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Multiple tree-ring proxies (earlywood width, latewood width and $\delta^{13}C$) from pedunculate oak *(Quercus robur* L.*)*, Hungary

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Abstract
The aim of this study was to analyse the effects of climatic factors (i.e. monthly mean temperature and total precipitation) on radial growth (earlywood width, latewood width, and total ringwidth) and on latewood stable carbon isotope composition in a pedunculate oak *(Quercus robur* L.*)* stand in northeastern Hungary. Earlywood widths showed the weakest common variance and lack of statistically significant relationship to monthly precipitation and temperature. Latewood width showed the strongest common chronological signal. Correlation analysis with the monthly climate series pointed out the strongest positive/negative correlation with June precipitation for latewood width/stable carbon isotope ratio. These parameters shared the strongest climatic response also for seasonal scale since the highest correlation coefficients, 0.49 and -0.62 for latewood width and stable carbon isotope ratio, respectively, were obtained for both with a 10-month precipitation total (from previous November to current August of the growing season).
A combined parameter, derived as difference between latewood width and stable carbon isotope indices showed improved statistical relationship compared to the hydroclimatic calibration target both for local and regional spatial scales. Spatial correlation analysis indicated that the hydroclimatic signal encoded in these moisture sensitive tree-ring parameters from Bakta Forest is expected to be representative for the northeastern Carpathians and for the large part of the Great Hungarian Plain. In addition, the hydroclimatic signal of latewood width chronology was compared to three independent records. Results showed that neither the strength nor the rank of the similarity of the local hydroclimate signals were stable throughout the past two centuries. Future palaeo(hydro)climatological efforts targeting the Carpathian(-Balkan) region are recommended to track carefully the spatial domains for which a given, local, proxy-derived hydroclimate reconstruction might provide useful information.

Key words: dendroclimatology, hydroclimate, precipitation, Carpathian Region, ring width, stable carbon isotope

1. Introduction

Tree rings are widely applied environmental recorders (Schweingruber, 1996). One of the most frequently studied species in Europe are oaks *(Quercus* spp.*)* owing to their longevity and relatively well crossdatable ring width pattern (Haneca et al., 2009).

The annual oak increment consists of two, visually well distinguishable parts. Earlywood (light coloured with large vessels) develops during spring, while latewood (dark coloured, denser, lacks large vessels) is laid during the latter part of the growing period.

Dendroecological and dendroclimatological information have already been tested widely on the Carpathian oak stands (Babos, 1984; Papp, 1986; Tissescu, 1990, 2001; Grynaeus et al., 1994; Popa, 2002, 2004; Horváth, 2004; Szabados, 2006; Dávid and Kern, 2007; Kern, 2007; Kern et al., 2009) as well as in the Balkans (Čufar and Levanič, 1999; Čufar et al., 2008a,b).However mostly the total annual increment was studied. The fact that stronger climatic signals were found in the latewood width of different oak species than in earlywood or entire tree ring width in mesic northern German sites (Eckstein and Schmidt, 1974) and in xeric northern Italian sites (Nola, 1996) encouraged us to test for environmental information retrievable from separately analysed earlywood and latewood width from oak species growing over various climatic/ecological conditions in the Carpathian-Balkan region. We report results from a northeastern Hungarian site where this separate analysis was conducted.

It is interesting to note that environmental information recorded in tree rings has never ever been studied earlier in the forests of Nyírség. Dendrochronological analyses have already started on the pedunculate oak stands of the area (Grynaeus, 1995, 1996) but these works concentrated exclusively on chronological characteristics. Only a relatively short local chronology (span 1902-1994) was constructed for total ringwidth.

Another family of tree-ring derived parameters can be obtained by analysing relative abundance of heavier isotopes to lighter ones in the wood, or in particular constituents (e.g. α-cellulose) (for review see: Leuenberger et al., 1998; McCarroll and Loader, 2004). For instance, stable carbon isotope ratios of European oak tree rings have been shown to preserve usually strong climate signal. It is true even for complacent sites, where ring width is under complex environmental control. Consequently, increment-based proxies cannot provide temporally stable and strong climate response needed for dendroclimatological reconstructions (e.g. Robertson et al., 1997; Raffali-Delerce et al., 2004; Loader et al. 2008; Hilasvouri and Beringer, 2010).

Stable carbon isotope ratios measured from oak tree rings will be also discussed in this paper. The potential of stable isotope dendroclimatology is totally unexploited in the Carpathian region. Up to our knowledge no any earlier research targeted stable isotope data from tree ring in Hungary before this study.

The aim of the study is to survey and compare the potential of the tree ring parameters from Nyírség oaks for a future tree ring based climate reconstruction. This is the first instance of separate analysis of earlywood and latewood signals in Hungary. However, the presented 80-year long $\delta^{13}C$ record is the first tree-ring derived stable isotope chronology not only from Hungary but also from the broader Carpathian region.

Addressed key questions are:

(1) What is the main climatic regulator for the different oak tree-ring parameters?

(2) Can we improve the obtainable climate signal if tree-ring parameters are combined?

(3) What is the spatial signature of the climatic information retrieved from the tree-ring parameters?

2. Materials and methods

2.1. Site and sampling

The Nyírség is a relatively elevated region of the north-eastern part of the Great Hungarian Plain (Alföld). The climate of the region is continental with warm summers (or hemiboreal Köppen code: Dfb). The mean annual surface air temperature is +9.5°C The warmest month is July (+20.4°C), the coldest month is January (-2.6°C). The vegetation season usually lasts from April to September. Late and early frost frequently appears at the beginning and end of the vegetation season (Pályi, 2010).

Due to the orographic effect of the Northeastern Carpathians this region is the cloudiest/wettest corner of the Great Hungarian Plain (Fig. 1). The long-term annual precipitation sum is 606 mm. The driest month is March (33 mm), the late spring/early summer (May-July) is the wettest period with a June precipitation maximum (77 mm) (Pályi, 2010).

Naturally a mixed common hornbeam *(Carpinus betulus* L.*)* forest type was the climax forest association of this region. Pedunculate oak *(Quercus robur* L.*)* has become the dominant tree species in the region only in the Middle Ages, by the 15th century (Willis et al., 1995), probably owing to forest management that preferred oak. Due to the extension of cropland agriculture these semi-natural oak forests have been restricted to a few survival patches only. One of these small patches is the Bakta Forest situated near the town of Baktalórántháza.

Cross-sectional disk samples from ~0.1-0.5 m height were sawn from 10 dominant pedunculate oak trees in August 2009. The site (N 47.98°, E 22.05°) coded as 12A in the local forest inventory.

The characteristic soil of the 12A district of the Bakta Forest is is Lamellic Stagnic Luvisols (IUSS, 2006) developed on fluvial/eolian sand (Kovács, 2010).

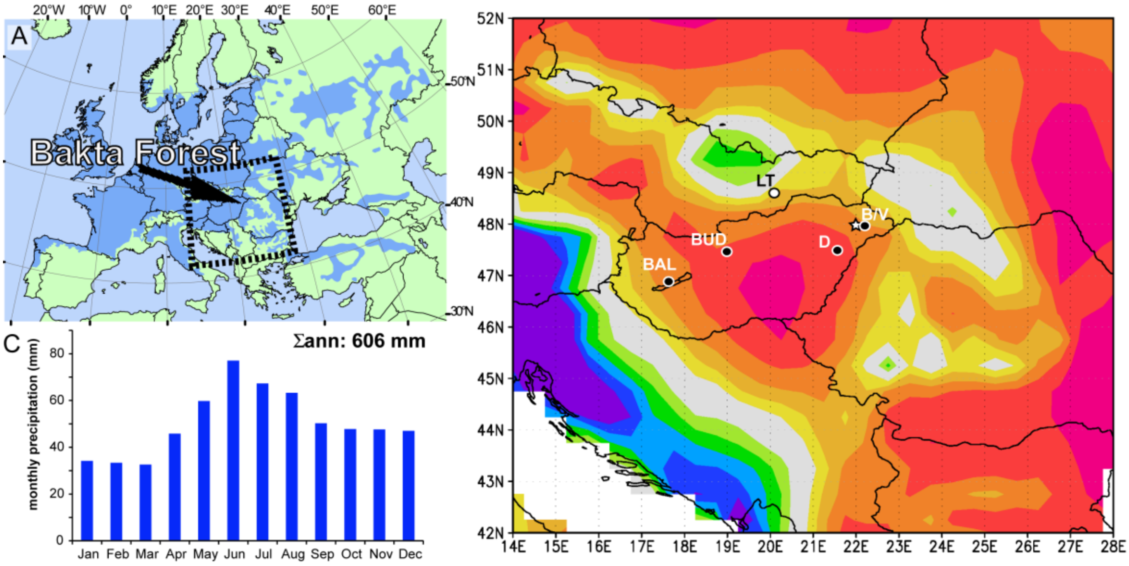


Fig. 1. Study site characteristics. A: Distribution map of pedunculate oak (*Quercus robur* L.) (EUFORGEN 2009) and the location of Bakta Forest. Dashed polygon shows the precipitation map of B part. B: Distribution of the long-term (1901-2007) annual precipitation total over the Carpathian-Balkan region (CRUTS3.1, Mitchell and Jones, 2005). Star shows the study site. The local meteorological stations used for climate response analysis is shown (B/V: Baktalórántháza & Vaja, D: Debrecen) Location of long-term hydroclimatological records used for comparison (see 4.2. section) are indicated LT: Low Tatras (Büntgen et al., 2010a), BUD: Budapest (Auer et al., 2007), BAL: Balaton Highlands (Kern et al., 2009). C: Long-term mean monthly precipitation totals at the study site (after Pályi, 2010).

2.2. Tree-ring chronology construction

Disks were half-sawn horizontally and one of the duplicate disks was sanded and polished to enhance the visibility of the ringwidth structure. Earlywood (EW) and latewood (LW) width were measured separately on each disk. Measurements were made with a resolution of 0.01 mm along two radii per each disk using LINTAB measuring table and TSAP-Win software (Rinn, 2003). Total ring width (TRW) was derived as EW+LW from the measurements. The final chronology spans from 1730 to 2008 and at least 4 trees are included from 1786. EW, LW and TRW series have been standardized fitting a cubic smoothing spline with maximum frequency cut-off at 67% of the individual series (Cook and Peters, 1981). Individual indices were derived as ratio between raw measurement and spline function. Autocorrelation was removed from each individual index and the mean chronology was calculated as biweight robust mean (Cook, 1985) for each variable. Variance adjustment was applied on the derived chronologies to minimize variance bias due to changing sample replication and the effect of fluctuating interseries correlation (Osborn et al., 1997; Frank et al., 2007).

Stability of the climate-related signal preserved in the index series was controlled by the Expressed Population Signal (EPS) statistic. EPS estimates how well a finite number of analyzed samples represent the theoretical stand average. Its widely accepted threshold is 0.85 (Wigley et al., 1984). Mean interseries correlation (Rbar) and EPS were calculated with 50 yrs running windows. Standardization and index calculation procedure was carried out using the ARSTAN software (Cook and Krusic, 2006).

2.3. Stable carbon isotope measurements and subsequent corrections

Three disks were chosen from the reserved duplicate disks with relatively wider rings. 1 cm thick laths were sawn from the disks using a low speed circular saw. Each analysed tree ring was splitted into early-and latewood using a scalpel. As earlywood formation starts even before bud burst, it is certainly influenced by the stored photosynthates (Hill et al., 1995). Therefore, to ensure the annual resolution of the environmental record, only latewood was analysed in this study. The measurements were carried out on wood since $^{13}C/^{12}C$ ratios determined in bulk wood showed the same relative variations as in isolated cellulose (Leavitt and Long, 1982; Borella et al., 1998; Loader et al., 2003) and moreover stronger climate response was found for bulk wood compared to cellulose, especially for pedunculate oak, without any temporal offset in the climate response (Loader et al., 2003).

Wood slivers (~1-5 mg) were combusted in a Pyrex tube with CuO (Boutton et al., 1983). The tube was sealed in vacuum then heated to 500°C for 16 hours. Formed H_2O was cryogenically removed and CO_2 was trapped. Stable carbon isotope ratio was measured on the CO_2 gas by a dual inlet Finnigan MAT delta S mass spectrometer at the Institute for Geochemical Research of the Hungarian Academy of Sciences, Budapest. Stable carbon isotope ratios are expressed by the conventional δ notation as relative $^{13}C/^{12}C$ values ($\delta^{13}C$) in per mil relative to VPDB standard (Craig, 1957). IAEA-CH-7 standard was used as reference material and IAEA-CH-7 and IAEA-CH4 for calibration against VPDB (Paul et al., 2007).

The standard deviation of the repeated analyses of CH-7 standard was better than 0.1 ‰. Duplicates were prepared from 6 latewood samples to test the full analytical uncertainty. Difference between the duplicates ranged from -0.15 ‰ to 0.17 ‰ with a median difference of -0.02 ‰. Altogether we estimate our analytical uncertainty as ±0.15 ‰.

The raw $\delta^{13}C$ data were corrected to account for changes in $\delta^{13}C$ of the atmospheric CO_2 (Suess effect) due to fossil fuel combustion (Leuenberger, 2007). Treydte et al. (2001) have suggested additional corrections on tree-ring stable carbon isotope ratios accounting for physiological changes in carbon isotope fixation due to increasing atmospheric CO_2 concentrations (for review see McCarroll et al., 2009). In this study we tested two scenarios assuming a moderate (0.0073 ‰/ppm; Kürschner, 1996) and an aggressive (0.02 ‰/ppm; Feng and Epstein, 1995) plant physiological response. The first factor is in line with coefficient derived from greenhouse experiments with trees while the latter one is statistically derived. These two scenarios represent the published lower and upper range of potential plant physiological response (Treydte et al., 2009). Corrected data combining atmospheric $^{13}CO_2$

drift with the moderate and aggressive scenario for plant physiological response will be marked as δ^{13}Ccorr1 and δ^{13}Ccorr2, respectively.

2.4. Climatological data

Two closest gauge stations where monthly precipitation totals are recorded are Baktalórántháza and Vaja (Fig. 1) has been operating since 1901 and 1970, respectively. Monthly values were carefully compared to other nearby gauge stations to detect measurement errors or inhomogeneities and a composite record was developed (Pályi, 2010). This local composite record of monthly precipitation totals, spanning 1901-2008, (hereafter Bakta/Vaja) was used in climate response analysis.

Monthly mean air temperature record was available on-line from Debrecen station (OMSZ, 2011) as a representative homogenized and high-quality record of the area for the 20th century. The distance between Debrecen station and the study site is ~60 km in the SSW direction (Fig. 1). This dataset was updated to 2008 using data extracted from the Climate Explorer database.

Relationship between annual tree-ring components and climatic parameters were evaluated by computing Pearson's correlation coefficients (Fritts, 1976) from June of the previous year to October of the current year of formation of tree rings. In addition (multi)monthly combined climatic data were also involved into the correlation analysis. Regarding that δ^{13}C data are available only after 1929 and the common signal in EW is still weak before 1930 (see Section 3.1.1.) the correlation analysis was restricted uniformly to the 1929-2008 period for each tree-ring parameter.

Table 1 Basic statistics of earlywood (EW), latewood (LW) and full ring (RW) width chronologies.

	Mean width	STDEV	MS[a]	AC1[b]
EW	0.81	0.27	0.22	0.71
LW	1.09	0.70	0.43	0.68
RW	1.90	0.83	0.26	0.75

a: mean sensitivity

b: first order autocorrelation of the original record (before AR prewhitening)

3. Results

3.1. Description of the tree-ring parameter chronologies

3.1.1. Chronologies of oak increment

Mean latewood width exceeds the mean earlywood width of oaks from Bakta Forest. Broadly, LW carries the most variable signal as documented by standard deviation (compared to the corresponding mean) and the mean sensitivity (Table 1). The first order autocorrelation is generally high for each parameter, however LW has the lowest and RW has the highest value.

Correlation calculated between the tree-ring parameters show the weakest similarity between LW and EW, moderate correspondence for the EW/RW and practically identical fluctuation for the LW/RW pairs (Fig. 2).

Running-window statistics provide an approach to assess the temporal behaviour of the signal strength of the three oak tree-ring parameters. Rbar runs generally below the 0.3 level for EW while exceed this level for LW and RW over the entire record (Fig. 2). EPS values further emphasize the above dichotomy of the parameters. EPS values for RW and LW run together dominantly well above the critical threshold, while EW not only lags behind the others, but from ~1930 drops below the 0.85 level. RW drops below the threshold before ~1790 and between 1830 and 1850. LW seems to retain the most stable and robust chronological signal since its EPS showed slight weakening around 1850 but after the recovery this parameter sustain the high EPS values throughout the end of the period of calculation.

The characteristics found agree with other studies on separate analysis of latewood and earlywood of *Quercus* sp. (Garcia-González and Eckstein, 2003; Lebourgeois et al., 2004; Fonti and Garcia-González, 2008).

Overall, dendrochronological statistics gave the impression that EW and LW carries different dendrochronological and probably different climatic signal as well. The signal of RW is dominated by LW variability despite the fact that LW takes only slightly more than half (~57%) of the mean annual increment.

3.1.2. Stable carbon isotope chronology

Latewood $\delta^{13}C$ chronologies provided much stronger common variability than incremental proxies. Pairwise computed correlation coefficients ranged from 0.68 to 0.87. Raw measured data displayed a prominent declining temporal trend validating the necessity of the correction procedure. The most important difference between the corrected records adopting a moderate ($\delta^{13}C$corr1) or aggressive ($\delta^{13}C$corr2) scenario for plant physiological response is that a persistent declining trend still remained when the first approach was applied, while the declining trend was removed from the large part and remained only after 1990 by the second approach (Fig. 3). Consequently, interseries correlation became weaker in the $\delta^{13}C$corr2 case.

We checked whether the number of samples could be sufficient to extract the robust isotopic signal. EPS statistic can be used to assess the needed minimum sample number taking into account the mean interseries correlation (McCarroll and Pawallek, 1998). Adopted 0.85, as the critical EPS value (Wigley et al., 1984) indicating adequate sample size, the minimum needed sample was estimated to 2.5 using mean correlation between raw measurements while 4.7 and 6.2 were obtained using mean correlation of the series after $\delta^{13}C$corr1 and $\delta^{13}C$corr2 correction procedure, respectively. The first value suggests that 3 individual series might seem to be enough to represent the site-specific latewood $\delta^{13}C$ signal. However, the steadily declining trend of the raw data related to changes of atmospheric CO_2 trend surely increases the mean interseries correlation, and influences this calculation, too. If the dendroclimatic signal is in the focus then definitely the minimum estimates derived from the corrected series are indicative. These results suggest that 5-6 individual series are expected to produce the robust climatic signal from pedunculate oak latewood material at the study area for a future stable isotope dendroclimatological reconstruction. It means that present results are to be regarded as preliminary, however – as will be shown in Section 3.2 - the climatic signal found in this preliminary chronology is quite strong and reasonable.

3.2. Climate response

A sole monthly precipitation/temperature has not provided statistically significant results for EW (Fig. 4). Although the negative coefficients obtained for the winter-spring temperature tend to agree with the response of *Q. petraea* in western France (Lebourgeois et al., 2004) but the correlation does not reach p=0.05 level here, even if months were averaged. The weaker climatic signal in EW compared to LW or RW usually observed in oaks (Eckstein and Schmidt, 1974; Nola, 1996; Garcia-González and Eckstein, 2003) and a complete lack of significant response to temperature or precipitation for EW was reported also from a multi-site study from Switzerland (Fonti and Garcia-González, 2008).

As could be expected from the high LW *vs* RW interseries correlation, fairly similar climate response were found for these parameters (Fig. 4). However, a faded counterpart of the relatively strong climate response of LW can be seen in the case of RW. The simple and plausible explanation is that LW variability dominates the RW (see 3.1.1 section) and - as we have seen above - EW contributes only some noise to this.

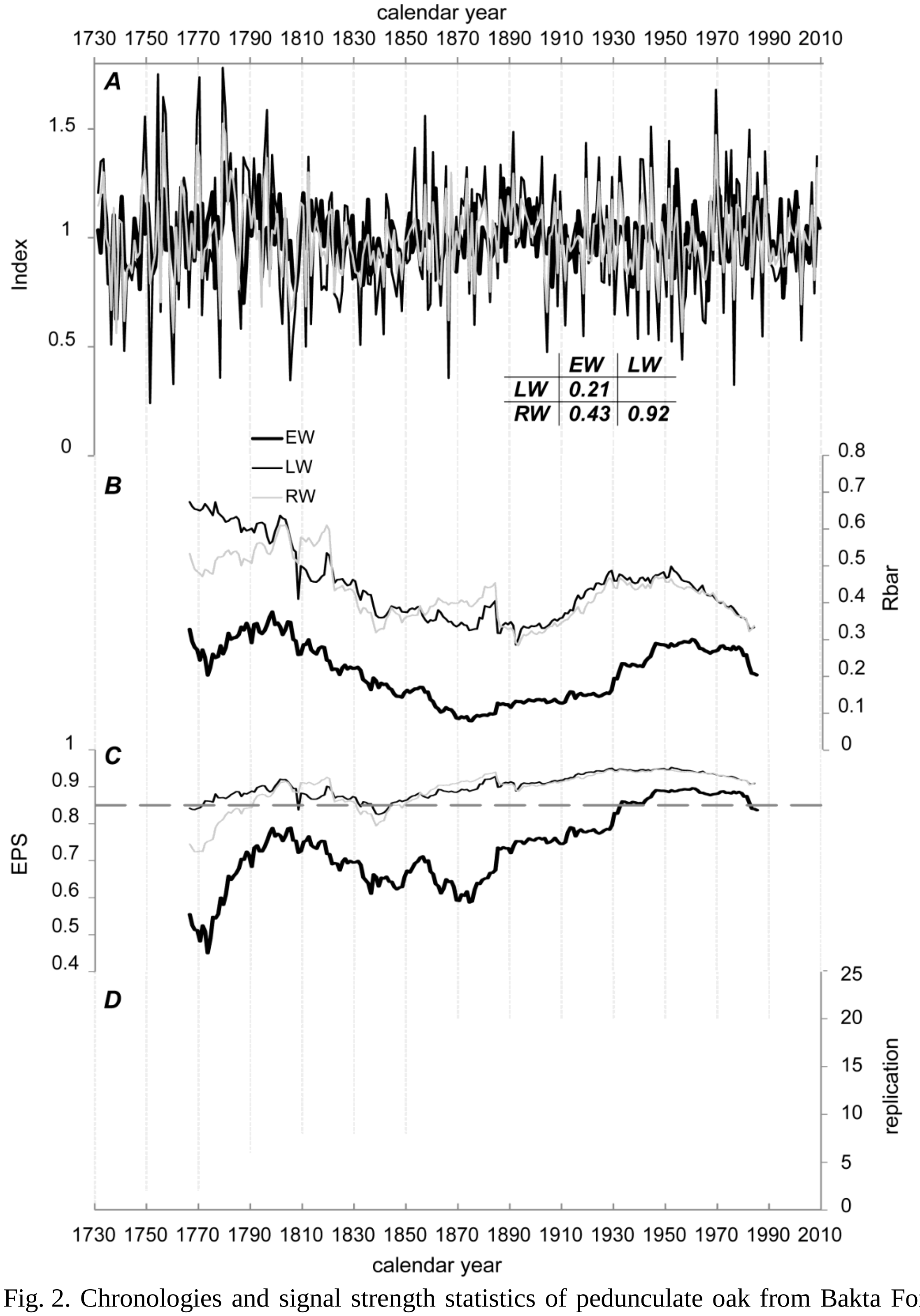


Fig. 2. Chronologies and signal strength statistics of pedunculate oak from Bakta Forest. A: Earlywood width (EW), latewood width (LW) and total ringwidth chronologies. Inset table show the cross-correlation matrix of the three tree-ring parameters. B-C: Mean interseries correlation (Rbar) and Expressed Population Signal were computed in 50 yr running windows. Dashed horizontal line indicates the 0.85 level for EPS. D: Coverage of the chronology.

In comparison to other European oak sites the found LW/RW climate response pattern is usual. June-July temperature seems to exert a negative impact on radial oak growth in the Bakta Forest. The strongest correlation was obtained with April but June and July showed also significant values. The pattern seems to be unchanged whenever RW or LW was regarded. The most important climatic factor is, however, the growing season precipitation. Correlation coefficient of June and July monthly records are above the 0.05 level for both LW and RW. Response window tends to expand toward late spring and late summer for RW and LW, respectively. Preceding year's autumn-winter precipitation seems also to stimulate the radial oak growth at this site but it plays only secondary role. It is interesting to note that similar intraseasonal tendency appears in the case of this secondary factor as was observed for the primary one. Maximum response tends to shift towards earlier (September) and later (November) for RW and LW, respectively.

The peak correlation between radial oak increment and summer moisture stress was reported from Slovenia (Čufar et al., 2008a,b) to southern Finland (Helama et al., 2009a). The relatively wide window of optimal response was also expected, as a detailed study conducted over a dendrochronological oak network in Germany also pointed out the clear sensitivity of *Q. robur* to moisture stress over a relatively longer (annual) window (Friedrichs et al., 2008).

It is worth mentioning that we tested whether the positive precipitation/negative temperature responses are amalgamated in an improved drought response. Various drought indices were tested and none bore stronger correlation than the precipitation alone.

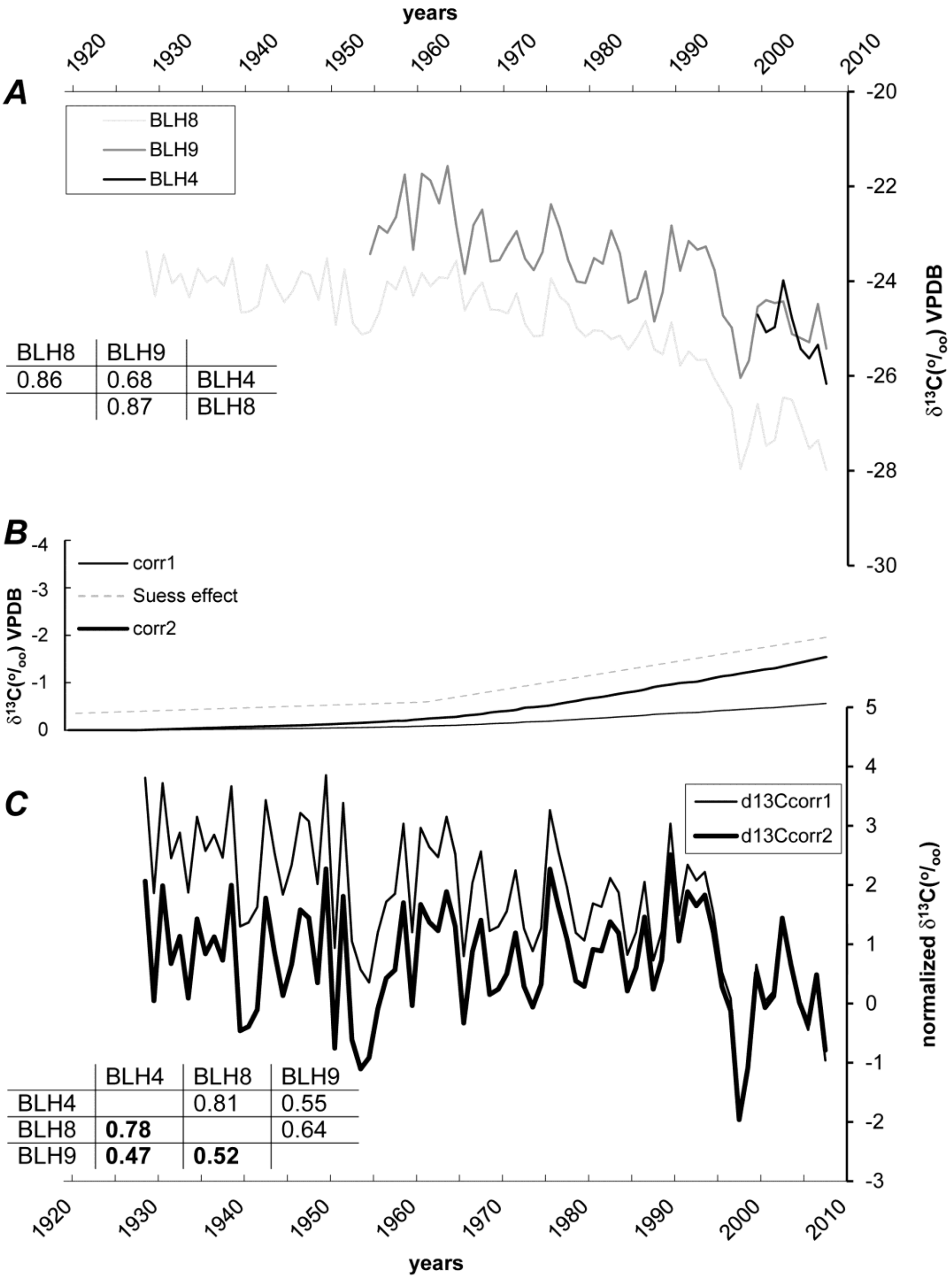
Interannual variability of latewood stable carbon isotope ratio showed generally negative correlation to the precipitation and lack of meaningful response to the temperature independently from the applied variant of correction. We compared the correlation response pattern between the two $\delta^{13}C$ chronologies assuming moderate ($\delta^{13}C$corr1) or aggressive ($\delta^{13}C$corr2) plant physiological response to increasing atmospheric CO_2 concentration. It clearly appeared that stronger correlation was found with $\delta^{13}C$corr2 for the month in the growing season (May-August), while diminished for the preceding seasons, for instance February and previous December when the coefficient for the $\delta^{13}C$corr2 dropped below the significance level. The fact that the pronounced response to the growing season conditions and the lack of response to the preceding is the characteristic response pattern of the tree-ring $\delta^{13}C$ records (Treydte et al., 2007) in combination with the higher coefficients argue that the corr2 correction scenario is more appropriate in the case of the studied pedunculate oaks. We have used the $\delta^{13}C$corr2 in the following calculations.

Strongest correlation were found for June (-0.44) and July (-0.37) precipitation, their bimonthly sum yielded r=-0.52 but coefficients exceeded the 0.05 level for each month over the April-August season. As lower coefficients, but with the same sign, were obtained for previous November-December and February as well, hence the extended pNov-Aug period was also tested. This 10-month season provided the strongest correlation (-0.62).

The strong response to high summer moisture conditions is characteristic for latewood $\delta^{13}C$ of European oaks (Raffali-Delerce et al., 2004; Loader et al., 2008; Hilasvouri and Beringer, 2010). Strength of the climatic signal depicted by the magnitude of the correlation coefficients is also comparable.

However, the response is usually strictly constrained to the meteorological summer. Although, for instance, significantly wider response window, including previous winter and autumn seasons, was recently reported for oaks from the Vienna Basin (Haupt et al., 2011).

The unusually wide optimal response window of the pedunculate oak latewood $\delta^{13}C$ of Bakta Forest is probably an interference of site- and species-specific ecological effects. On the one hand, the relatively low water use efficiency is a well-known ecophysiological character of *Q. robur* (Ponton et al., 2001). On the other hand, the extractable growing season soil water proved to be a key factor governing ^{13}C discrimination (Dupouey et al., 1993). The sandy soil of the study site surely has very low water holding capacity and the soil water reservoir is definitely very sensitive to the degree of the winter recharge.



BLH8	BLH9	
0.86	0.68	BLH4
	0.87	BLH8

	BLH4	BLH8	BLH9
BLH4		0.81	0.55
BLH8	**0.78**		0.64
BLH9	**0.47**	**0.52**	

Fig. 3. A: Results of the raw measurements of stable carbon isotope composition from the three pedunculate oaks (Bakta Forest, Hungary). B: Temporal evolution of the different correction terms. Note, the axis is reversed to better visualize the effect of the correction. C: Normalized mean chronologies of relative changes in latewood stable carbon isotope composition. δ^{13}Ccorr1 (thin line) and δ^{13}Ccorr2 (thick line) was derived assuming moderate or aggressive plant physiological response to increasing atmospheric CO_2 concentration, respectively. Cross-correlation matrices are shown in A and C. The latter shows coefficients of interseries correlation with normal (above the diagonal) and bold (below the diagonal) corresponding to the correction alternatives.

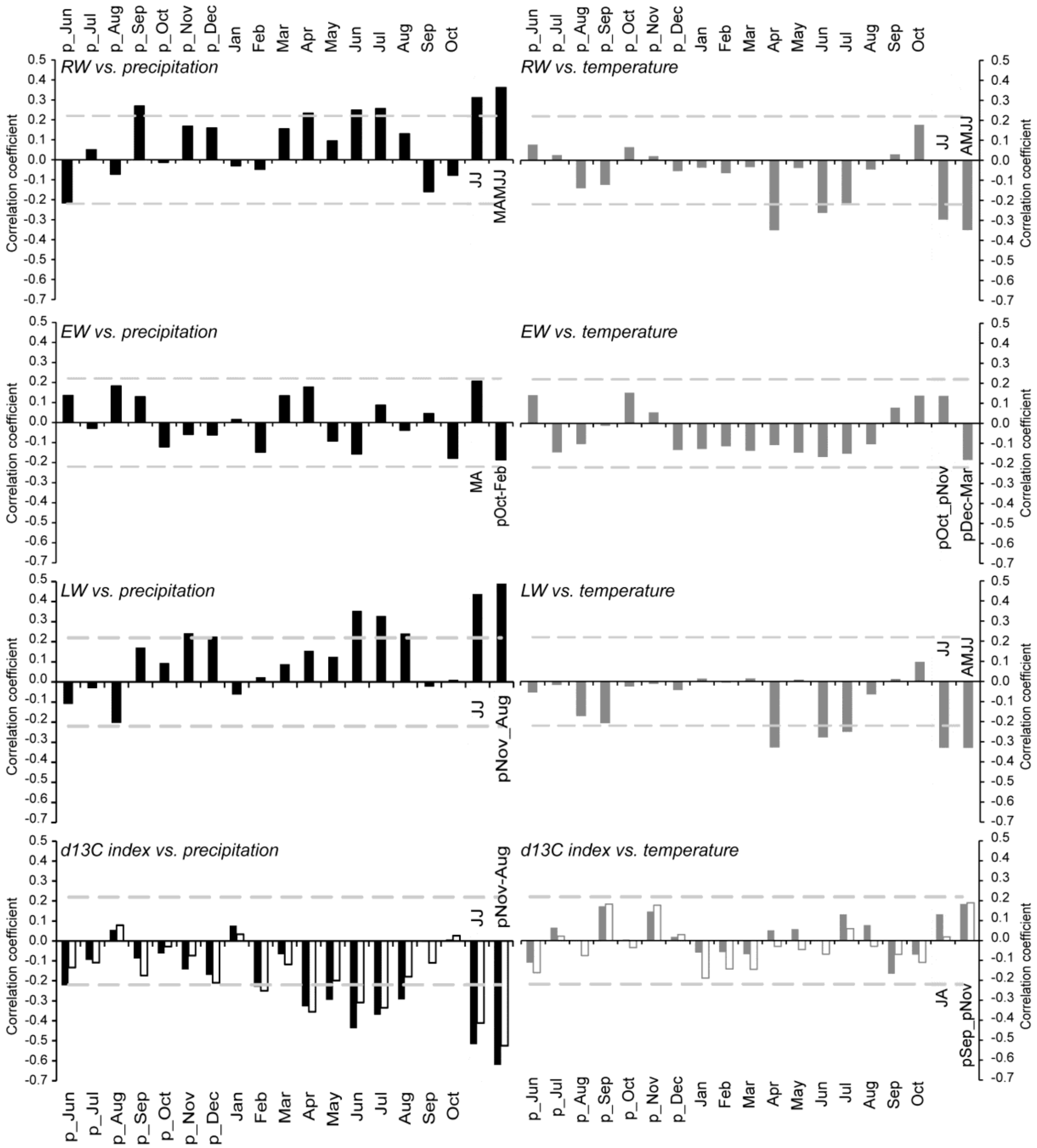


Fig.4. Climate response of proxies derived from oak tree-rings. Grey stripes mark the multi-monthly values corresponding to the period indicated in abbreviated form near to each bar. Empty and filled bars indicate δ^{13}Ccorr1 and δ^{13}Ccorr2, respectively in the bottom graphs. Horizontal dashed lines indicate the p=0.05 level.

4. Discussion

4.1. Potential signal improvement using combined tree-ring parameters

Regarding that LW and δ^{13}C seems to share fairly similar climatic information, their combination has the potential to improve this common climatic signal and reduce the noise (Mann, 2002; McCarrol et al., 2003). To test the rationale of this possibility a simple combined parameter, defined as difference of LW width index and δ^{13}Ccorr2, was calculated.

This secondary parameter yielded r=0.66 with pNov-Aug precipitation. The fact that this coefficient is higher than ones obtained for the primary parameters could be effective evidence, per se, to prove that the proxy combination is reasonable (McCarrol et al., 2003), however two further features are worth mentioning.

Firstly, spatial signature of the primary tree-ring parameters (LW, δ^{13}Ccorr) and the above defined secondary parameter (LW-δ^{13}Ccorr2) were compared computing spatial correlations with the prevNov-Aug precipitation totals derived from the CRUTS3.1 (Mitchell and Jones, 2005) precipitation grid. Secondly, the autocorrelation structures of these tree-ring derived parameters were compared with the Bakta/Vaja local instrumental target. Although the autocorrelation structure is usually overlooked, or at least non-reported in climate reconstruction studies, to model the autocorrelation structure of the climatic target is crucial in proxy-based climate reconstructions (Helama et al., 2009b). It is easy to see that alien autocorrelation component inherited from the proxy or introduced by the applied transfer function might contaminate the variance spectra of the derived reconstruction. For instance, if the proxy carries much higher (lower) autocorrelation than the real climate (i.e. the modelled instrumental target), then it will introduce more (less) low-frequency variability into the reconstruction. It will affect the red-end of the variance spectrum and lead to biased conclusions about long-term evolution of the modelled climatic parameter (Osborn and Briffa, 2004).

Spatial signature and autocorrelation structure of the primary (LW, δ^{13}Ccorr) and the secondary (LW-δ^{13}Ccorr2) tree-ring parameters are shown in Fig.5. We remark that $\delta^{13}C$ record was used with changed sign in the correlation analysis to get positive correlation coefficients with the instrumental target uniformly in the centre of the field for each case.

The fingerprint of the hydroclimatic signal encoded of the proxies on the pNov-Aug precipitation field is generally similar but few details must be emphasised. The pole of response field (r>~0.5) appeared quite remotely from the tree-ring site when LW and latewood $\delta^{13}C$ were tested. In the case of the combined proxy, the tripartite pole region covers the Nyírség as well. In addition, when LW signal was correlated against the instrumental target field, the validity zone was largely expanded in eastern direction, whereas latewood $\delta^{13}C$ signal showed a more restricted footprint. The combined proxy tracked roughly the latter one but with improved values as mentioned above. The larger validity zone of LW is tempting to interpret it as the best precipitation proxy. However, when the smaller footprint obtained for the other parameters was compared the present day climatology (Fig. 1), an interesting correspondence was realized. The sharp eastern termination of the response field fits well to the climatic divide outlined by the arc of the Carpathians. Despite the spatial signature being smaller, we argue that the latter one is climatologically more meaningful due to the agreement with the spatial structure of the precipitation field.

Regarding the autocorrelation function (ACF) of the individual proxies similarities and discrepancies alike could be seen to the ACF of instrumental precipitation (Fig 5). Fifth, sixth order autocorrelations are fairly well captured in LW. However, for 14-year lag the magnitude of the instrumental autocorrelation is badly overestimated ranking the 14-year lag the leading autocorrelation of the proxy record. Additionally, structure and sign of the ACFs are practically opposite for each other up to lag-20. ACF of latewood $\delta^{13}C$ mimicked fairly well the higher order autocorrelation structure, however, largely overestimated for lag-1, -2 and -3. This suggests that a reconstruction relying exclusively on latewood $\delta^{13}C$ is prone to show unreal low-frequency variability (Osborn and Briffa, 2004). The combined parameter mimicked almost perfectly the climatic autocorrelation structure. A critical point is that it still overestimates the first order autocorrelation, though the difference is the smallest also in this case. Its further reduction should deserve attention in a forthcoming quantitative reconstruction.

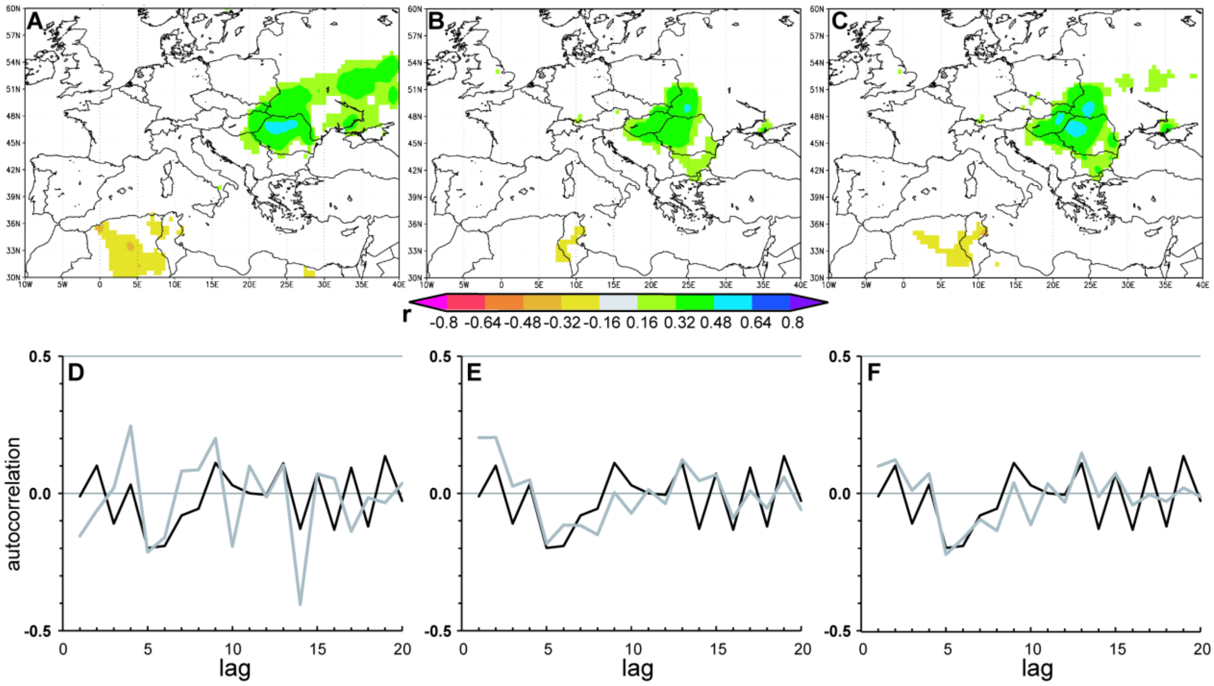


Fig. 5. Spatial signature of the climate signal and autocorrelation structure of the latewood width (LW), latewood δ^{13}C and their combination. Spatial correlations were computed between A: LW; (B) (-1)*δ^{13}Ccorr2; (C) their simple combination (LW-δ^{13}Ccorr2) and the November-August precipitation total field of CRUTS3.1 (Mitchell and Jones, 2005) for the period 1929-2007. Correlations exceeding p=0.05 level are displayed. Autocorrelation function of LW (grey) and the local instrumental target (Baka/Vaja) (black) (D), E and F are same as D but for δ^{13}Ccorr2 and their combination (LW-δ^{13}Ccorr2), respectively. Calculations were made using the web-based tools of Climate Explorer (van Oldenborgh and Burgers, 2005).

The better defined spatial signature and the almost perfectly mimicked ACF of instrumental climate probably better illustrate the improved climatic signal gained via proxy-combination than the tiny increase of correlation coefficient. Improvement of the climatic signal surely benefited from the fact that latewood increment and ^{13}C discrimination at latewood synthesis are under different plant physiological control (McCarrol et al., 2003). Consequently the shared common climatic signal emerged in the correlation analysis likely smeared by non-correlated noise components so common signal is amplified and the noise is quenched when proxies were combined. This agrees with Etien et al. (2008) who found more comparable spectral properties with instrumental record in combined proxy.

To establish climate reconstruction from these proxies in the future it is useful to get preliminary information about the potential spatial signature of the climate signal. Spatial correlation analyses indicate that the validity field of the obtainable hydroclimatic reconstruction is expected to cover eastern Slovakia and the large part of the Great Hungarian Plain (enclosing Ukrainian Transcarpathian District, E Hungary and western Romania).

The spatial signature of the retrievable hydroclimatic signal of studied oaks deserves attention from continental-scale hydroclimatic perspective because the core region of the response field is uncovered by the existing European multicentennial hydroclimate reconstructions (Büntgen et al., 2010b). In addition, the potential to expand the existing chronology is large in this area due to its richness in historical wooden structures dating back to the Medieval Times (Kovács, 1999; Sisa, 2001).

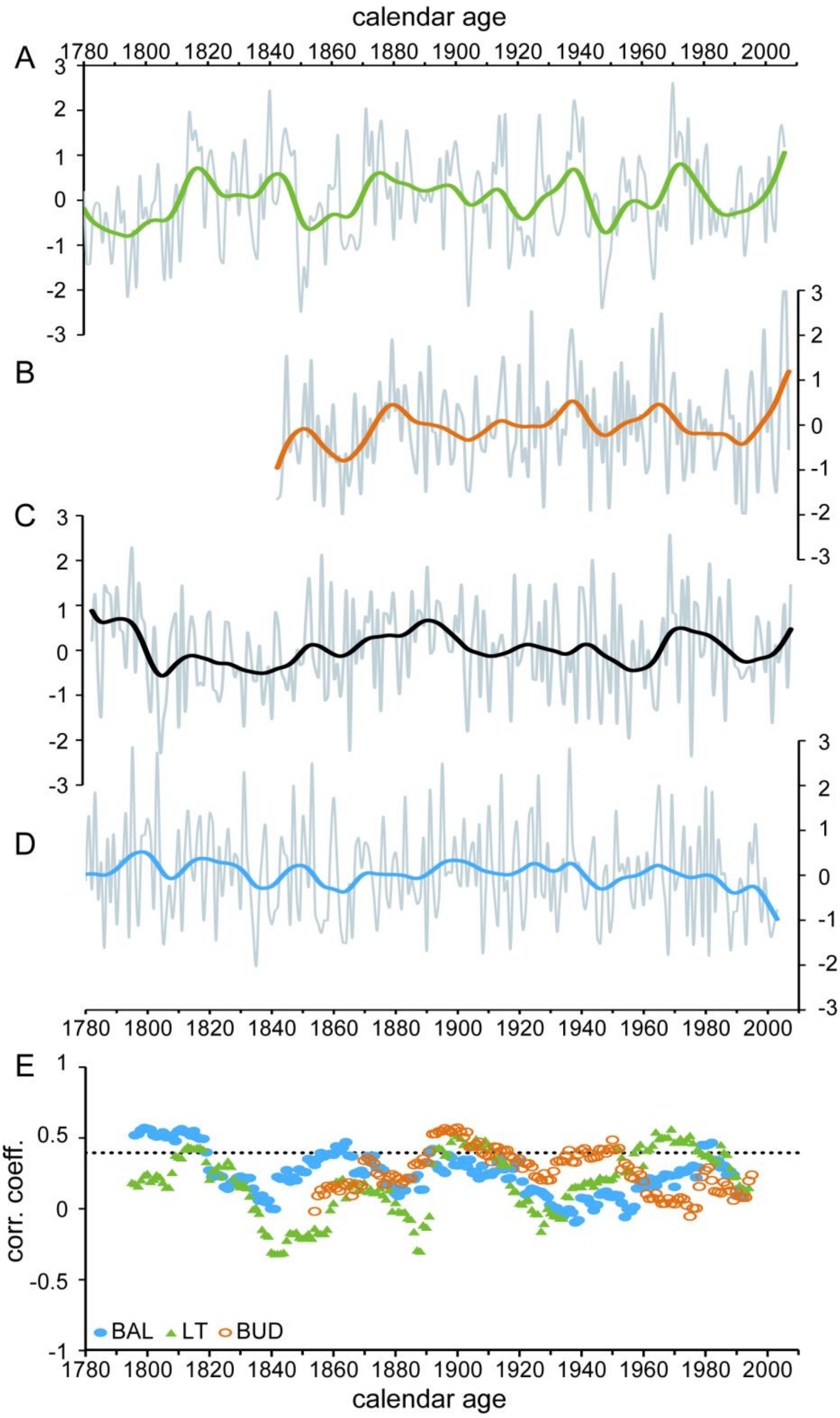


Fig 6. High-resolution multicentennial hydroclimatic records from the Carpathian region. A: Low Tatras summer drought (JJA sc-PDSI, for details see Büntgen et al., 2010a), B: November-August precipitation totals derived from the homogenized monthly precipitation record of Budapest (Auer et al., 2007), C: latewood width of pedunculate oaks from Bakta Forest northeast Hungary (this study), D: September-August precipitation total from Balaton Highlands (Kern et al., 2009). All records were converted to Z-scores to have zero mean and unit variance over the 20th century, with the bold lines being 20 year low-pass filters. E: 25 year running correlations between LW and the three other records.

Another lesson to learn from the spatial correlation analysis comes from overlap of the core of the response field with the distribution map of *Q. robur* (Fig.1, EUFORGEN, 2009) and with the regional forestry maps. Following this path one can outline optimal candidate sites for which the same hydroclimatic signal can be expected by simply integrating information about the distribution of the species, the strongest expected climate response, and taking into account the forestry metadata suggesting minimal disturbance and maximal stand age. This approach offer a plausible – maybe the only – way toward a more advanced elimination of a potential non-climatic signal related to stand dynamic processes, which is hardly eliminated by standardization techniques without the loss of the low-frequency component of the environmental signal.

4.2. Comparison between the preliminary 220-year long NE Hungarian hydroclimate history and other regional long-term records

Couple of high-resolution records of the hydroclimatic history of the Carpathian region have been developed or revised recently. These are ringwidth-based reconstruction of summer drought from the Low Tatras (hereafter LT, Büntgen et al., 2010a); September-August precipitation from the Balaton Highlands (hereafter BAL, Kern et al., 2009) and the homogenised monthly precipitation record from Budapest (hereafter BUD, Auer et al., 2007), representing the longest continuous instrumental precipitation record from the region.

It is still too early to build a formal quantitative hydroclimatic reconstruction for the Nyirség area, especially, as discussed above, proxy-combination obviously offers significantly improved reconstruction skills for the future.

However, regarding the fairly strong climate response and the exceptionally robust dendrochronological signal detected in the LW, a qualitative comparison between this new NE Hungarian hydroclimate record and the above mentioned ones offer an interesting exercise. It is especially exciting as each earlier reconstruction comes from a place that is located at or near to the margin of the response field of the hydroclimatic signal of the oak parameters from Bakta Forest (Fig. 1, Fig. 5). The records were compared by running window correlation analysis and visual comparison of the decadal variance emphasised by 20-year low-pass filtering.

Running window correlation analysis, similarly to spatial correlation analysis, tends to mirror the similarity/dissimilarity of the interannual variability. However, whilst the spatial correlation analysis shows the "mean" similarity averaged over the analysis window, running correlation is able to reveal temporal shifts, offering an alternative aspect. The low-pass filters highlight the decadal variance, hence their comparison gives the opportunity to compare the coupling/decoupling of the local hydroclimate histories over the lower domain of the variance spectra.

Both the visual comparison and the running correlation analysis gave the impression that neither the strength nor the rank of the similarity between Bakta and the other hydroclimate signals were stable throughout the past two centuries (Fig. 6).

The most characteristic features are briefly described here. Bakta shows the best common signal (above the 0.05 significance level) in the interannual variance with BAL from 1790 to 1820. Their decadal variance is also very similar (moist period in the late-1790s, triannual drought over 1805-07). The mid-1860s drought period corresponded between Bakta, BAL and BUD while it seems that Low Tatra was only moderately affected. The highest general agreement appeared among the four local hydroclimate signals between 1890 and 1915. Correlation run above or near to the 0.05 level and decadal fluctuation was also similar inasmuch as a moister decade (1890-1900) followed by drier years. A particular discrepancy is worth mentioning. The Bakta drought peak at 1904 is shared by BUD and LT but not by

BAL. BAL drought history has decoupled from the Nyírség and also from the Low Tatras for the rest of the 20th century. Bakta shows most common interannual variance with BUD over the ~1935-55 period however the pronounced fluctuation of decadal drought condition shared between BUD and LT seems to be weakly reproduced in the Bakta signal. The situation changed for the next 45 years when Bakta showed most interannual variance with LT. Their decadal variability is also very similar (moist years around 1970, drought period around 1990). Finally we note that the severest summer drought reconstructed in the Low Tatras (1850 AD) is not mirrored in either Bakta or the other records, and that the 1880s drop in the correlation agrees the pattern detected in a comparison with 9 Central European hydroclimate reconstructions and provides further evidence that this loss of coherency is mainly restricted to the LT (Büntgen et al. 2010a).

The main conclusions drawn from this qualitative comparison are that:

1-it is rather clear that no common hydroclimate signal can be expected for the entire Carpathian territory. General statements declaring drought/soak conditions over the region, relying on sole local proxy record, are hardly credible.

2- the viable approach to reveal/understand the regional hydroclimate history must take into consideration the spatial heterogeneities, climatological footprint of the proxy-based hydroclimatic signals and the potential proxy-specific seasonal responses.

5. Conclusions

Signal strength statistics of the chronologies, built from three tree-ring parameters we presented, indicate that latewood width carries the strongest environmental signal among the three proxies. Contrary, as a consequence of the weaker common variance, 10 trees were insufficient to obtain a robust chronology from earlywood width. Nevertheless, the hardly detectable climatic signal does not provide much motivation to work on the improvement of earlywood width chronology. Present results provide a clear imperative to future regional tree-ring investigations dedicated to dendroecological and dendroclimatological applications for *Quercus* sp., to apply separate analysis of earlywood and latewood width.

Stable carbon isotope composition data measured on bulk latewood material cover the 1929-2008 period and the presented 80 year long $\delta^{13}C$ record is the first tree ring derived stable isotope chronology from the broader Carpathian Region.

Correlation analysis revealed relatively strong response to growing season precipitation both for latewood width and latewood $\delta^{13}C$. This pronounced precipitation sensitivity of $\delta^{13}C$ and the lack of any response to temperature clearly indicate that dominant plant physiological control on ^{13}C discrimination of pedunculate oak is the stomatal conductance, rather than the photosynthetic rate at the Bakta Forest.

The strongest correlation was found for both parameters with the precipitation total from November of the year preceding the tree ring growth to August of the growth year. The shared common climate signal found between LW and latewood $\delta^{13}C$ invited test of signal improvement applying proxy combination. A combined parameter, defined as difference of the primary parameters showed strengthened statistical relationship compared to climatic target both for local and regional spatial scales.

Interannual and decadal variability of the hydroclimatic signal encoded in LW was compared to three high-resolution regional records spanning the past 220 years. The main impression gain from this exercise is that neither the strength nor the rank of the similarity between LW and the other hydroclimate signals were stable throughout the past two centuries. The general implication to take into consideration for future palaeo(hydro)climatological efforts targeted the Carpathian(-Balkan) region is that the spatial domains for which the given local proxy-derived hydroclimate reconstruction might provide useful information must be tracked more carefully, ideally regarding both high- and low-frequency climate signals. This approach is to be appearing in recent studies (Büntgen et al. 2010a, Magyari et al. this issue), but strongly recommended to adopt as a routine step in the future.

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