Preliminary Dendroclimatological Analysis of Sessile Oak (*Quercus petraea* (Matt.) Liebl.) in "Fruška Gora" National Park, Serbia

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Abstract

A dendroclimatological analysis of Sessile oak has been carried out for the first time in Serbia on the area of National park "Fruška gora" (the northern part of Serbia). Two versions of chronology (standard and residual) were first established according to conventional dendrochronological procedures. To eliminate the chance of biasing the chronology indices and to extract climatic signals, the most important well known techniques were applied. The resulted chronologies span a period of 92 years from 1919 to 2010 and, according to the values of obtained parameters (r_{bar}, EPS, SNR and PC1) for a common period (1938–2010), it was concluded that the established chronologies possess a satisfactory level of common signal, which represents the common variability present in all series of radial increment in a given site condition.

To ascertain the relationships between oak radial increment and monthly and seasonal precipitation and temperature data (1) correlation functions, (2) response functions and (3) pointer year's analysis were applied. It was obvious that radial increment of oak for the studied site was influenced more by precipitation than temperature. The tendency towards positive response to previous year's precipitation (especially in the period September-October) and negative response to current summer temperature (particularly in August) were recorded. The largest number of identified positive pointer years corresponded to wet previous September and October precipitation. The results described here represented a preliminary stage of dendroclimatological study of sessile oak for this region and for this reason future studies should be undertaken in order to expand data base and knowledge of the climate influence on sessile oak growth in the studied region as well as in many other regions in Serbia.

Key words: dendroclimatology, radial growth, correlation functions, response functions, pointer years, sessile oak, Serbia

Introduction

Studies of the influence of environmental factors on radial growth of forest trees despite the application of the most modern methodological procedures and instruments can be still a serious problem (Vučković et al. 2005). For example, various disturbances and competition can have a major impact on tree growth (Hordo et al. 2011). In addition to that, relationships between tree-ring growth and climatic parameters are sometimes very strong and constitute the basis for dendroclimatic studies (Leal et al. 2007). It is especially the case with trees growing on high-sensitive sites (at the upper and the lower distribution limit of the species, the driest sites, etc.) with the maximum tree growth response to variations in the basic growth factors. On the other hand, in temperate climates a variety of biotic and abiotic factors influence tree growth and, therefore, complicates our understanding of the interactions between growth and climate (Friedrichs et al. 2009).

Dendroclimatological studies, which are largely based on quantitative analysis of radial increment and its dependence on particular climatic elements, represent a part of the modern methods of studying the multiple interrelationships between living organisms and their inorganic surroundings (Stajić 2010). The results of these analyses are of specific importance to the functioning and management of forests in National parks and other forests with especially pronounced ecological function. In "Fruška gora" National park coppice and degraded forests cover more than 80% of the area and considering this situation it is necessary to implement an intensive silvicultural and meliorative procedure integrated into a modern, multi-functional management, which will ensure the conversion of coppice and degraded forests into high silvicultural system (Bobinac 2005). In the process of conversion and restitution of such stands, because of old age and large area participation, it is necessary to use an intensive man-made exertion. Improving the quality of these forests can be partly achieved by forming artificially established stands of non-native and native species. This is of particular importance for the most productive oak sites, where due to inadequate regeneration and thinning procedure, more valuable oaks are almost completely absent in the newly-formed stands and dominant species are *Quercus cerris* L., *Tilia* sp., *Carpinus betulus* L., *Fraxinus ornus* L. etc, predominantly of coppice origin (Bobinac 2003). It is important to note that the choice of tree species is a crucial moment in the planning and implementation of the reclamation of coppice and degraded stands. It must be based on specific experiential knowledge that was gained through credible experiments, but reliable assessment can be given only when growth characteristics of the used species are known (Vučković and Stajić 2008). In that sense, tree ring growth can be considered as natural archives of ”past management history” and according to Zielonka et al. (2009) this knowledge of a long tree and forest history may contribute significantly to our understanding of forest dynamics.

Sessile oak is one of the most important tree species in Serbia. In this country, sessile oak is adapted to the temperate climate of lowland and highland areas in conditions of uniform temperature (does not tolerate extreme temperatures) and sufficient moisture (Cvjetićanin et al. 2007). In general, oaks are some of the dendrochronologically and dendroclimatologically most studied tree species in Europe (Pilcher 1976, Baillie 1977, Becker 1981, Romagnoli and Codipietro 1996, Lebourgeois et al. 2004, Rozas 2005, Ruseckas 2006, Čufar et al. 2008a, Čufar et al. 2008b, García-Suárez et al. 2009, Kolár et al. 2012, Čufar et al. 2014 etc.). Oak, as a tree species with ring-porous and striking tree rings, with a sharp transition between the early and late zones within them and very rare or practically no presence of false rings, is very suitable for this kind of research. Despite numerous studies there are some countries and regions in Europe, where there is not so much relevant information about oaks growth-climate relationships. Therefore, such studies in yet unexplored oak areas are welcome because ”... *further knowledge on climate–growth relationships is necessary to better predict future scenarios of migration and growth of oak under the impact of climate change* ...” (Matisons et al. 2013).

To date, dendrochronological and dendroclimatological studies have not been intensively carried out in Serbia. In general, the first dendrochronological research of any tree species in Serbia conducted Stajić (2010). This author evaluated potential of beech for further dendroclimatological studies and, based on three master beech chronologies defined in the area of ”Šerdap” National park, he concluded that beech was able to record climate signals at the regional scale.

This study will represent the first dendroclimatological research of sessile oak in Serbia. Some facts about dendroclimatological behavior of oak in Serbia (the authors didn‘t specify which oak was studied – pedunculate or sessile oak), were presented by Čufar et al. (2014). Bearing in mind all of the above-mentioned, the primary goal of this study is to analyse the radial growth characteristics of sessile oak and its response to variations of some climate elements (precipitation and temperature) at one of the typical sites in ”Fruška gora” National park. In order to fulfill the stated goal, two versions of chronologies (standard – STD and residual – RES) will be first established according to conventional dendrochronological procedures. Furthermore, to ascertain the relationships between climate elements and oak radial increment (1) correlation functions (Pearson’s correlation coefficients), (2) response functions and (3) pointer year’s analysis will be applied. The obtained results on the influence of precipitation and temperature on oak radial increment will be an important part of the future spectrum of information relevant to determining the biological and optimal management and functioning of oak forests in Serbia.

Materials and Methods

The sampled trees were bored in artificially established sessile oak forest stand located in “Fruska gora” National Park (Figure 1). This site is classified as *Quercetum montanum tilietosum tomentosae*. The altitude is 240 m. Stand density was 256 oaks/ha, stand basal area averaged to 25.9 m^2/ha and the total stand volume was 366 m^3/ha. The diameters of oak trees ranged from 17.0 to 55.0 cm (mean tree basal diameter is 36.0 cm). Average basal diameter and height of dominant trees are 48.3 cm and 28.2 m, respectively.

Most of the climatic data were taken from “Iriški venac” weather station, which is located near the studied stand. Mean monthly temperature (line) and precipitation (bars) for the studied area (data from “Iriški venac” weather station) are presented in Figure 2. The average annual temperature from the “Iriški venac” weather station (10.0 °C) for the period 1965–1990 is the same as the value of the average annual temperature in Serbia in that period, which amounts to 10.1°C (Popović et al. 2005). The average annual precipitation for this location (795 mm) is greater than the average annual precipitation in Serbia (734 mm) for the period 1961–1990 (Popović et al. 2005). According to data from “Iriški venac” weather station, the growing season precipitation and temperature averaged 502 mm and 15.5°C, respectively.

Regarding the temperature in Serbia, the coldest month is January (on average 1.3°C), and the warmest is July (on average 19.9°C). According to data of the Republic Hydrometeorological Service of Serbia (http://www.hidmet.gov.rs/podaci/meteorologija/latin/Padavinski_rezim_u_Srbiji.pdf) it rains most in May and June (in June 12 to 13% of the total annual amount of precipitation) and least in February or October (on average 5-6% of the total annual precipitation).

When some climatic data were not available from “Iriški Venac”, additional data were obtained from weather stations located at Fruska Gora mountain (< 20 km, Table 1). Because the stand is located at 240 m a.s.l., the corresponding temperature lapse rate of +/-0.5°C per 100 m of altitude for all meteorological stations was applied (Fritts 1976).

Table 1. Some geographical information on the locations of the weather stations used in this study

	Long. (E)	Lat. (N)	Altit. (m)
Iriški Venac	19°50'	45°09'	445
Irig	19°52'	45°05'	183
Petrovaradin	19°52'	45°15'	119
S. Kamenica	19°51'	45°13'	150

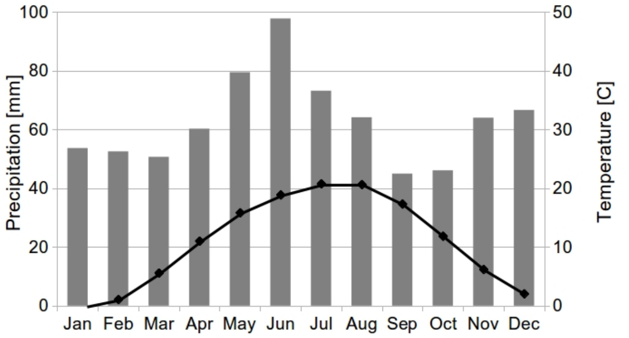

Figure 2. Climatic diagram – mean monthly temperature (line) and precipitation (bars) for the studied area, according to data from “Iriški venac” weather station

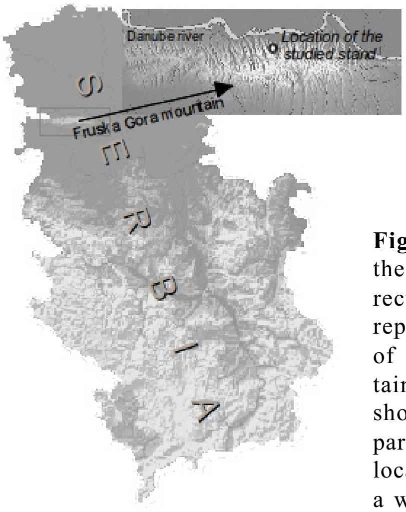

Figure 1. Location of the studied stand. The rectangle on the map represents the location of Fruška Gora Mountain, whose relief is shown on the enlarged part of the map. The site location is marked with a white dot

Because of the high quality and the economical value of the trees, only 22 dominant sessile oak trees were cored. One core per tree was taken at the breast height (1.3 m). A group of 1866 tree ring widths were measured using an LINTAB device by Frank Rinn. The accuracy of measuring was 1/100 mm. The ring widths were cross-dated visually (by using strikingly narrow and wide tree rings and sliding and overlapping of curves in TSAP software) and evaluated cross-dating quality using COFECHA (Holmes 1983). The quality checking in COFECHA was based on 40-year dated segments with 20-year lags significant at a 99% critical level of correlation of 0.367.

The growth series were standardized with a cubic smoothing spline having a 50% cutoff of 32 years (Cook and Peters 1981). Ring-width indices were computed by dividing each radial growth value by the value of the fitted curve of that year. The standardized series were averaged to obtain STD master chronology by applying a biweight robust estimation of the mean value function (Cook et al. 1990). In order to remove autocorrelation, chronology was prewhitened by autoregressive modeling and the RES master chronology was constructed. To compute the radial increment index chronologies, the ARSTAN software was used (Cook 1985). The existence of autocorrelation within calculated chronology was tested using the Ljung-Box Q-test (Biondi and Swetnam 1987). Robust estimation of the mean value function produces a chronology with a strong common signal and without persistence (Cook 1985). Analysis of radial increment series was also determined for the common period (1938–2010) for STD and RES chronology. The following characteristics of the chronologies were calculated: mean sensitivity–MS (Fritts 1976), Expressed population signal–EPS (Fritts 1976, Wigley et al. 1984), Signal-to-noise ratio–SNR (Wigley et al. 1984) and first principal component–PC1 (Fritts 1976).

To identify relationships between climatic variables and oak radial growth (growth indices) Pearson correlation coefficients between RES chronology and seasonal precipitation and temperature of the previous and the current year were first calculated. The correlation coefficients were also carried out between RES chronology and monthly precipitation and temperature with original growth-climate data and with pseudo-data of 1000 simulated sub-samples on the growth and monthly climate values with the same size as the initial sample of climatic and radial growth data, i.e. by bootstrap correlation analysis according to Zang and Biondi (2013). These 1,000 pseudo-data sets were created by random extraction with replication from the original data set and according to this procedure a set of 1,000 correlation coefficients was produced. Sessile oak growth-climate relationship was further studied by means of response functions. The applied response function analysis includes 24 precipitation and temperature variables from October prior to September of the current year. Response analysis was carried out for 38 years, by using DendroClim 2002 software (Biondi and Waikul 2004). PRECON software (Fritts 1999) was used to calculate response function coefficients and to estimate the value of the chronology variance predicted by the coefficients of climate. Finally, the mentioned growth-climate relationship was studied by pointer years analysis. Pointer years are determined according to the instructions from Becker et al. (1994). Pointer years are those, in which at least 75% of the series show the same trend of increase or decrease of radial growth, with tolerance threshold 10%. In this research, the Becker method was applied to the non-standardized values (raw data) and the standardized values (prewhitened series) of the radial increment. The entire process of calculation was done by using its own R code, whose results were compared with the dplR library results (Bunn 2008).

Results

Description of raw-tree ring series and master standard and residual chronology

The results triple the procedure of synchronization or dating tree rings showed that in two series of radial increment there was the existence of a problem in dating (the total number of problematic segments in all series in absolute terms was seven, while in the relative 7.7%). Therefore, as a result of poor matching in some sections of the oak master chronology, two oak trees were rejected. The definite sample was compiled from 20 trees, and the main statistical characteristics in Table 2 are presented.

In 10 radial increment series, the sample depth dates to 1925, in 13 series – to 1930 and in all 20 series – to 1937. The number of tree rings in the individual raw chronologies (N) ranges from 74 to 99 (84.8 in average). From the raw date, high maximum ring-width value ($i_{r\max}$) of up to 6.22 mm (4.93 ± 0.19 mm on average) and mean ring-width value ($\bar{i}_r$) up to 3.29 mm (2.35 ± 0.09 mm on average) were recorded (Table 2). The average level of correlation of each series with the master chronology ($r_{x,y}$) is 0.659 ± 0.029. Autocorrelation coefficients (AC1) of the raw ring series range from 0.422 to 0.904, on average 0.664 ± 0.026.

Table 2. Characteristics of 20 sessile oak tree ring series (raw date)

	$\bar{X}$	$S_{\bar{X}}$	Min	Max	S^2
N	84.8	1.37	74	99	41.6
$\bar{i}_r$ (mm)	2.35	0.09	1.39	3.29	0.19
$i_{r\max}$ (mm)	4.93	0.19	3.12	6.22	0.84
$r_{x,y}$	0.659	0.03	0.27	0.80	0.02
MS	0.239	0.008	0.185	0.309	0.001
AC1	0.664	0.026	0.422	0.904	0.14

* is mean value, is standard error of the mean, Min is minimum value, Max is maximum value and is variance. Please, refer to the text for other abbreviations

The STD and RES chronologies are shown in Figure 3. The chronologies span for 92 years from 1919 to 2010. The average number of tree-rings (series length) is 85. As mentioned before, the established oak master chronologies consisted of 20 tree-ring series, and seven of them have exceeded 90 years in length.

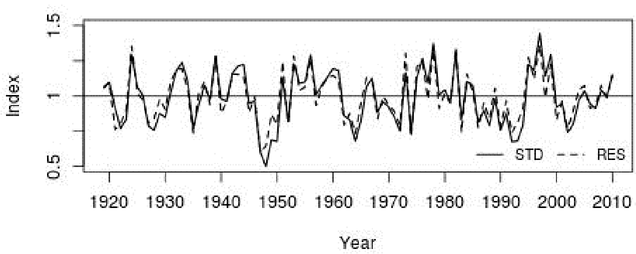

Figure 3. The STD and RES chronology for the studied stand and site

The basic features of the oak master chronologies developed for this study are presented in Table 3. AC1 is 0.381 for STD and 0.013 for RES. Mean sensitivity (MS) of RES chronology is higher than of STD, 0.205 and 0.175, respectively, but the standard deviation (S_d) is *vice versa*: 0.177 in RES and 0.192 in STD chronologies. The values of expressed population signal (EPS) and signal-to-noise ratio (SNR) of both chronologies are the same (EPS) or very similar (SNR).

Table 3. Characteristics of the oak chronologies developed for this study

Chronology	S_d	EPS	SNR	MS	AC1
STD	0.192	0.96	23.8	0.175	0.381
RES	0.177	0.96	23.0	0.205	-0.013

Please, refer to the text for the abbreviations

Values of r_{bar}, EPS, SNR and PC1 for a common period, from 1938 to 2010, are very similar for the both master chronologies (Table 4). Therefore, in order to evaluate the effects of precipitation and temperature variations on sessile oak radial growth, the residual chronology was selected in these studies, since the values of the indices within this chronology are “cleaned” from the strong influence of autocorrelation.

Table 4. The characteristics of STD and RES master chronologies for the common period (1938–2010)

Chronology	r_{bar}	EPS	SNR	PC1
STD	0.543	0.96	23.803	57%
RES	0.534	0.96	22.954	56%

* r_{bar} – average correlation between all the series. Please, refer to the text for other abbreviations

Correlation analysis

At first, we tried to detect the period during which precipitation and temperature correlated best with the radial increment. For this purpose, the Pearson correlation coefficients were calculated between RES chronology and seasonal data of precipitation and temperature (Table 5). The sum of precipitation in January-December ($p < 0.001$) and the sum of precipitation in September-October ($p < 0.001$) of the previous year show the highest values of positive correlation and the highest level of significance with RES chronology. There is also a positive correlation between the radial growth and precipitation during the vegetation period (April-October), in the warmest part of the year (July-August) and November-December of the previous year. A negative correlation between the above mentioned variables was established in September-October of the current year. A negative correlation was also obtained with seasonal data of temperature in June-August (-0.37) and July-August (-0.33) and a positive link with September-October (+0.35) of the current year.

Then correlation coefficients were conducted between RES chronology and monthly data of precipitation and temperature. Correlation coefficients from the original data and the bootstrap correlation coefficients with the limits of the confidentiality of 95%

Table 5. Correlation between RES chronology values and seasonal precipitation and temperature

Period	Correlation	
	Precipitation	*Temperature*
January–December (previous)	+ 0.42 ***	+ 0.14
April–October (previous)	+ 0.39 **	- 0.17
April–September (previous)	+ 0.27	- 0.15
April–May (previous)	- 0.03	- 0.06
June–July (previous)	+ 0.06	+ 0.06
June–August (previous)	+ 0.25	- 0.002
July–August (previous)	+ 0.37 *	- 0.04
September–October (previous)	+ 0.55 ***	- 0.30
November–December (previous)	+ 0.33 *	- 0.07
January–December	+ 0.01	- 0.20
January–Mart	+ 0.13	- 0.05
April–October	+ 0.01	- 0.17
April–September	+ 0.12	- 0.26
April–May	+ 0.20	- 0.32
June–July	+ 0.02	- 0.21
July–August	- 0.06	- 0,33 *
June–August	+ 0.08	- 0,37 *
September–October	- 0.32 *	+ 0.35 *

*$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ for two–tailed test

(solid line) and 99% (dashed line) are presented on Figure 4 (precipitation) and Figure 5 (temperature). The obtained correlation coefficients of original growth-climate data (Figure 4, left) indicate the existence of a statistically significant positive correlation between growth and precipitation in August ($r = 0.36$, $p = 0.025$) and October ($r = 0.51$, $p = 0.001$) of the previous year. It should be noticed that a significant correlation between growth and precipitation in the current year has not been established by this procedure. The values of correlation coefficients defined by the bootstrap procedure (Figure 4, right) confirmed and extended the obtained results. Exactly, a statistically significant positive correlation was found between growth and monthly precipitation for all months from August to

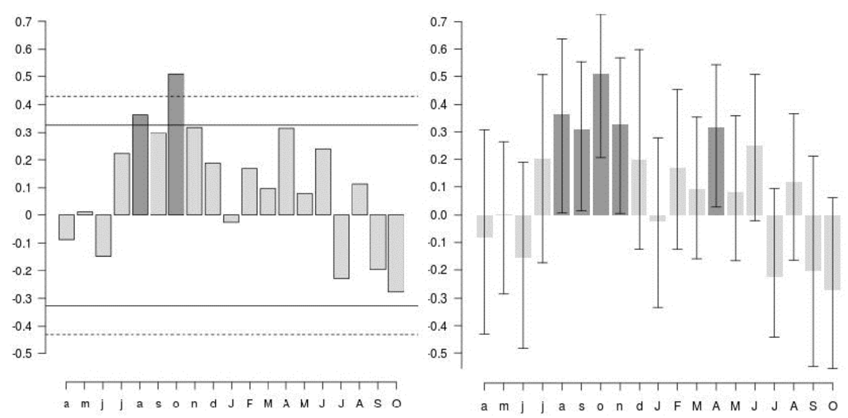

Figure 4. Values of the calculated correlation coefficients obtained by the bootstrap procedure (right) and without it (left). Correlations were calculated between the residual chronology and monthly precipitation from the previous April to the current October. A correlation coefficient above the horizontal solid line (darker bars) is referred as significant at the 0.05 α-level (two-tailed test). Horizontal dashed lines correspond to 99% significance level in a two-tailed test. Lower case denotes month in the year previous to the current year growth season. Upper case denotes month of the current year

November of the previous year and April of the current year. The values of the obtained correlation coefficients by bootstrap procedure for August-November of the previous year and April of the current year (0.36, 0.31, 0.51, 0.33 and 0.32) are virtually indistinguishable from the values obtained by the simple correlations (0.36, 0.30, 0.51, 0.32 and 0.32). The difference in the values of correlation coefficients by these two procedures exist in the fact that the coefficients obtained by a bootstrap procedure are within the limits of 95% confidentiality for all of the above months, while in the first case only for August (p = 0.025) and October (p = 0.001) of the previous year.

A statistically significant negative correlation was found between the radial growth and temperature in September (-0.38, p = 0.017) of the previous year and April (-0.37, p = 0.023) and August (0.40, p = 0.012) of the current year (Figure 5, left). Correlation coefficients obtained by the bootstrap procedure were -0.39, -0.37 and -0.40, respectively (all of $p < 0.05$) and they do not differ in their values nor the statistical significance (Figure 5, right).

Response function analysis

The results of the response function analysis are similar to those described by correlation analysis. The obtained climate models found three months to be statistically significant (current August temperature and previous October and November precipitation). In so doing, radial growth is positively correlated with precipitation and negatively with temperature. The highest influence on growth was observed in the current August temperature (-0.298, $p < 0.05$).

It is obvious that, according to this procedure, the influence of precipitation in the current month and year became much less pronounced. In addition, the impact of the previous September temperature was not detected by this procedure in comparison to the correlation analysis.

Pointer year analysis

Pointer years derived from raw tree-ring width series (white dots) and pointer years from prewhitened tree-ring series (black dots) are presented in Figure 6. Pointer years from raw tree-ring series cover longer period (1920–2002) than pointer years from prewhitened series (1936–2000).

The number of pointer years in raw data (n=31) is bigger than the number of pointer years in prewhitened data (n=28). However, if we exclude the defined pointer years from 1920–1935 (three positive and one negative), which were produced only for raw tree-ring data, then there are more pointer years in the prewhitened (28) than in the raw data (27). The positive pointer years of raw data were recorded in 1920, 1924, 1929, 1939, 1949, 1951, 1953, 1965, 1966, 1973, 1975, 1978, 1982, 1984, 1995 and 1997. Common positive pointer years for raw and prewhitened ring data series were detected in 1939, 1949, 1951, 1953, 1965, 1973, 1975, 1978, 1982, 1984, 1995 and 1997. Other positive pointer years of prewhitened tree-ring data were found in 1936 and 1991.

The negative pointer years of raw tree-ring series were found in 1935, 1940, 1945, 1947, 1952, 1957, 1962, 1964, 1968, 1979, 1983, 1986, 2000 and 2002. Common negative pointer years for raw and prewhitened ring data were detected in 1940, 1945, 1947, 1952, 1957, 1962, 1968, 1979, 1983, 1986 and 2000. The negative pointer years of prewhitened data were only observed in 1974, 1990 and 1998. There were not relatively long periods, when none of the pointer years were recorded. The recent period 2000–2010 was characterized by the lowest number of pointer years (only in 2002)

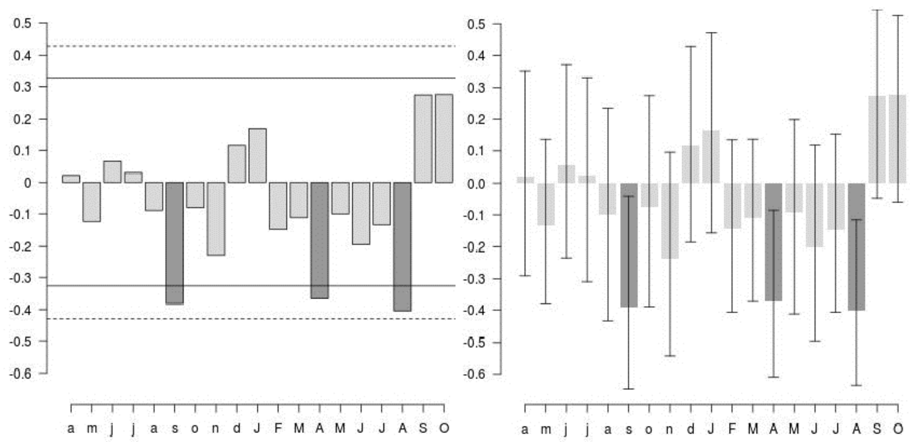

Figure 5. Values of the calculated correlation coefficients obtained by the bootstrap procedure (right) and without it (left). Correlations were calculated between the residual chronology and temperature from the previous April to the current October. A correlation coefficient above the horizontal solid line (darker bars) is referred as significant at the 0.05 α-level (two-tailed test). Horizontal dashed lines correspond to 99% significance level in a two-tailed test. Lower case denotes a month in the year previous to the current year growth season. Upper case denotes a month of the current year

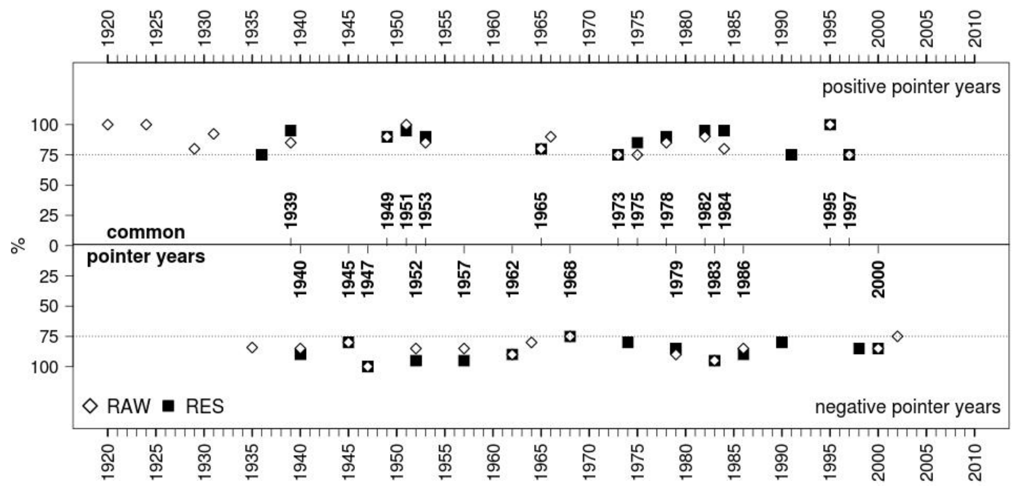

Figure 6. Pointer years for raw and prewhitened ring data

Discussion

Representativeness of the obtained chronologies

The extraction of climate signal from tree-rings is hampered by many factors, which influence tree growth and, therefore, it is necessary to explore a variety of climatic parameters in more integrated approaches to understand the complex relationships between variability of climate elements and tree physiologic responses in temperate forests (Fridrichs et al. 2009). For this goal, the first and basic step in the research is the proper selection of the final sample, which should contain a sufficient value of common signal in growth (Briffa and Jones 1990). This signal represents a common variability present in all series of radial increment in the given site conditions.

The quality of the analyzed samples was tested by using a variety of dendrochronological and statistical parameters. The series of tree-ring widths in a definite sample, on average, showed a satisfactory degree of interdependence, because the resulting average value of series intercorrelation (0.659 ± 0.029) is in the range of common values of these indicators for most chronologies (0.550-0.750), according to Grissino-Mayer (2001). The majority of recorded MS values of the analyzed empirical ring series (Table 1), as instructed by Grissino-Mayer's (2001), can be attached to the group of the middle sensitive series (MS values of 16 out of the 20 series were between 0.20 and 0.30). The obtained values of average AC1 are quite high (0.697 ± 0.015), but belong to Grissino-Mayer's (2001) most common category of values. Procedures implemented (standardization, averaging the obtained indices and performing the autoregressive modelling) removed the low-frequency trend and autocorrelation from the raw tree-ring data. The absence of autocorrelation within the RES chronology, which was selected to determine the growth-climate connections, was confirmed by the Ljung-Box test (p = 0.2257, df = 18, Q_m=22.1427). The average MS in STD and RES master chronologies is not high (0.175 and 0.205) and compared to raw data points to a slightly lower average variability of two consecutive indices of tree-ring width than two consecutive raw tree-ring widths. Both types of chronology show very high values of EPS (0.96) and SNR (H" 23). The percentage of the variance explained by PC1 for both types of chronology is almost identical (56% and 57%). The first three PCs for the STD chronology have eigenvalues above 1 and account cumulatively for more than 69% of the total variance. For the RES chronology the first four PCs have eigenvalues above 1, comprising for more then 71% of the total variance. Certainly, PC1 has the largest effect on the variation of radial growth while the effect of the PC2 and PC3 is much smaller. Finally, it can therefore concluded that the established chronologies possess a sufficient level of common signal and that used purified and homogenized definite sample was sufficient to obtain the desired signal, which represents the common variability present in all series of radial increment.

Growth-climate relationships

In general, deciduous oaks are sensitive to the environment and are characterized by homogeneous radial growth over the large areas as well as similar pattern of dendroclimatic response (Romagnoli and Codipietro 1996, Popa et al. 2013). It is, however, important to note that oaks can show a specific growth-climate relationship, which depends on species and region (Tessier et al. 1994, Cedro 2007, Čufar et al. 2008b, Drobyshev et al. 2008. Friedrichs et al. 2009, Čufar et al. 2014).

In our study, the influence of climatic factors on the radial increment of sessile oak trees was studied by means of (1) correlation analysis between radial increment (residual chronology) and seasonal precipitation and temperature data, (2) correlation analysis between original data of the radial growth and monthly climate values, (3) bootstrapped correlation between radial growth and monthly climate data, (4) response function and (5) pointer years analysis.

Radial increment-precipitation relationship

The obtained results showed a link between sessile oak radial increment and studied climate elements. After summarizing all the data we can infer that the radial increment of sessile oak in the investigated location depends mainly on the precipitation. The determined dependence of oak primarily on precipitation corresponds to the results of earlier research (Romagnoli and Codipietro 1996, Lebourgeois et al. 2004, Cedro 2007, Di Filippo et al. 2010, Anderson et al. 2011). In addition, the precipitation of the previous year is of the utmost importance for the formation of the radial growth of the current year. According to the results of correlations between radial increment and seasonal precipitation it can be concluded that a high total annual precipitation, rainfall during the vegetation period (April-October), warmest part of the year (July-August), autumn (September-October), late autumn and early winter period (November-December) of the previous year result in larger oak radial increment in the next growing season. Importance of summer and autumn monthly precipitation of the previous year for the radial growth in the next year was confirmed by the results of applied correlation analyses and response functions. According to these procedures, there is a statistically significant positive correlation between the radial increment and precipitation during August and October of the previous year (correlation coefficients from the original data), i.e. August-November (the bootstraped correlation coefficients) and October-November (response functions) of the previous year. A positive influence of the previous autumn (by seasonal precipitation data), previous August and October (by simple correlation analysis) and prior October and November (by response functions) precipitation on sessile oak radial growth is direct in accordance to the results of Lebourgeois et al. (2004) and Michelot et al. (2012) in France and Popa et al. (2013) in Romania.

In general, relationships between growth and climatic factors have been mostly studied by the correlation or response function analysis. However, the pointer year analysis can provide some additional information on an individual year basis and can be considered as a supplement to the calculation of linear regression models (Lebourgeois et al. 2004). For this purpose, we have also applied pointer years' analysis and the obtained results showed a similar pattern of dendroclimatic response of sessile oak as by prior procedures. Out of 15 pointer years of the common growth-climate time period (available data for both variables), 11 ones show the same previous year mean annual precipitation trend, 12 ones the same previous year September-October precipitation and 13 ones the same previous year October precipitation trend (Figure 7). Thus, the relationship between growth and previous year precipitation in the analyzed periods and months is clearly visible, i.e. when precipitation increases, the radial increment increases and *vice versa*.

The decisive influence of the precipitation of previous season on growth in the forthcoming year may be explained by the fact that buds, formed during the previous year contain primordial meristematic tissue from which the leaves in the coming years will be partly formed (Fritts 1963, Rentch et al. 2002). This may reflect the greater assimilation surface, which supports the larger ring width in the coming growing season. Nevertheless, a positive correlation between precipitation in September-November of the previous year and current radial increment is associated with the accumu-

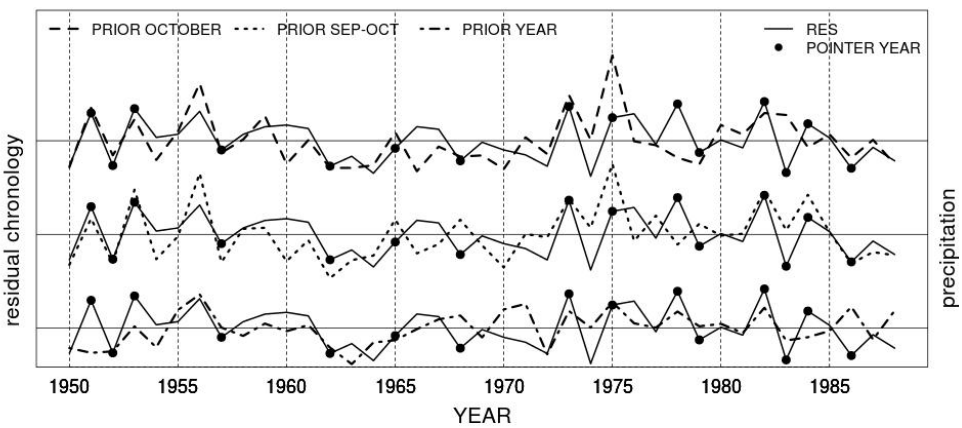

Figure 7. Comparison between the residual curve and the previous year precipitation, previous September—October precipitation and previous October precipitation

lation and concentration of non-structural carbohydrates to be used at the beginning of the next vegetation period (Barbaroux and Breda 2002). Another explanation regarding the positive influence of the previous September–November precipitation on the radial growth may be related to the growth of the root system. If there was enough rainfall in the previous autumn, the root system will continue to grow until winter and this well-developed root system from the previous year will provide the better growth of the aboveground parts of the plants and, therefore, the radial growth in the next year (Santini et. al. 1994, Lebourgeois et al. 2004). As the amounts of rainfall in September (44.5 mm) and October (46.1 mm) in our study are at the lowest level, which is far below the average monthly rainfall (62.8 mm), it can be concluded that quantity of precipitation in these months is probably essential for the radial growth of sessile oak in the next growing season. The established negative correlation between the radial growth and precipitation (positive correlation with temperature) in September–October of the current year can be explained by the specific physiological activity of oak at the end of the growing season. Namely, according to Bassow and Bazzaz (1998), oak in this period is much more sensitive to lower temperatures compared to the spring and summer period. Considering that the results of some studies (Akkemik et al. 2006) suggests that, especially during drought, 90% of the annual radial increment is already established by the end of July or mid-August and that tree completely stops radial increment in the mid-September, the aforementioned results and explanations should be taken with a grain of salt. This is demonstrated by the fact that the coefficients of above mentioned correlation between the radial increment and temperature/precipitation in September-October are near the margin of statistical significance (p_{temp} = 0.0477, p_{prec} = 0.0499). However, one should not exclude the possibility that warm September positively but slightly affect the radial growth of the current year, as previously noted by other researches (Bronisz et al. 2012). Of course, the results should be conditionally viewed in the light of the different length of the growth, i.e. the growing season in some regions.

Radial increment-temperature relationship

The obtained results of the correlation between sessile oak radial increment and seasonal temperature data pointed out that there is a significant negative influence of current summer temperature on the radial growth (Table 5). By this procedure also it has been noted a positive correlation between the radial growth and temperature in September–October of the current year. Although, the higher temperature at the end of the growing season (September–October) has a positive influence on the radial growth of the current year, this impact is negligible compared to the influence of precipitation during this period of the previous year, which shows the highest correlation coefficient (r = 0.55, p < 0.001). Nevertheless, current August temperatures may be less important because the tree-ring of the current year is mostly formed before August. Regarding the results of correlation and response functions, one could infer that September of the previous year and April and August temperature of the current year play an important role (both methods of correlation analysis), but when using the response function analysis only the impact of the current August temperature is distinguishable. Results of pointer year analysis have highlighted the effect of the current April temperature. According to this procedure, out of the 15 analyzed pointer years, 12 ones have the inverse current April temperature trend and only 10 ones have the inverse current August temperature trend (Figure 8).

The negative correlation between the radial increment and spring temperature of the current year can possibly be explained by the higher efficiency of assimilation and conversion food materials in certain

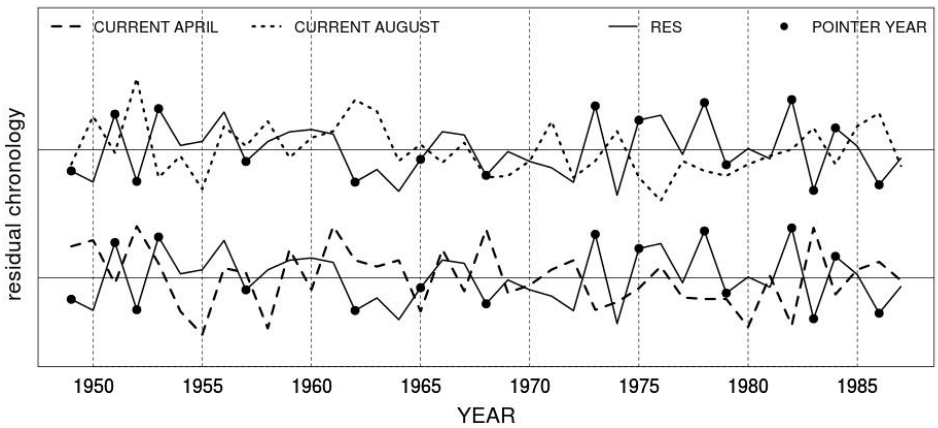

Figure 8. Comparison between the residual curve and current August and current April temperature

parts of the cells, when temperatures are lower (Fritts 1963). On the other hand, a lower temperature is often correlated with higher precipitation. In general, at the beginning of the growing season in Serbia, precipitation is usually not a limiting factor for the onset of radial growth, due to large amount accumulated during the late autumn and winter months. However, since the average precipitation in January-March (52.7 mm) was below the mean monthly precipitation (62.8 mm), lower temperatures and thus higher precipitation in April can be a much-needed for the plants. In addition, on a deep, high-quality and well drained soils (such as soil in this study area) lower temperatures and higher precipitation in April can have a beneficial effect on tree-ring width, which is related to a possibility of a deeper penetration of water into the soil and better water infiltration and soil aeration. These results in higher moisture content required for the growth of trees at the beginning of the growing season. The fact that in this study the soil is characterized by good water-air regime may also be evident on the basis of established negative correlation between the radial growth and temperature in August. Namely, on the shallow and poor-watered soils a negative impact of temperature is primarily reflected in July, which in some species can often result in reduced and even stopped radial increment. On the other hand, on the favourable soils (deep soil, well supplied with water and nutrients) the influence of temperature on the radial increment is probably expressed in August. Because of the prolonged retention of water in the soil, a tree withstands high temperatures in June and July without much difficulty. But, in case of further exposure to high temperatures in August, followed by small amounts of precipitation, radial growth can be much reduced in August. This statement is supported by the negative correlation between the radial increment and temperature in the period June-August and July-August and the absence of negative correlation in June-July. Of course, the effects of the negative impact of these events on the radial increment are different depending on the site conditions.

Regarding to the temperature, our results are in concordance with a common feature of the oak response (oaks react negatively to summer temperatures) in many European countries, as it is the case in Poland (Cedro 2007), Estonia (Läänelaid et al. 2008), Romania (Nechita and Popa 2011), Italy (Santini et al. 1994) and Hungary (Kern et al. 2012). Quite the opposite was found by Pilcher and Grey (1982) at thirteen sites in the British Isles and they concluded that high temperatures in early summer favour growth. The fact that higher April air temperature of the current year (here obtained by applying simple correlation analysis) decreases the radial increment of oak is related to the results of Nechita and Popa in Romania (2011) and Kern et al. (2012) in Hungary. A negative impact of previous year temperature on growth was not sufficiently clearly detected in our study, except for the previous September (by applying simple correlations). In contrast, the highest positive influence of the previous temperature (January-April) on the current radial increment was detected by Bednarz and Ptak (1990) for southern Poland area. That the previous September temperature negatively affected the radial growth in the current year was also a particular result of research conducted by Michelot et al. (2012).

According to the research by Čufar et al. (2014), which indicates the first features of dendroclimatological behavior of oak in Serbia (probably pedunculate oak), oak radial growth in the territory of Srem is not affected by air temperature in the summer months. However, their research was conducted in the plain area of Srem, at lower altitude located near the Sava river, contrary to our study that was carried out in the part of Srem near Fruska Gora Mountain. In addition, these authors did not find any statistically significant relationship between oak growth and any monthly temperature or precipitation data of the current year. These results are in accordance neither with our results nor with the results of some other studies in the neighbouring countries, for example in Romania (Nechita and Popa 2011) and Hungary (Kern et al. 2012). However, there are some results that our research have common with the results of the abovementioned research by Čufar et. al. (2014). Namely, the results (the negative impact of current August temperature on the oak radial growth) obtained from the oak site in Hungary (U02-Zamardi), at an altitude of 204 m, correspond to the results of our research.

If we recalculate the correlation coefficients of all growth-seasonal/monthly conducted correlation analyses to the coefficients of determination, we can infer that studied climatic factors explain only 9-30% of the radial increment variability. Based on these results we can conclude that the response of sessile oak radial increment to climate variations was relatively weak. On the other hand, results of the PC regression obtained by PRECON software (Fritts 1999) suggest that the value of variance in residual chronology explained by climatic parameters amounts to 58.3%. Significant coefficients of the response function obtained by PRECON are from the same months as coefficients from DendroClim2002, but values are somewhat different due to differences in the way, in which coefficients were calculated (median in DendroClim2002 and mean in PRECON).

Conclusions

The oak from the studied site showed good cross-dating possibilities and a satisfactory common signal, making them suitable for dendroclimatological studies. In order to detect climatic responses of sessile oak from the analyzed site correlation analysis, response functions and pointer year analysis were used. Radial growth of sessile oak for studied site conditions was influenced more by precipitation than by temperature. In addition, precipitation of the previous year, especially in September-October, is of the utmost importance for the formation of the radial growth in the forthcoming year. Temperature in April (less pronounced) and August (more pronounced) of the current year has a decisive impact on the values of radial increment. By applying pointer year analysis, the influence of current April temperature on oak radial growth has gained importance. The largest number of identified pointer years corresponded to wet previous September and October.

Finally, it should be noted that the results described here are a preliminary stage of dendroclimatological study of sessile oak in Serbia. Unfortunately, used chronology has been built only from living trees and it has a relatively short span. In addition, absence of satisfactory climate records has partly limited the definitive conclusions. Because oak at this site does not grow too far from its altitude limits, it may be expected that the radial growth depends on many climatic variables simultaneously. For this reason, future studies should be undertaken in order to expand the database and knowledge of the climate influence on the growth of oak in the studied region as well as in other regions of Serbia. In addition to simple correlations and response functions, in order to provide the most comprehensive dendroclimatological information about the dominant mode of response between sessile oak radial increment and precipitation or temperature some other well-known procedures (for example, calculation of multiple regression stepwise analysis) should be applied. Nevertheless, a specific investigative approach, which includes a separate analysis of early and latewood response to precipitation and temperature may be very helpful representing the next step forward in gaining new knowledge about the oak growth-climate complex relationships. The combination of these procedures should provide such information basis, which should emphasize the potential of oak trees as a proxy record capable of climate reconstruction in temperate conditions of Serbia. Therefore, the obtained findings are a necessary basis for a complex understanding of these ecosystems and development of sustainable management plans.

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