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Factors affecting the radial growth of *Juniperus foetidissima* Willd. and *J. excelsa* M. Bieb. in central Anatolia

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Abstract: Central Anatolia is one of the semi-arid regions of Turkey that does not offer very suitable conditions for the growth of trees. Tree growth is a process controlled by genetic, environmental and climatic factors. Trees record these signals, which provide valuable scientific data for dendrochronological research. We used raw annual tree-ring width (taken from trees under the age of 100 years) as one of the dendrochronological parameters to compare *Juniperus foetidissima* and *J. excelsa* in terms of affecting factors. We compared the annual tree-ring width of both species considering species, locations and research sites of the altitude range of 677–1 400 m a.s.l.. Environmental signals (longitude and latitude, altitude, slope, exposure, human impact and nearest settlement distance), as well as climatic factors (precipitation, temperature, moisture) affecting growth were examined. Results indicate that there is an obvious difference in raw annual tree-ring widths depending on species. *J. foetidissima* differs from *J. excelsa* in wider annual tree-ring widths and preferences to a low slope and altitude. While the annual tree-ring width of *J.* excelsa did not respond to the environmental signals, the annual tree-ring width of *J. foetidissima* was notably correlated with longitude, latitude, altitude and slope. The most remarkable variables affecting the growth of both species were summer temperatures and moisture.

Keywords: dendrochronology; annual tree-ring width; radial growth response; environmental signals; semi-arid

Growth is a natural process of trees that is affected by environmental factors (climatic signals, solar cycles, location slope, altitude, latitude, exposure) (Mäkinen et al. 2002; Vacek et al. 2019; Šimůnek et al. 2021). However, biological characteristics and genetic factors (species, age, lifespan, competition and sensitivity) also control growth (Martín-Benito et al. 2008; Remeš et al. 2015; Vacek et al. 2021). On the other hand, human activity (silviculture, air pollution load) and game damage (browsing, bark stripping) are also effective factors affecting tree growth (Vacek et al. 2017; Štefančík et al. 2018; Cukor et al. 2019). Although these factors constrain the existence of species within a region, some species, such as *Juniperus* spp., can be more widely distributed considering geographical conditions and elevations (Chambers et al. 1999). Moreover, various species living in the same region may show diverse growth characteristics (Bond 2000) as distinct plant groups can apply different resource use strategies, showing divergent growth characteristics with age (Lyon, Sagers 1998).

A relationship is seen between radial growth, tree size and lifespan. Slow-growing trees generally reach a longer lifespan (Bigler 2016), and such trees consequently provide more data for dendrochronological research. This reality encouraged us to work on juniper species. Another motivation was the drought resistance of juniper species: dry, sub-humid conditions occur in 60% of the total

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land area of Turkey (Çalışkan, Boydak 2017) and about 35% of the land surface is classified as semiarid and arid (Türkeş 1990). In such conditions, drought-resistant species are of great importance. As the main drought-resistant tree species of Turkey, junipers play an important role in expanding forest cover. The species also enable scientific research on growth as well as past and future climate estimations (Kahveci et al. 2018).

Juniperus excelsa M. Bieb *(Juex)* has a wide distribution in Turkey (Carus 2004) and is one of the four main tree species in Central Anatolia like *Juniperus foetidissima* Willd (Jufo). Both species grow under extreme environmental conditions (Farjon 1992). Juex is found in rare and fragmented woodlands in Turkey and has been severely fragmented in Central Anatolia (Quézel, Médail 2003). Jufo occupies largely the same habitats as Juex. Both species have a high ecological value, being frequently the only tree species that are able to grow in semiarid environments and therefore playing an important role in soil protection and climate change (Douaihy et al. 2011).

The parameters used in crossdating vary depending on geographic, climatological and behavioural variables and their effects on tree growth, as well as the research questions are of interest. The climate-growth relationship has been studied since the early part of the 20th century and remained stable for many tree species. Touchan et al. (2007), as one of the few scientists who worked on juniper, developed a May–June precipitation reconstruction (AD 1097–2000) and a Juex chronology for southwestern Anatolia in Turkey, which has shown the juniper response to climatic signals. Consequently, new studies are addressing the growth response to ecological signals. Esper et al. (2007) researched uniform growth trends among low- and high-elevation juniper tree sites in Central Asia. Soulé and Knapp (2019) worked on *Juniperus occidentalis* Hook. and found out that atmospheric CO_2 increases water-use efficiency for semiarid species, which is negatively associated with radial growth. By obtaining information on parameters such as tree age and growth rates, the relationships between tree growth and variable environmental factors can be determined via comparing annual variations in tree-ring width with annual variations in the climate parameters of interest (Sarangzai, Ahmed 2011). This study aims to compare radial growth (raw annual tree-ring width taken from trees under the age of 100 years) of both Juex and Jufo in terms of affecting environmental and climatic factors. The specific objectives were to determine (*i*) the characteristics of the tree-ring chronologies of both species on the basis of locations, (*ii*) the growth response of both species to the environmental signals (longitude and latitude, altitude, slope, exposure, human impact and nearest settlement distance) on the basis of plots and (*iii*) the effect of climatic variables (annual precipitation, summer precipitation, mean annual moisture, mean annual temperature, mean summer temperature, mean spring temperature) on the radial growth of both tree species on the basis of research sites.

MATERIAL AND METHODS

Research site. The present study was conducted in two research sites including eight locations; surroundings of Eskişehir Province (Mihalıççık, Alpu, Seyitgazi, Çifteler, Nallıhan) and surroundings of Kırıkkale Province (Bahşılı, Yahşıhan, Elmadağ) (Figure 1, Table 1). Limestone and crystallized limestone are the most common lithological units of research sites (Balkan et al. 2017). According to the soil classification system of the World Reference Base for Soil Resources**,** Leptosols, Calcisols and Cambisols are the dominant soil types (Dinç et al. 1997).

The forest resources of research sites of the altitude range of 677–1 400 m a.s.l. have frequently been exploited due to a high population density since ancient times and natural resources have been used by various cultures for thousands of years (Mikaeili 2015). As a result, 'forest relicts' were left behind in Central Anatolia. Despite a gradual decline in those effects, grazing and fodder practices continue today. The permanent human influence resulted in a significant decrease of woody species. We found the following woody plant species: *J. foetidissima*, *J. excelsa, J. oxycedrus* L., *Pinus nigra* J.F. Arnold subsp. *pallasiana* (Lamb.) Holmboe, *Quercus cerris* L., *Q. pubescens* Willd., *Amygdalus communis* L., *Berberis crataegina* DC., *Crataegus orientalis* Pall. ex M. Bieb., *C. monogyna* Lacq., *Cotoneaster nummularius* Fisch. & C.A. Mey., *Colutea cilicica* Boiss. & Balansa, *Cistus laurifolius* L., *Jasminum fruticans* L., *Lonicera sp*., *Paliurus spina-christi* Mill., *Cornus sanguinea* L. subsp. *Australis,* (C.A. Mey.) Jáv., *Origanum minutiflorum* O. Schwarz & P.H. Davis., *Pistacia palaestina* Boiss.,

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Figure 1. Research sites in Province Eskişehir and Kırıkkale located in Central Anatolia

1 – Mihalıççık; 2 – Alpu; 3 – Seyitgazi; 4 – Çifteler; 5 – Nallıhan; 6 – Elmadağ; 7 – Bahşılı; 8 – Yahşıhan

Pyrus elaeagnifolia Pall. *subsp. elaeagnifolia, Prunus domestica* L., *Rhamnus rhodopea* Velen., *Rosa canina* L., *R. pulverulenta* M. Bieb., *R. thymifolia* Bornm., *Spiraea crenata* L., *Ulmus minor* Mill.

Meteorological data. Central Anatolia belongs to climate region B (cold zone, Bsk semiarid climate) and climate region D (continental climate, Dsa, Dsb with either hot or cold dry seasons) according to the Köppen-Geiger climate classification (Köppen, Geiger 1954; Öztürk et al. 2017). Meteorological data of research sites (monthly precipitation, temperature and humidity) were obtained from the General Directorate of Meteorology (GDM) for the period 1965 to 2015 (GDM 2016). Climate data was taken from two main stations that represent the locations of research sites (Figure 2). The average annual total precipitation in these 50 years was 382.05 mm in Kırıkkale and 372.83 mm in Eskişehir. Precipitation was concentrated in the winter months. The average annual temperature from 1965 to 2015 was 12.45 °C in Kırıkkale and 10.95 °C in Eskişehir (Figure 2), while the average annual humidity was 61.75% in Kırıkkale and 65.15% in Eskişehir, with lower levels in July and August. Since our plots were located higher than the above-mentioned stations, we used interpolated precipitation and temperature values in our analysis. Temperatures were reduced by 0.5 °C for every 100 m, and precipitation values were increased by 54 mm per 100 m (Çepel 1988; Özyuvacı 1999). The growing season lasts for 160 days both in Eskisehir and Kırıkkale (Atalay, Gökçe Gündüzoğlu 2015).

Sampling methods and processing. The study was executed in Central Anatolia (Turkey), where Juex and Jufo are mainly grown in the remainder of long-degraded forest stands (relicts) in the mountains. Therefore, it was not possible to follow a certain sampling method. Firstly, Juniper relicts were selected with help of the Forest Management Plan. Then, the sampling was conducted in suitable areas where we focused on the occurrence of junipers in groups with relatively old juniper trees. A sampling plot was defined as a juniper stand of approximately 25 × 20 m in both research sites. For each sample plot, we took wood cores of all juniper trees in the case of diameter at breast height (*DBH*) > 5 cm and we recorded longitude and latitude (UTM), altitude (m), exposure (°), slope (%) and human impact (*HI*) using the following rating system: 0 = no impact; 1 = ancient and early medieval impact; 2 = cutting tree; 3 = commercial use, fire, beekeeping; 4 = destruction of the forest; 5 = complete destruction of the for-

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Table 1. Main characteristics of the research sites Eskişehir (1) and Kırıkkale (2)

Location	Coordinates	Altitude(m)	Slope(%)	Juniper species	Density (trees·ha^{-1})	Plots number	Number of wood core
Mihalıççık[1]	39°51'18."N, 31°30'34.2" E	1 077–1 128	2–30	Jufo	160–200	3; 4; 6	4
Alpu[1]	39°54'50.2"N, 31°09'23.9"E	1 235–1 286	2–16	Juex	200–260	7;10	19
				Jufo	200–540	7 –10; 27	
Seyitgazi[1]	39°22'35.7"N, 31°02'20.1"E	1 047–1 202	5–35	Juex	200–560	14–16; 26	7
				Jufo	350–500	14–16	
Çifteler[1]	39°11'41.8"N, 30°43'33.13"E	1 359–1 400	30–55	Jufo	140–420	18; 19; 23; 24	8
Nallıhan[1]	39°45'39.5"N, 30°57'58.3"E	677–946	40–55	Juex	120–260	58; 59	4
Elmadağ[2]	39°47'29.8"N, 33°15'49.6"E	1 010–1 021	8–50	Juex	100–240	46–48; 51–55; 57	30
				Jufo	100–120	46–56	
Bahşılı[2]	39°43'42.1"N, 33°21'21.2"E	978–1 099	10–70	Juex	100–220	28; 30–36	21
Yahşıhan[2]	39°47'37.8"N, 33°21'05.1"E	980–1 195	10–50	Juex	100–220	37–45	30
Total	–	–	–	–	–	47	123

Juex – *Juniperus excelsa*; Jufo – *Juniperus foetidissima*

est (Samojlik et al. 2013), nearest settlement distance (*NSD*), woody plants, and other observations (growth dynamics of trees, their diameter, height, insect and fungal damage, possible factors affecting the growth of tree communities).

Increment cores were taken from damage-free trees using a 14 Increment Borer, 3-Thread, 0.200 (5.15 mm) (JIM-GEM, USA). Above 250 plots were sampled, but we used 123 wood cores taken from trees under the age of 100 years from 47 sampling plots for this study, without considering exposure (Table 1). Because of internal decay, 20% of the wood cores were not taken at DBH. For the same reason, 40% of the cores were not taken from the two sides. Data were collected from sampling plots in October–November 2014 and 2015.

Data analysis. All collected wood cores were dried and sanded. Annual tree-ring width was measured to the nearest 0.01 mm using a LINTAB measuring table connected to the TSAP Win software (Rinntech, Germany). All tree-ring series were checked for missing rings, and false or double-ring series were edited in TSAP by adding missing rings and merging false or double rings. The quality of crossdating was checked using the COFECHA program (Holmes 1983). During data analysis, it was essential to consider the wood anatomical features of Juniper. For instance, juniper wood does not show an increment on one side, while the other side may create a distinctly larger annual ring. Moreover, Juniper trees older than 100 years may have missing and locally absent rings or false or double rings that make crossdating difficult (Kahveci et al. 2018). Therefore, we worked with the raw dendrochronological data in order to get more effective results like in other researches (Konter et al. 2016; Li et al. 2017; Jiao et al. 2017). For the reasons mentioned above and the availability of full climate data, we used the last 50 years of raw annual tree-ring width taken from trees under the age of 100. Data of the cores taken from the two sides were averaged. Statistical analyses of annual tree-ring widths were carried out separately according to species.

The relationships between raw annual tree-ring width for each plot averaged (*MTW*) of both species and environmental variables were tested using canonical correspondence analysis (CCA) in PC-ORD and results were presented with biplot CCA chart. In CCA analysis, the relationship between environmental variables and axes was determined by Pearson and Kendall correlation analyses (McCune, Mefford 2006). Those analyses were carried

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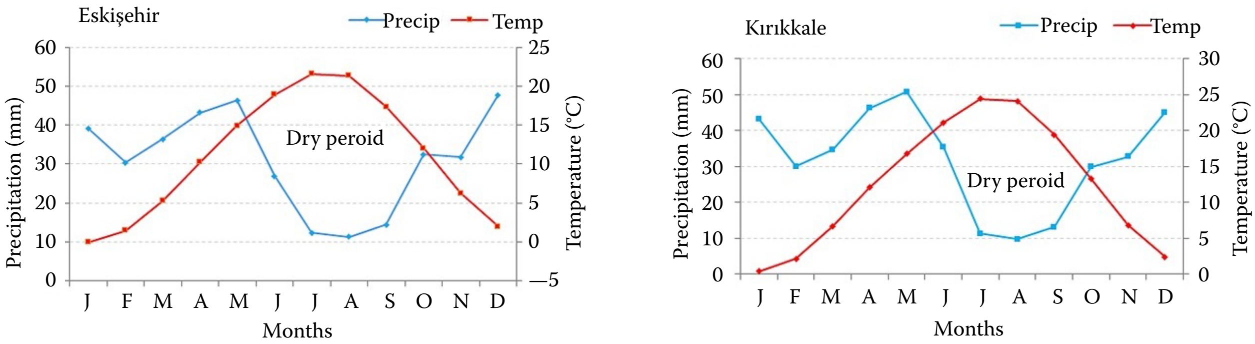

Figure 2. Climate diagram of the research sites; orange line represents monthly temperatures; blue line represents monthly precipitation for 1965–2015; distances of the locations to the meteorological stations are as follows: Bahşılı 18.85 km, Yahşıhan 17.12 km, and Elmadağ 22.23 km to Kırıkkale station; and Seyitgazi 27.69 km, Çifteler 67.95 km, Alpu 59.66 km, Mihalıççık 82.36 km, Nallıhan 85.90 km to Eskişehir station

out separately according to species (Juex and Jufo). Longitude and latitude (UTM), altitude (m), slope (%), exposure (°), *HI* and *NSD* were used as environmental variables in the analysis. The exposure was recorded as (°) and converted to the radiation index (*RI*) using formula (1) (Moisen, Frescino 2002; Aertsen et al. 2010).

$$RI = \frac{1 - \cos\left(\frac{\pi}{180} \times (Q - 30)\right)}{2} \qquad (1)$$

where:

RI – radiation index;

π – 3.14;

Q – azimuth angle of the sample plot to the north.

The single raw annual tree-ring series of both species were averaged into the site chronologies. Averaged raw annual tree-ring width and interpolated climatic variables (annual precipitation mm; summer precipitation mm; mean annual moisture %; mean annual temperature °C; mean summer temperature °C; mean spring temperature °C) were calculated by the Pearson correlation analysis using the SPSS program (Özdamar 2009).

RESULTS

Characteristics of tree-ring chronologies of both species. The raw tree-ring width chronologies of both species were created to compare the variation of annual tree-ring width between locations and research sites. In location chronologies, the annual ring widths of Jufo varied between 1 and 5 mm (Figure 3). If we do not consider Juex's peak point made by Seyitgazi, the annual ring widths of Juex are concentrated between 0.5 and 3.5 mm (Figure 4). The chronologies of both species from each research site showed similar results (Figure 5). While the mean annual tree-ring widths of Jufo were 2.25 mm in Eskişehir and 2.03 mm in Kırıkkale, the mean annual tree-ring widths of Juex were 1.76 mm in Eskişehir and 1.52 mm in Kırıkkale. Another difference between species in terms of annual tree-ring widths is the standard deviation. While the standard deviation values of Juex decreased with age, no significant age-related changes were determined for Jufo.

Relationship between tree-ring width of both species and environmental signals. According to the result of the CCA analysis applied to *MTW* of Jufo and environmental variables, the eigenvalues of Axes 1 and Axes 2 were less than 1 and the total variance explanation percentage was 35.4. The Pearson and Kendall correlation analysis between axes and environmental variables revealed relationships between Axis 1 and slope ($r = 0.639$), Axis 2 and altitude ($r = -0.785$), longitude ($r = 0.710$) and latitude ($r = 0.602$) (Table 2). According to the result of the CCA analysis as applied to the annual tree-ring width of Juex and environmental variables, the eigenvalues of Axes 1 and Axes 2 were less than 1 and the total variance explanation percentage was 18.5. No specific relationship was found between environmental factors and axes (Table 2).

A positive correlation was found between the altitude and annual tree-ring width of Jufo in Çifteler

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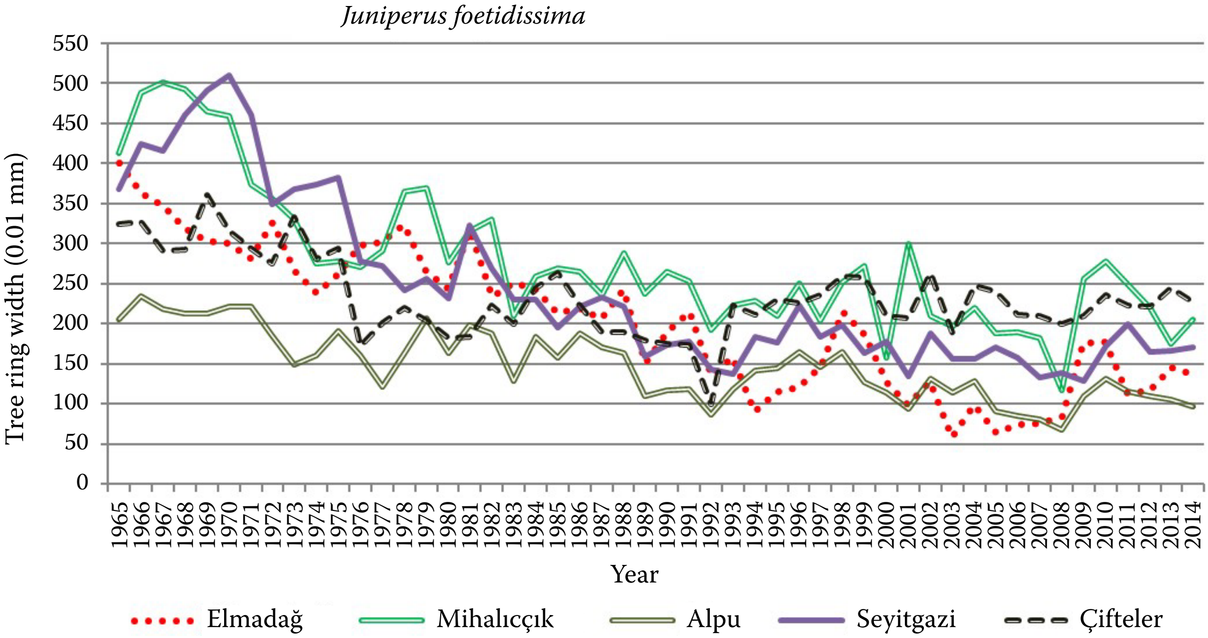

Figure 3. Comparison of mean tree-ring chronologies of *J. foetidissima* of locations for the period 1965–2014

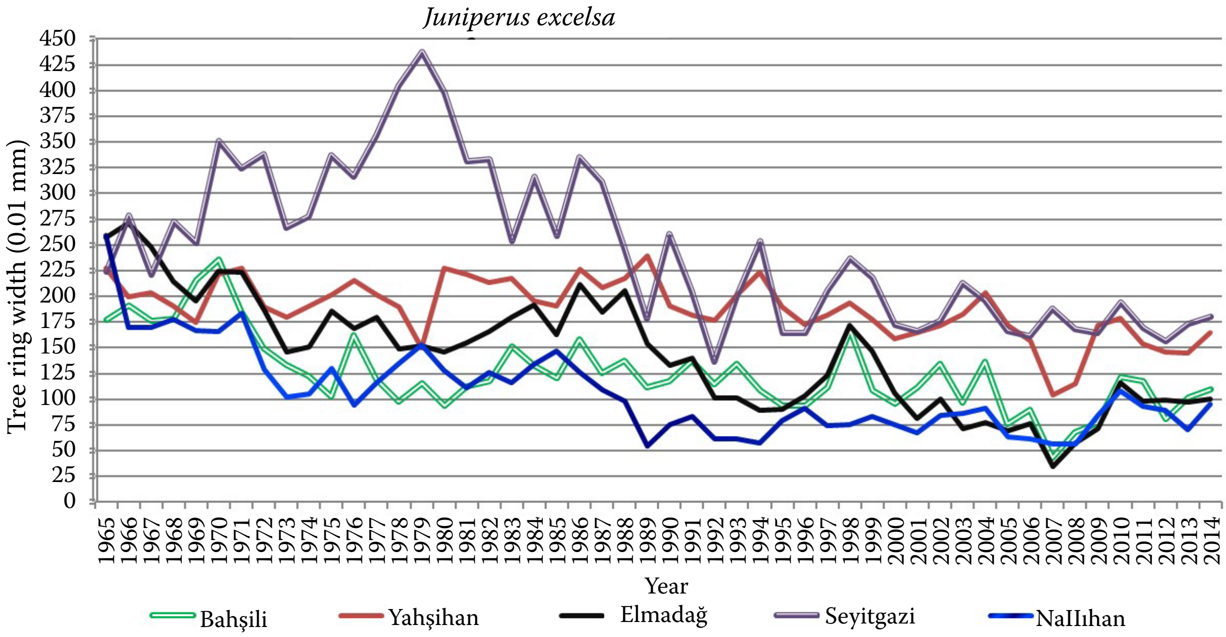

Figure 4. Comparison of mean tree-ring chronologies of *J. excelsa* of locations for the period 1965–2014

(sample plots 18, 19 and 24). Inverse relationships were revealed between longitude and latitude values and the annual ring widths of the same plots. The annual tree-ring widths of Jufo in Mihalıççık and Alpu located in the north of Eskişehir showed a positive relationship with longitude and latitude. 6M, 27A, 16S and 14S showed positive correlations with the slope (Figure 6). In these plots, the slope percentage is lower than in the other plots.

Comparisons between dendrochronological data and climatic patterns. Results of the Pearson correlation analysis between averaged (for each region) raw annual tree-ring widths of both species and climate variables showed that a sig-

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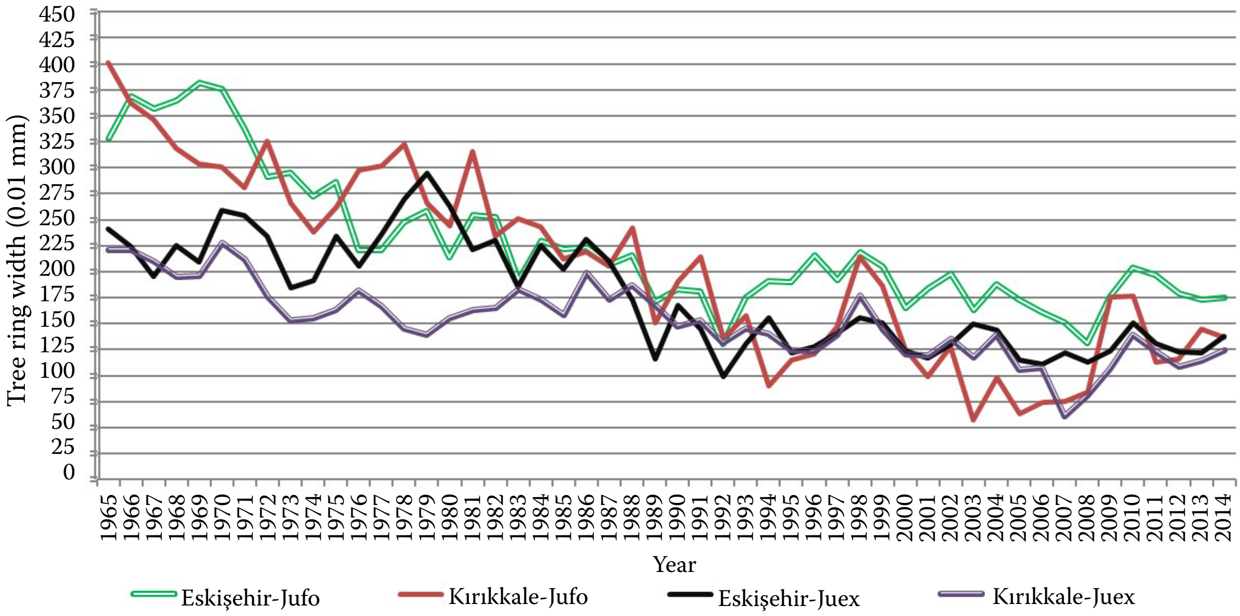

Figure 5. Comparison of mean annual tree-ring chronologies of *J. excelsa* and *J. foetidissima* from research sites Eskişehir and Kırıkkale for the period 1965–2015

Table 2. Pearson and Kendall correlation values between environmental variables and axes

Variables	Jufo		Juex	
	Axis 1	Axis 2	Axis 1	Axis 2
Longitude	–0.655*	0.422	0.048	–0.314
Latitude	–0.526*	0.101	–0.099	–0.059
Altitude	0.039	–0.358	–0.275	0.171
RI	–0.854*	–0.119	0.275	–0.014
Slope	0.553*	0.340	0.143	0.301
HI	–0.533*	0.107	–0.205	–0.221
NSD	–0.342	0.438	0.052	–0.301

*correlation signiicant at 0.05 level; *RI* – radiation index; *HI* – human impact; *NSD* – nearest settlement distance; Juex – *Juniperus excelsa*; Jufo – *Juniperus foetidissima*

nificant correlation was found between the mean tree-ring width of both species in each research site and mean summer temperature (P < 0.000, P < 0.001 in Kırıkkale and P < 0.000, P < 0.007 in Eskişehir) and moisture (P < 0.000, P < 0.000 in Eskişehir). Annual precipitation was significant (P < 0.008) only in Jufo in Eskişehiri. No significant correlation emerged between averaged raw annual tree-ring widths of both species and mean annual temperature (P < 0.109, P < 0.298 in Kırıkkale and P < 0.114, P < 0.737 in Eskişehir), summer precipitation (P < 0.179, P < 0.974 in Kırıkkale and P < 0.410, P < 0.791 in Eskişehir) and mean spring temperature (P < 0.316, P < 0.337 in Kırıkkale and P < 0.114, P < 0.737 in Eskişehir) in each research site (Table 3).

DISCUSSION

Two dominant types of junipers, Juex and Jufo, were identified in research sites of Anatolia. Although Juex or Jufo dominates in plots and locations alone, they are also seen together in a few locations. The results of this research and field observations lead us to infer that Juex and Jufo prefer different locations. Barga et al. (2018) claimed that spatial and temporal distribution of species varied with suitable climate and niche breadth. Corcuera et al. (2004) pointed out that the tree-ring width of a tree depends on the microclimatic condititons in the current year. Although it was not possible to prove a microclimatic effect on the occurrence of Juniper species, we accepted the idea of suitable microclimate niches, because Central Anatolia is known for the richness of microclimate niches (Öztürk, Savran 2020). According to the results of this study, slope and altitude may play an important role in this regard. While Juex

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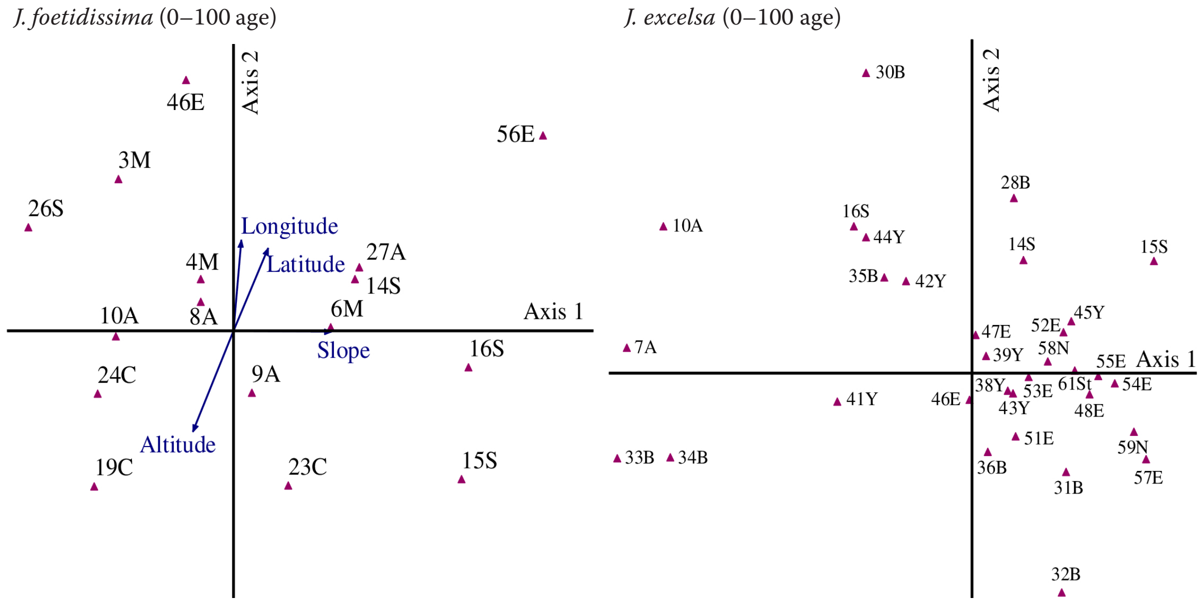

Figure 6. CCA chart showing the relationship between annual tree-ring widths of *J. excelsa* and *J. foetidissima* and environmental variables

M – Mihalıççık; C – Çifteler; S – Seyitgazi; A – Alpu; N – Nallıhan; E – Elmadağ; B – Bahşılı; Y – Yahşihan

Table 3. Results of the Pearson correlation analysis between the annual ring widths of the research sites and climate factors

Research sites	Species	Correlation	*Pa*	*Tm*	*M*	*Ps*	*Ts*	*Tsp*
Kırıkkale	Juex	*PCC*	0.124	–0.229	0.041	0.193	–0.551*	–0.145
		P	0.391	0.109	0.777	0.179	0.000	0.316
	Jufo	*PCC*	0.087	–0.150	–0.185	0.005	–0.441*	–0.139
		P	0.547	0.298	0.199	0.974	0.001	0.337
Eskişehir	Juex	*PCC*	0.204	–0.226	0.598*	–0.119	–0.527*	–0.226
		P	0.155	0.114	0.000	0.410	0.000	0.114
	Jufo	*PCC*	0.372*	–0.049	0.516*	0.038	–0.375*	–0.049
		P	0.008	0.737	0.000	0.791	0.007	0.737

*$P < 0.01$; *PCC* – Pearson correlation coefficient; *P* – significance level; *Pa* – annual precipitation (mm); *Ps* – summer precipitation (mm); *M* – mean annual moisture; *Tm* – mean annual temperature; *Ts* – mean summer temperature; *Tsp* – mean spring temperature; Juex – *Juniperus excelsa* M. Bieb; Jufo – *Juniperus foetidissima* Willd

grows on dry, rocky slopes, with shallow, gravelly soils, Jufo seems to be slightly more tolerant to dryness and heat (Farjon 1992). In fact, morphological studies also show that the two species have different origins (Marcysiak et al. 2007). The molecular characterisation and DNA analysis of juniper trees also revealed that Juex and Jufo are distinct species (Kasaian et al. 2011; Güvendiren 2015).

The results of this study demonstrated that the most important differences were seen between raw annual tree-ring widths of Juex and Jufo. Even if they grew in the same region, the annual tree-ring width of Jufo was wider than that of Juex (Figure 3, Figure 4), because tree radial growth is determined by genetic factors (Looney et al. 2016). This situation is clearly seen in the chronologies of Seyitgazi (Figure 3 and 4). Although Juex had a peak between the years 1970–1980 because of typical wood anomalies in one wood core, Jufo (2.6 mm) had wider annual tree-ring widths on average than Juex (2.1 mm).

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It was expected that annual tree-ring widths differed between regions, as they may differ even between separate locations in the same region because the most important factor in the development of annual tree rings is climate, which regardless varies between regions (St. George 2014). Rossi et al. (2008) claimed that the cambial activity of trees may change with age, species and region. Variations were revealed between averaged raw annual tree-ring widths of both species from different research sites, but it is difficult to say that these differences were due to regional diversity. Instead, the variance seems to be related to species (Figure 5). Here, it is possible to say that there are few differences in annual tree-ring widths between research sites, but the main difference is related to species.

To reveal the relationship between *MTW* and environmental variables, CCA was applied for Juex and Jufo (Figure 6). While the annual tree-ring width of Juex did not show a crucial response to environmental variables, *MTW* of Jufo was correlated with longitude, latitude, altitude and slope (Table 2). Longitude and latitude were the parameters most frequently correlated with *MTW* of Jufo. This leads us to infer that Jufo shows better growth at certain latitudes and longitudes. However, altitude has also a high relationship to *MTW* of Jufo. According to the result of our field survey, we know that Jufo prefers to grow at low altitudes. Esper (2000) found similar tree-ring width variations along elevational gradients in high mountain systems in Karakorum. He attributed this similarity to the change in climatic conditions with altitude because this region has steep precipitation gradients (Winiger et al. 2005). As an environmental variable, the slope was a factor affecting the tree-ring width of Jufo. Based on the results of this research, it is to infer that Jufo prefers low slopes and altitudes.

The environmental variables were also tested and no relationships were found between RI, HI, *NSD* and *MTW* of both species. In general, increasing growth is highly related to rising resources such as nutrients, water and radiation (Coley et al. 1985). The research area is a region that receives fairly good sunlight. It has consistently been proven that human activity has a destructive impact on forests (Stapania et al. 1997). The problem may be grounded on the method we used to measure human impact, or human influence does not affect the annual tree-ring width of the juniper.

Dendrochronological studies on different species have been conducted on annual tree-ring widths averaged in each research site and found that tree-ring width has a positive correlation with average monthly temperature and precipitation. Since juniper is not preferred in dendrochronological studies, few studies have been conducted on juniper species providing similar results (Touchan et al. 2007; Kahveci et al. 2018; Esper et al. 2007). Based on the results of the Pearson correlation analysis applied to the relationship between the climate variables of the research site and the mean annual tree-ring widths of both species, the most significant variables were summer temperature ($P < 0.000$ — $P < 0.007$, negatively) and moisture ($P < 0.000$, positively). Increasing evaporation during temperature increases had a negative effect on growth (Klos et al. 2009). Therefore, an inverse relationship between temperature and annual ring widths was an expected result. Pandey et al. (2020) also found that spring and summer moisture is critical for the radial growth of juniper in Nepal Himalayas. A relationship was also seen between annual precipitation and annual tree-ring widths of Jufo in Eskişehir, where precipitation was relatively low. No significant relationship was found between summer precipitation, mean spring temperature and annual tree-ring widths (Table 3). It is known that especially for this type of steppe region, the precipitation in summer evaporates immediately due to high temperatures, which is then unusable for plants (Schwinning et al. 2005).

CONCLUSION

Juniper is an excellent species that may have a higher representation in semi-arid regions of Anatolia. Based on the results of this study, though Juex and Jufo grow under very similar climatic conditions, however, they are different species and respond differently to environmental signals. While the annual tree-ring width of Juex did not respond to the environmental signals, remarkable correlations were found between the annual tree-ring width of Jufo and longitude, latitude, altitude and slope. Summer temperatures and moisture were the most crucial variables affecting the growth of both species in research sites. In addition, the results of field studies showed that Jufo differs from Juex in a wider annual tree-ring width and preference to low slopes and altitudes. It was

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not possible to prove the human impact on annual tree-ring width in this study. However, more research is needed to change the measurement methods and expand the area of interest to reach a clear conclusion. The results of these studies may help for protecting existing degraded juniper stands related to re-greening the mountains in Turkey, controlling erosion, improving the local climate, resulting in a higher diversity of woody species, restarting juniper rehabilitations that have been neglected for years and redesigning forest management plans.

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REFERENCES

Aertsen W., Kint V., Van Orshoven J., Özkan K., Muys B. (2010): Comparison and ranking of different modelling techniques for prediction of site index in Mediterranean mountain forests. Ecological Modelling, 221: 1119–1130.

Atalay İ., Gökçe Gündüzoğlu H.A. (2015): Türkiye'nin Ekolojik Koşullarına Göre Arazi Kabiliyet Sınıflandırılması. İzmir, Meta Basım Matbaacılık Hizmetleri: 272. (in Turkish)

Balkan E., Erkan K., Şalk M. (2017): Thermal conductivity of major rock types in western and central Anatolia regions, Turkey. *Journal of Geophysics and Engineering,* 14: 909–919.

Barga S.C., Dilts T.E., Leger E.A. (2018): Contrasting climate niches among co-occurring subdominant forbs of the sagebrush steppe. Diversity and Distribution, 24: 1291–1307.

Bigler C. (2016): Trade-offs between growth rate, tree size and lifespan of mountain pine (*Pinus montana*) in the Swiss National Park. Dryad Dataset. PLoS ONE, 11: e0150402.

Bond B.J. (2000): Age-related changes in photosynthesis of woody plants. Trends in Plant Science, 5: 349–353.

Carus S. (2004): Increment and growth in Crimean juniper (*Juniperus excelsa* Bieb.) stands in Isparta-Sütçüler region of Turkey. Journal of Biological Sciences, 4: 173–179.

Çalışkan S., Boydak M. (2017): Afforestation of arid and semiarid ecosystems in Turkey. Turkish Journal of Agriculture and Forestry, 41: 317–330.

Çepel N. (1988): Orman Ekolojisi. İstanbul Üniversitesi Orman Fakültesi Yayınları, İ.Ü. Yayın No: 3518, O.F. Yayın No: 399. İstanbul, Gençlik Basımevi: 536. (in Turkish)

Chambers J.C., Vander Wall S.B., Schupp E.W. (1999): Seed and seedling ecology of pinon and juniper species in the pygmy woodlands of western North America. The Botanical Review, 65: 1–38.

Coley P.D., Bryant J.P., Chapin F.S. (1985): Resource availability and plant antiherbivore defence. Science, 230: 895–899.

Corcuera L., Camarero J.J., Gil-Pelegrín E. (2004): Effects of a severe drought on growth and wood anatomical properties of *Quercus faginea*. Iawa Journal, *25:* 185–204.

Cukor J., Vacek Z., Linda R., Sharma R.P., Vacek, S. (2019): Afforested farmland vs. forestland: Effects of bark stripping by *Cervus elaphus* and climate on production potential and structure of *Picea abies* forests. PLoS ONE, 14: e0221082.

Dinç U., Şenol S., Kapur S., Cangir C., Atalay I. (1997): Soils of Turkey. Adana. University of Çukurova, Faculty of Agriculture: 233. (in Turkish)

Douaihy B., Vendramin G.G., Boratyński A., Machon N., Bou Dagher-Kharrat M. (2011): High genetic diversity with moderate differentiation in *Juniperus excelsa* from Lebanon and the eastern Mediterranean region. AoB Plants, 2011: plr003.

Esper J. (2000): Paleoklimatische Untersuchungen an Jahrringen im Karakorum und Tien Shan Gebirge (Zentralasien). Bonner Geographische Abhandlungen, 103: 137. (in German)

Esper J., Frank D.C., Wilson R.J.S., Büntgen U., Treydte K. (2007): Uniform growth trends among central Asian low and high elevation juniper tree sites. Trees, 21: 141–150.

Farjon A. (1992): The taxonomy of multiseed junipers (*Juniperus* Sect. *Sabina*) in southwest Asia and east Africa (Taxonomic notes on Cupressaceae I). Edinburgh Journal of Botany, 49: 251–283.

General Directorate of Meteorology (GDM) (2016): Available at: https://www.mgm.gov.tr/ (upon request)

Güvendiren A.D. (2015): Molecular phylogenetic analyses of *Juniperus* L. species in Turkey and their relations with other Junipers based on cpDNA. [PhD Thesis.] Ankara, Middle East Technical University.

Holmes R.L. (1983): Computer-assisted quality control in tree ring dating and measurement. Tree-Ring Bulletin, 43: 69–78.

Jiao L., Jiang, Y., Wang M., Zhang W., Zhang, Y. (2017): Age-effect radial growth responses of *Picea schrenkiana* to climate change in the eastern Tianshan Mountains, northwest China. Forest, 8: 294.

Kahveci G., Alan M., Köse N. (2018): Distribution of juniper stands and the impact of environmental parameters on growth in the drought-stressed forest-steppe zone of Central Anatolia. Dendrobiology, 80: 61–69.

Kasaian J., Behravan J., Hassany M., Emami S.A., Shahriari F., Khayyat M.H. (2011): Molecular characterization and RAPD analysis of *Juniperus* species from Iran. Genetics and Molecular Research, 10: 1069–1074.

Klos R.J., Wang G.G., Bauerle W.L., Rieck J.R. (2009): Drought impact on forest growth and mortality in the southeast USA: an analysis using Forest Health and Monitoring data. Ecological Applications, 19: 699–708.

https://doi.org/10.17221/42/2021-JFS

Konter O., Büntgen U., Carrer M., Timonen M., Esper J. (2016): Climate signal age effects in boreal tree-rings: Lessons to be learned for paleoclimatic reconstructions. Quaternary Science Reviews, 142: 164–172.

Köppen W., Geiger R. (1954): Klima der Erde (Climate of the earth). Wall Map 1:16 Mill. Gotha, Klett-Perthes.

Li D., Fang K., Li Y., Chen D., Liu X., Dong Z. Zhou F., Guo G., Shi F., Xu C., Li Y. (2017): Climate intrinsic water efficiency and tree growth over the past 150 years humid subtropical China. PLoS ONE, 12: e0172045.

Looney C.E., D'Amato A.W., Fraver S., Palik B.J., Reinikainen M.R. (2016): Examining the influences of tree-to-tree competition and climate on size-growth relationships in hydric, multi-aged *Fraxinus nigra* stands. Forest Ecology and Management, 375: 238–248.

Lyon J., Sagers C.L. (1998): Structure of herbaceous plant assemblages in a forested riparian landscape. Plant Ecology, 138: 1–16.

Marcysiak K., Mazur M., Romo A., Montserrat J.M., Didukh Y., Boratyńska K., Jasińska A., Kosiński P., Boratyński A. (2007): Numerical taxonomy of *Juniperus thurifera*, *J. excelsa* and *J. foetidissima* (Cupressaceae) based on morphological characters. Botanical Journal of the Linnean Society, 155: 483–495.

Mäkinen H., Nöjd P., Kahle H.-P., Neumann U., Tveite B., Mielikäinen K., Röhle H., Spiecker H. (2002): Radial growth variation of Norway spruce (*Picea abies* (L.) Karst.) across latitudinal and altitudinal gradients in central and northern Europe. Forest Ecology and Management, 171: 243–259.

Martín-Benito D., Cherubini P., del Río M., Cañellas I. (2008): Growth response to climate and drought in *Pinus nigra* Arn. trees of different crown classes. Trees, 22: 363–373.

McCune B., Mefford M.J. (2006): PC-ORD. Multivariate analysis of Ecological Data, Version 5. Gleneden Beach, MjM Software Design: 300.

Mikaeili M. (2015): Walled cities and the development of civilization in Asia Minor (Anatolia) and the Middle East. Spaces and Flows: An International Journal of Urban and Extra Urban Studies, 5: 1–25.

Moisen G.G., Frescino T.S. (2002): Comparing five modelling techniques for predicting forest characteristics. Ecological Modelling, 157: 209–225.

Özdamar K. (2009): Paket Programlar ile İstatistiksel Veri Analizi. 7. Eskişehir, Baskı, Kaan Kitabevi: 609. (in Turkish)

Öztürk M.Z., Çetinkaya G., Aydin S. (2017): Köppen-Geiger İklim Sınıflandırmasına Göre Türkiye'nin İklim Tipleri. İstanbul Üniversitesi Coğrafya Dergisi – Istanbul University Journal of Geography, 35: 17–27. (in Turkish)

Öztürk M.Z., Savran A. (2020): An oasis in the Central Anatolian Steppe: the ecology of a collapse doline. Acta Biologica Turcica, 33: 100–113.

Özyuvacı N. (1999): Meteoroloji ve Klimatoloji. İstanbul Üniversitesi Orman Fakültesi Yayınları No: 4196. İstanbul, Dilek Ofset Matbaacılık: 369. (in Turkish)

Pandey J., Sigdel S.R., Lu X., Salerno F., Dawadi B., Liang E., Camarero J.C. (2020): Early growing-season precipitation drives radial growth of alpine juniper shrubs in the central Himalayas. Geografiska Annaler: Series A, Physical Geography, 102: 317–330.

Quézel P., Médail F. (2003): Ecologie et biogéographie des forêts du bassin méditerranéen. Paris, Elsevier: 571. (in French)

Remeš J., Bílek L., Novák J., Vacek Z., Vacek S., Putalová T., Koubek, L. (2015): Diameter increment of beech in relation to social position of trees, climate characteristics and thinning intensity. Journal of Forest Science, 61: 456–464.

Rossi S., Deslauriers A., Anfodillo T., Carrer M. (2008): Age-dependent xylogenesis in timberline conifers. New Phytologist Foundation, 177: 199–208.

Samojlik Q., Roherham I.D., Jedrzejewska B. (2013): Quantifying historic human impacts on forest environments: A Case Study in Bialowieza Forest, Poland. Environmental History, 18: 576–602.

Sarangzai A.M., Ahmed A. (2011): Dendrochronological potential of *Junıperus excelsa* (M.Bieb) from dry temperate forest of Balochistan province, Pakistan. FUUAST Journal of Biology, 1: 65–70.

Schwinning S., Starr B.I., Ehleringer J.R. (2005): Summer and winter drought in a cold desert ecosystem (Colorado Plateau) part I: Effects on soil water and plant water uptake. Journal of Arid Environments, 60: 547–566.

Šimůnek V., Vacek Z., Vacek S., Ripullone F., Hájek V., D'Andrea G. (2021): Tree rings of European beech (*Fagus sylvatica* L.) indicate the relationship with solar cycles during climate change in central and southern Europe. Forests, 12: 259.

Soulé P.T., Knapp P.A (2019). Radial growth rate responses of western juniper (*Juniperus occidentalis Hook.*) to atmospheric and climatic changes: A longitudinal study from central Oregon, USA. Forests, 10: 1127.

St. George S. (2014): An overview of tree-ring width records across the Northern Hemisphere. Quaternary Science Reviews, 95: 132–150.

Stapanian M.A., Cassell D.L., Cline S.P. (1997): Regional patterns of local diversity of trees: associations with anthropogenic disturbance. Forest Ecology and Management, 93: 33–44.

Štefančík I., Vacek Z., Sharma R.P., Vacek S., Rösslová M. (2018): Effect of thinning regimes on growth and development of crop trees in *Fagus sylvatica* stands of Central Europe over fifty years. Dendrobiology, 79: 141–155.

Touchan R., Akkemik Ü., Hughes M.K., Erkan N. (2007): May-June precipitation reconstruction of southwestern Anatolia, Turkey during the last 900 years from tree rings. Quaternary Research, 68: 196–202.

https://doi.org/10.17221/42/2021-JFS

Türkeş M. (1990): Türkiye'de kurak bölgeler ve önemli kurak yıllar. [PhD Thesis.] Istanbul, İstanbul University. (in Turkish)

Vacek S., Vacek Z., Remeš J., Bílek L., Hůnová I., Bulušek D., Putalová T., Král J., Simon J. (2017): Sensitivity of unmanaged relict pine forest in the Czech Republic to climate change and air pollution. Trees, 31: 1599 1617.

Vacek Z., Vacek S., Slanař J., Bílek L., Bulušek D., Štefančík I., Králíček I., Vančura K. (2019): Adaption of Norway spruce and European beech forests under climate change: from resistance to close-to-nature silviculture. Central European Forestry Journal, 65: 129–144.

Vacek Z., Prokůpková A., Vacek S., Bulušek D., Šimůnek V., Hájek V., Králíček I. (2021): Mixed vs. monospecific mountain forests in response to climate change: structural and growth perspectives of Norway spruce and European beech. Forest Ecology and Management, 488: 119019.

Winiger M., Gumpert M., Yamout H. (2005): Karakorum–Hindukush–western Himalaya: assessing high-altitude water resources. Hydrological Processes, 19: 2329–2338.

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