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CLIMATE INFLUENCE ON RADIAL INCREMENT OF OAK (*QUERCUS* SP.) IN CENTRAL POLAND

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Abstract: The study investigates the influence of climate conditions on radial increment of oak, with special concern to the situations when analysed trees formed conspicuously wider or narrower tree-rings. The research material was collected in four locations in central Poland within natural range of pedunculate and sessile oaks. The elaborated residual chronologies were correlated with CRUTS 2.1 climate data. The analyses included thermal and pluvial conditions spanning from April of the year prior to ring formation to September of the current growth year. Special interest was paid to simple water ability index that combined both temperature and precipitation during the vegetation season. Additionally, pointer year analysis was carried out to determine situations when conspicuously smaller or larger increment was formed.

Investigated chronologies cover the period of 1927-1992 (Łochów), 1845-1992 (Płońsk), 1868-1992 (Pułtusk), and 1796-1992 (Sokołów). The analysed oaks from sites in central Poland exhibit growth patterns comparable with those known form previous studies concerning that species, where influence of precipitation (higher and positive) and temperature (negative) have been observed. Extreme growth reactions expressed by negative and positive pointer years turned to present high dependence of analysed oak' growth on water availability during vegetation season.

Keywords: Dendrochronology, oak, climate influence, Poland.

1. INTRODUCTION

Genus oak (*Quercus* sp.) consists of many individual species of different morphology, biology and ecology. There are three native oak species in the territory of Poland: pedunculate oak (*Quercus robur* L.), sessile oak (*Quercus petraea* Liebl.) and downy oak (*Quercus pubescens* Willd.) (Boratyńska *et al*., 2006). The last occurs in Poland only at one site and hence it is rather of botanical importance. That is why it was not included in the presented analysis. Pedunculate and sessile oaks (**Fig. 1**) are important from the ecological and economical point of view and are widely used in forest production in Poland.

Oak wood is very hard and durable and because of that it has been utilised as a construction material for a long time. This results in a wide use of that genus in dendrochronological research. So far a couple of hundreds of oak chronologies have been constructed, covering various time spans (Ważny, 2006).

Climate influences the tree growth process in great measure. Pace and intensity of tree-ring formation is shaped by different weather elements such as temperature, precipitation and moisture availability, sunshine duration or even snow abundance (Fritts, 1976; Schweingruber, 1996). Understanding these relationships is crucial, in

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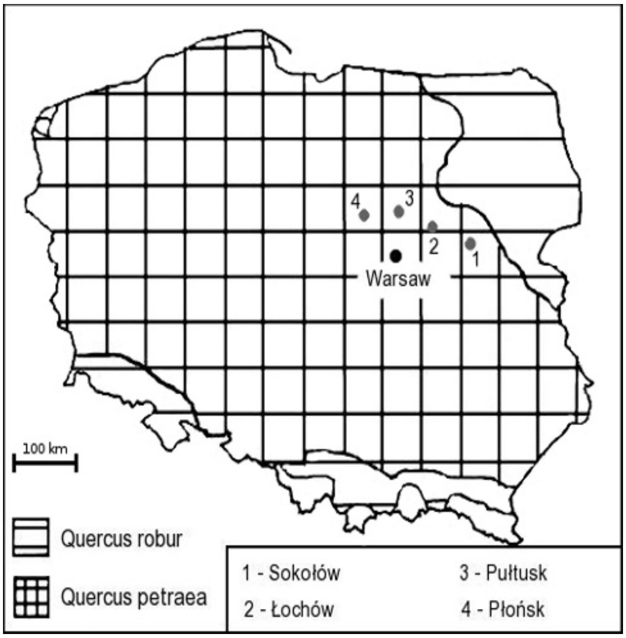

Fig. 1. *Location of the study sites (dots with numbers) and natural distribution range of* Quercus robur *and* Quercus petraea *in Poland.*

particular for the forest production, especially in the context of the observed ongoing climate changes.

For example, cambium cells begin their activity in spring yet before the buds burst (Ermich, 1959). Formation of new vessels proceeds thanks to supply resources gathered before. Climate conditions of both: current and previous growing seasons, are very important as onset of cambium activity depends mostly on temperature, while the process of tree-ring formation is usually controlled by precipitation.

Impact of climate on the growth of oaks was a subject of many studies across Europe and Poland following the abundance and importance of that genus. Several dendrochronological standards were elaborated and their relationships with climate conditions were studied. Influence of temperature, precipitation and other climatological parameters on various characteristics of radial increment of oaks in Europe was studied e.g. by Gray and Pilcher (1983); Santini *et al*. (1994); Rozas (2001) and Lebourgeois *et al*. (2004). Polish studies concerning that species include studies by Bednarz (1987); Ważny (1990); Bendarz and Ptak (1990); Ważny and Eckstien (1991) or Krąpiec (1998; 2001). More recent investigations focus on oaks' extreme increment reactions and their climate driving factors (Boryczka *et al.,* 2007; Bijak, 2009).

Dendrochronological studies on oak growing on dry sites in Central and Southern Europe showed positive correlation between tree-ring width and early summer precipitation, while a negative correlation was seen between high summer temperature. These studies could be the base of the thesis that oak will suffer because of summer drought (Pilcher and Gray 1982; Van der Werf *et al*., 2007). This is one of the reasons of oak decline in Europe during last decades (Bednarz, 1994; Siwecki, 1994; Methy *et al*., 1996; Vanini *et al*., 1996; Bruchwald and Dmyterko, 1999; Desprez-Loustau *et al*., 2006).

The objective of the current study was to investigate the influence of climate conditions on radial increment of oaks (*Quercus sp.*) growing in central Poland with special concern to the situations when analysed trees formed conspicuously wider or narrower tree-rings.

2. MATERIAL AND METHODS

Study sites

The research material was collected in Polish State Forests within the territory of Łochów (mean age 56 years, 18 trees sampled, 167-172 m a.s.l.), Płońsk (mean age 60 years, 46 trees sampled, 107-145 m a.s.l.), Pułtusk (mean age 59 years, 11 trees sampled, 84-99 m a.s.l.) and Sokołów (mean age 58 years, 62 trees sampled, 139-169 m a.s.l.) forest districts (**Fig. 1**). The study sites were located in stands where oak covers between 6% (Łochów) and 20% (Sokołów) of the forested area. The climate of the analysed area can be described as a transitional one, however continental features, i.e. hot summers and severe winters, prevail. Mean temperature in January equals -2.2°C, while in July it exceeds +18.1°C (1971-2000 IMiGW a, b). Precipitation is rather not profuse equalling 500-600 mm annually (1971-2000 IMiGW a, b; Lorenc, 2005). During the vegetation period that lasts 124 days on average between 160 and 220 mm of rain is noted. Soils are mostly poor and were formed on fluvial sands of riverbeds (www.warszawa.lasy.gov.pl).

Data processing

According to EKO strategy of dendrochronological studies (Zielski and Krąpiec, 2004), the selection of study sites guided by the principle of uniformity of growth conditions has been applied. Besides, to reach the goal of this study, only dominant, healthy and undamaged trees were sampled, because only such trees can be useful in determining the impact of climatic conditions on tree ring growth, therefore its allows to exclude the impact of anthropogenic and other non-climatic factors. A total number of 10-20 trees from each study site sufficiently represent the local dendrochronological signal. One increment core per tree was taken using a Pressler borer. The obtained material was prepared following standard procedures (Cook and Kairiukstis, 1990) and scanned. Tree-ring widths were measured on the increment cores with BP-Biotronic device to the accuracy of 0.01 mm.

Elaborated tree-ring width series were cross-dated visually using standard dendrochronological techniques (Cook and Kairiukstis, 1990). Quality of cross-dating was statistically checked with COFECHA program (Holmes, 1999; Grissino-Mayer, 2001). The series that showed evident dissimilarity were excluded from further analysis as they might limit the common signal in the chronology. Altogether series representing 107 trees were used to build the chronologies (**Fig. 3**). The obtained statistics of the elaborated chronologies show that they represent the common signal quite well as the mean Rbar is rather high (**Table 1**) and expressed population signal (EPS) values exceed critical level of 0.85 for the majority of the series time span (except Pułtusk) (**Fig. 2**). The expressed population signal describes the degree to which the particular chronology expresses the theoretical population chronology (Mäkinen and Vanninen 1999). For all sites the GLK coefficient (**Table 3**), explaining the compatibility of tree rings growth, was calculated (Eckstein and Bauch, 1969).

Dendroclimatological analyses

To pronounce climate-related high-frequency signal and to minimise long-term age-dependent trend, each tree ring width series was standardised in the two-staged detrending process using the negative exponential curve and the linear regression function (Fritts, 1976; Cook and Kairiukstis, 1990). In the next step, the indices were prewhitened using an autoregressive model selected, following the minimum of AIC and averaged across all series using bi-weight robust estimation of the mean (Cook, 1985). Standard and residual chronologies were computed for all sites with CRONOL software (Holmes, 1999).

DendroClim2002 (Biondi and Waikul, 2004) software was used to investigate the influence of climate on the growth of analysed oaks. The program utilises the response function concept (Fritts, 1976) that connects tree-ring width (dependent variable) and climatic predictors (independent variables) in multivariate correlation-regression model. The analysis included residual oak chronologies (**Fig. 3**) as well as thermal and pluvial conditions spanning from April of the previous growth year to September of the current growth year (18 months altogether). For each month in the June-August period simple water availability index was calculated by dividing monthly sum of precipitation by mean temperature. In the next step, individual values of this index were subtracted from the 1901-2000 average constituting the series of derivatives, which was later on correlated with the tree-ring chronology representing individual study sites. Climate data used in the study originates from the CRUTS 2.1 set (Mitchell and Jones, 2005). Significance of analysed relationships was assessed at the 0.05 level.

As extreme environmental factors are supposed to cause the formation of exceptionally wider or narrower tree ring as the response to unusually favourable or unfavourable conditions (Fritts, 1976; Schweingruber, 1996), pointer year analysis was carried out to determine situations when conspicuously smaller or larger increment was formed. 'Normalisation-in-the-moving-window' procedure (Cropper, 1979) was applied. A given year was considered as a pointer one when at least 80% of trees from individual site exhibited the same (positive or negative) extreme type of increment reaction. Calculations were performed in WEISER program (Gonzales, 2001) for 5-years-long window.

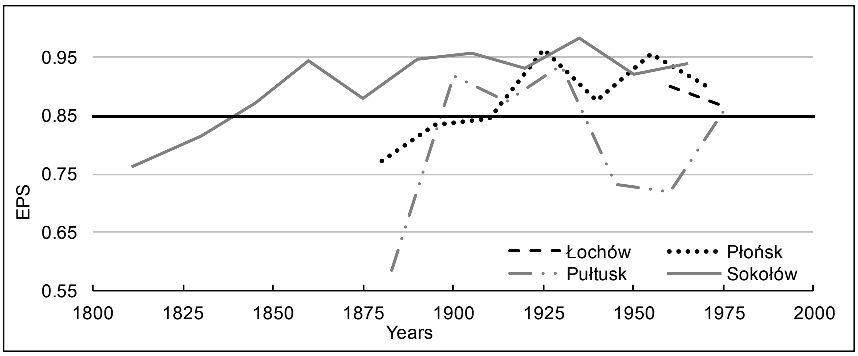

Fig. 2. *Running EPS values for tree-ring width series of oaks for analyzed study sites. The black vertical line indicates the 0.85 threshold.*

Table 1. *Basic statistical characteristics of oak chronologies from study sites.*

Forest District	Interval	Years	Mean	Standard deviation	Mean sensitivity	Autocorrelation	Mean Rbar
				tree-ring chronology			
Łochów	1927-1992	66	2.43	0.53	0.16	0.6	0.43
Płońsk	1845-1992	148	1.86	0.66	0.22	0.74	0.5
Pułtusk	1868-1992	125	1.9	0.95	0.2	0.86	0.53
Sokołów	1796-1992	197	1.85	0.61	0.2	0.72	0.69

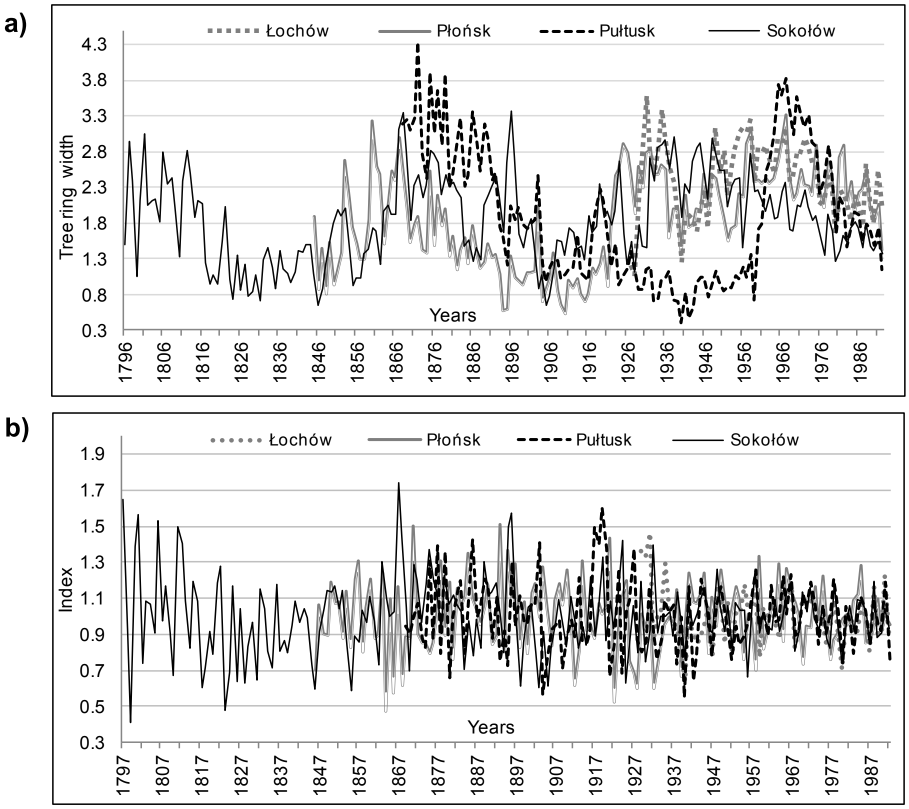

Fig. 3. *Tree-ring width series (a) and residual (b) chronologies of oaks from analysed study sites.*

3. RESULTS

Elaborated chronologies that present radial mean tree-ring widths spanned from 1.85 mm (Sokołów) to 2.43 mm (Łochów) and standard deviations of raw measurements varied from 0.53 to 0.95 mm (**Table 1**). All analysed chronologies show rather moderate similarity, as calculated values of GLK index amounted to 63-70%. Mean sensitivity of constructed raw chronologies equalled 0.16 (Łochów), 0.20 (Pułtusk, Sokołów) and 0.22 (Płońsk). As for standard and residual chronologies this parameter describes vulnerability of the analysed trees to be influenced by climate conditions. Obtained values of mean sensitivity confirm grounds of applying the constructed chronologies in climate-increment analyses.

The radial increment of oaks in Łochów Forest District significantly depends on thermal conditions in August of the year prior to tree-ring formation. The temperature in July and August (previous year) as well as in June (the year of ring development) is important in the Płońsk Forest District. In the Pułtusk Forest District significant dependence is observed only for previous August. June (year of ring development) is a month which is reflected by significant temperature influence in the Sokołów Forest District (**Fig. 4a**). All of these relationships are negative, which means that high temperature in summer is not a favourable factor influencing the increment of the analysed trees. In turn, temperature in September of the year of tree-ring formation was of significant positive importance in case of the Sokołów Forest District. Warm end of the vegetation season results in wider rings in that area (**Fig. 4a**). Positive correlation between tree-ring width and the sum of precipitation reveals great moisture demand of analysed trees during the process of increment formation. Such relationship was observed for the Łochów, Płońsk and Pułtusk Forest Districts (**Fig. 4b**). Positive influence of precipitation was recorded for June and July (Pułtusk), August (Płońsk, Pułtusk) and November (Łochów) of the year prior to growth. In year of tree-ring formation significant correlation was observed for June (Płońsk, Pułtusk) and August (Pułtusk). No significant relationship between radial increment and precipitation was detected for oaks in Sokołów Forest District (**Fig. 4b**).

Analysis of the influence of water availability in the June-August period revealed strong dependence of radial growth of investigated oaks on that factor. The strongest relation was found for June (**Fig. 5**). Water shortage very often resulted in narrow rings and, in contrary, increased water availability went with wider increment. For example, years 1936-1942 was quite dry at all investigated sites and growth depressions and very narrow ring can be noticed in all oak chronologies. In turn, very wet year 1947 resulted in a large tree-ring.

Altogether 18 individual negative (13) and positive (5) pointer years were determined (**Table 2**). Especially wide tree-ring was formed in 1967 in the Płońsk and Sokołów Forest Districts. 1941 and 1982 were positive pointer years for Płońsk site. For the Łochów Forest District positive pointer year was 1991. Very narrow increments can be observed in 1940 and 1952 (Łochów, Płońsk) as well as in 1992 (Płońsk, Pułtusk) and 1969 for the Sokołów and Pułtusk Forest Districts.

Table 2. *Pointer years of analysed oaks.*

	Łochów	Płońsk	Pułtusk	Sokołów
negative	1940, 1947, 1952, 1959, 1976, 1980, 1987	1940, 1952, 1992	1969, 1992	1969
positive	1991	1941, 1967, 1982		1967

4. DISCUSSION

Mean tree-ring width of analysed oaks is similar to the values reported in studies from other areas in Poland. Ważny and Eckstein (1991) obtained results from 0.83 mm (Wolin, NW Poland) to 2.33 mm (Gołdap, NE Poland). Ufnalski (2001) reports 1.42 and 1.53 mm for sessile and pedunculate oak, respectively. Mean tree-ring width from north-eastern Poland presented by Krąpiec and Szychowska-Krąpiec (2004) varied from 1.59 to 2.31 mm. Cedro (2004) obtained 1.59 mm for sites in

Table 3. *GLK coefficient for all analyzed sites.*

Łochów	Płońsk	Pułtusk	Sokołów
Łochów	65%	70%	70%
	Płońsk	66%	68%
		Pułtusk	63%

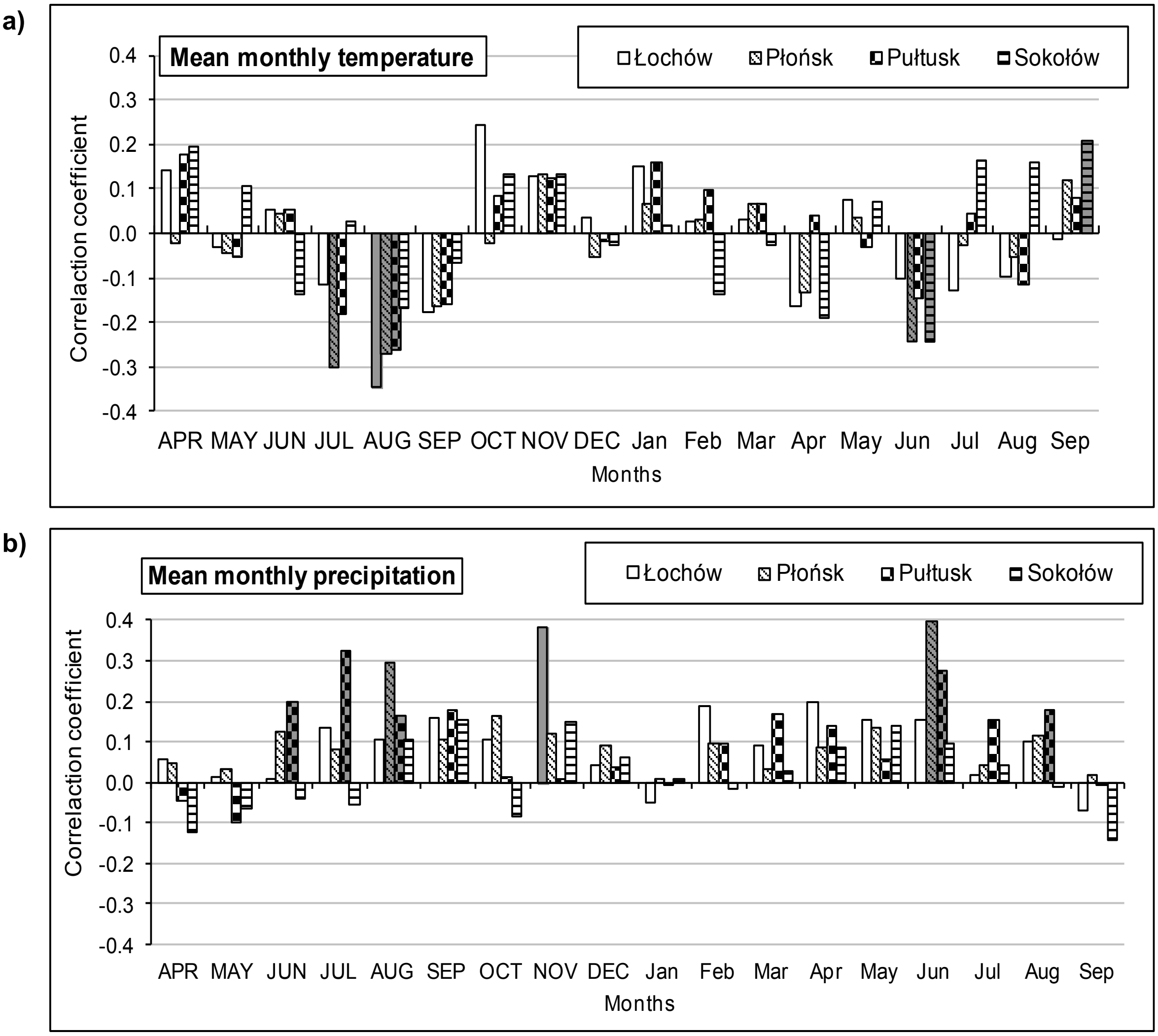

Fig. 4. *Impact of mean monthly temperature (a) and precipitation (b) on growth of oaks from analysed study sites – correlation coefficients. Shaded bars indicate values significant at 0.05 level, capital letters – year prior to ring formation.*

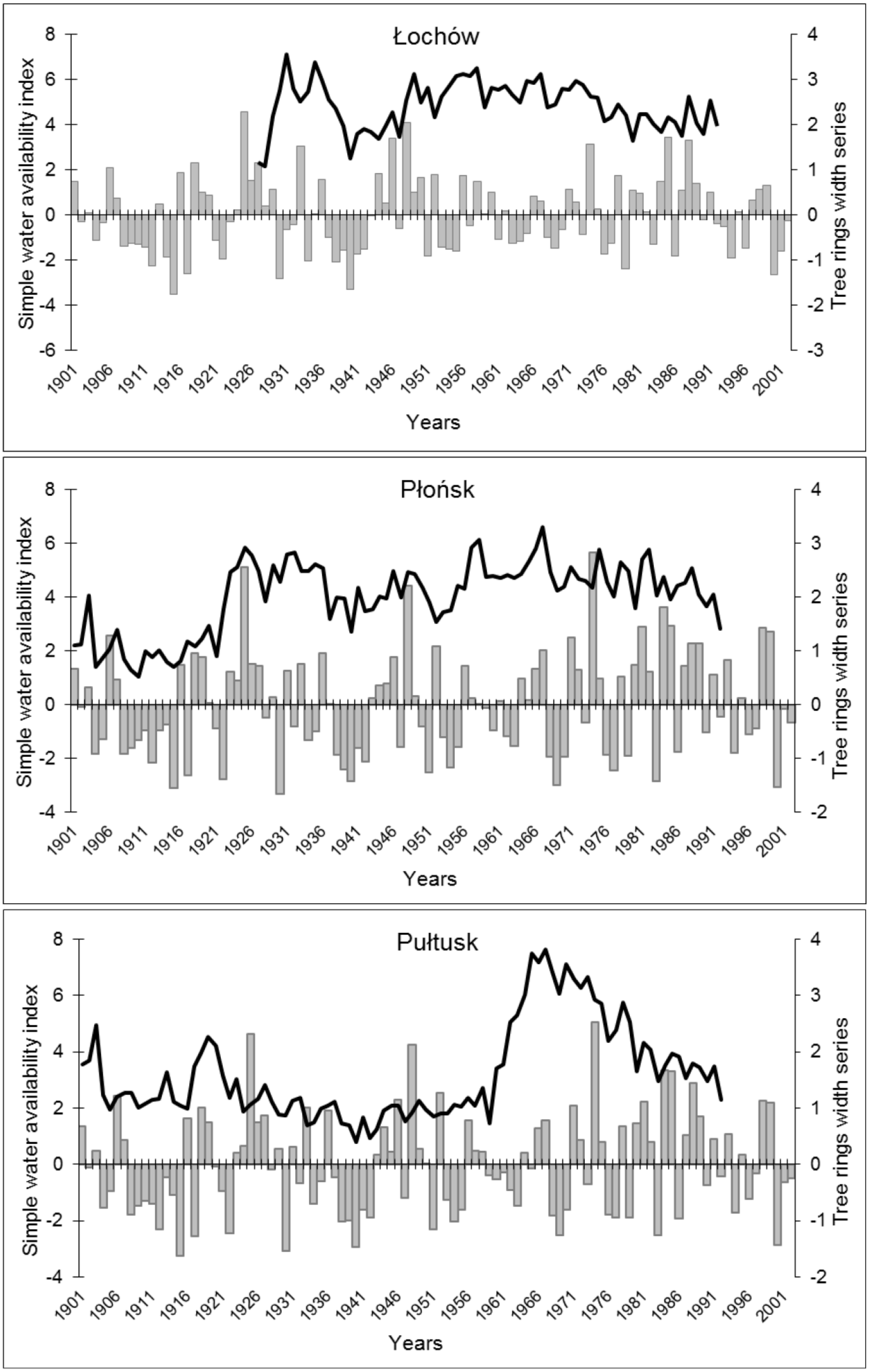

Fig. 5. *Dependence of oak annual increment (right scale, black line – tree ring chronology) on water availability (left scale, grey bars) in June.*

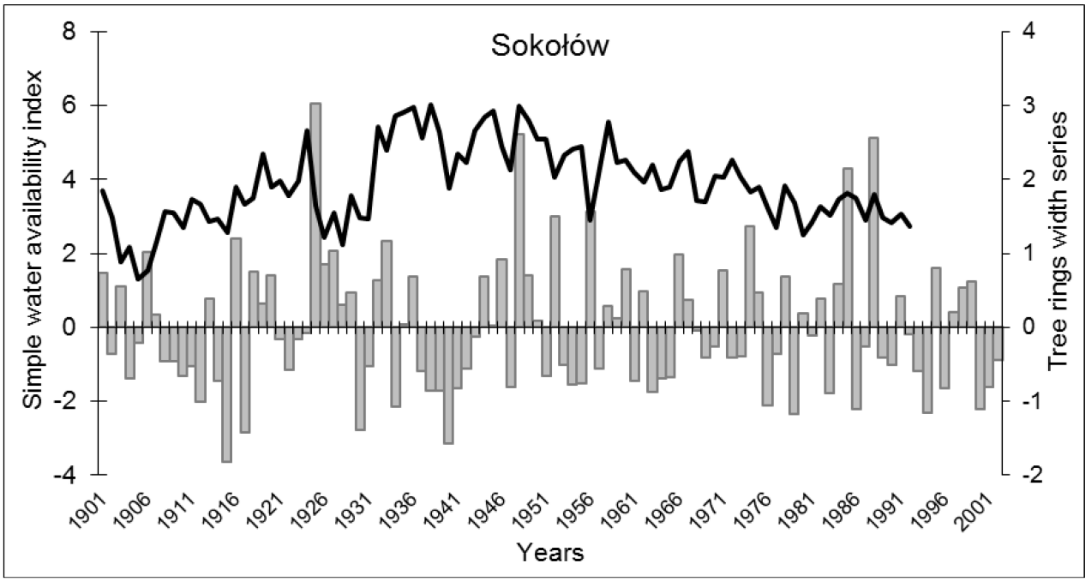

Fig. 5. *Continuation.*

the Pomorze Zachodnie region. In the Bielinek reserve (NW Poland) mean ring widths changed from 1.09 to 1.48 mm (Cedro, 2007).

Results presented in the analyses conducted to date confirm a negative temperature influence on radial increment of oaks. Ermich (1953) already reported such conclusion. Also, Ważny and Eckstein (1991) show that as far as oaks from different localities in Poland are concerned, temperature has a negative influence, but quite evidently analysed oaks prefer mild winters. Ufnalski (2001) found that thermal conditions in August and October of the year prior to ring formation have a negative influence on that process. In turn, Cedro (2004) reported negative correlation between tree-ring width and temperature in July and August of the previous year in northwestern Poland. Similar observations were made for downy, sessile and pedunculate oaks in the Bielinek Natural Reserve (NW Poland). Additionally, the same type of relationship was found for May and June of the year of ring formation (Cedro, 2007). This negative influence of temperature on radial increment of oaks is also mentioned in many studies over Europe. Rozas (2001) and Santini *et al*. (1994) found it for July analysing factors shaping growth of *Quercus robur* L. in northern Spain. Tessier *et al*. (1994) report such relationship for May-July in the Mediterranean region. Also in case of oaks growing in the Netherlands heat in summer results in formation of a narrower ring next year (van der Werf *et al*., 2007). In turn, Tardif and Conciatori (2006) observed negative influence of temperature of previous May on the growth of white and red oaks in Quebec (Canada). A positive correlation with temperature was found for the Niepołomice Forest, where Bednarz and Ptak (1990) observed that a warm end of summer (August) favours wider rings. Similar results were shown in Szczepanek *et al*. (2006) where the authors describe the correlation between isotopes in the annual growth and climatic factors. Analogous pattern occurs at the Sokołów site. In that case positive influence of temperature is for September (**Fig. 4a**). Cedro (2004), as well as Gray and Pilcher (1983), report the same type of relationship for October of the year prior to ring formation.

Positive character of the relationship between radial increment of the analysed oaks and summer precipitation suggests their vulnerability to moisture deficit during the vegetation period. Such observation is confirmed by many studies in Poland and Europe. According to Ważny and Eckstein (1991), growth of Polish oaks is positively dominated by precipitation, especially from April to August. Bednarz (1994) points out the importance of May-July rainfall for the process of tree-ring formation of oaks in the Niepołomice Forest. Ermich (1953) reports positive correlation between tree-ring width and June precipitation. He claims that this is the time of the most intensive radial growth and oaks may produce up to 35% of annual wood production. Ufnalski (2001) and Cedro (2004) present similar conclusions. In the Bielinek Nature Reserve positive increment reaction to precipitation occurred in October and December of the year preceding the growing period and April of the current period were of influence; the relationships were extremely strong in February and June (Cedro, 2007). Dependence of oak growth on summer precipitation was also found in studies in different places in Europe. Rozas (2001) reports positive correlation of June precipitation and increment of Spanish oaks. Santini *et al*. (1994) in Tuscany (Italy), as well as Gray and Pilcher (1983) in the United Kingdom, received comparable relationship for May-July precipitation. In the Mediterranean area the same was observed for May-August period (Tessier *et al*., 1994). Van der Werf *et al.* (2007) found positive character of growth of Dutch oaks-precipitation relationship for previous December and current March. Oaks from Canada also favoured wet June (Tardif and Conciatori, 2006).

Extreme increment reactions of oaks from Łochów, Płońsk, Pułtusk and Sokołów show slight similarity to those reported for other regions. Narrow rings observed at these sites in years 1952, 1959, 1969 and 1992 turned out to be also negative pointer years at seven study sites analysed by Ufnalski (2001) and in the Bielinek Nature Reserve (Cedro 2007). The results of the presented research correspond with that of Boryczka *et al*. (2007), especially as far as eastern Poland is concerned. Corresponding negative pointer years of oak were determined for Suwałki (1940, 1947, 1969 and 1976). The narrow ring of 1940 was also found in oaks growing in Gołdap (NE Poland) as well as Poznań and Wrocław (W Poland). Year 1947 was observed in Warszawa and Wrocław chronologies. Those narrow rings are probably a result of insufficient precipitation during the growing season. Weber *et al*. (2005) and Eilmann *et al*. (2006) discussed such drought vulnerability of oaks. As Ważny and Eckstein (1991) noticed, such country-wide signature years for Poland are e.g. 1800, 1940 and 1952. All can be explained by unfavourable climate conditions. The same reason of narrow rings, but in different years, was reported by Čufar *et al.* (2008) and Büntgen *et al*. (2011). Inglot (1968) found that narrow ring of 1800 was caused by a drought in the previous year. In 1940 there was an extremely cold winter with subsequently little precipitation and in 1952 trees suffered from a preceding dry autumn and winter. Harsh winter followed by a dry summer was observed in 1940, 1947, 1952, 1962, 1976, 1980 and 1987. Such situation was also reported by Mager *et al.* (1999). In years 1941, 1967, 1982 and 1991 analysed oaks produced very wide rings. Pointer years determined for the analysed sites correspond with some extent to those found for whole Poland by Boryczka *et al*. (2007). Probable cause of production of so wide tree rings in those years may lay in profuse rainfall in spring-summer time, as suggested by Cedro (2004).

5. CONCLUSIONS

The analysed oaks from sites in central Poland exhibit a growth pattern comparable with ones known from previous studies concerning that species. Also, relationships between tree-ring widths and basic climate variables are similar (temperature – negative, precipitation – positive). Extreme growth reactions expressed by negative and positive pointer years in general correspond to one observed on other sites in Poland.

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