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Research paper

Climate change impact on a mixed lowland oak stand in Serbia

Dejan Stojanović[1*]; Tom Levanič[2]; Bratislav Matović[1]; Andres Bravo-Oviedo[3]

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Abstract - Climatic changes and bad environmental conditions may lead to forests vitality loss and even mortality. This is the reason why increased sanitary felling operations were performed in mixed oak forests in northern Serbia in 2013 in order to solve the severe dieback which affected some Pedunculate oak (*Quercus robur* L.) and Turkey oak (*Quercus cerris* L.) stands, after the very dry years 2011 and 2012. Dendrochronological techniques were applied to both these oak species collected in a stand, to examine the impact of temperature, precipitation and ground water level on forest growth and investigate the potential causes of the dieback. Differences in tree-ring patterns between surviving and dead trees were not significant according to t-value (from 5.68 to 14.20) and *Gleichläufigkeit* coefficient (from 76% to 82%), this meaning no distinctive responses of the two ecologically different oak species. As for radial increment, pedunculate and Turkey oak trees showed a similar response to environmental variables in this mixed stand. The Simple Pearson's correlation analysis, which was conducted, showed that among three basic environmental variables (the mean monthly air temperature, the monthly sum of precipitation and the mean monthly water level, proxy of ground water level), the water level of Danube river in May and the temperature in April were statistically related to the growth of the four tree groups: (i) pedunculate oak vital, (ii) pedunculate oak dead, (iii) Turkey oak vital and (iv) Turkey oak dead trees, for the period 1961-2010 ($p<0.05$, $n=60$). Similar phenomena had already been observed in the Sava River basin for the growth of pure pedunculate oak forests. The long-term decline of the Danube River water level may be related to climate variations and to the changes of water management, river bed, as well as land-use. Together with the increase of temperature, this decline of the water level, and its potential unavailability in the soil, represents a serious challenge for the mixed oak forests silviculture in the Danube basin.

Keywords - *Quercus cerris*, *Quercus robur*, dendroecology, Danube, dieback.

Introduction

The causes of forests decline are complex and uncertain, as the issue involves different abiotic and biotic factors which are predisposing, inciting and contributing to the decline itself (Manion 1991). Some projections indicate that the global land area that is experiencing heat waves may double by 2020, and quadruple by 2040. This may impact on a wide variety of tree processes such as photosynthesis, leaf area development, stomatal conductance, and transpiration among others (Teskey et al. 2014). Drought-induced forest decline may affect carbon, energy and water balance, with an adverse effect on ecosystem services (Martinez-Vilalta et al. 2012). In fact, many cases of drought-induced forest decline in the European continental climate zone have been already reported (Spathelf et al. 2014).

During the last decades, oak decline and mortality were frequently recorded in lowlands of Serbia. There were several hypotheses about the causes of oak dieback (Stojanović et al. 2013): (i) construction of protective embankment along rivers, which prevented occasional flooding in forests which had been flooded in the past; (ii) inappropriate forest management measures; (iii) change of climatic factors; (iv) attacks of pests and diseases.

Medarević et al. (2009) first reviewed the occurrence of oak mortality in this area stating that economic benefits were reduced from 64% to 95% of what expected due to this problem.

Furthermore, Bauer et al. (2013) provided some useful details regarding sanitary felling on permanent plots.

Stojanović et al. (2013), using dendro-ecological methods, rejected the hypothesis about the negative impact of protective embankments along the Sava River as the main cause of pedunculate oak decline and dieback in the Srem region. Effectively other scientists like Matić (1989) had already argued that intensive thinning operations may lead to oak mortality and Vajda (1948) had recognized the change of climatic trends as the potential cause of occasional oak diebacks in the region.

Application of dendrochronology in the research

[1] Institute of Lowland Forestry and Environment, University of Novi Sad, Antona Cehova 13d, Novi Sad, Serbia
[2] Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia
[3] Forest Research Center - National Institute of Agricultural and Food Research and Technology & Sustainable Forest Management Research Institute University of Valladolid-INIA, Madrid, Spain
[*] corresponding author: dejan.stojanovic@uns.ac.rs

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on forest decline is not actually a new approach (Cook et al. 1987), also for oak species outside Europe (Dwyer et al. 1995). For instance, Levanič et al. (2011) investigated pedunculate oak mortality in Slovenia using advanced dendrochronological methods.

Moreover, Stojanović et al. (2014a) recognized the significance of Danube water level for the growth of oak forests, with preliminary results, later extended in this study. Stojanović et al. (2014b) found the same linear trend in the Sava River water level and in the tree-ring widths and provided projections of the Sava future dynamics.

Finally, Stojanović et al. (2015) investigated the statistical relationships between the growth of pedunculate oak stands, the Sava water level, the temperature and the precipitation. Water level in the nearby river, as a proxy of ground water table depth, appeared to be positively correlated with tree growth, while air temperature was negatively correlated.

The aim of this study is to consider more in depth both the drivers of growth (temperature, precipitation and water level) and decline of the observed mixed pedunculate-Turkey oak stand, as well as to analyse the patterns among different tree groups: (i) pedunculate oak vital, (ii) pedunculate oak dead, (iii) Turkey oak vital and (iv) Turkey oak dead trees.

The novelty of this research is in the evaluation of mixed Turkey-pedunculate oak stand, in the parallel analysis of living and dead trees, as well as in the evaluation of Danube River impact to the forest. Besides the evaluated parameters, it may be that air pollution, paired with climate change, played a role in the decline of these forests (Bytnerowicz et al. 2007), but long-term time-series of air pollutants are not available in the area. Our hypotheses were to find out close relationships between environmental factors and growth; distinctive response between Turkey and Pedunculate oak, as well as the difference among living and dead trees.

Materials and Methods

The samples were taken in the late 2013 and early 2014 from a mature stand experiencing severe dieback (Branjevina 08i, Forest Management Unit "Sombor", 45° 28' N, 19° 10' E). Its distance from the Danube River is about 5 km. Such stands in Serbia are managed according to the shelterwood system, with several thinnings and the establishment of a new generation at the end of the cycle. 10 dead and 10 vital trees of pedunculate oak (*Quercus robur* L.) and Turkey oak (*Quercus cerris* L.) were selected. The latter species was dominant because of the larger number of trees.

The stand was arranged according to a single tree mixture. Ecological condition within the stand can be considered uniform. The age of the trees was 120 years, according to forestry plans. Cross-sections were taken at 1/5 height (between 5 and 7 m), because it is assumed that this part of the trunk has the most balanced growth due to water and sugars flow. The samples were dried, cut and polished with sandpaper. They were first scanned in high resolution using the ATRICS system (Levanič 2007) and then the tree-ring width was measured using WinDENDRO.

The chronologies were cross-dated and synchronized with the PAST-5™ dendrochronological software, using both visual on-screen comparisons and statistical parameters (t-value after Baillie and Pilcher (tBP), Baillie and Pilcher 1973, and Gleichläufigkeit coefficient (GLK%), Eckstein and Bauch 1969).

Individual tree-ring widths (TRW) were standardized using ARSTAN for Windows (Cook and Holmes 1999) to remove age-related trends (Cook 1985) and averaged into four tree-ring chronologies, representing each one of the studied groups. ARSTAN was also used for the calculation of all the basic statistical parameters of the tree-ring widths.

BootRes package (Zang 2010) allowed the calculation of the bootstrapped Simple Pearson's correlation between environmental factors (water level of the Danube River, air temperature and precipitation) and TRW residuals for the period 1961-2010. We analysed the months of the year prior to ring formation up to the end of the growing season in the year of ring formation (displayed on the x-axis marked as small letters and capital letters, respectively). Significant correlations ($p<0.05$, $n=60$ years) were displayed with darker colour.

R package berryFunction was used to construct climate diagrams, according to Walter and Lieth (Boessenkool 2015). The mean monthly climate data and Danube water level data were obtained from the Hydro-meteorological Service of the Republic of Serbia for the station Sombor (45° 46' N, 19° 09' E) and the measuring point Bezdan (45° 50' N, 18° 51' E), respectively.

Results

The differences between the chronologies of the surviving and the dead trees and the tree species were not significant in dendrochronological terms (Tab. 1). All the four analysed groups showed a declining trend over the past decades (Fig. 1).

With respect to the tree-ring widths, pedunculate and Turkey oak trees, in this mixed stand, showed a similar growth pattern. According to tree-rings, 7

Table 1 - Statistical parameters among the four groups of oaks. Values of GLK coefficient >75.00% and t_{BP} >4.00 mean that the pairs of chronologies are similar.

	Pedunculate oak - live	Pedunculate oak - dead	Turkey oak - live	Turkey oak - dead
Pedunculate oak - live	x	81.60	78.20	76.00
Pedunculate oak - dead	10.50	x	79.10	78.60
Turkey oak - live	9.27	10.90	x	82.00
Turkey oak - dead	5.68	12.80	14.20	x

out of 10 Turkey oaks, that experienced mortality, died in 2012, while just 2 out of 10 pedunculate oaks died the same year and all the others in 2013.

Time-series and climate diagrams, according to Walter and Lieth, show the increasing air temperature trend, the decreasing water level trend and the change of precipitation regime (more intensive extreme events) in the period 1991-2010, as compared with the reference period 1961-1990 (Fig. 2, 3 and 4).

The mean annual air temperature in the period 1991-2010 increased by 0.8 °C, while the annual amount of precipitation dropped by 55 mm in 20 years. Besides the change in climate statistics, we also observed seasonal changes in the temporal distribution and in the amount of precipitation, with a heavy decrease in winter and early spring. This might lead to a decreased water accumulation in the soil and an increased drought stress in the trees, especially at the peak of the growing period.

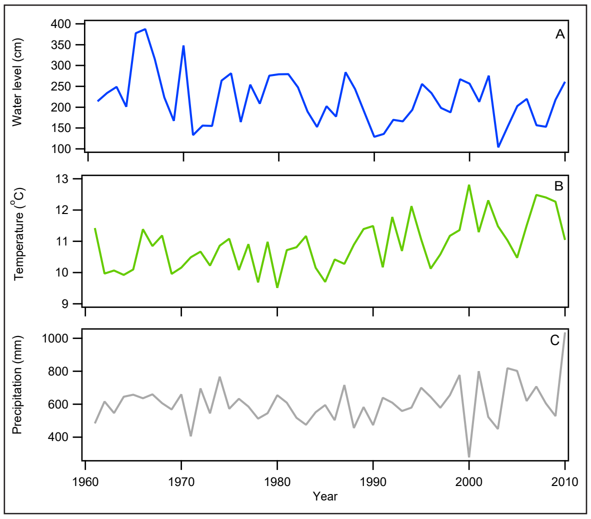

Figure 2 - Time-series of (A) mean annual Danube water level (Bezdan station), (B) mean annual temperature (Sombor station) and (C) annual sum of precipitation (Sombor station) for the period 1961-2010.

An in-depth analysis of the water level data of Danube River shows that, beside a decrease of more than 50 cm in the height of water level in the summer months (June, July and August) there is also a shift in the peak of the highest water level from summer months (1961-1990) to spring months (1991-2010).

A correlation analysis between the tree-ring indices and the three environmental variables, i.e. air temperature, precipitation and water level of Dan-

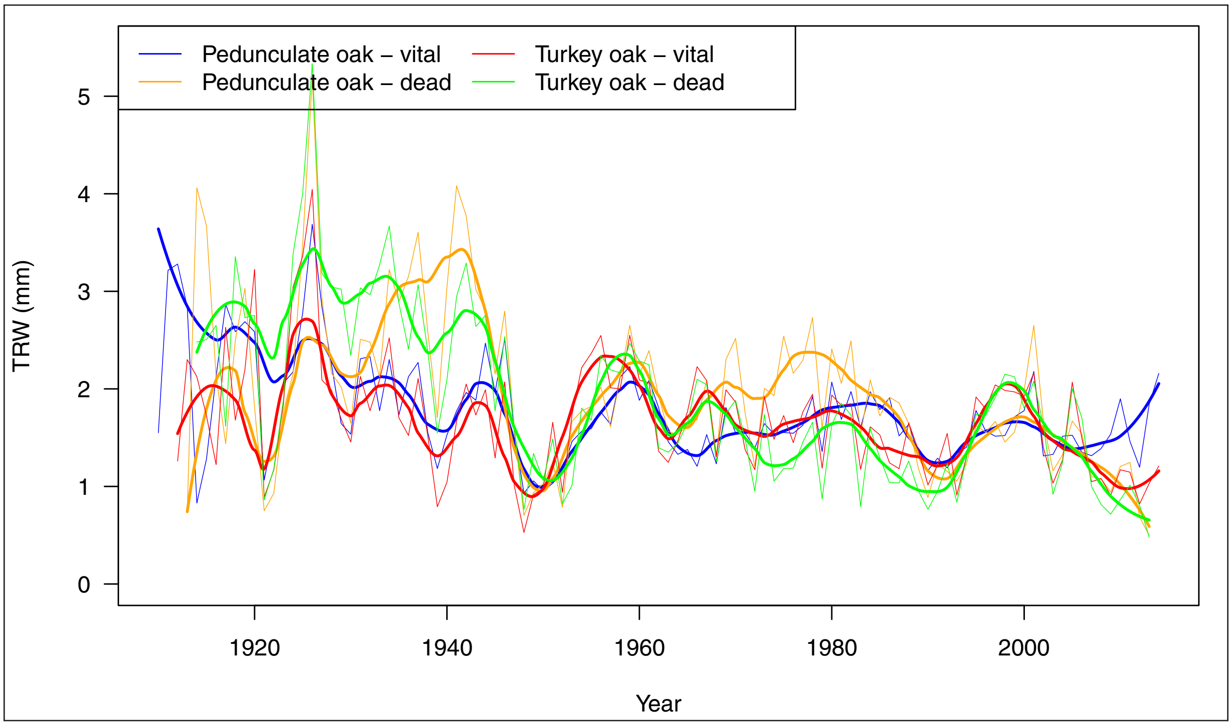

Figure 1 - Mean tree-ring width chronologies (thin lines) of the four tree groups (pedunculate and Turkey oak, vital and dead trees) at the Branjevina stand. Spline curves (thick lines) describe the low frequency growth trend. Each tree-ring width chronology is based on 10 trees.

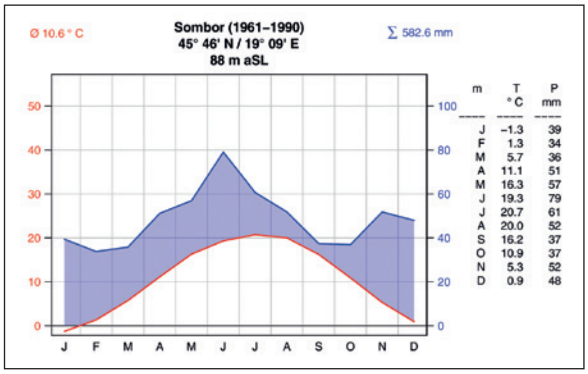

Figure 3 - Climate diagram at the Sombor station for the period 1961-1990.

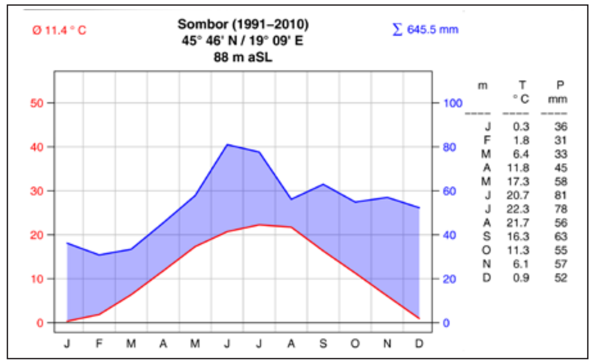

Figure 4 - Climate diagram at the Sombor station for the period 1991-2010.

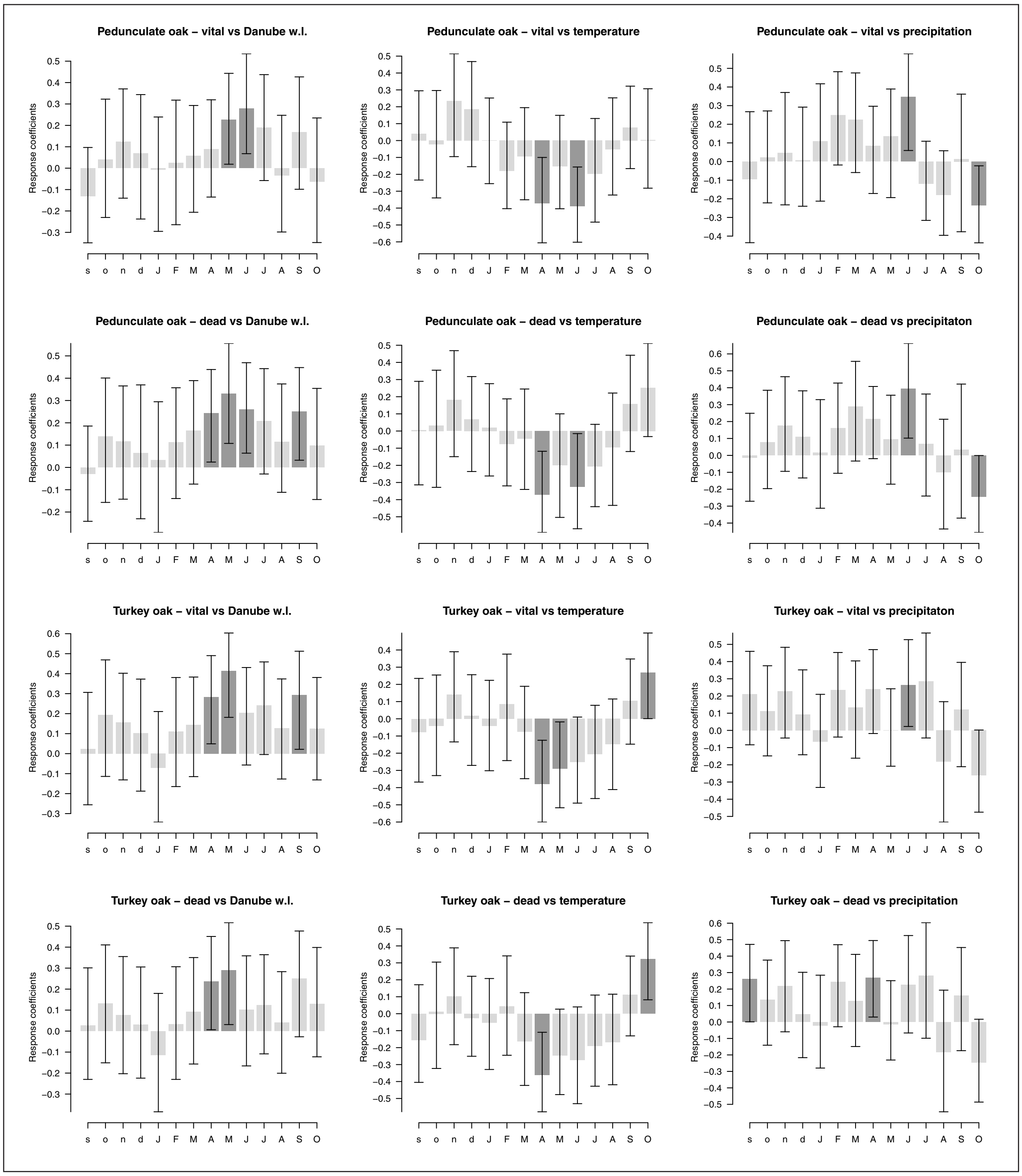

Figure 5 - Bootstrapped Pearson's correlation between tree-ring width residuals and Danube water level (left), air temperature (middle) and precipitation (right) at the Sombor station in the period 1961-2010 for the four groups of trees (top-bottom): (i) pedunculate oak vital, (ii) pedunculate oak dead, (iii) Turkey oak vital and (iv) Turkey oak dead. Months marked by small letters are from the year prior to the growth and capital letters represents the year of the growth. Dark colour represents significant correlation at $p<0.05$ (n=60).

ube River for the period 1961-2010, showed that the water level in May (as a proxy of the ground water level) and the air temperature in April were significantly correlated for all the four tree groups (Fig. 5). The precipitation in June correlated significantly with the growth of pedunculate oak tree groups for the observed period.

Discussion

The results confirm the hypothesis of a relationship between the growth of mixed oak forests and specific environmental variables (the water level in May and the temperature in April for pedunculate and Turkey oak). The observed change (decrease of water level, increase of air temperature and change of precipitation regime, Fig. 2) took place along with the increased mortality in oak forests.

A few other studies support the findings of this research. For instance, Stojanović et al. (2014c) focused on pedunculate oak as one of the most potentially endangered tree species in Serbia, according to different climate change scenarios and the use of ecological niche modelling. Since the extremely dry years 2011 and 2012, about 7% of the growing stock in a compartment of 400 ha was cut in sanitary felling operations (more than 10,000 m^3 of wood) in 2013, in the wider area concerned with this research (Public Enterprise *Vojvodinašume* - Serbia).

A similar phenomenon regarding the impact of environmental variables on tree growth was recently observed in the Sava River basin. Stojanović et al. (2015) found that the Sava River water level and the air temperature in April, May, June, July and August played a key role in the growth of pedunculate oak in the lowlands. A new finding was that the relationship between tree-ring growth and water level has smoothly weakened during the last decades, according to a running correlation analysis, whilst the one between growth and precipitation became more evident, which led to the conclusion that the water level of Sava river, and consequently the ground water level, became so low that roots could not reach the ground water anymore and the trees needed to rely only on precipitation.

The similar growing patterns of pedunculate and Turkey oak, within the investigated mixed stand (Table 1), draw attention to the non-distinctive response of two ecologically different species, this leading to reject the former hypothesis. The phenomenon may be explained by the functional redundancy (Rosenfeld 2002), i.e. the observational evidence that a few species perform similar roles in communities and ecosystems, with the implication that they may be substituted without compromising the ecosystem processes (Lawton and Brown 1993). The full mixture of the two oak species may also explain their common growth response. The analysis of C and O isotopes will, in case, further contribute to the understanding of physiological traits within the investigated tree species and tree groupings.

The long-term decline of Danube River water level may be related to multiple factors: the climate change, the water management, the river bed and/or land-use (Stojanović et al. 2014a). Teskey et al. (2014) pointed out that the drought stress followed by heat waves can lead to an increased tree mortality. With regards to this statement, the increase of air temperature and the change of precipitation regime should be accounted in future studies, where, in particular, the change in precipitation regime means namely less rain during the winter months and a decrease of the overall amount of precipitation (Fig. 2 and 3).

Here, the Danube water level was used as the proxy of ground water table. According to Stojanović et al. (2015), the Sava River water level was highly correlated with the ground water table throughout a sixty-year period. The correlation was above 0.7 with a two-month lag. Since the Danube and the Sava River are both flowing through lowlands and the oak forests are similar with respect to their distance from the rivers and management practice, we assumed that similar ecological impacts exist.

These are the variables to be accounted in the context of future forest management: the observed trend in the Danube River water level drawdown, the air temperature increase, the precipitation regime change, as well as the growth decline of mixed oak forests.

Conclusions

- The recorded differences in tree-growth patterns between pedunculate oak and Turkey oak, both for living and dying trees, were not statistically significant in dendrochronological terms in the analysed context, in opposition to own ecological requirements, according to general forestry knowledge.
- The correlation analysis showed that, according to three basic environmental variables (i.e. the mean monthly temperature, the mean amount of precipitation and the mean monthly water level), the Danube river water level in May (as a proxy of ground water level) and the air temperature in April were statistically related to the growth of all the four studied tree groups over the period 1961-2010.

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