formation of thick and insulating bark,

* Corresponding author.

E-mail address: sahan17@itu.edu.tr (E.A. Şahan).

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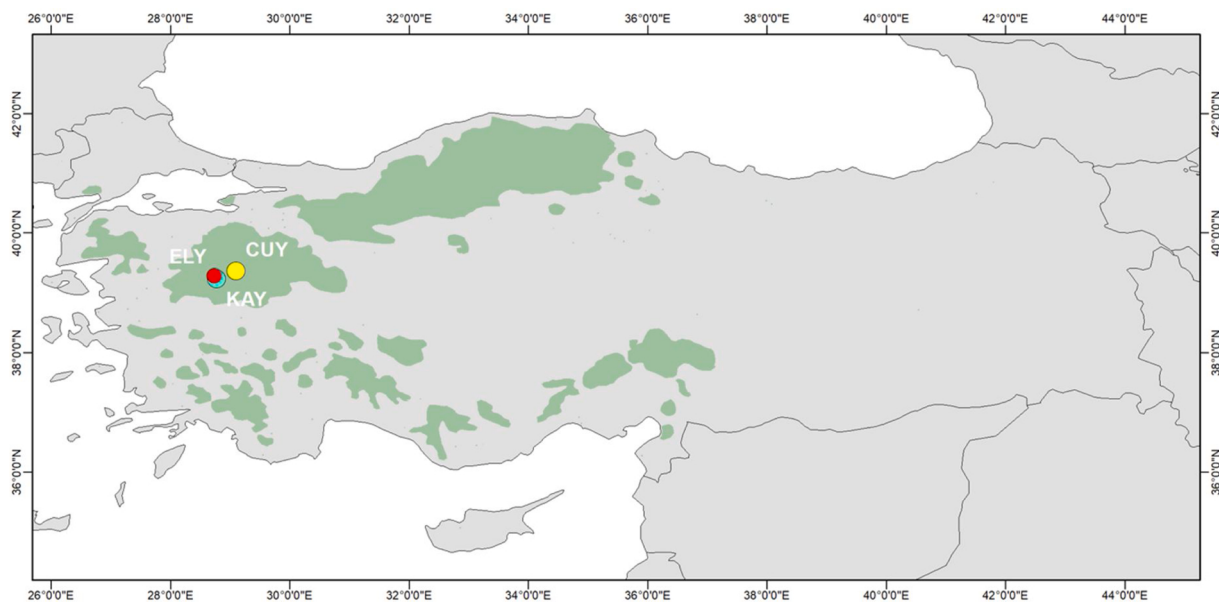


Fig. 1. Distribution of *P. nigra* in Turkey (EUFORGEN, 2004) and the three study sites.

post-fire seedling recruitment, and resprouting from basal or epicormic buds (Pausas et al., 2008; Paula et al., 2009; Keeley et al., 2012; Çatav et al., 2018; Tavşanoğlu and Pausas, 2018). Unlike species adapted to crown fires, the post-fire recovery of *Pinus nigra* JF Arnold (black pine) relies solely on surviving individuals within the burned site and seed dispersal from surrounding unburned forest patches (Richardson, 2000; Tavşanoğlu, 2008; Christopoulou et al., 2014; Prichard et al., 2017; Szymczak et al., 2020). In this species, the thick bark protects vital tissues from the impact of fire and enhances the probability of survival of the trees during surface fires, while self-pruning of dead branches at the lower part of the bole creates a gap between the understorey and tree crown that inhibits the transition of a surface fire into a crown fire (Pausas et al., 2008; Keeley, 2012; Keeley et al., 2012; Touchan et al., 2012).

There are concerns, however, over the change of severity and fire regimes from low-intensity surface fires to local crown fires in the mountainous forest ecosystems of the Mediterranean basin (Fyllas and Troumbis, 2009; Keeley, 2012; Christopoulou et al., 2013). Indeed, such crown fires have occurred more frequently in recent years in these ecosystems and may result in local and regional extinctions (Christopoulou et al., 2013) or vegetation changes (Fyllas and Troumbis, 2009; Christopoulou et al., 2019). Moreover, recent evidence suggests that warming and increasing drought negatively affect seedling establishment and tree growth in montane conifer species (Janssen et al., 2018; Rodman et al., 2020). Understanding the response of dominant tree species in the mountainous Mediterranean forests to past climatic variability and fire regimes is therefore important for the development of better management strategies to conserve these forests under climate change.

To put recent fire trends in a long-term context and to understand the contribution of anthropogenic climate change to these trends, we need records of past fires at a high spatial and temporal resolution that extend back over decades or centuries. Written records of annual and seasonal fire variability can be used for this purpose (Swetnam, 1993; Keeley et al., 2012). In Turkey, the first written forest fire records start during the Ottoman Era in 1918 (Kılıç, 2020), but for many areas of Anatolia, such documentary data have only short-term coverage.

Another method to study regional fire history at annual resolution is through tree-ring based fire reconstruction. Dendrochronological methods are widely used to determine past regional fire regime characteristics (Piha et al., 2013), including fire interval statistics (Bowman

et al., 2009; Drobyshev et al., 2012; Pausas and Fernández-Muñoz, 2012; Prichard et al., 2017; Slimani et al., 2014), and fire-climate relationship (e.g., Lafon et al., 2005; Taylor et al., 2008; Skinner et al., 2009; Drobyshev et al., 2012; Margolis et al., 2017; Taylor et al., 2016). Such dendrochronological studies have focused primarily on North America (e.g., Swetnam and Baisan, 1996; Falk et al., 2011), and to a lesser extent have also included studies in Northern Europe (Lageard et al., 2000; Kitenberga et al., 2019), Asia (Ivanova et al., 2010; Mazarzhanova et al., 2017; Yao et al., 2017), and the Mediterranean basin (Fulé et al., 2008; Touchan et al., 2012; Christopoulou et al., 2013; Fournier et al., 2013; Slimani et al., 2014; Molina-Terrén et al., 2016; Szymczak et al., 2020). However, no high-resolution, tree-ring based fire history records are available for Turkey, despite various dendroclimate and ecology applications in regional black pine forests (Akkemik, 2000; Akkemik and Aras, 2005; Akkemik et al., 2008; Akkemik and Aras, 2005; Köse et al., 2005, 2012, 2013, 2017; Güner et al., 2016; Janssen et al., 2018; Doğan and Köse, 2019).

In this study, we explore the fire history of *P. nigra* forests in western Anatolia (Turkey), using dendrochronological methods. Our objectives are: 1) to develop a high-resolution reconstruction of the fire history of black pine forests in Turkey, 2) to determine the seasonality of historical fires, 3) to understand the association between climate variability and fire occurrence, and 4) to compare relatively recent fire records from dendrochronological data with those compiled by local forest management units.

2. Materials and methods

2.1. Study area and sampling

To develop the longest fire history, we sampled the trees from old-growth black pine forests in Kütahya, in western Anatolia (Fig. 1). The climate is of a warm-summer Mediterranean type according to the Köppen classification (Peel et al., 2007). The distribution of black pine forests continues under transitional climate conditions between Central Anatolia and Marmara (Fig. 1) (Ocak and Konuk, 2018). The long-term (1950–2020; data from Turkish State Meteorological Service) records of the closest meteorological station (Kütahya, 969 m a.s.l.) indicate a mean annual total precipitation of 560.7 mm (monthly peak in December, 77.7 mm and minimum in August, 18.3 mm) and a mean annual temperature of 10.8 °C, with January as the coldest (mean

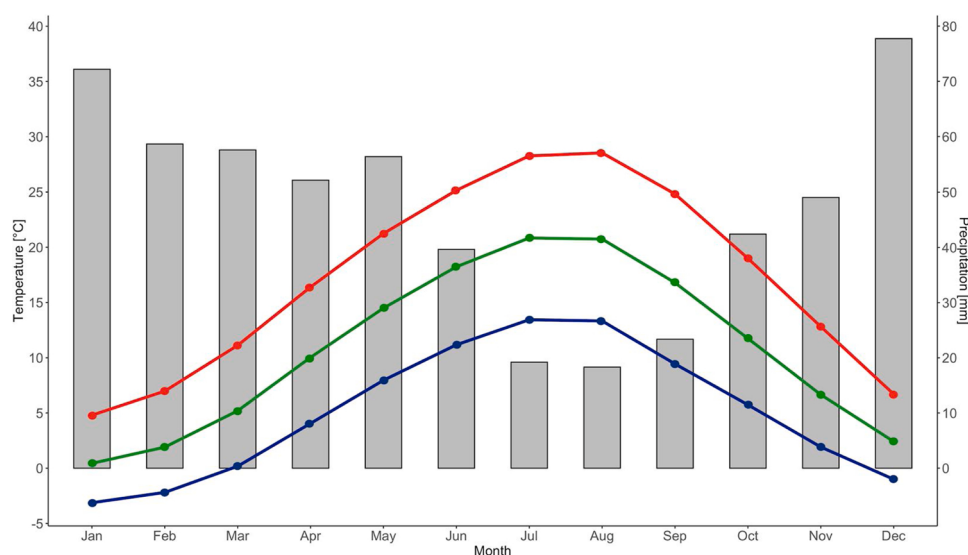


Fig. 2. The climograph for Kütahya meteorological station (1950-2020). Bars indicate precipitation (mm), and red, green, and blue lines represent the maximum, mean, and minimum temperature (°C), respectively.

Table 1

Site characteristics.

Site	Çukurçayır	Elmaalani	Karagöl
Code	CUY	ELY	KAY
Latitude	39°22'8"N	39°16'55"N	39°14'26" N
Longitude	29 ° 5'55"E	28°44'58"E	28°46'10"E
Elevation Range (m)	1508 - 1558	1427 - 1484	1404 - 1456
Average Slope (%)	37	31	20
Aspect	S-SW	W-NW	E-SE
Samples collected/used	21/20	20/20	21/19

temperature is 0.4 °C) and July as the warmest (mean temperature is 20.8 °C) month (Fig. 2).

We sampled three black pine sites: Çukurçayır (CUY), Elmaalani (ELY), and Karagöl (KAY) in June 2019 (Fig. 1). Akdere creek valley, a branch of the Simav stream, spatially separates CUY from ELY and KAY (Fig. 1). Consequently, the distance between the CUY site and ELY and KAY sites is approximately 33 km. Sites differed significantly in terms of geographic features. CUY, which is the site with the youngest trees, is located in the Alaçam mountains and was partly logged in 2017. The elevation of the site ranges from 1508 to 1558 m a.s.l. and it occupies a southern to southwestern aspect, with a steep slope (24–46 %) (Table 1). ELY and KAY are located on Mount Eğrigöz. The elevation of ELY ranges from 1427 to 1484 m a.s.l. and the site occupies a western to north-western aspect with a medium to steep slope (9–45 %). Trees struck by lightning were observed at this site (Fig. 3D). The elevation of KAY ranges from 1404 to 1456 m a.s.l. The site occupies a southeastern to eastern aspect with a medium to steep slope (12–26 %).

Observation of fire scars on stumps and the presence of catface formation on trees, logs, and snags lead us to select suitable samples. At least 20 samples were collected from each site as wedges from living trees and as discs from dead trees (logs, snags, and stumps) using a chainsaw. We selected the oldest black pines with the highest numbers of repeated, well-preserved fire scars for sampling (Fig. 3). In total, we collected 62 partial cross-sections from dead trees and 23 of the samples were from living trees.

2.2. Laboratory methods

The samples were dried for several weeks before sanding, as the resin leakage continued even immediately after sampling. Each cross-section was sanded progressively with a belt sander (60-grit, 280-grit). To allow

for the determination of fire scar seasonality, fire scars were then polished by hand with finer sandpaper (800-grit, 1200-grit) to make the scars better visible. First, we've crossdated samples visually based on the characteristic years of previously developed reference chronologies from Kütahya (Mutlu et al., 2011; Köse et al., 2012). Then, cross-sections were scanned at 600 dpi resolution to measure the ring widths in WinDENDRO software (Regent Instrument Inc., 2002). Tree-ring widths were measured with an accuracy of 0.01 mm on a path far from the scars to avoid ring anomalies associated with injury. The accuracy of cross-dating was verified with the statistical software COFECHA (Holmes, 1986). Rotten and/or undated samples were not used for further analysis.

Fire can affect tree-ring patterns in various ways, and we identified scars on the cross-sections of dated samples based primarily on callus tissues and cambial injury (Schweingruber, 1988; Guyette and Spetich, 2003). All fire scars and scarlets with callus tissue formations were marked. The seasonality of scars was determined based on the intra-ring position of the scars within the calendar year (Baisan and Swetnam, 1990). The intra-ring position of each scar was described as EE (early earlywood), ME (middle earlywood), LE (late earlywood), L (latewood), D (dormant), or U (undetermined) (Fig. 4). The dormant season was used to represent fires that occur after cambial cell division has ceased and here were interpreted as occurring in the calendar year corresponding to the adjacent latewood cells (Caprio and Swetnam, 1995).

2.3. Recent fire records from local forest management units

Seventy-one years (1950–2020) of fire records were obtained from the local forest management unit (Fig. 1). All details of data in fire record books were digitized and prepared for analysis. Since data coverage showed variability among forest management sub-units (between 21 and 71 years of coverage), all analyses were performed using the pooled data of the forest management unit. Specific large fire years in the annual fire data were examined for the forest management unit and also for each sub-unit individually. We defined the fire season of the forest management unit as the time of year when >80 % of all fires recorded in the area occur. For each year, the percentage of total burned area was also calculated by dividing the total burned area by the total land area of the forest management sub-units considered for the corresponding year. In this way, the burned area (%) data was standardized to avoid any bias due to different coverage lengths of fire data in different forest management sub-units. We used these estimates in further statistical



Fig. 3. Sampling from A) a living tree with a catface formation. B) A collected sample, C) sampling from a remnant stump, and D) a tree with a lightning scar from the ELY site.

analyses to detect possible trends in the total burned area (%) over time (1950–2020) and compared this trend to our tree-ring based fire chronology. For this purpose, we performed a linear regression analysis. The total burned area (%) data were log-transformed before analysis to approximate normal distribution of residuals.

2.4. Data analysis

We calculated fire interval statistics for each site with years in which either at least two or at least 25 % of the recording trees were scarred. We selected the filter of two scarred trees for the occurrence of a fire in a given year to minimize the possible detection of false negatives and the 25 % filter to represent ‘major fires’ (e.g., [Fulé et al., 2009](#)). We used

both recording and non-recording periods of time for each sample during calculations ([Rother et al., 2020](#)). Using the recording and non-recording periods is significant for the analysis of possible gaps in the samples (such as partial wood deterioration and missing pieces of the samples). For this purpose, dated cross-sections were recorded from the most recent year to the first fire year, while gap periods among wood pieces were entered as non-recording periods. We developed three site-specific fire chronologies, as well as a regional fire chronology (hereafter RFC) from a combination of all fire scars (unfiltered) from all three sites. We then applied the same two filters to the regional fire chronology.

To understand the spatial and temporal fire patterns, we calculated fire regime parameters ([Fulé et al., 2009](#)). We used the burnr package

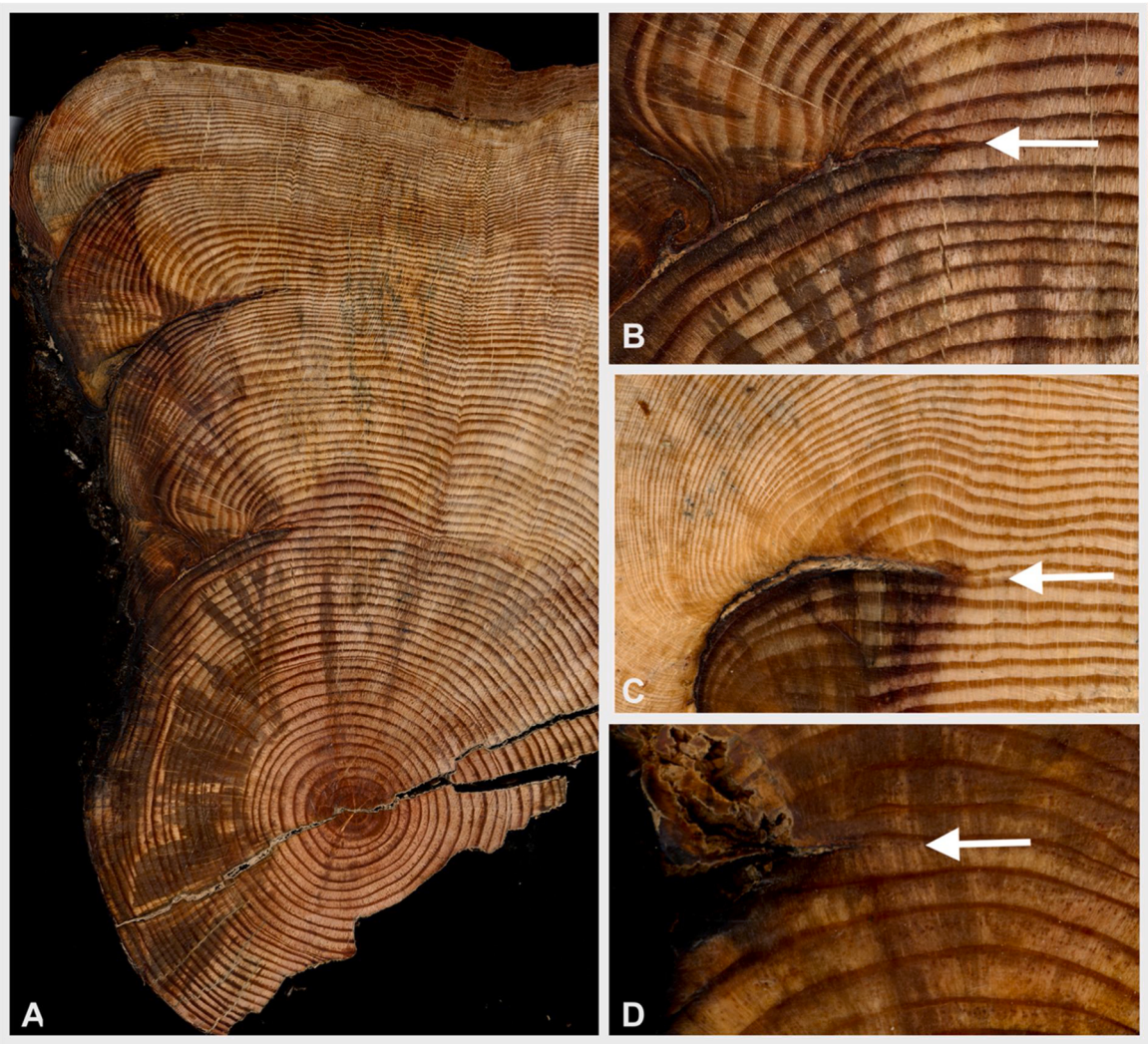


Fig. 4. A) Scanned cross-section of a sample (CUY21) and B) latewood (CUY21), C) dormant (KAY06), and D) late earlywood (CUY20) intra-ring positions of scars.

Table 2
Descriptive statistics of the fire interval data of the study area.

Parameters	CUY		ELY		KAY	
	Min 2-scars	25 % scarred	Min 2-scars	25 % scarred	Min 2-scars	25 % scarred
Period	1840–1973	1840–1954	1751–1934	1751–1916	1822 - 1920	1822- 1920
Mean Fire Interval (MFI)	12.1	16.3	8.7	11.8	8.2	9.8
Minimum Fire Interval	2	8	1	4	2	6
Maximum Fire Interval	23	36	17	17	15	18
Fire Frequency	0.08	0.06	0.12	0.08	0.12	0.10
Weibull Median Probability Interval (WMPI) ± Standard Deviation	11.6 ± 6.1	15.5 ± 9.3	7.7 ± 5.5	11.8 ± 4.4	7.8 ± 4.2	9.7 ± 4.0
Lower Exceedance Interval	5.4	6.9	2.8	7.0	3.7	5.3
Upper Exceedance Interval	19.0	26.5	15.2	16.6	13.0	14.4

(version 0.5.0) (Malevich et al., 2018) in the R environment (R Core Team, 2020) to record the fire years as .fhx files and for fire interval statistical analysis. For each site and for the regional chronology, we computed minimum, maximum, and mean fire interval (MFI), fire frequency, standard deviation, and lower/upper exceedance intervals based on two-samples, as well as 25 % filtered fire chronologies (Table 2). The MFI provides information about site fire frequency. Lower/upper exceedance intervals indicate if a fire interval is significantly longer or shorter than the mean (per time period) (Sutherland et al., 2015). We also calculated the Weibull median probability interval (WMPI) for each fire chronology, which is a better estimator than MFI

because fire intervals are often not normally distributed (Margolis and Balmat, 2009; Fulé et al., 2009; Tarancon et al., 2018). WMPI represents a measure of central tendency. We applied Superposed Epoch Analysis (SEA) to test the relationship between past fires and past drought (Haurwitz and Brier, 1981; Rao et al., 2019). We used the burnr package in the R environment (Malevich et al., 2018) for the SEA. We used the two-sample, as well as 25 % filtered site-specific and regional fire chronologies as event years in the SEA analysis, and a regional self-calibrated Palmer Drought Severity Index (scPDSI) reconstruction (Cook et al. (2015); 0.5°0.5 degree) as the continuous climate time series. We used the scPDSI data for the

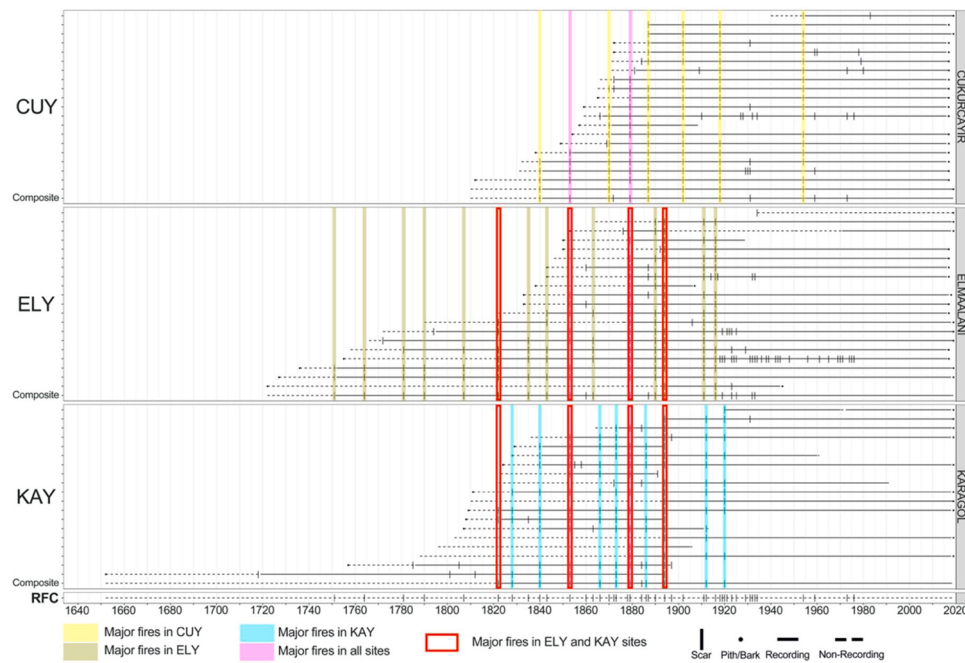


Fig. 5. Fire chart of three sites with composite local chronologies and regional fire chronology (with minimum 2 scarred trees). Highlighted colours represent the major and common major fire years.

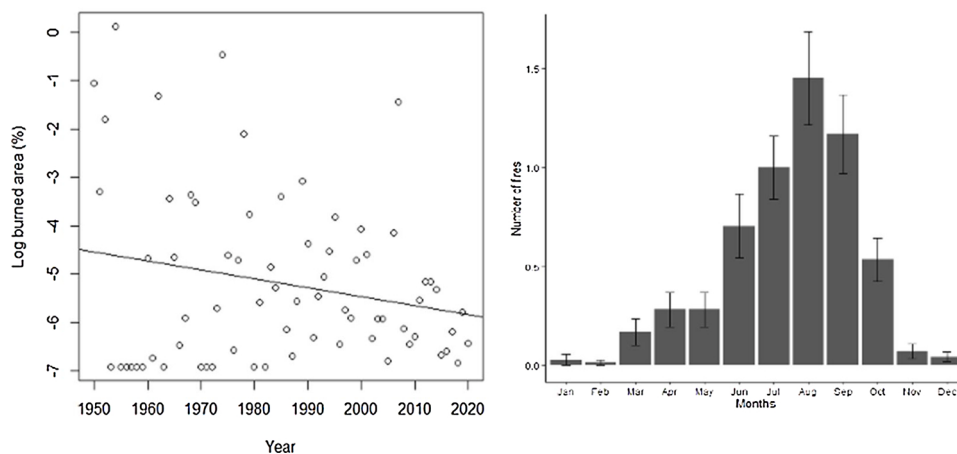


Fig. 6. Trend (1950–2020) in the total burned area (%) (left) and the seasonality of fires (mean number of fires in months) (right) in the forest management unit. Burned area (%) data are presented in the log scale and the line is the regression line fitted to data (left). Error bars represent the standard error of the mean (right).

Table 3

Seasonal distribution of fires and statistics of each site according to fire scar data.

Parameters	CUY		ELY		KAY	
	No	%	No	%	No	%
Total Number of fires	126	–	160	–	116	–
Number of events with season recorded	99	79	103	64	83	72
Number of 'D' fires	5	5	18	17.5	14	17
Number of 'EE' fires	1	1	0	0	0	0
Number of 'ME' fires	0	0	0	0	0	0
Number of 'LE' fires	9	9	0	0	0	0
Number of 'L' fires	84	85	85	82.5	69	83

gridpoints between 39–40 ° N, 28–30 ° E and from 1600 to 2012.

3. Results

3.1. Western Anatolia fire history

3.1.1. Tree-ring based fire history

We recorded 88 fire years across the three sites (30 in CUY, 55 in ELY, and 26 in KAY) (Fig. 5). Three samples (1 from CUY and 2 from KAY) were excluded from the analysis due to failure of cross-dating caused by wood deterioration. At all sites, fires were frequent from the start of the record in the 18th or 19th century until the early twentieth century (Fig. 5). A sharp decline in fire frequency occurs after 1954 in CUY, 1916 in ELY, and 1920 in KAY (Fig. 5).

The CUY fire chronology shows thirty fire years (at least two trees scarred) for the period 1810–2019, including eight major fire years (at least 25 % of the trees scarred; 1840, 1853, 1870, 1879, 1887, 1902, 1918, and 1954). The ELY composite fire chronology (1722–2019)

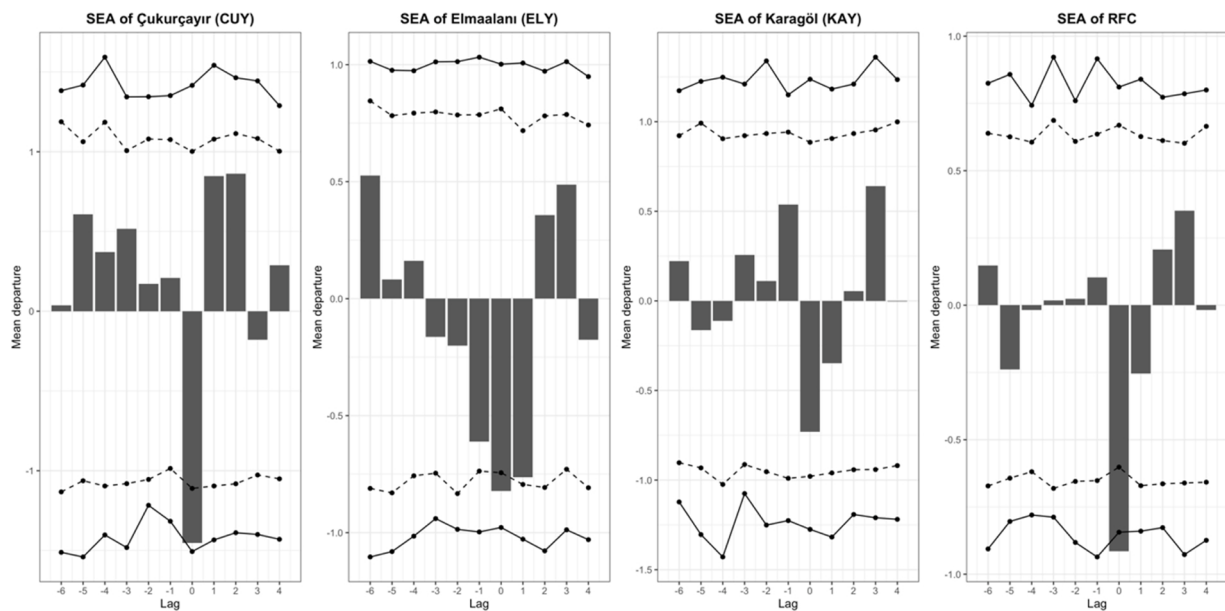


Fig. 7. SEA results of major fire years based on site-specific and regional fire chronologies with the scPDSI reconstruction (Cook et al., 2015). Solid lines represent the 99 % confidence limits and dashed lines represent the 95 % confidence limits.

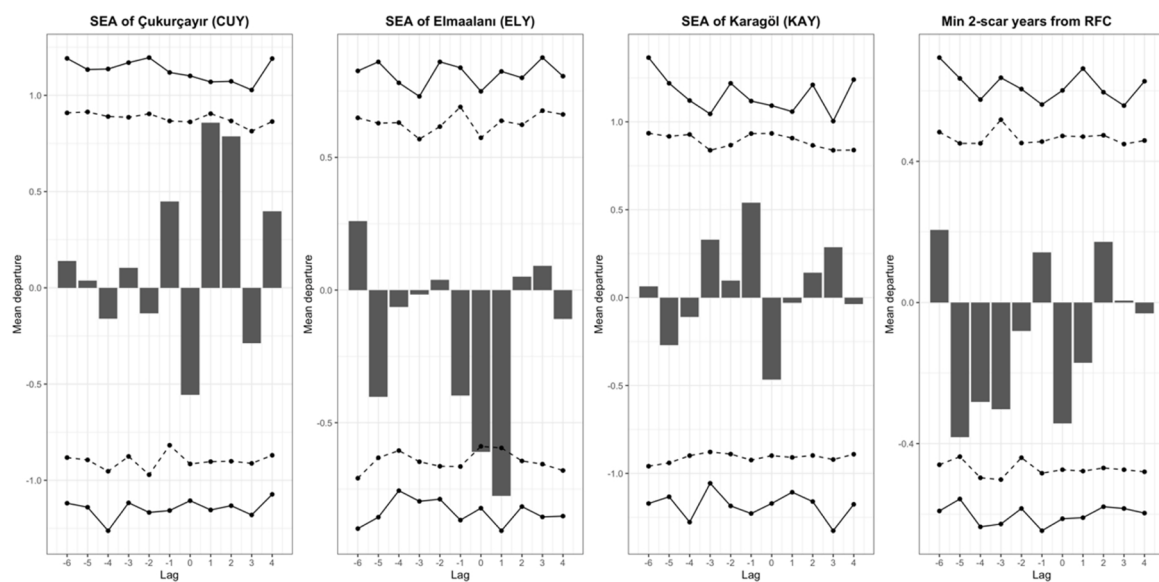


Fig. A1. Superposed Epoch Analysis results of fire years (minimum 2 scarred trees) based on site-specific and regional fire chronologies with the scPDSI reconstruction (Cook et al., 2015).

consists of 55 fire years, with 15 major fires (1751, 1764, 1781, 1790, 1807, 1822, 1835, 1843, 1853, 1863, 1879, 1890, 1894, 1911, and 1916). The KAY composite fire chronology (1652–2019) shows 26 fire years, including eleven major fire years (1822, 1828, 1840, 1853, 1866, 1873, 1879, 1886, 1894, 1912, and 1920).

Only two major fire years, 1853 and 1879, were common to all three sites. ELY and KAY share two additional common major fire years (1822 and 1894), while CUY and KAY have one additional common major fire year (1840) (Fig. 5). The highest number of common major fire years occurred in ELY and KAY. Among the regular fire years, only 1887 was found common between CUY and ELY.

3.1.2. Fire history from documentary data

According to the data from the local forest management unit, a total of 405 fires that burned 2857 ha of forest area occurred between 1950

and 2020 in the Kütahya area. Most fires were surface fires and occurred in black pine stands. Of the 150 fires whose causes are known or recorded, ca. 25 % were caused by lightning and the remaining were of human origin. The percentage of lightning-caused fires is possibly underestimated due to the lack of accuracy in detecting lightning fires in the past. 1954 (also recorded as a major fire year in CUY) was a significant fire year in the records of the two forest management sub-units with the longest coverage (1950–2020 and 1954–2020), with three of four fires larger than 100 ha occurring in this year. Moreover, eight of the twelve fires larger than 25 ha occurred in or before 1954 and the burned area per year is lower in later years. Indeed, the linear regression analysis indicates a critically decreasing trend in the burned area (%) between 1950 and 2020 ($R^2 = 0.05$, $p = 0.068$; Fig. 6).

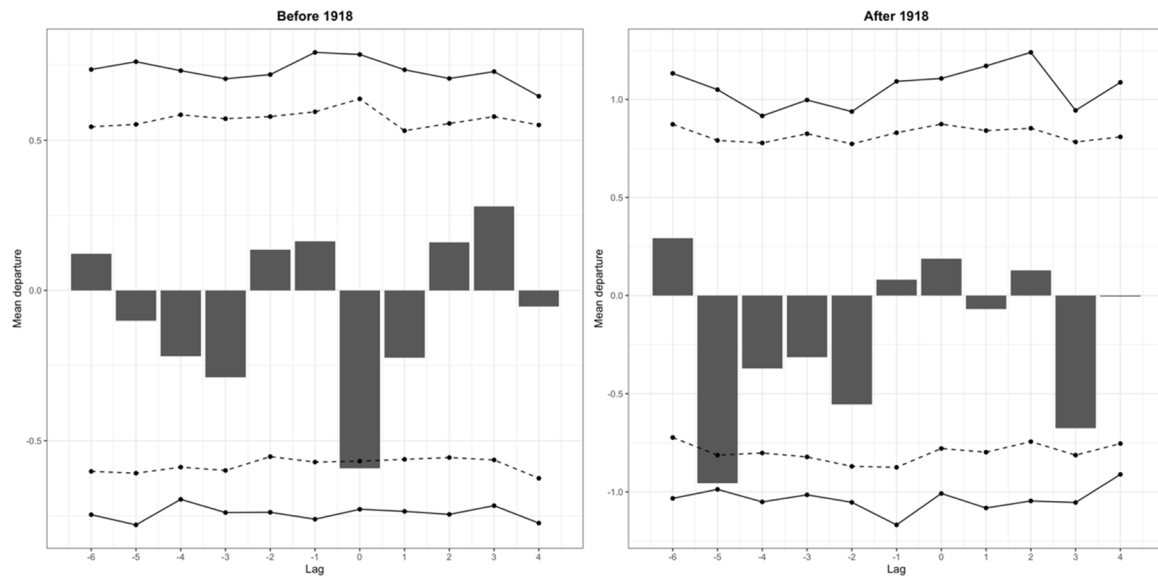


Fig. B1. Superposed Epoch Analysis of regional fire years (minimum 2 scarred trees) with the scPSDI reconstruction (Cook et al., 2015). SEA is calculated for two periods with high fire frequency (before 1918) (left) and low fire frequency (after 1918) (right).

3.2. Seasonality of fires

We were able to determine the seasonality of between 64 % (ELY) and 79 % (CUY) of the fire scars. Most fires occurred in the latewood (Table 3). This seasonality was confirmed by the documentary fire records, which showed that the majority of fires (87 %; 1950–2020) occurred between June and October, with more than half of the fires (231 fires or 51 %; Fig. 6) occurring from August–October, the season of latewood formation.

3.3. Fire-climate association

Major fire years in CUY, ELY, and RFC occurred during anomalously dry years ($p < 0.05$) (Fig. 7). We found no significant relationship between drought years and major fire years in KAY (Fig. 7) or regular fire years at all sites and RFC (Fig. A1).

4. Discussion

We present the first tree-ring based fire history reconstruction for Turkey. We developed a 368-year long fire history from three sites in the black pine forests of Kütahya (Fig. 5). The three sites have two common major fire years (1853 and 1879), with ELY and KAY sharing the most common major fire years. The spatial proximity of these two sites (5 km) suggests that these major fires were likely common not only temporally but also spatially. Fire return intervals were also similar for these two sites. The last important fire in the region recorded in the tree-ring record occurred in 1954 and is corroborated by fire management unit data.

Fire frequency at all sites peaked in the first quarter of the 20th century, after which a dramatic decline in fire frequency occurred (Fig. 5). In the last hundred years, we found four (one major fire year) in CUY, five in ELY (no major fire) and only one fire year, which is also a major fire, in KAY. This decreasing trend in fire and fire frequency is maintained in the second half of the 20th century, as shown by documentary total burned area data (Fig. 6). Decreasing fire frequency in the 20th century has been witnessed in many parts of the world and is primarily attributed to fire suppression efforts (Marlon et al., 2008; Taylor et al., 2016; Camarero et al., 2018; Chavardès et al., 2018; Li et al., 2018). Indeed, fire exclusion policies result in longer fire return intervals in surface fire ecosystems (Pausas and Keeley, 2021) such as black pine

forests. Our results on the lack of fire scars in our samples since the 1920s at two sites and the 1950s at one site and a decreasing trend in the total burned area of the region since the 1950s are thus in accordance with these observations in other regions.

The sharp decline in fire frequency after the beginning and mid-20th century coincides with the promulgation of the first laws governing land and forest use in Turkey (Table 3; Fig. 5). During the Ottoman Era (ca. 1299–1922), various regulations were applied to protect forests, such as the 1870 Forest Regulation (“Orman Nizamnamesi”). The 1870 Forest Regulation came into force to protect forests and to organize fire suppression efforts. Early suppression activities, however, were only of limited success when faced with large fires due to a lack of planning, experience, and organization (Küçükosmanoğlu, 1987; Koç, 2005; Kılıç, 2020). The first forest law (Forest Law No. 3116) was enacted during the early Republican period of Turkey (ca. 1923–1945) in 1937 and the task of protecting forests was handed to the state (Official Gazette, 1937).

In addition to the effects of this regulation change on our fire frequency results, the SEA showed that major fires in two of the three sites occurred in anomalously dry years, revealing a significant effect of climate conditions on fire occurrence. Moreover, documented catastrophic drought and famine events during the Ottoman Era coincided with some major fire years, such as 1870 (Tekemen Altındaş, 2018) for CUY, 1873 (Kuniholm, 1990) for KAY, 1886 (Tekemen Altındaş, 2018) for KAY and 1887 (Gül, 2009; Tekemen Altındaş, 2018) for CUY, 1894 (Tekemen Altındaş, 2018) for ELY and KAY. High pre-twentieth century fire frequency could therefore be related to droughts, whereas low post-twentieth century fire frequency can be caused by fire suppression. In order to see the effects of climate on the frequent fires in the 19th century, we calculated the SEA between fire years in our RFC and drought separately for the periods before and after 1918 (Fig. B1). We found that fire years correspond to drought years prior to 1918, but not after. This result suggests that the drought-fire relationship in the study region has disappeared after that period due to fire suppression activities. Our results thus confirm the impact of the increase in fire suppression efforts and forest management activities since the first forest law in modern Turkey and resulting active prevention of the spread of fires. In conclusion, fire suppression and forest management, not climate, are responsible for the decrease in the fire activity of our study area during the 20th century. Fire exclusion results in the accumulation of surface fuels over years in black pine forests (Camarero et al., 2018), which in turn may lead to more intense fires (i.e., crown fires) under

ongoing warming. Such a fire regime shift is a major concern for the persistence of black pine forests (Christopoulou et al., 2013), especially because black pine trees have no adaptation to survive under crown fire regimes (Tapias et al., 2004; Pausas et al., 2008). The revival of historic surface fire regimes by using prescribed fires may help to protect the Mediterranean black pine populations from local extinctions due to intense crown fires in future.

Most (~84 %) Kütahya fire scars occurred in the latewood and very few (~4%) scars occurred in the earlywood (Table 3). Our results correspond to fire seasonality in other black pine forests in the Mediterranean basin (Christopoulou et al., 2013; Fulé et al., 2008). This fire seasonality was further confirmed by our analysis of recent documentary fire records, which revealed that the majority of fires occurred between June and October, which corresponds to the period of mature latewood tracheid cell formation (August–October) in Mediterranean black pine forests (Guada et al., 2016). The similarity of fire seasonality between the recent (post-1950) and historical (from 1751 onwards) periods suggests that fire seasonality has remained unchanged over the past 350+ years, despite fire-suppression related disruptions of the fire regime.

We present the first results of a broader research program that is mainly focused on historical fires in the entire range of black pine in Western Anatolia, Turkey. Providing evidence about the components of past fire regimes is valuable for future forest management strategies under a changing climate and human influences in high fire risk regions such as the Mediterranean basin. Furthermore, long-term monitoring and research following major fire events are necessary to understand changes in stand dynamics and species composition. This combined knowledge could serve as important guidance to managers and foresters for future forest protection strategies and plans and as a reference for future restoration studies.

Declaration of Competing Interest

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Appendix A

Appendix B

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