

A 200-year reconstruction of Kocasu River (Sakarya River Basin, Turkey) streamflow derived from a tree-ring network

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Abstract The Sakarya River Basin (SRB) contains one of the most important agricultural areas for Turkey. Here, we use a network of 18 tree-ring chronologies and present a reconstruction of the mean June–July Kocasu River discharge, one of the main channels in the SRB, during the period 1803–2002 CE, and place the short period of instrumental flows (since 1953 CE) into historical context. Over the past two centuries, we found 33 dry and 28 wet events and observed the longest wet period between the years 1880 and 1920. The driest years were 1845 and 1873, and the wettest years were 1859 and 1960. Our reconstruction showed that the extreme short-term drought events that occurred in recent years were minor compared to the severity and duration of droughts that occurred previous to instrumental data. We found four pre-instrumental severe and sustained low streamflow events during the periods 1819–1834, 1840–1852, 1861–1875, and 1925–1931, during which historical records show reduced agricultural production, death, famine, plague, economic crisis, and widespread human migrations. More concerning, however, are current hydroclimate conditions in the SRB, marked by decadal-scale mean flows that dip below the long-term mean (1803–1953) in the late 1970s and have since failed to recover. With the Mediterranean region currently likely experiencing the worst drought in the past ca 1000 years due to human-induced climate change, the future outlook of water resource

availability in the SRB could prove catastrophic for human and natural systems.

Keywords Dendrohydrology · *Pinus nigra* · *Pinus sylvestris* · Drought · Anatolia

Introduction

The importance of water as a resource has received much attention in recent years due to impending effects of climate change, particularly in arid and semi-arid regions. In 1989 and 1994, extreme droughts occurred in Turkey, which placed an economic and social strain on the entire country. Because people depend on streams and rivers for drinking water and to irrigate agricultural fields, human livelihoods and the economy were negatively affected by droughts over the past several decades (Turkish Ministry of Agriculture 2008; Dernek 2006; Akkemik et al. 2005, 2008; Köse et al. 2010). To understand the historical context of these most recent droughts, an understanding of the past variability in streamflow can provide valuable information for water resource planning. Recently, tree-ring data have been used as a proxy to reconstruct the past streamflow of rivers in the USA (Stockton and Jacoby 1976; Woodhouse 2001; Woodhouse and Lukas 2006; Wise 2010; Margolis et al. 2011; Maxwell et al. 2011; DeRose et al. 2015), Pakistan (Cook et al. 2013), Mongolia (Pederson et al. 2001, 2013a), and China (Gou et al. 2007).

In Turkey, instrumental streamflow records are shorter (usually less than 50 years) than meteorological records. Here, the Porsuk River (in Sakarya River Basin) and Göksu River (in Seyhan River Basin) contain the longest streamflow records, starting in 1936. Although the instrumental records of streamflow are short, one dendrohydrological study revealed past streamflow from Turkey. Akkemik et al. (2008) provided

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a May–August Filyos River streamflow reconstruction for the period 1650–2000 and described drought and flood events for north-western Turkey. The Sakarya River is the second longest river in Turkey, and the Sakarya River Basin (SRB) drains 7 % of the land area in Turkey (Bulut 1998). The SRB is the third largest basin (land area) but contains the largest forested area, covering 32 % of the basin (Hızal et al. 2008). Within the SRB lies one of the most important agricultural areas for Turkey; however, this area experienced rapid industrialization in recent decades. Hence, the importance of water as a resource in the SRB is increasing. The goals of this study were (1) to build new drought-sensitive tree-ring chronologies, (2) to use these chronologies, in combination with chronologies from previous investigations, to reconstruct past streamflow in the SRB, and (3) to describe historical drought and flood events for this region of Turkey.

Material and methods

Site description

The SRB, which includes Ankara, Bolu, Bilecik, Eskişehir, Kütahya, and Sakarya provinces, is located in northwest

Anatolia (Fig. 1). The drainage area of the basin is 58,160 km² and the mean elevation is 509 m (Bulut 1998). The Sakarya River, the primary river of the basin, is 842 km long (Bulut 1998). Mean annual streamflow in the SRB is 6.4 km³, which constitutes 3.4 % of the total streamflow in Turkey. Despite its large area, the basin receives little precipitation (Mutlu 2005). The SRB area includes tree floristic regions shape under different climates such as the Euxin (western Black Sea Region), Irano-Turanian (northwest of inner Anatolia), and Mediterranean (Marmara region). In the Euxin region, temperate broad leaf deciduous forests (*Fagus L.*, *Castanea Mill.*, *Alnus Mill.*, *Tilia L.*, and *Quercus L.*) dominate. The plateaus and mountains behind the Black Sea are characterized by cold, sub-humid coniferous forests. The Mediterranean region is composed of dry (maquis and *Pinus brutia Ten.*) and sub-humid forests (*Pinus nigra Am.* and *Quercus L.*). Finally, Irano-Turanian is mostly characterized by steppe and dry steppe-forests (*Pinus nigra Am.* and *Quercus L.*) (Mayer and Aksoy 1998; Atalay 1983, 2002).

Tree-ring data

We used 16 tree-ring chronologies developed from previous investigations from the SRB in our streamflow reconstruction. Additionally, we built two *P. nigra Am.* chronologies (Fig. 1,

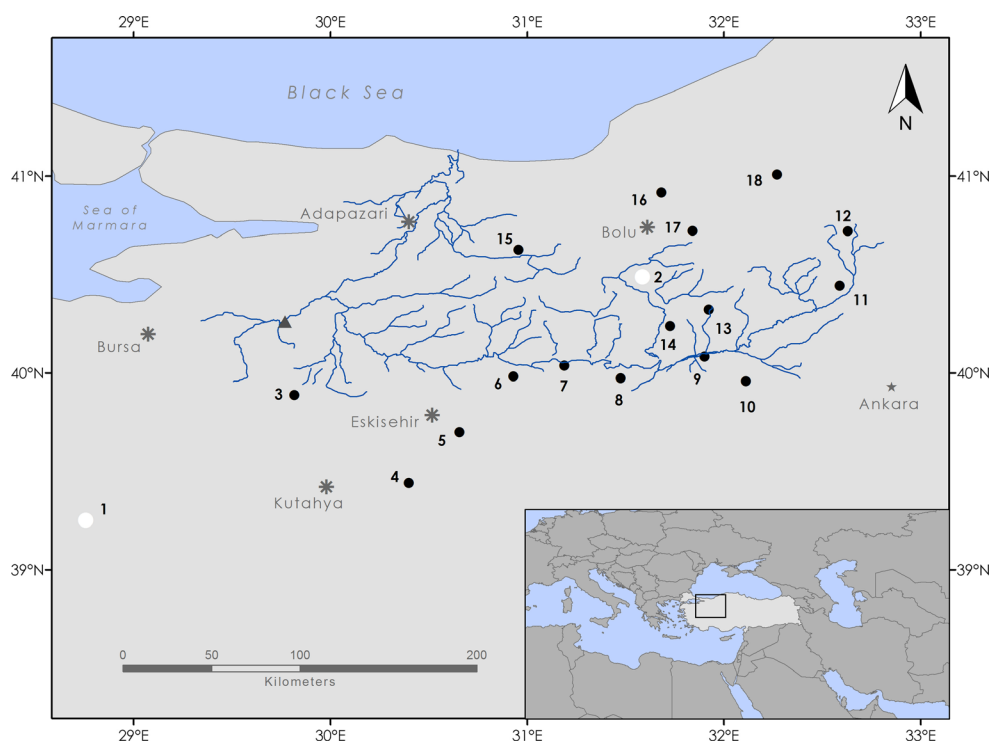


Fig. 1 Tree-ring chronology sites in the Sakarya River Basin used to reconstruct streamflow. The white circles represent the new sampling efforts from this study (1 = AHM, 2 = SEB), the black circles represent previously published chronologies (9 = TEK, 10 = FIR, 13 = USA, 14 = KEL, 15 = KIZ (Köse et al. 2011); 4 = CAT, 5 = GOV, 11 = INC,

12 = KAS (Köse et al. 2005); 3 = ERC, 6 = TAN, 7 = EKS, 8 = SAV, 16 = YED, 17 = YUB (Köse et al. unpublished data); 18 = YAU (Mutlu et al. 2012)), gray asterisks represent cities within the SRB with at least 250,000 population, and the gray triangle represents the Rüstümköy gauge on Kocasu River

Table 1 Site information for the new chronologies developed by this study in Sakarya Basin

Site name	Site code	Species	No. trees/cores	Aspect	Elev. (m)	Lat. (N)	Long. (E)
Kütahya, Ahmetin yaylası	AHM	<i>P. nigra</i>	14/28	SW	1440	40° 30'	31° 35'
Bolu, Seben	SEB	<i>P. nigra</i>	15/27	SE	1590	39° 15'	28° 46'

Table 1) by taking two cores per tree with a Haglōf increment borer. Cores were dried, mounted in wooden core mounts, sanded to a high polish, and processed using standard dendrochronological methods (Stokes and Smiley 1968; Speer 2010). Tree-ring widths were measured to the nearest 0.001 mm using the LINTAB-Tsap Measuring System (Rinntech, Germany), then visually cross-dated using the list method (Yamaguchi 1991). We used the computer program COFECHA, which uses segmented time-series correlation techniques, to statistically confirm our visual cross-dating (Holmes 1983; Grissino-Mayer 2001). To

remove non-climatic trends related to tree age, size, and effects of stand dynamics, the computer program ARSTAN was used to standardize each cross-dated tree-ring measurement series by fitting a 67 % cubic smoothing spline with a 50 % cutoff frequency (Cook 1985; Cook et al. 1990). These detrended series were then pre-whitened with low-order autoregressive models to remove persistence not related to climatic variations. The minimum sample depth for each chronology was determined according to expressed population signal (EPS; cutoff of 0.85), which we used as a guide for assessing the likely loss of reconstruction

Fig. 2 Tree-ring chronologies used for streamflow reconstruction

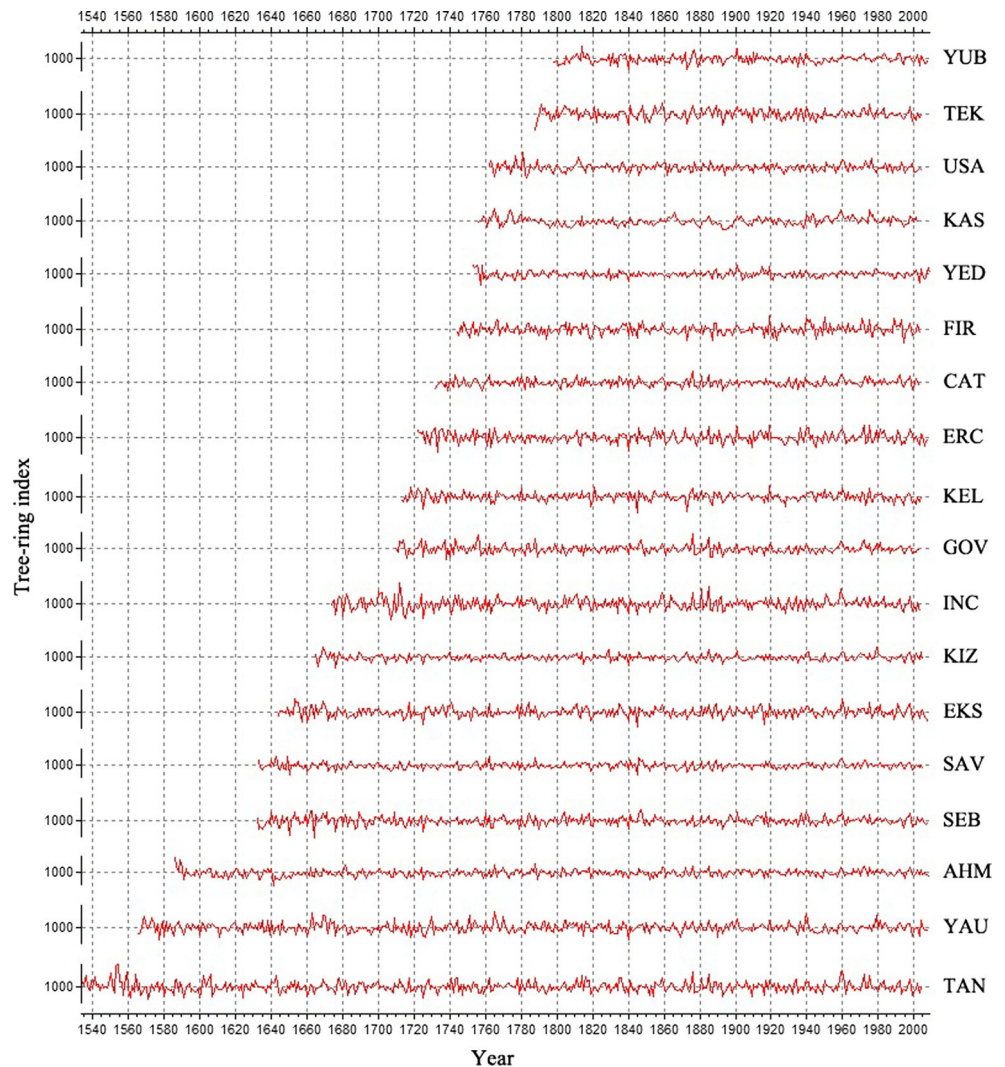


Table 2 Summary statistics for the new chronologies developed by this study in Sakarya Basin

Site code	Total chronology			Common interval		
	Time span	First year (SSS > 0.85)	Mean sensitivity	Time span	Mean radii corr.	Variance expl. by PC ₁ (%)
AHM	1583–2009	1684	0.19	1824–2009	0.38	42
SEB	1630–2008	1696	0.19	1814–2005	0.30	35

SSS subsample signal strength (Wigley et al. 1984)

accuracy (Wigley et al. 1984). We used 18 residual chronologies in all, 16 derived from *P. nigra* Arn. and 2 from *Pinus sylvestris* L., to reconstruct streamflow within the SRB (Fig. 2).

Streamflow reconstructions

Monthly flow data from these gauges were obtained from the General Directorate of Electrical Power Resources Survey and Development Administration (EIEI). In the SRB, six gauges (Porsuk-Beşdeğirmen, Dinsiz Çayı-Yağbasan, Sakarya Nehri-Doğançay, Kocasu-Rüstümköy, Aladağ Çayı-Karaköy, Mudurnu Çayı-Dokurcun) were available. First, we attempted to use our SRB tree-ring chronology network and all six gauges to create reconstructions. The Porsuk-Beşdeğirmen gauge contained the longest continuous record starting in the year 1936, but the location of the gauge was changed, and therefore resulted in data inconsistencies. We could only obtain statistically significant models for the Rüstümköy gauge on the Kocasu River, which is one of the main tributaries that

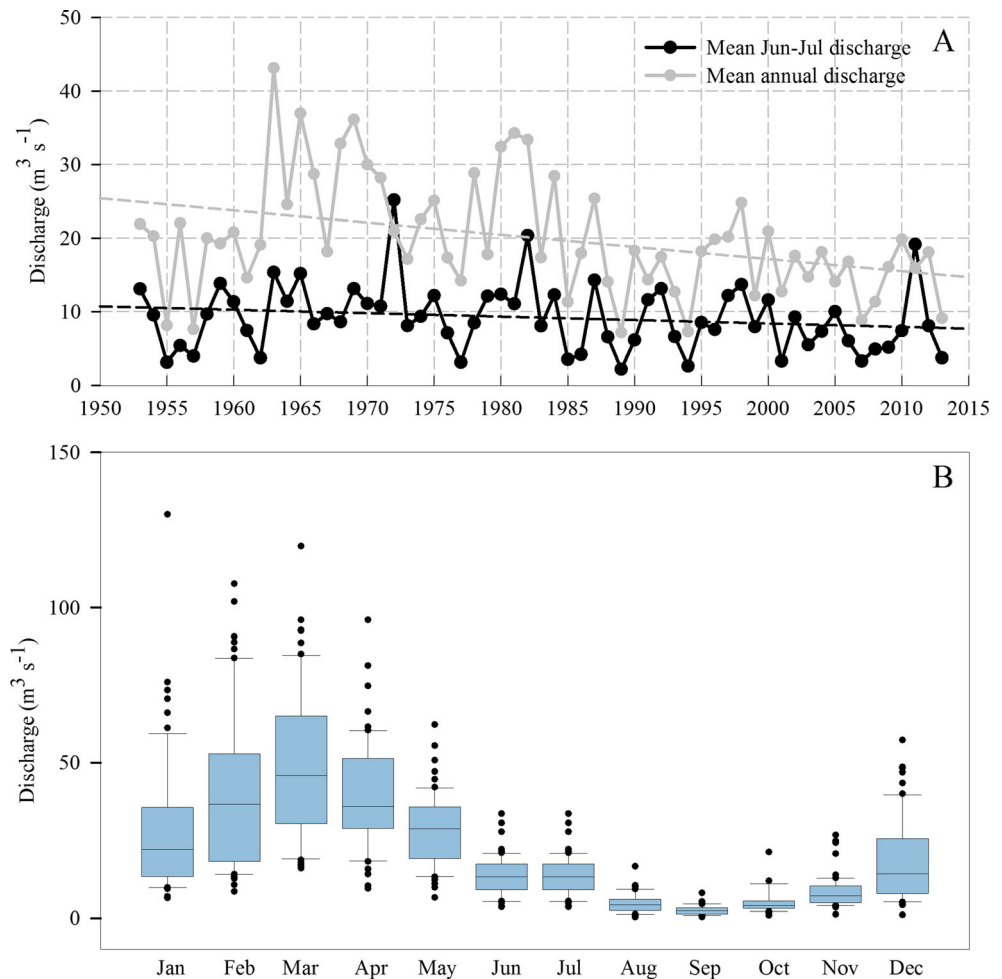
feeds the Sakarya River, as all other gauges contained short records (e.g., < 50 years) or data gaps that could not be reasonably filled using statistics. Relationships between tree-ring chronologies and streamflow data were described using correlation analysis for biological growth year from the previous November to the current October. Monthly correlation coefficients showed that streamflow for the months June and July were significant predictors for reconstruction.

We first investigated the use of a nested principle components regression technique to account for varying temporal length of the 18 candidate chronologies (cf Maxwell et al. 2011; Pederson et al. 2013b). However, nests that extended further back in time beyond the common period of all chronologies (1803–2002) failed to validate, suggesting the nested technique was unwarranted for the reconstruction. Thus, principle component analysis (PCA) was performed on all 18 chronologies within the study area. Stepwise regression was used to select predictors, which were the principle components

Table 3 Correlation matrix of the chronologies. All correlation coefficients between the chronologies are statistically significant ($p \leq 0.01$)

	TAN	YAU	AHM	SEB	EKS	BOL	YUB	KAS	INC	GOV	CAT	FIR	KIZ	KEL	TEK	USA	SAV	ERC
TAN	1																	
YAU	0.49	1																
AHM	0.69	0.43	1															
SEB	0.69	0.65	0.60	1														
EKS	0.76	0.51	0.58	0.71	1													
BOL	0.38	0.60	0.28	0.48	0.50	1												
YUB	0.55	0.54	0.45	0.55	0.56	0.60	1											
KAS	0.46	0.33	0.35	0.47	0.42	0.37	0.39	1										
INC	0.74	0.46	0.59	0.64	0.63	0.39	0.53	0.49	1									
GOV	0.68	0.48	0.66	0.64	0.62	0.41	0.45	0.51	0.59	1								
CAT	0.78	0.50	0.66	0.65	0.60	0.35	0.51	0.47	0.66	0.69	1							
FIR	0.44	0.47	0.39	0.58	0.65	0.46	0.46	0.37	0.44	0.47	0.39	1						
KIZ	0.59	0.67	0.54	0.63	0.59	0.57	0.50	0.43	0.49	0.58	0.59	0.50	1					
KEL	0.50	0.33	0.40	0.54	0.65	0.34	0.37	0.23	0.50	0.43	0.95	0.58	0.33	1				
TEK	0.66	0.53	0.56	0.62	0.67	0.43	0.56	0.39	0.69	0.59	0.53	0.53	0.45	0.51	1			
USA	0.70	0.39	0.56	0.57	0.59	0.32	0.48	0.47	0.66	0.60	0.62	0.36	0.50	0.40	0.63	1		
SAV	0.69	0.47	0.64	0.71	0.68	0.40	0.47	0.39	0.63	0.60	0.68	0.57	0.60	0.55	0.53	0.57	1	
ERC	0.63	0.62	0.62	0.64	0.66	0.57	0.59	0.44	0.60	0.62	0.56	0.51	0.66	0.49	0.62	0.50	0.58	1

Fig. 3 Kocasu River (at Rüstümköy) gauge statistics showing **a** the mean June–July (black) and mean annual (gray) discharge (m^3/s) during the period 1953–2014 plotted with annual linear trend line (dashed black) and **b** the monthly hydrograph for Rüstümköy (1953–2014) shown as boxplots indicating mean, interquartile range, and outliers



(PCs) of the chronologies, of the mean June–July Kocasu River streamflow. The instrumental period (1953–2002) was split into two equal periods for calibration (1953–1977) and verification (1978–2002) (Meko and Graybill 1995). Calibration models were verified using two tests of fit, the reduction of error statistic (RE), and coefficient of efficiency (CE) (Fritts 1976; Cook et al. 1994). A positive RE (range from $-\infty$ to +1) denotes that the calibration model is more skillful than the mean of the instrumental data during the calibration period. The CE has the same range and calculation, yet it relies on the verification period mean for a baseline of predictive skill and is thus more difficult to pass (value >0). The resulting model for the full period (1953–2002) was then used to create our reconstruction. To identify the extreme June–July drought and flood events, standard deviation (SD) values were used. Years 1 or 2 SDs above or below the mean were identified as dry, very dry, wet, and very wet years, respectively.

Table 4 Summary of correlation coefficient results

	N	D	J	F	M	A	M	J	J	A	S	O
TAN	–	+	+	+	+	+	+	+	+	+	+	+
YAU	+	+	–	+	+	+	+	+	+	+	+	+
AHM	–	+	+	–	+	+	+	+	+	+	+	+
SEB	–	+	+	+	+	+	+	+	+	+	+	+
EKS	+	+	+	+	+	+	+	+	+	+	+	+
YED	+	+	+	+	+	+	+	+	+	+	+	+
YUB	+	+	+	+	+	+	+	+	+	+	+	+
KAS	–	+	–	–	+	–	–	–	+	+	–	–
INC	–	+	+	+	+	+	+	+	+	+	+	+
GOV	–	+	+	+	+	–	–	+	+	+	+	+
CAT	–	+	–	–	–	+	–	+	+	+	+	+
FIR	+	+	+	+	+	+	+	+	+	+	+	+
KIZ	–	+	+	+	+	+	+	+	+	+	+	+
KEL	–	–	+	+	+	+	+	+	+	+	+	+
TEK	–	+	+	–	+	+	+	+	+	+	+	+
USA	–	+	+	+	+	+	+	+	+	+	+	+
SAV	–	+	–	–	–	+	+	+	+	+	+	+
ERC	+	+	+	+	+	+	+	+	+	+	+	+

“+” represents the positive effects of climate variability on tree ring width; “–” represents the negative effects of climate variability on tree ring width; gray filled boxes represent significant correlation coefficients. Correlation coefficients were calculated for 12 months from November (N) of the prior year to October of current year

Results and discussion

Tree-ring chronologies

We produced two new *P. nigra* Arn. chronologies from Kütahya (AHM) and Bolu (SEB), 427 and 377 years long, respectively (Table 2). Both chronologies had a mean sensitivity value of 0.19. Mean sensitivity is a metric of the year-to-year variability in ring width. Previous investigations from the region reported a mean sensitivity value range of 0.13 to 0.25 for *P. nigra* Arn. (Akkemik et al. 2008; Köse et al. 2011), so the values of AHM and SEB indicated that these chronologies were climatically sensitive. In addition to the development of AHM and SEB chronologies, 16 previously published chronologies were used to produce the streamflow reconstruction (e.g., Akkemik et al. 2008; Köse et al. 2011). In all, the 18 tree-ring time series used in analysis were strongly and positively correlated with one another (r range = 0.33–0.78, $p < 0.01$) (Table 3). Moreover, explained total variance of tree growth by the first PC of the chronologies is very high (57 %),

which confirms that all the chronologies has a similar climate signal.

Kocasu River June–July mean streamflow reconstruction

Both annual and June–July Kocasu River discharge, as shown by the Rüstümköy gauge, has been in a steady decline during the instrumental period (1953–2014; Fig. 3a). The monthly hydrograph at Rüstümköy reveals a normal precipitation distribution, with the highest value during March and the lowest value during September and low-flow months of June–October (Fig. 3b). The primary mode of SRB recharge in the early spring is heavy rain associated with cold fronts. As spring transitions to summer, convective thunderstorm events provide primary recharge inputs from May to October. Instrumental flow variability demonstrates flood, and drought events have occurred in the SRB over the past six decades. The lowest mean annual flow ($2.2 \text{ m}^3/\text{s}$) occurred in 1989 as a result of one of the most extreme droughts during the instrumental period. Record-low monthly flows over the past few

Fig. 4 The time series of PCs selected as predictors by stepwise regression

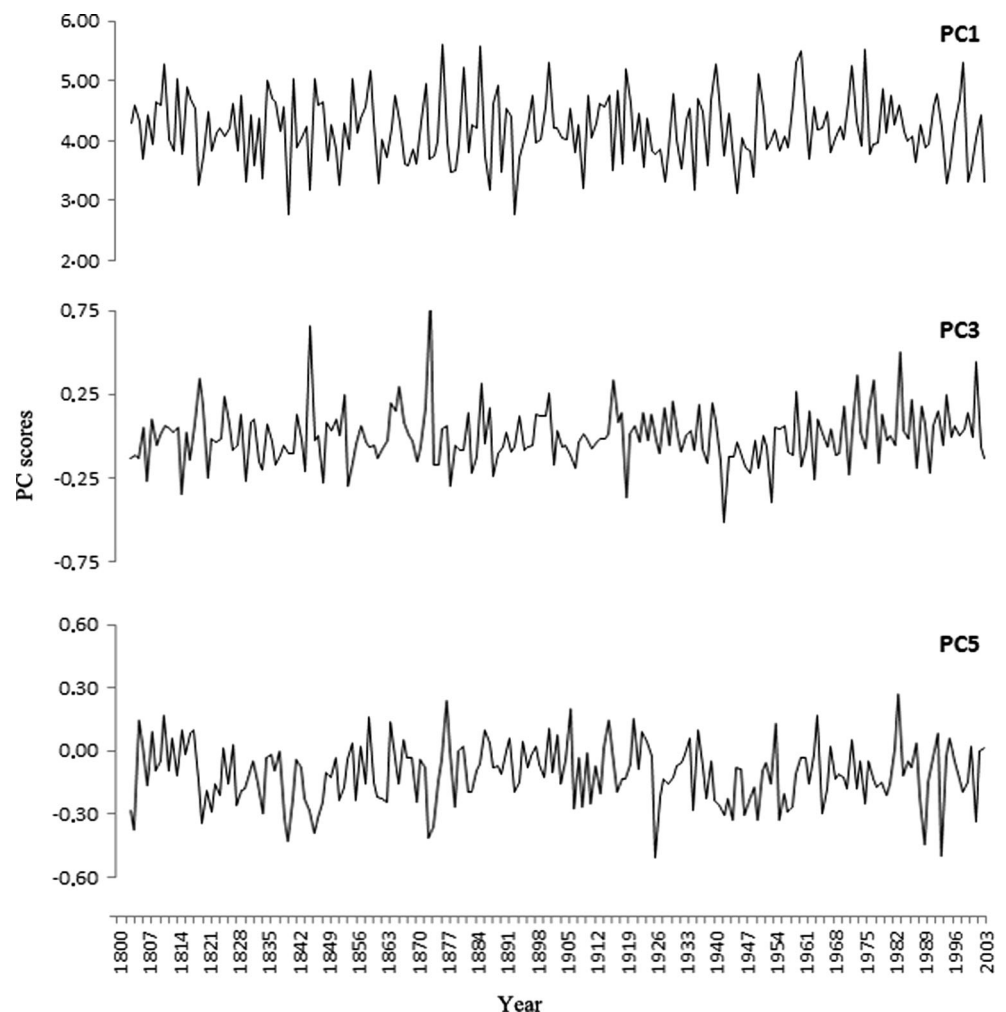


Table 5 Results of the statistical calibrations and cross-validations between June–July mean streamflow and tree growth

Calibration period	Verification period	R^2	Adj. R^2	F	RE	CE
1953–1977	1978–2002	0.49	0.42	$6.69p < 0.01$	0.46	0.40
1978–2002	1953–1977	0.50	0.42	$6.85p < 0.01$	0.46	0.41
1953–2002	–	0.47	0.44	$13.83p < 0.01$	–	–

F: F value, RE: reduction of error, CE: coefficient of efficiency, P: p value significance

decades had widespread negative impacts on the economy and ecology of the SRB basin. Conversely, the maximum monthly flow ($25 \text{ m}^3/\text{s}$) occurred in 1972, which was also considered one of the worst flood events during the instrumental period.

Correlation coefficients between tree-ring chronologies and monthly streamflow data of the Kocasu River are shown in Table 4. Tree-ring chronologies were positively correlated with streamflow data in most months from the current March to October, and coefficients were significant in June and July. The SRB flow regime is generally described as being rainfall-dependent, but snow melt in high elevation areas contributes to discharge (İnadık 1958). In Turkey, the most important and significant relationships between tree-ring chronologies and precipitation were found in May and June (D'Arrigo and Cullen 2001; Hughes et al. 2001; Touchan et al. 2003, 2005a, 2005b, 2007; Akkemik and Aras 2005; Akkemik et al. 2005, 2008; Griggs et al. 2007; Köse et al. 2011). When we compared strong and significant relationships with streamflow (in June–July) and precipitation (in May–June), we found a 1-month lag between them.

Based on the correlation analysis results, we decided to reconstruct the June–July mean streamflow. The June–July

mean streamflow was obtained from PC₁, PC₃, and PC₅ of the 18 site chronologies, which explained 66 % of the total variance. Within the first five PCs, PC₁, PC₃, and PC₅ showed the highest correlations (0.52, –0.35, and 0.29, respectively) with the June–July mean streamflow. PC₂ and PC₄, which have lower correlations (–0.11 and 0.16), were not selected as predictors by stepwise regression. Figure 4 shows the time series of the selected PCs. The decreasing trend observed in the instrumental data also appeared in all selected PCs. Because of negative correlation between PC₃ and the June–July mean streamflow, this trend was shown as an increase in the time series of PC₃.

The calibration and verification statistics indicated a statistically significant reconstruction (Table 5). Because of the similarity and strength of the derived calibration equations and verification tests, the full calibration period (1953–2002) was used for reconstruction (Fig. 5). The regression model accounted for 50 % of the actual streamflow variance over the full calibration period (1953–2002).

Our streamflow reconstruction from the Kocasu River spans 1803–2002, which is limited to the common interval of the chronologies (Fig. 6). For the last two centuries, we

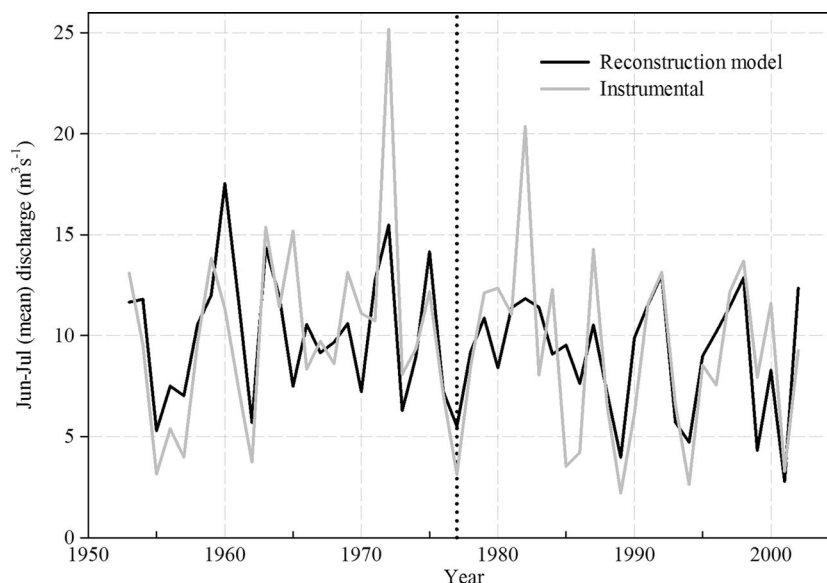


Fig. 5 Actual (instrumental; gray) and reconstructed (black) mean June–July Kocasu River streamflow (m^3/s) for the calibration (1953–1977) and verification (1978–2002) periods of split-sample procedure. Vertical black dashed line represents split calibration and verification periods

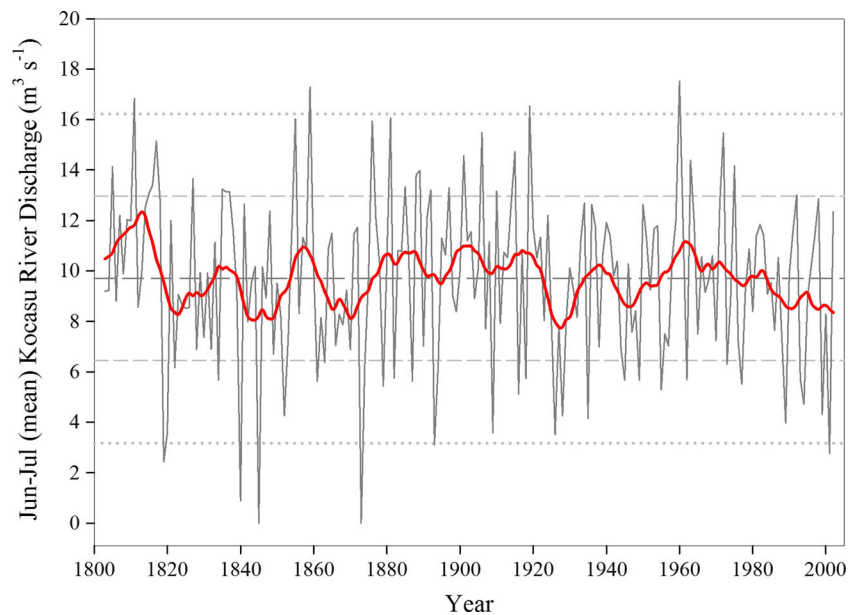


Fig. 6 The June–July mean streamflow (m^3/s) reconstruction for Kocasu River for the period 1803–2002. The *central horizontal line (dashed dark gray)* shows the mean of estimated values; *inner and outer horizontal*

lines (dashed light gray) show the border of 1 and 2 SDs from the mean, respectively; and the *solid red line* shows the 11-year low-pass filter values

found 33 dry and 28 wet events, which exceed ± 1 and ± 2 SDs (Table 6). Of these events, 1819, 1840, 1845, 1873, 1893, and 2001 were very dry and 1811, 1859, 1919, and 1960 were very wet. The driest years were 1845 and 1873. Extreme dry and wet events were usually 1 year long; the longest extreme dry events were no more than 2 years (1819–1820, 1873–1874, 1893–1894, 1993–1994) and the longest extreme wet events were 3 years long (1815–1816–1817, 1835–1836–1837) in duration.

The reconstructed extreme events also coincided with accounts from historical records. Extreme drought in 1845, one of the driest reconstructed years resulted in widespread crop failure and famine (Seyf 1985). The second driest year in our reconstruction was 1873, and streamflow during these 2 years was calculated as almost $0 \text{ m}^3/\text{s}$, suggesting the possibility that the river was completely dry. Historical documents recorded

an infamous drought-derived famine that occurred in Anatolia from 1873 to 1874 (Kuniholm 1990; Quataert 1996), which claimed the lives of 250,000 people and a large number of cattle and sheep (Faroqi 2009). This drought caused widespread mortality of livestock and depopulation of rural areas through death and migration from rural areas to cities. Conditions worsened when the international stock exchanges crashed in 1873, marking the beginning of the “Great Depression” in the European economy (Zürcher 2004). Another severe drought and famine occurred throughout the Ottoman Empire in 1887 (Gül 2009), which also was a noteworthy dry year in our reconstruction.

During the years 1893 and 1894, low streamflow was observed in our reconstruction, and Ozger (2008) reported 3 years of prolonged drought during the period 1891–1893 in Anatolia and Trablus. Further, the Old World Drought Atlas compiled by Cook et al. (2015) highlights the broad spatial implications of the 1893 drought, which is a widely

Table 6 Dry and wet years obtained from the June–July streamflow reconstruction

Very dry years (-2 SD)	1819, 1840, 1845, 1873, 1893, 2001
Dry years (-1 SD)	1819–20, 1822, 1834, 1840, 1845, 1852, 1861, 1863, 1873–1874, 1879, 1882, 1887, 1893–1894, 1909, 1916, 1918, 1926, 1928, 1935, 1945, 1949, 1955, 1962, 1973, 1977, 1989, 1993–1994, 1999, 2001
Wet years ($+1$ SD)	1805, 1811, 1815–1816–1817, 1827, 1835–1836–1837, 1855, 1859, 1876, 1881, 1885, 1888–1889, 1892, 1897, 1901, 1906, 1910, 1915, 1919, 1960, 1963, 1972, 1977, 1992
Very wet years ($+2$ SD)	1811, 1859, 1919, 1960

Table 7 Comparison of wheat production of provinces in SRB in 1989, a dry year, and in 1995, which receive almost average precipitation during the period of 1950–2006 (Turkish Ministry of Agriculture 2008)

Province	Wheat production in 1989, the driest year (Ton)	Wheat production in 1995, an average year (Ton)
Bolu	0	143,992
Bilecik	124,51	155,055
Eskişehir	196,840	323,033
Kütahya	0	274,675
Sakarya	59,846	68,446

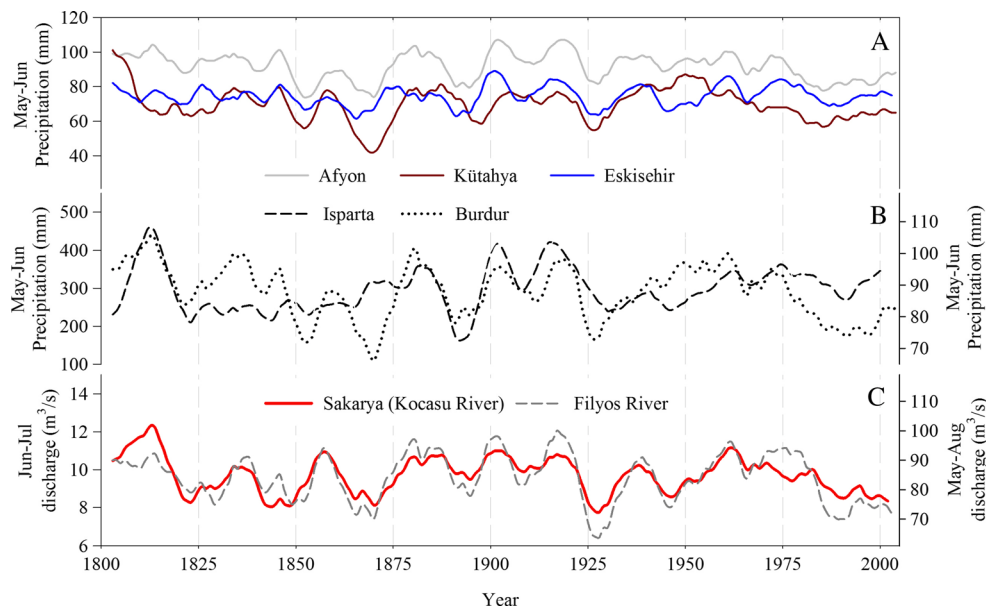


Fig. 7 Regional comparison of hydroclimate reconstructions for Turkey including reconstitutions of the mean May–June precipitation (mm) for **a** Afyon, Kütahya, Eskisehir (Köse et al. 2011); **b** mean May–June precipitation (mm) for Isparta (Köse et al. 2011) and Burdur (Köse et al. 2012);

and **c** mean May–August Filyos River discharge (m^3/s) (Akkemik et al. 2008) and mean June–July Kocasu River discharge (this study; m^3/s)

known hydroclimatic extreme. Besides the effect of sustained drought to agriculture during this time, crops were also infested by insects, resulting in widespread migration of people to the Black Sea Region (Ozger 2008). Similarly, Purgstal (1983) reported prolonged drought in Anatolia from 1925 to 1928, of which 1927 and 1928 appear to be dry years in our reconstruction.

Conversely, 1901 was one of the wet years in the reconstruction. In June and July 1901, flood events were recorded in the Sivas, Konya, Bursa, Kütahya, and Isparta provinces. For example, in Kütahya, which is in SRB, floods cause widespread mortality of animals and many buildings (including grain storage towers) were destroyed. In Bursa, floods claimed the lives of six people and more than 100 homes and businesses were destroyed. Floods also caused similar destruction in Isparta (Gönüllü 2010).

Historical documents showed that drought, observed in our reconstruction, reduced agricultural production and caused death, famine, plague, economic crisis, and widespread human migrations within the last 200 years in SRB. Other climate factors, such as temperature, can also have an impact on water resource availability, particularly during drought conditions. In the western USA, recent research suggests that increased air temperature over the past decade has exacerbated drought in California (Griffin and Anchukaitis 2014; Diffenbaugh et al. 2015; Cheng et al. 2016) and had deleterious effects on streamflow in the Colorado River basin (e.g., McCabe and Wolock 2007; Woodhouse et al. 2016). Paleo

perspectives of temperature variability in Turkey would provide a more comprehensive understanding of how other climate factors have influenced past streamflow in SRB and across the broader Mediterranean region.

According to the drought action plan published by the Ministry of Agriculture and Rural Affairs, agricultural production is one of the most vulnerable aspects of Turkey's economy with the potential of being adversely affected by future droughts in the region. Based on annual precipitation data, the driest year during the period 1950–2006 was 1989, and during this year, the production of wheat in the SRB provinces was much lower compared to an example year of average production (Table 7). Our reconstruction showed that the extreme droughts that occurred in 1989 and 1994 were minor compared to the severity and duration of events that occurred previous to instrumental period, such as the years 1819, 1840, and 1845.

Our reconstruction shows similar variability with previous tree-ring-based precipitation and streamflow reconstructions (Köse et al. 2011; Akkemik et al. 2008) from the region (Fig. 7). A smoothing spline (11-year low-pass filter) fit to reconstructed values revealed that the longest wet (pluvial) period was observed between the 1880s and the 1920s, which also appeared in the Filyos River (northeast of and adjacent to the SRB) streamflow reconstruction (Akkemik et al. 2008). Moreover, from 1803 to 1953, four events marked by low streamflow levels occurred during the periods 1819–1834, 1840–1852, 1861–1875, and 1925–1931 (Fig. 6). These historical drought events were more sustained and severe than

any event recorded during the instrumental period. Although our reconstruction demonstrates short-term (e.g., single year) low-flow events in the SRB, more concerning, however, is the steady decline in discharge since ca 1960 CE, whereby the 11-year mean flows dip below the long-term mean in the late 1970s and have failed to recover. With new research suggesting the Mediterranean region is currently experiencing the worst drought in the past ca 1000 years (e.g., Cook et al. 2015, 2016) due to climate change, the future outlook of water resource availability in the SRB appears bleak. Longer-term streamflow data from more gauge sites are needed to better understand the spatiotemporal properties of these extreme streamflow years and help better plan for these catastrophes that originate from extreme dry and wet events.

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