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Dendroclimatological analyses in a protected area and its surroundings: A case study of the Örümcek Forest

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Abstract: Protected areas are facing challenges arising from both climate change and human activities. Dendrochronological studies can be used to understand tree growth dynamics in protected areas and provide a significant perspective in comprehending the effects of climate change on the trees growing in these regions. To achieve this goal, the study focused on *Picea orientalis* and *Pinus sylvestris* trees at different elevations in the Örümcek Forest Conservation Site in the Eastern Black Sea region of Türkiye. The study area is located in the Caucasian ecoregion and is designated as a Grade I protected area by the International Union for Conservation of Nature due to its undisturbed ecosystem. In the study, five new tree-ring chronologies, with the longest one spanning 300 years, were produced. Linear and non-linear growth analyses between tree-ring widths and main climate factors revealed that the growth of trees in the conservation area and its surroundings was found to respond to late winter-early spring (January–April) temperatures and late spring-early summer (May–June) precipitation. Moving correlation analyses further revealed that these relationships were not consistent over time. Precipitation was found to be a more critical factor for *P. orientalis* trees, whereas temperature changes were more influential on the growth of *P. sylvestris* trees. Through Generalised Additive Mixed Model (GAMM) analyses, it became possible to understand the critical periods affecting the growth of both coniferous tree species in more detail

Keywords: Dendroclimatology, Protected area, Anatolia, Caucasus ecoregion, Örümcek Forest Conservation Site, Climate change

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** This study is based on the first author's master thesis

Introduction

Protected areas are designated and managed to conserve biological diversity and ecosystems (Dudley, 2008), where climate change and human activities cause a number of problems (Hannah, 2008; Hoffmann, 2021; Schulze et al., 2017). Climate-related changes, in particular, impact biodiversity by causing habitat degradation and shifts in species distribution (Habibullah et al., 2022; Ranius et al., 2023).

Furthermore, anthropogenic impacts, such as land-use issues, resource overexploitation, and problems affecting the well-being of local communities and individuals, as well as political and economic concerns within conservation and management strategies, also play a significant role in influencing protected areas and their surroundings (Folharini et al., 2022; Gatiso et al., 2022; Jones et al., 2018). In addition, the lack of technological equipment, data and staff within governmental agencies also impacts the management of conservation areas and the effectiveness and sustainability of protected areas (Appleton et al., 2022; Jiménez López & Mulero-Pázmány, 2019).

Forests are a key component in protected areas in mitigating the impacts of climate change and controlling biodiversity loss (Duncanson et al., 2023; Melillo et al., 2016). Therefore, trees are an source of data for understanding an ecological and environmental processes (Fonti et al., 2010; Smith, 2008). Specifically, the growth characteristics of trees based on tree ring provide valuable insights into the complex interactions of climate and other factors such as mass movements, fire history, and insect outbreaks (Fritts, 1976). Dendrochronological studies in protected areas include various topics, such as examining the relationship between trees with climate (Irby et al., 2013; Ponce-Calderón et al., 2023), analyzing the contribution of trees to the ecosystem and growth processes (Čada et al., 2013; Martin-Benito et al., 2020; Pukinskaya, 2022, 2023; Sanogo et al., 2016), taking measures against fires (Sáenz-Ceja & Pérez-Salicrup, 2019), defining the boundaries and extent of protected areas (Čada et al., 2020), monitoring illegal logging activities (Köse et al., 2018; Wolodarsky-Franke & Lara, 2005), addressing property and management issue (Seijo et al., 2020) and tourism (Ciapała & Adamski, 2015).

Türkiye is in the eastern part of the Mediterranean Basin, which is one of the most important biodiversity hotspots in the world located at the intersection of three important biodiversity hotspots (Mediterranean Basin, Caucasus and Irano-Anatolian) (Myers et al., 2000). The environmental conditions and paleogeographic evolution have contributed significantly to Türkiye's biological diversity (Avcı, 2005; Byfield et al., 2010; Şekercioğlu et al., 2011). Our study area located in the Eastern Black Sea region in north-eastern Türkiye is also part of the Caucasus biodiversity hotspot and the Caucasus ecoregion (Olson & Dinerstein, 2002; Zazanashvili et al., 2020). Forests cover approximately one-fifth of this ecological region and constitute a significant portion of protected areas (Zazanashvili et al., 2020). Örümcek Forest Conservation Site and its surroundings are among the protected areas in the Caucasian ecoregion due to its undisturbed ecosystem (Nakhutsrishvili et al., 2015; Zazanashvili et al., 2020). According to the International Union for Conservation of Nature (IUCN) protection category, the Örümcek Forest Conservation Site has the status of a Grade I protected area (Dudley et al., 2010; Zazanashvili et al., 2020). This forest consists of mixed or pure stands of *Picea orientalis* (L.) Peterm and *Abies nordmanniana* (Steven) Spach subsp. *nordmanniana*, *Fagus sylvatica* L. and *Pinus sylvestris* L. *P. orientalis* is distributed in the Eastern Black Sea region of Türkiye and the Caucasus (Akkemik, 2020; Farjon, 2017). *P. orientalis* forests in our study area, constitute the richest populations in Türkiye in terms of genetic diversity (Güney et al., 2019; Özdilek, 2015). *P. sylvestris*, has one of the southernmost distribution areas in Türkiye (Farjon, 2017). It is generally distributed between 1000 and 2500 meters above sea level. It reaches sea level between Of and Sürmene (Çamburnu) in the Black Sea region. In Eastern Anatolia, it grows up to 2700 meters in Kars (Sarıkamış) and over 2500 meters in Ardahan (Göle) and Erzurum (Şenkaya) (Akkemik, 2020; Atalay et al., 1985).

The Mediterranean Basin is highly sensitive to climate change, with projections indicating increasing temperatures, decreasing precipitation, and more extreme weather events (IPCC, 2021; MedECC, 2020). Türkiye is one of the countries most affected by these changes (Giorgi, 2006; IPCC, 2021; MedECC, 2020). In particular, tree-ring studies in Türkiye forests have been crucial in understanding climate change impacts and developing strategies (Akkemik et al., 2005; Köse et al., 2011; Köse et al., 2017; Touchan et al., 2005). Despite these efforts, there is a notable lack of tree-ring data for northeastern Türkiye. Dendrochronological research in this region would provide valuable insights into climate change adaptation and management of conservation strategies, particularly in protected areas like our study site, the Örümcek Forest Conservation Site. For this purpose, the objectives of this study aims to: 1) obtain climate-sensitive tree-ring chronologies in the Eastern Black Sea region, and contribute to the tree-ring data network of *P. sylvestris* and *P. orientalis*, 2) identify climate factors affecting the radial growth of both species in similar growing environments, 3) determine the stability of climate-growth relationships over time, 4) and examine non-linear growth relationships in climate-growth relationships.

Materials and methods

Study area

The study area is located in the Eastern Black Sea region of Türkiye (40°50'–40°25'N and 38°49'–39°07'E), is notable for its distinctive topography and climatic features (Fig. 1). The Black Sea climate,

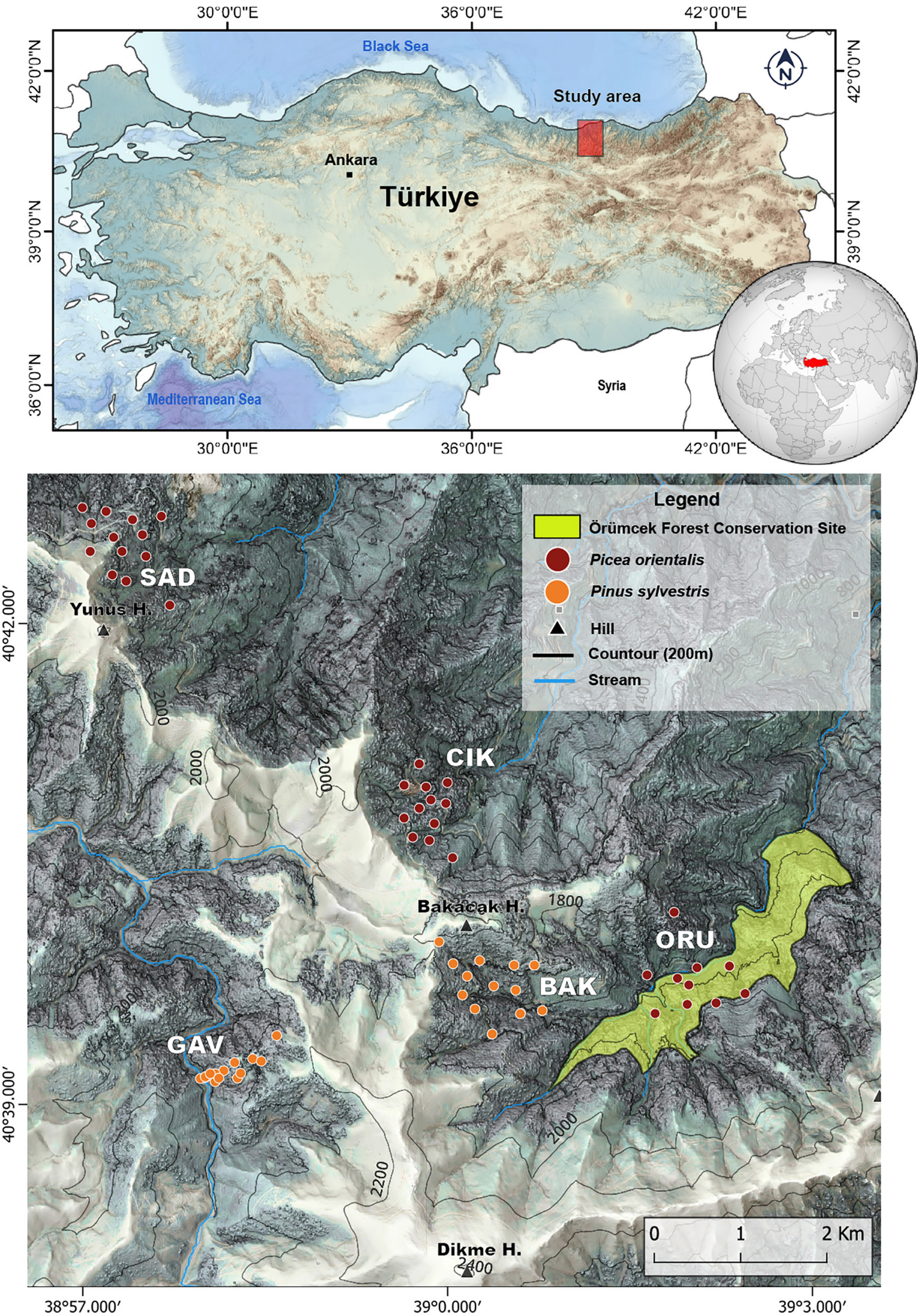

Fig. 1. Location of sites and sampled trees. The maroon dots represent *P. orientalis*, while the orange dots represent *P. sylvestris* sampled trees. The polygon shows the Örümcek Forest Conservation Site

in northern Türkiye, is characterized by a year-round wet season, with peak precipitation occurring in autumn. In the Eastern Black Sea region, which includes the study area and its surroundings, a special sub-climatic area is formed due to different global atmospheric systems active in winter and summer (Karaca et al., 2000), the marine influence on climate elements such as temperature and precipitation caused by the Black Sea water mass (Bozkurt & Şen, 2011; Kindap, 2010) and the topographical features of the area. The region's topography, dominated by the Eastern Black Sea Mountains, features steep slopes, deep valleys and varying elevations. This complex landscape/topography plays a crucial role shaping local microclimates and supports the area's rich biodiversity. Additionally, other physical geographic characteristics, such as soil composition and vegetation types, are also strongly influenced by the dynamic interplay between topography and climate.

Tree-ring chronologies development

A total of 143 increment cores were collected from 68 living trees across five different sites and elevation ranges, where *P. orientalis* and *P. sylvestris* are distributed. Samples were collected from trees in pure forest stands at the GAV site and SAD site, while cores from the CIK and BAK sites were taken from coniferous mixed forest composed of *P. orientalis, P. sylvestris, A. nordmanniana* subsp. *nordmanniana*. At the ORU site, cores were taken from a mixed forest consisting of conifers such as *P. orientalis, A. nordmanniana* subsp. *nordmanniana, and broad-leaved F. sylvatica* trees (Table 1). Two increment cores (occasionally three) were collected from each tree, and each sample was meticulously labeled in the field with details such as site code, tree number, and core number. Additional site-specific information, including coordinates, elevation, aspect, and slope, was recorded in field notebooks, and photographs of each sampling site were taken. On sloped terrains, cores were taken perpendicular to the slope direction to minimize the formation of compression wood (Fritts, 1976). The labeled samples were stored in paper, chosen specifically for their moisture-absorbing properties.

The increment cores were air-dried and mounted on wooden holder to ensure stability and facilitate precise measurements. To prepare the samples for analysis, the cores were progressively sanded using sandpaper ranging from 60 to 600-grit, ensuring clear visibility of annual rings and boundaries. Before measurement, each core was divided into 10-year sections from bark to pith end visually cross-dated. This method reduces the risk of measurement errors and allows for localized corrections, enhancing the accuracy of the measurements (Stokes & Smiley, 1996). Some of these samples could not be used due to cross-dating problems. For this reason, only the number of trees and samples used are given (Table 1). Tree ring of each increment core sample was measured with a precision of 0.01 mm using the LINTAB-TSAPWin measurement system (Rinn, 2003). The accuracy of the measurements was verified using the COFECHA program (Holmes et al., 1986), which identifies problematic samples or segments or segment.

To remove non-climate growth trends (e.g., age-related growth patterns and stand dynamics), individual series were detrended fitting a negative exponential curve. Autoregressive models were then applied to eliminate autocorrelation caused by the influence of previous years' growth (Cook, 1985). Then individual series were averaged using the biweight robust mean to produce five site chronologies (Cook, 1985). All these analyses were performed using the ARSTAN Program (Cook, 1985). Additionally, the visualization of site chronologies (Fig. 2) was conducted using the "dplR" package in R (Bunn, 2008).

Relationship between tree-ring width and climate

The number of meteorological stations representing the climatic characteristics of mountainous areas is limited in Türkiye. This poses a challenge in explaining the variable climatic conditions over short distances due to the complex topography in regions like our study area (Mountain Research Initiative EDW Working Group, 2015; Yılmaz & Darende, 2021). Due to the absence of mountain stations within the study area boundaries and the short observation durations of existing stations, the CRU TS4.05 grid climate dataset was chosen for climate-growth relationships analysis (Harris et al., 2020). Monthly average temperature and total precipitation variables for the period 1930–2020 were downloaded from KNMI Climate Explorer (https://climexp.knmi.nl/

Table 1. General and geographical information about the sample sites

Location	Sites	Sample species	Trees/cores	Aspect	Elevation (m a.s.l.)	Lat.	Lon.	Stand
Kürtün, Gümüshane	SAD	*Picea orientalis*	11/24	N-NE	1850	40°42'	38°57'	Pure
	BAK	*Pinus sylvestris*	14/30	S-SE	1800–1850	40°39'	39°00'	Coniferous Mix.
	GAV		16/34	S-SW	1800–1850	40°39'	38°57'	Pure
	CIK	*Picea orientalis*	10/21	N-NE	1700	40°40'	38°59'	Coniferous Mix.
	ORU		11/24	N-NE	1500	40°39'	39°01'	Mixed

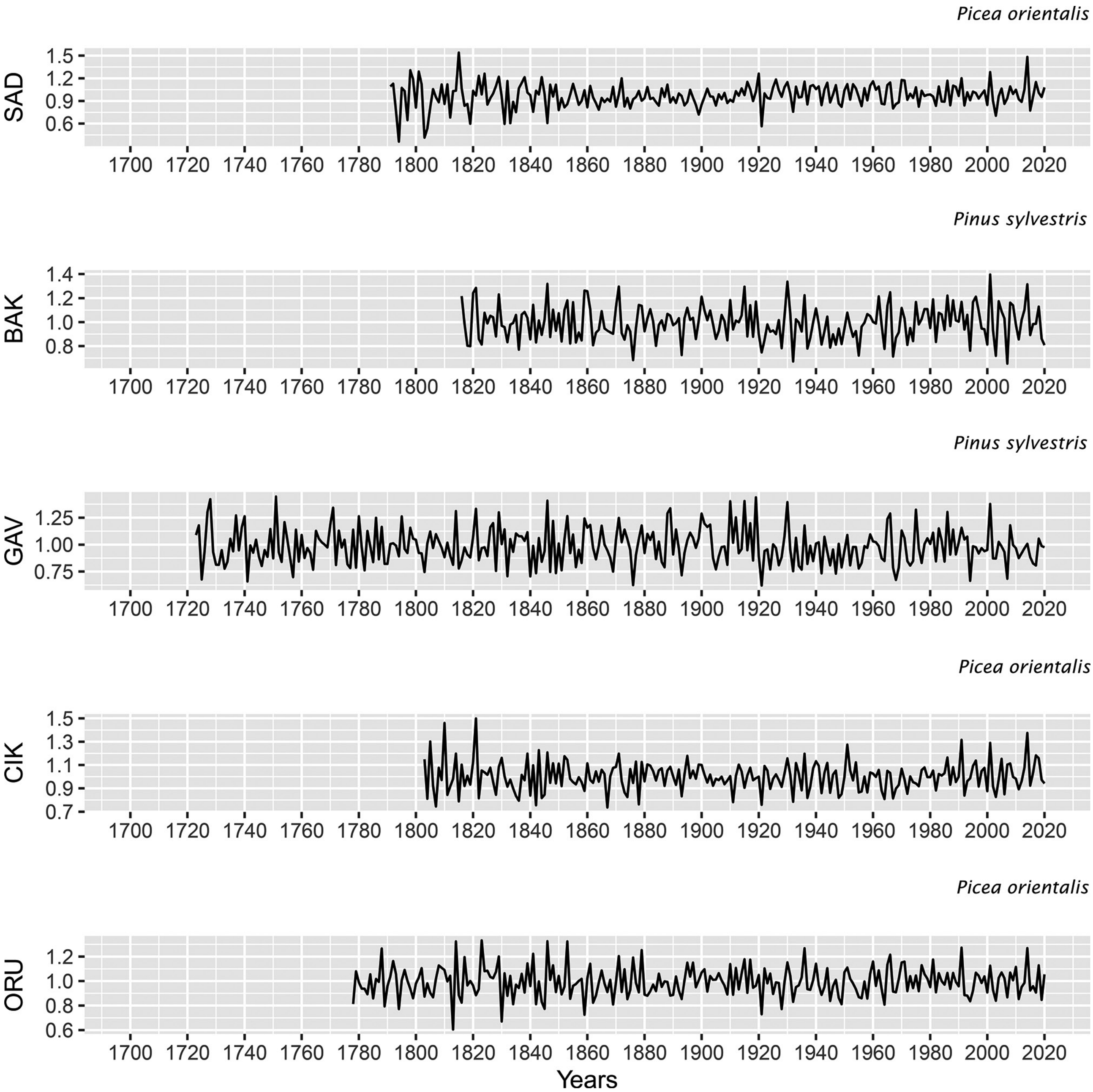

Fig. 2. Site chronologies (the sites are ordered from the highest (on top) to the lowest (on bottom) elevation). The species information for each chronology is shown at the top right

start.cgi) for use in all analyses (Harris et al., 2020). The time range for the climate data (1930–2020) has been determined because the systematic meteorological records being kept in Türkiye since 1930.

The correlation coefficient was used to determine the limiting climatic factors for tree growth. Correlation analysis was calculated for the biological year, representing the year from previous October to the current October. The temporal changes and stability of these climate-radial growth relationships based on significant and high correlations were determined using the moving window correlation function. Moving correlations were calculated for each chronology with a 35-year window with a 5-year offsets using the 'treeclim' package (Zang & Biondi, 2015). Generalised Additive Mixed Model (GAMM) was applied to estimate the non-linearity in climate-growth relationships and to determine the thresholds of possible response of species to changing climatic conditions. GAMM is a model that allows the identification of non-linear relationships between dependent variables (tree-ring width) and independent variables (climatic factors) (Wood, 2011). The model run for each species separately. Site chronologies (tree-ring growth data reflecting species-specific climatic responses, e.g., ORU, CIK, and SAD for *P. orientalis*, and BAK and GAV for *P. sylvestris*) and years (representing inter-annual variability) were included in the model using the random effect function in the model specification and testing phase. The effective degrees of freedom (hereafter referred as edf) is a summary statistic of GAMM and reflects the degree of linearity of a curve (Wood, 2006). In this study, we used the following thresholds for edf to determine the degree of linearity: edf equal to 1 indicate a linear relationship, values between 1 and 2 ($1 < \text{edf} \leq 2$) indicate a weak non-linear relationship, and values greater than 2 indicate a non-linear relationship (Hunsicker et al., 2016). GAMM analyses were performed using the 'mgcv' package in R (version 1.8-33) (Wood, 2017). All analyses performed in the R environment (R Core Team, 2013).

Results

Site chronology characteristics

In this study, we built five tree-ring chronologies for two coniferous tree species. For *P. sylvestris*, the chronologies were 300 years-longong (1721–2020) in GAV and 206 years (1815–2020) in BAK. As for *P. orientalis*, they were 246 years-longong (1775–2020) in ORU, 232 years (1789–2020) in SAD, and 219 years (1802–2020) in CIK (Fig. 2). When the mentioned sites and species were analyses in terms of the mean sensitivity (MS) value, which expresses the sensitivity of tree rings, the value ranged between 0.12–0.19. The chronologies constructed using *P. sylvestris* trees (GAV 0.19 and BAK 0.17) exhibit higher values compared to the *P. orientalis* chronologies (ORU 0.13, CIK 0.12, and SAD 0.14) (Table 2).

Linear and non-linear growth response to the climate

Linear correlation coefficients showed that January–April temperatures, which are significant correlated across nearly all sites, represent important limiting factor for *P. orientalis* and *P. sylvestris* growth in the study area, with March exhibiting the highest correlation (Fig. 3). During this period, high temperatures positively affect the radial growth of the trees. The influence of temperatures in July and August on annual growth is also favourable particularly showing significant values in *P. orientalis* trees (Fig. 3). On the other hand, temperatures in current year

Table 2. Descriptive chronology statistics for each site (EPS – Expressed Population Signal, MS – Mean sensitivity, SNR – Signal-to-noise ratio, Rbar – The mean interseries correlation between all series)

Sites	Chronology time span	First year EPS > 0.85	MS	SNR	Rbar
SAD	1789–2020	1911	0.14	5.25	0.35
BAK	1815–2020	1825	0.17	3.76	0.28
GAV	1721–2020	1740	0.19	6.53	0.36
CIK	1802–2020	1836	0.12	4.90	0.34
ORU	1775–2020	1775	0.13	1.92	0.26

Note: Detailed statistics for the chronologies are available in the supporting information Table S1, S2.

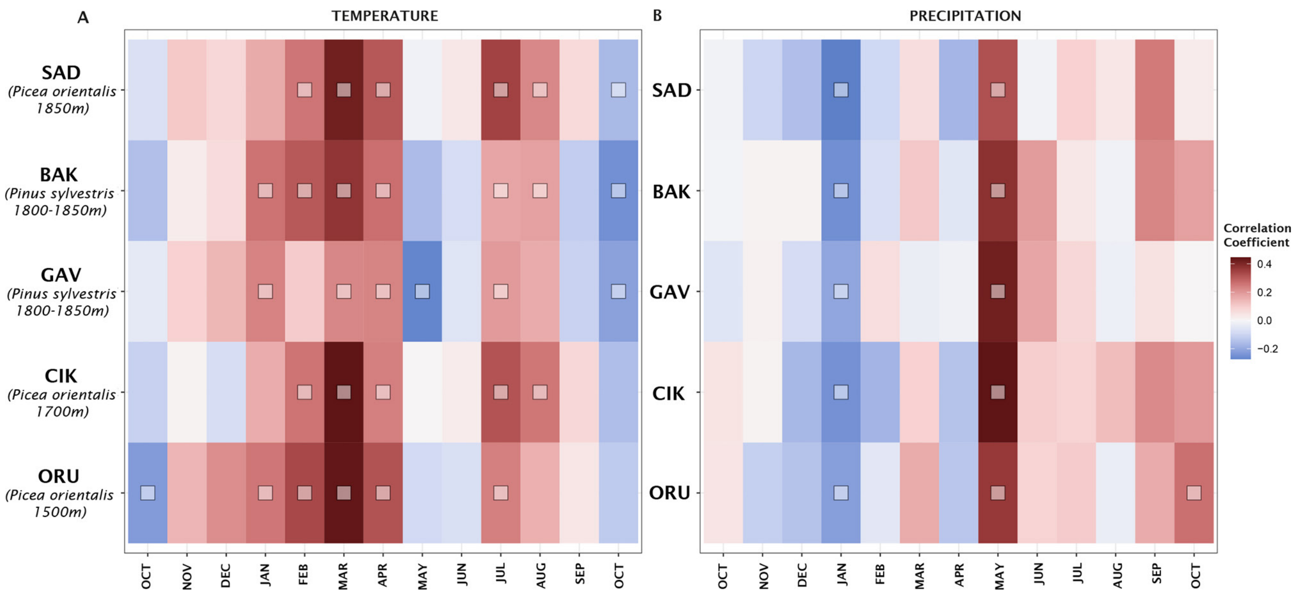

Fig. 3. The correlation coefficients of climatic variables with radial growth of *P. sylvestris* and *P. orientalis* between 1930 and 2020. Squares indicate months with statistically significant correlation coefficients ($p < 0.05$)

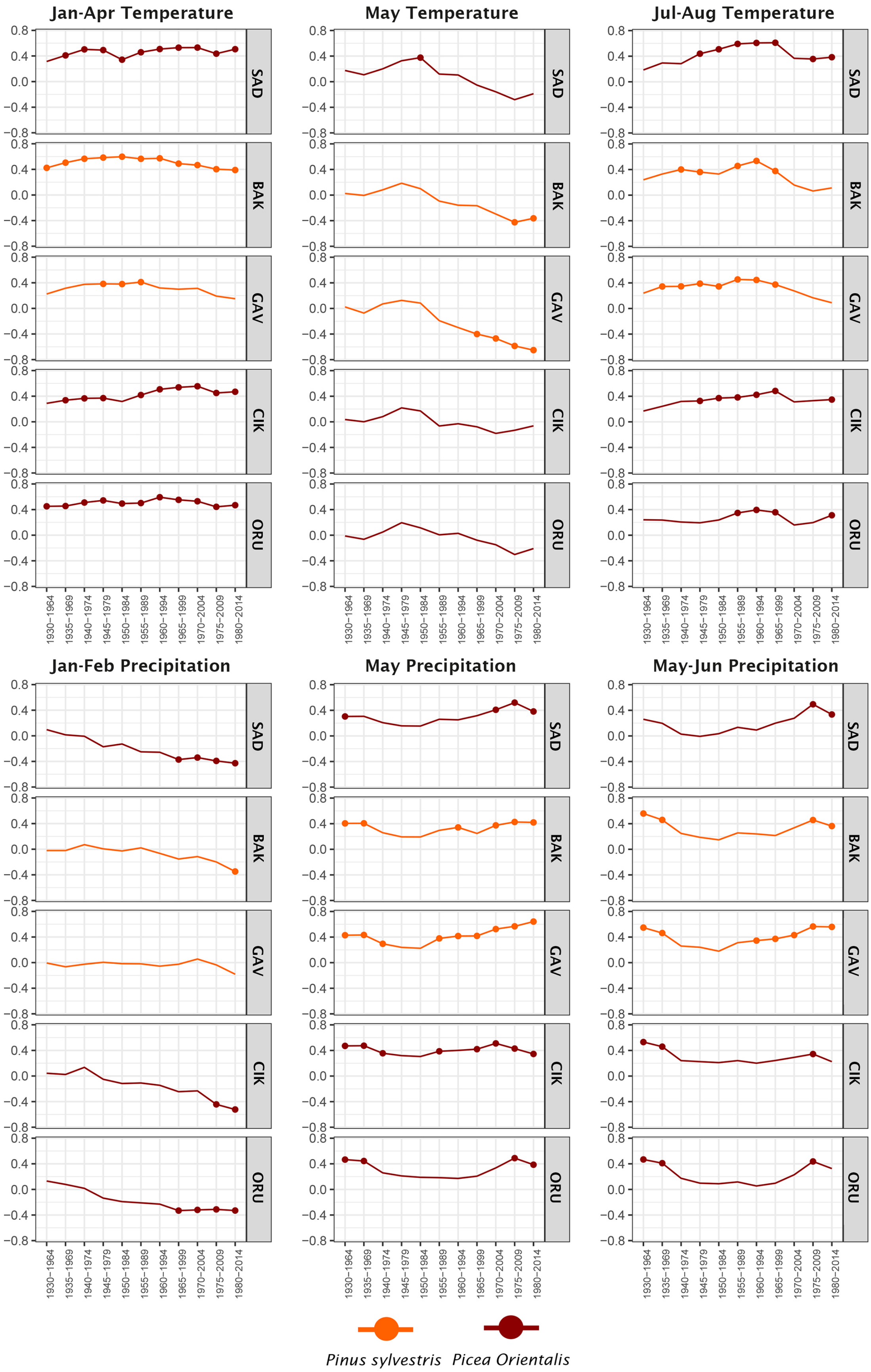

Fig. 4. Moving correlation (35-year window) between RWIs and months determined for temperature and precipitation. Species are represented by colors (e.g. orange for *P. sylvestris*, maroon for *P. orientalis*). Dots indicate significance at $p \leq 0.05$

May (statistically significant for the GAV site) have a negative impact on the growth of *P. sylvestris* trees (Fig. 3). In addition, October temperatures of the current year also have a negative effect in the study area. This effect is statistically significant for *P. sylvestris* trees and *P. orientalis* trees at higher elevations.

The influence of precipitation on radial growth showed similar growth responses for both *P. orientalis* and *P. sylvestris*. Statistically significant positive correlation was found between May precipitation and the tree-ring width of these two tree species (Fig. 3). Moreover, precipitation during almost the entire vegetation period (May–October) has an overall positive effect on growth. In addition, January precipitation in the current year has been found to negatively affect the tree growth of both coniferous tree species (Fig. 3). This effect seems to become stronger with increasing elevation.

The moving correlation analyses have contributed to our understanding of the changes in climate-growth relationships in *P. orientalis* and *P. sylvestris* trees during the period from 1930 to 2020. The positive and significant effect of late winter-early spring temperatures on growth in *P. orientalis* trees (ORU, CIK, and SAD sites) during the analyses period is the most consistent relationship (Fig. 4). There have been no statistically significant relationships observed over time in the growth relationships,

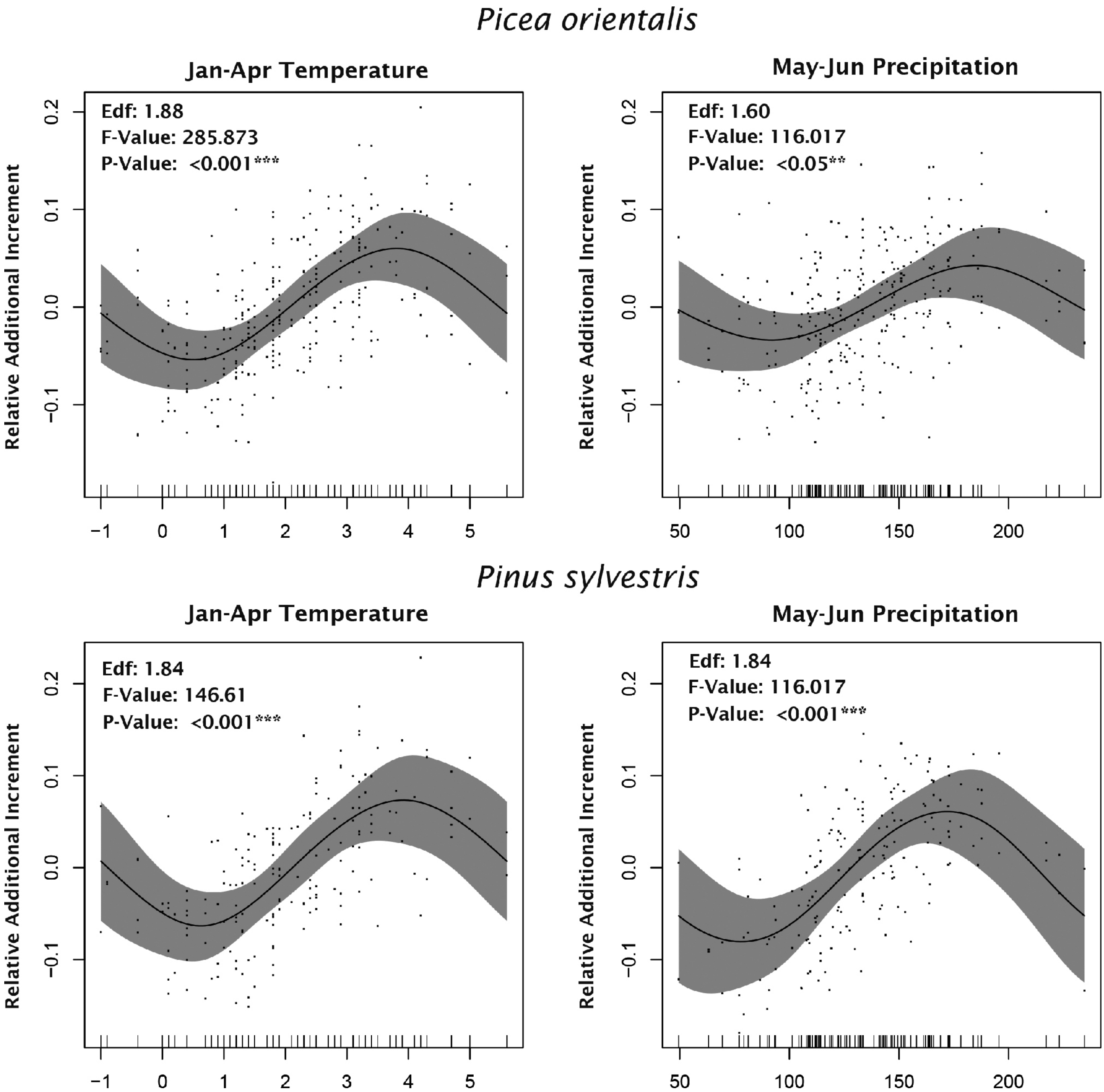

Fig. 5. GAMM output by limiting factors between 1930 and 2020 (shades of grey indicate 95% confidence intervals. r^2 for *P. orientalis*: 0.74 while r^2 for *P. sylvestris*: 0.77

except for the period 1950–1984 at the SAD site, related to May temperatures. After 1955, there has been a notable negative shift in the relation between May temperatures and tree-ring growth. *P. orientalis* growth showed a positive correlation with July–August temperatures during the analysis period, with statistically significant relationships emerging after 1950, regardless of elevation (Fig. 4).

In terms of precipitation-growth relationships, the negative effect of winter (January–February) precipitation on the growth of *P. orientalis* gradually became stronger. After 1940, the correlation values, which were nearly 0 at the start of the analysis period, changed negatively. After 1965, the adverse effect reached statistical significance (after 1975 for CIK). The positive effect of May/May–June precipitation on growth is observed throughout the whole period (Fig. 4). On the other hand, variations in the amount of rainfall in late spring and early summer have a periodic impact on *P. orientalis* growth. Growth relationships occasionally became (statistically) ambiguous over time and then returned to significance as a result of these changes.

P. sylvestris trees showed similar growth relationships to *P. orientalis* trees, but there are also significant differences. These differences are also evident among the *P. sylvestris* sites, particularly in the varying responses to late winter-spring temperatures. In the BAK site, the effect of late winter-spring temperatures on growth was positive and significant during the whole analysed period. In the GAV site, the relations, which were significant and positive between 1945 and 1989, weakened afterwards (Fig. 4). The negative effect of May temperatures on *P. sylvestris* has gradually intensified and become statistically significant after 1975 in the BAK site and after 1965 in the GAV site (Before 1955, the positive correlation values close to zero and turned negative after 1955). It is seen that the sensitivity of *P. sylvestris* growth to May temperatures has increased. Furthermore, at both the GAV and BAK sites, positive and significant growth responses to July and August temperatures weakened after 1970.

In terms of precipitation-growth relations, the effect of winter precipitation on *P. sylvestris* trees was negative. However, these relationships are not statistically significant except for the period 1980–2014 in the BAK site (Fig. 4). May/May–June precipitation shows a positive relationship with the growth of *P. sylvestris* trees in the entire analysis period. Compared to *P. orientalis* trees, the growth of *P. sylvestris* is more susceptible to variations in late spring and early summer precipitation. The period in which May precipitation-growth relationships become statistically significant (after 1970) matches the common period with the negative effects seen in the temperatures of the same month.

GAMM analysis showed that the response to January–April temperatures and May–June precipitation is weak non-linear for both species (Fig. 5). For the two conifer tree species, mean January–April temperatures between approximately 2–5.5 °C (peaks 4 °C) promote positive additional increment, while higher and lower temperatures cause negative relative additional increment. On the other hand, the non-linear effect of precipitation slightly differed for the species in terms of edf values and thresholds. For *P. orientalis*, total May–June precipitation between approximately 135–235 mm (peaks 185 mm) promote positive additional increment. For *P. sylvestris* these values are 130–210 (peaks 170 mm) while higher and lower precipitation cause negative relative additional increment.

Discussion

Site-level chronologies

In our study, we have developed five chronologies for two coniferous species. The chronologies developed have contributed to the extension of the previously developed chronologies having low sample depth (Özkan, 1990, 1999; Kuniholm, 1991; Özkan & Akbulut, 2003) until 2020 period. The longest chronology was obtained from the GAV site (1721–2020, 300 years) in pure *P. sylvestris* stands, while the shortest chronology was from the BAK site (1815–2020, 206 years), composed of *P. sylvestris* trees from a mixed coniferous forest stand. For *P. orientalis*, the longest chronology was developed from the Örümcek Forest Conservation Site (ORU, 1775–2020, 246 years). Despite differences in elevation, *P. orientalis* chronologies showed similar lengths (ORU 246, CIK 219, SAD 232). The longest chronology for this species, 510 years (spanning 1498–2007), was built by Martin-Benito et al. (2018) from a managed forest at 1750 m in Artvin, Borçka, northeastern Türkiye.

MS values were generally low for *P. orientalis* trees (ORU 0.13, CIK 0.12, SAD 0.14), regardless of elevation. Similar results have been reported in other dendrochronological studies of this species distributed in the Eastern Black Sea and Caucasus (Işık et al., 2024; Köse et al., 2017; Özkan, 1990, 1999; Kuniholm, 1991; Özkan & Akbulut, 2003). However, due to local topographic factors such as aspect (Işık et al., 2024), elevation (İmren & İrdem, 2023), slope (İmren & İrdem, 2023; Işık et al., 2024), or in areas where *P. orientalis* grows outside its natural distribution area (Song et al., 2021), the MS value seems to have changed. *P. sylvestris* trees (GAV, 0.19, BAK, 0.17) have higher MS values than *P. orientalis*. We can say that *P. sylvestris* trees sampled in this study are moderately sensitive to climate, when we compare the MS values with the results of previous studies ranging from 0.14 to 0.30 (Bogino et al., 2009; Ergül Bozkurt et al., 2021; Herrero et al., 2013; Kopabayeva et al., 2017; Köse et al., 2017; Linderholm & Linderholm, 2004; Rigling et al., 2002; Tabakova et al., 2020). In the mountainous areas such as our study area, topography significantly affects the direction and intensity of light, which is very crucial for plants. In addition, in the Northern Hemisphere, the southern slopes get more sunlight than the northern slopes. Therefore, south-facing slopes have higher temperatures and lower soil moisture. It was assumed that the highest MS value in *P. sylvestris* at the GAV site may be due to the fact that the sampled area is located on the southern slope. It is also thought that the hillside properties (e.g. slope, unconsolidated bedrock) in the GAV could also strengthen these effects.

Climate Growth relationships

January–April mean temperatures strongly influenced tree growth, with cold winter and spring limiting growth for *P. orientalis* and *P. sylvestris*. Similar growth responses have been reported in many studies with different conifer tree species in the northern hemisphere (Harvey et al., 2020; Herrero et al., 2013; Jevšenak et al., 2021; Sánchez-Salguero et al., 2017). Higher winter and early spring temperatures can activate cambium earlier (Buttò et al., 2020; Rossi et al., 2007), increase soil moisture from snowmelt (Fritts, 1976), and extend the growing season (Jevšenak et al., 2021). On the other hand, it has also been emphasized that changes at the beginning of the growing season or during the growing season may also cause plants to become vulnerable (D'Orangeville et al., 2018; Liu et al., 2018). In particular, *P. orientalis* is sensitive to frost and there are many reports of bark beetle disease-induced drying in the natural distribution area of the species (Abatay, 1989; Pukinskaya, 2022, 2023). Considering the elevation conditions of the study area, in cases where the vegetation season starts early, potential risks such as early frost damage and hazards triggered by temperature-induced insect or fungal diseases can occur. Therefore, in years when the vegetation period starts early or lasts long, trees may be vulnerable to various climatic (such as frost damage) and biological (such as insect or fungal diseases) risks (Alkan Akıncı et al., 2022; Allen et al., 2010; Camarero et al., 2015).

The coniferous trees in our study also showed different growth responses temporally (1930–2020), although they were found in similar growing conditions. For *P. orientalis* trees, the positive and significant effect of winter temperatures on growth was the most temporally consistent relationship. However, for *P. sylvestris*, we observed that this effect varied across sites and was not always stable over the analyses period. This pattern may reflect the impact of increasing warming trends on growth in Türkiye, one of the southernmost distribution areas of *P. sylvestris*. The fact that the change was more apparent in the GAV site suggests that the local conditions of this area (aspect and slope characteristics) make the species even more sensitive to climate change. Increased temperature sensitivity has been reported in many studies assessing the response of *P. sylvestris* to changing temperature conditions (Billings et al., 2015; Ergül Bozkurt et al., 2021; Matisons et al., 2021; Tabakova et al., 2020).

Non-linear growth analyses revealed similar growth thresholds for *P. orientalis* and *P. sylvestris* trees for January–April temperatures. For both species, average January–April temperatures between about 2 and 5.5 °C positively affected growth and stimulated an increase. However, temperatures above or below these thresholds have negative effects on growth. The physiological growth thresholds of trees in the study area, based on long-term January–April temperature averages, shed light on the species environmental adaptation thresholds. In the short-, medium-, and long-term climate change projections made in the Mediterranean Basin and Türkiye, it is predicted that the Eastern Black Sea region will also be affected by climate change and that seasonal and annual temperatures will increase (IPCC, 2021; MedECC, 2020). This shift may alter the temperatures range to which local trees in the area are adapted, increasing their environmental stress.

Precipitation during winter (especially January) has a negative impact on the species. In mountainous areas, elevation conditions often influence climatic factors (such as temperatures, precipitation pattern and duration, and wind) and can have direct or indirect consequences on plants (Pepin et al., 2022). Physiological drought, frost-induced damage to roots or trunks, falling due to strong winds, or various morphological damages may occur, even if the cambium cells in the trees are not active (Körner, 2012). In our study, *P. orientalis* trees in particular showed a stronger negative relationship with winter precipitation than *P. sylvestris* trees. This effect may be related to the shallow root system of *P. orientalis* trees (Körner, 2012; Martin-Benito et al., 2018). Similar negative responses were also reported in different distribution areas of the species (İmren & İrdem, 2023; Işık et al., 2024; Martin-Benito et al., 2018).

The combined effect of high temperature and low precipitation on annual growth leads to the formation of narrow ring in *P. sylvestris* trees. These results align with the previous research by Ergül Bozkurt et al. (2021) on the growth responses of *P. sylvestris* trees in Türkiye. Similarly, higher May temperatures have been highlighted as one of the important limiting factors for *P. sylvestris* and *P. orientalis* trees in the Caucasus (Martin-Benito et al., 2018; Martin-Benito et al., 2016). Moving correlation analyses indicate a negative shift in the growth responses of both *P. orientalis* and *P. sylvestris* after 1955, with significance observed after 1975 at the BAK site and after 1965 at the GAV site. After this year, it was observed that the need for precipitation for the trees in the region gradually increased. In many studies, *P. sylvestris* has been evaluated as one of the tree species most affected by climate change due to its wide distribution over a large area and in different habitats around the world (Kullman, 2007; Matías et al., 2017; Sánchez-Salguero et al., 2015). Studies have also reported that temperature increases, and lack of precipitation are the main abiotic factors responsible for the tree mortality of *P. sylvestris*. Our results provided an additional record for increased temperature stress for *P. sylvestris* trees. In addition, topography and local area conditions have been reported to influence growth responses to climate (Oberhuber & Kofler, 2000; Xenakis et al., 2012). The more significant effect of May temperatures on *P. sylvestris* trees in the GAV site suggests this interaction.

On the other hand, in temperate forests, the cambium is typically most active in late spring and early summer (Fritts, 1976). For *P. sylvestris*, cambium activity and the production of new cells lasts from early/mid-April to late June/early July (at Austrian sites) and until September/October (in Spain), with the highest cell production occurring in early/mid-May (Gruber et al., 2010; Martinez del Castillo et al., 2016; Swidrak et al., 2014). The increase in cambium and other physiological activities with temperature makes trees more sensitive to precipitation and soil moisture (Fritts, 1976). As a result, in our study area, positive growth responses to May and May–June precipitation were identified as another strong factor after winter temperatures. This growth response is the most common climate signal not only in our study area but also in a large area covering the Mediterranean Basin and the Caucasus (Dolgova & Solomina, 2010; Ergül Bozkurt et al., 2021; Martin-Benito et al., 2018; Martin-Benito et al., 2016).

Positive responses to May and May–June precipitation are also positive for the species over the analysed period. It is noteworthy that the positive responses of trees to precipitation increased during the period when the negative effects of May temperatures became stronger (after 1955). After 1975, the growth responses of *P. orientalis* and *P. sylvestris* trees to precipitation are statistically significant in the whole study area. Increasing temperatures seem to increase the sensitivity of trees to precipitation. and in our study, the physiological thresholds of *P. sylvestris* and *P. orientalis* for May–June precipitation were also determined. Species with similar thresholds for winter temperatures had different thresholds for precipitation. While a threshold value of approximately 135 - 235 mm was determined for *P. orientalis*, this value was found between 130–210 mm for *P. sylvestris*. Similar threshold value (>120 mm) for May–June precipitation were calculated for *P. sylvestris* in the Türkiye distribution by Ergül Bozkurt et al. (2021). Moreover, our non-linear growth analysis clearly showed differences in the ecological and environmental adaptations of the two conifer species in our study area. *P. orientalis* requires higher precipitation amounts than *P. sylvestris*. On the other hand, *P. sylvestris* can adapt to more arid conditions than *P. orientalis* and can be content with lower precipitation (Farjon, 2017). The higher drought tolerance of *P. sylvestris* compared to *P. orientalis*, along with its ability to grow in drier areas, is also supported by the findings from the Caucasus reported by Martin-Benito et al. (2018).

Correlation analyses reveal that late summer temperatures (July–August) have a positive effect on the radial growth of both species in the study area. The topographical features (especially the elevation) and the climate of our study area seem to support tree-ring growth. Similarly, positive relationships between temperature and radial growth are also common in mountainous areas and other areas of high-elevation in the Northern Hemisphere (George, 2014; Martin-Benito et al., 2018; Shi et al., 2021; Tshering et al., 2024; Wang et al., 2017) Furthermore, studies in the Eastern Black Sea region have reported different responses of *P. orientalis* to temperature changes at similar altitudes (Işık et al., 2024). Nevertheless, there is evidence that summer temperatures have a positive effect on tree growth in mountainous and high-elevation regions in the Northern Hemisphere (Wang et al., 2017). Moving correlation analyses conducted in our study area; in the post-1965 period, the positive response of trees in our region to late summer temperatures has weakened, and the significance of cold limitation was lost. A comparable shift has been documented in *P. sylvestris* trees situated at elevated altitudes in the Caucasus (Martin-Benito et al., 2018). Dendroclimatological studies indicate that the disappearance of cold limitation may result in increased tree-ring growth of trees at high altitudes in response to global temperature increases (Shi et al., 2021; Zheng et al., 2021). However, some studies indicate that the seasonal and annual temperature increases associated with a warming climate may result in reduced tree growth due to water and soil moisture deficits (McDowell & Allen, 2015; Jump et al., 2017). This has the potential to have significant implications, including the possibility of tree or forest mortality.

The point to be highlighted is the seasonal and annual changes of temperature and precipitation in regional climate models (RCMs) for Türkiye and the Black Sea region. Temperature increase trends are projected to persist until the end of the 21st century, particularly during the summer season, with pessimistic scenarios predicting increases of up to 10 °C (Nacar et al., 2024). These projections are consistent with those of other studies on Türkiye, which indicate a notable rise in temperature, particularly during the winter and summer months. (IPCC, 2021; MedECC, 2020; Önol et al., 2014; Türkeş et al., 2020). Precipitation patterns in the Eastern Black Sea site exhibit a more complex structure, with increases in spring and winter precipitation and decreases in summer and autumn precipitation. However, predictions indicate that the Black Sea climate, known for its every-season rainy, will change significantly in the future (Bağçaci et al., 2021).

The tree species in our study area are expected to be affected by climate change. Climate projections show that increasing temperatures and changing precipitation patterns will directly influence tree growth dynamics. *P. orientalis* and *P. sylvestris* share similar habitats but respond differently to climate change. *P. orientalis* is more sensitive to rising temperatures and decreasing summer precipitation, making its growth potential likely to decline earlier under these conditions. *P. sylvestris*, with its ability to adapt to a wider range of conditions, initially appears to have a competitive advantage. However, long-term stress caused by climate change may also affect this species. These changes could lead to significant shifts in the species composition of forest ecosystems in the study area. In areas lacking regular monitoring, tree-ring data play a critical role in addressing gaps in evaluating environmental changes. Tree rings not only provide insights into past environmental conditions but also aid in developing future projections based on climate scenarios (Kazimirović & Stajić, 2024). This approach serves as a valuable guide for conservation and adaptation experts in developing effective strategies for protected areas.

Conclusions

In this study, the climate-growth relationships of *P. orientalis* and *P. sylvestris* trees in and around the Örümcek Forest Conservation site were comprehensively examined. Our findings show that tree-ring data have significant potential for developing effective conservation and adaptation strategies for protected areas and surrounding forests. Future studies should focus not only on climate-growth relationships but also on the effects of other abiotic and biotic factors on tree growth. This approach will enable a more comprehensive understanding of the impacts of climate change, considering various ecosystem components.

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References

Abatay M (1989) Doğu ladini hastalıkları ve mücadelesi: Doğu Ladini (ed. by ÖS Erkuloğlu) Ormancılık Araştırma Enstitüsü Müdürlüğü Yayınları, Ankara, pp. 203–216.

Akkemik Ü (2020) Pineceae: Türkiye'nin Bütün Ağaçları ve Çalıları (ed. by Ü Akkemik) Türkiye İş Bankası Kültür Yayınları.

Akkemik Ü, Dağdeviren N & Aras A (2005) A preliminary reconstruction (AD 1635–2000) of spring precipitation using oak tree rings in the western Black Sea region of Turkey. International Journal of Biometeorology 49: 297–302. doi:10.1007/s00484-004-0249-8.

Alkan Akıncı H, Genç Ç & Akıncı H (2022) Susceptibility assessment and mapping of *Ips typographus* (L.) (Coleoptera: Curculionidae) in oriental spruce forests in Artvin, Turkey. Journal of Applied Entomology 146: 1185–1199. doi:10.1111/jen.13045.

Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, Vennetier M, Kitzberger T, Rigling A, Breshears DD, Hogg EHT, Gonzalez P, Fensham R, Zhang Z, Castro J, Demidova NL, Jong-Hwan, Allard G, Running SW, Semerci A & Cobb N (2010) A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259: 660–684. doi:10.1016/j.foreco.2009.09.001.

Appleton MR, Courtiol A, Emerton L, Slade JL, Tilker A, Warr LC, Malvido MÁ, Barborak JR, de Bruin L, Chapple R, Daltry JC, Hadley NP, Jordan CA, Rousset F, Singh R, Sterling EJ, Wessling EG & Long B (2022) Protected area personnel and ranger numbers are insufficient to deliver global expectations. Nature Sustainability 5: 1100–1110. doi:10.1038/s41893-022-00970-0.

Atalay İ, Tetik M & Yılmaz Ö (1985) Kuzeydoğu Anadolu'nun ekosistemleri : The Ecosystems of North-Eastern Anatolia. Ormancılık Araştırma Enstitüsü, Ankara.

Avcı M (2005) Diversity and endemism in Turkey's vegetation. Istanbul University Journal of Geography: 27–55.

Bağçaci SÇ, Yucel I, Duzenli E & Yilmaz MT (2021) Intercomparison of the expected change in the temperature and the precipitation retrieved from CMIP6 and CMIP5 climate projections: A Mediterranean hot spot case, Turkey. Atmospheric Research 256: 105576. doi:10.1016/j.atmosres.2021.105576.

Billings SA, Glaser SM, Boone AS & Stephen FM (2015) Nonlinear tree growth dynamics predict resilience to disturbance. Ecosphere 6: 1–13. doi:10.1890/ES15-00176.1.

Bogino S, Fernandez Nieto MJ & Bravo F (2009) Climate effect on radial growth of *Pinus sylvestris* at its southern and western distribution limits. Silva Fennica 43: 609–623. doi:10.14214/sf.183.

Bozkurt D & Şen ÖL (2011) Precipitation in the Anatolian Peninsula: sensitivity to increased SSTs in the surrounding seas. Climate Dynamics 36: 711–726. doi:10.1007/s00382-009-0651-3.

Bunn AG (2008) A dendrochronology program library in R (dplR). Dendrochronologia 26: 115–124. doi:10.1016/j.dendro.2008.01.002.

Buttò V, Deslauriers A, Rossi S, Rozenberg P, Shishov V & Morin H (2020) The role of plant hormones in tree-ring formation. Trees 34: 315–335. doi:10.1007/s00468-019-01940-4.

Byfield A, Atay S & Özhatay N (2010) Important plant areas in Turkey: 122 key Turkish botanical sites. WWF Turkey, İstanbul.

Čada V, Svoboda M & Janda P (2013) Dendrochronological reconstruction of the disturbance history and past development of the mountain Norway spruce in the Bohemian Forest, central Europe. Forest Ecology and Management 295: 59–68. doi:10.1016/j.foreco.2012.12.037.

Čada V, Trotsiuk V, Janda P, Mikoláš M, Bače R, Nagel TA, Morrissey RC, Tepley AJ, Vostarek O, Begović K, Chaskovskyy O, Dušátko M, Kameniar O, Kozák D, Lábusová J, Málek J, Meyer P, Pettit JL, Schurman JS, Svobodová K, Synek M, Teodosiu M, Ujházy K & Svoboda M (2020) Quantifying natural disturbances using a large-scale dendrochronological reconstruction to guide forest management. Ecological Applications 30: e02189. doi:10.1002/eap.2189.

Camarero JJ, Gazol A, Sancho-Benages S & Sangüesa-Barreda G (2015) Know your limits? Climate extremes impact the range of Scots pine in unexpected places. Annals of Botany 116: 917–927. doi:10.1093/aob/mcv124.

Ciapała S & Adamski P (2015) Methodological aspects of the potential use of dendrochronological techniques when analyzing the long-term impact of tourism on protected areas. PLoS One 10: e0136830. doi:10.1371/journal.pone.0136830.

Cook ER (1985) A time series analysis approach to tree ring standardization. School of Renewable Natural Resources. University of Arizona, Arizona.

D'Orangeville L, Houle D, Duchesne L, Phillips RP, Bergeron Y & Kneeshaw D (2018) Beneficial effects of climate warming on boreal tree growth may be transitory. Nature Communications 9: 3213. doi:10.1038/s41467-018-05705-4.

Dolgova EA & Solomina ON (2010) First quantitative reconstruction of air temperature for the warm period in the Caucasus based on dendrochronological data. Doklady Earth Sciences 431: 371–375. doi:10.1134/S1028334X10030220.

Dudley N (2008) Guidelines for applying protected area management categories. IUCN, Gland, Switzerland.

Dudley N, Parrish JD, Redford KH & Stolton S (2010) The revised IUCN protected area management categories: the debate and ways forward. Oryx 44: 485–490. doi:10.1017/S0030605310000566.

Duncanson L, Liang M, Leitold V, Armston J, Krishna Moorthy SM, Dubayah R, Costedoat S, Enquist BJ, Fatoyinbo L, Goetz SJ, Merow C, Roehrdanz PR, Tabor K & Zvoleff A (2023) The effectiveness of global protected areas for climate change mitigation. Nature Communications 14: 2908. doi:10.1038/s41467-023-38073-9.

Ergül Bozkurt A, Şahan EA & Köse N (2021) Growth responses of *Pinus sylvestris* L. to climate from the southeastern limit of its natural distribution area, Turkey. Dendrochronologia 70. doi:10.1016/j.dendro.2021.125897.

Farjon A (2017) A handbook of the world's Conifers. 2nd ed. Brill, Leiden, Boston.

Folharini SdO, de Melo SN & Cameron SR (2022) Effect of protected areas on forest crimes in Brazil. Journal of Environmental Planning and Management 65: 272–287. doi:10.1080/09640568.2021.1881885.

Fonti P, von Arx G, García-González I, Eilmann B, Sass-Klaassen U, Gärtner H & Eckstein D (2010) Studying global change through investigation of the plastic responses of xylem anatomy in tree rings. New Phytologist 185: 42–53. doi:10.1111/j.1469-8137.2009.03030.x.

Fritts HC (1976) Tree rings and climate. Academic Press, London.

Gatiso TT, Kulik L, Bachmann M, Bonn A, Bösch L, Eirdosh D, Freytag A, Hanisch S, Heurich M, Sop T, Wesche K, Winter M & Kühl HS (2022) Effectiveness of protected areas influenced by socio-economic context. Nature Sustainability 5: 861–868. doi:10.1038/s41893-022-00932-6.

George SS (2014) An overview of tree-ring width records across the Northern Hemisphere. Quaternary Science Reviews 95: 132–150. doi:10.1016/j.quascirev.2014.04.029.

Giorgi F (2006) Climate change hot-spots. Geophysical Research Letters 33: L08707. doi:10.1029/2006GL025734.

Gruber A, Strobl S, Veit B & Oberhuber W (2010) Impact of drought on the temporal dynamics of wood formation in *Pinus sylvestris*. Tree Physiology 30: 490–501. doi:10.1093/treephys/tpq003.

Güney D, Yahyaoglu Z, Bayraktar A, Atar F & Turna I (2019) Genetic diversity of *Picea orientalis* (L.) Link populations in Turkey. Sumarski List 143: 539–547. doi:10.31298/sl.143.11-12.4.

Habibullah MS, Din BH, Tan S-H & Zahid H (2022) Impact of climate change on biodiversity loss: global evidence. Environmental Science and Pollution Research 29: 1073–1086. doi:10.1007/s11356-021-15702-8.

Hannah L (2008) Protected areas and climate change. Annals of the New York Academy of Sciences 1134: 201–212. doi:10.1196/annals.1439.009.

Harris I, Osborn TJ, Jones P & Lister D (2020) Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Scientific Data 7: 1–18. doi:10.1038/s41597-020-0453-3.

Harvey JE, Smiljanić M, Scharnweber T, Buras A, Cedro A, Cruz-García R, Drobyshev I, Janecka K, Jansons Ā, Kaczka R, Klisz M, Läänelaid A, Matisons R, Muffler L, Sohar K, Spyt B, Stolz J, van der Maaten E, van der Maaten-Theunissen M, Vitas A, Weigel R, Kreyling J & Wilmking M (2020) Tree growth influenced by warming winter climate and summer moisture availability in northern temperate forests. Global Change Biology 26: 2505–2518. doi:10.1111/gcb.14966.

Herrero A, Rigling A & Zamora R (2013) Varying climate sensitivity at the dry distribution edge of *Pinus sylvestris* and *P. nigra*. Forest Ecology and Management 308: 50–61. doi:10.1016/j.foreco.2013.07.034.

Hoffmann S (2021) Challenges and opportunities of area-based conservation in reaching biodiversity and sustainability goals. Biodiversity and Conservation 31: 325–352. doi:10.1007/s10531-021-02340-2.

Holmes RL, Adams RK & Fritts HC (1986) Tree-ring chronologies of western North America: California, eastern Oregon and northern Great Basin with procedures used in the chronology development work including users manuals for computer programs COFECHA and ARSTAN. Laboratory of Tree-Ring Research, University of Arizona.

Hunsicker ME, Kappel CV, Selkoe KA, Halpern BS, Scarborough C, Mease L & Amrhein A (2016) Characterizing driver–response relationships in marine pelagic ecosystems for improved ocean management. Ecological Applications 26: 651–663. doi:10.1890/14-2200.

İmren A & İrdem C (2023) The effect of climate on tree-ring of Fir, Spruce and Scotch pine in Karçal Mountains. Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi 24: 206–217. doi:10.17474/artvinofd.1246843.

IPCC (2021) Climate Change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (ed. by V Masson-Delmotte, P Zhai, A Pirani, SL Connors, C Péan, S Berger, N Caud, Y Chen, L Goldfarb, MI Gomis, M Huang, K Leitzell, E Lonnoy, JBR Matthews, TK Maycock, T Waterfield, O Yelekçi, R Yu & B Zhou) Cambridge University Press, pp. 3–32.

Irby CM, Fulé PZ, Yocom LL & Villanueva-Díaz J (2013) Dendrochronological reconstruction of long-term precipitation patterns in Basaseachi National Park, Chihuahua, Mexico. Madera y Bosques 19: 93–105.

Işık F, Bahadır M, Zeybek Hİ & Kutlu Hatipoglu İ (2024) Elevation-dependent growth trends of *Picea orientalis* (L.) Peterm forests in the Fırtına Creek Basin (Rize/Turkey). Dendrobiology 91: 56–69. doi:10.12657/denbio.091.005.

Jevšenak J, Tychkov I, Gričar J, Levanič T, Tumajer J, Prislan P, Arnič D, Popkova M & Shishov VV (2021) Growth-limiting factors and climate response variability in Norway spruce (*Picea abies* L.) along an elevation and precipitation gradients in Slovenia. International Journal of Biometeorology 65: 311–324. doi:10.1007/s00484-020-02033-5.

Jiménez López J & Mulero-Pázmány M (2019) Drones for conservation in protected areas: Present and future. Drones 3: 10. doi:10.3390/drones3010010.

Jones KR, Venter O, Fuller RA, Allan JR, Maxwell SL, Negret PJ & Watson JEM (2018) One-third of global protected land is under intense human pressure. science 360: 788–791. doi:10.1126/science.aap9565.

Jump AS, Ruiz-Benito P, Greenwood S, Allen CD, Kitzberger T, Fensham R, Martínez-Vilalta J & Lloret F (2017) Structural overshoot of tree growth with climate variability and the global spectrum of drought-induced forest dieback. Global Change Biology 23: 3742–3757. doi:10.1111/gcb.13636.

Karaca M, Deniz A & Tayanç M (2000) Cyclone track variability over Turkey in association with regional climate. International Journal of Climatology 20: 1225–1236. doi:10.1002/1097-0088(200008)20:10<1225::AID-JOC535>3.0.CO;2-1.

Kazimirović M & Stajić B (2024) Potential effects of climate change on growth and the implications for conservation of the endangered Serbian spruce (*Picea omorika* (Pančić) Purk.). Forest Ecosystems: 100287. doi:10.1016/j.fecs.2024.100287.

Kindap T (2010) A severe sea-effect snow episode over the city of İstanbul. Natural Hazards 54: 707–723. doi:10.1007/s11069-009-9496-7.

Kopabayeva A, Mazarzhanova K, Köse N & Akkemik Ü (2017) Tree-ring chronologies of *Pinus sylvestris* from Burabai Region (Kazakhstan) and their response to climate change. Dendrobiology 78: 96–110. doi:10.12657/denbio.078.010.

Körner C (2012) Alpine treelines. Springer Basel.

Köse N, Akkemik Ü, Dalfes HN & Özeren MS (2011) Tree-ring reconstructions of May–June precipitation for Western Anatolia. Quaternary Research 75: 438–450. doi:10.1016/j.yqres.2010.12.005.

Köse N, Güner HT, Harley GL & Guiot J (2017) Spring temperature variability over Turkey since 1800 CE reconstructed from a broad network of tree-ring data. Climate of the Past 13: 1–15. doi:10.5194/cp-13-1-2017.

Köse N, Okan T & Akkemik Ü (2018) Understanding the impacts of illegal logging in Turkey: A case study on junipers in Eskişehir. Baltic Forestry 24: 109–116.

Kullman L (2007) Tree line population monitoring of *Pinus sylvestris* in the Swedish Scandes, 1973–2005: implications for tree line theory and climate change ecology. Journal of Ecology 95: 41–52. doi:10.1111/j.1365-2745.2006.01190.x.

Kuniholm PI (1991) A 1503-Year Chronology for the Bronze and Iron Ages: 1990–1991 Progress Report of the Aegean Dendrochronology Project, VII. Arkeometri Sonuçları Toplantısı, 27-31 Mayıs Çanakkale, pp. 121–130.

Linderholm HW & Linderholm K (2004) Age-dependent climate sensitivity of *Pinus sylvestris* L. in the central Scandinavian Mountains. Boreal environment research 9: 307–317.

Liu Q, Piao S, Janssens IA, Fu Y, Peng S, Lian X, Ciais P, Myneni RB, Peñuelas J & Wang T (2018) Extension of the growing season increases vegetation exposure to frost. Nature Communications 9: 426. doi:10.1038/s41467-017-02690-y.

Martin-Benito D, Pederson N, Köse N, Doğan M, Bugmann H, Mosulishvili M & Bigler C (2018) Pervasive effects of drought on tree growth across a wide climatic gradient in the temperate forests of the Caucasus. Global Ecology and Biogeography 27: 1314–1325. doi:10.1111/geb.12799.

Martin-Benito D, Pederson N, Lanter C, Köse N, Doğan M, Bugmann H & Bigler C (2020) Disturbances and climate drive structure, stability, and growth in mixed temperate old-growth rainforests in the Caucasus. Ecosystems 23: 1170–1185. doi:10.1007/s10021-019-00462-x.

Martin-Benito D, Ummenhofer C, Köse N, Güner HT & Pederson N (2016) Tree-ring reconstructed May–June precipitation in the Caucasus since 1752 CE. Climate Dynamics 47: 3011–3027. doi:10.1007/s00382-016-3010-1.

Martinez del Castillo E, Longares LA, Gričar J, Prislan P, Gil-Pelegrín E, Čufar K & De Luis M (2016) Living on the edge: contrasted wood-formation dynamics in *Fagus sylvatica* and *Pinus sylvestris* under Mediterranean conditions. Frontiers in Plant Science 7: 370. doi:10.3389/fpls.2016.00370.

Matías L, Linares JC, Sánchez-Miranda Á & Jump AS (2017) Contrasting growth forecasts across the geographical range of Scots pine due to altitudinal and latitudinal differences in climatic sensitivity. Global Change Biology 23: 4106–4116. doi:10.1111/gcb.13627.

Matisons R, Elferts D, Krišāns O, Schneck V, Gärtner H, Bast A, Wojda T, Kowalczyk J & Jansons Ā (2021) Non-linear regional weather-growth relationships indicate limited adaptability of the eastern Baltic Scots pine. Forest Ecology and Management 479: 118600. doi:10.1016/j.foreco.2020.118600.

McDowell & Allen CD NG (2015) Darcy's law predicts widespread forest mortalityunder climate warming. Nature Climate Change 669–672. doi:10.1038/nclimate2641.

MedECC (2020) Climate and environmental change in the Mediterranean Basin – current situation and risks for the future. First Mediterranean Assessment Report (ed. by W Cramer, J Guiot & K Marini) UNEP/MAP, Marseille, France.

Melillo JM, Lu X, Kicklighter DW, Reilly JM, Cai Y & Sokolov AP (2016) Protected areas' role in climate-change mitigation. Ambio 45: 133–145. doi:10.1007/s13280-015-0693-1.

Mountain Research Initiative EDW Working Group (2015) Elevation-dependent warming in mountain regions of the world. Nature Climate Change 5: 424–430. doi:10.1038/nclimate2563.

Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca GAB & Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853–858. doi:10.1038/35002501.

Nacar S, Şan M, Kankal M & Okkan U (2024) Trends and amount changes of temperature and precipitation under future projections in high–low groups and intra-period for the Eastern Black Sea, the Wettest Basin in Türkiye. Natural Hazards 120: 9833–9866. doi:10.1007/s11069-024-06588-z.

Nakhutsrishvili G, Zazanashvili N, Batsatsashvili K & Montalvo Mancheno CS (2015) Colchic and hyrcanian forests of the Caucasus: similarities, differences and conservation status. Flora Mediterranea 25: 185–192. doi:10.7320/FlMedit-25SI.185.

Oberhuber W & Kofler W (2000) Topographic influences on radial growth of Scots pine (*Pinus sylvestris* L.) at small spatial scales. Plant Ecology 146: 229–238. doi:10.1023/A:1009827628125.

Olson DM & Dinerstein E (2002) The Global 200: Priority ecoregions for global conservation. Annals of the Missouri Botanical Garden 89: 199–224. doi:10.2307/3298564.

Önol B, Bozkurt D, Turuncoglu UU, Sen OL & Dalfes N (2014) Evaluation of the twenty-first century RCM simulations driven by multiple GCMs over the Eastern Mediterranean–Black Sea region. Climate Dynamics 42: 1949–1965. doi:10.1007/s00382-013-1966-7.

Özdilek A (2015) Assessment of genetic diversity in *Picea orientalis* (L.) Link. in genetic resources by microsatellites. Middle East Technical University, Türkiye.

Özkan ZC (1990) Türkiye'deki doğu Ladini (*Picea orientalis* (L.) Link.) üzerinde dendrokronolojik araştırmalar. Karadeniz Teknik Üniversitesi, Türkiye.

Özkan ZC (1999) Dendrochronology of the Oriental Spruce (*Picea orientalis* (L.) Link.) in Turkey. Turkish Journal of Agriculture and Forestry 23: 263–267.

Özkan ZC & Akbulut S (2003) Dendrochronology of *Abies nordmannıana* (Stev.) Spach. subsp. *nordmannıana* in the Örümcek Forests in Kürtün-Gümüşhane. Kafkas University Journal of Forestry Faculty 4: 8–13.

Pepin NC, Arnone E, Gobiet A, Haslinger K, Kotlarski S, Notarnicola C, Palazzi E, Seibert P, Serafin S, Schöner W, Terzago S, Thornton JM, Vuille M & Adler C (2022) Climate changes and their elevational patterns in the mountains of the world. Reviews of Geophysics 60: e2020RG000730. doi:10.1029/2020RG000730.

Ponce-Calderón LP, Villanueva-Díaz J, Rodríguez-Trejo DA, Bilbao BA & Álvarez-Gordillo GdC (2023) Response to climate and influence of ocean-atmosphere phenomena on annual radial increments of *Pinus oocarpa* Schiede ex Schltdl. & Cham in the Lagunas de Montebello National Park, Chiapas, Mexico. iForest - Biogeosciences and Forestry 16: 174–181. doi:10.3832/ifor4112-016.

Pukinskaya MY (2022) Regeneration of dark coniferous species in the groups of *Picea orientalis* (Pinaceae) drying in the Teberda Nature Reserve (Western Caucasus). Doklady Biological Sciences 506: 202–211. doi:10.1134/S0012496622050106.

Pukinskaya MY (2023) Reconstruction of the dynamics of dark coniferous forests of Teberdinskii Nature Reserve and prospects for their natural recovery after mass drying-out. Biology Bulletin 50: 2647–2658. doi:10.1134/S1062359023100126.

R Core Team (2013) A language and environment for statistical computing.

Ranius T, Widenfalk LA, Seedre M, Lindman L, Felton A, Hämäläinen A, Filyushkina A & Öckinger E (2023) Protected area designation and management in a world of climate change: A review of recommendations. Ambio 52: 68–80. doi:10.1007/s13280-022-01779-z.

Rigling A, Bräker O, Schneiter G & Schweingruber F (2002) Intra-annual tree-ring parameters indicating differences in drought stress of *Pinus sylvestris* forests within the Erico-Pinion in the Valais (Switzerland). Plant Ecology 163: 105–121. doi:10.1023/A:1020355407821.

Rinn F (2003) TSAP-Win, software for tree-ring measurement, analysis and presentation: Rinntech.

Rossi S, Deslauriers A, Anfodillo T & Carraro V (2007) Evidence of threshold temperatures for xylogenesis in conifers at high altitudes. Oecologia 152: 1–12. doi:10.1007/s00442-006-0625-7.

Sáenz-Ceja JE & Pérez-Salicrup DR (2019) Dendrochronological reconstruction of fire history in coniferous forests in the Monarch Butterfly Biosphere Reserve, Mexico. Fire Ecology 15: 1–17. doi:10.1186/s42408-019-0034-z.

Sánchez-Salguero R, Camarero JJ, Hevia A, Madrigal-González J, Linares JC, Ballesteros-Canovas JA, Sánchez-Miranda A, Alfaro-Sánchez R, Sangüesa-Barreda G, Galván JD, Gutiérrez E, Génova M & Rigling A (2015) What drives growth of Scots pine in continental Mediterranean climates: drought, low temperatures or both? Agricultural and Forest Meteorology 206: 151–162. doi:10.1016/j.agrformet.2015.03.004.

Sánchez-Salguero R, Camarero JJ, Gutiérrez E, Gonzalez Rouco F, Gazol A, Sangüesa-Barreda G, Andreu-Hayles L, Linares JC & Seftigen K (2017) Assessing forest vulnerability to climate warming using a process-based model of tree growth: bad prospects for rear-edges. Global Change Biology 23: 2705–2719. doi:10.1111/gcb.13541.

Sanogo K, Gebrekirstos A, Bayala J, Villamor GB, Kalinganire A & Dodiomon S (2016) Potential of dendrochronology in assessing carbon sequestration rates of *Vitellaria paradoxa* in southern Mali, West Africa. Dendrochronologia 40: 26–35. doi:10.1016/j.dendro.2016.05.004.

Schulze K, Knights K, Coad L, Geldmann J, Leverington F, Eassom A, Marr M, Butchart SHM, Hockings M & Burgess ND (2017) An assessment of threats to terrestrial protected areas. Conservation Letters 11: e12435. doi:10.1111/conl.12435.

Seijo F, Godoy MM, Guglielmin D, Ciampoli C, Ebright S, Picco O & Defossé G (2020) Conflicting frames about ownership and land use drive wildfire ignitions in a protected conservation

area. Environmental Management 65: 448–462. doi:10.1007/s00267-020-01265-w.
Shi S, Liu G, Li Z & Ye X (2021) Elevation-dependent growth trends of forests as affected by climate warming in the southeastern Tibetan Plateau. Forest Ecology and Management 498: 119551. doi:10.1016/j.foreco.2021.119551.
Smith KT (2008) An organismal view of dendrochronology. Dendrochronologia 26: 185–193. doi:10.1016/j.dendro.2008.06.002.
Song Y, Sass-Klaassen U, Sterck F, Goudzwaard L, Akhmetzyanov L & Poorter L (2021) Growth of 19 conifer species is highly sensitive to winter warming, spring frost and summer drought. Annals of Botany 128: 545–557. doi:10.1093/aob/mcab090.
Stokes MA & Smiley TL (1996) Introduction to tree-ring dating. University of Arizona Press, Tuscon, Arizona.
Swidrak I, Gruber A & Oberhuber W (2014) Xylem and phloem phenology in co-occurring conifers exposed to drought. Trees 28: 1161–1171. doi:10.1007/s00468-014-1026-x.
Şekercioğlu ÇH, Anderson S, Akçay E, Bilgin R, Can ÖE, Semiz G, Tavşanoğlu Ç, Yokeş MB, Soyumert A, Ipekdal K, Sağlam İK, Yücel M & Dalfes HN (2011) Turkey's globally important biodiversity in crisis. Biological Conservation 144: 2752–2769. doi:10.1016/j.biocon.2011.06.025.
Tabakova MA, Arzac A, Martínez E & Kirdyanov AV (2020) Climatic factors controlling *Pinus sylvestris* radial growth along a transect of increasing continentality in southern Siberia. Dendrochronologia 62: 125709. doi:10.1016/j.dendro.2020.125709.
Touchan R, Xoplaki E, Funkhouser G, Luterbacher J, Hughes MK, Erkan N, Akkemik Ü & Stephan J (2005) Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation. Climate Dynamics 25: 75–98. doi:10.1007/s00382-005-0016-5.
Tshering C, Thomte L, Dukpa D & Shah SK (2024) Increasing growth sensitivity of Pinus wallichiana to summer season maximum temperature–evidence from central Bhutan Himalaya. Dendrobiology 91: 125–136. doi:10.12657/denbio.091.010.
Türkeş M, Turp MT, An N, Özturk T & Kurnaz ML (2020) Impacts of climate change on precipitation climatology and variability in Turkey: Water resources of Turkey (ed. by NB Harmancioglu & D Altinbilek) pp. 467–491. doi:10.1007/978-3-030-11729-0_14.
Wang W, Jia M, Wang G, Zhu W & McDowell NG (2017) Rapid warming forces contrasting growth trends of subalpine fir (*Abies fabri*) at higher-and lower-elevations in the eastern Tibetan Plateau. Forest Ecology and Management 402: 135–144. doi:10.1016/j.foreco.2017.07.043.
Wolodarsky-Franke A & Lara A (2005) The role of "forensic" dendrochronology in the conservation of alerce (*Fitzroya cupressoides* ((Molina) Johnston)) forests in Chile. Dendrochronologia 22: 235–240. doi:10.1016/j.dendro.2005.05.008.
Wood SN (2006) Generalized additive models: An introduction with R. CRC Press, United States.
Wood SN (2011) Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society: Series B: Statistical Methodology 73: 3–36. doi:10.1111/j.1467-9868.2010.00749.x.
Wood SN (2017) Generalized additive models: an introduction with R. 2nd ed. Chapman and Hall/CRC, New York.
Xenakis G, Ray D & Mencuccini M (2012) Effects of climate and site characteristics on Scots pine growth. European Journal of Forest Research 131: 427–439. doi:10.1007/s10342-011-0516-2.
Yılmaz E & Darende V (2021) Türkiye'de yağış ölçümü yapılan manuel-otomatik meteoroloji gözlem istasyonu verilerinin karşılaştırılması. Turkish Geographical Review 77: 53–66. doi:10.17211/tcd.834500.
Zang C & Biondi F (2015) treeclim: an R package for the numerical calibration of proxy-climate relationships. Ecography 38: 431–436. doi:10.1111/ecog.01335.
Zazanashvili N, Sanadiradze G, Garforth M, Bitsadze M, Manvelyan K, Askerov E, Mousavi M, Krever V, Shmunk V, Kalem S & Devranoglu Tavsel S (2020) Ecoregional conservation plan for the Caucasus: 2020 Edition. World Wide Fund for Nature (WWF), Kfw, Tblisi.
Zheng L, Gaire NP & Shi P (2021) High-altitude tree growth responses to climate change across the Hindu Kush Himalaya. Journal of Plant Ecology 14: 829–842. doi:10.1093/jpe/rtab035.