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Distribution of juniper stands and the impact of environmental parameters on growth in the drought-stressed forest-steppe zone of Central Anatolia

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Abstract: Juniper is one of the three main tree species in Central Anatolia, where it grows under extreme environmental conditions. Although dendrochronological studies of juniper are challenging because of cross-dating problems, these types of studies on long-lived tree species have the potential to provide long time series, which reflect changes in climatic conditions. Juniper has been neglected as a scientific research subject in Turkey due to degraded populations and low economic expectations. This study analysed the distribution and present state of *Juniperus* spp. (*Juniperus excelsa* M. Bieb., *Juniperus oxycedrus* L., and *Juniperus foetidissima* Willd.) stands and used dendrochronological data to examine relationships between growth and environmental parameters. We hypothesised that there may be differences in the radial growth of juniper in areas of different exposure in drought regions. During a field survey, we sampled 31 plots of 25 m × 20 m and data, including information on wood cores, were collected. For dendrochronological investigation, 95 wood cores were manually measured and cross-dated. Residual chronologies of tree-ring width series of juniper from four wind directions and regional chronology of Kirikkale and Ankara Province were provided and similarities between the chronologies were tested using Gleichläufigkeits test. The relationships between climate parameters and growth were examined using a simple correlation analysis and multiple linear regression model analysis in SAS 9.0 program and response function analysis in the DENROCLIM2002 program. The results of this study indicated that *Juniperus* spp. in Central Anatolia are sensitive to environmental parameters and mainly respond to changes in precipitation. Juniper show differences in radial growth in areas of different exposure in drought regions. We conclude that juniper may offer an excellent opportunity for large-scale dendrochronological and dendroecological studies in drought regions.

Keywords: Dendrochronology, dendroecology, tree-ring width, exposure

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Introduction

Most forest ecosystems globally have been affected by human activities (Blondel & Aronson, 1999). The impacts in drought-prone regions can be particularly severe as low precipitation and high evaporation can lead to land degradation (Dai, 2013). Tree vitality is one of the key processes that influence drought impacts on forests (Bhuyan et al., 2017). Woody species that can survive and maintain their vitality under human pressure and worsening climatic conditions are very important for the future of forest ecosystems. Long-lived tree species also have the potential to provide long time series that reflect changes in climatic conditions (Saass-Klassen et al., 2008). Such species include those of genus *Juniperus*, which can be used in dendrochronological studies.

Genus *Juniperus* is the second most diverse genus of conifers, with 67 species worldwide (Adams, 2004). The genus is represented by 8 species in Turkey, four of which (*J. excelsa* M. Bieb., *J. foetidissima* Willd., *J. oxycedrus* L., *J. sabina* L.) grow naturally in Central Anatolia (Yilmaz et al., 2011). Due to semi-arid conditions and long-term human impacts, the forests in Central Anatolia have been fragmented and are excessively degraded (Kahveci, 1998). The remaining relics of natural forests are mainly seen in mountain regions. The woodland is composed of different types of forest including *Quercus* spp., *Pinus nigra* Arnold, *Juniperus* spp., and other woody shrubs; however, oak species are dominant (Woldring & Cappers, 2001). Even though oak species are dominant in the region, there are pure and mixed stands of *Juniperus* spp. and these are the only surviving trees in some places.

Long-lived *Juniperus* in drought regions can be very useful for dendrochronological studies. Dendrochronology is widely applied in ecological studies for determining tree age, growth rates, and to study the relationships between tree growth and variable environmental factors by comparing annual variations in tree-ring width with annual variations in the climate parameters of interest (Sarangzai et al., 2011). Dendroarchaeology can involve reconstructions of past climate and predictions of climate trends. However, juniper wood can have missing and locally absent rings and false or double rings under extremely dry conditions (Wils & Eshetu, 2007); therefore, they have largely been ignored by dendrochronologists. This challenge can be overcome by increasing the number of dendrochronological studies on juniper (Sarangzai et al., 2011). In this respect, each study is valuable. Touchan et al. (2007) produced the longest reconstruction of *Juniperus excelsa* (AD 1076-2000), for southwestern Anatolia. Esper et al. (2007) investigated growth behaviour in Central Asian juniper trees at different elevations by controlling solar radiation. Opala et al. (2017) investigated the climate-growth relationship in *Juniperus semiglobosa* Regel in the Pamir-Alay mountain system.

Junipers are not dominant tree species because their populations have been greatly reduced due to overuse, which has reduced the frequency of scientific research on these species. However, it is especially important to recognize the reasons and factors influencing the presence of juniper in some locations, particularly when other tree species have difficulty growing there. The present study analysed the distribution and present state of *Juniperus* spp. (*Juniperus excelsa* M. Bieb., *Juniperus oxycedrus* L., and *Juniperus foetidissima* Willd.) stands and provided dendrochronological data, which was used to examine the relationships between growth and environmental parameters. We hypothesized that there may be differences in radial growth of junipers in areas of different exposure in drought regions.

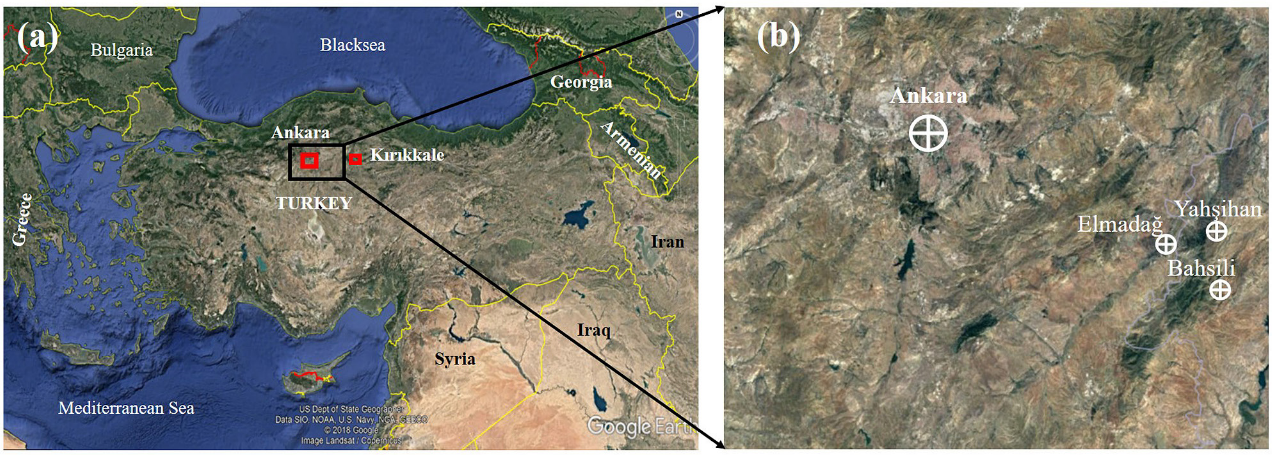

Fig. 1. Research site located in Central Anatolia (a). Sub-district Elmadag is in Ankara Province, and Bahsili and Yahsihan are in Kirikkale Province (b)

Material and Methods

Research site

The study was carried out in Kirikkale and Ankara Province, located in the centre of Central Anatolia, where pure juniper stands are often found (Fig. 1). The present study was conducted in three sub-districts: Elmadag, Bahsili, and Yahsihan (Table 1). The region includes large-grass steppe in the plains, and woodlands in the mountain area, including forest relics with pure and mixed stands (Kahveci, 1998). Over the study period, the following woody plants were recorded: *Quercus* ithaburensis subsp. macrolepis (Kotschy) Hedge & Yalt., *Q. cerris* L., *Q. pubescens* Willd., *Juniperus excelsa* M. Bieb., *J. oxycedrus* L., and *J. foetidissima* Willd., *J. sabina* L., *Pyrus elaeagnifolia* Pall., *Rosa canina* L., and *Berberis crataegina* DC., which constitute the remaining ancient natural forests.

Daily human activities, such as grazing, collecting firewood, and fodder use, overexploitation, and shifting cultivation have changed forest ecosystems and resulted in deforestation and fragmentation since ancient times (Mikaeili, 2015). Despite a gradual decline in those impacts, grazing and some fodder use still continue today.

Meteorological data

Meteorological data from the General Directorate of Meteorology (GDM) in Turkey were used for this study, which included monthly precipitation, monthly temperature, and monthly relative humidity, from 1963 to 2016 (GDM, 2016).

The annual precipitation was 383.86 mm, the majority of which was experienced during the winter months. The summer months had less than 15 mm rainfall. The average annual temperature was 12.44 °C and ranged from 24.47 °C in July to 0.37 °C in January (Fig. 2). The average annual humidity was 78.01%, but this dropped to 46% in July and August.

Sampling methods and processing

Data were collected from sampling plots in autumn 2014 and 2015. The sampling methodology

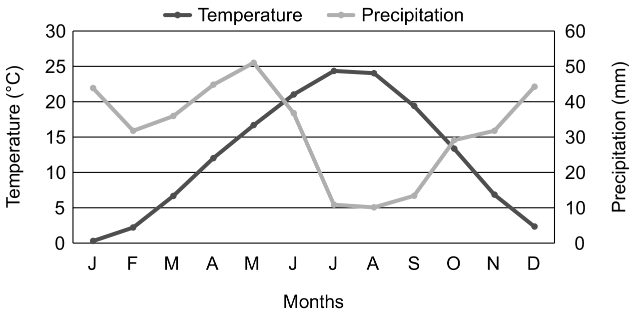

Fig. 2. Climate diagram of the research site. The blue line represents monthly precipitation and orange line represents monthly temperature for 1963–2016 at Kirikkale meteorological stations

was designed specifically for these forest stands, which have been excessively fragmented and have semi-arid conditions and long-term human disturbance; sampling was only conducted in forest relics (Fig. 3a). Sampling locations were determined using the Forest Management Plan of Kirikkale and Ankara Forest Districts and juniper stands that exhibited relatively intensive growth were selected as research sites. Sample plots were located where junipers grew in a group; a sampling plot was defined as a juniper stand of approximately 25 m × 20 m. Thirty-one plots were sampled, including 12 in Elmadag (39°47'29.8"N, 33°15'49.6"E), 9 in Bahsili (39°43'42.1"N, 33°21'21.2"E), and 10 in Yahsihan (39°47'37.8"N, 33°21'05.1"E) (Table 1). The following data were recorded for each sample plot: coordinates, altitude (m), exposure (wind direction), slope (%), tree and shrub species, height (m), diameter at breast height of 1.30 m (DBH) (cm) in the case of DBH >5 cm, and other observations.

Increment cores were taken from damage-free trees using an increment borer. In total, 265 trees were sampled, but not all wood cores could be taken at DBH because of internal decay. Rotten and damaged wood was excluded from the assessment. Only 126 wood cores from 95 trees (some of them could be taken from two sides) were suitable for analysis; 31 increment cores with consistent, long time series were excluded because of missing and locally absent rings or false or double rings, and adequate stem disks were not available to cross-date these cores.

Table 1. Characteristics of the research site

Sites	Coordinates	Altitude (m)	Slope (%)	Number of plot	Number of tree	Number of wood core
Elmadag	39°47'29.8"N, 33°15'49.6"E	970–1099	55	12	107	22
Bahsili	39°43'42.1"N, 33°21'21.2"E	980–1200	33	9	75	39
Yahsihan	39°47'37.8"N, 33°21'05.1"E	1010–1030	26	10	83	34

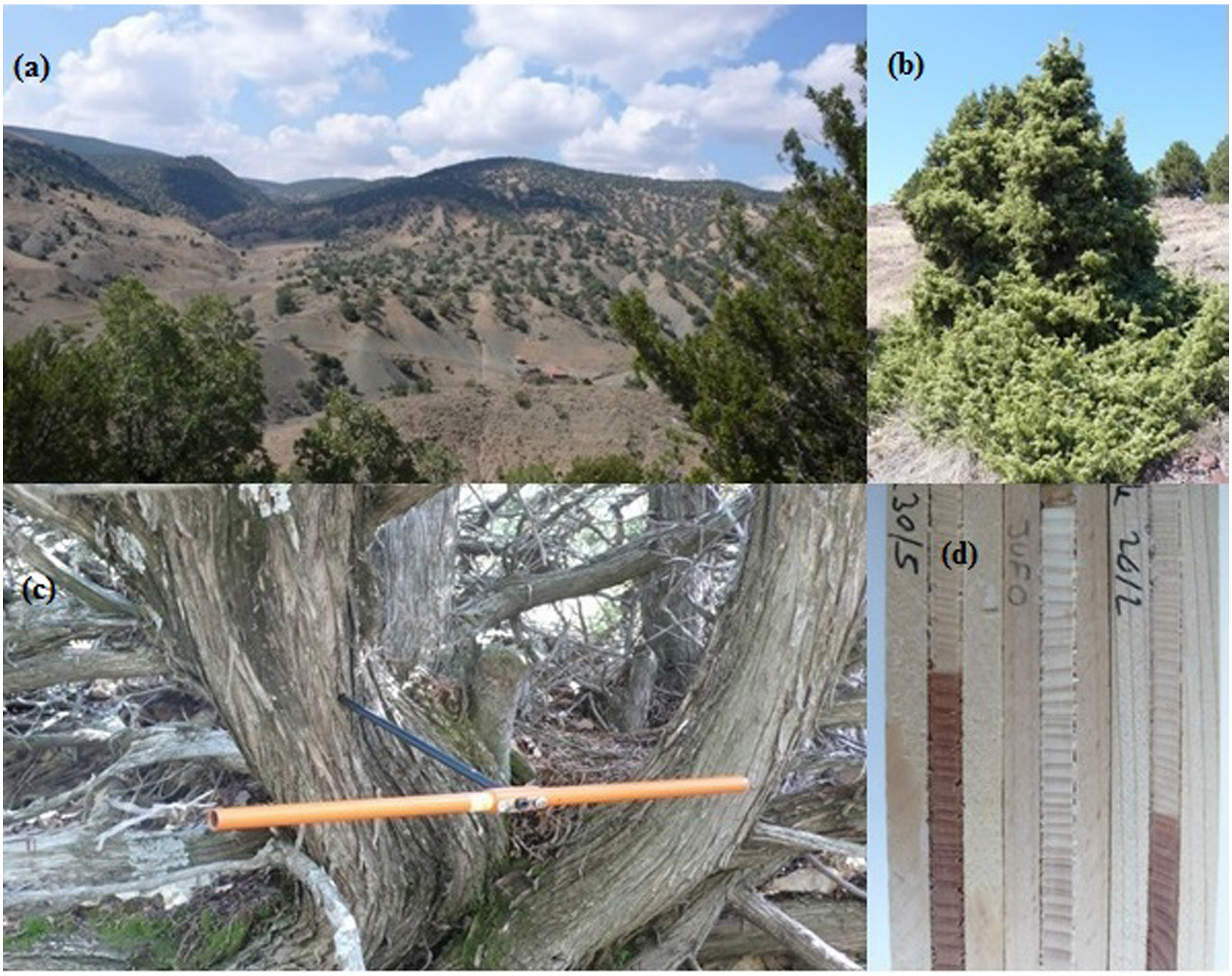

Fig. 3. *Juniperus spp*. research site; distribution (a), growth form (b), multistemmed individual (c), wood cores standing on the edge of *J. excelsa* and wood core standing in the middle of *J. foetidissima* (d)

Data Analysis

All collected wood cores were dried and sanded. Tree-ring width was measured using a LINTAB measuring table connected to TSAP Win software (Rintech, Germany), with 0.01 mm precision. 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 cross-dating was checked using the COFECHA program (Holmes, 1983). The raw data for 95 cross-dated ring-width series were transformed into indices by fitting a detrending function using the ARSTAN program (Cook & Krusic, 2005). Autoregressive models were applied to remove persistence from each ring-width series. Residual chronologies of four wind directions (N, E, S, W) were obtained from averaged annual indices of each series (Cook, 1985). A Gleichläufigkeit (coefficient of agreement) test was used to calculate the percentage of common trends between two series (Eckstain & Bauch, 1969). GLK and T_{BP} values (the t-value adapted to time-series by Baillie & Pilcher, 1973) were used to measure the similarity between residual tree-ring series for the four wind directions; because the GLK and T_{BP} values were significant for the four chronologies, we built a regional residual chronology for the area.

The relationships between the climate parameters and growth were examined in two ways. Firstly, annual precipitation (AP), annual mean temperature (AMT), and annual mean humidity (AMH), as the independent variables/predictors, were obtained from meteorological stations surrounding Kirikkale, and correlated with juniper regional chronology as the dependent variable using a simple correlation analysis and multiple linear regression model analysis. We developed three models for the multiple linear regression analysis: model 1 (predictors: AP, AMT, AMH), model 2 (predictors: AP, AMT), and model 3 (predictors: AP). These models helped us to understand the change in the dependent variable with changes in the independent variables, and to find any positive or negative trends in the influence of the climate parameters on tree-ring width. Statistical analyses were performed with SAS 9.0 (SAS Institute Inc., 2002).

A climate-growth analysis was carried out to assess the effect of changes in monthly mean temperature and a monthly total precipitation (from October of the previous year to October of the current year) on the tree-ring width using DENDROCLIM2002 program, which uses 1000 bootstrapped samples to compute response function coefficients (Biondi & Waikul, 2004). The response function coefficients were calculated for each wind direction (N, E, S, W) chronology and the regional chronology separately.

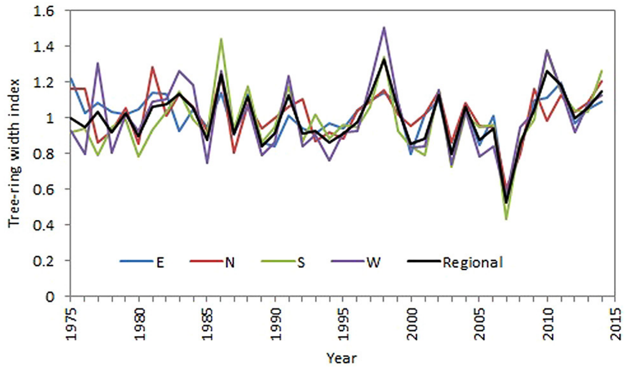

Fig. 4. Residual chronologies of tree-ring width series of *Juniperus* spp. from four wind directions and regional juniper chronology for Kirikkale-Ankara province for the period of 1975–2014

Results

3.1 Distribution and present state of *Juniperus* spp. stands

Junipers sampled in the 31 plots covered an area of 15.5 ha. The total number of all measured trees (DBH >5 cm) was 265, which consisted of *Juniperus excelsa* (254), *Juniperus foetidissima* (5), and *Juniperus oxycedrus* (6). Mean density was 17.10 trees/ha. Although the lower and upper bounds of the forest varied between 900 and 1299 m above sea level (a.s.l.), the highest number of *Juniperus* spp. was found between 1000 and 1100 m a.s.l. (Table 2). The number of trees on the south- and west-facing slopes was lower than on east- and north-facing slopes.

Based on our observations, most trees did not grow strictly vertically and branched from the bottom. This multi-stemmed form supported horizontal growth of stems in the middle of the trees (Fig. 3b). The surrounding stems were exposed to grazing and other physical pressures, while stems in the middle of the tree had an opportunity to grow upward (Fig. 3b). In some places *Juniperus sabina* also surrounded the stems, which resulted in good protection of the juniper tree. Despite this finding, many of the trees had partial decay inside. Interviews with local villagers about past use of juniper trees revealed that, until recently, juniper had been used as fodder in the winter months by cutting at the root collar. Although grazing still continues, the use of junipers as fodder has been abandoned.

Results of the dendrochronological studies

Observations of the sampled wood cores revealed that wood of *J. excelsa* was light brown or golden, with clearly distinguishable, more reddish heartwood. The latewood consisted of small tracheids and appeared darker, while earlywood had wider tracheids. The wood of *J. foetidissima* looked similar to *J. excelsa*, but its wood core was lighter (Fig. 3d).

Four residual chronologies for each wind direction were built using the cores obtained from the trees living on N, E, S, and W slopes for the periods of 1960–2014, 1945–2014, 1932–2014, 1939–2014, respectively. Regional juniper chronology was built using a standardized 95-tree-ring series, which ranged from 1929 to 2014. Most of the wood cores considered for cross-dating provided short time series, generally less than 90 years. We excluded tree rings before 1975 to provide more precise results for the analysis (Fig. 4).

The results of the Gleichläufigkeit (GLK) test and T_{BP} values are summarised in Table 3, which shows statistically significant values ($p < 0.05$, $p < 0.01$, and $p < 0.001$). Although the values for slopes with a southerly exposure and those associated with a westerly exposure showed the greatest similarity (85%), values for easterly and southerly exposure showed little overlap (Table 3). Other residual tree-ring series related to the four wind directions overlapped in a certain percentage, which encouraged us to build a regional chronology.

Results of the Pearson correlation analysis showed linear relationships between the variables, which were statistically significant at the 0.01 significance level. It indicated positive correlations between the standardized tree-ring series and annual precipitation (0.39), and the standardized tree-ring series and mean annual humidity (0.31), which were the only statistically significant correlations. The correlation between tree-ring width and mean annual temperature (0.098) was very low.

Table 2. Summarised results of sampling plots in research site

	900–1000 m a.s.l.	1000–1100 m a.s.l.	1100–1299 m a.s.l.	N	W	S	E
Number of trees	15	178	76	72	63	64	66
Number of plots	2	21	8	8	8	8	7

Table 3. Gleichläufigkeit and T_{BP} values between residual chronologies of N, W, S, E, and the regional chronology for the period of 1975–2014

	N	W	S	E	Regional	
N	–	3.5	6.5	7.4	7.0	
W	72**	–	7.2	5.6	12.9	
S	72**	85***	–	6.7	15.5	T_{BP}
E	72**	74**	59NS	–	10.5	
Regional	72**	100***	85***	74**	–	
	GLK Value					

"**", "***" indicate statistically significant values, $p<0.01$ and $p<0.001$ respectively. "NS" indicates insignificant values. "–" indicate no common interval between two time series.

The results of the multiple linear regression models were statistically significant ($p = 0.039$). The correlation coefficient value, R, which is a measure of the relationship between the dependent and predictor variables, was similar for all models: model 1 (0.431), model 2 (0.404), and model 3 (0.388). Precipitation was the most significant predictor in all models (Table 4).

Results of the response function analysis are presented in Fig. 5. None of the response function coefficients related with temperature and precipitation were significant for the juniper trees found on north-facing slopes. The response function coefficients calculated between the western residual chronology and precipitation were positive and significant for the previous December, current May–June and September, while temperature positive and significant in only February. For the trees sampled from southern slopes, the positive effect of precipitation was high for the previous December and current May–June, but was only significant for the previous December. The effect of temperature on radial growth of these trees was negative and significant in June. For the eastern residual chronology, only winter precipitation from the previous December to current January had a significant effect. Response function results of regional chronology highlighted the positive and significant effect of temperature in February and, positive effect of precipitation in the previous December and current May–June (only significant for December and May).

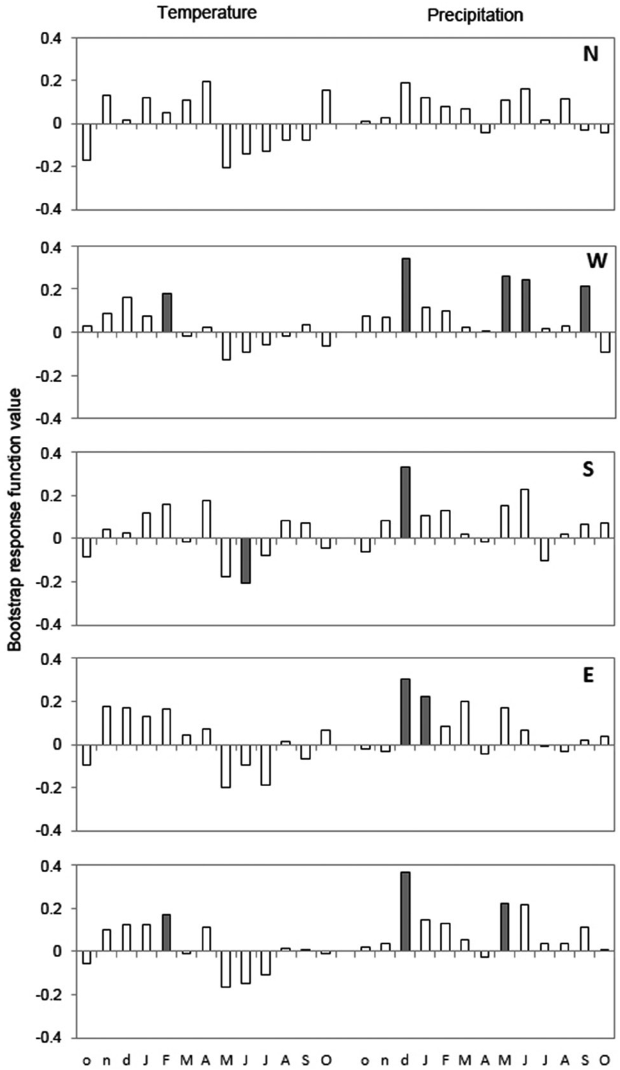

Fig. 5. Response function coefficients between the residual chronologies (from N, W, S, and E slopes and regional chronology, respectively) and monthly mean temperature and monthly total precipitation. Grey bars represent significant coefficients ($p < 0.05$) with the related month

Discussion

Juniper trees can grow under harsh climatic conditions and occur in North America, Europe, North Africa, and West, Central, and South Asia (Sarangzai et al., 2012). Features such as the ability to live under extremely dry conditions and human impacts, the capacity to regenerate, long life, and a strong survival capacity make trees in the genus *Juniperus* indispensable for ecological restoration and soil protection in drought regions (Douaihy et al., 2011). *J. excelsa,* which has a large global distribution, is located in Pakistan between 2000 and 3000 m a.s.l. (Sarangzai et al., 2012), between 100 and 3500 m a.s.l. in Iran

Table 4. Summarised results of Multiple Linear Regression Model Analysis

Parameters	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
Precipitation (M1)	0.001	0.000	0.383	2.863	0.006
Precipitation (M2)	0.001	0.000	0.392	3.029	0.004
Precipitation (M3)	0.001	0.000	0.388	3.006	0.004

(Pirani et al., 2011), and between 500 and 2300 m a.s.l. in Turkey (Carus, 2004). The location of the research site was between 900 and 1200 m a.s.l., while optimal growth was seen between 1000 and 1100 m a.s.l.. When compared to other countries, the *Juniperus* spp. are located at low elevations.

Even though *Juniperus* spp. were not established in the high forest research sites, there are 1.2 million ha of degraded and 78.583 ha of healthy high forest in Turkey (Carus, 2004). Although human impacts, such as habitat destruction, deforestation, fragmentation, and overexploitation, have a significant effect on forest structure and composition (Hauck & Lkhanvadorj, 2013), the climate has also had impacts on these ecosystems that render them more fragile and make natural regeneration difficult (Kahveci, 2017). The Genus *Juniperus* is overused and degraded in many regions of the world, due in part to the fact that they grow in arid regions and are the only trees that can grow in some of these areas (Negussie, 1997; Pirani et al., 2011; Sarangzai et al., 2012). However, juniper use as fodder has not been widely reported. We observed that stems of junipers were cut down in clear cuttings. These trees could regenerate, however stem quality was low and nearly all stems had decayed wood. We observed a limited number of juniper seeds, but conditions such as a clear canopy and low humus content are needed for juniper seed germination (Negussie, 1997). Douaihy et al. (2011) suggested that low germination rates and the impacts of land exploitation have resulted in limited regeneration of juniper.

High summer temperatures and low precipitation during the growing season are correlated with the occurrence of narrow tree rings (Dulamsuren et al., 2011), and extremely dry conditions may result in missing and locally absent rings and false or double rings (Couralet et al., 2005; Sass-Klaassen et al., 2008), which is problematic for dendrochronological studies (Esper et al., 2003). According to the results of this study, missing and locally absent rings and false or double rings did not occur much until the tree was around 90 years old. However, older wood cores taken in the research site were not cross-dated because of such wood anomalies, which made cross-dating extremely difficult. In order to make cross-dating older samples viable, it is necessary to have a wood disk from some of the juniper trees (Sass-Klaassen et al., 2008). We were not able take wood disks because junipers are under legal protection.

Growth responses to climatic parameters can vary depending on the climatic zone (boreal, temperate, or continental), growing season, type of ecosystem (steppe, tundra, or rainforest), tree species, etc. (Dulamsuren et al., 2011; Köse et al., 2012; Liang et al., 2012; Bhuyan et al., 2017; Nechita & Chiriloaei, 2018). Previous studies in drought regions have shown that precipitation is the most important limiting factor for tree-ring growth (Touchan & Hughes, 1999; Köse et al., 2012; Fonti et al., 2016).

Positive correlations were found between mean annual precipitation and mean annual relative humidity and regional chronology, but with low correlation values. The reason for these low correlation rates could be the use of annual average values. Liang et al. (2012) developed a ring-width chronology of *Juniperus pingii* var. *wilsonii* in the Tibetan Plateau and climate and growth relationships using a correlation analysis and bootstrapping correlations. The results of this study revealed that mean monthly precipitation and relative humidity were positively correlated with tree-ring width in the growing season, and mean monthly temperature was negatively correlated with tree-ring width; moisture was the main factor limiting Wilson juniper growth. Ren et al. (2018) worked on xylogenic activity of *Juniperus przewalskii* Kom. in the Tibetan Plateau. They indicated that temperature and moisture thresholds for the onset of xylogenesis should be in balance, otherwise forest vulnerability can increase in semi-arid areas. Bayramzadeh et al. (2018) found that *Juniperus polycarpos* K. Koch in low elevations responded strongly to drought/precipitation variability. However, it responded mainly to temperature at higher elevations.

Response function analysis result of regional chronology indicated that the highest significant correlations were between the chronology and the December and May to June precipitation (Fig. 5). The research site receives more precipitation in winter and spring then in summer and autumn. It appears that higher winter precipitation and precipitation in May–June have a positive influence on radial growth. Opala et al. (2016) found the highest positive correlation between the residual chronology of *Juniperus semiglobosa* Regel and December to February precipitation during their investigation in Pamir-Alay. They indicated that moisture via snowmelt in the non-growing season influenced the ring-width formation of juniper trees. The highest negative correlation was found between residual chronologies and May to June temperature. Touchan et al. (2007) showed that May-June precipitation in southwestern Anatolia had a significant influence on the growth of *J. excels*a.

Our hypothesis was that there may be differences in radial growth of juniper between areas of different exposure in drought regions. The results of response function analysis supported the hypothesis. Even though chronologies from different exposures showed some similarities, there were differences between them: chronologies from north-facing slopes differed from the others most prominently. The effects of drought on the radial growth of juniper trees that live on the northern slopes, which represent insignificant response function coefficients, were not strong as the trees that live on the western and southern slopes. For the trees on the eastern slopes, only winter precipitation has significant effect. The growth responses of trees to climate variables on north-facing and east-facing slopes, which receive less sunlight, fell into the same group. On the other hand, the effect of the climate was similar for the trees that live on the southern and western slopes. The effect of the drought was stronger for these trees, which need more precipitation on western slopes, and suffer temperature increase in June on southern slopes. The effect of water stress normally increases on southern slopes because they receive sunlight for a longer period than other slopes, and are, therefore, more affected by drought in semi-arid regions (Kahveci, 2017). In this context, we could say that the westerly exposures also receive a longer period of sunlight.

Conclusion

In conclusion, *Juniperus* spp. are some of the most important tree species in Central Anatolia and are very important for forest ecosystem and dendrochronological investigations. *Juniperus* spp. have high regeneration potential, are very resistant to drought and human impacts and, as long-lived dry temperate species, may offer an excellent opportunities for large-scale dendrochronological and dendroecological studies. Missing and locally absent rings and false or double rings and other wood anomalies make cross-dating difficult. However, this problem can be overcome by increasing the number of dendrochronological studies. In addition, finding a sufficient number of stem disks could substantially help with cross-dating.

Central Anatolia is a drought region and the main period of precipitation is in winter. Drought is the primary limiting factor for vegetation. The results presented in this paper indicate that the main climate influence on growth is precipitation; in particular, rain falling in winter and during May and June strongly influence the radial growth of *Juniperus* spp. in Central Anatolia. All the analyses used support our hypothesis that juniper exhibit differences in radial growth in areas of different exposure.

For future research on *Juniperus* spp. in Central Anatolia, or in other drought regions concerned with dendrochronology, dendroecology, climate reconstruction, and similar studies, suitable stem disks are required. For the dendroecological investigations, measuring soil moisture can help demonstrate the influence of humidity.

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