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Elevation-dependent growth trends of *Picea orientalis* (L.) Peterm forests in the Fırtına Creek Basin (Rize/Turkey)[1]

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Abstract: Changes in climatic conditions have ecological and economic consequences or impact for trees and forest stands. In this respect, it is crucial to understand the radial growth trends of trees, their ecological response across elevation gradients, and the possible impacts of climate change on the species. In this study, *Picea orientalis* (L.) Peterm, located in the Fırtına Creek Basin in the northern part of the Eastern Black Sea Mountains in northeastern Turkey, was investigated along different elevation gradients in the context of climate-growth response. In the study, six site chronologies along an elevation gradient from 900 m to 2050 m were developed. Dendroclimatological methods were applied to assess the elevation-dependent radial growth characteristics of trees. In total, 200 increment cores were collected from 98 living trees. The relationships between climate and tree ring growth along the elevation gradient showed a positive relationship between growth and temperature at upper elevations (1700–1900 m) and a positive relationship between growth and precipitation at middle elevations (1400–1600 m). In particular, January–April mean temperatures and May rainfall were positively correlated with tree-ring growth. At lower elevations (900–1100 m), the correlation coefficients between climate and growth are insignificant because, at these altitudes, the species have optimum ecological conditions. It was also found that mean temperatures between 0 °C and 2 °C in January–April and total precipitation between 60 and 100 mm in January–February positively affect tree growth. However, if these thresholds are exceeded, it is possible that growth may be adversely affected. This research underscores the complex interplay between climate variables and tree growth along elevation gradients, highlighting the need for adaptive management strategies in the face of changing climatic conditions.

Keywords: Climate change, elevation gradient, tree-ring analysis, GAMM, climate-tree growth

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[1] This study is based on a chapter of the first author's PhD thesis.

Introduction

Forests have played an important role in mitigating the negative impacts of climate change and providing hydrology, carbon cycling, and habitats for both humanity and wildlife. (Bonan, 2008). Its most important role in the ecosystem is to host large terrestrial carbon sinks. (Magnani et al., 2007; Pan et al., 2011). However, in the last century, the dynamics (Moritz & Agudo, 2013; Nunes et al., 2022) and geographical distribution of forests (Chen et al., 2011; Kueppers et al., 2017) have been effected by climate change. According to the 6th assessment report of the IPCC (2021), greenhouse gases from human activities increased global temperature by about 1.1 °C between 2010–2019, compared to 1850–1900. The global temperature is expected to further increase by 1.5 °C within the next 20 years, or even exceed this threshold (IPCC, 2021). Forests will release large amounts of carbon, which will accelerate climate change instead of slowing it down (Leon et al., 2022; Silva et al., 2020). Therefore, understanding how increasing temperatures and extreme weather conditions affected and will affect forest ecosystems has become an important issue. In this context, the field of paleoclimatology assists us in comprehending historical climates and elucidates the emergence and transformations of existing ecosystems (Ramstein et al., 2021). Dendrochronology, with tree rings serving as a crucial proxy, plays a pivotal role in unraveling past climatic conditions and their impact on forest ecosystems (Anchukaitis, 2017; Fritts, 1976; George, 2014; Tucker & Pearl, 2021).

Living organisms have their own unique desires and behaviors. Growth and climate sensitivities of different species may vary (linearly or non-linearly) according to the conditions of the natural environment (Yang et al., 2022). In general, at higher elevations and latitudes, tree growth is limited by temperature among climatic elements (Körner, 2021). In linear terms, increasing temperatures are expected to increase tree growth and forest productivity at higher elevations (Schurman et al., 2019). On the one hand, trees growing at lower elevations and latitudes are more sensitive to moisture (Bai et al., 2019; Shi et al., 2021). On the other hand, complex and non-linear relationships between tree growth and climate at different altitudes have also been reported (Yang et al., 2013). As a result, the response of tree growth to climate change along elevation gradients is still controversial. Therefore, understanding how tree growth responds to climate change at different elevations and species is important for effectively managing forest ecosystems under future climate change.

The Eastern Black Sea Region is one of the areas that have attracted the attention of researchers in dendroclimatology research in recent years (Köse & Güner, 2012; Martin-Benito et al., 2018, 2020; Özkan, 1990, 1999). The first dendrochronological studies on *Picea orientalis* in the Eastern Black Sea Region was conducted by Özkan (1990, 1999), standard chronologies for the period of 1749–1988 were established, and annual growth changes were analyzed. In the study conducted by Köse and Güner (2012), the effects of temperature and precipitation on the tree ring growth of *Fagus orientalis* Lipsky trees in Artvin were investigated. The study showed that the most significant effect of temperature on tree ring growth occurred at the maximum temperature. However, in these studies, climatic factors regulating tree growth along an elevation gradient are not clearly expressed. A study by Martin Benito et al. (2020) examined *F. orientalis* and *P. orientalis* from the Colchic woodland in the Western Caucasus. The study provides information on forest structure, growth, stability, and the dynamics of natural disturbance and regeneration. According to Martin Benito et al. (2018) radial growth has been reduced in many species, including *P. orientalis*, due to spring or summer drought, and the positive response to summer and winter temperatures has declined over the last few decades. In this article, the effect of elevation on tree growth is addressed. Furthermore, this study uniquely contributes to the field by systematically addressing elevation gradients, thereby filling a spatial gap in *P. orientalis* research and emphasizing its distinctiveness from previous works.

P. orientalis is a forest tree located between mountain ranges running parallel to the coast in the southeastern part of the Black Sea. This species, one of the 50 *Picea* in the world, is found in the northeast of Glowinsk, in the Greater Caucasus, in the Lesser Caucasus and along the water division line of the Northern Anatolian Mountains on the Black Sea-facing flanks, and is distributed as far as the Melet River in Ordu province (Avcı, 1993, 2005, 2018; Kayacık, 1960). This species can be found on the northern slopes in the Eastern Black Sea Region, starting at an elevation of about 500 m from the coast and reaching up to 2400 m in mixed forests, fragmented, or zones. The species covers an area of approximately 365.845 ha in Turkey (OGM, 2021). It is mixed with broadleaved trees such as *Quercus, Fagus, Castanea, Carpinus,* and *Acer* between 500–1000 m along the elevation levels. Around 1500 m, it forms pure stands dominated by *P. orientalis*, while at higher elevations, it is mixed with other conifers such as *Abies nordmanniana* and *Pinus sylvestris*. (Atalay, 1984).

Over the last 30 years, the problems related to climate change have been discussed, and our knowledge has increased considerably. In particular, it has been presented as an undisputed fact that human activities are causing climate change and making extreme weather events more frequent and severe (IPCC, 2021). This has affected each region in different ways and is expected to continue to do so (Watson et al., 1998). The research site and its surroundings are also among the places already affected or predicted to be affected by these changes (Tonkaz & Bostan, 2016; Türkeş, 2003, 2012; Türkeş et al., 2007). In this context, the impact of climate change on the growth of plant species is increasingly being discussed (Dullinger et al., 2012; Sharma et al., 2022). Therefore, in the Eastern Black Sea Region, it will become increasingly important to explain the capacity and ability (phenotypic plasticity) of species to adapt to environmental conditions (Nicotra et al., 2010). In Turkey, as in the rest of the world, the physiology, behavior, morphology, or development of plants may change as environmental conditions change. One of the studies on this subject was conducted on *P. sylvestris* L. According to the study, early spring temperatures (March-April) are a driving force for *P. sylvestris*, and temperatures as high up to 7 °C are an important threshold (Bozkurt et al., 2021). In the context of this information, the study will also focus on the response of *P. orientalis*, an important species for Turkey, to temporal and spatial climatic factors.

In this context, the aim of the current study is to examine the responses and variability of *P. orientalis*, whose distribution area is limited worldwide to climate change along an elevation gradient, given the limited number of studies on this subject. In addition, the study aims to evaluate 1) the important growth control factors of the species, 2) the responses of chronologies to climate change, and 3) the temporal variability/stability of limiting factors.

Materials and Methods

Study areas

The study area is located between latitudes 40°41'00"N and 41°11'30"N and longitudes 40°47'39"E and 41°20'36"E on the northern axis of the Eastern Black Sea. This area, which is one of the largest river basins in the Eastern Black Sea Region of Türkiye with a surface area of approximately 1150 km², is administratively located within Ardeşen and Çamlıhemşin districts of Rize province. The research area is bounded by the Black Sea from the

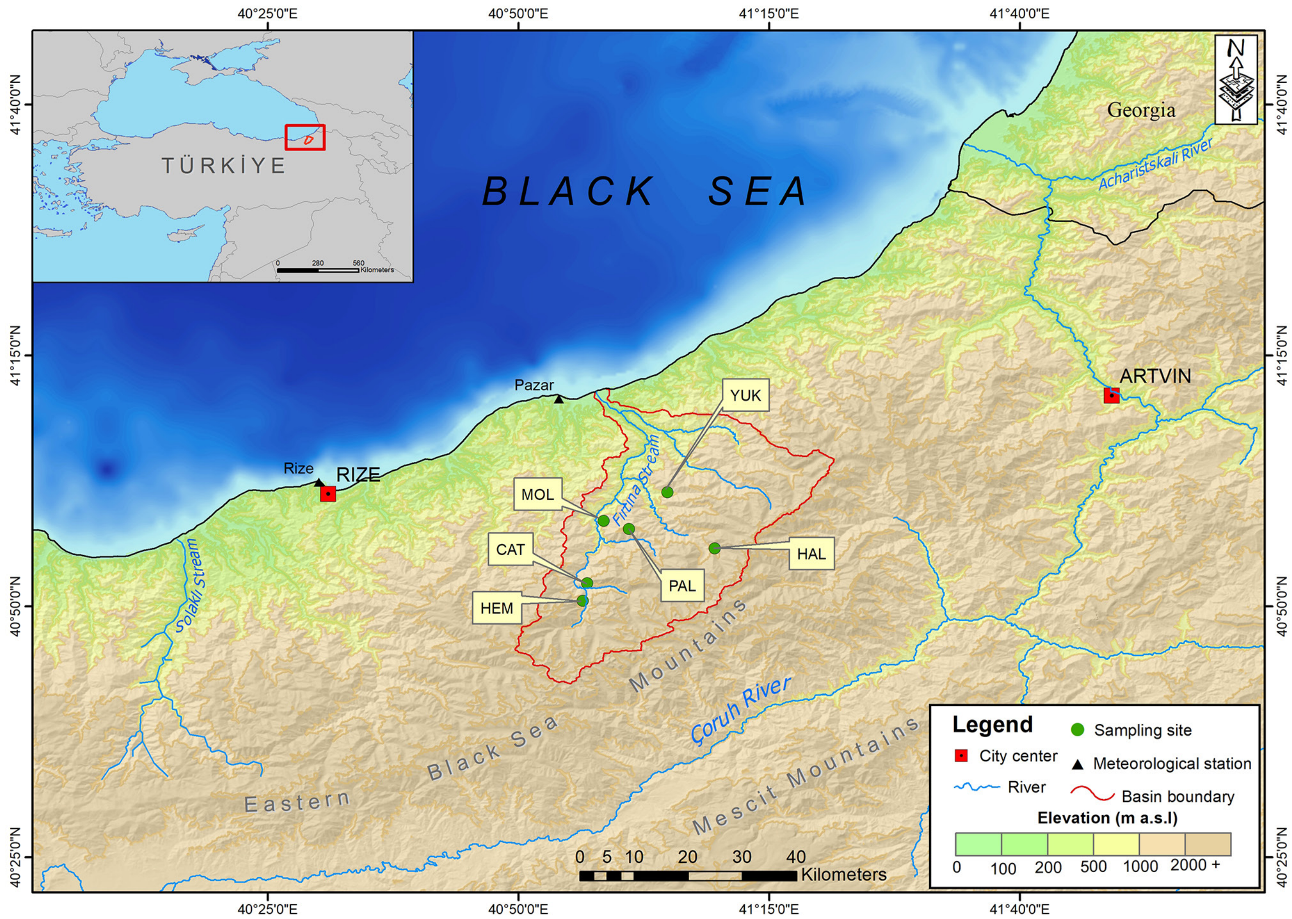

Fig. 1. Location map of the study area. The basin boundary is depicted by a red line, and the sample collection areas are marked with green dots (CAT: Çatköy settlement, HAL: Hala creek, HEM: Hemşin creek, MOL: Mollaveyis village, PAL: Palovit plateau, YUK: Yukarışimşirlik village)

north and the water division line on the Kaçkar and Soğanlı Mountains from the south (Fig. 1). In the basin, the mountains rising like a wall in the NE–SW direction from the seashore reach an elevation of 3900 m at a distance of 35 km as the crow flies. Mount Kaçkar, which has the fourth largest peak in Turkey (3932 m), also has the highest point of the water division line that borders the study area from the south.

Humid-temperate and humid-cold Black Sea climates are observed due to the geomorphological features of the Fırtına Creek Basin (FCB) and its coastal location (Atalay, 2013; Atalay & Mortan, 2011). The Eastern Black Sea region has generally increased elevation values from the coastal area to the inland areas, which causes a significant change in the temperature values of the FCB. In particular, the Eastern Black Sea Mountains, which extend in the northeast-southeast (NNE–SSE) direction, effectively trap the moist air mass coming from the sea. This increases the overall cloudiness of the basin and significantly affects the total annual precipitation. For this reason, depending on the elevation in the basin, temperature values vary between −2 °C and 14 °C, while total annual precipitation is generally above 1700 mm (Işık, 2022).

Climate Data

Meteorological station data with long-term observations used in determining the climatic characteristics of the research area were obtained from the 11th (Trabzon) Regional Directorate of Meteorology. In the study, monthly total precipitation (Pre.) and monthly mean temperature (Tmean) data of the nearest long-term Rize (41°02'24.0"N, 40°30'04.7"E, 3 m) and Pazar (41°10'40.9"N, 40°54'00.6"E, 78 m) meteorological stations covering the years 1964–2020 were used to calculate the correlation coefficients between tree ring indices and climate data (Table 1). On the other hand, Climatic Research Unit (CRU) Time-Series (TS) version 4.05 climate dataset (Harris et al., 2020) was used for moving correlation analyses. In general, the density of measurement stations in Turkey increased in 1950, and by 2003, automatic meteorological observation stations started to be established. However, there are no meteorological stations with very old (at most 1960) climate records in and around the basin. Therefore, the CRU TS v. 4.05 climate dataset covering a wider time period (1930–2020) was used to analyze the climate-tree relationship in the study.

The mean annual temperature of the study area is about 14 °C in the coastal area. The hottest month in the basin is July (average 22 °C) and the coldest month is January (average 4 °C). Inland, the temperature decreases depending on the elevation. At 2000 m, the average annual temperature is between 0 and 2 °C. The lowest temperatures (−12 °C / −10 °C) are observed in the high parts of the mountainous masses of the area and in the mountain ranges of the basin extending NE–SW. According to the annual average temperature map of the basin, temperatures generally vary between −2 °C and 14.2 °C. Total annual precipitation is over 2000 mm at both stations. The Eastern Black Sea Region is the part of Turkey that receives the most precipitation. The basin receives the highest precipitation during the year in autumn with a rate of approximately 36%. To assess the long-term temperature trends in the basin, graphs illustrating the long-term average temperature and total precipitation data from Rize and Pazar stations were prepared. According to the long-term average temperatures at Rize and Pazar stations, temperatures show a decreasing trend between 1964 and 1992 and an increasing trend between 1993 and 2020. According to the graph, temperatures have shown an upward trend since the early 1990s. Rize and Pazar are

Table 1. Monthly average temperatures and monthly total precipitation for Rize and Pazar stations and CRU data (1964–2020)

Months	Mean Monthly Temperature (°C)			Monthly Total Precipitation (mm)		
	Rize	Pazar	CRU	Rize	Pazar	CRU
January	6.6	6.2	−3.4	221.0	182.7	65.7
February	6.7	6.4	−2.1	170.7	144.7	53.9
March	8.3	8.0	2.1	147.4	121.6	60.5
April	11.7	11.4	7.9	95.9	79.6	71.4
May	16.1	15.5	12.3	97.9	82.1	78.6
June	20.5	19.6	15.9	135.9	140.6	73.9
July	23.0	21.9	19.1	150.6	142.1	51.3
August	23.4	22.3	19.4	188.4	173.5	52.3
September	20.5	19.5	15.7	245.8	238.3	62.3
October	16.4	15.6	10.5	296.2	284.1	80.9
November	11.9	11.2	4.3	249.2	240.8	76.0
December	8.5	8.0	−1.2	241.1	227.4	77.7
Mean/Total	14.5	13.8	8.4	2240.2	2057.4	804.7

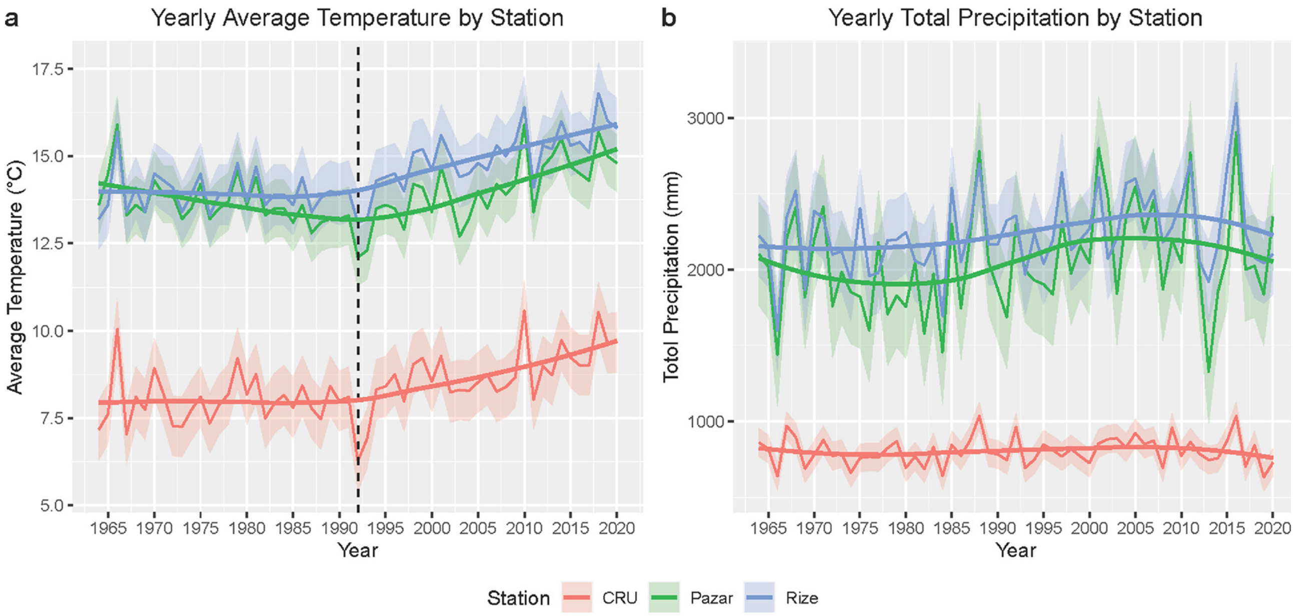

Fig. 2. Course of long-term average temperatures (a) and total precipitation (b) for Rize and Pazar stations and CRU data (The dashed vertical line in Fig. 2a indicates the break year in the increasing trend of temperatures starting from 1992)

similar both in the range of values and in the direction of increase-decrease in long-term temperature measurements. The Pearson correlation coefficient analysis revealed a strong positive correlation of 0.85 ($p < 0.05$) between the temperatures recorded at the Rize and Pazar stations. This correlation is consistent with the trends observed in the CRU data (Fig. 2), indicating a similar pattern between the observed temperatures and the broader dataset.

Tree-ring chronologies

Obtaining annual tree-ring data in the research was carried out using standard dendrochronological methods. Samples were selected from pure *P. orientalis* stands and from the 900–2050 m elevation range (Table 2). Each sampled area has been coded according to their respective location names: CAT for the western slope of Çatköy settlement, HAL for Hala Creek in Ayder Plateau, HEM for Hemşin Creek, MOL for Mollaveyis Village, PAL for Palovit Plateau, and YUK for Yukarışimşirlik Village. Tree-ring samples were taken from a height of ~130 m with the use of a 50 cm Pressler Increment Borer, two from each living tree. The collected increment cores were glued into the carriers and then sanded to make the rings more distinct (Stokes & Smiley, 1968). Ring width measurements for CAT site were performed using the LINTAB-Tsap measuring system (Rinntech, Germany) with a precision of 0.01 mm due to the large number of narrow rings and their long length (not fitting in the scanner) (Rinn, 2003). Tree-ring width measurements for the other five sites was measured using the CDendro & CooRecorder program (Larsson, 2016). Then, the accuracy of the measurements for each site was checked in the COFECHA software (Grissino-Mayer, 2001; Holmes, 1983).

Tree-ring chronologies and growth – climate relationship analysis

A total of six tree-ring chronologies were used to establish the climate-growth relationship of *P. orientalis*. All chronologies have different elevation, aspect, and slope values, reflecting the diversity of environmental conditions. The ARSTAN software (Version 6.05P) was also utilized to eliminate the long-term effects of tree age, size, soil conditions, closure, aspect and slope on tree ring occurrences

Table 2. Field information of tree-ring chronologies in the FCB

Site	Code	Latitude (N)	Longitude (E)	Elevation (m a.s.l.)	Time span	Aspect	Slope (%)
Çatköy Settlement	CAT	40.872237	40.945499	1800–2050	1739–2020	West	45
Palovit Plateau	PAL	40.961784	41.016895	1800–2000	1802–2020	South-western	38
Hala Creek	HAL	40.926290	41.163241	1700–1900	1792–2020	West	38
Hemşin Creek	HEM	40.841158	40.939834	1350–1500	1760–2020	South	50
Mollaveyis (Ülkü) Village	MOL	40.974161	40.974776	900–1100	1877–2020	West	41
Yukarışimşirlik Village	YUK	41.022701	41.079135	950–1100	1869–2020	South	43

in the site chronologies (Fritts, 1976; Cook et al., 1990, Akkemik, 2004). In the software, a negative exponential function is used to eliminate age-related effects. Autoregressive models are also chosen to eliminate the effect of the ring width in year t on the next ring width (Biondi & Swetnam, 1987). On the other hand, the EPS (Expressed Population Signal) value that best reflects or represents the sample depth that can be used is taken as 0.85 (Briffa & Jones, 1990; Wigley et al., 1984). In addition, graphical plots of site chronologies were made using the 'dplR' package (version 1.7.1.) (Bunn, 2008) in R environment (R Development Core Team, 2013). Tree ring development is directly related to climatic events. Especially temperature and precipitation are one of the most important factors that directly affect the tree ring width (Fritts, 1976). Therefore, monthly average temperature and total precipitation data were used to analyze the climate-growth relationship between 1930 and 2020. Relationships between climate and ring data were calculated based on the biological year (October of the previous year to October of the current year). Correlation coefficient was used to calculate the relationships. The limiting factors on growth of *P. orientalis* were identified according to the high and significant correlations between site chronologies and climatic factors. This analysis was performed using the 'treeclim' package (version 2.0.5.1) (Zang & Biondi, 2015) in R (R Development Core Team, 2013). In order to capture the similarities and differences between the sites, cluster analysis was performed with the 'hclust' function in the 'stats' package (version 3.6.2) (Becker et al., 1988) in R (R Development Core Team, 2013). For this analysis, the 'complete' method was employed to determine the clustering of sites based on their similarities. The 'complete' method considers observations to be completely linked if they are similar to each other and clusters them accordingly (Becker et al., 1988). Consequently, each site was grouped with others based on their similarities, providing insight into the relationships between sites. Then, a 35-year moving correlation analysis with a 5-year offset was performed on the clusters formed to see how the effect of the limiting factors changes over time. Given the wide geographical range covered by the study, we used the Generalized Additive Mixed Model (GAMM) in the 'mgcv' package (Wood, 2011) in R (R Development Team, 2013) to identify non-linearity between growth and climate. With this model, both the non-linearity of species' growth responses was estimated and the thresholds of tree ring responses to changing climatic conditions were determined. Here, chronologies were used as response variables and climate variables as predictors. Effective degrees of freedom (edf) values indicate a smoother degree of linearity, with higher edf values indicating strongly nonlinear smoothing curves.

Results

Site chronology characteristics

In this study, we built six site chronologies for *P. orientalis* (Fig. 3). The longest chronology was the 282 years-long CAT chronology from the upper elevations while the shortest one was the 144 years-long MOL chronology from the lower elevations. In each site, maximum age has a positive correlation with elevation (R^2 = 0.74, P< 0.05; this linear relationship is shown graphically in Fig. 4a). Correlation coefficients between site chronologies for the period 1930–2020 show high values in areas with high elevation (Fig. 4b). When the sites are analyzed in terms of sensitivity, the HEM site located at 1500 m has the highest mean sensitivity (MS) value (0.1872), while the YUK site, located at the lowest elevation level, exhibits the lowest mean sensitivity value (0.1231).

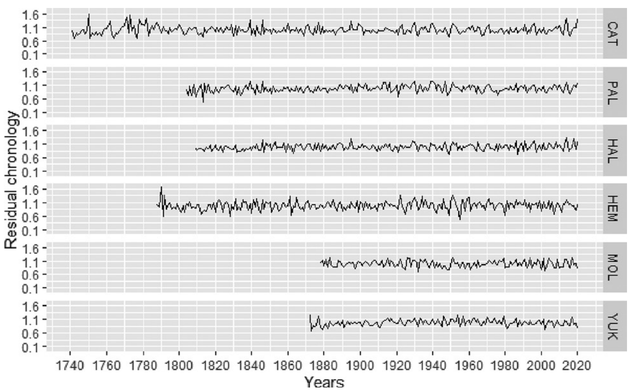

Fig. 3. Residual site chronologies (The site chronologies ordered from upper to lower elevation)

Table 3. Descriptive statistics of the chronologies of each site.

Code	N. cores / trees	Chronology time span	First Year EPS > 0.85	Mean Sensitivity (MS)	Standard Deviation (SD)	Signal-to-noise ratio	Rbar
CAT	20/41	1739–2020 (282)	1794	0.1545	0.1490	7.807	0.347
PAL	17/35	1802–2020 (219)	1805	0.1448	0.1523	1.159	0.372
HAL	16/34	1808–2020 (213)	1816	0.1315	0.1140	0.845	0.328
HEM	14/28	1786–2020 (235)	1790	0.1872	0.1540	1.139	0.386
MOL	16/32	1877–2020 (144)	1881	0.1468	0.1242	1.154	0.403
YUK	15/30	1869–2020 (152)	1882	0.1231	0.1108	0.636	0.261

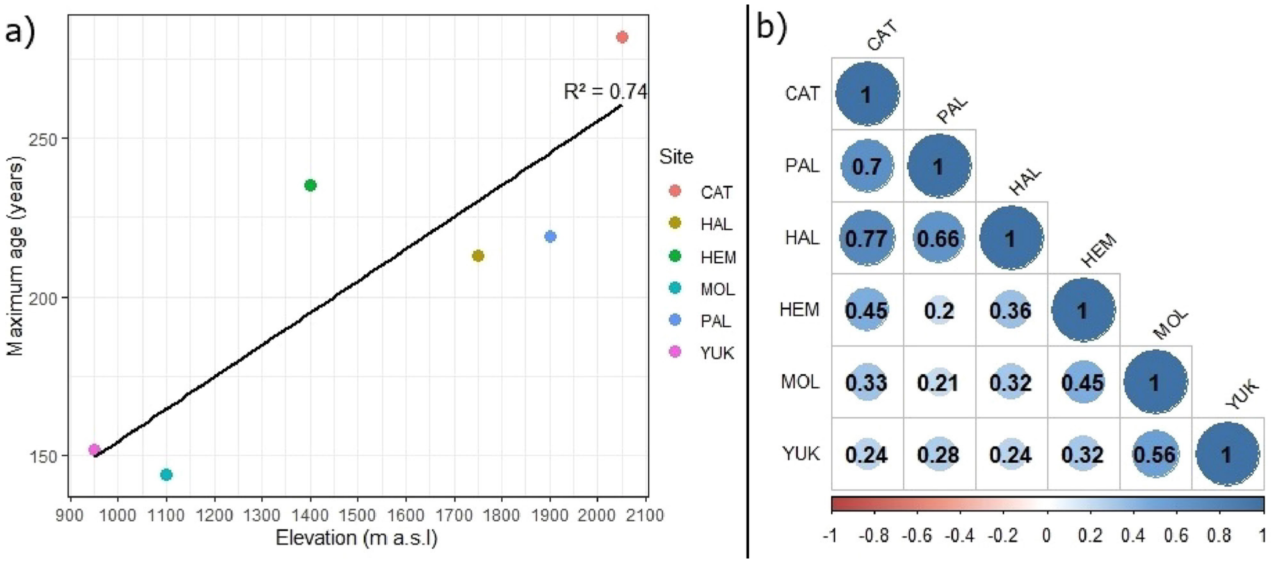

Fig. 4. Relationship between maximum age and mean elevation in each sampled site (a) and correlation coefficients between site chronologies (b) for the period of 1930–2020

The EPS > 0.85 threshold allowed the use of data for the period 1930–2020, the time period of reliable climate records, for the analysis of the climate-growth relationship (Table 3).

Linear and non-linear growth response to climate

The effects of temperature and precipitation on the radial growth of *P. orientalis* were analyzed according to the linear correlation coefficient. The effect of temperature and precipitation on the species radial growth in the basin differ at the upper and lower altitudes on the elevation gradient. The main limiting factor for the trees from the upper elevations located between 1750 and 2050 m elevation (CAT, PAL, and HAL sites) is the temperature in January–February–March–April and July–August–September. Temperatures in these months have mostly significant and positive effect on tree ring growth. On the other hand, higher precipitation in May located at lower elevations and 1350 m. This relationship demonstrates decreases with increasing elevation at all sites. Therefore, in the study area, May precipitation at 1500 m (±100) appears to be an important limiting factor for the development of *P. orientalis* tree rings. In addition, total precipitation in October also has a positive effect on tree ring growth. In contrast, April total precipitation has a negative effect on growth at all sites (Fig. 5). In addition to dendroclimatological analyses, hierarchical cluster analysis was applied to local

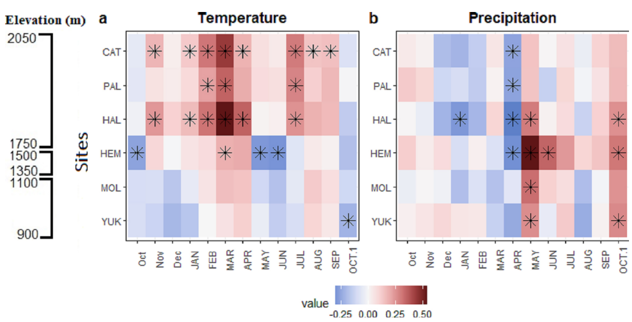

Fig. 5. Correlation coefficients of climate variables (temperature (a) and precipitation (b)) with the radial growth of *P. orientalis* between 1930 and 2020. Squares with stars indicate months with statistically significant correlation coefficients. Each site is ranked from upper to lower elevation, respectively

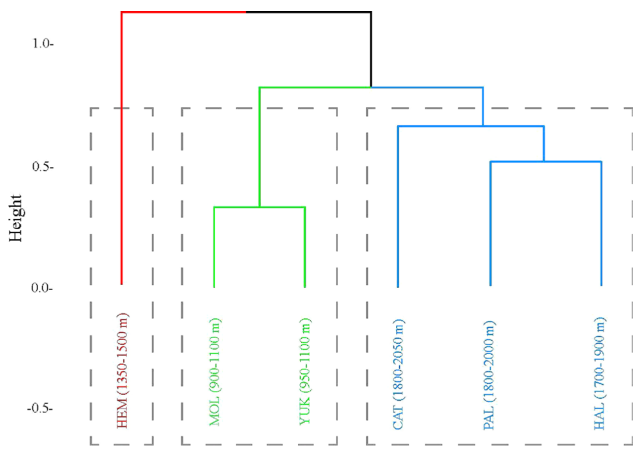

Fig. 6. Dendrogram of response function coefficients of the *Picea* site chronologies (The height in the figure represents Euclidean distance, while the algorithm linking the clusters (dashed gray lines) is indicative of the 'complete' method). In the dendrogram, the HEM site between 1350 and 1500 m is in the first cluster in red, the MOL and YUK sites between 1100 and 900 m are in the second cluster in green, and the CAT, PAL, and HAL sites between 1700 and 2050 m are in the third cluster in blue

chronologies. Chronologies were grouped into three main clusters depending on their response to temperature and precipitation climatic elements (Fig. 6). The change in climatic conditions due to altitude has been effective in creating the three clusters.

In the three clusters, a moving correlation function was used to test the temporal stability of climate growth relationships in winter and early spring ($T_{January–April}$), $T_{May–June}$, $T_{July–Seprember}$, P_{April}, P_{May} and $P_{May–June}$. The relationship between $T_{January–April}$ and *Picea* climate and growth remained positive and significant in the third cluster (Fig. 7a). However, in the HEM, MOL, and YUK sites below 1500 m elevation, the positive effect of winter temperatures has diminished and has become insignificant. The relationship between $T_{May–June}$ and the HEM site (ca. 1500 m) in the first cluster was negative and significant (Fig. 7b). The positive and significant effect of $T_{July–September}$ on tree growth is seen in the third cluster. However, this positive effect started to decrease after 1995 (Fig. 7c). In the other clusters (HEM, MOL, and YUK), the effect of summer temperatures is uncertain. The positive impact of P_{May} on growth remained stable at all sites. The significant effect of May precipitation in the first cluster became insignificant after 1976 (Fig. 7e). On the other hand, in the third cluster, while May precipitation had no effect on growth in the period 1930–1990, it started to have a positive effect from about 1990 onward. The course of $P_{May–June}$ on ring growth is positively significant (Fig. 7f).

Climate variables were used in the GAMM analysis. As with the correlation coefficients, average temperatures between January-April and total precipitation between January–February explained the growth. According to the output of the GAMM analysis, mean temperatures between 0 °C and 2 °C in

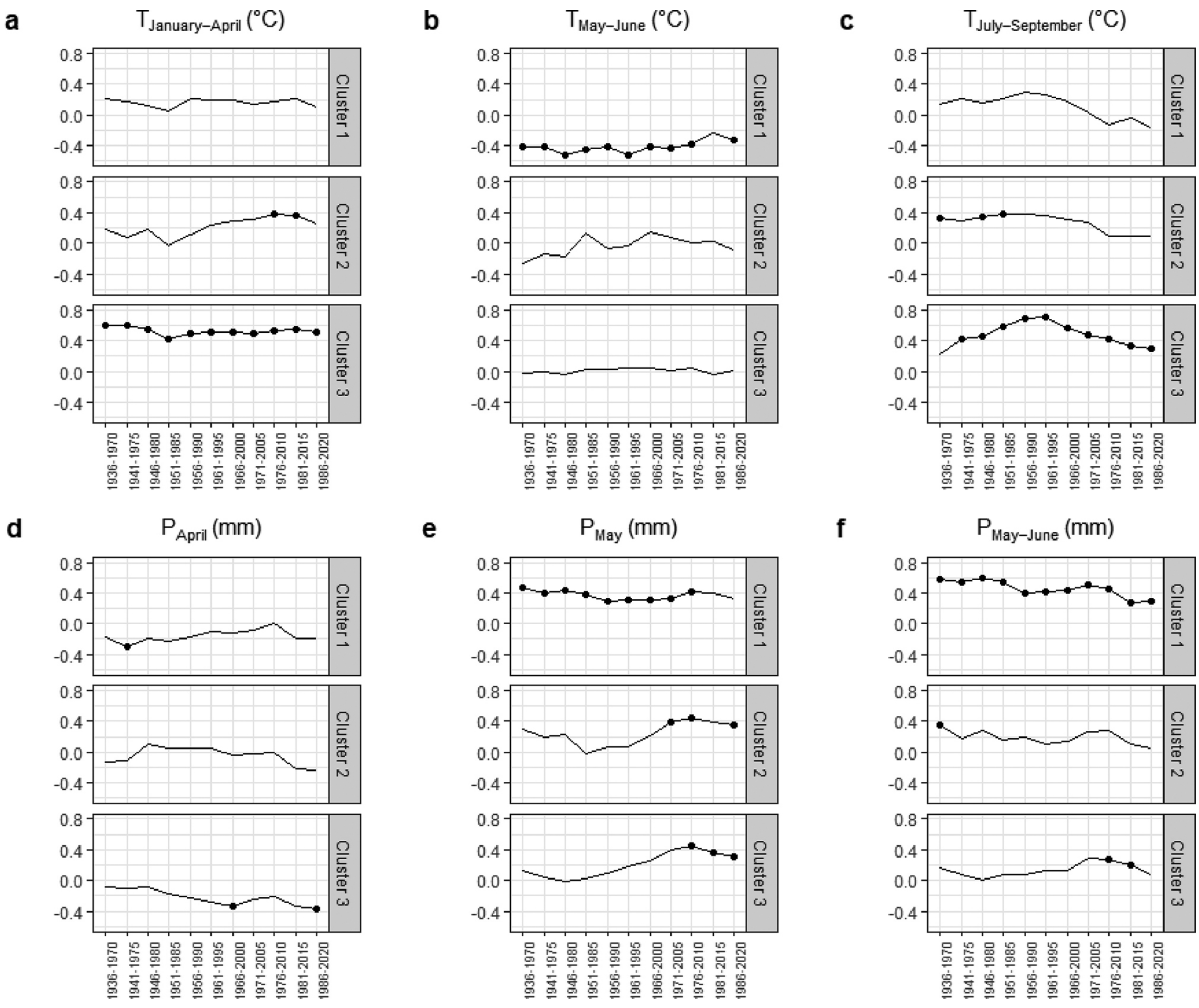

Fig. 7. Temporal variation of correlations between 1930 and 2020. Moving correlations are calculated for each cluster, showing the climate-growth relationship for the significant months. a) The first cluster represents HEM; b) The second cluster represents MOL and YUK; c) The third cluster represents CAT, PAL, and HAL. Dots indicate significant relationships at $p \leq 0.05$

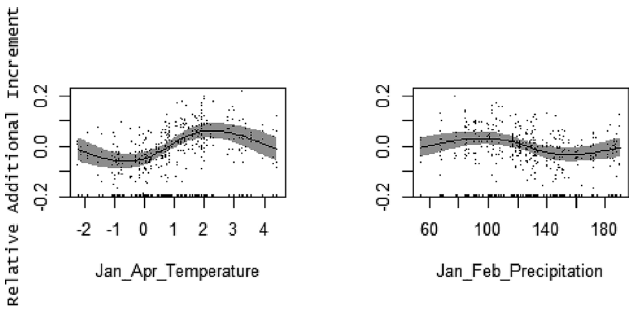

Fig. 8. GAMM output by limiting factor between 1930 and 2020 (gray shades indicate 95% confidence intervals. R^2 is 0.725)

Table 4. Curve line smoothing statistics are calculated from GAMM outputs

Smoothening term	Effective degree of freedom (edf)	F-value	p-value
Jan–Apr temperature	1.80	693.803	< 0.001
Jan–Feb precipitation	1.53	195.085	< 0.050

January–April and total precipitation between approximately 60 mm and 100 mm in January-February positively influenced *P. orientalis* growth and constituted critical thresholds for tree ring production (Fig. 8). The estimated smoothing lines with cubic curves helped to identify the climatic thresholds of the site that influence growth (Table 4). The model is statistically significant with R^2 0.72 (p-value<0.001). The model output on the established relationships showed that in FCB, temperature has a stronger effect on *P. orientalis* species growth than precipitation.

Discussion and conclusion

Mean sensitivity (MS) values ranged from 0.12 to 0.18. These values are similar to those found in published studies on *P. orientalis* in Turkey (Gürçay, 2022; Köse et al., 2017; Özkan, 1999; Zheng et al., 2019). Elevation-dependent changes in climatic elements occur. These changes bring about a number of differences and requirements for the growth of trees (Chen et al., 2011; Matías et al., 2017).

In general, studies on the climate-growth relationship have found that forests are more sensitive to temperature at higher elevations and to humidity at lower elevations (Babst et al., 2013; Harsch et al., 2009; Köse & Güner, 2012; Sevgi & Akkemik, 2007). Thus, our analysis of climate and tree growth revealed the same results for *P. orientalis* at different elevation levels in the basin. At elevations above 1500 m (±100 m), winter-early spring and summer temperatures, as well as winter (January) and spring (April–May) precipitation, were found to be the controlling factors for the annual growth of the species. At elevations of 1500 m (±100 m) and below, notable changes in the species' climatic responses are observed. At 1500 m elevation, *Picea* trees are more sensitive to moisture. Especially the rainfall in May–June–July affects the growth positively. This situation for *P. orientalis* in FCB was similar in other distribution areas of the species (Martin-Benito et al., 2018). The negative effect of April precipitation on tree growth, especially at higher elevations, may be due to the fact that precipitation falling in the form of snow decreases soil temperature. When approaching 1000 m (±100 m) elevation levels, the species shows weakened climatic responses to both temperature and precipitation. This has been observed in studies conducted at different sites and with different species (Di Filippo et al., 2007). As ecological conditions change in the environment, its responses may change in line with the demands of the species. Especially in plants living in optimal conditions, stress conditions will be less common, and its response to climatic variables may become uncertain. In addition, at lower elevations (due to the early onset and late end of temperature increases), the early onset and late end of cambium activities ensure a longer vegetation period. A similar situation is considered for *P. orientalis,* which is located at lower elevations in the FCB.

The stability of the results in terms of climate-growth relationships over time was revealed by moving window correlation analysis. During the period 1930–2020, temperature at upper elevations (1900–2100 m) and precipitation at middle elevations (1400–1600 m) determined the change of the tree ring network over time. This instability observed at the sites is due to the fact that the growth response due to climate change is not stable over time. In the basin, it is observed that precipitation and temperature values increased at all points between 1930–2020 (Çeribaşı, 2019; Yılmaz et al., 2021). These temperature and precipitation increases are thought to affect growth stability. The increase of about 1°C in the long-term average temperatures since 1980 can be seen in both local stations (Rize, Pazar) and CRU data (Fig. 2). Accordingly, the positive effect of summer temperatures (July–September) at higher elevations has decreased since 1980 due to climate change. It should not be ignored that increasing temperatures in the summer may lead to negative trends in growth in the long term. The significant positive effect of May precipitation has increased at upper elevations and decreased at middle elevations over the last 40 years. Most of the precipitation falls around 1500 m (+100 m) inland from the coast due to the process of orographic elevation and intensification (Türkeş, 2019). It is thought that this situation may have moved to higher elevations as a result of the climate change. Under warming conditions, there may be a decrease in the limiting effect of low temperatures on tree growth at higher elevations. At middle and lower elevations, there may be a tendency for an increase in the effect of moisture stress. In this case, the radial growth of trees is likely to increase at upper elevations (2000–2300 m) and decrease at middle and lower elevations (1000–1500 m) (Zhang et al., 2023).

Dendroclimatological analyses showed that late winter-early spring and summer temperatures and May precipitation positively affected growth. Above 1500 m (±100 m) elevation, late winter-early spring (January–April) cold constraint was tested by nonlinear correlation analysis. According to our nonlinear analysis, mean temperatures between 0 °C and 2 °C in January-April and total precipitation between 60 and 100 mm in January-February positively affected *Picea* growth. These values correspond to critical thresholds for the study area's tree ring growth. These thresholds in winter temperatures indicate that even a small warming has a positive effect on growth and that winter temperatures play a vital role in the physiological activities of trees (Matisons et al., 2021). Increases in temperatures as a result of climate change may raise these critical thresholds for long-term averages. Together, this could lead to two processes, positive and negative, in *Picea*. On the positive side, earlier cambium triggers reactivation (Rahman et al., 2020) and influences the onset of the vegetation period (Rossi et al., 2016). This activates the photosynthesis processes in conifers, leading to carbohydrate storage. As a result, this has a positive effect on growth (Matisons et al., 2021; Michelot et al., 2012). The accompanying rising temperatures could melt snow cover, increasing water availability and leading to milder winter conditions. On the downside, a continuation of this trend would extend the growing season for conifers and possibly increase winter carbon fixation. However, warming can also increase respiration rates in trees (Haeni et al., 2017) or reduce their cold hardiness. Frost damage can occur (Schaberg, 2000) if extremely low temperatures are experienced during the climate change process (Liu et al., 2018).

Tree-ring width chronologies of *P. orientalis* were collected along an elevation gradient in the FCB of the northern part of the Eastern Black Sea Mountains. The results of the species' radial growth variations and climate-growth relationships showed that elevation plays an important role in determining tree growth patterns in this mountainous basin. These findings are important for understanding the future development of forests (Shi et al., 2021). Changing limiting climatic factors associated with elevation gradients were proposed as determinants of elevation-dependent tree growth patterns. Moisture availability was found to be the major limiting factor for tree growth at moderate elevations (1400–1600 m). At increasing elevations (1900–2100 m) tree growth was mainly controlled by lower temperatures. At higher elevations, average temperatures between 0 °C and 2 °C in January-April were found to be critical growth thresholds. At lower elevations (900–1100 m), the limiting factors for tree growth were found to be uncertain due to sub-optimal climatic conditions. Therefore, further work is needed on tree growth at different elevations to better understand climate-growth relationships in relation to the effects of local topographic factors and to learn more about possible growth responses to future climate change. Moreover, exploring the combined effect of temperature and precipitation or utilizing drought indexes (such as SPEI, etc.) may provide additional insights into this uncertainty.

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