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Research Article

The effect of temperature and precipitation on the intra-annual radial growth of *Fagus orientalis* Lipsky in Artvin, Turkey

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Abstract: In this paper, we present the longest tree-ring chronology of oriental beech from Artvin, identify the most important climate factors affecting radial growth, and compare our results with the oriental beech chronology from Belgrad Forest. Stem disks were taken from 10 living oriental beech trees, and earlywood and latewood bands were measured separately in addition to ring width. The longest (442-year-long) chronology of earlywood, latewood, and total ring width for oriental beech were built from Artvin, Turkey. All chronologies (earlywood, latewood, and total ring width) were found to be highly sensitive to climate with mean sensitivity values of 0.3034, 0.286, and 0.294, respectively. Pearson correlation coefficients were used to identify relationships between tree radial growth and climate. The results showed that the most distinctive effect of temperature on tree-ring growth occurred with maximum temperature. High mean and minimum temperatures in the period of March to July (especially in May) resulted in growth early in the growing season and wide earlywood, latewood, and total ring formation. Different from Belgrad Forest chronology, precipitation was a limiting factor on tree growth, but only in June. High temperatures had a positive effect during the period of March to July and did not cause a drought problem.

Key words: Climate-growth relationship, earlywood, latewood, oriental beech, tree-ring

Introduction

The genus *Fagus* L. is distributed in temperate areas of the northern hemisphere, East Asia, Europe and West Asia, and North America (Fang and Lechowicz 2006). Of all of the *Fagus* species, *Fagus orientalis* Lipsky. (Oriental beech), which is more common, and *Fagus sylvatica* L. (European beech) naturally grow in Turkey. Oriental beech is also distributed in Bulgaria, Caucasia, and Iran. In Turkey, it grows widely across the Black Sea region, from Demirkoy to Hopa, and locally in the Marmara region, Amanos Mountains, Adana-Pos forests, and Maraş-Andrın (Yaltırık and Efe 2000). The main elevational distribution of this species is quite wide, from sea level to 2100 m (Şanlı 1978). Beech trees constitute 1,751,484 ha of pure and mixed forest area, which means that it is the fourth most abundant tree genera after oak (*Quercus* L.), Turkish pine (*Pinus brutia* Ten.), and black pine (*Pinus nigra* Arn.) in Turkey (OGM 2011).

In Turkey, many studies have focused on climate-tree growth relationships (Akkemik 2000a, 2000b, 2003; Akkemik and Aras 2005; Köse et al. 2011). These researchers generally focused on the Gymnospermae species and their results showed that the most important limiting factor of radial growth was in the late spring to early summer, especially

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May-June precipitation. The most common species, which have been used in dendroclimatological and dendroecological studies in Turkey, are black pine, Taurus cedar, and Juniper sp. Touchan et al. (2007) used juniper trees to extend the reconstruction of May-June precipitation. Köse (2007) identified the climate factors affecting the radial growth of black pine in western Anatolia and classified its responses to climate.

Conversely, studies focused on climate-tree growth relationships in the Angiospermae species are rare. Akkemik and Dağdeviren (2000) discovered the effect of monthly mean temperature and total precipitation on *Quercus petraea* (Matt.) Liebl. in Belgrad Forest. Later tree-ring analysis was done on *Fagus orientalis* Lipsky. in Belgrad Forest (Akkemik and Demir 2003). In the present study, an 80-year-long (1921-2000) chronology was built using 11 oriental beach trees. To better understand the relationship between the radial growth of oriental beach and climate, we need more chronologies from different habitats. In this paper, we (1) present the longest tree-ring chronology of oriental beech from Artvin (2), identify the most important climate factors affecting radial growth (3), and compare our results with the oriental beech chronology from Belgrad Forest.

Materials and methods

Study area

The study area was located in Kayabaşı Yaylası, Balcı, Borçka, Arvin (41.30°N, 41.90°E) (Figure 1). Here, the average slope was 80%, the aspect was north, and the altitude ranged from 1830 to 2120 m. The dominant forest tree species in the area were *Picea orientalis* (L.) Link, *Abies nordmanniana* (Steven) Spach., and *Fagus orientalis* Lipsky. The total annual precipitation and mean temperature (1949-2004) from the Artvin meteorological station, which was the closest to the study area, was 689 mm and 12.2 °C, respectively. The study area was higher in elevation than the Artvin meteorological station (628 m). Therefore, higher precipitation and lower temperature were expected in the study area. The lowest precipitation during the year occurred in July (30 mm) and August (28 mm). In addition to low precipitation, the highest mean temperature values occurred in the same months, 20.6 and 20.7 °C, respectively (Figure 2).

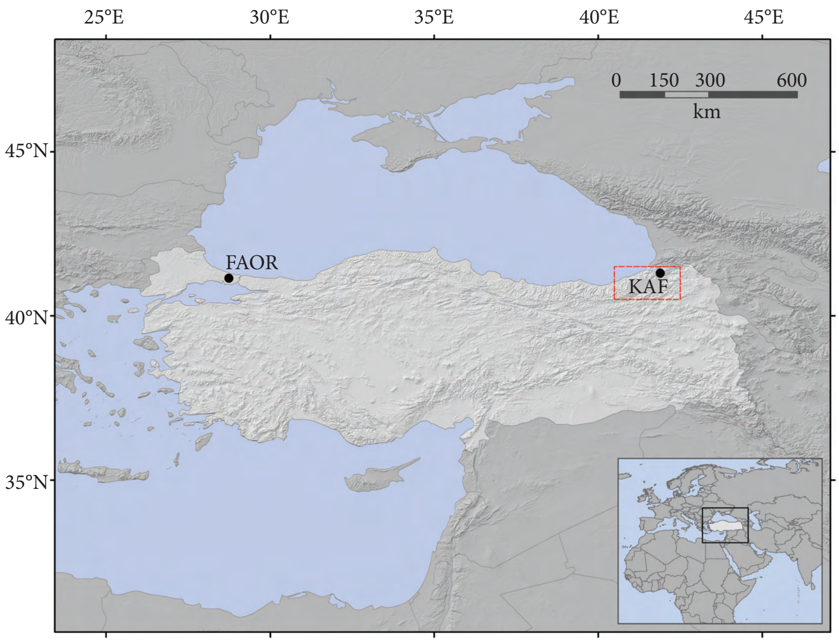

Figure 1. Site information. The box represents the area for gridded climate data which was used to identify climate tree-growth relationships. “FAOR” represents the oriental beech chronology built by Akkemik and Demir (2003).

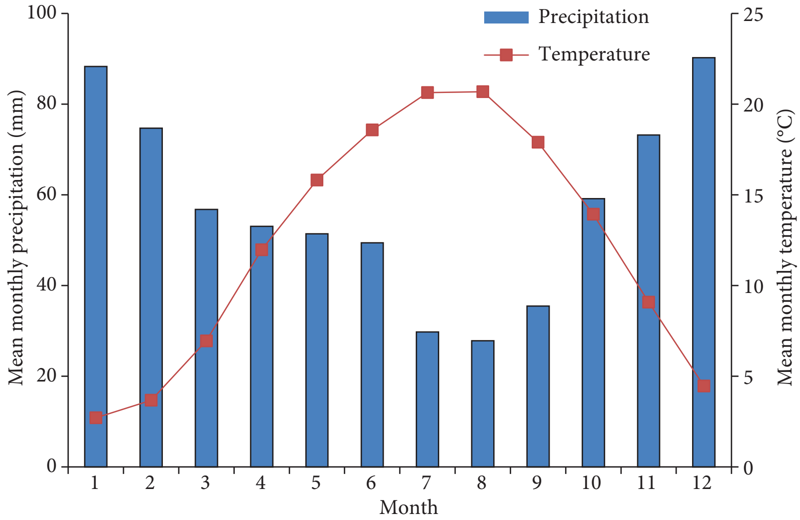

Figure 2. Mean monthly precipitation and mean monthly temperature values (1948-2004) from the Artvin meteorological station.

Chronology development

Stem disks were taken from 10 living oriental beech trees using a chainsaw during logging operations. Then 2 thin cross-sections were obtained from each sample using a band saw. To make the wood surface clear, which is essential when working with this species, cross-sections were sanded with belt sanders using progressively finer grit paper (Orvis and Grissino-Mayer 2002). Samples were cross-dated following standard dendrochronological techniques (Swetnam 1985; Stokes and Smiley 1996).

The earlywood and latewood bands were measured separately in addition to ring width on the cross-sections, with the precision to the nearest 0.01 mm using the LINTAB-TSAP Measuring System (RinnTech, Germany). The computer program COFECHA was used for testing the cross-dating quality of the ring-width measurements (Holmes 1983; Grissino-Mayer 2001). The program ARSTAN (Cook 1985; Grissino-Mayer et al. 1996) was used to standardize each measurement series by fitting a 67% cubic smoothing spline with a 50% cutoff frequency. This process removes the non-climatic trends, such as the age-size related trends, and the effects of stand dynamics (Fritts 1976; Cook et al. 1990a). Autoregressive models were applied to remove persistence from each ring-width series. To obtain the mean chronologies, the annual indices of each series were averaged (Cook 1985, Cook et al. 1990b). Tree-ring chronologies were developed for earlywood, latewood, and total ring width separately. Residual chronologies were used, which remove autocorrelation and keep a robust climate signal, to explore climate-radial growth relationships.

Growth-climate relationship analysis

We acquired gridded climate data to identify the climate-tree growth relationship, because the length of the Arvin meteorological station data was short. The monthly mean, maximum, and minimum temperature and monthly total precipitation records of the CRU TS 3 gridded dataset, at a resolution of 0.5°, were downloaded from the KNMI Climate Explorer (http://climexp.knmi.nl) for 40.5-41.5°N, 40.5-42.5°E.

Pearson correlation coefficients were used to assess relationships between tree radial growth and climate (e.g. Miina 2000; Buckley et al. 2007) using the program DENDROCLIM 2002 (Biondi and Waikul 2004). Correlation coefficients were calculated using monthly mean, maximum, and minimum temperature and monthly total precipitation for the duration of the biological year (from October of the previous year to September of the current year) for the period of 1930-2006.

Results

Chronology characteristics

In this study, a 442-year-long (1567-2008) chronology of earlywood, latewood, and total ring width were built for oriental beech (Figure 3). Mean sensitivity values were very high, from 0.286 to 0.3034. Common interval analysis statistics of each chronology showed that ring-width and earlywood chronologies had a higher mean correlation and signal to noise ratio than the latewood chronology. Similarly, the variance explained by the first eigenvectors of these chronologies was higher (Table 1).

The correlation matrix of the chronologies was also calculated to determine similarities between the chronologies. All of the correlation values were very high and statistically significant (Table 2). There was a stronger relationship between the earlywood and total ring width chronologies than for the latewood chronology. This result was attributed to the fact that most of the tree-ring width consisted of earlywood.

Growth-climate relationship

Correlation coefficients between each chronology (earlywood, latewood, and total ring width) and climate variables (monthly mean, maximum and minimum temperature, and monthly total precipitation) are shown in Figures 4-7.

The effect of precipitation on the radial growth was very similar for all of the chronologies. The

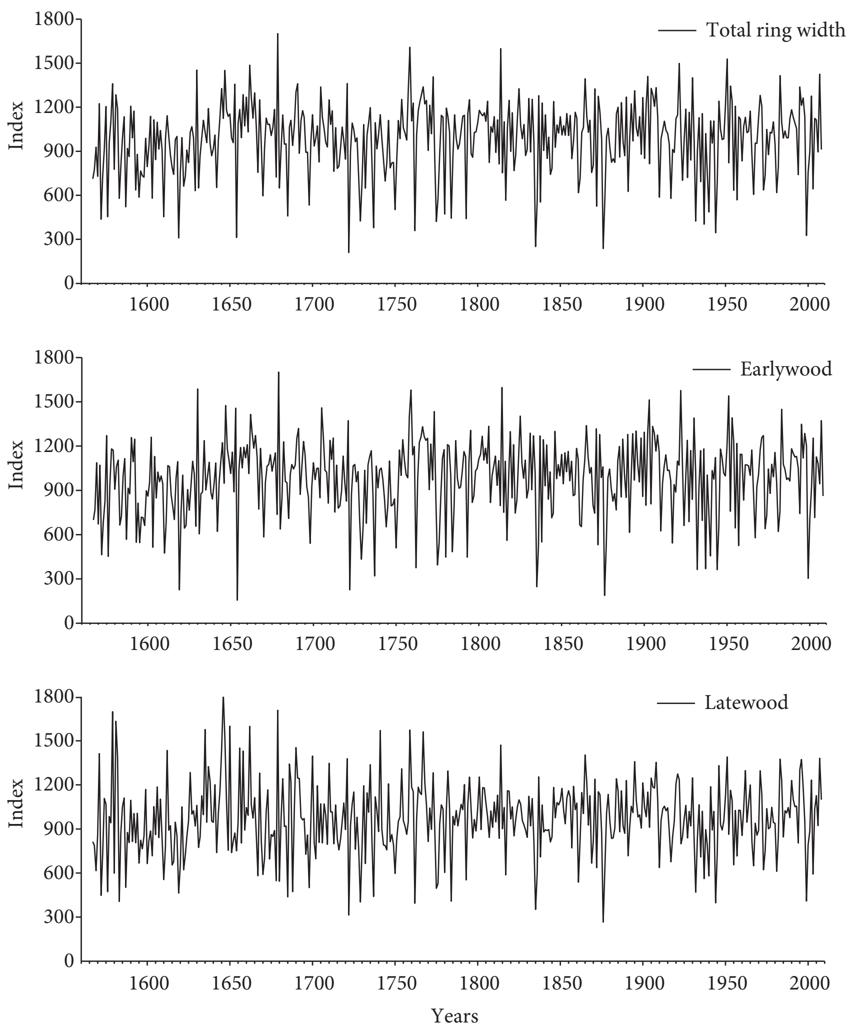

Figure 3. Comparison of the total ring-width, earlywood, and latewood index chronologies for oriental beech.

Table 1. Summary statistics of the chronologies from the ARSTAN program.

	Chronology type	Ring-width	Earlywood	Latewood
Total chronology (1567–2008)	Mean	0.9978	0.9979	0.9690
	Median	1.0294	1.034	0.9620
	Mean sensitivity	0.2941	0.3036	0.2863
	Standard deviation	0.246	0.2550	0.2452
	Skewness	–0.6409	–0.637	0.1126
	Kurtosis	0.7892	0.7547	0.6743
	Autocorrelation order 1	0.0082	0.0131	0.0354
	Partial autocorr. order 2	0.0004	–0.0034	–0.0412
	Partial autocorr. order 3	–0.006	–0.0027	0.0131
Common intervals (1779–2006)	Mean correlations:			
	Among all radii	0.552	0.518	0.269
	Between trees (Y variance)	0.539	0.504	0.260
	Within trees	0.733	0.702	0.400
	Radii versus mean	0.750	0.728	0.540
	Signal-to-noise ratio	9.368	8.143	2.805
	Agreement with population chronology	0.904	0.891	0.737
	Variance in first eigenvector (%)	58.19	54.96	32.45
	Chronology common interval mean	0.996	0.995	0.977
	Chronology common interval standard deviation	0.239	0.252	0.208

Table 2. Pearson correlation coefficients between the chronologies.

	Ring-width	Earlywood	Latewood
Ring-width	1		
Earlywood	0.98***	1	
Latewood	0.84***	0.75***	1

"***" Represents correlation coefficients, which is statistically significant at the level of P ≤ 0.001.

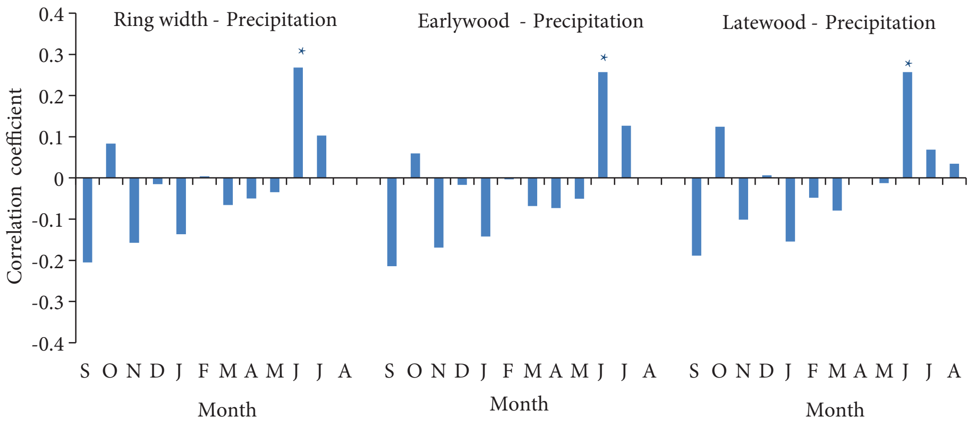

Figure 4. Correlation coefficients of the chronologies (total ring with, earlywood, and latewood) and monthly total precipitation. Asterisks represent significant correlation coefficient (95% level) with the related month.

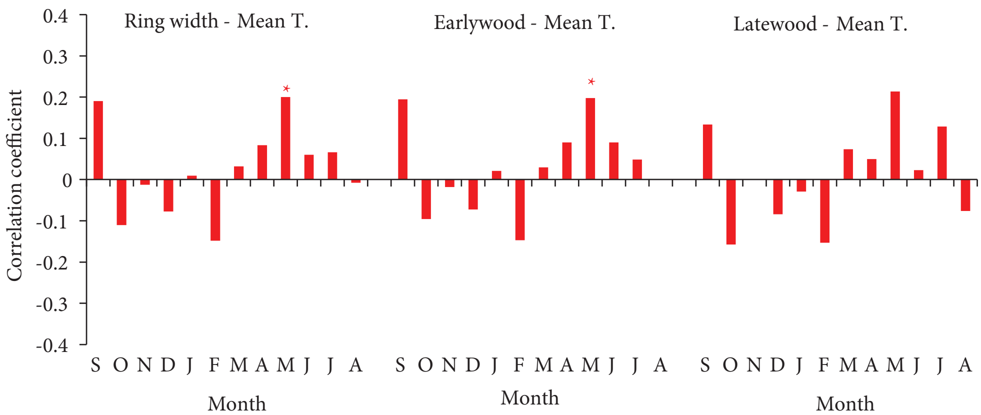

Figure 5. Correlation coefficients of the chronologies (total ring with, earlywood, and latewood) and monthly mean temperature. Asterisks represent significant correlation coefficient (95% level) with the related month.

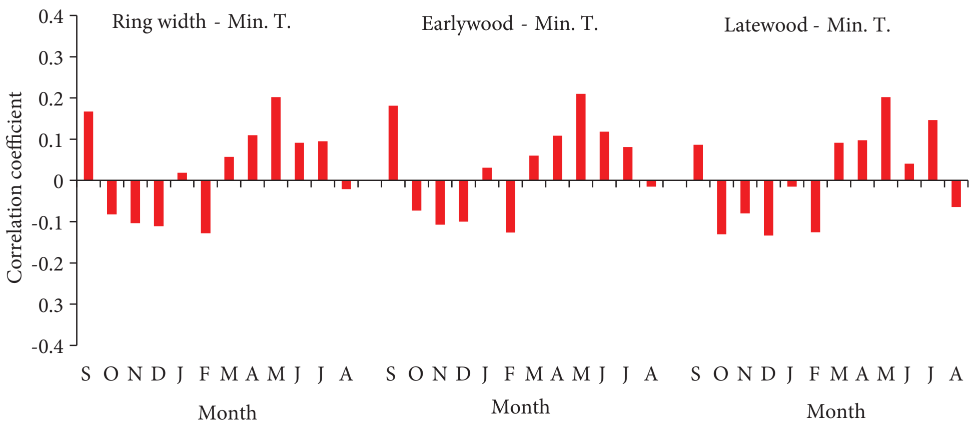

Figure 6. Correlation coefficients of the chronologies (total ring with, earlywood, and latewood) and monthly minimum temperature.

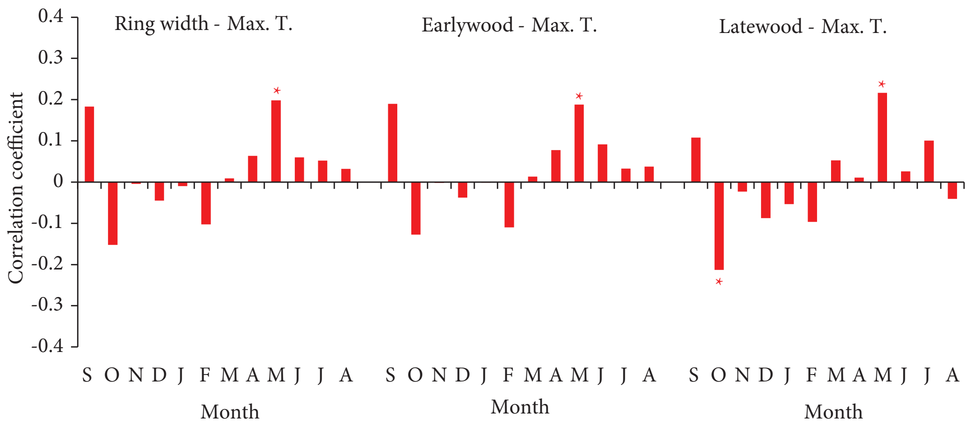

Figure 7. Correlation coefficients of the chronologies (total ring with, earlywood, and latewood) and monthly maximum temperature. Asterisks represent significant correlation coefficient (95% level) with the related month.

correlation coefficients were positive and significant only in June of the current year. On the other hand, precipitation was shown to be a negative effect in September and November of the previous year and in January of the current year. The effect of precipitation was very weak for all of the other months (Figure 4).

The effect of the mean temperature on radial growth was generally positive during the period of March to July of the current year for all of the chronologies. This positive effect appeared with higher correlation coefficients in May, which was significant for the total ring width and earlywood chronologies (Figure 5). In addition to mean temperature, correlation coefficients associated with maximum and minimum temperature were also calculated to better understand the effect of temperature on earlywood, latewood, and total tree-ring width formation of oriental beach (Figures 6 and 7). A stronger relationship was found with maximum temperature values than minimum temperature. No significant correlation associated with minimum temperature was found. The positive effect of minimum temperature was very similar for all of the chronologies and was distinctive during the period of April to June of the current year (Figure 6).

The correlation coefficient associated with maximum temperature was positive in the period of March to July, and reached the highest value in May, which was significant for all of the chronologies. Different from the other chronologies, the latewood chronology also had a negative effect of maximum temperature in October of the previous year (Figure 7).

Discussion and conclusion

In this study, we present the longest (442-year-long) oriental beech chronology from Turkey. In addition to ring-width chronology, the earlywood and latewood chronologies were built for the same period. Previously, there was only 1 oriental beech chronology, which was built by Akkemik and Demir (2003) for the Belgrad Forest, İstanbul, Turkey. This chronology was quite short (1921-2000), but it gives valuable and comparable information for the radial growth of oriental beech. We compared 2 chronologies in an 80-year common period (Figure 8). Although the correlation coefficients between the 2 are statistically significant (0.20, $P < 0.05$), the relationship is quite weak, visually and statistically. The chronologies were from the western and eastern natural distribution in Turkey, and they were also from very different altitudes; therefore, these trees grow under different climate conditions and their radial growth is affected by different climatic factors (see below). Only the trees under similar climatic conditions had similar tree-ring patterns (Fritts 1976), even if they were different species (Köse et al. 2011).

All of the chronologies (earlywood, latewood, and total ring width) were found to be highly sensitive to climate, with mean sensitivity values of 0.3034, 0.286, and 0.294, respectively. Akkemik and Demir (2003) found mean sensitivity to be 0.201 for the same species and claimed the species was too complacent. These values ranged from 0.13 to 0.25 for black pine (Köse et al. 2011) and 0.29 for umbrella pine (Akkemik 2000a, 2000b) in Turkey.

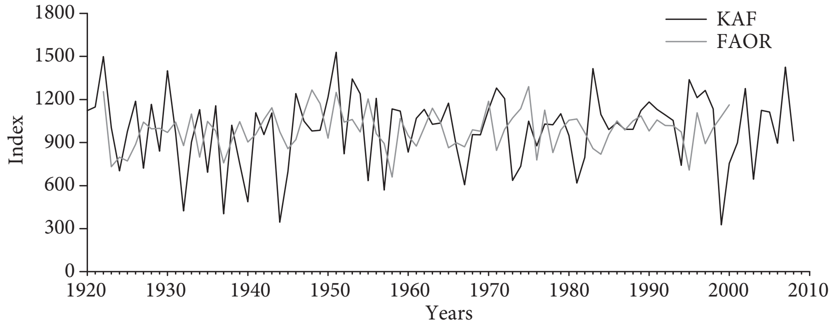

Figure 8. Comparison of oriental beech tree-ring chronologies from Belgrad Forest, İstanbul (FAOR), built by Akkemik and Demir (2003) and from Artvin (KAF).

Correlation coefficient results showed that high precipitation in June increased earlywood, latewood, and total ring width in this region, when low precipitation decreased. The effect of precipitation was not significant in other months. The most distinctive effect of temperature on tree-ring growth occurred with maximum temperature. High mean and minimum temperatures in the period of March to July (especially in May) resulted in growth early in the growing season and wide earlywood, latewood, and total ring formation. The effect of high maximum temperature is slightly different. Increased maximum temperature values in May of the current year and September of the previous year caused larger earlywood and total ring width. On the other hand, higher maximum temperatures in May and lower maximum temperatures in previous year October resulted in wider latewood bands.

Akkemik and Demir (2003) were the first to define the climatic factors affecting the radial growth of oriental beech in Turkey. Their results showed that the effect of precipitation was generally positive, and the coefficient was significant in February. High temperatures in May-June caused soil drought and decreased ring-width, while high temperatures in March, at the beginning of the vegetation period, caused an increase. In this study, samples were collected from northwestern Turkey and lower elevational areas of the species (110 m). Therefore, drought effects, which were represented by positive coefficient associated with precipitation during almost the whole biological year and negative coefficient associated with temperature in May-June, were distinctive on the radial growth of the trees at this site. In contrast, we collected our samples from the northeastern distribution limit of oriental beech in Turkey. Furthermore, the sampling area of 1830 to 2118 m elevation is very close to the upper vertical limit of this species (Şanlı 1978). Precipitation, therefore, was a limiting factor on tree growth, but only in June. Moreover, high temperatures had a positive effect during the period of March to July and did not cause a drought problem. Drought occurrence is a limiting factor for growth of trees only near arid forest limits, whereas low temperatures are a limiting factor for growth of trees near the upper elevational or high latitudinal forest limits (Fritts 1976). Our results revealed the same general rules explained by Fritts (1976).

The oriental beech chronologies represented in this study are useful for dendroclimatological reconstructions, because of its long and high sensitivity to climate. However, for significant reconstructions, more samples need to be collected around Artvin. This research provided preliminary information about the radial growth of oriental beech. Unfortunately, not enough is known about the physiology of the species. Our knowledge on this species could be improved by sampling different sites throughout the natural distribution of the species.

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