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Preliminary report

Pendunctulate and Turkey Oaks Radial Increment and Stable Carbon Isotope Response to Climate Conditions through Time

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Abstract: In this work, the relationships of pendunctulate and Turkey oak tree-ring width and stable carbon isotope ratio ($\delta^{13}C$) with climatic variables (temperature and precipitation) through 50-year chronology were analyzed. Tree sensitivity over time was assessed in terms of Pearson's correlation strength and the moving correlation with a 20-year window (presented in the form of heat maps) was calculated for the 1960–2010 timespan. The obtained results indicate that ongoing intensive climate changes induce variations in the correlation strength between climatic variables and the tested tree-ring parameters. Moreover, compared to tree-ring width, stable carbon isotope records were found to be more sensitive to, and to vary more strongly with, climate variations. The strongest correlations were obtained between temperature and precipitation during the late spring months and isotope content. Likewise, climatic conditions in the preceding year strongly correlated with tree-ring width, while isotope ratio was more sensitive to the climate in the current year. Although species-specific differences in correlation strength were noted, their variations were rather weak and did not follow a discernible pattern.

Keywords: stable isotope, $\delta^{13}C$, tree-ring width, dendrochronology, climate change, lowland forest, *Quercus robur, Quercus cerris*.

1. Introduction

Climate significantly shape the vegetation growth and their distribution (Williams and Dumroese 2013). During the last century, especially in the last few decades, climate has started changing more rapidly (Paul et al. 2019). Moreover, all IPCC (2018) scenarios suggest that this increasing trend will intensify in the future. In the late 20th century, and in particular during the 21st century, oak mortality across the Balkan Peninsula and beyond has intensified as a result of rapid climate changes (Choat et al. 2012; Stojanović et al. 2018). In extant studies, temperature and precipitation were identified as the main forest mortality drivers (Liu et al. 2017), as they undermine forest ecosystem service capacity (Zorić et al. 2019).

Pendunctulate and Turkey oak are widespread and economically important species in lowland European forests across the continental climate zone (Medarević et al. 2009; Alexandrov and Iliev 2019). However, over the last four decades, their mortality rate in the lowland region in Serbia has rapidly increased, as indicated by the oak mortality assessments conducted by Medarević et al. (2009) in 1983, 1986, and 2000, and data published by Stojanović et al. (2015a) for 2013. These authors posited that temperature and precipitation could contribute to lowland oak forest degradation (Stojanović et al. 2015b, 2018).

Tree-ring records provide significant information on trees' sensitivity to the variations in their surrounding environment (McCarroll and Loader 2004). Consequently, radial increment and stable isotope ratio in tree rings have emerged as powerful dendroclimatology and dendroecology tools (Robertson et al. 2008), because they provide "view in past" along their lifespan. Stable carbon isotope ratio in tree rings is more sensitive measure than radial growth due to its greater sensitivity to climate variations. Its variability is based on photosynthesis intensity and opening of the stomata which regulates inflow of CO_2. In situation when photosynthesis is still active but stomata are closed due to reduced water availability plants develop deficiency in the lighter ^{12}C isotope in intracellular CO_2 and must introduce the heavier isotope ^{13}C into the Calvin cycle and thus to plant metabolism, which is reflected in embedding of different ratios of stable carbon isotope into the tree trunk (Loader et al. 2007).

Temperature and water balance are widely recognized as the most significant factors affecting tree-ring variations (Hafner et al. 2015). Empirical evidence further indicates that plant physiological performance and tree architecture define specific inter-species variability, i.e. species-specific response to environmental influences (McCarroll and Loader 2004; Gessler et al. 2016).

In the present study involving two oak species (*Quercus robur* and *Q. cerris*) from the same stand, radial increment and stable carbon isotope ratio were examined and correlated with climatic variables (temperature and precipitation). The results of this study should provide insight into the species-specific response to climatic conditions and their temporal changes, as indicated by stable carbon isotope ratio and radial increment observations.

2. Material and Methods

Stable carbon isotope ratios ($^{13}C/^{12}C$) and radial increments were analyzed in penduntculate oak (*Quercus robur* L., QR) and Turkey oak (*Quercus cerris* L., QC). The samples were collected in the autumn of 2013 and winter of 2014, in lowland oak forest near Danube river (~5 km) in the northwestern part of Serbia, known as Branjevina (45° 28' N, 19° 10' E), located near Sombor. All analyzed samples were ~120 years old and were obtained from the same mixed-species stand to ensure consistency in environmental conditions over time (Stojanović et al. 2015a).

Two cross-sections from each tree trunk were taken at 1/5 of tree height. In total 24 cross-sections (six from each combinations) were taken from dominant trees in the stand. The tree-ring width analyses were conducted in line with the standard dendrochronological procedures described by Stojanović et al. (2015a). Prepared samples were scanned and measured using the ATRICS system (Levanič 2007) and WinDENDRO software, and the data were synchronized using the PAST-5™ dendrochronological software. Stable carbon isotopes were sourced from extracted cellulose, following the methodology described by Loader et al. (1997). Stable carbon isotope ratio was measured using Isoprime 100 (Isoprime, UK) isotope ratio mass spectrometers in continuous flow mode connected to Elemental Analyser (Elementar GmbH, Germany).

Radial increment expressed as tree ring width (TRW) and the stable carbon isotope ratio was denoted as $\delta^{13}C$. Radial increment and stable carbon isotope sensitivity to climatic conditions—temperature (expressed in ˚C, and denoted as TEMP) and monthly precipitation (expressed in mm and denoted as PCPT)— Pearson's correlation statistics were calculated on a monthly basis for the entire period and for a 20-years moving window spanning the period from April of the previous year to September of the current year. Results are presented in a form of heat maps. Chronology analyses covered the 1960–2010 period and were conducted using R software packages "treeclim" (Version 2.0.3) (Zang and Biondi 2015) and "ggplot2" (Version 3.2.0).

3. Results

Different response of $\delta^{13}C$ and TRW trough the time were noted (Figure 1). Obvious pattern between different dendrochronological techniques and species limitation weren't obtained completely, but the general trend trough chronology were noted. In detail, following the isotope content, more unfavorable years were 1974, 2002 and 2010 years and the smallest radial increment were noted in 1993, 2003, 2008 and 2011 years. Obtained deviations matched two unfavorable periods (2002-2003 and 2010-2011) following both measurements. In contrast, the same interactions were noted in favorable periods the mode less isotope ratio and higher radial increment were noted in 2001 year and the first decades of analyzed chronology.

Isotope in contrast of tree-ring chronology, showed stronger differentiations between analyzed oak species. Specifically, higher $\delta^{13}C$ values were obtained for Turkey oak, whereas tree-ring chronology yielded similar results for both species. The highest radial increment was observed around 1970 and toward the end of 1990s. In contrast, the lowest radial increments were noted in the 21st century, as well as in late 1980s and early 1990s.

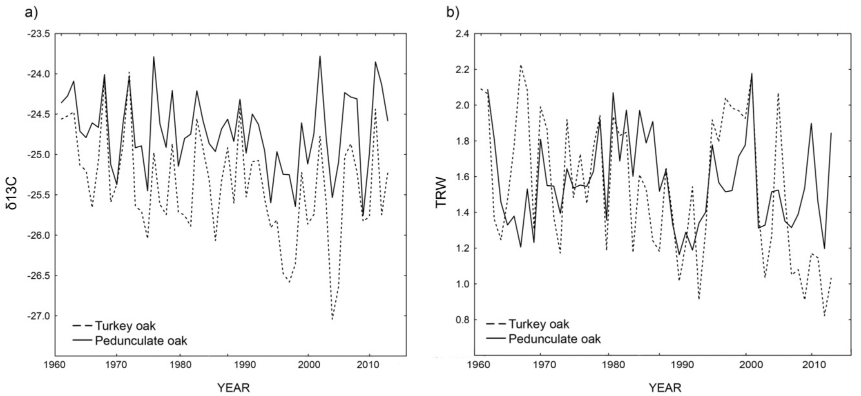

Figure 1. Pendunculate oak (bold line) and Turkey oak (dashed line) Tree-ring width (TRW) (a) and isotope records variation ($\delta^{13}C$) (b) through the analyzed timespan.

Throughout the 50-year period, following the isotope ratio and radial increment analyzed species exhibited different responses to climate conditions (see Figure 2). However, non-uniform patterns in the analyzed parameters and analyzed oaks were noted. Differences of tree increment and carbon isotope relations to climate conditions were obtained for both tested oaks. The heat maps 20-year window interpreted tree-ring parameters sensitivity to climate conditions, as well as their deviations in response over time. Higher sensitivity to climate in the current year was noted relative to the previous year, whereby stronger dependence on temperature compared to precipitation was observed.

Similar patterns, albeit associated with weaker correlations, were established for TRW and isotope relationships with precipitation. Our results further indicate that precipitation in the preceding year exerts a stronger effect than temperature on both radial increment and $\delta^{13}C$. In all cases, analyzed trees were shown to be most sensitive to the climatic conditions in the spring months, whereby QR was more sensitive than QC.

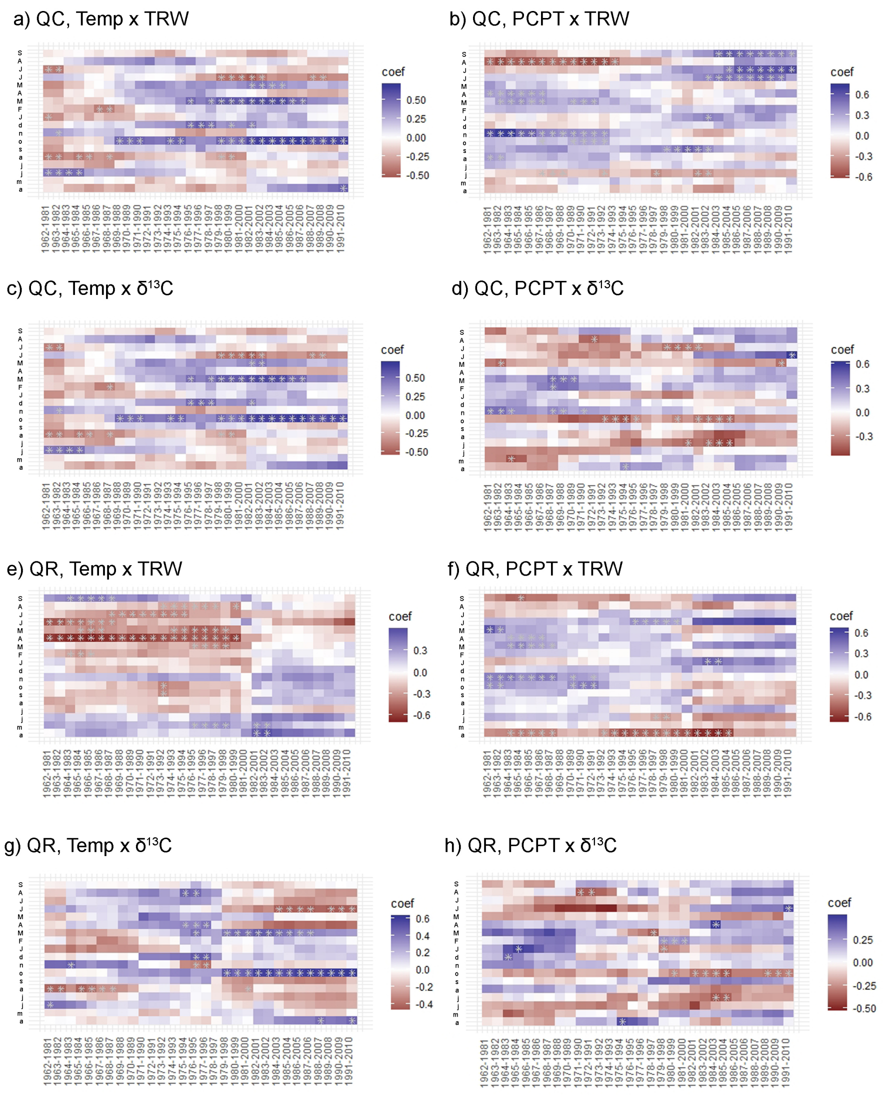

Figure 2. Moving Pearson's correlation in a 20-year window, between climate conditions (TEMP and PCPT) and TRW and $\delta^{13}C$, from QR and QC tree rings.

4. Discussion

Forests are highly affected by climatic conditions and their changes over time. In particular, climate changes affect species distribution (promoting migration to more suitable stands), wood density, stem volume (Pretzsch et al. 2018) and species physiological response to changes in their immediate environment (which induces isotope and radial increment variations) (McCarroll and Loader 2004), as well as promote changes in tree species mixture combinations (Williams and Dumroese 2013).

Twenty-year moving correlation between tree-ring width, $\delta^{13}C$ and monthly temperature and precipitation, based on the data covering the 50-year timespan from 1960 to 2010, showed significant deviations, which were most pronounced in the 1960−1980 and 2000−2010 periods. These findings are attributed to the more intensive climate changes and deviations in precipitation and temperature from the reference period (1960-2012 years). The higher deviation during the last decades obtained in this work are in line with the findings reported by Levanič et al. (2011) who analyzed penduncULATE oak, as well as those obtained by Csank et al. (2016) for spruce and Sun et al. (2018) for poplar.

General comment on our interaction of TRW and $\delta^{13}C$ with temperature and precipitation was that they equally correlated with tree-ring increment and isotopes throughout the whole chronology. However, stronger correlations were obtained between temperature and TRW for both species during the first few decades included in the analysis.

In contrast, precipitation strongly correlated with TRW and $\delta^{13}C$ during the last decades. We hypothesize that lack of interaction during the most recent decades can be attributed to stand locations near river in plain relief. According to Hilasvuori and Berninger (2010), Levanič et al. (2011), and Stojanović et al. (2018), precipitation should have stronger interaction with dendrochronological parameters than temperature in lowland forests. Likewise, given the more pronounced climate changes in the 21st century (IPCC 2018), higher deviation in the last decade included in the analysis (2000−2010) is expected, and similar trend is forecasted to continue in the future.

Oak lowland forests in SE Europe have been strongly affected by climate changes (Alexandrov and Iliev 2019). Reduced radial increment is generally observed in tree species characterizing European forests (Reyer et al. 2017). Hence, following the IPCC's (2018) climate change scenarios and tree-ring sensitivity to environmental factors noted in both analyzed oaks, further decrease in the biomass productivity of lowland forest oaks could be expected in the future.

5. Conclusion

Penduncualte and Turkey oaks radial increment and stable carbon isotope records vary trough analyzed time-span as well as between analyzed species. Moreover, while radial growth and isotope records pertaining to both species were found to be sensitive to climate changes, greater variations were noted in stable isotope ratios. Throughout the chronology, different correlation strengths between analyzed parameters and meteorological measurements (precipitation and temperature) were noted. In detail, temperature effect strongly in the first part, but stronger effect of precipitation was obtained in the last analyzed decades.

These findings confirm that oaks from analyzed lowland forests are climate-sensitive species, as confirmed by the radial growth and stable carbon isotope records, and the more pronounced differences between species toward the end of the 50-year analyzed period. However, obtained variations and observed pattern, could be potential to further deeper research about sensitivity of lowland oak forests on large scale and water balance and temperature meteorological parameters.

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