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Dendroclimatic investigations on *Quercus rubra* and *Quercus robur* in north-western Poland

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Abstract: The study was aimed at investigations of the relationships growth-climate at two oak species growing in forests of north-western Poland; the red oak, the most abundant deciduous tree species of foreign origin, in terms of the appearance sites and surface, and the common oak, the most abundant domestic oak species. The research material were samples taken with a Pressler increment borer from 51 oak trees from two research plots. Within the surfaces selected, trees grow in a fresh forest habitat, in the floral association of the lowland fertile beech forest, also called the Pomerania beech forest, with plants characteristic for the association of the lowland humid beech forest with mercuries, encountered only in the Puszcza Bukowa (Beech Forest). The trees investigated were in good and very good health conditions, only scarce branch and bough deadwood could be observed in the canopies. On the basis of measurements of the annual growth widths, three local chronologies were constructed; two for the red oak and one for the common oak. After the indexation, they were used for dendroclimatical analyses; signature years, correlation and response function. The red oaks forming the shortest chronology (79-year-long pattern representing ca. 90-year-old trees) exhibited the narrowest mean annual increments (1.27 mm), in comparison to the longer chronologies (156 and 151 years in length, the increment widths 1.55 and 1.59 mm, respectively). This could be due to relatively high density of the tree stand, formation of the second stage, beneath the main canopies, as well as lack sufficient amount of the sunlight for the red oaks from that research plot. At both the species analysed, the predominating factor affecting the annual growth widths proved to be the amount of precipitation in the growth season, particularly in June and July, as well and thermal conditions of October of the year preceding the vegetation season in question. In the time of present climatic changes, as well as shifting ranges of the species of plants and animals (including insect pests of the forest trees), knowledge of the relation growth-climate for one of the foreign trees, most often introduced in Poland, characterized by fast growth, resistance on insect pests, and high quality of wood, becomes highly important for the forest management, particularly at planning seedlings, of which effects would be possible to evaluate in over 100 years.

Additional key words: tree-ring width, growth-climate associations, common oak, red oak, Western Pomerania

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Introduction

The red oak (*Quercus rubra* L.) is one of the most valuable of the introduced tree species planted in Poland (among others, on account of the quality of wood). It came from the eastern part of the North America, where it grows in rich, florally diversified oak-tuliptree forests (Podbielkowski 1995). This species was brought to Europe at the end of the seventeenth century; it was noted in Switzerland in 1691 (Hereźniak 1992) and in England in 1724 (Mitchell 1996). According to Hereźniak (1992), it arrived to Poland, to the Botanical Garden in Cracow, in 1806. The red oak is characterized by fast growth and high resistance to diseases. In less favourable and drier sites it grows better than domestic oak species (Król 1967). It is widespread mainly due to forest plantations, however, it has also been widely planted in parks and along streets, as a decorative tree species (Mitchell 1996; Seneta and Dolatowski 2012). The common (pedunculate) oak (*Quercus robur* L.) is a tree species of a broad spectrum of appearance (Europe and Asia) and the most widespread oak species in Poland. It has high soil requirements – likes fresh, deep and fertile soils. It is a long-living species – the longest of our deciduous trees, even over 1000 years.

The field investigations were carried out in the years 2012–2013. The study was aimed at determination of the influence of climate conditions on the tree-ring widths, as well as the assessment of the state of health of trees growing in forest posts in NW Poland.

Methods

Two samples from each tree for the dendrochronological analysis were taken from 51 oak trees (30 red oaks and 21 common ones) with a Pressler increment borer at the level of 1.3 m above the ground, in October 2012 and May 2013 (Table 1). In the laboratory the cores sampled were glued into wooden mounts, then, after drying, their surfaces were cut with a preparation knife in order to get legible images of the annual growth rings. The measurements of the annual ring widths, with 0.01 mm accuracy, were made with help of the Dendrometer program (Mindur 2000), starting from the internal parts, towards the bark. Altogether 5212 annual growth rings were measured (Table 1). Then, using classic methods of the dendrochronological dating (cross-dating method) (Cook and Kairiukstis 1992; Schweingruber 1989; Zielski and Krąpiec 2004), chronologies were constructed, of which quality was tested with the COFECHA program, from the DPL package (Holmes 1983, 1994) – Table 1. The RES chronologies (de-trended, autocorrelation removed) constructed were subjected to the indexation (using a negative exponential curve and autoregressive modelling), in order to eliminate the age trend and to emphasize the annual changeability of the annual growth ring widths, in the ARSTAN program (Cook and Holmes 1986) – Table 1. The expressed population signal (EPS) analysis was used to assess the degree, to which chronologies of each plot portrayed the perfect hypothetical chronology (Wigley et al. 1984).

Mutual similarity values between the chronologies were expressed with the coefficients *t* and *GLK (Gleichläufigkeitswert)*, calculated with the TCS program (Walanus 2002). Dendroclimatological analyses carried out encompassed analysis of the signature years, correlation, and response function. The signature years are such years, in which majority of the trees examined demonstrated the same incremental tendencies: increase of the ring width with respect to the neighbouring years (+, positive pointer year) or decrease of the increment width (–, negative year) (Meyer 1997–1998). The signature years were calculated from minimum 10 trees, assuming the minimum threshold of unanimity of the incremental reactions at 90%. In analysis of the correlation and response function the RES ring index chronologies were compared with meteorological data from the station situated 6–8 km NW from the forest branches investigated. The values of the monthly average air temperatures and total monthly precipitations were analysed for the period of 65 years (1948–2012). For every year, in which an annual growth was formed, its width was confronted with meteorological data for the period of 16 months, i.e. from June of the year preceding growth (pJUN) till September of the current growth year (SEP). In every case the multiple

Table 1. Selected statistics of un-indexed raw ring width and indexed (residual) oak chronologies. SDT – standard deviation, MS – mean sensitivity, A1 – 1st order autocorrelation.

Lab. code	No. of trees	No. of tree-rings	No. of samples	No. of years	Time span	Mean width tree-ring (mm)	Un-indexed raw ring width				Residual chronology		
							STD	MS	A1	EPS	STD	MS	A1
Red oak 1	13	946	11	79	1934–2012	1.27	0.682	0.206	0.870	0.87	0.153	0.174	0.007
Common oak 1	21	2275	14	156	1857–2012	1.55	0.593	0.227	0.724	0.91	0.209	0.193	0.029
Red oak 2	17	1991	15	151	1862–2012	1.59	0.531	0.208	0.708	0.92	0.141	0.164	–0.034
Σ	51	5212											

regression coefficient of determination (r^2) was calculated, determining strength of the relationship between the features analysed (RESPO program from the DPL package, Holmes 1994).

Habitats, in which the research plots were distinguished, were characterized from the phytosociological point of view, including characteristic plant species and their floral associations. The attention was also paid to the state of health and development conditions of the trees. Any appearance of trunk damages and/or branch and bought deadwood was registered as well.

Study area

The research plots are situated in the area of Gryfino forest district, forestry Śmierdnica (NW Poland), in forest divisions (branches): 94c, d and 127n (Fig. 1). These are the oldest forest surfaces in the region, and the only ones, in which several specimens of the red oak grow in the proximity of the common oak trees. According to the physiographical regionalization of Poland, the study area is lying within the terrain of the South-Baltic Coast sub-province (313), in the macro-region Szczecin Coast (313.2/3), meso-region Puszcza Bukowa (313.27) – Kondracki (1988). The branch 94 lies in the immediate proximity of a little stream Leszczyniec (tributary of Płonia) – Domian and Kupiec (2010), the habitat is predominated by the fresh forest, characterized by its water-protection functions. The tree stand consists of the common oak (*Quercus robur* – 60%) and the red oak (*Quercus rubra* – 20%) with the admixture of beech (*Fagus sylvatica* L.) and sycamore (*Acer pseudoplatanus* L.). The main-canopy trees achieve the height of 32 m and diameter at breast height (DBH) of 49 cm (Operat Leśnictwa Śmierdnica 2007). The undergrowth consists of, among others, American milletgrass (*Milium effusum* L.), wood anemone (*Anemone nemorosa* L.),

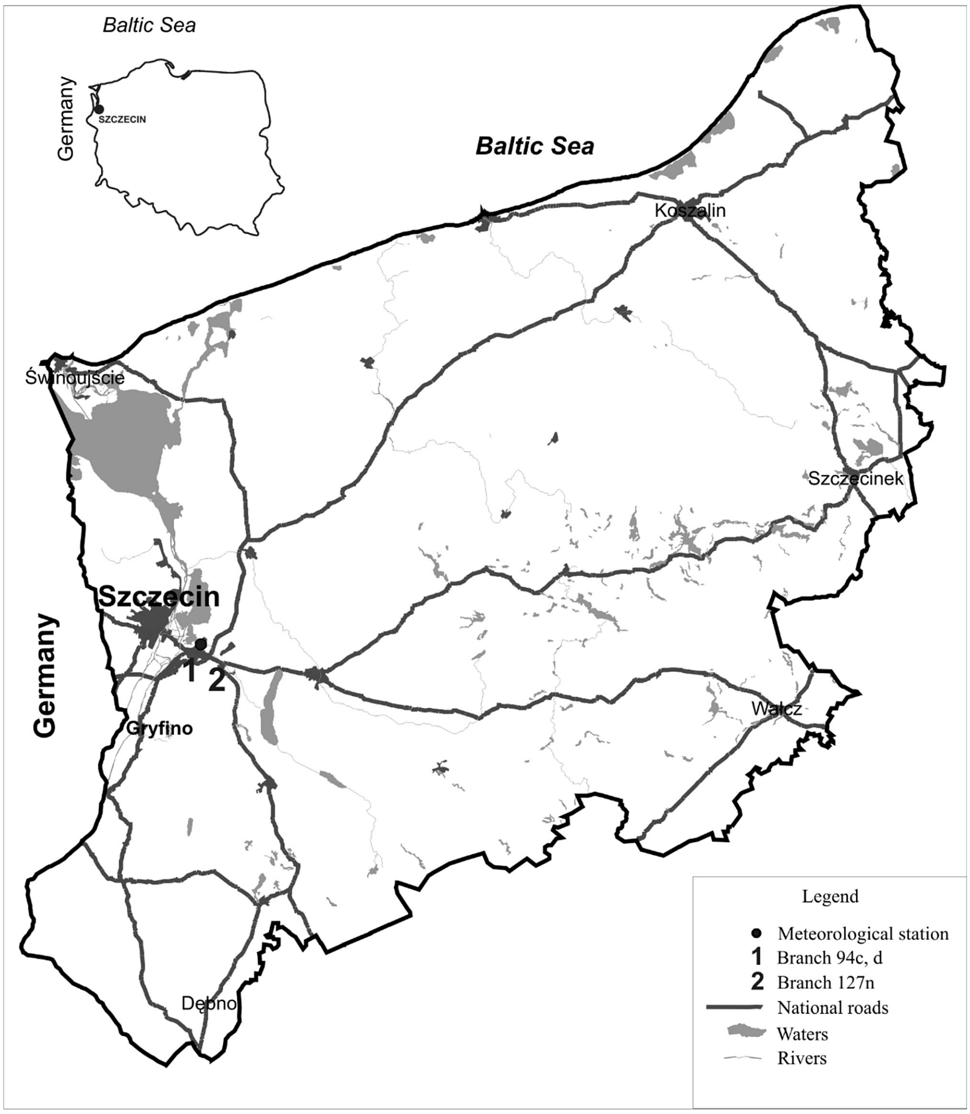

Fig. 1. Locations of study area and meteorological station

toothwort (*Dentaria bulbifera* L.), May lily (*Maianthemum bifolium* L.), yellow archangel (*Galeobdolon luteum* Huds.), sweet woodruff [*Galium odoratum* (L.) Scop.], wood sorrel (*Oxalis acetosella* L.), garlic mustard [*Alliaria petiolata* (M. Bieb.) Cavara et Grande], small yellow balsam (*Impatiens parviflora* L.) and touch-me-not (*I. noli-tangere* L.), ground-ivy (*Glechoma hederacea* L.), lesser celandine (*Ficaria verna* Huds.), male fern [*Dryopteris filix-mas* (L.) Schott], dog's mercury (*Mercurialis perennis* L.), as well as seedlings of sycamore and common beech. It is the floral association of the lowland fertile beech forest, so-called the Pomeranian beech forest [*Galio odorati-Fagetum* (Rübel (1930) ex Sougnez et Thill 1959, syn. *Melico-Fagetum*], and plants are characteristic for the association of the lowland humid beech forest with mercuries [*Fagus sylvatica-Mercurialis perennis* Cel. 1962, syn. *Mercuriali-Fagetum* Cel. 1962], being formed only in the Puszcza Bukowa (Beech Forest). The branch 127n is characterized by fresh forest habitat, this site proved to be drier and poorer than the research plots in the branches 94 c and d. The undergrowth consists of, among others, lesser celandine, sweet woodruff, wood melick (*Melica uniflora* Retz), toothwort, and male fern. The red oaks investigated, achieving 35 m in height and 55 cm in DBH, present themselves remains of an old lane, several of them grow at a bank of a small water reservoir. At present these trees form the main canopy of the tree stand, beneath which young trees develop, among others sycamore (*Acer pseudoplatanus* L.) and common beech (*Fagus sylvatica* L.). Within the research plots selected, in some sites the trees grow quite densely. Within the research plots selected, the trees grow in irregular gauge, in some sites relatively densely – in distances of 2–3 metres.Health conditions of the common and red oaks investigated were generally good and/or very good. Only one specimen, growing in the branch 94d, exhibited an unnatural development of bark at the heights of about 1 m and 3 m, in the form of circular overgrowths, perpendicular to the trunk, most probably caused by tying the trunk with a wire. Only scarce branch bough deadwood could be observed in the tree canopies. The trunk bases are generally wide, with distinct root buttresses.

The average annual temperature amounts to 8.6°C, the coolest month is January (–0.5°C), and warmest one – July (18.0°C). The early spring lasts, in average, 45 days, the spring – 67 days, the summer – 96 days, the autumn – 66 days, the early winter – 45 days, whereas the proper winter lasts only 45 days (Koźmiński 2010). Taking into account the climatic zones distinguished for Europe by Heinze and Schreiber (1987), according to the principles adapted for the United States by Krüssmann and Rehder, Poland is situated in the subzones 5b (with average minimal temperatures from –26.0°C to –23.4°C), 6ab (with average minimal temperatures from –23.3°C to –17.8°C), and 7ab (with average minimum temperatures from –17.7°C to –12.3°C). The quota plants for the zones distinguished are: *Acer campestre, Cornus mas,* and *Taxus cuspidata* for the zone 5, *Buxus sempervirens, Hedera helix, Juglans regia, Quercus petraea,* and *Taxus baccata*, for the zone 6, and *Cedrus atlantica, Ilex aquifolium*, and *Prunus laurocerasus* for the zone 7 (Tumiłowicz 2000). The period with spring frosts is relatively long; lasting until the end of May. The average annual sum of precipitation amounts to 534 mm, with the maximum rainfall in July (67 mm), and the minimum in February (30 mm). The snow cover persists about 20 days per year, in average (Koźmiński 2010).

Results

The longest chronology was produced for the common oak (Common oak 1 – 156 years in the period 1857–2012), comparable in length with the chronology for the red oak (Red oak 2 – 151 years, 1862–2012) – Table 1, Fig. 2. Only the red oaks growing in one research plot (branch 94c, d) together with the common oaks proved to be significantly younger (Red oak 1 – 79-year-long chronology, 1934–2012); the juvenile wood and by-core zones observed in the samples allowed to evaluate the age of the trees examined for about 90 years. The Expressed Population Signal (EPS) values are above the applied threshold of 0.85 (Wigley et al. 1984) (Table 1). These ages of the trees do not agree with the forest administration data (Operat Leśnictwa Śmierdnica 2007). In case of the branch 94c, d (Red oak 1 and Common oak 1) the age of 117 years is indicated for both, common and red oaks, whereas in the branch 127n (Red oak 2) the age of the trees is given as 123 years. Mean widths of the annual growths at the trees composing the Common oak 1 and Red oak 2 chronologies are similar (1.55 and 1.59 mm), only the red oaks forming the Red oak 1 chronology are marked with narrower growth rings (1.27 mm) – Table 1.

The chronologies constructed exhibit high graphical (Fig. 3) and statistical (Table 1) convergence as to the course of the dendrochronological curves. The highest value of the *t*-rate was obtained for the chronologies Red oak 1 and Red oak 2, whereas the GLK-rate – for Red oak 1 and Common oak 1, and also Red oak 1 and Red oak 2 (Table 2).

Table 2. Similarity of oak chronologies as measured with *t* and *GLK* value

t/GLK	DC3	DC4	DC5
DC3	X	4.3	6.1
DC4	65*	X	4.6
DC5	65*	62*	X

* significant values ($p \leq 0.05$).

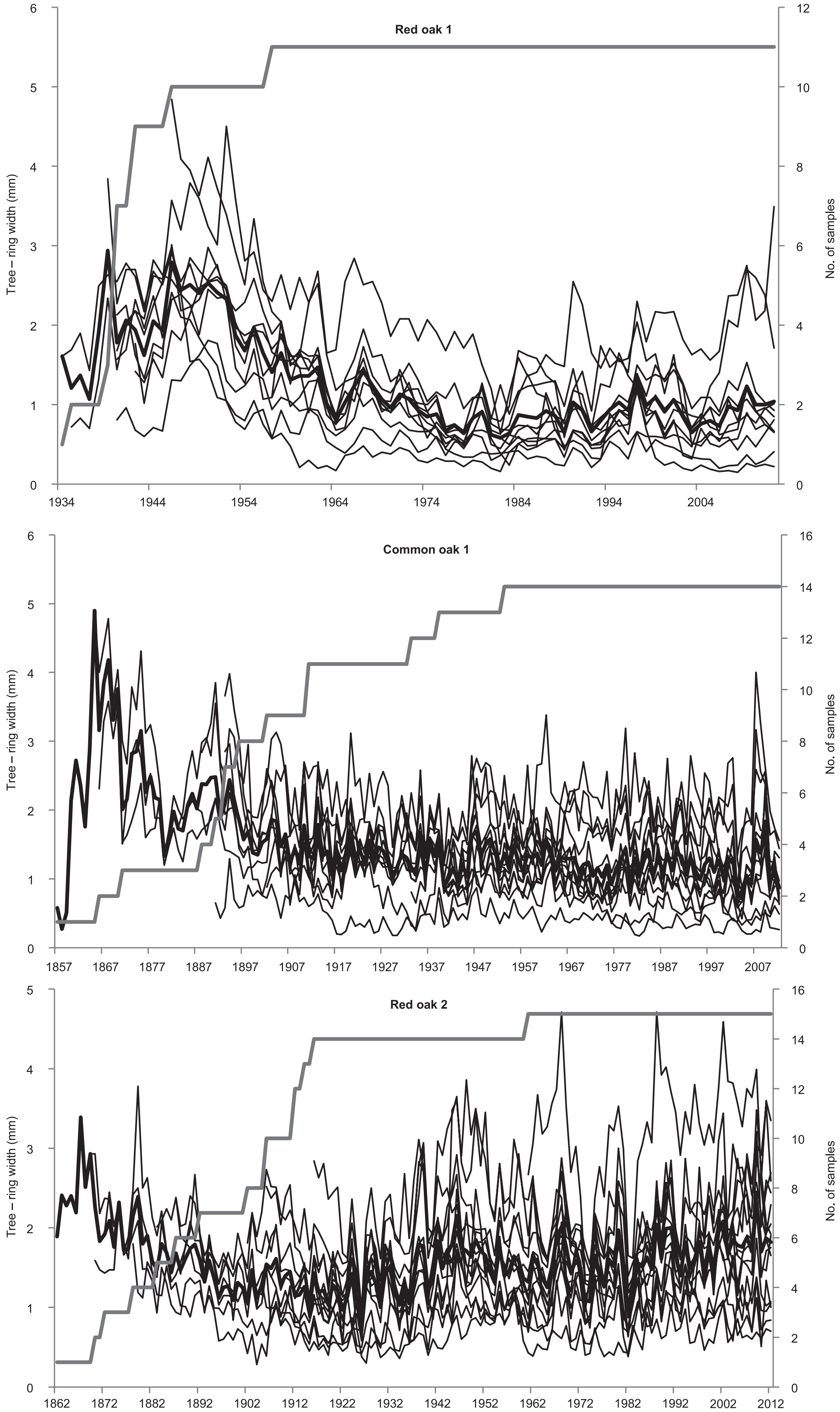

Fig. 2. Dendrochronological sequences (thin line) making up oak mean width series (thick line) and number of samples in chronology (grey line)

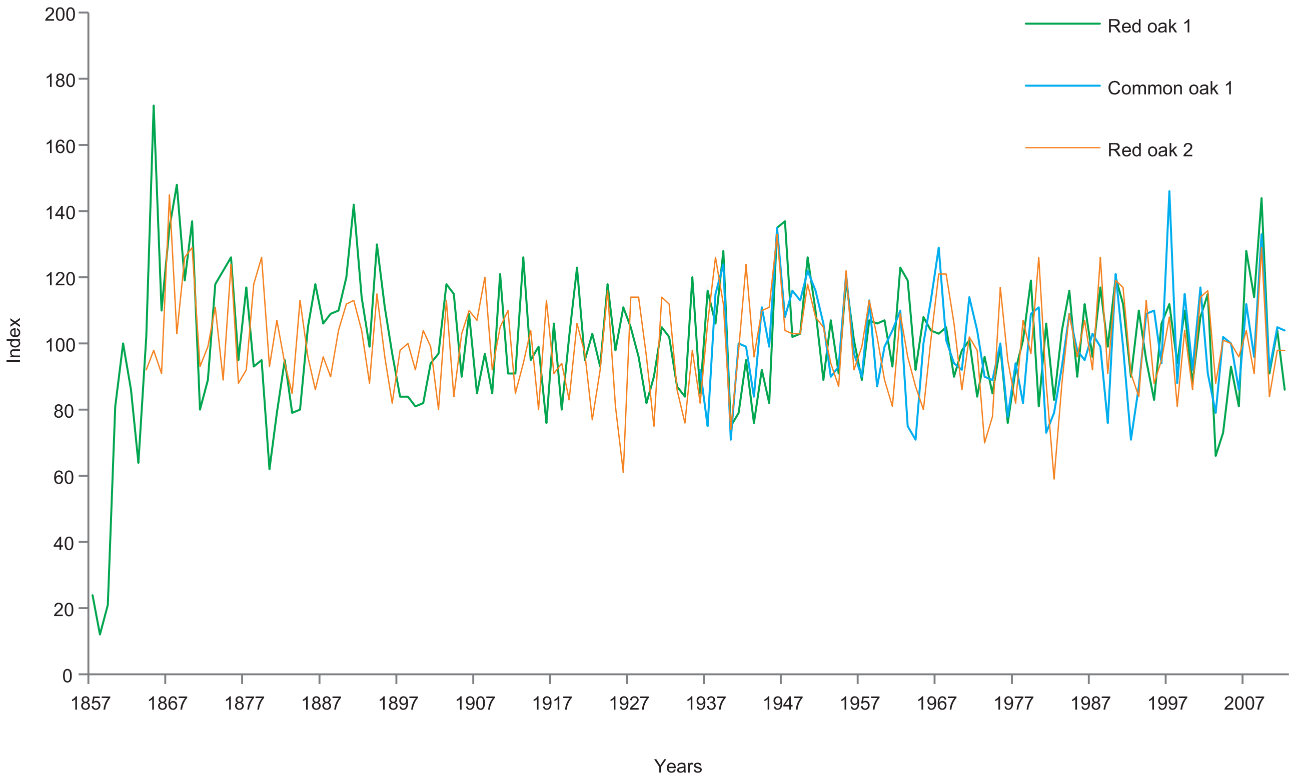

Fig. 3. Comparison of oak chronologies

Altogether 111 signature years were determined; 24 ones for the chronology Red oak 1 (10+ and 14–), 40 years for the Common oak 1 (13+ and 27–), and 47 ones for the pattern Red oak 2 (22+ and 25–) – Table 3. Analysis of the meteorological conditions in the signature years distinguished permitted to bound the positive years with periods with total rainfall higher than average, particularly with the humid period May–July. Negative years are related to periods of the deficiency of rainfall in the growth season, often connected with high air temperatures in the summer period.

Analysis of the correlation and response function points to the precipitation in the growth season (June for Red oak 2, June–July for Common oak 1, and the period April–July for Red oak 1) and thermal conditions in October of the year preceding the current growth season (the higher the temperature in that month, the wider the growth) as the predominating factors affecting the annual growth widths (Fig. 4). However, the analysis carried out allowed to distinguish other months, of which meteorological conditions also affected the incremental condition of the trees examined; high temperatures of summer months of the year preceding growth had negative impact on the tree-ring width, the amount of rainfall of the winter period, particularly February, as well as thermal conditions of the growth season (negative values of the correlation and regression for June and July, and positive ones for August and September).

The multiple regression coefficient of determination (r^2) exhibited higher values for the precipitations in the case of the Red oak 1chronology, whereas in the cases of the Common oak 1 and Red oak 2 chronologies higher values were obtained for the air temperatures (Fig. 4).

Discussion and conclusions

The average width of the annual growths, as a rule correlating with the age (the older trees, the narrower tree rings), proved to be a non-typical result. In spite of relatively young ages, the red oaks from the branch 94c, d (Red oak 1) exhibit lower average widths of the annual growth rings in comparison to almost twice older common oaks from the same research plot, and also to the red oaks from the branch 127n (Red oak 2). This is plausibly due to relatively high density of the tree stand, formation of the second level beneath the main canopy, and lack of sufficient amounts of the sunlight.

The dendroclimatical investigations of the red oak are relatively scarce. They were led, among others, by Bijak et al. (2012a, 2012b), who compared the influence of climatic conditions on growth of the common and red oaks in the Forest Experimental Unit and Arboretum in Rogów (central Poland), as well as Cedro and Nowak (2013), who studied, among others, trees growing in urban conditions of Szczecin (north-western Poland). For the red oak trees growing within the Forest Experimental Unit and Arboretum in Rogów, the authors demonstrated relationships

Table 3. Summary of signature years for oak chronology. (+) positive signature years, (–) negative signature years

	Red oak 1	Common oak 1	Red oak 2		Red oak 1	Common oak 1	Red oak 2
1913		+		1965	+		
1914		–		1966	+		+
1915			–	1967			+
1916		–	+	1969		–	
1917			–	1970	–		–
1918		–		1971	+		
1919		+	–	1972		–	
1920		+		1973			–
1921		–		1975		+	+
1922			–	1976	–		
1924		+	+	1977			–
1925		–		1978	–		+
1926			–	1979	+		
1927			+	1980		–	+
1929		–		1981	–	+	–
1930			–	1982		–	–
1931		+	+	1983			+
1933			–	1984	+		+
1934		–	–	1985		–	
1935		+		1987		–	
1937		+	+	1988			+
1938			+	1989	–	–	–
1940		–	–	1990	+		+
1943			–	1992	–		–
1944			+	1994			+
1946		+	+	1995			–
1947			–	1997	+		
1948		–		1998	–		–
1951		–		1999			+
1952		–		2000	–	–	–
1954		–	–	2001	+		+
1955		+	+	2002	–		
1956			–	2003	–	–	
1957		–		2007	+	+	
1959	–			2008		–	
1961		–	–	2009	+		+
1962		+		2010	–	–	–
1963	–			2012		–	
1964		–					

in the year preceding the growth analysed: for thermal conditions in September (negative values of the correlation) and for pluvial conditions in April and August (positive correlation values). The signature years determined (positive years in 2001 and 2009) could be characterized by humid and cool vegetation periods (Bijak et al. 2012a, 2012b). For the red oak trees growing in urban conditions of Szczecin and in the forest posts analysed, lower values of the annual growths were obtained, in comparison to the trees growing in surroundings of Rogów (2.31 and 2.27 mm and 1.55, 1.59 and 1.27 mm vs. 3.75 mm). This could be related, among others, to the ages of the trees composing the chronologies; 78- and 87-year chronologies from Szczecin, 151- and 79-year ones from the forest branches, comparing to the 55-year Rogów chronology (Bijak et al. 2012a, 2012b; Cedro and Nowak 2013). The incremental reactions of trees growing along urban streets reflected certain impact of conditions in the previous growth season (negative correlation and regression with temperatures in June, July, and August and positive values for October), however, the annual growth widths were mostly affected by the precipitations in February and June of the current growth season. For February, such high relationships could be possibly explained by the end of the period of usage of chemical substances, containing chlorides, used for de-icing streets and pavements (Bach et al. 2009; Breś 2008; Szulc 2007); high precipitations facilitated removal of these easily soluble chemicals from the root zones. On the other hand, high February precipitations

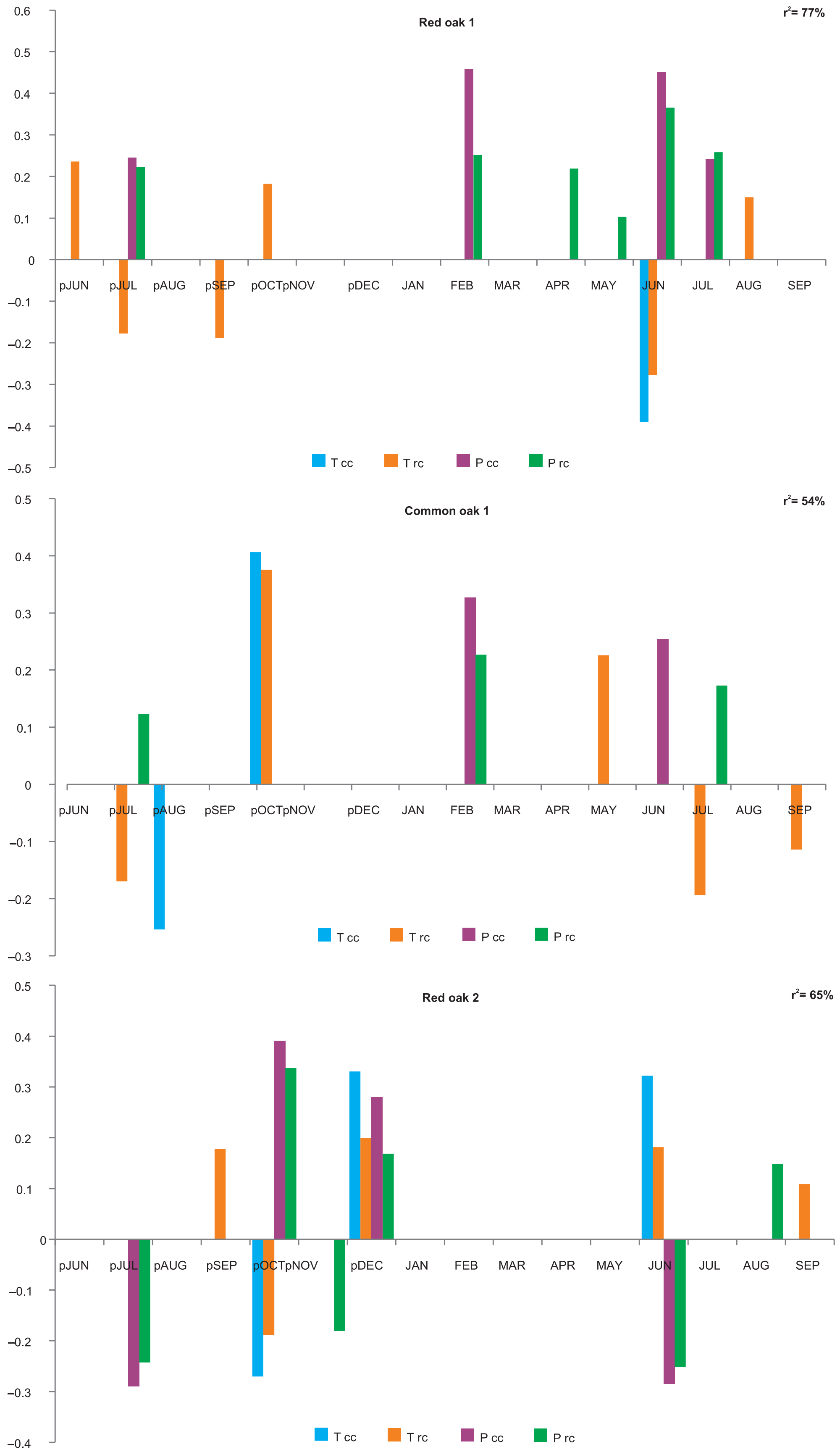

Fig. 4. Results of correlation and response function for oak chronologies and temperature (T) and precipitation (P); bars denote correlation coefficients (Tcc, Pcc) and represents response function (Trc, Prc); all values are significant ($p \leq 0.05$); p, previous year

could be connected with relatively mild temperatures of that month. For June, the highest positive values of the correlation and regression were obtained for the atmospheric precipitation, which could be correlated with the period of the most intensive growth of the wood tissues.

The amount of rainfall in the growth season was also pointed out as the predominating factor affecting the annual growth widths at the red oaks introduced in Latvia, where high summer temperatures combined with scarce precipitation caused incremental depressions, whereas high temperatures at the end of the previous growth season and in spring of the current growth season favoured expansion of the earlywood vessel lumen area (Matisons et al. 2014).

In the area of its natural appearance (eastern part of the North America) the red oak is also sensitive to the amount of the rainfall; summer drought was presented as a factor limiting growth (Fekedulegn et al. 2003; Haavik et al. 2008; Speer et al. 2009; Tardif and Conciatori 2006; LeBlanc and Tarrell 2009, 2011; White et al. 2011). Thermal conditions were indicated as an additional factor affecting incremental dynamics of the red oaks; negative values of the correlation and regression were noted in both, southern Canada (Tardif et al. 2006), as well as the eastern United States (Fekedulegn et al. 2003; Haavik et al. 2011; Pan et al. 1997; Pederson et al. 2004). For 82 sites of red oak in eastern North America the strongest and most spatially replicated growth-climate variables for the early growing season (May-July) (LeBlanc and Tarrell 2011). Radial growth is correlated with climate variables for prior September and there was no significant correlations between winter mean or maximum temperatures (LeBlanc and Tarrell 2009, 2011). Warm and rainless end of the previous vegetation season, prolonging the vegetation season, causes and supports a good training of trees for the season of the rest coming (collecting and withdrawing nutrients from leaves and limbs) (Cedro 2004).

Taking into account that the red oak is the most abundant deciduous tree species of foreign origin Poland, in terms of both, the surface occupied as well as the appearance sites, broadening our knowledge on its ecology and adaptation to local habitat conditions and climate is essential. It should be remembered, however, that the red oak is an invading species; for this reason monitoring of its appearance sites is of key importance. On account that this species proved to be highly resistant to the air and soil pollution and of low habitat requirements, it may be introduced, in justified cases, e.g. in the terrains subjected to the rehabilitation (Nowak 2012), or planted in urban areas, along streets (Cedro and Nowak 2013), in parks or communal green areas. On the other hand, habitats in which successful cultivation of domestic oak species were possible should be unconditionally preserved and protected.

Similarities in incremental reactions on varying meteorological conditions of the oak trees described from the area of their natural appearance and from Poland are presumably due to similar climate conditions. Reasons for resemblance of the course of the chronologies, signature years and the reactions growth-climate at the red oak and the common oak, most abundant in Poland, should be looked for in a broad ecological spectrum, high intra-population variability, as well as effective strategies of the adaptation and surviving of both these tree species.

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