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BIOMETRICS OF TREE-RING WIDTHS OF (*POPULUS X CANADENSIS* MOENCH) AND THEIR DEPENDENCE ON PRECIPITATION AND AIR TEMPERATURE IN SOUTH-WESTERN POLAND

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ABSTRACT

The aim of this study was to explore the structure of the basic biometric characteristics of Canadian poplar (*Populus x canadensis* Moench) growing on former farmland, and the influence of meteorological elements on the variability of tree-ring widths (TRW). The test was performed on stem discs. Measurements of TRW were made with the use of LINTAB^{TM} 6. The impact of meteorological conditions on the TRW of the examined poplars was determined using correlation analysis for the dependent variable - residual chronology and independent variables - rainfall and air temperature in the current year and the year preceding the formation of rings. The average TRW of the Canadian poplar was 6.70 mm, with a coefficient of variation of 45.6%. The average TRW in sapwood was 5.37 mm, 2.11 mm less than in heartwood. The site chronology represented the period 1967-2014 (48 years). Our study demonstrated a significant correlation between rainfall and temperature on TRW in *Populus x canadensis*. The greatest demand for water by the Canadian poplar was observed in April and September of the current year. In contrast, the effect of air temperature most negatively affected TRW in June-July of the previous year (especially July) and April-May of the current year. In the designated chronology we established 13 pointer years, 7 positive and 6 negative. Negative years were determined in the years in which the shortage of rainfall was up to 50% of the norm, and positive indicator years where precipitation was higher than in the multi-annual period, even >150%. Both the correlation analysis and the analysis of indicator years indicated rainfall as a factor determining the size of the tree-ring width in Canadian poplars. In recent years, Poland has seen a resurging interest in planting poplars, following a long-term global trend in forestry and the paper industry which requires fast-growing tree plantations. The authors of this study attempted to address the gap in knowledge about the impact of meteorological elements on the tree-ring widths of *Populus x canadensis* in the conditions of south-west Poland.

KEYWORDS: Dendroclimatology, tree-ring widths (TRW), Canadian poplar, sapwood, heartwood, weather conditions.

INTRODUCTION

Many researchers have examined the impact of meteorological elements on the tree-ring widths of trees growing in different environmental conditions (Gillner et al. 2013, Stravinskiene et al. 2013, Kalbarczyk et al. 2016, Poljanšek and Marion 2016). Studies on fast-growing tree species often analyze trees grown on plantations due to their wide range of applications. These include poplars, the fastest growing trees in the temperate zone of the northern hemisphere (Białobok 1973). Their growth is especially rapid in fertile and sufficiently moist alluvial soils (Bergez et al. 1989). The rate of growth is responsible for the popularity of poplar wood as a raw material, a source of biomass (Rytter and Stener 2005, Tullus et al. 2012) and biofuel (Bergez et al. 1989, DeBell et al. 1996, Rae et al. 2004).

In comparison to other tree species, poplars live for a relatively short time. These are typical photophilous species with a high assimilative capacity requiring large quantities of water, with strong transpiration, as well as high photosynthetic activity (Barigah et al. 1994). Poplar wood is light, soft, and classified as diffuse-porous wood (Stanton et al. 2010). One of the most interesting species of poplar is the Canadian poplar (*Populus x canadensis*) conventionally assigned to the Euro-American group, which includes numerous hybrids of the American Black poplar (*Populus deltoids* Marsh.) and European Back poplar (*Populus nigra* L.), along with their varieties (Białobok 1973, FAO 1979, Broeck et al. 2004, Ziegenhagen et al. 2008). Euro-American poplars not only include hybrids of the 1st generation F1 *Populus deltoides* x *Populus nigra*, but also hybrids resulting from backcrossing with ancestral species, and F2 hybrids. *Populus deltoides* and *Populus nigra* were first introduced to Europe around 1700 (Białobok 1973).

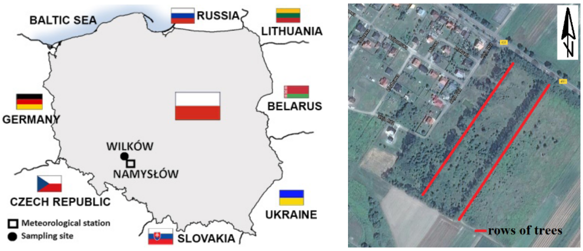
The traits of the hybrids resulted in the popularity of these poplars in Europe, including Poland where it began to displace the native *Populus nigra*. These traits included strength of growth (the phenomenon of heterosis), high resistance to diseases and pests, straight and long trunk, an easy method of reproduction, and low sensitivity to adverse growing conditions. In Poland at the turn of the eighteenth and nineteenth centuries, Euro-American hybrids were very common, especially *Populus canadensis* 'Serotina', resulting in an intense process of replacing the native species of poplar. In the 1960s, the share of Populus used in plantings was 30%. As a tree that grows very large in all types of green areas, the poplar was an important element in landscaping. After World War II, Canadian poplars in Poland played an important role as a species used in many variations for a quick greening of the war-torn country. The species was also important in reducing the postwar deficit of industrial wood (Schreiner 1959, Banoun et al. 1982, Antolak et al. 2014).

In this paper we determined the basic biometric characteristics of this popular tree growing on former farmland in south-western Poland, and the relationships between TRW and rainfall, air temperature and the thickness of the snow cover. The direct reason for undertaking this research was the growing interest in poplar cultivation in Poland resulting from modern energy policy requirements, the growing demand for wood, and the economic development of Poland and its environmental conditions. In addition, the body of research regarding the relationship between TRW of the Canadian poplar and climatic variations is very modest. In Poland, it is mostly based on unpublished experiences of those professionally involved in tree cultivation. Our assumption was that the tree-ring widths of *Populus x canadensis* would be determined by meteorological conditions in the year preceding the ring formation and in the current year. Based on previous research on other species in Poland, we suspected that rainfall variations in spring - maybe responsible for particularly wide and particularly narrow tree-ring widths.

MATERIAL AND METHODS

Location of the study area and conditions for tree growth

Until March 2015, the studied Canadian poplars had grown on former farmland, 5.45 ha in the village of Wilków (ϕ=51°05'56"N, λ=17°40'13"E, Hs=155 m) situated in south-western Poland (Fig. 1a). The trees had been a wind-break for a flax field warehouse (Fig. 1b).



(a) (b)*

*Fig. 1: Location of the study area and the meteorological station from which the data was acquired (a); the distribution of the analyzed trees. (b) *https://www.google.pl/maps (10.10.2016).*

The research material consisted of 55 stem discs collected from straight trees at a height of 1.3 m, in line with the ECO strategy (Zielski and Krąpiec 2009). Felling of the trees was carried out on the basis of a decision by the local authorities in accordance with applicable Polish law. In relation to agricultural evaluation of arable soils in Poland, poplar trees have been grown on medium-quality soils. The soil was classified as brown earth (Cambisols) and lessive (Luvisols) on a flat terrain. We did not determine the origin of the genotype or the plant material.

Preparation of material for research and dendrochronological analysis

Before measuring TRWs, the stem discs were dried and planed. Then, filtered water was used to increase the contrast between the early and late diffuse-porous wood (Cedro 2016a). The ring widths were measured along three paths, each from bark to pith, avoiding reaction wood. The measurements took into account sapwood and heartwood. All analyses of the tree-ring widths were undertaken using LINTAB$^{\text{TM}}$ 6 and TSAPWin software (Time Series Analysis Program, Heidelberg, Germany) to the nearest 0.01 mm (Sander 2004, Rinn 2012). After the measurements, the incomplete tree rings from 2015 were discarded from the study as felling had taken place in the first quarter of 2015, i.e. before the end of late summer cambium activity. Each individual sequence of TRW was assigned a WN code, from 1 to 55. The percent share of the fragments of sequences with the same (i.e. converging) waveforms in the total number of common intervals was determined by GLK convergence coefficient (Gleichläufigkeit, %) (Eckstein and Bauch 1969, Kaennell and Schweingruber 1995). The correctness of measurements of TRW was verified according to the graphical similarity of dendrograms, and also by the t value according to Bailie and Pilcher (TVBP) and Hollstein (TVH) (Baillie and Pichler 1973, Kraler et al. 2012, Barsoum et al. 2014). The quality of the individual sequences was also measured by the cross-dating index (CDI), which included the results of both t-tests (TVBP an TVH) and the GLK (Rinn, 2012). We also established cross-correlation (CC, %) and overlapping coefficients (OVL) (Kraler et al. 2012). Coefficients describing the quality of the individual sequences (GLK, TVBP, TVH, CDI, CC and OVL) were calculated with the TSAP-Win software. Synchronization of TRW against the mean for all the sequences was performed by COFECHA software (Grissino-Mayer 2001). After a thorough statistical analysis, 16 outlying sequences were excluded from further study. Individual sequences were characterized by the number of years in sapwood (Ws, years) as well as heartwood

(Wt, years). The biometric characteristics of TRWs were also described using statistical indicators such as mean ($\bar{x}$, mm), standard deviation (SD, mm), extremes – minimum (min, mm) and maximum (max, mm), and the coefficient of variation (V, %). Then we established a site chronology with an assigned WINAP code. The analyses also used ARSTAN software (Holmes 1994) to transform the raw data into indexed values to form the residual chronology (WINAPre), devoid of the age trend and auto-correlation (Cook et al. 1990, Cook and Holmes 1999, Rybníček et al. 2010). In the first stage of standardization, an exponential or simple curve was fitted to each of the individual curves, depending on the nature of the observed trend (to remove fluctuations associated with the aging of the tree). The next step was to obtain indexed values by dividing each of the actual values of the individual curve by the corresponding value of the fitted curve at a given point. With the use of ARSTAN software we determined the expressed population signal (EPS), a measure of the similarity between a given tree-ring chronology and a hypothetical chronology that had been infinitely replicated from the individual radii for a specific common time interval (Wigley et al. 1984).

The analysis of correlation was used to assess the impact of meteorological conditions on the variability of TRW. In the assessment of the relationship between TRW and weather, the dependent variable was TRW in the form of a residual chronology, while the independent variable was the considered meteorological element in the individual months of the current year (from January to September) and the previous year (from June to December). The meteorological elements studied were total rainfall (Rf, mm), air temperature (T, °C), minimum temperature

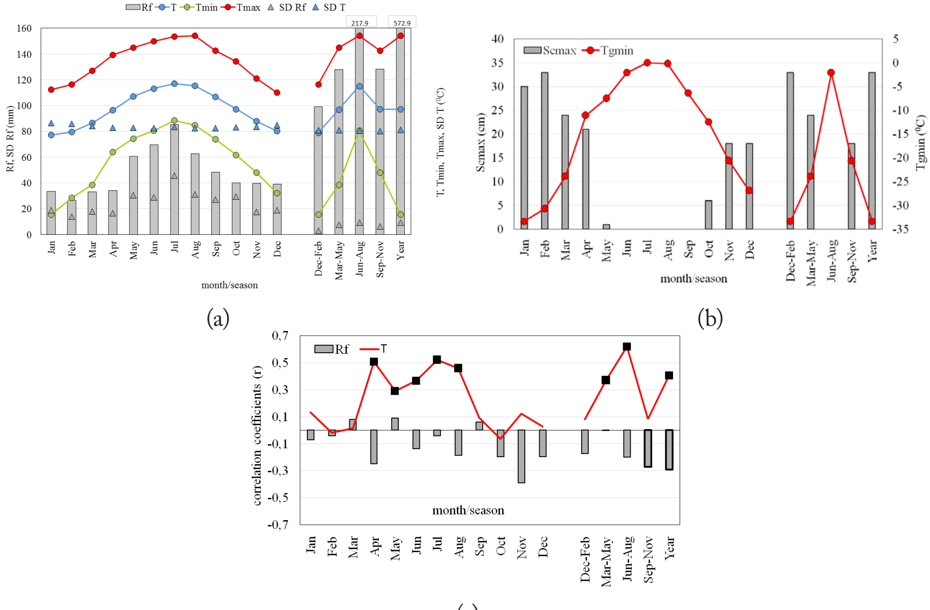
(T_{min}, °C), maximum temperature (T_{max}, °C), minimum temperature at ground level (Tg_{min}, °C), and snow cover thickness (Sc_{max}, cm).

Pointer years were defined as those where more than 90% of the poplars shared an increase (positive pointer year) or decrease (negative pointer year) in TRW. The pointer years were described by mean values of raw data and residual chronologies, as well as by raw data differences between mean TRW in the current and the preceding year. Pointer years allowed us to study and determine the radial growth response to a signal sent by the changing weather conditions (Garcia-Suarez et al. 2009, Gillner et al. 2013, Barsoum et al. 2014). In addition, each designated pointer year was described in terms of the temperature and rainfall in 6 seasons: previous summer (June to August – 6p-8p, where the number denotes the month and p represents a year preceding the formation of tree rings), previous autumn (from September to November – 9p-11p), winter (from December to February – 12p-2), spring (from March to May – 3-5), current summer (from June to August – 6-8), and current autumn (from September to November – 9-11). In describing the rainfall during individual seasons (in pointer years) we adopted the classification by Kaczorowska (1962). A season was considered normal in terms of rainfall when, in a given pointer year, rainfall was 90% to 110% of the long-term mean; dry – from 75% to 89%; very dry from – 50% to 74%; and extremely dry at less than 50% of the mean long-term rainfall. On the other hand, a season was consider humid when rainfall was – 111% to 125% of the long-term mean, very humid from – 126% to 150%, and extremely humid at more than 150%

of the long-term mean. The air temperature was analyzed using two statistics – mean ($\bar{x}$) and standard deviation (SD) established for the multi-annual period from 1967 to 2014, and the average calculated for a pointer year (δ) (Kalbarczyk and Kalbarczyk 2012). A given season was considered normal (average) when the air temperature in a given pointer year met the following conditions $\bar{x}$ - 1.0 SD ≤ δ ≤ $\bar{x}$ + 1.0 SD; warm – $\bar{x}$ + 1.0 SD < δ ≤ $\bar{x}$ + 1.5 SD; hot – δ > $\bar{x}$ + 1.5 SD; ; cool – $\bar{x}$ - 1.5 SD ≤ δ < $\bar{x}$ - 1.0 SD; cold – δ < $\bar{x}$ - 1.50 SD, and extremely cold – δ < $\bar{x}$ - 2.0 SD.

Characteristics of climatological conditions in the study area

The local meteorological station, operating within the national network for monitoring the atmosphere, was only 5 km from the surveyed trees. It can therefore be concluded that the data used in the analysis represented the climatic conditions at the site of tree growth. To illustrate the climate at the measurement site of the Canadian poplars, we described the rainfall and air temperature in a multi-annual period (Fig. 2a,b,c).



(a)

(b)

(c)

Fig. 2: Climograph of rainfall (Rf, mm) and air temperature: mean (T, °C), the absolute minimum (T_{min}, °C) and the absolute maximum (T_{max}, °C) (a). Climograph of maximum absolute thickness of the snow cover (Sc_{max}, cm), and the absolute minimum temperature of the soil (Tg_{min}, °C) (b) and a diagram of the correlation coefficients (r) for the linear trends of Rf and T in the years 1967-2014 (c). Significant values of r, at least at the level of P<0.1 were indicated with a bold black line in the shape of a rectangle (Rf, mm) or a square black tag (T, °C).

Average annual rainfall (Rf, mm) from 1967-2014 was 573 mm, ranging from 27 mm in February to 85 mm in July. Rainfall in transition months of spring and autumn was almost equal at 127.8 and 128.3 mm respectively. The standard deviation of rainfall from January to April and from November to December was on average 15 mm less than in the months from May to October. A significant year-to-year linear trend of rainfall was statistically proven only in April (r = -0.25, P<0.1) and November (r = -0.39, P<0.01). A reverse trend was observed for absolute maximum thickness of the snow cover (Sc_{max}, cm). The highest Sc_{max} was measured in February (33 cm) and then in January (30 cm). In the years 1967-2014 the average annual air temperature (T, °C) was 8.5°C and ranged from -1.4°C in January to 18.5°C in August. In autumn the average air temperature was higher by 0.2°C than in spring and was 8.6°C. The highest standard deviation of T was in winter (SD = 2.8°C), and the lowest for summer (SD = 1.4°C). In the multi-annual period, a significant increase in T was demonstrated in five months, from April to August. The strongest positive increase in T was found for July ($r = 0.52$, $P<0.01$) and April ($r = 0.50$, $P<0.01$).

Minimum (T_{min}, °C) and maximum (T_{max}, °C) absolute air temperatures varied widely, as it ranged from -32.3°C in January to 37.1°C in August. Apart from January, T_{min} below -20°C was also recorded in February (-25.8°C), March (-20.7°C) and December (-24.0°C). Significantly lower absolute minimum air temperatures were recorded at the ground level (5 cm agl) than at the height of 2 m above the ground level in all months of the year, especially in February (4.9°C), May (4.7°C), July (4.3°C), and November (4.6°C). T_{max} above 30°C was recorded in five months, from May to September and was 32.4°C in May and 34.9°C in June, 36.7°C in July and 37.1°C in August and 31.3°C in September.

RESULTS

Statistical verification of individual sequences

Only 39 consistent sequences were selected after statistical evaluation of all 55 stem discs. The relatively short time series justifies the adoption of extensive statistical criterion for determining the reliability of dating. Gleichläufigkeit (GLK, %) was approximately 78% and also higher than the minimum threshold indicated by Eckstein and Bauch (1969), Cook and Briffa (1990), Rybníček et al. (2010), Sohar et al. (2012). Similarity between individual sequences was also tested using the Bailie-Pichler (TVBP) and Hollstein (TVH), t-tests which were respectively 6.24 and 6.89. In addition to EPS, GLK, TVBP and TVH, the dating quality of the tested 39 individual sequences was also evaluated using the cross-dating index (CDI), cross-correlation (CC) and overlapping (OVL). All three statistical characteristics confirmed the correct choice of sequences for creating site chronologies. The values of the indicators were 52 for CDI, approx. 66% for CC and 44 for OVL and were significantly higher than those reported in the literature (Rinn 2012; Kraler et al. 2012, Malik et al. 2014).

The biometric characteristics of individual sequences

Circumferences of 39 trunks (Ct, cm) selected for further statistical analyses were characterized by high variation (V = 17.7%, SD = 34.0 cm), ranging from 113 to as much as 260 cm (Tab. 1).

Tab. 1: Statistical characteristics of some parameters describing the individual sequences with assigned WN codes.

Parameters (n = 39)	Symbol (unit)	Characteristics			
		$\bar{x}$±SD	min	max	V (%)
Trunk circumference at a height of 1.3 m	Ct (cm)	192.0±34.0	113.0	260.0	17.7
Age recorded in the sequence (cambial age of tree rings)	W (years)	43.0±2.0	38.0	48.0	4.7
Number of years in sapwood	Ws (years)	15.8±3.1	10.0	24.0	19.6
Number of years in heartwood	Wt (years)	27.2±3.6	20.0	34.0	13.3

Explanation: $\bar{x}$ - mean, SD - standard deviation, min - minimum, max - maximum, V - coefficient of variation.

The average age of the analyzed sequences of *Populus x canadensis* was approx. 43 years and ranged from 38 to 48 years. The average number of years determined for sapwood was approx. 16 years and ranged between 10 and 24 years and showed high variation (V = 19.6%, SD = 3.1 cm). Heartwood ranged from 20 to 34 years, with average approx. 27, and with the variation of 13.3%. Most individual sequences (trees), as many as 7 developed 13 rings in sapwood, while 11 trees had 16 or 17 rings in sapwood (Figs. 3, 4).

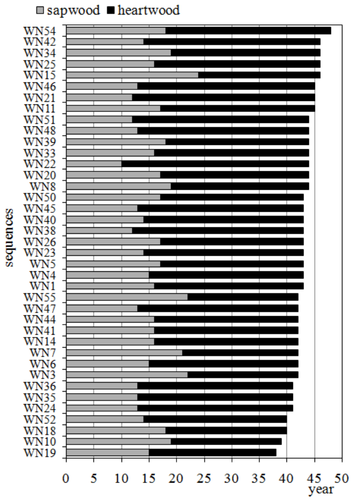


Fig. 3: Diagram of dendrochronological dating of the analyzed individual sequences with assigned WN codes.

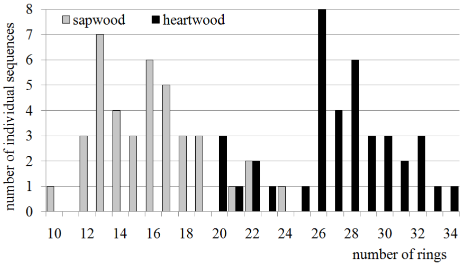


Fig. 4: The number of tree rings divided into sapwood and heartwood, describing individual sequences with WN codes.

In total, we measured 1.678 tree rings (TR), of which approx. 63% were in heartwood (TRh), and approx. 37% in sapwood (TRs) (Tab. 2, Fig. 5). The average tree-ring width was 6.70 mm (V = 45.6%), 5.37 mm in sapwood, and on average 2.11 mm narrower than in heartwood (7.48 mm).

Tab. 2: Biometric features of tree rings widths in individual sequences with WN codes.

Biometric features (n = 39)	**Number of trees**	**Symbol**	**Statistical indicators**						
			Number		$\bar{x}$	**SD**	**min, year**	**max, year**	**V (%)**
			(no.)	**(%)**	**(mm)**				
Tree-ring widths - total	39	TR	1 678	100	6.70	3.05	0.70 2005	18.58 1980	45.6
Tree-ring widths in sapwood		TRs	619	37	5.37	2.12	0.70 2005	12.76 2008	39.5
Tree-ring widths in heartwood		TRh	1 059	63	7.48	3.24	0.89 1970	18.58 1980	43.4

Explanation: as in Tab. 1.

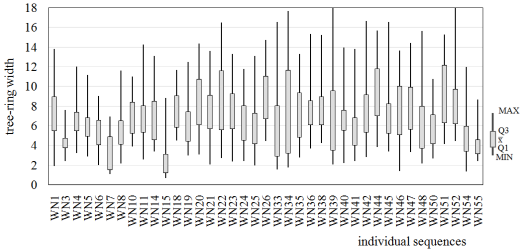


Fig. 5: The variability of tree-ring widths in individual sequences with WN codes. Q1 – first quartile, Q3 – third quartile, $\bar{x}$ – average. Other explanations as in Tab. 1.

Most frequently, i.e. in over 28% cases, tree rings were 2.1-3.0 mm wide; then 3.1-4.0 mm (approx. 24%) and 1.1-2.0 mm and 4.1-5.0 mm (approx. 15% each) (Fig. 6). Much less frequent were rings >5.1 mm (approx. 13%) and in the 0-1 mm range (a little over 3%). The frequency distributions of tree-ring widths in sapwood and heartwood were similar to that found for the entire disc from the pith to the bark. The biggest difference in frequencies between sapwood and heartwood was observed in three intervals: 2.1-3.0 mm (14.1%), 4.1-5.0 mm (11.4%) and 1.1-2.0 mm (9.9%). The first four ranges, i.e. from 0 to 4 mm, were dominated by sapwood, and the next intervals by heartwood. Within the range of 3.1 to 4.0 mm, except the ranges >7.0 mm, the percentage of tree rings was most similar for sapwood and heartwood, and amounted to -1.6% for sapwood, and +1.1% for the heartwood.

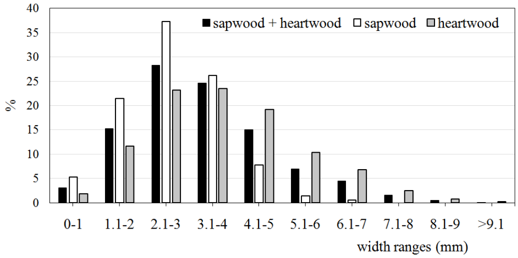


Fig. 6: The percentage of tree-ring widths of individual sequences with WN codes according to the adopted ranges.

Dendroclimatological analyses

The dendrochronological curves of individual sequences (WN) of Canadian poplar and the site chronologies - raw data and residual, designated by codes WINAPrz and WINAPre, are presented in Fig. 7. Site chronology was established by averaging 39 curves; it contained 48 years and represented the period 1967-2014. The expressed population signal (EPS) for the 39 individual sequences was as high as 0.96. EPS is a valuable means for assessing the representation of a population signal, but it will not reveal whether this signal is closely related to the reconstructed parameter or any other source of common growth variation (Buras 2017). EPS signal shows that the tree-ring series are representative for the test site (Wigley et al. 1984).

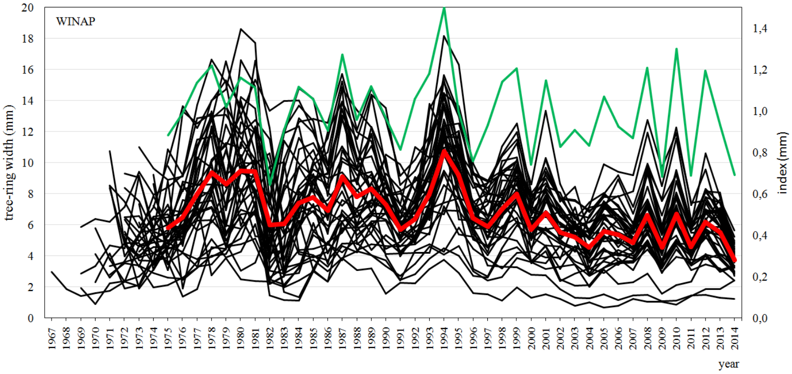


Fig. 7: Site chronology WINAP composed of WN individual sequences. Black lines – individual sequences, the red line – raw data chronology (WINAPrz), green line – residual chronology (WINAPre).

In the years 1975-2014, in which the sample consisted of at least 37 individuals in each year, the average width of WINAPrz tree rings was 6.81 mm, and ranged from 3.73 mm to 10.73 mm. SD and V for WINAPrz were 1.63 mm and 23.9%, while for WINAPre 0.19 mm and 19.3% (Tab. 3).

Tab. 3: Selected characteristics of the WINAP chronology – raw data and residual.

Chronology	$\bar{x}$	$\bar{x}_w$	min	max	SD	V	t	rt	rp	EPS
	(mm)					(%)				
Raw data (WINAPrz)	6.81	0.208	3.73	10.73	1.63	23.9	25.34**	0.460**	0.57***	0.97
Residual (WINAPre)	1.00	0.210	0.65	1.50	0.19	19.3	31.31**	0.014n.s.	-0.25n.s.	0.97

Explanation: $\bar{x}_w$ - mean sensitivity, t - t test value, *** significant at P <0.01, ** significant at P <0.05, ns - statistically non-significant at P<0.1; rt - linear trend, rp - autocorrelation coefficient Io, EPS – expressed population signal. Other explanations as in Tab. 1.

Average sensitivity ($\bar{x}_w$) calculated for both the raw data and residual chronology was above 0.2 and did not differ from values determined for the other site chronologies of deciduous trees growing in Europe (Bronisz et al. 2012, Jansons et al. 2015). The raw data chronology, as opposed to residual, was characterized by a significant positive linear trend (rt = 0.46, P<0.05) and a significant positive coefficient of autocorrelation Io (rt = 0.57, $P<0.01$). Correlation analysis showed a significant effect of meteorological factors, e.g. rainfall (Rf) and temperature (T) on the tree-rings widths of *Populus x canadensis* (Tab. 4).

Tab. 4: The influence of selected meteorological elements, from June of the year preceding the formation of the ring to September of the current year on tree-ring widths in the multi-annual period 1975-2014.

Month		**Meteorological element**								
		Rf (mm)		**T (°C)**		**T_{min}**	**T_{max}**	**Tg_{min}**	**Sc_{max} (cm)**	
						(°C)				
6p	previous year				-0.27*					
7p				-0.37**						
8p										
9p										
10p										
11p							-0.32**			
12p										
1	current year									0.29*
2									0.37**	
3										
4		0.41***			-0.27*					
5							-0.29*			
6										
7										
8			0.38**							
9		0.32**				0.31**				

Explanation: p - previous year, Tmin - minimum air temperature, Tmax - maximum air temperature, Tgmin - minimum air temperature at ground level, Scmax - maximum thickness of the snow cover, * significant at $P<0.1$. Other explanations as in Tab. 4 and Fig. 2.

The analyzed meteorological elements influenced tree-ring width with different strength and direction. Rainfall in April and September of the current year had the strongest positive effect. Slightly weaker, and mainly negative, was the correlation between tree-ring width and air temperature – T, T_{max}, T_{min} and Tg_{min}. The most negative effect on TRW was exerted by T in the period of June-July, and especially in July of the year preceding the formation of the ring ($r = -0.37$, $P<0.05$) and in the period April-May of the current year ($r = -0.27$, $P<0.1$). When it comes to T_{max}, the most negative influence was exerted by its values in November of the previous year ($r = -0.32$, $P<0.05$) and in May of the current year ($r = -0.29$, $P<0.1$). September of the current year was the month in which the minimum air temperature had a positive influence on TRW, i.e. contributed to the formation of wide rings. However could not confirm a significant impact of minimum air temperature at ground level on TRW. The positive impact of the maximum thickness of the snow cover was demonstrated for its levels in January-March, especially in February of the current year ($r = 0.37$, $P<0.05$) (Tab. 4).

Characteristics of climatological conditions in pointer years

For the site chronology of *Populus x canadensis* with assigned WINAP codes, we determined 13 pointer years, including 7 positive (1978, 1987, 1994, 2005, 2008, 2010, 2012) and 6 negative

(1982, 1996, 2000, 2009, 2011, 2014) (Tab. 5). The pointer years were those in which at least 90% of the analyzed trees shared an increase (or decrease) in tree-ring width relative to the previous year.

Tab. 5: Pointer years for WINAP site chronology and weather conditions during the period from the summer of the previous year to the autumn of the current year.

Pointer years		**>90% Number of samples sharing an increase of decrease (%)**	**The course of weather conditions****			
Positive (wide tree-rings)	**Negative (narrow tree-rings)**		**in seasons preceding the pointer year (summer, autumn)**		**in the pointer year (winter*, spring, summer, autumn)**	
			rainfall	**temperature**	**rainfall**	**temperature**
1978		92	extremely humid summer	cold summer	humid spring and very humid autumn	very cold summer
	1982	92	humid summer, very humid autumn		dry winter, very dry summer and extremely dry autumn	hot autumn
1987		90	very humid summer,		extremely humid winter, dry summer	cold winter and summer, a typically cold spring
1994		90	dry summer, humid autumn	cold summer, atypically cold autumn	very humid winter, humid spring, very dry summer and autumn	warm summer
	1996	100	very humid summer, humid autumn		very dry winter	very cold winter and cold spring
	2000	97	very dry summer and autumn		very humid spring, dry summer, and very dry autumn	warm spring and atypically hot autumn
2005		90	very dry summer,		dry summer, extremely dry autumn	normal
2008		97		cold autumn	humid spring, very dry summer and autumn	warm winter
	2009	100	very dry summer and autumn		extremely humid summer and dry autumn	warm spring
2010		97	extremely humid summer and dry autumn		very humid spring and autumn	cold winter and warm summer

	2011	92	extremely humid autumn	warm summer	humid summer, dry spring and very, dry autumn	warm spring
2012		100	humid summer, very dry autumn		very humid winter (dry spring and autumn)	warm spring
	2014	92	humid autumn		dry winter, extremely humid spring, dry summer, dry autumn	warm winter hot spring

Explanation: *winter (from December of the previous year to February of the pointer year **not described seasons did not deviate from the multi-annual average, i.e. were considered normal (criteria given in the section "MATERIAL AND METHODS")

In the positive pointer years the values of residual chronology were greater than 1 mm, and ranged from 1.1 mm in 2005 to 1.47 mm in 1994. Six out of seven positive pointer years (1978, 1987, 1994, 2008, 2010, 2012) were characterized by humid calendar seasons. Usually, they were associated with unusually humid summers in the previous year and unusually humid springs during the pointer year. For instance, in 1994, when the average tree-ring width was 11 mm, winter and spring were very humid and humid, respectively, and the summer was very dry and warm. Autumn in the previous years was humid and unusually cold, and the summer was dry and cold. 2005 was an atypical positive pointer year, in which the summer and autumn were dry and extremely dry, respectively, with average thermal conditions.

Negative pointer years were often characterized by dry seasons of varying degrees of severity, from dry to extremely dry. The year 1982 had below-average rainfall in winter, summer and autumn; 1996 in winter; in 2000 – summer, autumn; in 2009 – in autumn, and 2011 – spring, autumn. Thermal conditions of air in negative pointer years were less diverse than rainfall. Years 2000, 2009 and 2011 had warm springs; in 1982 – hot autumn, and in 1996 – very cold winter and cold spring. Thermal conditions in the years preceding negative pointer years usually did not differ from the average.

DISCUSSION

Rainfall and temperature conditions are very important for TRW. Climate is the main factor for secondary growth (Cook 1992, Fritts 2001, Speer 2010). Therefore, in accordance with the Liebig's law, deficiency of one of the factors limits the population size (George and Ault 2014). In the relationship between climate and TRW, the law of the limiting factor is particularly evident in determining pointer years, both positive and negative. Knowledge on the impact of rainfall and temperature on secondary growth of hybrid poplars is small due to the short production cycles of these trees, used mainly as a raw material and a source of biomass for the energy sector (Zajączkowski and Wojda 2012, Tullus et al. 2012, Šēnhofa et al. 2016). In the climatic conditions of Poland, maximum activity of cambium in the genus *Populus* is observed at the end of May and beginning of June, after flowering. Cell division, resulting in the cambium circumference, is observed until the end of the growing season (Białobok 1973).

The process of tree ring formation of the genus Populus depends crucially on the reactivation of cambium in spring, which for poplars starts 2-3 weeks after the development of leaf buds, with a significant role of the air temperature in the period of April-June. Cessation of cambium activity is independent of the natural process of leaf shedding (October) (Białobok 1973). The activity of cambium ends one or even two months before leaf shedding. Analysis of tree ring-widths in Latvia showed much narrower tree-rings (by as much as 3 mm) than our results from SW Poland (Šēnhofa et al., 2016). Smaller differences were shown by hybrid aspens growing in eastern part of Latvia, which may result from the lack of information on the origin of the plant material (genotype), different features of the same hybrids within the genus Populus, growth conditions, the type of cultivation (plantation in Latvia, while in Poland rows of trees performing the functions of a wind-shield). In Latvia, the dendroclimatological analysis of hybrid poplars was carried out at 2 sites in the western part of the country (experimental plantations), while hybrid aspens at 1 site in the eastern part of the country (Šēnhofa et al., 2016). That study began in 2013; a total of 48 samples were collected from trees. Thermal conditions were shown to exert the a decisively dominant role on the width of tree-rings in hybrid poplars. The direction and strength of the effect of air temperature in July of the current year on TRW was similar in both countries.

A study carried out in south-western Slovakia by Paganova et al. (2009) showed a statistically significant influence of hydrological and climatic conditions on TRW in poplars. The research showed that the annual increase was correlated to the groundwater level (especially during periods of lower levels) from June to August of the year preceding the ring formation. The study also showed a statistically significant correlation of extremely high temperatures from June to August of the current year on TRW. In our study, in Lower Silesian conditions in Poland, however, TRW was statistically significantly correlated with maximum air temperature (Tmax) in the May of the current year and also minimum air temperature (Tmin) in the September of the current year. Trnka et al. (2016) indicated the possibility of using dendrochronological methods in assessing the productivity of species from the Populus in plantations. That study found that the height of young trees (in plantations of hybrid poplars) and TRW of mature trees (P. nigra) were positively correlated to thermal conditions from May to June and pluvial conditions (positive water balance) from September of the previous year to August of the current year (which gave a higher yield). Similar to our study on Populus canadensis, TRW was negatively affected by dry springs, which probably resulted in a delayed period of full cambium activity. However, there is a lack of research concerning pointer years for Populus hybrids growing in diverse edaphic and climatic conditions.

Taking into account the climatic conditions of Poland and studies with chronologies of deciduous trees, one may find overlapping positive and negative pointer years. A 1996 study on oaks Quercus robur (Kędziora and Tomusiak 2012) established the same negative pointer years as in our study on 39 individual sequences. The year 1996 had very cold winter months and low rainfall at the turn of winter and spring. There were also many years of drought in the period 1988-1995 (Łabędzki 2004). Similar results indicating 1996 (preceded by drought) as a year with significantly reduced TRW, have been shown by other researchers in Europe (Cedro 2007, Čejková and Kolář 2009, Rybníček et al. 2012). In addition, the year 2000, also with a serious drought, was shown as a negative pointer year in many dendroclimatological studies (Čejková and Kolář 2009, Bijak et al. 2012, Rybníček et al. 2012, Stajić et al. 2015, Cedro 2016b). In Poland, strong droughts also occurred in 1982-1984 (Kalbarczyk 2010). The year 1982, a negative pointer year for Populus canadensis, was dry in three seasons: winter, summer and autumn. Cedro (2007), in a study on oaks: *Quercus pubescens, Q. robur* and *Q. petrea*, also established several pointer years: negative in 1978 and 1996, and positive in 1994, which coincided with the pointer years calculated for *Populus canadensis*. Given that the climate is one of the main factors affecting tree growth and productivity of forest ecosystems, TRW of *Populus hybrids* are susceptible to the same ongoing climate change (Kirschbaum 2000, Lindner et al. 2010). This study was carried out as a pilot study. The next stage will involve research on several areas of preserved poplar plantations established in the 1960s in southern Poland.

CONCLUSIONS

The established site chronology of *Populus x canadensis* was 48 years long, from 1967 to 2014. The widest absolute TRW among all the analyzed sequences with WN codes was 18.58 mm (in 1980), and the narrowest was 0.70 mm (in 2005). In heartwood, the average tree-ring width was 7.48 mm, about 2.11 mm wider than in sapwood.

1.678 tree-rings of *Populus x canadensis* were measured, of which only approx. 37% were in sapwood. The majority of all rings, more than 52%, were in two ranges: 2.1-3.0 and 3.1-4.0 mm.

Among the analyzed meteorological elements, the greatest positive correlation on TRW of the Canadian poplar was by rainfall in April and August-September of the current year, especially in September, and snow cover in January-March of the current year, mostly in February. Average and maximum air temperatures adversely influenced TRW, especially temperatures in April-May, as well as in the months prior to the growing season, in June-July and November.

In the analyzed multi-annual period 1976-2014, 13 pointer years were established. These were the years where at least 90% of rings shared an increase (or decrease) in their width. There were seven positive pointer years 1978, 1987, 1994, 2005, 2008, 2010, 2012, and six negative pointer years: 1982, 1996, 2000, 2009, 2011. Positive pointer years were recorded mostly in the seasons with above-average rainfall, and negative with below-average rainfall, especially in the current year of ring formation. Thermal conditions in the seasons preceding the pointer years usually did not differ from the average.

There are surprisingly few reports on the impact of meteorological elements on the TRW of the Canadian poplar. This can be explained by the short production cycle of this species, often used as raw wood or a source of biomass. Therefore, research on both the structure of TRW and the impact of meteorological elements on the ring widths of Canadian poplar should be continued, especially in a variety of edaphic and climatic conditions.

The present study was an attempt to add to the limited body of data on determining the dependence of tree-ring widths of Canadian poplar on climate conditions in south-west Poland.

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