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Original Article

Hydrological evaluations and effects of climate on the radial growth of oriental beech (*Fagus orientalis* lipsky) in Abdipaşa, Bartın, Turkey

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ABSTRACT

Based on a 41-year-long (1978-2018) ring-width chronology (RWI), we have determined the main climate variables affecting the radial growth of Oriental beech trees (*Fagus orientalis* Lipsky) and the correlation coefficients between RWI and the streamflow drought index (SDI) of the Kocaırmak River in northwestern Turkey. Higher average maximum temperatures (T_{max}) in June caused decreased radial growth (r = -.34, p < .05), whereas higher total precipitation (P_{rep}) in the same month caused increased radial growth (r = .29, p < .05). Moreover, the mean and minimum temperatures (T_{mean} and T_{min}) in December of the previous year caused increased radial growth (r = .27 and .32, respectively, p < .05). Compared to Period 1 (1978-1996), there was a significant relationship between RWI and climate variables (P_{rep} and T_{max} in June and T_{mean} and T_{min} in December) for Period 2 (1997–2015). Moreover, significant correlations were obtained for February (r = .41, p < .05), June (r = .51, p < .01), and August (r = .44, p < .05) between RWI and SDI_1 (1-month SDI), which indicates that radial growth was reduced in the years with negative SDI_1 values in February, June, and August. Similarly, significant correlations between RWI and SDI_3 (3-month SDI) for July–September (r = .51, p < .05) and June– August (r = .57, p < .01) indicated the reduced radial growth in the years with negative SDI_3 values.

Keywords: Anatolia, dendroecology, streamflow drought index, tree ring

Introduction

IPCC (2014) assessments and special reports have provided overwhelming evidence that global warming and climate change are scientific realities (Hoegh-Guldberg et al., 2018). Many researchers have also declared that the world is in a climate crisis (Archer & Rahmstorf, 2009; Ripple et al., 2020). Dendroclimatology studies have helped researchers to better understand Earth's historical climate, and the climate–growth relationships of forest tree species under climate change conditions (Anchukaitis, 2017; Cook et al., 2015; Jacoby & D'Arrigo, 1997; Khaleghi, 2018; Williams et al., 2010), but relatively few of these studies have focused on the Oriental beech trees in Turkey (Akkemik & Demir, 2003; Köse & Güner, 2012; Martin-Benito et al., 2018; Yaman et al., 2020).

Oriental beech is one of the most important tree species in Turkey that has been studied in terms of its silviculture (Özel et al., 2010; Yılmaz, 2010), ecology, forest yield (Kalıpsız, 1962; Carus, 1998; Kahriman et al., 2016), dendroclimatology (Akkemik & Demir, 2003; Köse & Güner, 2012; Yaman et al., 2020), and wood anatomy (Şanlı, 1978). Most Oriental beech forests are found in the northern region of Turkey, although a relict population exists in the Hatay province in the eastern Mediterranean region, which is the southernmost distribution of the species (Kandemir et al., 2009; Yılmaz, 2018). The optimal altitudinal range of this species is between 700 m and 1300 m a.s.l., but its altitudinal distribution can range from 30 m to 2100 m a.s.l. (Kandemir & Kaya, 2009; Yılmaz, 2018). Oriental beech trees can be found as pure or mixed stands. Other species found in mixed stands with Oriental beech trees include *Pinus sylvestris* L., *Picea orientalis* (L.) Peterm., *Abies nordmanniana* (Steven) Spach, *Pinus nigra* J.F.Arnold, *Castanea sativa* Mill., *Carpinus betulus* L., *Carpinus orientalis* Mill., and *Quercus* L.

Forest ecosystems help to protect and regulate freshwater resources, drinking water, and utility water through their hydrological functions (Carvalho-Santos et al., 2014; Yannian, 1990), but these

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functions are also impacted by climate change (Gribovszki et al., 2019). Akkemik et al. (2008) and Güner et al. (2017) used tree-ring width data to study streamflow changes during a 200 year period. By investigating the relationship between tree-ring width and climatic conditions, researchers can better understand how climate change has affected river and streamflow over time, also known as dendrohydrology. Such information can provide a theoretical basis for future waterflow predictions. In this study, a sensitive tree-ring chronology was created, in order to determine the effects of changing climate parameters on tree-ring width, and to find the correlation coefficients between tree-ring chronology, and monthly streamflow values from the Kocaırmak River, which is found in the same basin as the beech trees sampled in this study.

Method

Study Field

The study field (exposition: south-west, slope: 10%–15%, altitude: 920 m. a.s.l.) is located in compartment no. 118, in the town of Abdipaşa, Turkey, which is located in the Forestry Directorate of Ulus, Bartın (Figure 1). The selected stand is a pure, monolayer, even-aged, mature beech forest, with a canopy closure of .4–.7. The stand's Oriental beech trees were in good health at the time of the study, except for some low density galls by *Mikiola fagi* Hart. found on the upper leaf surfaces of some of the trees. *Rhododendron ponticum* L. was the main understory species in the stand's low canopy. Oriental beech stands have yellow-red podzolic soils and brown forest soils, which developed on the Upper Cretaceous flysch facies in this region (Turoğlu, 2014).

Tree-Ring Data

Increment core samples were taken in 2019 from 11 living Oriental beech trees found in the study area. These samples were taken in order to date illegal logging practices in the area (Figure 1). Standard techniques were used to prepare the core samples collected with an Haglöf Sweden increment borer that had a

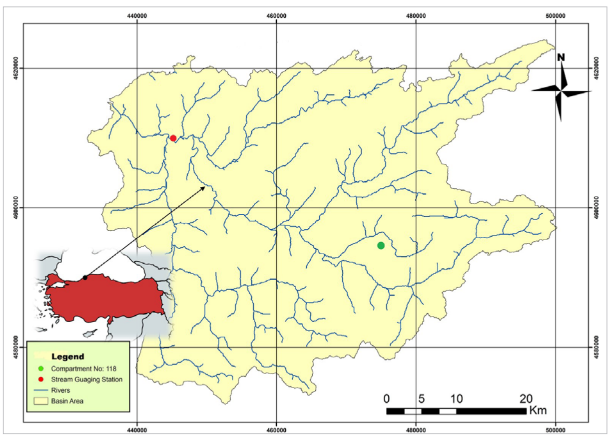

Figure 1
River Network in Bartın Province. Green Dot Remarks the Stand of Which Increment Cores Were Taken from Beech Trees. Red Dot Shows the Stream Gauging Station

length of 300 mm, and a core diameter of 5.15 mm (Orvis & Grissino-Mayer, 2002). The cores were cross-dated using standard dendrochronological techniques (Swetnam, 1985; Stokes & Smiley, 1996). Core cross-sections were scanned at a high resolution, and tree-ring width (RW) measurements were performed using Image J software (Fiji) that had an accuracy of .01 mm (Schindelin et al., 2012). COFECHA software (Holmes, 1983; Grissino-Mayer, 2001) was used to verify our cross-dating. The collected RW data was standardized using negative exponential curves (ModNegExp). The mean-index chronology (RWI) was computed using the package dplR from the R statistical computing environment (Bunn, 2008; Bunn et al., 2020; R Development Core Team, 2019). The following chronology statistics were also computed using dplR: mean correlation between trees (r_{bt}), effective mean correlation (r_{eff}), expressed population signal (EPS), signal to noise ratio (SNR), and first-order autocorrelation (ar_1) (Cook & Kairiukstis, 1990).

Growth–Climate Relationship Analysis

Climate data for the period from 1978 to 2015 was collected from the closest meteorological station to the study site (Bartın Meteorological Station, no. 17020). An ombrothermic diagram, also known as a Walter climate diagram of Bartın, is shown in Figure 2. Monthly precipitation amounts were used to investigate the climate-radial growth relationship, as well as the monthly mean, maximum, and minimum temperatures. Bootstrap response values were computed using DENDROCLIM software (Biondi & Waikul, 2004) for the duration of the biological year, which was defined as being from October of the previous year to September of the current year. After determining statistically significant response values, both RWI and climate variables were split into two equal series (Period 1: 1978–96, Period 2: 1997–2015), in order to determine which period had the most significant impact on the radial growth of the sampled trees. Next, the relationship between RWI and climate variables were determined using a Pearson's correlation test in the R Stats Package. For this analysis, we first controlled the distribution of all the climate variables using the Shapiro–Wilk normality test (Ghasemi & Zahediasl, 2012), then we transformed some of the data to the normal distribution in R using a transformation method called the square-root for moderate skew (Kassambara, 2019). Finally, Buishand's range test in R was used to calculate change point detection (Buishand, 1982; Jaiswal et al., 2015).

Streamflow data

This study also tested whether the mean ring-width index chronology built for Oriental beech trees could be used to reconstruct the historical streamflow of the Kocaırmak River. To do this, we calculated the streamflow drought index (SDI) using DrinC software (Nalbantis, 2008; Nalbantis & Tsakiris, 2009; Tigkas et al., 2015). For this calculation, the average monthly streamflow values (in m^3 sn^{-1}) of the Kocaırmak River was taken from the General Directorate of Electrical Power Resources Survey and Development Administration (hydrometric station number 1331 (32° 21′ 21″ E - 41° 38′ 32″ N, 15 m a.s.l.) (EIE, 1978-2003). The mean, maximum, and minimum monthly temperatures, and the monthly precipitation amounts were taken from the Bartın Meteorological Station for the Period (1978–2003). The average monthly streamflow values were presented as million m³ in Figure 3.

Results

Chronology

A mean-index chronology (site code: TRABFAOR) was built by averaging the RWI data using Tukey's biweight robust mean. Common summary statistics, such as mean, median, and first-order autocorrelation (ar_1) were also computed. The first ar_1 quartile was found to be .32, the third ar_1 quartile was found to be .58, and the median of ar_1 was found to be .44, while the mean was found to be .42. All statistics computed during the building of the RWI using dplR are shown in Table 1. The EPS was found to be .889, which is above the .85 threshold, and reflects how well our RWI represents a theoretically infinite Oriental beech population in our study area. SNR was found to be 8.021, and is defined as the ratio of signal power to noise power. The RWI spans from 1978 to 2018 (Figure 4). The correlations between each tree-ring series and RWI are shown in Figure 5. All correlation coefficients are statistically significant ($p < .05$), with an average of .60.

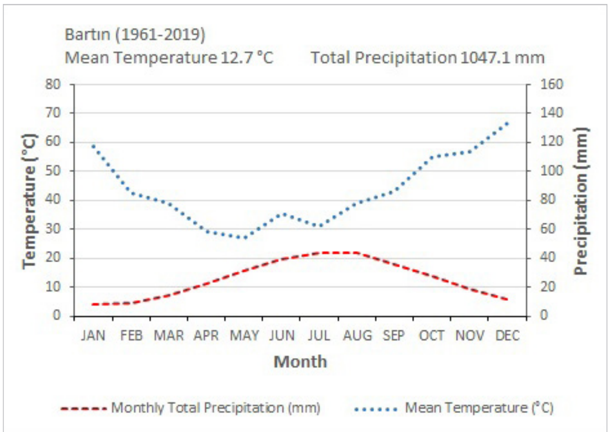

Figure 2
The Blue Dotted Line Shows Average Monthly Precipitation Amounts. The Red-Dashed Line Shows the Average Monthly Temperatures

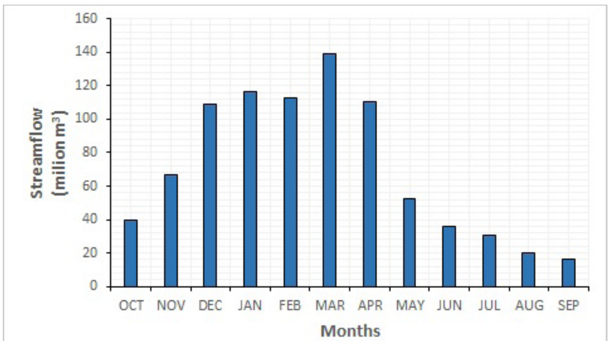

Figure 3
Mean Monthly Streamflow Values (Million m³) for the Kocaırmak River

Climate–Growth Relationships

The Walter climate diagram indicates that the Bartın climate does not have a dry period (Figure 2). October to January can be considered a wet period, with average monthly precipitation amounts of over 100 mm. In the remaining months, the precipitation line is over the temperature line, despite the precipitation in these months remaining below 100 mm. These results indicate that Bartın's climate is humid, with a total precipitation of 1047 mm year⁻¹. The bootstrap response values indicate that the statistically significant limiting factor on tree-ring width was only the maximum temperature in June. The monthly maximum temperature in June has a negative effect on RWI (Figure 6), although the monthly total precipitation effect was positive (Figure 7 and 8). The mean and minimum temperatures also had a positive effect on RWI in December of the previous year (Figure 8).

A comparison of correlation coefficients for Period 1 (1978–1996) and Period 2 (1997–2015) found that only the correlation coefficient for Period 2 were significant in regards to the climate variables and radial growth (Table 2). This result implies that changes in climate variables triggered changes in the growth responses of the sampled beech trees. Results of the Buishand range test for the entire study Period (1978–2015) indicated that

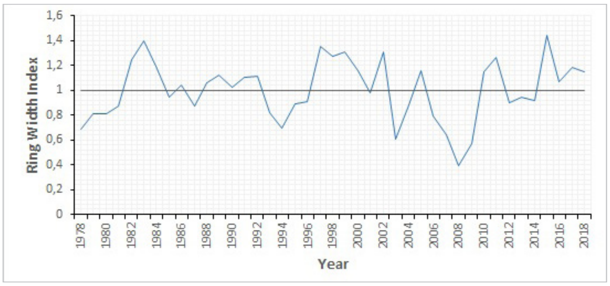

Figure 4
Mean Ring-Width Index Chronology of Oriental Beech in Abdipaşa, Bartın

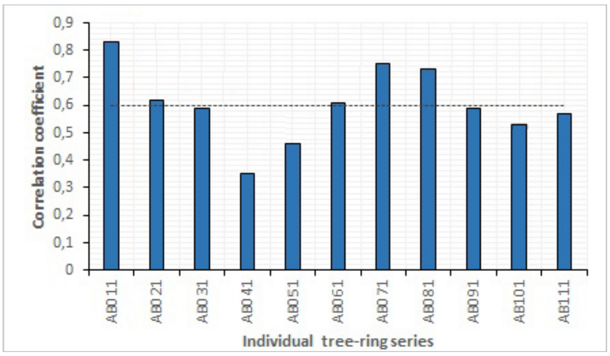

Figure 5
Correlations between Individual Tree-Ring Series and Mean Ring-Width Index Chronology (RWI), Coded as TRABFAOR. Dashed Line Shows Mean Correlation. All Correlation Coefficients are Statistically Significant (p < .01), Except for AB041 (p < .05)

there was only one probable change point (2005) for the maximum temperature of June (Table 3).

Streamflow-Growth Relationship as a Proxy

The Kocaırmak River, which is located in the Western Black Sea Region of Turkey, has an irregular flow throughout the year. In a water year, streamflow increases from October to March, then begins to recede after March (Figure 3). The highest streamflow occurred in March on average, while the lowest streamflow occured in September on average. There were significant correlations for June ($r = .51$, $p < .01$), August ($r = .44$, $p < .05$) and February ($r = .41$, $p < .05$) between RWI and SDI_1, as seen in Figure 9. In addition, significant correlations were found between RWI and SDI_3 for April–June ($r = .40$, $p < .05$), July–September ($r = .51$, $p < .01$) and June–August ($r = .57$, $p < .01$). The highest correlation occured in the June–August period (summer). Figures 10, 11, and 12 show the month or period that the correlation coefficients between RWI and SDI were over .50.

Discussion

In this study, we built a 41-year Oriental beech chronology for a beech tree stand in Abdipaşa, Bartın, Turkey. Despite its short time span (1978–2018), the results of this study provide valuable and comparable information for the correlation of climate variables and radial growth in the study area. Moreover, this chronology provides the theoretical basis upon which the hy-

Table 1
Statistics of Mean-Index Chronology (RWI)

n_t	n_c	c_{eff}	r_{bt}	r_{eff}	eps	snr
11	11	1	.43	.43	.889	8.021

Note. Total number of trees (n_t), total number of cores (n_c), the effective number of cores per tree (c_{eff}), the mean correlation between trees (r_{bt}), the effective mean correlation (r_{eff}), the expressed population signal (EPS), and the signal to noise ratio (SNR).

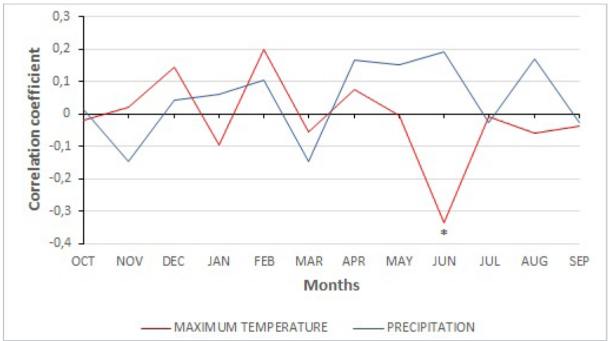

Figure 6
Correlation Coefficients between the Monthly Maximum Temperature-Precipitation Interactions and the Mean Ring-Width Index Chronology

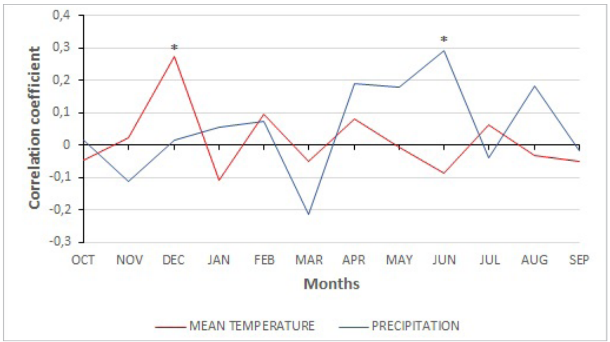

Figure 7
Correlation Coefficients between Monthly Mean Temperature-Precipitation Interactions and Mean Ring-Width Index Chronology

Table 2
Correlation Coefficients between RWI and Climate Variables for Two Different Periods

Correlation coefficients between RWI and climate variables		1978–1996	1997–2015
June	Precipitation	$.27^{ns}$	.61**
	Maximum temperature	$.13^{ns}$	-.70***
December	Mean temperature	$.31^{ns}$	.49*
	Minimum temperature	$.31^{ns}$	.58**

Note. RWI: Ring-Width Index, *$p < .05$, **$p < .01$, ***$p < .001$, ns: non-significant

Table 3
Buishand Range Test for Change Point Detection

Buishand range test		$\frac{R}{\sqrt{n}}$	p	Changepoint year
June	Precipitation	1.22	$.28^{ns}$	-
	Maximum temperature	1.73	.01*	2005
December	Mean temperature	1.11	$.42^{ns}$	-
	Minimum temperature	0.77	$.91^{ns}$	-

Note. *$p < .05$, ns: non-significant

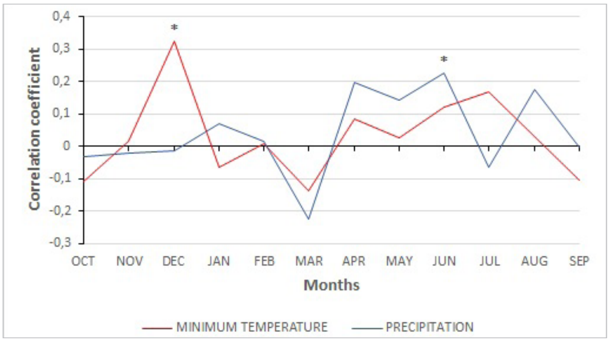

Figure 8
Correlation Coefficients between Monthly Minimum Temperature-Precipitation Interactions and Mean Ring-Width Index Chronology

drology of the Kocaırmak River could also be studied in regards to climate variability or change.

Higher monthly maximum temperatures in June were found to have caused a decrease in the radial growth of our sampled trees, whereas higher precipitation amounts in the same month increased radial growth. This suggest that radial growth is negatively or positively impacted by drought or humidity in June, respectively. Moreover, the mean and minimum temperatures in December of the previous year caused an increase in radial growth, which indicates that the growing season started earlier due to high temperatures. Akkemik and Demir (2003), Köse and Güner (2012), Haghshenas et al. (2016), Martin-Benito et al. (2018), and Yaman et al. (2020) investigated the growth–climate relationships of Oriental beech trees from various sites across its natural distribution. Yaman et al. (2020) found that the radial growth of Oriental beech along the southern limit of this species in the eastern Mediterranean region of Turkey was negatively affected by the average maximum temperatures in June and July, whereas June's total precipitation had a positive effect. This study also found that the total precipitation in February and March delayed the start of the growing season. Martin-Benitto et al. (2018) found that June and July temperatures had a positive effect on the radial growth of the species at high-elevation sites in the Western Caucasus, which disagrees with the results of the present study and the results reported by Yaman et al. (2020). A study by Haghshenas et al. (2016) found that December temperatures also had a positive effect on the radial growth of Oriental beech trees in the Caspian forests of Northern Iran, which agrees with the results of the present study. In the Belgrade Forest of the Marmara Region of Turkey, February precipitation was the only climate variable that had a significant effect on the growth of Oriental beech trees (Akkemik & Demir, 2003). However, Köse and Güner (2012) reported that high precipitation in June increased the earlywood, latewood, and total RW of Oriental beech trees in Artvin, which is near to the Caucasus. The results discussed here indicate that Oriental beech trees respond in different ways to different climate conditions across its natural distribution range. Under similar climatic conditions, trees have similar tree-ring patterns, regardless of species (Fritts, 1976).

We also investigated the changes that the sampled trees underwent in response to significant climate variables in June and December. Our results showed that there were significant dif-

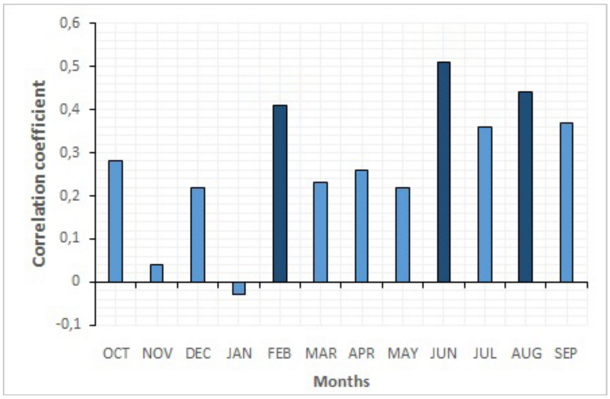

Figure 9
Correlations between Mean Ring-Width Index Chronology (RWI) and 1-Month Streamflow Drought Index (SDI_1). Correlation Coefficients for Dark Blue Columns are Statistically Significant ($p < .05$)

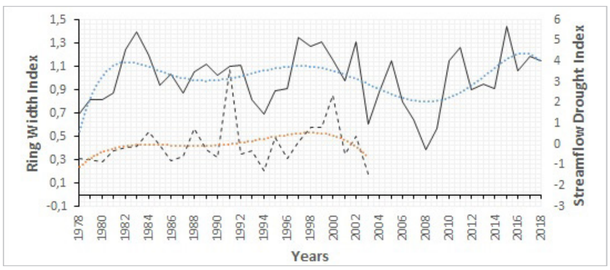

Figure 10
Mean Ring-Width Index Chronology (RWI) (Solid Line) and June's Streamflow Drought Index (SDI_1) (Dashed Line). Dotted Lines Show the Polynomial Trendline of Each Graphic. Correlation Coefficient between RWI and SDI_1 is .51 ($p < .05$)

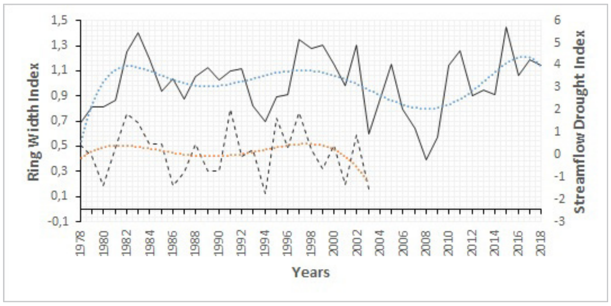

Figure 11
Mean Ring-Width Index Chronology (RWI) (Solid Line) and 3-Month Streamflow Drought Index (SDI_3) for July–September (Dashed Line). Dotted Lines Show the Polynomial Trendline of Each Graphic. Correlation Coefficient between RWI and SDI_3 is .51 ($p < .05$)

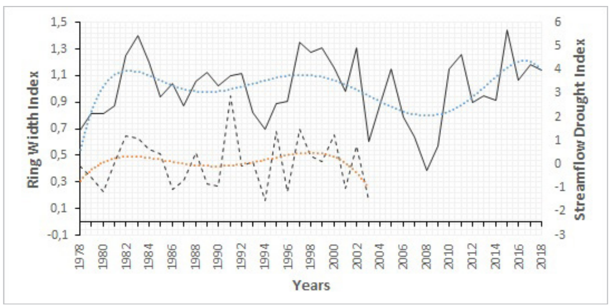

Figure 12
Mean Ring-Width Index Chronology (RWI) (Solid Line) and 3-Month Streamflow Drought Index (SDI_3) for June–August (dashed line). Dotted Lines Show the Polynomial Trendline of Each Graphic. Correlation Coefficient between RWI and SDI_3 is .57 ($p < .01$)

ferences in the sampled trees' responses to climate variables in Period 2 (1997–2015). In this period, the mean and minimum December temperatures, the maximum June temperatures and precipitation amounts significantly affected tree-ring width. These results demonstrated that climate sensitivity changed in Period 2 compared with Period 1, with the trees becoming more sensitive to June droughts, which have been characterized by high maximum temperatures and low precipitation since 1997. The positive effect of stronger mean and minimum temperatures in December was also higher and statistically significant on the radial growth of Oriental beech. Babst et al. (2019) investigated how tree growth responds to climate variability worldwide and found that drought is becoming the dominant limitation of tree growth. This limitation is expected to continue with continued climate change.

Although climate reconstructions based on tree-ring data have been relatively adequate in Turkey (Akkemik & Aras, 2005; Akkemik et al., 2005 and 2008; D'Arrigo et al., 2001; Köse et al., 2011, 2013, and 2017; Touchan et al., 2003, 2005, and 2007), streamflow reconstructions have been less adequate (Akkemik et al., 2008; Güner et al., 2017). The study done by Akkemik et al. (2008) was the first one to be related to streamflow reconstruction in Turkey. The study determined major drought and flood events for northwestern Turkey since AD 1650. Güner et al. (2017) determined the severe and sustained low streamflow events during 1819–1834, 1840–1852, 1861–1875, and 1925–1931 for the Kocasu River basin using a reconstruction of the June–July streamflow using a network of 18 tree-ring chronologies.

Conclusion and Recommendation

A lack of both sufficiently long streamflow data and mean ring-width index chronology was a limiting factor in this study. Even so, we studied the dendrohydrology of the Kocaırmak River by calculating the correlations between RWI for a local stand of Oriental beech trees and the river's SDI. Significant positive correlations were found between RWI and SDI_1 for February ($p < .05$), June ($p < .01$), and August ($p < .05$). This result indicates that radial growth was reduced in years with negative SDI1 values in February, June, and August. Similarly, the significant correlations between RWI and SDI3 for July–September ($p < .05$), and June–August ($p < .01$) indicate reduced radial growth of the species in years with negative SDI_3 values in these months. With sufficiently long Oriental beech chronology and streamflow data, the SDI_3 values could be reconstructed for the years having no streamflow data for the Kocaırmak River basin.

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