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Climate Signals in Earlywood, Latewood and Tree-Ring Width Chronologies of Sessile Oak (*Quercus petraea* (Matt.) Liebl.) from Majdanpek, North–Eastern Serbia

Klimatski signali u kronologijama ranog drva, kasnog drva i širini goda hrasta kitnjaka (*Quercus petraea* (Matt.) Liebl.) iz Majdanpeka, sjeveroistočna Srbija

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ABSTRACT • *In this article, the dependence of the sessile oak (Quercus petraea (Matt.) Liebl.) radial growth (tree-ring, earlywood, and latewood widths) on climate (the mean monthly temperature and precipitation totals) was studied in the Majdanpek area, north-eastern Serbia. The growth response of the oak trees to the prevailing climate conditions was dendroecologically investigated, by applying the correlation and response function, as well as by pointer years analysis. The site chronology covered 159 years (1855-2013). We found that latewood and total tree-ring width contain the imprinted positive response to the amount of precipitation in summer months (June and July) of the current growing season. The earlywood width showed no direct dependence on climate data, but it was significantly affected by the previous-year latewood width. Moreover, 40 % of the variation in the latewood width is explained by the earlywood variation in the same season. The temperature was not found to have any significant effect on the growth of oak at the study site. The use of pointer years, determined by applying several calculation procedures, has highlighted previous results, indicating that the precipitation in summer months was the deciding climate factor leading to the occurrence of the years with exceptionally wide or narrow tree-rings and latewood. To enhance our understanding of the response of the sessile oak growth at south-oriented sites with a shallow soil profile to precipitation and temperature variations, and expand the current database and knowledge, future studies should be undertaken.*

Keywords: *dendroecology; earlywood; latewood and tree-ring; pointer years; sessile oak; Serbia*

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SAŽETAK • *U radu je proučavana ovisnost radijalnog prirasta (širine goda, širine ranoga i kasnog drva) hrasta kitnjaka (Quercus petraea (Matt.) Liebl.) o klimi (srednjoj mjesečnoj temperaturi i količini oborina) na području Majdanpeka, u sjeveroistočnoj Srbiji. Odziv radijalnog rasta hrastovih stabala na prevladavajuće klimatske uvjete istražen je dendrokronološki, primjenom korelacijske i odzivne funkcije, kao i analizom pokaznih godina. Kronologija staništa obuhvatila je 159 godina (1855. – 2013.). Otkrili smo da kasno drvo i ukupna širina goda sadržavaju utisnut pozitivan odziv na količinu oborina u ljetnim mjesecima (lipnju i srpnju) tekuće sezone rasta. Širina ranog drva nije pokazala izravnu ovisnost s klimatskim uvjetima, ali je na nju značajno utjecala širina kasnog drva iz prethodne godine. Nadalje, 40 % varijacija širine kasnog drva objašnjava se varijacijama ranog drva iz iste sezone. Na istraživanom staništu nije utvrđeno da temperatura ima značajan utjecaj na rast hrasta. Primjena pokaznih godina, koje su određene primjenom nekoliko računskih postupaka, potvrdila je prethodne rezultate upućujući na to da je prevladavajući klimatski čimbenik koji je doveo do pojave izrazito širokih ili uskih godova i kasnoga drva u pojedinim godinama bila količina oborina u ljetnim mjesecima. Da bi se sveobuhvatno razumjela reakcija rasta hrasta kitnjaka na promjene temperature i količinu oborina na južnim ekspozicijama i s plitkim profilom tla, trebalo bi provesti dodatne studije kako bi se proširila baza podataka i spoznaja.*

Ključne riječi: *dendrokronologija; rano drvo; kasno drvo i god; pokazne godine; hrast kitnjak, Srbija*

1 INTRODUCTION
1. UVOD

Although oaks are among the most investigated tree species in Europe in terms of dendrochronology and dendroclimatology, oak dendrochronology is a dynamic and continuously evolving discipline (Haneca *et al.*, 2009). The majority of oak chronologies have been developed in Central and Western Europe (Čufar *et al.*, 2014b). In the Balkan Peninsula, the highest number of oak dendrochronological and dendroclimatological studies have been performed in Slovenia (Čufar and Levanič, 1999; Čufar *et al.,* 2008; 2014a; 2014b; Čater and Levanič, 2015 etc.), Romania (Popa *et al.*, 2013; Ważny *et al.,* 2014; Nechita *et al.,* 2017 etc.) and Bulgaria (Asenova *et al.,* 2001; Mirtchev *et al.,* 2012; Zafirov and Kostov, 2019 etc.). The studies of oak growth-climate relationships, based on the latest dendrochronological procedures, have been rather poorly performed in other countries of this part of SE Europe. In Croatia, Čufar *et al.* (2014a) constructed a pedunculate oak radial growth chronology from Kobiljak and investigated the oak climate-growth relationships for this site near Zagreb. This chronology and an oak chronology from Serbia have been used within a network of 41 local oak tree-ring chronologies to detect common climatic signals in oak tree rings in SE Central Europe (Čufar *et al.,* 2014b). The pedunculate oak sensitivity to climate and hydrological parameters in the floodplain forests in the lowland Croatia was studied by Mikac *et al.* (2018). In Serbia, similar research of the pedunculate oak growth and mortality in oak floodplain forests, depending on the change of water regime and climate, was performed by Stojanović *et al.* (2015). Some facts about the dendroclimatological behaviour of sessile oak in Serbia were presented by Stajić *et al.* (2015). The relationships between the radial increment and stable carbon isotope of *Q. robur* and *Q. cerris* and climatic variables have been most recently examined by Kostić *et al.* (2019), etc.

Despite numerous studies that have been conducted across Europe in the past decades, information about the oak growth-climate response is still lacking in South-Eastern Europe (Stajić *et al.,* 2015). Therefore, given the substantial potential significance of SE Europe for dendrochronological research (Ważny *et al.,* 2014), as well as the insufficient number of such studies in Serbia, the first goal of this research was to construct the sessile oak tree-ring chronology for the study site conditions near Majdanpek (North-Eastern Serbia). After defining the new oak chronologies, further research efforts will be focused on identifying the most important climatic elements that influence the radial growth of this species. To obtain the strongest climatic signal possible, we developed sessile oak chronologies separately for the total ring width (TR), earlywood width (EW), and latewood width (LW).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The research was carried out in a pure mature sessile oak forest (*Quercetum montanum tilietosum tomentosae*) in a regeneration phase, in the locality of Debeli Lug, Majdanpek, in north-eastern Serbia (Figure 1). The sampling (stem discs at breast height) was conducted at around 300 m a.s.l, on shallow soil of slightly steep, south-facing terrain. The climate data were obtained from the "Debeli Lug" meteorological station (290 m a.s.l.). The available climate data covered the period from 1949 to 2013, but the records were quite incomplete. To fulfil the gaps and prepare the data for a dendroclimatological analysis correctly, we applied the Inverse distance interpolation with five nearest nearby meteorological stations (Žagubica, Kučevo, Negotin, Donji Milanovac and Bor), and the data were tested for homogeneity. The average annual temperature (9.8 °C) is close to the average value in Serbia amounting to 10.1°C. The warmest and coldest months are July (20.3 °C) and January (-1.3 °C). The annual sum of precipitation is 734 mm/m^2 and it also reflects the country's average (Popović *et al.,* 2005).

To study oak radial growth-climate relationships, we sampled 19 dominant sessile oak trees with a diameter ranging from 42.6 to 72.3 cm. The measurements of EW, LW, and TR widths were performed in two directions using a Lintab device (38 empirical RAW series). The obtained series were cross-dated visually and

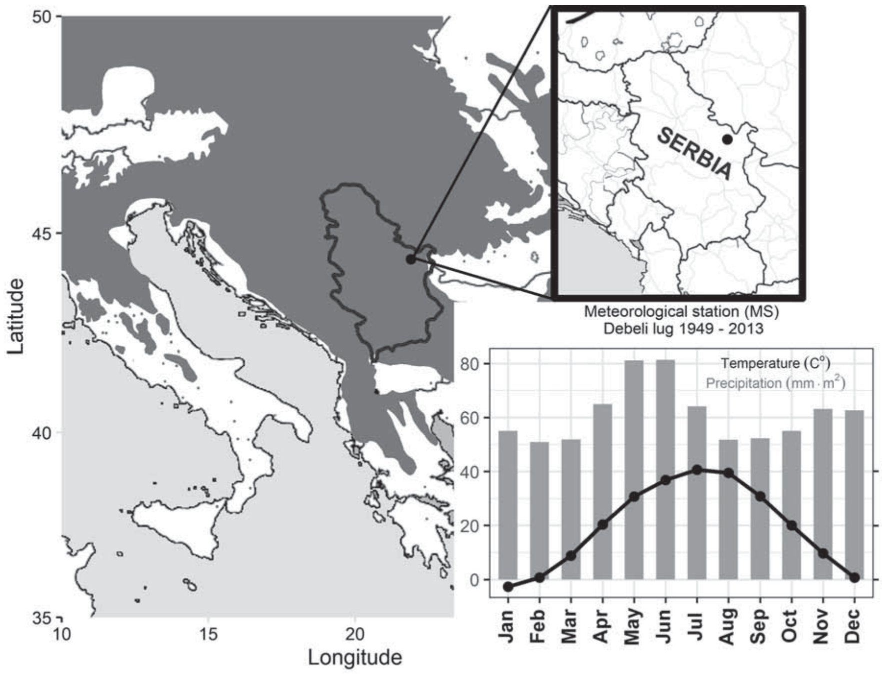

Figure 1 Location of the study stand (black dots) within the sessile oak areal (dark grey) and within the state border of Serbia (upper right corner). The sum of precipitation (grey bars) and mean air temperature (black line with dots) are given in the lower right part

Slika 1. Lokacija istraživane sastojine (crne točkice) unutar područja rasprostranjenosti hrasta kitnjaka (tamnosivo) i unutar državne granice Srbije (gornji desni kut). Ukupna količina oborina (sivi stupci) i srednja temperatura zraka (crna linija s točkama) dani su u donjem desnom dijelu slike.

statistically in the R environment (R Development Core Team, 2008). At the same time, the conventional statistical parameters were calculated. The stand w regularly managed and, therefore, the series were detrended by using a cubic smoothing spline having a 50 % cut-off at 67 % of the series length (Cook and Peters, 1981). The series of standardised indices were obtained after the measured widths were divided by the estimated values. The “prewhitened” series were then established as a residual of the autoregressive modelling, where the order for the individual series was determined by the Akaike Information Criterion. Both types of indices were subsequently averaged by applying a biweight robust estimation of the mean value (Cook *et al.*, 1990). Thus, we developed a standard (STD) and a residual (RES) chronology for each part of the radial increment separately. The presence and the strength of the common signal in the series were evaluated by computing several widely-applied dendrochronological parameters: the mean total, the correlation within and between the trees (r_{tot}, r_{wt}, r_{bt}), Expressed Population Signal (EPS) and Signal-to-Noise Ratio (SNR).

The influence of climatic factors on the width of EW, LW, and TR was studied using (1) the correlation analysis between the developed chronologies and climate and (2) the response function analysis. We used the monthly sum of precipitation and the mean temperature data of the previous August to October of the current year (30 independent variables). Besides, TR, EW, and LW from the current and the previous year were also included in the analysis. The significance of the obtained correlation coefficients was determined following the bootstrapping procedure (Zang and Biondi, 2015). The temporal stability of the radial growth-climate relationships was evaluated using moving windows. Because of the higher number of predictors included in the regression, the coefficients were calculated for 50-year long periods, moved for one year across the common period. Furthermore, pointer years in the longest common period of RES were examined by using three different approaches, i.e., nine calculation variants. For the interval trend (IT), we applied the routines suggested by Schweingruber (1983) and Becker *et al.* (1994), following the instruction of Jetschke *et al.* (2019) for pointer year threshold of 0.95. The calculation of the relative growth change (RGC) was based on four preceding years (Schweingruber *et al.*, 1990). The normalisation in a symmetrically moving window (NW) was implemented by using a window of different sizes as well as different thresholds for the event year occurrence (Cropper, 1979; Neuwirth *et al.*, 2007). For the pointer year identification within RGC and NW methods, we adopted the threshold of 0.75, as recommended by Jetschke *et al.* (2019). All calculations were conducted in R language (R core team, 2008), with the application of dplR (Bunn, 2008), pointRes (Van der Maaten-Theunissen *et al.*, 2015) and treeclim library (Zang and Biondi, 2015).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

To establish a sound basis for a dendroecological study in a new region, it is necessary to understand the characteristics of the sampled trees of the locally avail-

Table 1 (A) Correlation statistics of STI and RES indexed series (1880 – 2013), (B) the main statistical parameters of the STD and RES oak chronology (1855 – 2013). Abbreviations: r_{tot} – total correlation, r_{wt} – within-trees correlation, r_{tb} – between-trees correlation, EPS – Expressed Population Signal, SNR – Signal-to-Noice Ratio, SD – standard deviation, MS – mean sensitivity and AC1 - Autocorrelation order 1.
Tablica 1. (A) Korelacijska statistika STI i RES indeksiranih sekvencija (1880. – 2013.); (B) glavni statistički pokazatelji definiranih STD i RES kronologija hrasta (1855. – 2013.). Kratice: r_{tot} – ukupna korelacija, r_{wt} – korelacija unutar stabala, r_{tb} – korelacija između stabala, EPS – izraženi signal populacije, SNR – omjer signal : šum, SD – standardna devijacija, MS – srednja osjetljivost, AC1 – autokorelacijski red 1.

	Chronology type *Tip kronologije*		r_{tot}	r_{wt}	r_{bt}	EPS	SNR			SD	MS	AC1
(A)	TR *Širina goda*	STI	0.46	0.73	0.45	0.97	32.1	(B)	STD	0.24	0.23	0.34
		RES	0.47	0.70	0.46	0.97	33.8		RES	0.22	0.26	-0.05
	EW *Širina ranog drva*	STI	0.20	0.36	0.20	0.91	9.8		STD	0.11	0.10	0.44
		RES	0.18	0.31	0.18	0.90	8.5		RES	0.10	0.10	0.23
	LW *Širina kasnog drva*	STI	0.47	0.73	0.46	0.97	33.2		STD	0.32	0.34	0.28
		RES	0.47	0.71	0.47	0.97	34.1		RES	0.30	0.36	- 0.04

able material (Hughes *et al.*, 1978). The longest chronology was composed of 159 tree rings (1855-2013), while the average number of tree rings (N) amounted to 152. The mean width of the TR, EW, and LW raw series amounted to 1.75, 0.60, and 1.15 mm, respectively. Hence, LW amounted to 66 % of the TR width, on average. For raw series, the mean sensitivity coefficient (MS) for LW, TR, and EW was 0.43, 0.30, and 0.24, respectively. Autocorrelation coefficients of the first order (AC1) for raw series varied from 0.58 (LW) to 0.66 (TR). The detrending procedure and the calculation of the standardised indices significantly reduced the AC, while the MS values slightly changed. After the autoregressive modelling of the standardised indices series, the MS values increased, while the AC was removed entirely.

The results of the correlation statistics of the indexed series (standardised – STI and residual – RES) show that the average values of the calculated parameters (r_{tot}, r_{wt}, r_{bt}, EPS and SNR) are almost the same for TR and LW and higher compared to EW (Table 1), indicating that EW contains the lowest common signal. Having averaged the individual series, the STD and RES site chronologies were obtained (Figure 2), and their basic statistical parameters are shown in Table 1B. As the RES chronologies are slightly more sensitive than the STD ones, we decided to use the RES chronologies of TR, EW, and LW for further analysis.

The results of the climate-growth correlations reveal that the EW chronology is significantly positively correlated (r = 0.41, p <0.01) with the LW formed in the previous year (LW_{t-1}) and not directly related to the monthly climate data (Figure 3). The findings that EW is correlated with LW_{t-1} are also confirmed by the results of the response function (Figure 3), indicating that 16 % (p <0.01) of the total variation are related to LW_{t-1}.

The insensitivity of the EW chronologies to the studied monthly climate parameters was also determined by Nechita and Popa (2011) for oak growing in Vaslui region, Romnia. In some cases, when the direct climate-growth relationship could not be confirmed, the dependence of EW on the LW of the preceding year can be noticed (García González, Eckstein 2003; Sohar *et al.*, 2013). Since LW reflects the amount of summer precipitation, this can be seen as a kind of “indirect” climate influence on the EW width in the following year. Contrary to EW and LW, the TR chronologies

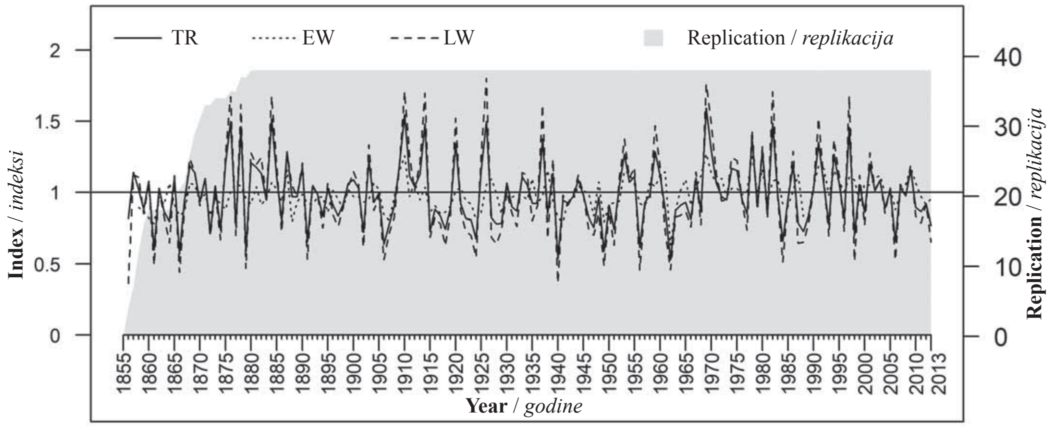

Figure 2 Residual oak chronologies (RES) for TR, EW and LW (1855 – 2013). Abbreviations: TR- tree ring, EW – earlywood and LW – latewood
Slika 2. Rezidualna kronologija hrasta (RES) za TR, EW i LW (1855. – 2013.). Kratice: TR – širina goda, EW – rano drvo i LW – kasno drvo.

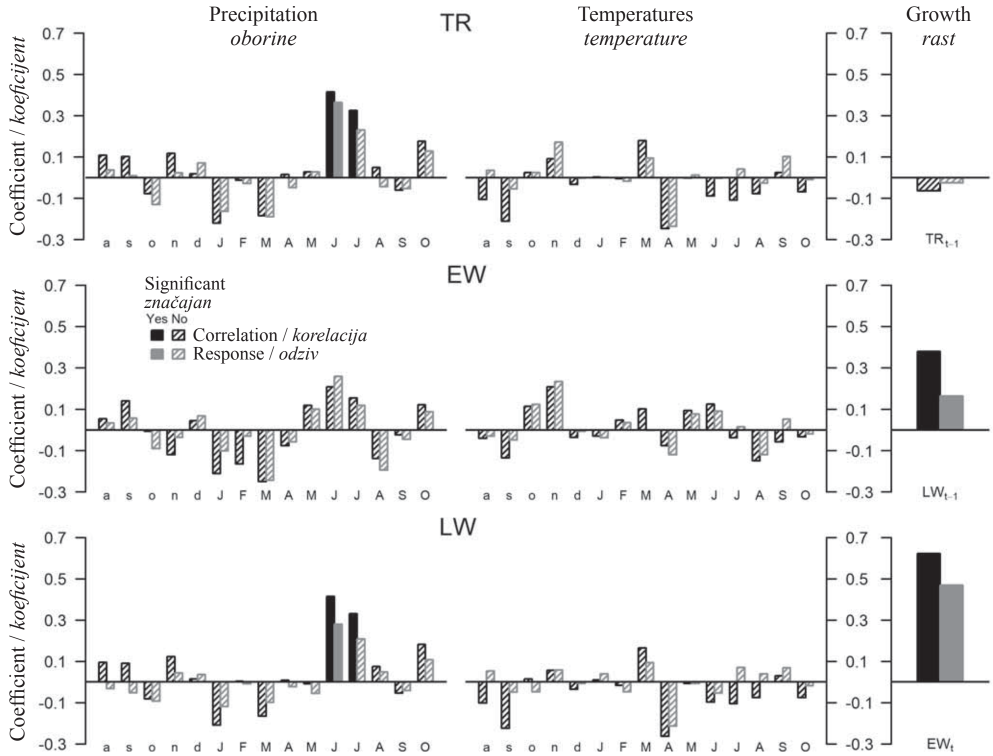

Figure 3 Correlation and response coefficients of TR, LW, and EW, calculated between residual chronologies and monthly temperature and precipitation (1950 – 2013). Lower and upper cases denote month of the previous year and the current year, respectively. Filled bars indicate significant correlation (black) and response (grey) coefficients at the 99 % level

Slika 3. Koeficijenti korelacije i odziva TR, LW i EW izračunani između rezidualne kronologije i mjesečne temperature i količine oborina (1950. – 2013.). Mala i velika slova označuju mjesec prethodne odnosno tekuće godine. Ispunjeni stupci upućuju na značajne koeficijente korelacije (crni) i odziva (sivi) pri razini od 99 %.

were not significantly related to any of the analysed growth independents from the previous growing season (Figure 3). Further, the TR and LW chronologies were positively influenced by the precipitation in the current June (r_{TR} = 0.42, r_{LW} = 0.41) and July (r_{TR}=0.32, r_{LW}= 0.34), indicating that the high precipitation during the summer months of the current year is of the utmost importance for the formation of sessile oak TR and LW in the studied conditions. The LW chronology was also strongly correlated (r = 0.61) to the EW of the current year (EW_t). The results of the conducted response function additionally clarified the obtained findings, suggesting that the widest LW and TR are expected to be produced in the years with abundant June precipitation. Namely, these results showed that TR was positively influenced by the current June precipitation and this variable explained 17 % (p<0.001) of the total variation in the TR chronology.

Climate response and correlation models for LW found June precipitation and EW_t to be statistically significant. These variables (16 % - June precipitation and 40% - EW_t, p <0.001) explained almost 50 % of the total variance in the LW chronology. It must be noted that neither the correlation nor the response analysis found any significant influence of monthly temperatures. Such dependency of the sessile oak radial growth on water availability in early summer is not typical for the growth of sessile oak in the northwestern part of Serbia, on Fruška Gora Mountain (Stajić *et al.*, 2015). These authors found no statistically significant relationships between the sessile oak growth and the current summer monthly precipitation data. The main reason for the observed divergence in the growth reactions of sessile oak is the fact that the soil of the stand on Fruška Gora Mountain is characterized as deep, high-quality, and well-drained soil with a good water-air regime. On this soil, oak trees withstand a lack of precipitation and high temperatures in June and July without much difficulty (Stajić *et al.,* 2015). However, in case of further exposure to high temperatures in August, followed by small amounts of precipitation, it can be expected that typically low growth of oak in August could be even significantly lower, as reported by Stajić *et al.* (2015) for oak in the north-western part of Serbia. On the other hand, oak trees at warmer, south-oriented sites with a shallow soil profile are highly exposed to summer droughts, as is the case in the present study. In such circumstances, during dry summer months, trees suffer from water deficit that acts as a growth-limiting factor.

Besides that, June is characterized by a prolonged photoperiod, which can be an additional reason for increased demand for water supply. Therefore, in case of wet and sunny conditions in June, the maximum wood growth can be expected in many sites in SE Central Europe (Čufar *et al.*, 2014a). However, Čufar *et al.* (2014a) concluded that there were some similarities, but they also found some differences concerning the

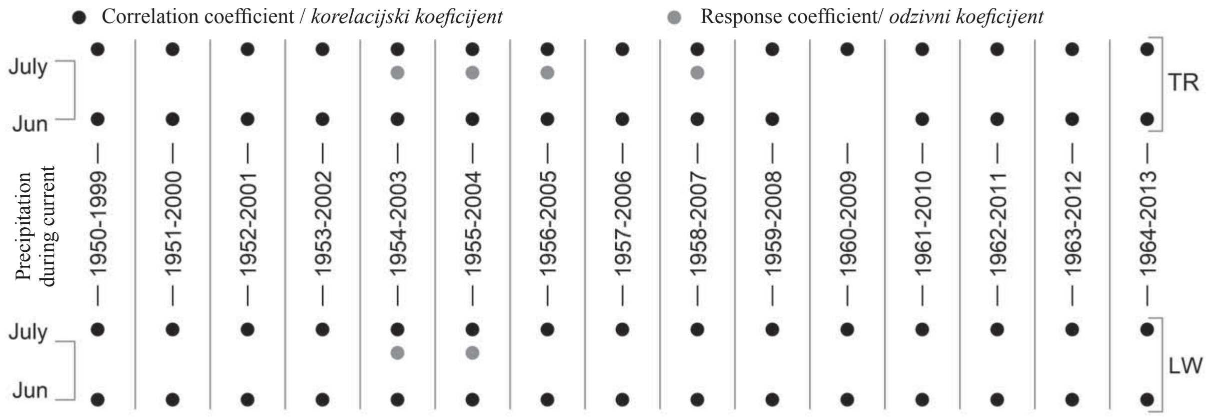

Figure 4 Temporal stability of dendroclimatic relationships, a 50-year moving window of correlation and response function for TR and LW chronology. Only significant coefficients are shown ($p<0.01$)
Slika 4. Vremenska stabilnost dendroklimatskih odnosa, 50-godišnji pomični prozor korelacijske i odzivne funkcije za TR i LW kronologiju; prikazani su samo značajni koeficijenti ($p<0,01$)

effects of climate on the oak tree-ring variability among the studied localities in SE Central Europe. Regarding oak stand in Serbia, which is located near the Sava River in the lowland area of Srem, Čufar *et al.* (2014a) did not find a statistically significant relationship between the oak growth and monthly temperature or precipitation data of the current year. Also, no significant impact of precipitation on the oak growth in Serbia was found for the pedunculate and Turkey oak growing in the lowland area in the northern part of the country (Stojanović *et al.*, 2015).

To evaluate the temporal stability of the dendroclimatic signal observed, we implemented the bootstrap moving response function. The months, which had been previously highlighted as important for the radial growth, were included in this procedure. The results indicated that the detected impact of monthly climate conditions established quite a stable correlation across the common period (Figure 4). The July correlation is significant in each investigated position of the window, while the June correlation showed occasional insignificance. A similar performance was ascertained for the response coefficients in the TR, while the most unstable correlation was revealed for the LW chronology.

The detected link between the sessile oak TR and LW growth and the precipitation in summer months was confirmed by the results of the pointer year analysis (Figure 5). The determination of the pointer years represents a common practice applied in dendroclimatological studies, but the existence of various calculation procedures has caused a sort of selection bias. Therefore, Stajic *et al.* (2017) and Jetschke *et al.* (2019) highlighted the need for standardisation, which would enable reliable comparisons of various results. To address this problem, we have proposed that only those years that are determined by two or more methods used here can be marked as pointer years. Following these recommendations, we determined positive (1997, 1982, 1969, 1926, 1920, 1910, 1903, and 1884) and negative (2006, 1962, 1956, 1940, 1902 and 1891) pointer years common to LW and TR. The positive years of 1994 and 1887 were identified only for TR, while an exceptionally narrow LW portion was formed during 1998, 1984, and 1886. A strict routine in terms of selected thresholds and the use of more than one of the applied methods resulted in the identification of noticeably fewer pointer years (16 for TR and 17 for LW) than in some other oak dendroclimatologial studies. The applied procedures for the pointer year calculation detected the absence of the years with an exceptionally wide or narrow EW portion of a tree ring. The detected pointer years occurred with precipitation anomalies. Both types of pointer years for TR and LW are related to the below and above long-term averages of precipitation in summer months. Three common positive pointer years for TR and LW were 1997, 1982, and 1969, which were characterized by exceptionally abundant precipitation summer months. Compared to the average reference period values (1961-1990), these years in August (1997), July (1982), and June (1969) had 172 %, 209 %, and 257 % more precipitation. Three common positive pointer years for TR and LW that occurred in the years with exceptionally abundant precipitation in July (1982), June (1969), and August (1997) were equal to or higher than the reference period values (1961-1990).

Within the group of negative pointer years, pronouncedly low values of TR and LW were determined by different dry periods of the current year. Namely, these common pointer years (2006, 1962, and 1956) were characterized by the following prevailing low-amounted precipitation drivers: Sep-Oct, May and August, respectively, when the amount of precipitation was 67-91 % below the 30-year average value. Extremely narrow LW widths are related to very pronounced anomalies in the precipitation in June (1998) and August (1984), with 53 % and 19 % of the 30-year average precipitation value, respectively.

The present climate-growth results are mostly in concordance with the common feature of the oak's response in the Balkans and surrounding countries. In Croatia, the pedunculate oak growth was positively

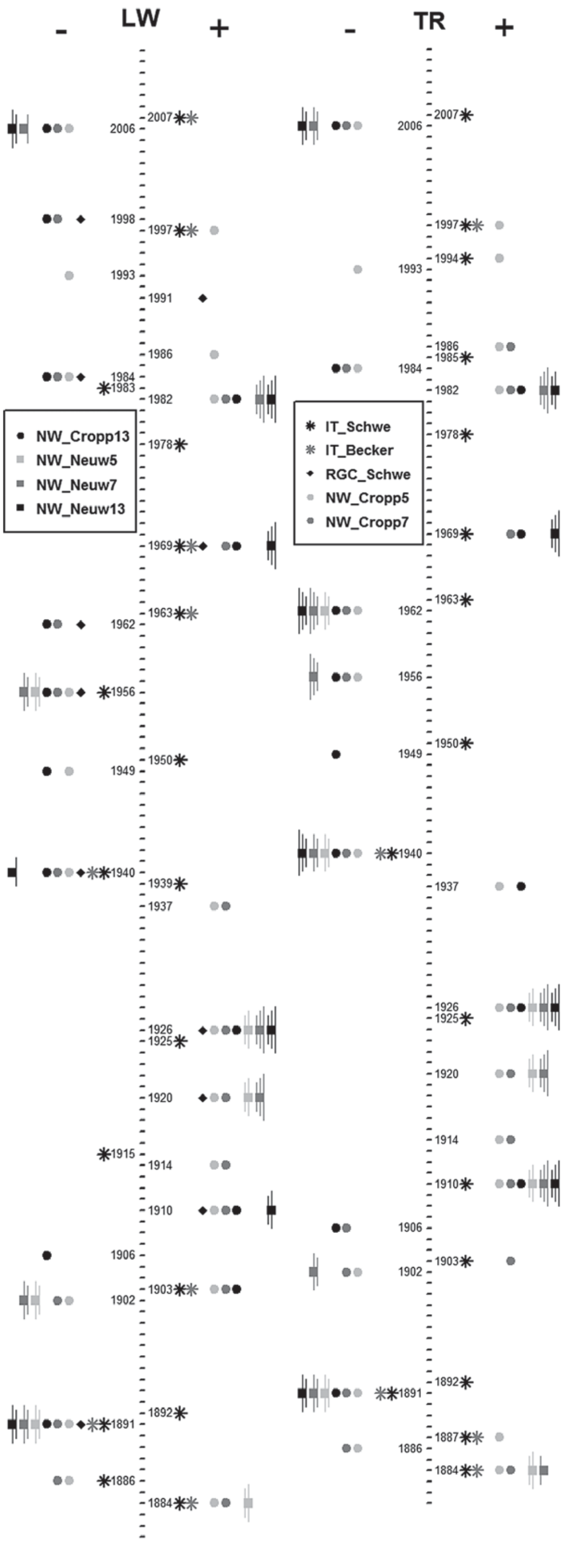

Figure 5 Pointer years for TR and LW determined by applying Interval trend approach, given by Schweingruber (1983) - IT_Schwe and Becker *et al*. (1994) - IT_Becker, relative growth change approach of Schweingruber et al. (1990) - RGC_Schwe and Normalisation in a symmetrically moving window of 5, 7 and 13 years, suggested by Cropper (1979) and Neuwirth et al. (2007) - NW_Cropp5, 7, 13 and NW_Neuw5, 7, 13. The number of vertical lines on Neuw* points indicates the strength of pointer year. One vertical line over squares designates a weak pointer year (C values > 1), two are for strong (C > 1.28), and three are for extremely strong (C > 1.645)

Slika 5. Pokazne godine za širinu goda i širinu kasnog drva određene primjenom pristupa intervala trenda prema Schweingruberu (1983.) – IT_Schwe i Becker *et al*. (1994.) – IT_Becker, pristupa relativne promjene rasta prema Schweingruberu *et al*. (1990.) – RGC_ Schwe i normalizacije u simetričnome pomičnom prozoru širine 5, 7 i 13 godina, predloženima od Croppera (1979.) i Neuwirtha *et al*. (2007.) – NW_Cropp5, 7, 13 i NW_Neuw5, 7, 13. Broj vertikalnih linija na točkama Neuw* svjedoče o snazi pokazne godine. Jedna vertikalna linija iznad kvadrata označava slabu (vrijednosti C>1), dvije jaku (C> 1,28), a tri izrazito jaku pokaznu godinu (C> 1,645).

correlated to June precipitation (Čufar *et al.*, 2014 b). Similar results were found in Romania, in the western part (Popa *et al.*, 2013) and North-West part of the Carpathian Mountains (Nechita *et al.*, 2017), where the sessile oak shows a particular dependency on the precipitation regime in June. In the most comprehensive research of the common climatic signal in the oak chronologies in central Europe and the Balkans, Čufar *et al.* (2014a) determined a positive correlation between the June precipitation and PC1 from 41 studied chronologies. Similarly, Griggs *et al.* (2006) and Kern *et al.* (2012) identified the precipitation in May-June as the most influential period for the oak growth in the Aegean area (Turkey) and western Hungary, respectively. Further, May-August precipitation was the main factor driving the oak growth in the eastern part of the Great Hungarian Plain (Árvai *et al.,* 2018).

4 CONCLUSIONS
4. ZAKLJUČAK

Conversely to many other regions and countries, dendroclimatological studies have not been intensively carried out in Serbia. The results of this study showed that the main factor limiting the process of the TR and LW growth formation in the sessile oak from Majdanpek (Eastern Serbia) was summer precipitation, especially in June. The fact that a higher amount of summer precipitation increases the TR and LW width was confirmed by the multi-approach dendroclimatological procedure. The absence of a significant negative reaction of sessile oak to temperature is not such a common feature of the oak response in many European and Balkan countries. Additionally, the impact of the previous year's climate on the sessile oak growth was not detected. Finally, the main limitation of this research is the spatial representativeness of the sampled stands, since the obtained results represent the first insight into the dendroclimatological behaviour of sessile oak in this part of Serbia. To achieve a better and deeper insight into the reaction of the sessile oak growth at south-oriented sites with a shallow soil profile to precipitation and temperature variations, as well as to expand the existing database and knowledge, future studies should be undertaken.

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