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THE 443-YEAR TREE-RING CHRONOLOGY FOR THE SCOTS PINE FROM UPPER SILESIA (POLAND) AS A DATING TOOL AND CLIMATE PROXY

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Abstract: An annually resolved and absolutely dated ring-width chronology spanning 443 years has been constructed using the historical and living-tree Scots pine samples from the Upper Silesia, south of Poland. The constructed regional chronology, based on six object chronologies, covers the period of 1568–2010. It is composed of 178 wood samples with the mean correlation of 0.51, mean series length of 104 years and mean EPS of 0.85. In total, 65 extreme years were distinguished. Their independent verification, based on the historical and meteorological data, showed significant correlation with the exceptionally cold/mild winters as well as severe droughts. The comparison of the extreme years with the other Polish pine chronologies showed similarities in the years with the anomalous winter conditions. Some extreme years can be associated with the exceptional pluvial conditions; these years are common in the Central European hydroclimatic tree-ring records. The construction of this regional pine chronology enables for the absolute dating of many architectural monuments from investigated region. The application of the new chronology for the dating of local wood can support interpretations of changes in the environment of the Upper Silesian region. In the future it can also be used as the basis for climate reconstruction.

Keywords: long term chronology, tree-ring dating, cultural heritage, historic wood, *Pinus sylvestris*, S Poland.

1. INTRODUCTION

The existing meteorological time series are relatively short, particularly with regard to the climate change research. In southern Poland the exceptionally long series extends no further back than over the last two centuries (Kraków since 1772 (Trepińska, 1997) and Wrocław since 1792 (Bryś and Bryś, 2010)). This determines the necessity to seek new climate proxies, among which tree-ring data are of a special interest due to their annual resolution. It has been shown that the dendrochronological techniques were successfully applied to reconstruct past climate (e.g. LaMarche, 1974; Fritts, 1976; Briffa *et al.*, 1990). This method can also provide information about paleo-environments (e.g. Billamboz, 2003 and Friedrich *et al.*, 2004) and geomorphological activity of surface processes (e.g. Alestalo, 1971; Krąpiec and Margielewski, 2000). The usefulness of dendrochronology was also successfully applied to date wood from historic buildings (e.g. Douglas, 1935; Stahle, 1979; Shyatov *et al.*, 2005, Vitas, 2008, Bernabei and Bontadi, 2012) and reconstruct prehistoric (e.g. Dean, 1996; Krąpiec, 2000) and historic human activities (e.g. Büntgen *et al.*, 2006; Eckstein, 2007; Opała and Kaczka, 2008; Büntgen *et al.*, 2011).

Tree-ring local chronologies are mostly based on living trees; it is, however, possible to build long term chronologies using wood from archaeological, historical, and

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ethnographical wooden monuments. The chronologies obtained from old wooden monuments allow the extension of time series over a period of 200–300 years and even thousand years or more in the case of wood from the archaeological structures. Such studies are carried out primarily in Europe (e.g. Bartholin, 1991; Thun, 1991; Baillie, 1995; Kyncl and Kyncl, 1999; Szychowska-Krąpiec and Krąpiec, 2001; Büntgen *et al*., 2004; Wilson *et al.*, 2004; Szychowska-Krąpiec and Krąpiec, 2005; Čufar *et al*., 2008; Vitas 2008; Tegel *et al*., 2010) and Russia (Kozlov and Kisternaya, 2004; Gurskaya, 2007), while American studies using timber for extending the tree-ring chronologies are scarce (Nielsen *et al.*, 1995; Bortolot *et al*., 2001).

Scots pine (*Pinus sylvestris*) is the main forest species in Central and Eastern Europe. Nowadays Scots pine exists primarily as pine monocultures, but the high content of pine in the composition of the Polish forests in historic times causes frequent presence of wood of this species in buildings structures. This led to the creation of a few long-term chronologies of this species for different parts of Poland (Zielski, 1992; Szychowska-Krąpiec, 1997; Szychowska-Krąpiec and Krąpiec, 2001; Zielski *et al*., 2001; Szychowska-Krąpiec and Krąpiec, 2005) and the neighbouring countries (Heußner, 1996; Läänelaid and Eckstein, 2003; Vitas, 2008). Besides the existing tree rings chronologies, there is a great potential for such investigations in other forested parts of Central Europe, where timber was the most common construction material available to settlers.

Excellent conditions for developing the regional composite chronology exist in Silesia, as this region is rich in old wooden cottages and churches built using the horizontal log technique. The abundant dendrochronological material of this region remained so far unexploited. Although in the study area one of the oldest in Poland semi-natural pine stand with specimens reaching the age of 270 years has been found (Opała *et al*., 2011), the utilisation of historical wood is essential to obtain a proxy record reaching back far beyond the instrumental climate data. Therefore the research aimed at developing new series of the proxy data are of great importance for the reconstruction of climate and studies of climate change.

Dating of the construction timber is also important from the historical point of view. This border area between Poland, the Czech Rep. and Germany was particularly vulnerable to the war destruction. This mostly relates to World War II, when a huge amount of archival material was destroyed and there is no information about the age of many architectural monuments. At present, the precise determination of the age of these monuments is possible only by using the dendrochronological method, which proves the importance of this type of research.

This study aims at: (1) the construction of the first long-term chronology for Upper Silesia using living trees and historical wood from monuments present in the area, (2) investigation of its features and possible teleconnections, and (3) determination of its potential as a dating tool and climate archive.

2. STUDY AREA

The study area is situated within two geographical units: the Silesian Lowland and Silesian Upland (**Fig. 1**). Flat areas and low elongated hills of different origins dominate in the relief of the region. Southern Poland was covered with the Scandinavian ice sheet at least twice. A large thickness of the glaciofluvial and glacial deposits and lack of solid rock outcrops in the analysed areas determine the structure of historical buildings. The main construction materials were bricks and timber. High availability of historic wood materials was one of the reasons why this area was chosen for the dendrochronological research. Additionally, a lot of nature reserves, which protect the old pine stands, occur in Upper Silesia. These small reserves are the remains of the ancient Silesian Forest, which covered the entire area in the early medieval times. Nowadays, the dominant tree species in the investigated sites are: *Pinus sylvestris*, *Quercus petraea*, *Quercus robur*, *Fagus sylvatica* and *Picea abies*, *Betula pendula*, *Abies alba*, *Larix deciduas* (Michalak, 1971). In the study area there is a large mosaic of soil types, with the domination of the soils formed on the Pleistocene sediments, mainly on glacifluvial sands, glacial tills and loess deposits. Alluvial soils have developed within the Holocene river valley bottoms (Atlas, 2008).

The climate of Upper Silesia is characterised by the variability of the weather conditions associated with the active inflow of the air masses from the west and the rapid movement of baric systems. Predominantly, the moist polar maritime air contacts drier continental masses (Niedźwiedź, 1998). The study area is classified as the Wrocław-Opole pluvio-thermal region, that is the warmest thermal region and moderately dry pluvial region

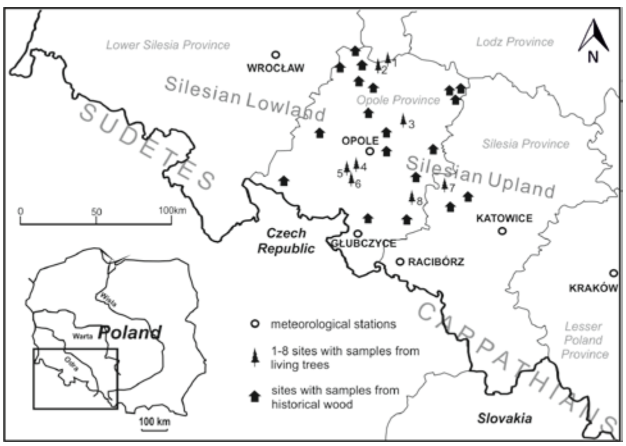

Fig. 1. *Map of the study area. Nature reserves: 1 – Komorzno, 2 – Krzywiczyny, 3 – Bażany, 4 – Jaśkowice, 5 – Blok, 6 – Jeleni Dwór, 7 – Hubert, 8 – Boże Oko.*

(Schmuck, 1965). Upper Silesia has a relatively short winter with unstable snow cover and a long, warm summer. Compared to other regions, fewer days of frosty weather are particularly characteristic. The study area is one of the warmest in the country. At the same time, the investigated area shows a relatively low thermal variation. The average annual temperature ranges from 8°C to 8.5°C. The study area receives an average of 600–700 mm of precipitation annually. The maximum occurrence of rainfall is recorded during the summer months (June-August), while the minimum occurs in the winter months. Upper Silesia is the area with one of the longest vegetation periods in Poland, which lasts more than 220 days (Atlas, 2008).

3. MATERIALS AND METHODS

The research material from living trees was collected in 8 nature reserves: Bażany, Hubert, Jeleni Dwór, Boże Oko, Krzywiczyny, Jaśkowice, Blok and Komorzno (**Fig. 1**), in the years 2009–2010. At every site up to 20 *Pinus sylvestris* were sampled with the Pressler borer. One core was taken per tree. The obtained material was prepared following the standard procedures (Cook and Kairiukstis, 1990; Speer, 2010).

The timber samples were taken during the field investigation in the Open Air Museum in Opole and during the conservation works at the selected monuments in the Opolskie Voivodeship (Opole Province) in the years 2008–2011. In general, the timber for the extension of the regional tree-ring chronology originated from wooden historic rural buildings, such as farm houses, barns, mills, granaries and churches (**Fig. 2**). The buildings collected in the museum represent the oldest and well preserved rural architecture monuments of the Upper Silesian region, with the construction timbers provided from the nearby forests. Part of the material was also collected from the ceilings and timber roof truss in historical brick buildings (the Bishops' Palace in Nysa, the watermill in Kuźnica Dąbrowska and the manor house in Miejsce (**Fig. 3**)). The samples were collected by sawing or coring with respect to the location of the outermost ring. Due to the availability and condition of wood the number of samples per building varied: manor house in Miejsce (97 samples), Bishops' Palace in Nysa (36 samples), church from Gręboszowo (13 samples), farm granary from Grudynia Mała (11 samples), granary from Ligota Górna (11 samples), watermill in Kuźnica Dąbrowska (10 samples), barn from Dąbrówka Łubniańska (10 samples), cottage from Kamieniec (10 samples), watermill from Siołkowice Stare (10 samples), granary from Sławęcice (10 samples), cottage from Wichrowo (10 samples), granary from Sternalice (10 samples), barn from Dąbrówka Dolna (10 samples), cowshed from Wichrowo (7 samples), granary from Murów (5 samples), farm granary from Sternalice (5 samples).

Further analyses were carried out in the dendrochronological laboratory at the Faculty of the Earth Sciences, the University of Silesia. The species identification was performed (Schweingruber, 1990) on approximately 200 timber samples taken. According to the first assumption, the pine samples predominated and were selected for further investigation. Among other wood material, a few samples of oak (*Quercus sp.*), alder (*Alnus sp.*) and fir (Abies sp.) were also found. The pine samples with more than 50 growth rings were sanded in order to obtain clear cross-sections and perform measurements of ring widths. All measurements were made to the nearest of 0.01 mm using the LINTAB 6 device with a microscope and the TSAPWin software (Rinn, 2010).

The synchronisation of the timber samples was carried out by the visual matching of ring-width graphs and checking them statistically (Baillie and Pilcher, 1973; Bailie, 1995; Ważny, 2001). The similarity of the pattern was calculated in the TSAPWin software using the statis-

Fig. 2. *Examples of investigated wooden monuments: The Church of St Catherine from Gręboszów (A), Granary from Sławęcice (B), Watermill from Siółkowice Stare (C), Cottage from Kamieniec (D).*

Fig. 3. *The Manor House in Miejsce as an example of investigated brick monument.*

tical values applied in the dendrochronological dating, such as: *Gleichlaeufigkeit,* t-value, t-value according to Hollstein, Baillie and Pilcher, and the crossdate index (Rinn, 2010). The correctness of the dating procedure was checked with the program COFECHA (Holmes, 1994).

Based on the graph of the curves, the sequences with the distorted course (e.g. with the growth reductions or abrupt width increase) were eliminated, because they content weaker climatic signal. Additionally, the sequences with the missing rings were not used for the construction of the regional chronology. In the next step, the site's chronologies were produced using the sequences with the best concordance. In total, one chronology of living trees and five chronologies of buildings or building groups were constructed. The absolute dating of floating chronologies was made against the local chronology of living trees and absolute regional standards for the neighbouring areas.

The regional chronology constructed for Upper Silesia was tested for teleconnection by comparison with the pine chronology for the Małopolska region (Szychowska-Krąpiec, 2010), north-eastern Poland (Szychowska-Krąpiec and Krąpiec, 2005), northern Poland (Zielski and Krąpiec, 2004) and Central Germany (Heußner, 1996), Lithuania (Vitas, 2008) and Gotland (Bartholin, 1987, from ITRDB).

In the standardised data the extreme years were distinguished, using two threshold values: ±3σ and ±2σ, for the comparison purposes. Independent verification of the extreme years was based on the historical data on the weather phenomena compiled by Inglot (1962, 1968), Rojecki (1965), Kwak (1987) and Ratajczak (1987).

4. RESULTS

The pine tree-ring chronology for Upper Silesia

As a result of the conducted dendrochronological analyses six object chronologies were obtained (**Fig. 4**):

1) LTR – living trees from nature reserves (1767–2010, 244 years)
2) RWM – restoration wood from the Open-Air Museum in Opole (1880–1972, 93 years)
3) WKD – watermill from Kuźnica Dąbrowska (1825–1919, 95 years)
4) RBM – rural buildings from the Open-Air Museum in Opole (1568–1866, 299 years)
5) MHM – manor house in Miejsce (1710–1850, 141 years)
6) BCN – Bishops' Palace in Nysa (1578–1836, 259 years)

The local chronologies were used for building of 443 years long regional chronology for Upper Silesia (USR). The USR chronology covers the years 1568–2010 (**Fig. 5**, **Fig. 6**). Finally, it was built from 178 wood samples with the mean correlation of 0.51 and expressed population signal >0.85 (up to A.D.1600). The mean length of the

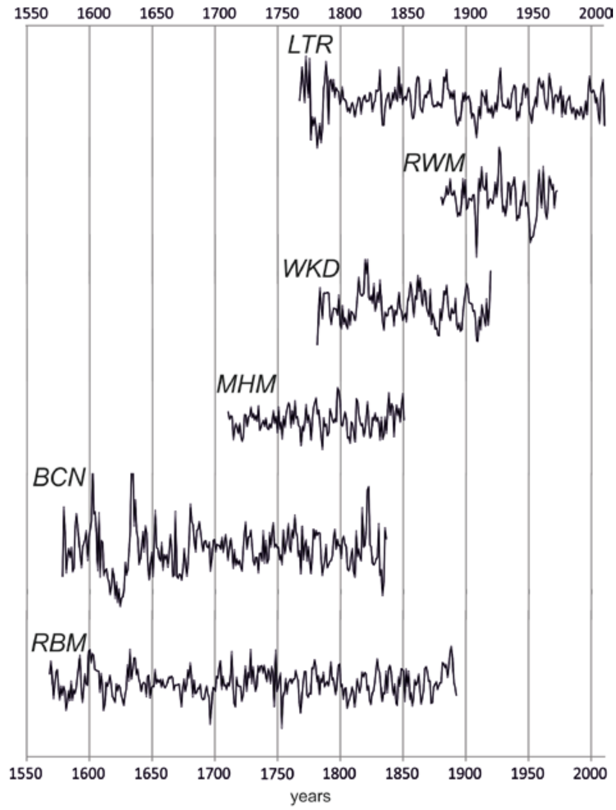

Fig. 4. *Object chronologies building the regional chronology for Upper Silesia. Abbreviations are explained in Section 4.*

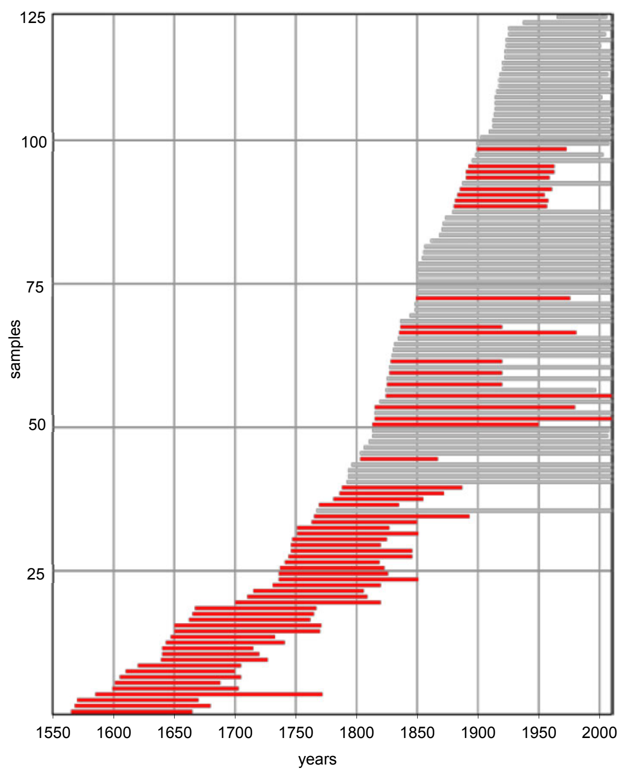

Fig. 5. *Temporal samples distribution for historical (red bars) and recent wood (grey bars).*

single tree-ring series is 104 years. The statistical parameters of the created regional (USR) and object chronologies are presented in **Table 1**. The newly created regional pine chronology for the area of Upper Silesia meets the statistical criteria that allow to use this absolute scale as a tool for the reconstruction of climate (e.g. EPS>0.85, different age classes, chronology length exceeding the period of instrumental measurements).

Based on the established regional chronology extreme years were also determined. Seventeen extreme years (negative years: 1581, 1696, 1908, 1940, 1976, 2010 and positive years: 1599, 1602, 1632, 1635, 1680, 1703–1704, 1713, 1846, 1912, 1926–1927, 1966) where found with the application of more strict conditions (values of the threshold: ±3σ). Fifty-nine extreme years were received when less strict conditions were applied (values of the threshold: ±2σ) (**Fig. 6**). The largest number of the extreme years occurred in the 20th c. (18). In the 17th and 18th c. 13 extreme years each were determined, while in the 19th c. — only 10 extreme years.

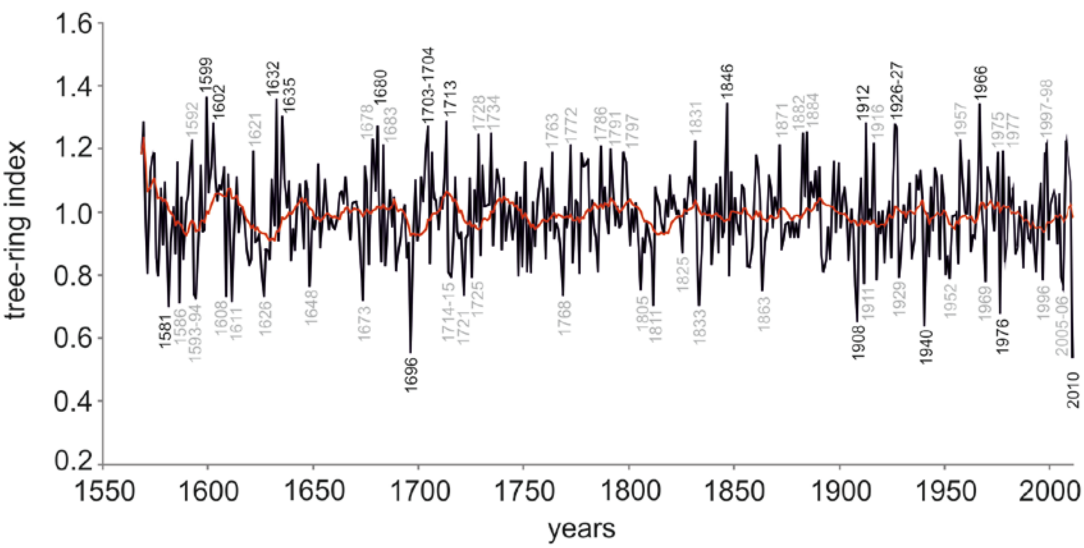

Fig. 6. *The regional chronology of Scot pine from Upper Silesia, with extreme years marked.*

Table 1. *Descriptive statistics of the Upper Silesia regional and local chronologies, based on 178 wood samples and 16,656 growth rings of pine.*

Chronology name	Amount of samples	Time span (number of years)	Mean segment length	Correlation with master	Tree-ring width (mm)	Standard deviation (mm)	Mean sensitivity	1st order Autocorrelation (Raw)	1st order Autocorrelation (Residual)	Type of material
USR	**178**	**1568–2010 (443)**	**104**	**0.51**	**1.68**	**0.86**	**0.25**	**0.76**	**0.00**	**Composite**
LTR	70	1767–2010 (244)	143	0.52	1.62	0.85	0.25	0.88	0.01	Living trees
RWM	14	1880–1972 (93)	74	0.55	1.74	0.82	0.26	0.74	0.00	Historical wood
WKD	12	1825–1919 (95)	87	0.46	1.08	0.75	0.23	0.90	0.00	Historical wood
RBM	45	1568–1866 (299)	85	0.49	1.69	0.85	0.24	0.78	0.00	Historical wood
MHM	42	1710–1850 (141)	74	0.53	1.81	0.88	0.24	0.75	0.00	Historical wood
BCN	15	1578–1836 (259)	55	0.45	1.80	0.90	0.30	0.60	0.01	Historical wood

Examples of historical structures dating

The hunting castle of the Duchy of Oleśnica in Miejsce

The conducted dendrochronological dating of wood from the manor house in Miejsce near Namysłów (the hunting castle of the Duchy of Oleśnica), clearly showed that there were a few phases or stages of the extension or renovation of this building (**Fig. 7**). The dated wood samples came primarily from the ceilings and roof truss (97 taken samples / 42 dated samples). The mean length of individual sequences varied from 45 to 115 rings, with mean correlation with master chronology 0.55. The object chronology (MHM) covers the years 1710–1850, 141 years) (**Fig. 4**). The investigation showed that the oldest timber came from the end of the 17th c., which is fairly consistent with the historical documents placing the time of the construction of the manor house at the turn of the 16th and 17th c. (Skarbek, 1998). The timber for the second building period of the object was logged from 1716 to 1719, and for the following phase from 1742 to 1757. The most number of wood came from the turn of the 18th and 19th c. up to the mid-19th c. (**Fig. 7**). The preliminary investigations showed that the new timber roof trusses were laid in the 1830s (Opała and Kłys, 2011). There are some architectonical and historical indications that the renovation and rebuilding of the structure of the hunting castle took place in the second half of the 19th c. (Małachowicz, unpublished report), which is entirely confirmed by the performed dendrochronological dating.

The Bishops' Palace in Nysa

According to the historical information, the palace dates from the 13th c.; it underwent numerous reconstructions, the largest conducted in the 17th c. (Sikorski, 1999; Staffa, 2008). Despite the availability of a relatively small number of samples for such a significant size of this object (36 taken samples / 15 dated samples), the wood dating was possible. The mean length of individual sequences varied from 45 to 99 rings, with mean correlation with master chronology 0.47. The object chronology (BCN) covers the years 1578–1836 (259 years) (**Fig. 4**). The samples taken from the ceilings and timber-framed walls in the eastern tower of the Bishops' Palace are the signs of the subsequent phases of the construction and renovation works. The oldest dated element (from the year 1606) comes from the ceiling beam on the ground floor. The further stages of the development of this structure can be identified on the basis of the obtained dendrochronological dating: 1638, 1699, first half of the 18th c. and the turn of the 18th and 19th c. (**Fig. 8**).

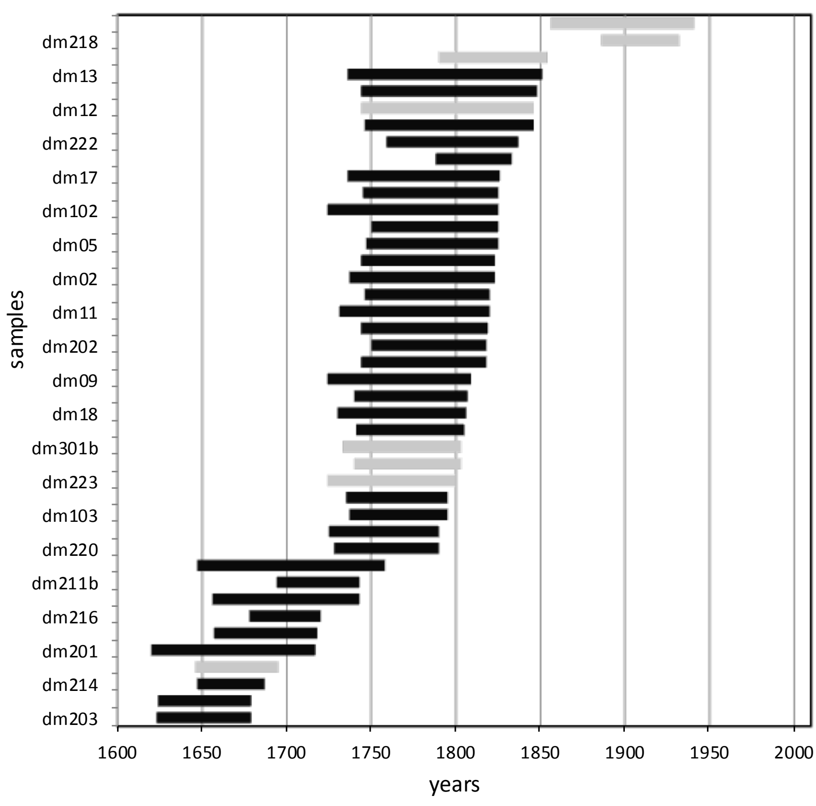

Fig. 7. *Bar diagrams which show the position of the dated samples of wood from the manor house in Miejsce against the time scale. Black bars indicate complete wood sequences (with the outermost ring) and grey bars indicate incomplete wood sequences (without outermost ring).*

The Open-Air Museum in Opole

The successful dating was also possible for 10 from the 13 investigated monuments of the rural architecture of the Opole region (wooden buildings sampled in the Open-Air Museum in Opole). The oldest structure was the church from Gręboszowo. The oldest part of this church came from the mid-17th c., but most of the timber was obtained between 1730 and 1740. The timber from the granary from Sternalice was dated to the years 1687 and 1702–1726. Some elements from the cottage from Kamieniec was also dated to 1725–1726. The dendrochronological dating of the wood from the granary from Ligota Górna indicated that it was constructed in ca. 1732–1736. The beams from the barn from Dąbrówka Dolna were dated back to the period 1701–1767. Another three wooden monuments are from the first half of the 19th c.: the watermill from Siołkowice Stare dated to 1818–1826, the granary from Sławęcice dated back to 1819–1820 and the granary from Grudynia Mała dated to 1759–1834. The wood from the three architectural monuments from the investigated open-air museum proved to be from the 20th c.. The obtained dendrochronological dates (1957–1962) of the beams from the cottage from Kamieniec, the cowshed from Wichrowo and the barn from Dąbrówka Łubniańska are consistent with the time of the relocation of the historic buildings and the creation of the open-air museum (Gil, 1976). In general, the dendrochronological dating of timber confirmed the historical dates of the constructing and repairing of the wooden monuments and provided new, more precise information on the time of the objects' foundation (**Fig. 9**). However, in some cases different results (younger dates) were obtained. This might be due to the lack of complete sequences (the outermost ring missing from the wood sample) resulting from a relatively small number of samples per object and from using a less destructive method of collecting cores instead of discs (discs enable to measure

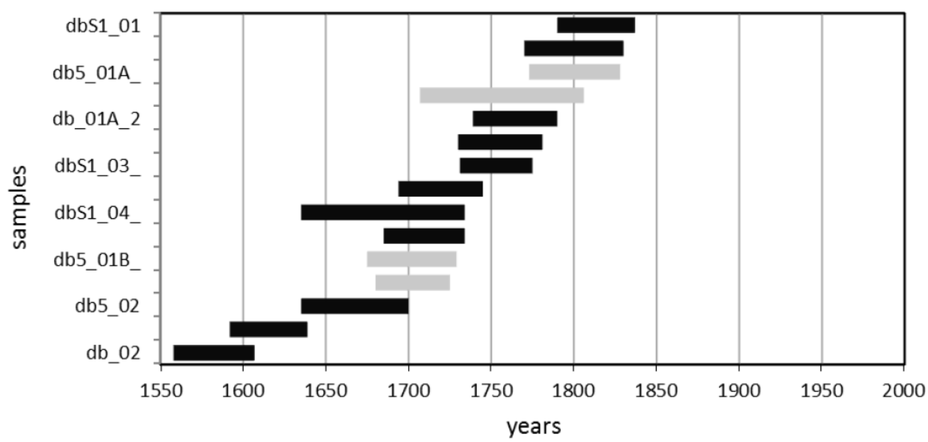

Fig. 8. *Bar diagrams which show the position of the dated samples of wood from Bishop's Court in Nysa against the time scale. Black bars indicate complete wood sequences (with the outermost ring) and grey bars indicate incomplete wood sequences (without outermost ring).*

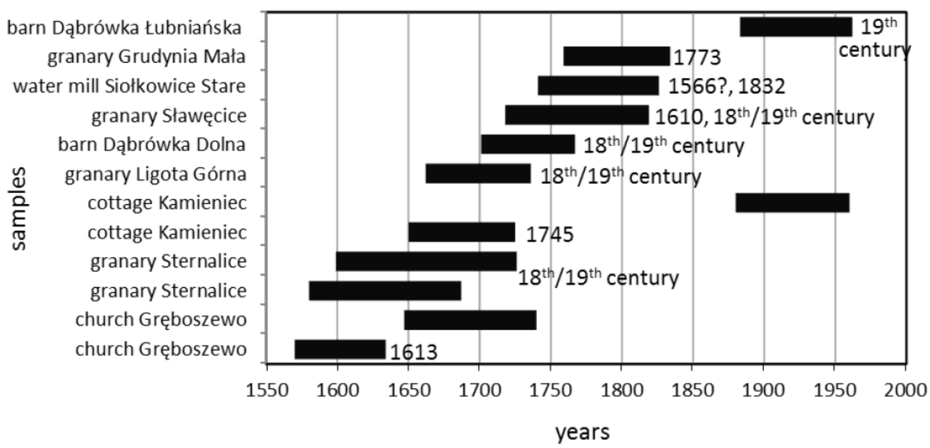

Fig. 9. *Dendrochronological dating of monuments of rural wooden architecture (black bars indicate complete wood sequences) with historical information about time of buildings foundation (dates) from Opole Silesia Region.*

growth ring sequences in different radii). These limitations are the result of the specific nature of the research in the ethnographic museum, where only the minimum number of cores could be sampled. Despite these shortcomings for most objects valuable results were obtained; they were included in the museum documentation of the examined monuments.

Climatic verification of the extreme years

In the analysed regional chronology in total 65 extreme years were found (**Fig. 6**). The distinguished negative years (29), as the most important for the climatological analyses, were compared with the historical records (1575–1884) and instrumental data (1885–2010) on the weather conditions and flood events (presented in **Table 2**). For most years (except 1586, 1714–15, 1721, 1825, 1863) descriptive information about extremes was available. The occurrence of most of pine negative years can be explained by extreme weather conditions prevailing in a given year, in most cases connected with cold winters (1608, 1805, 1811, 1833, 1929, 1940, 1969, 1996, 2006, 2010) or severe droughts in summer (1581, 1594, 1611, 1626, 1952, 1976) (**Table 2**). The exceptionally low growth also arises in the years where the course of the weather is quite different then the long-term average. Such a situation occurred, for example, in 1696, which is recorded in the chronicles as the year with the unusually short winter and the spring weather in January, or in 1908 when a very mild winter and very high July rainfall were recorded.

The explanation of the positive years is more difficult, as the favourable climatic conditions were less frequently reported in the chronicles than the catastrophic events. The positive years in the Scots pine chronology from Silesia occurred in the years with warm winters and the years with the presence of the periods of the above-average summer precipitation totals. In many cases, however, the positive years are not directly connected with the meteorological conditions, and are merely the result of the regeneration of the extremely unfavourable conditions of the tree growth in the previous year (Schweingruber, 1996).

Table 2. *Comparison of dendrochronological negative extreme years of* Pinus sylvestris *with climatic interpretation based on historical archives for Silesia (Namaczyńska (1937), Inglot (1962, 1968), Rojecki (1965), Kwak (1987), Brázdil* et al. *(2005, 2007) and instrumental data (reference period 1885–2010).*

Extreme year	Description of the course of weather and other natural phenomena
1581	Droughts, hails
1586	No information available
1594	Droughts
1608	Cold and snowy winter
1611	Droughts
1626	Droughts
1648	The rainy winter with hurricane storms in February
1673	Storms in winter
1696	Very short winter 1695/96, spring weather in January
1714	No information available
1715	No information available
1721	No information available
1725	Wet year
1768	Spring frosts
1805	Frosts in January. 1-2 monthly excess of moisture. Flood on the Upper Oder River
1811	Frosts in January, summer droughts, locally summer air temperature reaching 38ºC
1825	No information available
1833	Frosts in January. Flood on the Upper Oder River
1863	No information available
1908	Warm winter, heavy summer rainfall (134% of norm), very high rainfall in July (200% of norm). Flood on the Upper Oder River
1911	Droughts in June, July and August. Flood on the Upper Oder River (May)
1929	Severe frosts in January and February. Flood on the Upper Oder River
1940	Severe frosts in January and February. Flood on the Upper Oder River
1952	Droughts in July, deficits of summer precipitation in the two previous years
1969	Frosts in January
1976	Droughts in February, March, April, June and August
1996	Frosts in January and February, droughts in July
2006	Frosts in January
2010	Frosts in January

5. DISCUSSION

The study presented in this paper provides some examples, which demonstrate the effectiveness and reliability of using dendrochronology for dating, verifying or refining the construction dates. Thanks to building the composite chronologies of living trees and historical wood, in different parts of the world the knowledge about the history of localities and regions with priceless wooden cultural heritage has been enlarged (e.g. Schulman, 1948; Ważny and Eckstein, 1987; Bridge, 1988; Krąpiec, 2000; Kuniholm, 2000; Büntgen *et al*., 2006; Obelić *et al*., 2007; Čufar *et al*., 2008; Myglan *et al*., 2009; Grissino-Mayer *et al*., 2013). The Upper Silesian regional chronology also proved to be useful for dating of charcoal and other wooden remains of objects, used for the reconstruction of smelter settlement in the Opolskie Voivodeship (Malik *et al*., 2014).

Despite the significant progress of research aimed at the reconstruction of the Polish climate, few long-term dendroclimatological reconstructions have been developed so far, therefore the new reference material is valuable. Existing reconstructions cover the Kuyavian-Pomeranian (Koprowski *et al*., 2012) and Suwałki regions (Krąpiec *et al*., 2009) in northern Poland as well as the Małopolska Voivodeship (Szychowska-Krąpiec,

2010) and the Tatra Mountains (Niedźwiedź, 2004, 2010; Büntgen *et al.*, 2007) in southern Poland.

The constructed chronology was compared to other pine chronologies in the surrounding areas, showing the greatest similarity to the nearest located Małopolska standard (Szychowska-Krąpiec, 2010) with t = 9.4, Gotland (Bartholin, 1987) with t = 8.0, the northern Germany chronology (Heußner, 1996) with t = 7.2 and northern Poland standard (Zielski, 1992) with t = 6.5. Despite the significant and relatively high similarity values (t), only some extreme years determined for the Upper Silesian chronology are in accordance with the pointer years described by Szychowska-Krąpiec (2010) and Koprowski *et al.* (2012). The consistent years are the following: 1602, 1680, 1734, 1772, 1884, 1916, 1957, 1977, 1997 (positive year) and 1593, 1608, 1811, 1833, 1911, 1929, 1940, 1969, 1976 (negative years). The extreme years 1811 and 1940 are also present in the Lithuanian chronology of pine (Vitas, 2008). The comparative analysis of pine chronologies from other Polish regions showed that the years with very cold or mild winters in Upper Silesia are in accordance with the pointer years for other locations. In general, the results obtained in this study clearly showed that there is a potential for the reconstruction of winter temperature over the five centuries in the Upper Silesian region. These results are also confirmed by the climate response analysis performed for living pine trees from this area, showing that this species is most sensitive to February (r = 0.36) and March (r = 0.41) temperature (Opała and Mendecki, 2014). The dendroclimatological studies of pine trees for other areas of Poland have also provided similar results — the growth of trees positively correlated with the January-April air temperature (e.g. Zielski, 1992; Feliksik and Wilczyński, 2000; Wilczyński and Skrzyszewski, 2002; Cedro, 2004; Krąpiec *et al.*, 2009, Szychowska-Krąpiec, 2010; Koprowski *et al.*, 2012).

The extreme years not matching the chronologies of other Polish regions are also interesting. These years are consistent with the pointer years for the tree-ring records from Central Europe i.e. the fir chronology from southern Moravia (Büntgen *et al.*, 2011) and the pine chronology from Slovakia (Büntgen *et al.*, 2010). Common for both the Upper Silesian record and the hydroclimatic reconstructions from Slovakia and the Czech Rep. are extremely dry years: 1594, 1811, 1825, 1863, 1929 and extremely wet years: 1713, 1772, 1871, 1916, 1926, 1927. These results indicate the local character of some extreme hydro-meteorological events. From the perspective of the sensitivity to water availability, the Upper Silesian chronology is more similar to the Slovakian and Czech records than to other Polish pine scales. These differences make the chronology developed for Upper Silesia a valuable reference material and an important contribution to the study of climate change in recent centuries in Central Europe. Besides the extreme years, which are partially related to the pluvial conditions, the response function analysis of pine from Upper Silesia also showed a significant correlation with the summer precipitation (June precipitation r = 0.38, July precipitation r = 0.55), as demonstrated by Opała and Mendecki (2012). Such dependencies were not obtained for the other locations in Poland. Because of the existing mixed dendroclimatic signal, which is characteristic to the trees outside the extreme locations (upper timberline, limit of species range), further investigations on wood anatomical features that may allow for a more precise distinction of rain and thermal signal, are therefore necessary. Similar studies of Liang *et al.*, 2013 have showed significant correlations between cell structure variables and temperature in northeastern Germany, representing the temperate climate zone. Also Helama *et al.*, 2014 have demonstrated the usefulness of microdensitometric measurements for reconstruction of summer temperatures (using MXD data) and precipitation in the early part of the growing season (using earlywood variation) in southern Finland.

6. CONCLUSIONS

1) The construction of the annually resolved 443-year regional ring-width chronology for Upper Silesia was possible by using living trees and historical timber from the 16th–19th c. monuments. The obtained results — the absolute dates of individual beams, construction phases of the buildings and rural settlements dating — are a valuable historical and ethnographic documentation. The use of the dendrochronological techniques to provide the means for supporting the archaeological, architectural, and socio-historical methods to help determine the construction history has been suggested. Although many historic structures still exist in the Upper Silesian region, their numbers is decreasing due to neglect, destructions, land development, timber decay and collapse. Thus, the obtained results might also be important information, useful to determine the proper way for the reconstruction of these ruined monumental buildings.
2) The successful dating of historic wood from manorial and rural architectural monuments from the Upper Silesian region has demonstrated the usefulness of the created chronology for timbers dating. The application of this new regional pine chronology for the analysis of local wood can support research on the history of architecture and human activity as well as provide interpretation of changes in the natural environment of the Upper Silesian region.
3) The climatic interpretation of the extreme years inferred from the created chronology confirmed the legitimacy of application of this record as a climate proxy. In the future it can be used as the basis for the climate reconstruction. The validation of the designated extreme years by other evidence, such as the written records and meteorological measurements, showed the potential for the reconstruction of both

winter temperature and summer precipitation for the past 443 years, which will allow the study of climate change in Upper Silesia since the Little Ice Age.

4) The great number of timber from monuments and wooden artefacts of different ages from Upper Silesia, as yet uninvestigated, offers good opportunities to extend the existing tree-ring chronology into the past for both purposes, dating cultural objects as well as reconstructing past climate and environmental changes.

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