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Minimum winter temperature reconstruction from average earlywood vessel area of European oak (*Quercus robur*) in N-Poland

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ABSTRACT

Tree-ring-based temperature reconstructions form a substantial part of the international proxy data base used to examine and model global climate variations of the last Millennium. However, most tree-ring-based reconstructions are derived from study sites in the high latitudes or high altitudes, paying very little attention to low elevation sites. Thus, a large gap in the geographical coverage of climate reconstructions from temperate low elevation sites in central Europe still exists. This motivated us to concentrate our efforts on the European oak (*Quercus robur*) in N-Poland. We developed a new robust tree-ring width chronology (TRW), as well as four wood anatomical chronologies (e.g. average vessel area and number of vessels) from *Q. robur* for the period 1810 to 2010. The chronologies were examined for their climatological responses. While TRW was found to have weak correlations with climate, the earlywood vessel parameters (EVP), especially average vessel area (AVA), revealed significant positive correlations to minimum winter temperatures. Based on stable climate–growth correlations, a reconstruction of minimum winter temperatures (29th November to 20th January) back to 1810 was performed for north Poland. The reconstruction indicates a promising potential to reveal low-frequency climate information. An additional extreme year analysis suggested that in cold winters, a cold–warm–cold pattern in the minimum temperatures was responsible for the relatively small earlywood vessels. Spatial field correlations imply that our reconstruction is more related to temperature variations towards the east of Europe. The reconstructed temperature compared well with two existing temperature reconstructions, especially during most of the 20th century, even though the temperature reconstructions differ spatially and temporally. Based on these findings, the relatively extensive resource of archeological oak material from this region may be useful to perform multicentennial climate reconstructions in the temperate climate zone.

1. Introduction

Climate reconstructions based on tree rings are mainly derived from sites with extreme climates at high latitudes or altitudes (Gagen et al., 2006). The closer a tree grows to its distribution limits, the stronger is the influence of one principal climate parameter mainly limiting growth (Fritts, 1966; Hughes, 2002). Dendroclimatology uses this strong relation between climate and tree rings to generate robust climate proxies. Since forests cover large parts of the continental earth surface, theoretically, dendroclimatological studies may facilitate climate reconstructions almost everywhere. However, in reality, the climate signal strengths implemented in tree-ring parameters such as tree-ring width (TRW) are often not strong enough for reconstructions at sites with less extreme climate conditions (Buckley et al., 1997), and thus most temperature reconstructions are from remote and sparsely populated regions where the climate–growth relations are less diffuse (Young et al., 2012).

In order to challenge this geographical imbalance concerning tree-ring-based climate reconstructions, new dendroclimatological parameters such as stable isotopes (Gagen et al., 2006; Treydte et al., 2007) and wood cell structures (Fonti et al., 2010) were established as new proxies in dendroclimatology studies. Recent studies revealed the large potential of stable isotopes and quantitative wood anatomy for high-quality dendrochronological reconstructions to overcome such geographical restrictions to extreme sites only (Fonti et al., 2010; Young et al., 2012). By analyzing conifers growing in the temperate lowland forests of southern Australia (Drew et al., 2011) and northeastern Germany

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(Liang et al., 2013) the existence of strong climate information in series of wood anatomical parameters was demonstrated, while the tree-ring widths did not correlate well with climate. Likewise, wood anatomical parameters of Siberian larch trees (*Larix cajanderi*) were used for the longest existing temperature reconstruction based on a tracheid dimensions series (Panyushkina et al., 2003).

Wood anatomical parameters of deciduous trees such as earlywood vessel size, however, were mostly used either for ecophysiological (Fonti and García-González, 2004) or hydrological studies (Eckstein et al., 1977; García-González and Eckstein, 2003; Fonti and García-González, 2008; Bryukhanova and Fonti, 2012). Nevertheless, a few studies also investigated the relation between temperature and xylem anatomy. Studies of vessel dimensions of oaks growing in Latvia (Matisons and Dauškane, 2009; Matisons and Brūmelis, 2012) and Canada (Tardif and Conciatori, 2006) revealed a close relation between the average earlywood vessel lumen areas and temperatures. Likewise, vessel lumen areas of trees growing in the Mediterranean demonstrated high sensitivities toward late-winter-to-early-spring temperatures (Fonti et al., 2007). Gea-Izquierdo et al. (2013) found a strong dependency between the earlywood vessel anatomy of the evergreen shrub *Erica arborea* and winter temperatures. Such correlation patterns with winter temperatures are under scientific debate, since during European winters many tree physiological processes are minimized in evergreen species or even dormant in deciduous species, and thus the correlations cannot readily be explained. The explanations proposed for this particular relation so far ranged from temperature influences on physiological processes determining vessel sizes to externally induced freezing embolisms in the vessels during colder winters (Fonti et al., 2007; Gea-Izquierdo et al., 2013).

Previous studies of wood anatomical parameters suggested little age-related trends in the mature sections of the series and it was demonstrated that climate reconstructions at less extreme sites will be feasible on the basis of wood anatomical parameters where tree-ring widths have failed so far (Liang et al., 2013; Pritzkow et al., 2014). Following the promising results of these pilot studies, the current study aims to (a) produce a long earlywood vessel chronology of lowland oaks in Northern Poland, (b) screen the chronology for its climate signals and, if possible, to (c) reconstruct a selected climate variable.

2. Materials and methods

2.1. Study site and wood material

In northern Poland, two cores per tree of 21 trees (*Quercus robur*) were collected at breast height with an increment corer (Ø 5 mm) in June 2011. The study site (53° 50′ N, 18° 17′ E, 120 m a.s.l.) belongs to the UNESCO biosphere reserve Tuchola Forest (supplementary S1). The forest consists largely of *Q. robur*, approximately 200 years old, mixed with *Pinus sylvestris*. The Tuchola Forest region was almost constantly under environmental protection during the 20th century which resulted in undisturbed tree growth. Northern Poland is influenced by a temperate and warm climate with high amounts of precipitation and fairly cool summers. In the eastern part, continental climate conditions are characterized by frosty winters and hot and dry summers. The coastal zones at the northern border to the Baltic Sea are mainly of maritime character. The study site is located in the intermediate climate between maritime and continental influences. The annual mean temperature is 8 °C, whereas the mean winter and summer temperatures are −0.6 °C and 16.8 °C, respectively. The highest temperature variability occurs naturally in the winter months (Kozuchowski and Degirmendzic, 2005). The annual precipitation amounts to about 650 mm. The average vegetative season on the western Polish Baltic Sea starts on 20th March and ends on 16th November (Tylkowski, 2015). The lowlands of Northern Poland were shaped by the Weichselian Late Glacial period resulting in soils which are dominated by nutrient-poor podsols or semipodsols (Miotk-Szpiganowicz, 1992; Roering, 1999).

2.2. Chronology development

For the tree-ring widths (TRW) measurements, all samples were prepared according to dendrochronological procedures described by Stokes and Smiley (1968), Schweingruber (1983), Cook and Kairiukstis (1990). Afterwards, all samples were scanned on a flatbed scanner and the TRW were measured by WinDENDRO™. To ensure correct dating, the TRW were visually cross-dated and also statistically analyzed using the COFECHA program (Holmes, 1983). Age-related trends in the TRW were removed by a 66-year smoothing spline in ARSTAN (Cook and Kairiukstis, 1990) and the residual chronology was used for investigations.

The analysis of the anatomical measurements was performed for a subset of 14 cores from 7 trees which were found to be highly correlated with the mean TRW chronology. The surfaces of the cores were cut with a core microtome (Gärtner and Nievergelt, 2010). Tyloses and wood dust were removed from the vessels with blasts of high-pressure water. Finally, according to the suggestions of Fonti and García-González (2008), the wood surface was stained black with a permanent marker and the vessels were filled with white soft wax to increase the contrast between the vessels and the surrounding wood. Afterwards, the surfaces of the cores were scanned using a flatbed scanner and analyzed in WinCELL™. The enhanced contrast of the wood surface allowed for a semi-automatic detection of the vessel lumen areas. Several EVP were derived from the measurements and considered for this study: average vessel area (AVA), average radial vessel diameter (AVD), average tangential vessel width (AVW), and number of vessels (NV). Since no long-term trends were found in the EVP, detrending of the time series was omitted and raw values without any modification were used instead. The yearly values of each variable were averaged into individual chronologies. For each chronology, the following descriptive dendrochronological statistics were calculated: standard deviation (SD), mean sensitivity (MS), first-order autocorrelation (AC1), mean correlation between trees (r) and expressed population signal (EPS). In order to test the five EVP chronologies for possible similarities a principal component analysis (PCA) as well as a bootstrapped cross-correlation was conducted with the individual chronologies as input data. Significance of PCA axes was evaluated by a Monte Carlo test. All performed correlations were repeated 1000 times with a random process to derive robust correlation results (bootstrap method; Guiot, 1991). The PCA tested all chronologies against each other for the years of 1810–2010 by using SPSS v 22.0 software.

2.3. Climate–growth relations and extreme year analyses

The climate–growth relationships were examined with Pearson's correlation coefficients determined pairwise for the tree-ring variables and climate parameters. Equally to the performed cross-correlations also, the climate–growth correlations were bootstrapped (1000 times). For this, the daily weather data from the meteorological station Koscierzyna (54° 8′ N, 17° 58′ E) were averaged into monthly mean, minimum, and maximum temperatures and sums of precipitation for further analysis. The meteorological station runs since 1951 and is located approximately 30 km northwest of the study site.

Besides the monthly correlations, climate response analyses using daily climate data from the meteorological station Koscierzyna were also conducted. For this purpose, the computer program CLIMTREG allows investigation of the relation between the measured wood variables and climate data with a high temporal resolution rather than using the traditional monthly correlations. In the program, moving Pearson's correlations between climate and tree-ring data are calculated. Daily meteorological data are summarized by the program for a minimum period of 21 days and a maximum of 121 days. Correlations are first