

Original article

The history of fire, human and climate in black pine forests of western Anatolia: The Taurus mountains

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ABSTRACT

The interactions between fire occurrence-human-climate are highly complex to understand and also difficult to predict due to having many sources of variations in fire regimes. However, we can gather information about the effect of human influence on the regional fire regimes where human influence is high, and the history of locations is well-known by conducting retrospective fire history studies in locations. Here, we present the impact of human settlements on fire occurrence by comparing and discussing the previous drought-driven tree-ring-based fire history reconstruction sites in western Anatolia. For this purpose, we collected cross-sections from Miyarcık highland, Antalya, and developed a 519-y long (1503–2021 CE) composite fire chronology using dendrochronological methods. Our study site location is known for the seasonal inhabitants of “Yörüks”, who led a nomadic life in the Taurus Mountains for centuries, and forests were used for livestock grazing. Since the temperatures increase significantly at the beginning of spring in the lower elevations of Antalya, the yörüks move towards the upper highlands with their animals from May to November. We found lower fire frequency and no fire-climate association compared to other sites that experienced drought-driven wildfires, even though this site is located in a high-fire-risk region. Low-frequency fires might be due to moderate-level livestock grazing by yörüks in this area. Grazing contributes to reducing the amount of accumulated combustible materials, causes discontinuity of fuel in the understory of forests, and affects the dynamics of the spatial distribution of wildfires. This study showed that moderate-level grazing might support effective fire management activities as fuel management because of modifying the fuel properties, changing the fuel-fire interaction (e.g., the fuel continuity and amount of accumulated fuel), and reducing the wildfire probability over space and time.

1. Introduction

Wildfires play a crucial role in shaping the composition of ecosystems, species evolution and distribution at a global scale (Bowman et al., 2009; Pausas and Keeley, 2009; Moritz et al., 2014). The fire regime parameters (frequency, intensity, and extent of wildfires etc.) are influenced by climate change, land use changes, and practices by human activities (Fernandez-Anez et al., 2021). Climate change can alter temperature, precipitation, and humidity, leading to drier and warmer conditions that increase the likelihood of wildfires. The anthropogenic effects of human activities such as land use changes, fire suppression policies, and ignitions also change the occurrence and severity of

wildfires, land fragmentation, fuel loads etc (Bekar et al., 2020; Ryzhkova et al., 2020). On the other hand, fire suppression policies have led to the accumulation of fuel, which increases the intensity and extent of wildfires. The dynamics of fire occurrence-climate-human processes and interactions are complex and variable, which also should not be ignored that human-induced wildfires will also take place under the control of changes in vegetation and climate on a spatiotemporal scale (Blarquez et al., 2015). For this reason, it is important to increase the knowledge of the connecting or distinguishing relationship between the human and the climate on fire occurrences for the future of pyrogenic forest ecosystems (Moritz et al., 2014). We know that the focus on unravelling the knowledge of fire-climate-human interaction is still uncertain for some

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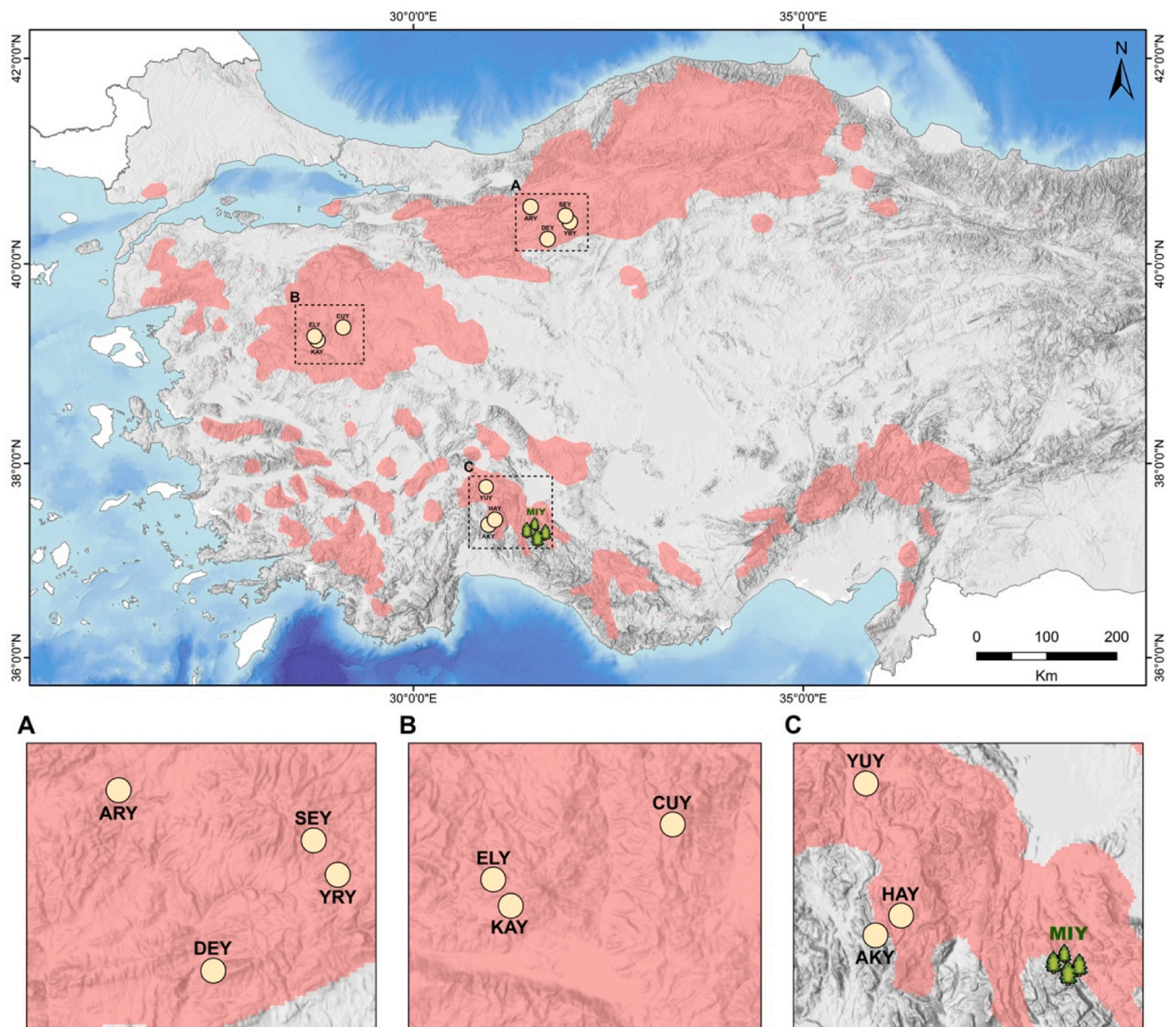


Fig. 1. The tree symbol is the location of our site in this study, Antalya (Miyarcik Highland, as the MIY site). Dark blue dots represent the previously studied western Anatolia fire history reconstruction sites in Şahan et al., (2021, 2022). The red color shows the distribution of black pine forests (data from EUFORGEN, 2004).

regions and understanding this complex interplay is crucial for effective wildfire management and adaptation (Guiterman et al., 2019).

In order to understand the uncertainty of the mechanism and disentangle anthropogenic vs climate influence on wildfires, it is necessary to carefully question the purposes of forest use. With sufficient knowledge of the historical, socio-cultural structure and high-resolution tree-ring-based fire history studies can offer striking results about both climate and human influence on the regional fire regime. Such studies help to reveal this distinction or effects are already available in the literature on a broad scale in different anthropogenic landscapes (Madany and West, 1983; Veblen et al., 1999; Skinner et al., 2009; Holz and Veblen, 2011; Taylor et al., 2016; Margolis et al., 2022 and many others). Anatolia is one of the locations that has a long history of human settlements since prehistory and land use activities for agriculture, logging, and nomadic pastoralism (e.g., grazing). Antalya, on the other hand, is known for being one of the fire-prone regions where most fires occur in Anatolia. Previous studies for fire and ignition risk prediction have shown that this area has a very high risk of fire and ignition (Güney

et al., 2016). The city itself is an extremely popular tourist destination in the coastal areas, while forest-covered highlands in the Taurus Mountains have been used as migration routes of Turkish tribes for centuries. These Turkish tribes, also called “Yörüks”, which still preserve their socio-cultural characteristics led a nomadic life in the Taurus Mountains (Antalya) (İnalçik, H, 2014). Yörüks, living in our study area, migrate to the highlands in May with their animals from the villages where they live at lower elevations (İHA, 2022). Since the air temperatures are quite high for the animals to survive in lower elevations during summer, nomads temporarily migrate to the upper highlands at an altitude of approximately 2000 m a.s.l until the beginning of November in order to continue livestock herding. These forests were used by the Yörüks for centuries and land use change has a strong grazing influence on the regional fire regime.

Livestock grazing can have a significant impact on the frequency and severity of wildfires in forest ecosystems (Önodi et al., 2008; Christopoulou et al., 2014; Fernandez-Anez et al., 2021). Settlements near forests often lead to an increase in human-caused fires either

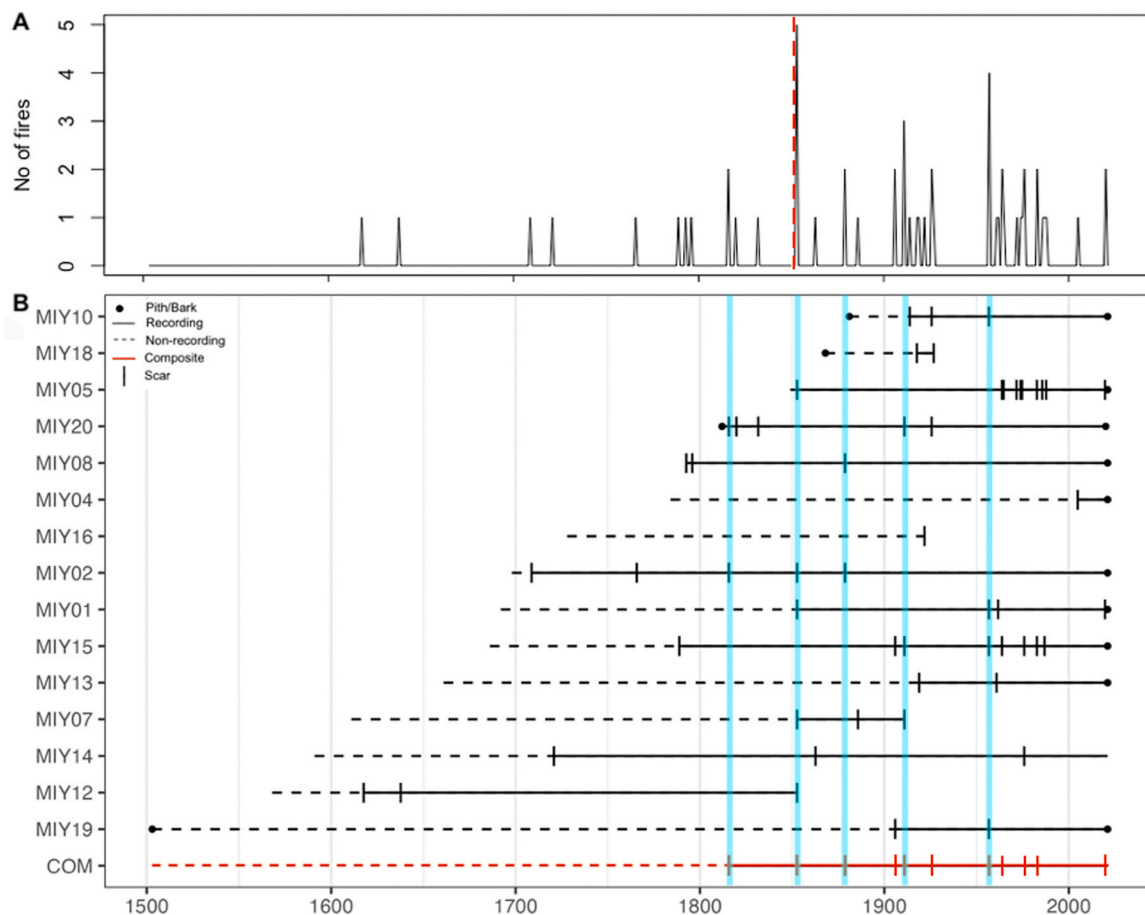


Fig. 2. The overview of the old black pine stand in the MIY site (left) and tents of Yörük settlements in Miyarcık highland ~ 2000 m a.s.l (right).

accidentally or intentionally. On the other hand, livestock grazing can affect the understory vegetation in forests and lead to changes in fuel load and continuity, which can decrease the likelihood and intensity of wildfires (Madany and West, 1983; Moreira et al., 2011; Hessl et al., 2016). For many years, studies show the harmful influence of overgrazing pressure on land degradation by changing the rate of infiltration, percolation of forest soil or preventing seedling regeneration (Patric and Helvey, 1986; Lipson et al., 2011). However, the use of the land for moderate grazing by the local people living in fire-prone forest ecosystems positively influences the characteristics of the accumulated combustible material (Etienne et al., 1996; Valette et al., 1993; Lovreglio et al., 2014). It was observed that there is a decrease in the severity and size of the burned area (Davies et al., 2022), as well as the fire activity by reducing the fuel load (Kitenberga et al., 2019). Especially in the studies of the last years, moderate livestock grazing as fine fuel treatment (low vegetation, woody fuel, and shrub layer) is supported to be an effective fire management strategy (Lovreglio et al., 2014; Hessl et al., 2016; Rouet-Leduc et al., 2021; Davies et al., 2022; Siegel et al., 2022). Therefore, it is important to understand and manage the socio-ecological conditions such as human settlements and grazing in and around forests to minimize the risk of wildfires and protect the environment.

This paper is part of a series of studies on retrospective tree-ring-based fire history reconstruction to understand the drivers of regional fire regime dynamics as influenced by both climatic variation and humans across western Anatolia over the centuries (Şahan et al., 2021, 2022). One new site record from Antalya in this study was used to highlight the effect of human settlements on regional fire regimes. In our previous studies, we find out the strong effect of the drought period, however, we wondered about the human impact on the forests in

Anatolia. We put particular focus on direct anthropogenic influence in a high-fire-risk forested region. For this purpose, we asked the following questions: i) How do humans play a role in shaping the fire regime of a region? and ii) what are the signals to understand the human and climate influence from fire history to unravel the insights into broader human–fire–climate dynamics? To our knowledge, no such study comprehensively assessed the influence of humans and climate in changing the fire regime in the Mediterranean basin on such an outstanding broad regional scale. With this study, we aim to compare the fire management strategies of foresters using intensive suppression activities and the sociocultural behaviour of the nomadic pastoralism who have lived in these mountains for centuries, affecting fuel properties, fuel-fire interactions and changing the regional fire regime.

2. Materials and methods

2.1. Study area

Our sampling area for this study is located in Miyarcık highland, Antalya (hereafter MIY) (31°17' N – 31°34' E), which is under the influence of the Mediterranean climate and classified as a high fire risk region according to the General Directorate of Forestry (2013). We collected 20 samples from living trees and remnant wood using a chainsaw. Most of the living trees were sampled and few samples were taken from the logs. However, only 15 of the samples were used for further analysis due to undateable and intensely rotten wood pieces. Sampling this area provided an important data source regarding the initial understanding of the interaction of climate-human-fires occurrences in western Anatolia. Fig. 1.

The characteristics of this region differ from the other sites we have



Fig. 3. Photos showing the observed axe incisions made by the yörük shepherds on the catface formation.

published in Western Anatolia (Şahan et al., 2021, 2022). Here, we observed nomadic pastoralism and forests were used by the yörük community. The yörük tents were observed near our study (Fig. 2). On the other hand, a large number of axe incisions were observed on the trees, which indicates strong human pressure (Fig. 3) and grazing activity.

2.2. Laboratory methods

Collected samples left for drying for several weeks to avoid resin leakage. Samples were first sanded with a belt sander (60, 280, and 400-grits, respectively) and, later, polished finely to see fire scars and the seasonality of the scars under the microscope. The polished samples were scanned with the EPSON Expression® scanner and the tree-ring width measurements were completed with WinDENDRO™ software (Regent Instrument Inc, 2002). Lastly, the correction of measurements was statistically checked with COFECHA software (Holmes et al., 1986). Determination of fire years was made by following the fire scars in the corresponding year. We then determined the seasonality of these fires using the classical method as developed by 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).

2.3. Data analysis

A database consisting of the fire years and seasonality information was created for further analysis. We determined regular and major fire years, in which min-2 scarred of the recording trees had that year called regular fire year and 25% of the recording trees and min-2 trees had that year called major fire years. The descriptive fire statistics of both regular and major fire years were calculated. To evaluate the effect of drought on major fires, we applied the Superposed Epoch Analysis (SEA). 'strucchange' package was used to determine breakpoint dates in the time series of the number of fires (Zeileis et al., 2002). We used the gridded summer (June, July, August) self-Palmer Drought Severity Index (PDSI) reconstruction (1500 – 2021; Cook et al., 2015) for the SEA as a continuous time series and were downloaded for the grid points of 37.00 – 38.00° N and 30.50 – 31.50° E. 'burnr' package (Malevich et al., 2018) in R statistical software (R Core Team, 2020) was used to develop composite chronologies, calculate fire statistics, and the SEA.

Table 1

The descriptive fire statistics of the MIY site.

Parameters	Regular fire year	Major fire years
Period	1816–2020	1816–1957
Mean Fire Interval	20.4	35.2
Standard deviations (±)	12.6	8.5
Minimum Fire Interval	5	26
Maximum Fire Interval	37	46
Weibull Median Probability Interval (WMPI)	18.6	35.7

3. Results

3.1. The fire chronology and history of the MIY site

A 519-y (1503 – 2021 CE) site-level composite fire chronology record was developed (Table 1). In total, we recorded 38 fire years for this site and five major fire years were recorded in the area, with more than 25% of the trees recorded: 1816, 1853, 1879, 1911, and 1957 (Fig. 4). We were able to determine 78% of the fire scars and the majority of these fires occurred in the latewood formation period (95%) (Table 2).

3.2. Documentary records from the local forest management unit in Akseki, Antalya

During the fieldwork, documentary fire data were obtained from the local forest management units of Akseki, Antalya. Data and statistics on the number of fires by months, the average size of the burned area, the size of the total area burned, the number of fires by years, the size of the burned area and the average size of the burned area were calculated. According to these records, a total of 191 ha of forest area was burned in 204 fires between 2001 and 2017. The majority of the fires (86%) occurred between June and October and most of the fires occurred in September (Fig. 5). According to SEA, no fire-climate associations were found in our study site (Fig. 6).

4. Discussion

4.1. Climate- vs. human-fire occurrence relationship

In order to understand the effect of anthropogenic influence on the regional fire regime, we used the results of previous multi-century-long

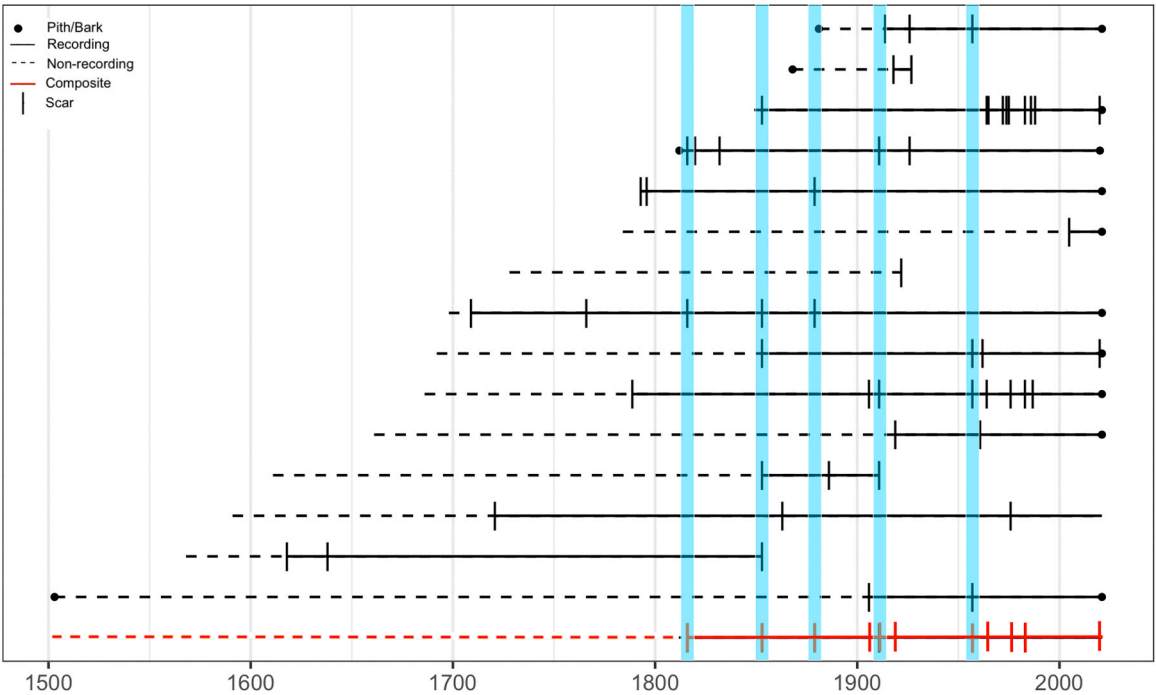


Fig. 4. A) The number of individual trees recording a fire between 1503 and 2021 and estimated break date in 1852 (red vertical dashed line). B) The fire chart and the composite chronology of the MIY site. Cyan lines represent the major fire years (1816, 1853, 1879, 1911, and 1957, respectively) and the red line shows the site-level composite fire chronology (1816, 1853, 1879, 1906, 1911, 1926, 1957, 1964, 1976, 1983, and 2020, respectively).

Table 2
The seasonality and statistics of the fires in the MIY site.

Parameters	No	%
Total Number of fires	55	-
Number of events with season recorded	43	78
Number of (D) fires	2	5
Number of (EE) fires	0	0
Number of (ME) fires	0	0
Number of (LE) fires	0	0
Number of (L) fires	41	95

fire history reconstruction studies to discuss the differences between human and climate impact on regional fire regimes. Compared to this study site (Fig. 4), the other ten sites are relatively far from the influence of human settlements and experienced climate-driven wildfires during the drought period (see Şahan et al., 2022 for previous site-level fire charts). The Anatolian composite fire chronology showed the drought-induced frequency increase in the fire regime for the period of 1853–1934 CE and a sharp frequency decrease was observed due to aggressive fire suppression activities. However, no similar frequency differences were found among centuries in the MIY site (Antalya), even though the site is located in a high fire-risk region.

The statistical comparison also showed that the mean fire interval of

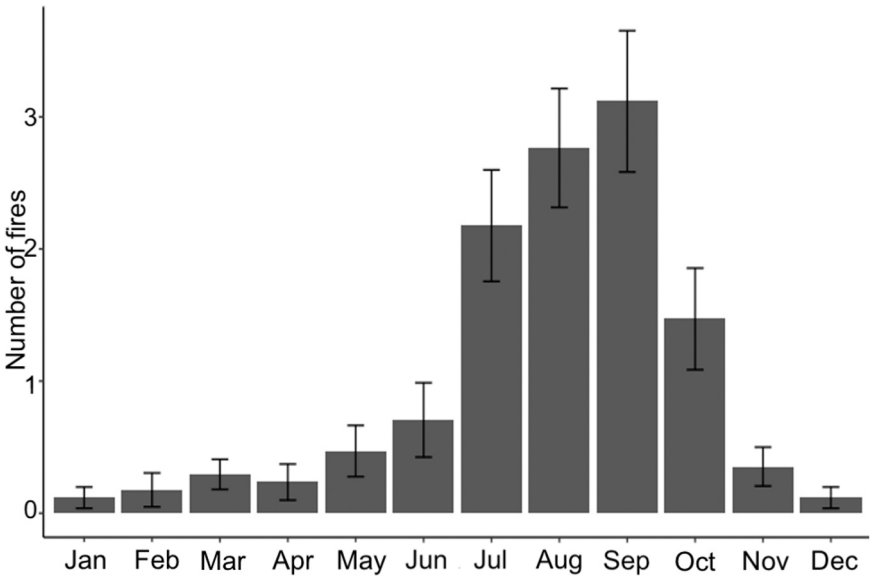


Fig. 5. The fire seasonality (mean number of fires for each month) in the forest management unit. Error bars represent the standard error of the mean.

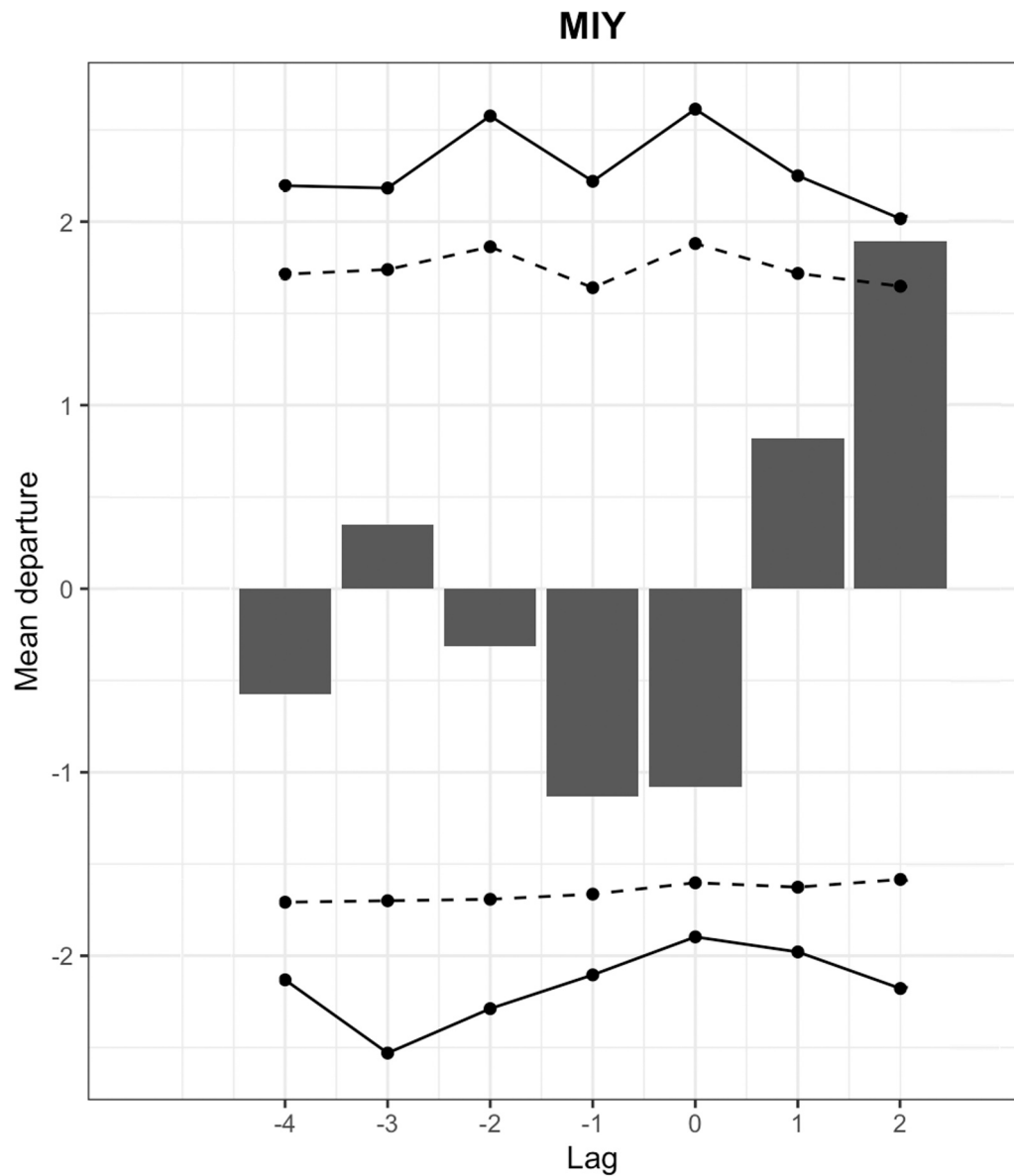


Fig. 6. The SEA result of major fire years is based on site-specific fire chronology with the scPDSI reconstruction (Cook et al., 2015). Solid lines represent the 99% confidence limit and dashed lines represent the 95% confidence limit.

the MIY site is higher than the sites of the other study (except for one site from Ankara; the DEY site; is dominant by continental climate). This difference refers directly to the human use of the forest in relation to human settlements. In our current site in Antalya, similar to the Ankara (DEY) site, higher mean fire interval (for major fire years) and Weibull median probability interval (both for regular and major fire years) were calculated. However, the MIY site, unlike the DEY site, is located in the Mediterranean climate zone and is classified among the forests with the highest fire risk, where fires occur more frequently in the forest fire risk map of Turkey (OGM, 2013). On the other hand, the Weibull median fire range of the MIY site in Antalya and the DEY site in Ankara were much higher than the other sites.

The low fire frequency in this study area unravels the region's intense use of forests by human settlements for grazing purposes. The interviews we made with the local people living in the highlands of the Taurus mountains revealed that nomads use the forests for grazing when they seasonally inhabit the highlands during the summer, which these months also corresponds to fire season (Şahan et al., 2023). In addition, old trees were considered especially sacred and could not be

touched. Nomadic groups in Anatolia, including Yörüks, sacred trees were symbol of the life in their common belief (Büyükcın Sayılır, 2021). Due to this core meaning, protecting forests is dominant and damaging or cutting down the trees are not acceptable in their culture (Büyükcın Sayılır, 2021).

We can also notice from the fire charts (see Şahan et al., 2022 for the fire charts of other sites) many fires were recorded in individual trees and that shows the fires spread less to other individuals. Considering the chronological length and fire risk conditions, the number of regular and major fire years was relatively less than in other sites. During our fieldwork in the area, we observed fresh and old lightning scars on the trees (Fig. 2), which shows that there might be lightning-induced wildfires. Even though these old and fresh lightning scars show that wet conditions might cause wildfires at that site, we found no significant relationship between climate (wet conditions prior to the event year) and fire occurrence in our SEA results (Fig. 6). Due to lightning, a fire in a tree, mostly in rainy weather, immediate respond to the ignition before it has a chance to spread around. Due to the way graze, shoots close to the ground also decrease, and the probability of conversion from surface

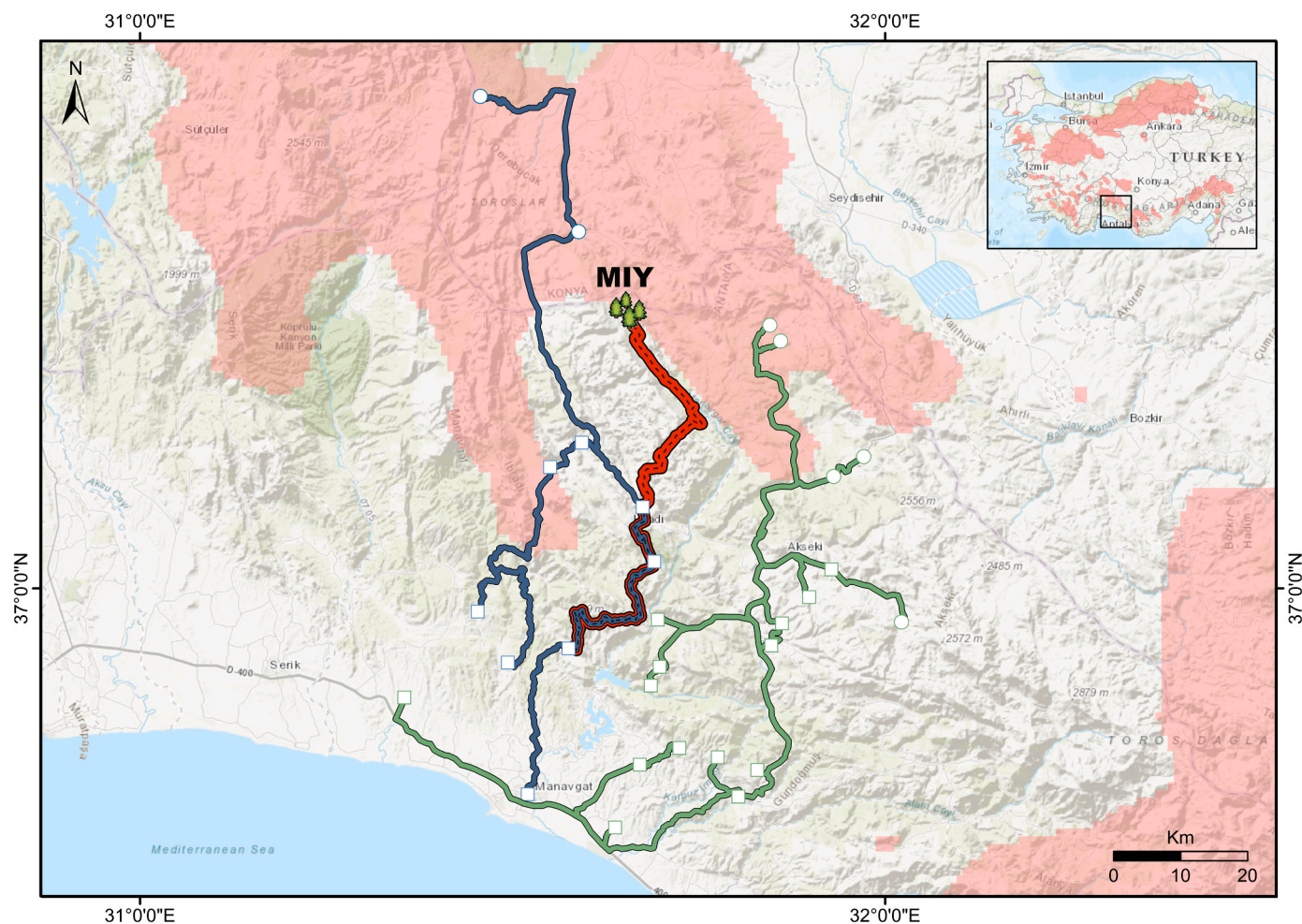


Fig. 7. Two different migration routes of the Antalya-İbradı (blue line on the left) and Antalya-Akseki nomads (green line on the right) (Tolunay et al., 2018; 2020). The migration route of the nomads' inhabitants in the Miraycık highland (red dashed line) was visualised after the interview with the local people. Circle symbols on the migration routes show the summer settlement locations while square show the winter settlement locations.

fire to crown fire decreases.

4.2. Effects of livestock grazing

As mentioned earlier, the individual-level recorded fire years (Fig. 4), nomadic tents of yörüks (Fig. 2) and the axe incisions on the catface formations (Fig. 3) point out the anthropogenic influence on local forest use. The interviews made with the chief of the local forest management unit and the local community stated that these forests were also used intensively by the yörüks in order to graze livestock. Tolunay et al. (2018) visualised the nomadic routes of yörüks in Akseki, Antalya (closest to the MIY site) (Fig. 7). Although the yörüks mentioned in Tolunay et al. (2018); (2020) do not use this route (Miraycık), it is an indicator of the intense nomadic life in the broad regional scale (Fig. 7). The nomad route using the Miraycık highland (red line), which was determined after the interviews with the local people by the chief of the local forest management unit, was also added to the migration routes of Akseki nomadic communities (Fig. 7).

This study site is under a high risk of fire and the grazing effect which reflects the low fire frequency due to reducing the fine fuel material in the understory of the forest. However, the potential negative effects of livestock grazing pressure also need to be discussed. Intense grazing pressure can lead to forest and soil cover degradation as it reduces soil properties by changing the rate of infiltration, percolation, and inhibits tree regeneration, alters ecosystem processes, and loss of biodiversity (Thurow, 1991). For these reasons, the Ministry of Forest and Water

Affairs of Türkiye prepared the “Reducing Goat Damages Action Plan” in 2008 (GDF, 2008). This action plan aimed to reduce the number of goats by 50% in Türkiye, especially in the Mediterranean Region (Türkoğlu et al., 2016). This inaccurate livestock policy caused a huge number of debates and problems for the local producers. This action plan, fortunately, was abolished in 2011 with a radical change in forestry legislation (Türkoğlu et al., 2016). Some of the yörüks also cut down the branch of trees to feed the goats during the migration, therefore, it is necessary to educate and raise awareness among the nomadic herders about the importance of plant regeneration in those forests (Günlü and Alaşahan, 2010) and ministry should keep the number of grazing animals under control for the forest protection (Bilgili et al., 2017). On the other hand, goats consume not only grass but also fresh shoots, the combustible material under the forest, and the branches of the trees closer to the ground. Due to the grazing, shoots close to the ground also decrease which causes fuel patch heterogeneity, lower fire occurrence, less fire-climate association, and reduces the probability of shifting from surface fire to crown fire. We believe preserving and promoting the yörük socio-culture in the Taurus Mountains with awareness of forest protection will be an important way to protect both the culture and the forests from intense, severe wildfires.

It is well-publicised that human-induced suppression activities cause a transition in the regional fire regimes both in our study region and in different parts of the world. Studies showed that settlement and population changes (especially indigenous communities) (Holz and Veblen, 2011; Liebmann et al., 2016; McWethy et al., 2010; Ryzhkova et al.,

2020; Taylor et al., 2016), socioeconomic activities (Mundo et al., 2017; Roos et al., 2022), local and regional laws (Camarero et al., 2018; Kipfmüller et al., 2021; Saladyga et al., 2013), religious and cultural beliefs (Fulé et al., 2011; Fulé et al., 2008; Roos et al., 2021) play an important role in fire regime changes. Rapid wildfire prevention and aggressive fire suppression activities are not intended to manage the fire regime led to the fuel load, which might cause larger or even mega fires in the future. However, the anthropogenic effect we observed in this study slightly differs from human-induced suppression activities. This effect deals with the fuel management (combustible understory material) that was a concern before. Grazing at a moderate level changes the properties of vegetation and combustible material and also affects the fuel-fire interactions under the forest both fuel continuity and amount. That affects the spatial distribution of wildfire and reduces the fire probability. Our main concern for the future is the possibility of a fire regime shift of a species like black pine not only for our study site but across the distribution range of the species. Black pine is adapted to surface fires due to its thick bark formation and self-pruning, however, it might experience crown fires due to human-induced suppression activities that contribute to fuel load in the understory of the forest. For this reason, we recommend more pragmatic and efficient silvicultural practices for fuel management to avoid more severe or mega-fires.

5. Conclusion

This study aims to understand the complex fire occurrence-human-climate interactions by using retrospective fire history studies. Our findings highlight a need to enhance our knowledge of human-fire interactions to improve the skill of future projections of fire driven by climate change. In forest ecosystems where fire regime shifts pose a high risk, our major concern is the threat posed by the combustible material load because of aggressive fire suppression activities. In order to prevent this problem, more efficient silvicultural-based management strategies of the fire regime are recommended (e.g., fuel treatment). This study shed light on the importance of fuel management and changing the perception of moderate-level livestock grazing as a tool for mitigating large-extent and high-severity wildfires. Grazing can help reduce the connectivity of accumulated fine fuel by directly consuming potential fuels and trampling vegetation. Additionally, the trampling of vegetation can mix fine fuels with mineral soil, reducing their flammability and rearranging their spatial distribution, making it more difficult for fires to spread. As a result, grazing can effectively reduce the risk of wildfires in areas with high fuel loads. This reduces the availability of fine fuels, which are more easily ignited and contribute to the intensity and spatial spread of fires, spread of fires, and is a valuable method for minimizing the risk of wildfires in regions with high fuel loads. Lastly, we recommend that herders and people working on animal husbandry must be trained by the Ministry of Agriculture and Forestry, Türkiye by also keeping the number of grazing animals under control. Awareness should be raised to control the potentially harmful influence of overgrazing pressure.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Evrim A. Şahan reports financial support was provided by Scientific and Technological Research Council of Turkey. Evrim A. Şahan reports financial support was provided by Council of Higher Education of the Republic of Turkey. Bedirhan Gurcay reports financial support was provided by Scientific and Technological Research Council of Turkey. H. Tuncay Guner reports financial support was provided by Scientific and Technological Research Council of Turkey.

Data Availability

Data will be made available on request.

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