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TREE-RING WIDTH AND ITS INTERRELATION WITH ENVIRONMENTAL PARAMETERS: CASE STUDY IN CENTRAL HUNGARY

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Abstract

Tree ring width is influenced by several internal and external factors, among which climate became one of the most dominant due to the altering conditions and patterns of precipitation and temperature. The study aims to analyse the interrelationship between tree ring-width and the dominant environmental parameters in a landscape exposed to water scarcity in the past decades due to climate change and human interventions. Scots pine (*Pinus sylvestris)*, black locust (*Robinia pseudoacacia*) and white poplar (*Populus alba*) plantations were sampled to reveal their exposure to climatic forcing and water scarcity (different water availability). Correlation and similarity analysis were carried out to compare the calculated ring-width indices to climatic parameters and aridity indices. Tree ring sensitivity was assessed to reveal the impact of water scarcity on yearly ring-growth. Spatial overlapping of significance levels and mean sensitivity with the hydrological changes of the past decades were evaluated to reveal presumable spatial differences of the investigated samples. In the study area (South Danube-Tisza Interfluve) droughts and the deep groundwater table had both impacts on tree growth. The spectacular decrease of ring-width corresponds to the drought years determined by the investigated aridity indices. The relationship between the climate parameters and the ring-widths varies spatially with the changing site conditions. The highest level of correlation coefficients was experienced in areas with the lowest level of water availability. Ring-width sensitivity assessments showed an increasing tendency of sensitivity when comparing the consecutive decades, except for samples with favorable water availability.

Keywords: tree ring, sensitivity, climate change, water scarcity

INTRODUCTION

Recent climate change influences the species distribution and tree growth in many regions of Europe (Lenoir et al., 2008; Way and Oren, 2010) and due to the projected changes in climate extremities further impacts are expected (Mátyás, 2010; Lindner et al., 2014). Tree responses depend on both internal (species characteristics) and external (local site conditions) factors (Fritts, 1976). Climate change results in both positive and negative responses on forests, e.g. drought-induced increase of mortality and species range retraction (Allen et al., 2010; Hlásny et al., 2011), increased risk of forest fires (Venäläinen et al., 2014), and increased productivity at higher elevations and latitudes (Jolly et al., 2005). Due to the experienced impacts of the past decades, there is an increased need for the exact knowledge on how and to which extent the factors influence the functioning of the environmental systems.

Consistent with global and continental trends an increasing trend of the regional temperature was experienced in the Carpathian Basin. There is also a rise in the regional intensity and frequency of extreme precipitation, while the total precipitation has decreased (Bartholy and Pongrácz, 2007). As a result, the area has been increasingly exposed to hydro-climatic extremes e.g. drought, inland excess water, high magnitude flood (Pálfai and Herczeg, 2011; Mezősi et al., 2014). According to regional climate model predictions, more areas will face increasing temperature and changing precipitation conditions (Bartholy, 2011; Blanka et al., 2013), and the further increase of the hydro-climatic extremes is also projected (Mezősi et al., 2014).

The relation between tree ring growth and climatic parameters was investigated for several species in Hungary. The impact of precipitation on Turkey oak (*Quercus cerris*) was investigated by Szabados (2008), where tree rings were sensitive to the annual changes of precipitation, furthermore precipitation from April to June proved to be the most important period of tree growth. Kern et al. (2013) carried out separate investigation on early and latewood width of Pedunculate oak (*Quercus robur*), where the correlation analysis revealed relatively strong response to growing season precipitation for both, and the strongest correlation was found with the precipitation total from November of the year preceding the tree ring growth to August of the growth year. The impact of climate change on beech (*Fagus sylvatica)* was assessed by Garamszegi and Kern (2014), who identified late spring-early summer precipitation as the primary climatic factor governing the beech growth. The authors indicated no evidence of a distinct decline in radial increment, but a significant increase in climatic impact on growth including probable changes and shifts in the vegetation period. Szabados et al. (2012) analysed black locust *(Robinia pseudoacacia L.)* samples from Nyírség region, and found the precipitation of May-July period, especially the precipitation in May as the most determinant for tree increment. The increasing temperature of the vegetation period has negative impact on tree growth.

The consequences of climate change and the anthropogenic activities (e.g. water drainage, water exploitation) contributed to groundwater table decrease in significant part of the Great Hungarian Plain (Pálfai, 1994; Kuti et al., 2002). The highest lowering is experienced in the Danube-Tisza Interfluve, where the missing groundwater resource is approximately 6-9 km^3 in dry years that almost equals to the annual water consumption of Hungary (Rakonczai, 2011, 2014). Several studies investigated the causes and the consequences of this phenomenon in the past 3 decades and estimated the role of the natural and anthropogenic factors. Nowadays, the natural factors (decreasing precipitation, increasing temperature and evapotranspiration) are assigned as the most dominant contributing parameters to the phenomena, especially on the higher-elevated part of the Interfluve (Völgyesi, 2006; Szanyi and Kovács, 2009; Rakonczai, 2014). The water scarcity became the most dominant limiting factor for vegetation in this region and results in changes of wetland habitats (Biro et al., 2007; Deák, 2010; Ladányi et al., 2010; Rakonczai, 2011) and decreased forest productivity determined by remote sensing (Kovács, 2007). The knowledge of forest responses to different hydro-climatic changes in this region is scarce.

This study aims at the investigation of the interrelationship between tree ring-width and t dominant environmental parameters by correlation analysis of time series and by the assessment of their spatial distribution. The study area is highly exposed to water scarcity, thus the main question is how tree-ring sensitivity is influenced by the different availability of water.

STUDY AREA

The study area is located between the Hungarian sections of the Danube and Tisza rivers in the Carpathian Basin (Fig. 1). The area developed of fluvial sediments, the ancient alluvial fan of the Danube River (Borsy 1989). The surface is covered by blown sand on most of the area, but silty and clay sediments are also appear close to the rivers. The area is influenced by continuous groundwater table decrease compared to the 1970s due to climate change and anthropogenic activities (Rakonczai, 2011). The present groundwater level has high spatial variability: in the highly elevated areas it varies between 5-20 m (e.g. Illancs microregion in Bácska Plain Mesoregion), and towards the rivers it decreases. Close to the rivers the depth of groundwater table is around 1 m or less. Thus vegetation growth is highly dependent on precipitation, especially on elevated areas. These areas are the most exposed to water shortage in drought years, thus vegetation development is strongly influenced by the changes of the climate parameters. The annual mean temperature is around 11 °C and the annual amount of precipitation is between 500-600 mm. In July the mean temperature is around 21 and 23 °C, the precipitation in the summer half-year is at about 300 mm (OMSZ, 2014). The temperature shows

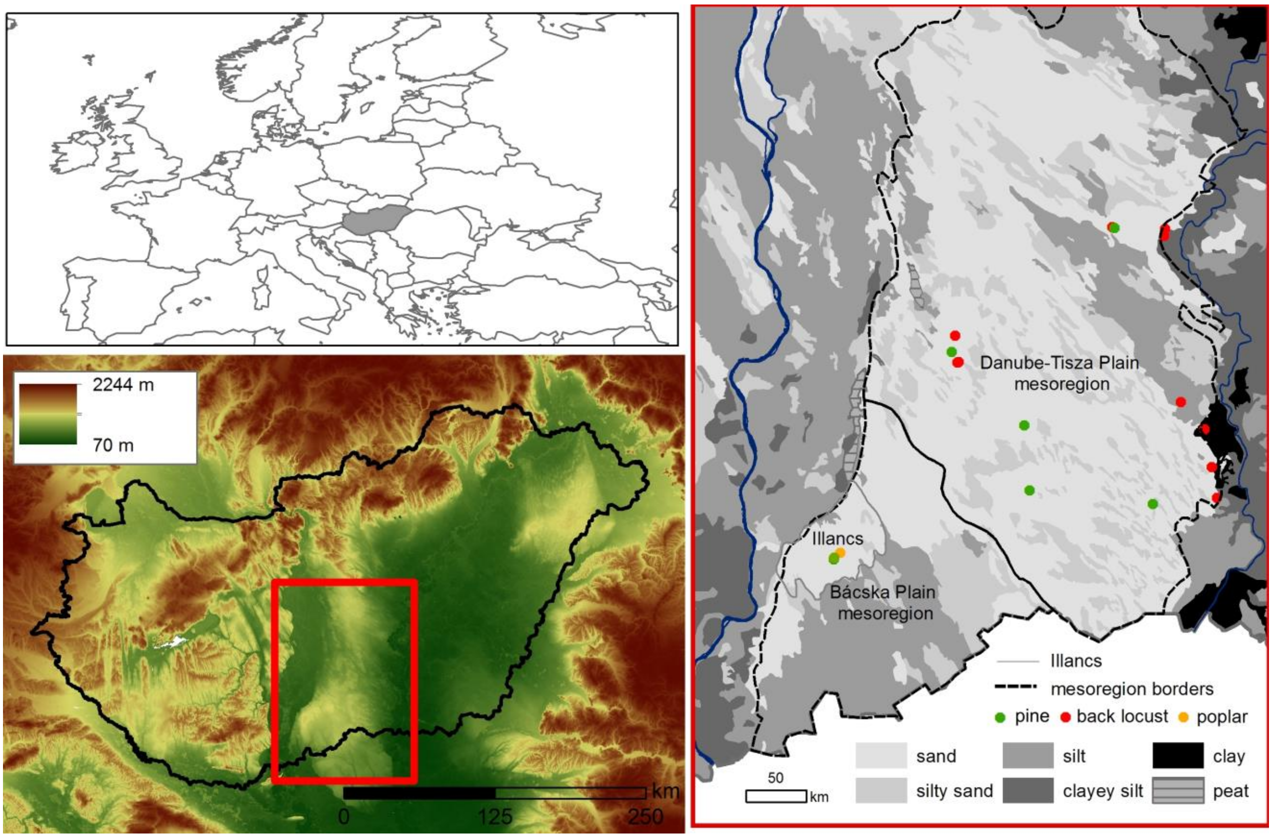


Fig. 1 Location of the study area in the Carpathian Basin and the sampling sites

significant yearly variability, however, an increasing tendency of the temperature can be clearly detected. Since the 1990s, warm years occurred more frequently. In terms of the precipitation conditions of the area, decreasing tendency can observed, years drier than the average occur more frequently and the temporal distribution of precipitation is less favorable. Therefore, drought years occurring increasingly frequently.

The dominant land use type in the area is arable land based on Corine Land Cover 2006. The proportion of forests is low and large part of them are planted with introduced species (e.g. *Robinia pseudoacacia*, *Pinus sylvestris* and *Pinus nigra).*

METHODS

Scots pine (*Pinus sylvestris*) (abbr. pine), black locust (*Robinia pseudoacacia*) and white poplar (*Populus alba*) (abbr. poplar) planted forests were investigated to analyse the sensitivity and the exposure of forests to climate parameters. Altogether 10 pine and 10 poplar trees from two forests were sampled in the highest-elevated, blown sand covered areas in the Bácska Plain mesoregion (Illancs microregion), further 5 pine and 9 black locust plantations were also investigated at lower elevation of the sand ridge (Danube-Tisza Plain mesoregion) on soils characterised by sand, silty sand and silt textures. During sampling tree height, tree health, foliage and trunk were considered. The age of trees varies between 23-47 years (Table 1).

Table 1 Age of the investigated samples

	Age of trees (Illancs, Bácska Plain mesoregion)	Nr of trees (pcs)	Age of trees (Danube-Tisza Plain mesoregion)	Nr. of trees (pcs)
pine	31-45 yrs	10	24-37 yrs	5
black locust	-	-	23-47 yrs	9
poplar	27-43 yrs	10	-	-

Samples were mostly collected by increment borers, though trunk slices were also studied, where investigations were carried out for 4 main directions. After sample preparation ring widths were measured using LINTAB 5 Tree-ring measuring station and TSAP-Win software.

Ring widths vary not only with the fluctuations of environmental conditions, but also with systematic changes in tree age. The standardization of ring-width measurements are necessary to remove the decrease in size associated with increasing age of a tree (Alestalo, 1971). Thus, ring-width indices were calculated by fitting a curve to each measured series and dividing each ring width by the corresponding value of the curve (Fritts, 1976) (Fig. 2).

Detailed assessment was carried out at the highest elevated Illancs microregion. Here, ring-width indices were compared to climate parameters (annual precipitation (Pa), precipitation of the vegetation period (Pv) and mean temperature in the vegetation period (Tv)) based on the neighboring meteorological stations (Szeged, Kiskunhalas), furthermore to drought indices that combine basic meteorological parameters to describe the yearly exposure to water scarcity or surplus. In the assessment Pálfai Drought Index (PAI, Pálfai, 1990) and Forest Aridity Index (FAI, Führer et al., 2011) were calculated (Eq.1-2). For the comparison of climatic indices and ring-width indices correlation coefficients were calculated. The similarity of ring-width and drought index pattern was also evaluated, based on the Gleichläufigkeit test method (Schweingruber, 1989), which analyse the agreement between the interval trends of two curves. The similarity was expressed in percentage.

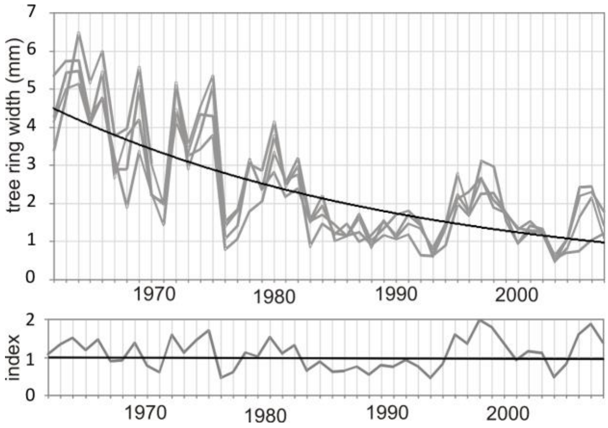


Fig. 2 Method of ring width index calculation

Forest Aridity Index (Führer et al., 2011):

$$FAI = \frac{T_{VII-VIII}}{P_{V-VII}+P_{VII-VIII}} * 100 \qquad \text{(Eq.1)}$$

where, T: monthly mean temperature, P: monthly precipitation sum

Pálfai Drought Index (Pálfai, 1990):

$$PAI = \frac{t_{IV-VIII}\,(°C)}{P_{X-VIII}\,(mm)} * 100 * k_1 * k_2 * k_3 \qquad \text{(Eq.2)}$$

where, T: monthly mean temperature, P: monthly precipitation sum, k_1: correction factor estimating heat waves, k_2: correction factor estimating duration of dry spells, k_3: correction factor estimating groundwater depth.

Based on the calculated ring-with indices, ring-width sensitivity was also assessed (Eq. 3-4) which showed the variability of ring-widths in the consecutive years reflecting changing environmental conditions. Ring width sensitivity was calculated following Fritts (1976):

$$S_{i+1} = \frac{(x_{i+1} - x_i) * 2}{(x_{i+1} + x_i)} \qquad \text{(Eq. 3)}$$

where S_{i+1} is the sensitivity of the tree rings in i+1 year, x_i is ring width

Mean tree-ring sensitivity was defined as:

$$S = \sum_{i=1}^{i=n-1} \frac{Si}{n-1} \qquad \text{(Eq. 4)}$$

where n is the total number of tree-rings

According to Horváth et al. (2003), mean tree ring sensitivity classes are the followings:

S<0.2 low sensitivity

0.2<S<0.3 medium sensitivity

S>0.3high sensitivity

At the study sites of Danube-Tisza Plain mesoregion tree-ring sensitivity was calculated, furthermore correlation coefficients of ring-width and PAI and FAI were calculated for spatial assessment.

Based on the results, spatial assessment was carried out, where the correlation coefficients of PAI and FAI and the tree-ring sensitivity were analysed to reveal the effect of exposure to water scarcity (different water availability) on tree growth.

RESULTS

Assessment of tree samples in the highest elevated Illancs microregion

Pine samples showed increasing variability in the past two decades compared to previous periods (Fig. 3a). The lowest ring-width indices were experienced in the most severe drought years (e.g. 1993, 2003) and the humid periods (e.g. the end of the 1990s) were indicated by the highest values. The period between the end of the 1970s and the early 1990s showed the lowest variability of ring-width indices.

A strong similarity of the ring-width to aridity indices could be identified. The percentage of the years, where the interval trends of two curves agree, varies between 64.3–85.3% and 60.0–85.3% in case of PAI and FAI respectively. The percentage values were somewhat higher in case of PAI compared to FAI at all pine samples.

Poplar samples also showed increasing variability in the past two decades compared to the previous periods (Fig. 3b). The lowest and highest ring-width indices were experienced in the same periods as it was observed in case of pine trees. In this case the 1980-1990 decades had the lowest variability of ring-width indices.

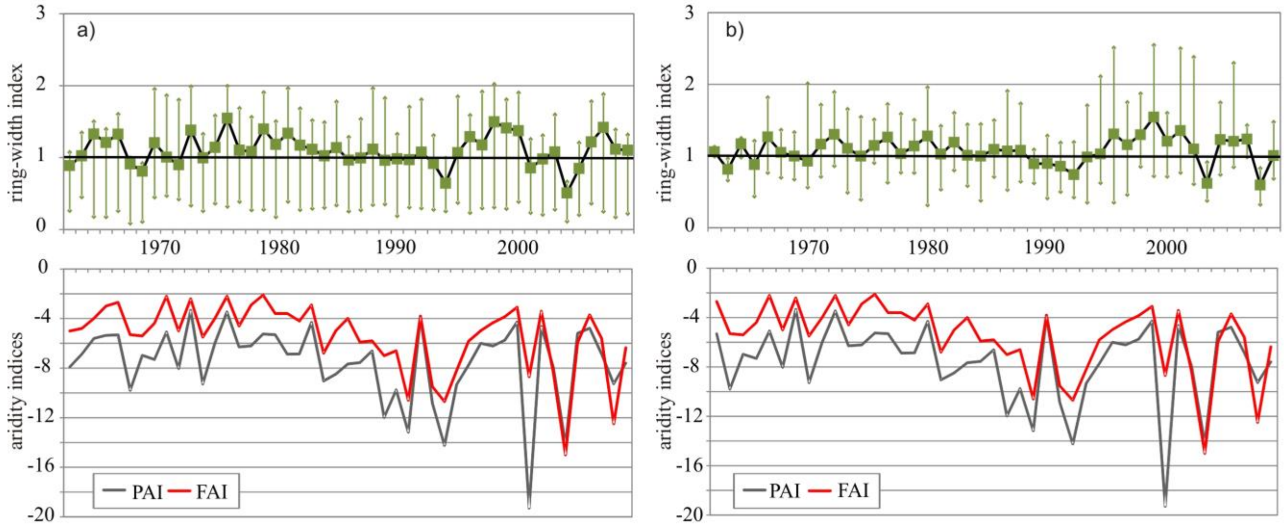
The similarity of the ring-width and the aridity indices of poplar samples were similar to the pine, percentage values related to PAI and FAI were 61.0–81.4% and 60.5–88.4%, respectively. However, in case of poplar trees the higher percentage values varied between PAI and FAI from sample to sample and FAI showed higher similarity in case of 7 samples.

As a result of the correlation analysis, PAI and the FAI values indicated the highest correlations with the ring-width indices in the case of all samples (Fig. 4a). The correlation was significant at the 0.01 level and the 0.05 level for 50-50% of the samples, respectively.

The relationship of the ring-width indices with the precipitation (Pa and Pv) was lower compared to the aridity indices, and in case of a few samples the correlation was not significant, however the correlation with the precipitation of the vegetation period (Pv) was somewhat higher. The lowest level of correlation could be identified in case of the mean temperature of the vegetation period (Tv) with the ring-width indices, and more than half of the samples showed no significant correlation with this factor.

The relationship between the investigated variables was not so evident like it was in case of the pine trees, they showed a higher standard deviation. PAI was the investigated factor, where the most samples showed significant relationship with the ring-width indices (Fig. 4b). The relationship with the precipitation was higher compared to the temperature in this case as well.

The calculated decadal mean tree-ring sensitivity of the pine samples indicated medium and high sensitivity of ring-widths for almost the whole period, except for some samples between 1970-1980 and 1980-1990 periods (Fig. 5). An increasing tendency in sensitivity values was identified towards the past two decades.



%	1	2	3	4	5	6	7	8	9	10
PAI	79.5	80.4	82.6	81.2	64.3	68.7	85.3	78.5	77.5	77.5
FAI	75.0	76.1	73.9	78.1	60.0	62.5	85.3	80.5	72.5	67.5

%	1	2	3	4	5	6	7	8	9	10
PAI	61.0	78.4	81.4	75.0	79.5	70.0	56.1	64.1	55.8	69.2
FAI	73.2	81.1	88.4	71.9	76.9	73.3	61.0	61.5	60.5	73.1

Fig. 3 Mean, minimum and maximum values of the investigated ring-width indices and the similarity between the samples and the aridity indices of pine (a) and poplar samples (b)

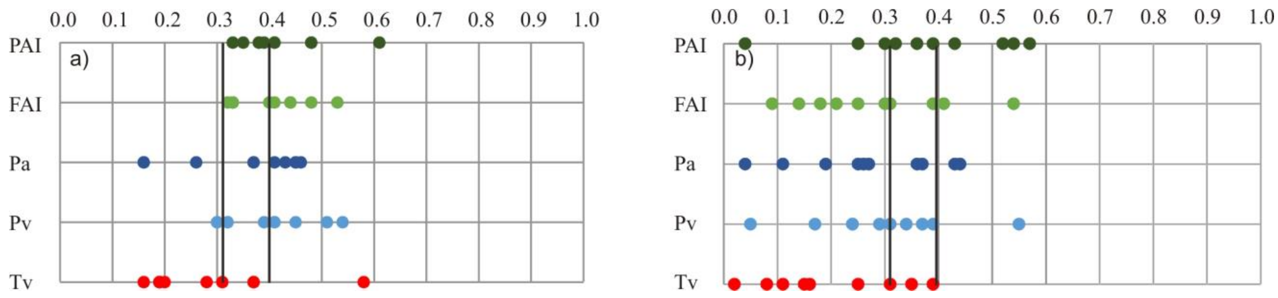


Fig. 4 Correlation factor (|R|) between the ring-width index of the samples and the investigated variables in case of pine (a) and poplar samples (b); PAI: Pálfai Aridity Index, FAI: Forest Aridity Index, Pa: annual precipitation, Pv: precipitation of the vegetation period, Tv: mean temperature of the vegetation period. The black lines represent the significance levels (0.01 and 0.05)

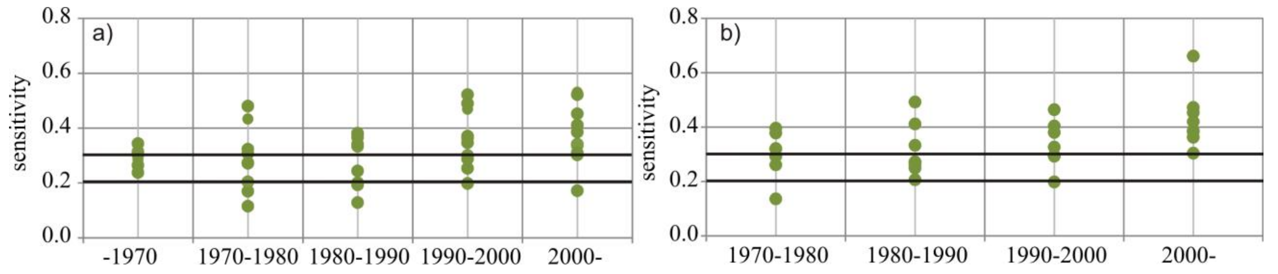


Fig. 5 Tree ring sensitivity (Illancs, Bácska Plain mesoregion) in case of pine (a) and poplar samples (b). The black lines represent the thresholds of low, medium and high sensitivity

Similarly to pine samples, the calculated decadal mean tree-ring sensitivity of poplar also indicated medium and high sensitivity f ring-widths for almost the whole period (Fig. 5b). The increasing tendency of sensitivity values was much more intensive compared to the pine samples and for the past decade, all samples were described by high sensitivity values.

Assessment of samples at Danube-Tisza Plain mesoregion

On the lower lying areas ring-width indices show lower correlation with the PAI and the FAI values. Only 21 % of the samples (1 pine and 2 black locust samples) showed significance at 0.01 level and further 57 % at the 0.05 level with the PAI. The correlations with the FAI were similar to the PAI, except for a few samples. The correlation was significant at the 0.01 level and the 0.05 level for 64% of the samples.

The similarity of the ring-width with the PAI varies between 60.7%–77.1% for pine, similarly to the samples from the Illancs microregion. The variability of the similarity values were higher in case of the black locust samples (48.8%–82.6%). With the FAI the similarity values were slightly lower (57.1%–75.0% for pine and 51.2–71.7% for black locust). In case of only a few samples (4 of the 14) similarity was higher with the FAI.

A strong similarity of the ring-width with the aridity indices was identified for black locust. The percentage of the years, where the interval trends of two curves agree, varied between 64.3–85.3% and 60.0–85.3% in case of PAI and FAI, respectively. The percentage values were somewhat higher in case of PAI compared to FAI at all samples.

The decadal mean tree-ring sensitivity for samples of the other part of the study area was lower compared to the samples of Illancs microregion (Fig. 6). In case of pine mostly low or medium sensitivity was observed, only one sample showed high sensitivity. The tree ring sensitivity of the sampled pine trees not increased in the last decades as it was observed in the Illancs region.

The samples also indicated low or medium tree ring sensitivity in case of black locust and few sample showed high sensitivity. The sensitivity changes of the

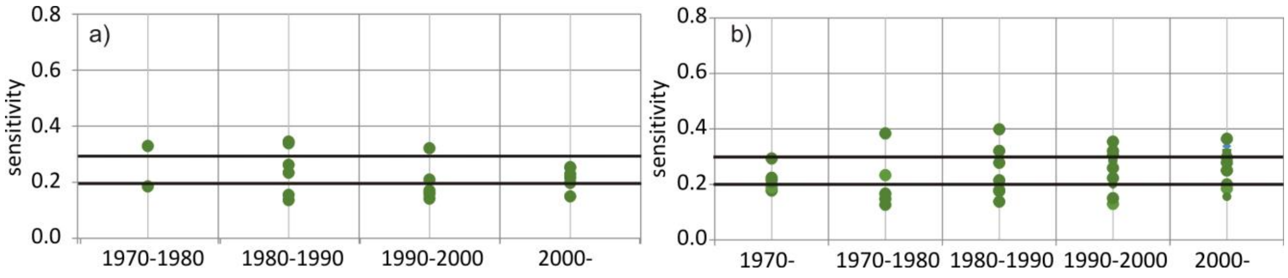


Fig. 6 Tree ring sensitivity (Danube-Tisza Plain mesoregion) in case of pine (a) and black locust samples (b). The black lines represent the thresholds of low, medium and high sensitivity

black locust trees showed higher variability, and most of the samples did not show increasing values, only in case of a few samples increasing sensitivity was observed and the rate of increase was lower compared to the samples of Illancs microregion.

Spatial assessment of ring-width and site conditions

The effect of exposure to water scarcity (different water availability) on tree growth was revealed by spatial assessment. The significance level of correlation between ring-width index and aridity indices, and the mean tree ring sensitivity were overlapped by the relative groundwater depth on Figure 7. In case of pine samples the strength of the correlation increased with the decreasing groundwater depth in case of both PAI and FAI. Samples closer to the rivers, where groundwater level situated closer to the surface, no significant relationship was identified. Similar spatial pattern was recognized in case of the black locust compared to pine samples. The poplar samples from the highest elevated Illancs microregion also confirmed the revealed spatial relationship between the tree growth and the exposure to water scarcity.

The spatial pattern of mean tree-ring sensitivity values (calculated for the whole tree sample) indicate similar differences than the correlation pattern. High sensitivity was identified in case of the samples from the Illancs microregion and from areas of low groundwater table. All the other samples belonged to the medium and low categories of sensitivity.

DISCUSSION AND CONCLUSIONS

Ring width is influenced by several external factors that can be both permanent and variable in a few decades-long period. Soil conditions and relief are among the factors that do not significantly change, however, meteorological and hydrological factors can vary significantly. As it is well-known, severe drought years result in narrow ring widths, while humid years cause wide increment. The changes of the groundwater availability can also be a limiting factor of tree growth.

In the study area droughts and the deep groundwater table have both impact on tree growth. Tree responses to these changing conditions were reported earlier from this area: the decrease of green biomass and foliage in drought years were described by Kovács (2007) using remote sensing methods.

The spectacular decrease of ring-width (in arid years even below 1 mm for both pine and poplar in the highest elevated Illancs microregion, where the most significant high groundwater table decrease was recorded since the 1970s) corresponds to the drought years determined by the investigated aridity indices. Their yearly changes compared to the changes of the ring-width indices are also relatively high and varies between 60-88% in Illancs region. The other samples are characterized by the same or lower similarity when closing to the rivers or areas of more favourable water supply.

The relationship between the climate parameters and the ring-widths varies spatially with the changing site conditions (e.g. elevation, groundwater depth, soil). The highest level of correlation coefficients were experienced in the highest elevated Illancs microregion, while the lowest ones occurred on the relatively lower lying areas, especially near to the Tisza River, where ground-water supply ensures sufficient water for tree growth.

The ring-width sensitivity assessments showed an increasing tendency of sensitivity when comparing the consecutive decades. Along with the increasing extremities and the lowering groundwater-table, the yearly variation of ring-with increases to the highest rate in Illancs microregion, while towards the rivers, the increasing tendency becomes moderate, and in certain cases even no trend can be observed.

The investigated planted forests are in a landscape that is dominantly used by agriculture and which is exposed to high water scarcity. The exposure to climatic forces will tend to continue (Bartholy et al., 2011; Blanka et al., 2013; Mezősi et al., 2014) that is why the more ex-

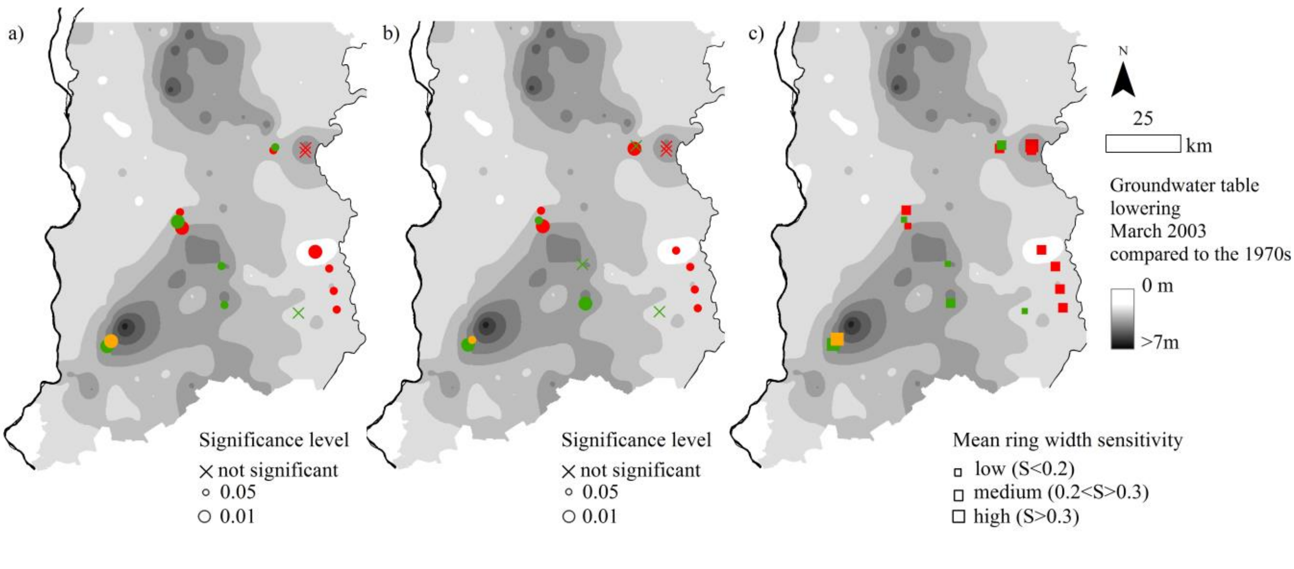


Fig. 7 Spatial distribution of correlations between pine (green), black locust (red) and poplar (orange) samples and aridity indices in the case of PAI (a) and FAI (b), and spatial distribution of mean ring width sensitivity (c)

act knowledge on impacts is highly important. The detailed information on the observed changes can help adaptation and mitigation measures to the potential impacts of climate change.

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