



Growth-climate relationships at yew and wild service trees on the eastern edge of their range in Europe

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Abstract

Aim of study: The aim of the study was the construction of regional chronologies for South-Western Poland for yew (*Taxus baccata* L.) and wild service tree (*Sorbus torminalis* L.), two of the rarest native tree species on the edge of their range in Europe. The relationships growth-climate and incremental dynamics at both these species were investigated as well.

Area of study: The eastern borders of the ranges of yew and wild service trees run across Poland. The majority of the yew occurrence sites are situated in South Poland, within the area of uplands and mountains, whereas the wild service tree grows in the western part of the country. The study plots (5 for yew trees, 4 for wild service trees) were located in nature reserves in SW Poland.

Material and Methods: The research materials were cores from 200 trees (115 yew trees and 85 wild service trees). The annual growth widths were measured, then, local chronologies were constructed using classic methods of dating. Regional chronologies were based on yew trees with the Student's test $t > 6.0$, and wild service trees with $t > 5.9$. The chronologies were subjected to the indexation and used for dendroclimatological analyses: pointer years, correlation and response function.

Main results: The yew chronology, spanning 219 years (1790-2008), was established on the basis of 51 samples, the average width of annual growths amounted to 0.61 mm. The wild service tree chronology, representing the period 1841-2013 (173 years), was produced from 37 samples, the average width of annual growth amounted to 0.60 mm (from 0.27 up to 0.58 mm). Dendroclimatological analyses of the yew indicated thermal conditions of the winter months and beginning of spring (straight correlations) as the predominating factor affecting the annual growth widths. Summer drought was an additional factor limiting growth. For the wild service trees cool and humid summer months in the growing season favour the formation of wide growths.

Research highlights: On account of strong dispersion and limited small populations of these two tree species, there are few dendrochronological studies available. Therefore, every piece of information on the ecology of the yew and wild service tree allows us to broaden our knowledge of these rare species enriching the biodiversity of the native tree flora.

Keywords: tree-ring width; *Taxus baccata* L.; *Sorbus torminalis* L.; dendroclimatology; Poland.

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Introduction

Yew (*Taxus baccata* L.) in Europe occurs in the north to 63°N in Norway and Sweden, the eastern limit of its range runs through Estonia, Poland, Carpathian Mountains and descends to Greece and Turkey. Relatively abundant populations are growing in the Caucasus Mountains, up to the western coast of the Caspian Sea. On the western reaches of the continent yew occur in England and Ireland and in Spain and Portugal (including Azores and Madeira Islands). In Africa, isolated populations can be found in the Atlas Mountains

(from Morocco across Algeria to Tunisia) (Thomas & Polwart, 2003, Spjut, 2007).

The yew is one of the rarest coniferous trees in Poland; protected legally, written down in the Polish Red List of Threatened Species (Kruszelnicki, 2001), and the majority of its occurrence sites are protected in the form of nature reserves. The eastern border of the range of this species runs across Poland: the yew trees appear in the northern, western and southern parts of the country, but not in the central-eastern areas. Most of the yew sites are situated in southern Poland, in the belt of uplands and mountains: in the Sudetes Mountains and

Sudetes Foothills, as well in the Carpathians and Carpathian Foothills (Boratyński *et al.*, 1995, 1997, Zając & Zając, 1997, 2001). The highest location of the yew in Poland is at 1380 m asl in the Tatra Mountains (Zembrzuski, 1975, Zwijacz, 2005). The yew is considered as a slowly growing and long-living plant. In Great Britain it grows from 0.051 up to 5.5 mm/year in thickness (Moir, 1999), in Ireland – from 0.095 to 3.0 mm/year, and in Denmark – from 1.4 to 2.6 mm/year (Thomas & Polwart, 2003). In Poland the average width of tree rings for the yew population amounts to 0.83 mm (from 0.27 up to 1.47 mm) (Cedro, 2012). Numerous authors point to shade tolerance and resistance to pollutants of this species, which allows for its successful growth in the urban conditions (Król, 1975, Mitchell, 1996, Iszkuło & Boratyński, 2005, Thomas & Polwart, 2003, Linares, 2013).

The wild service tree (*Sorbus torminalis* (L.) Crantz) is a species occurring in central, western and southern Europe. To the west it grows in England, France, Spain, and to the east in Poland, Slovakia, Ukraine (the south-western edge), Romania and Hungary. The northern limit of its range is northern Germany and Poland, as well as the Danish Zealand and Bornholm. It is also found in Asia Minor and north-west Africa (Algeria, Morocco) (Bednorz 2010). The Southern European range is mainly in the foothills of the mountains, to the north grows on the lowlands, mostly on the slopes of the hills.

The wild service tree is one of the rarest deciduous trees appearing naturally in Poland; it has been noted in 84 natural sites, with the whole population estimated to be ca 3500 individual specimens (without seedlings) (Bednorz, 2010). Similarly as in the case of the yew, the eastern border of the range of this species runs across Poland; the wild service tree appears in the western part of the country, only in a few sites crossing the River Vistula – in the south in the Island Beskid Mts, and in the north in the Gdańsk Pomerania. In the Island Beskid Mts it grows in its highest site 500-550 m asl (Szeszycki, 2008, Bednorz, 2010). The wild service tree is a light- and warm-demanding species, generally growing on slopes of south and/or south-western positions, preferring brown soils and stable (not too high) groundwater levels. The average width of annual growths amounts to from 0.66 mm in Rugen to 16.1 mm in central Germany (Rasmussen, 2007), and from 0.2 up to 4.5 mm in South-Western Germany (Pyttel *et al.*, 2011, 2013). Trees of this species are also legally protected, in reserves or as natural monuments, which, however, not always results in improvement of the state of health of individual trees or even whole populations. Lack of silvicultural cuttings often leads to lower competitiveness of the spe-

cies, disappearance of older specimens, missing seed years, and, in turn, perturbations in renewal of its populations.

The study consists of: (i) the construction of regional chronologies for both tree species on the eastern edge of their range in Europe, (ii) analysis of growth-climate relationships, (iii) comparison of incremental dynamics and cambium reactions to changing meteorological factors in the yew and wild service trees.

Material and methods

The research plots are situated in south-western Poland, within two administrative provinces (voivodeships): Lower Silesian and Opole. Five plots with yew trees are located in the Bardzkie and Kaczawskie Mountains and the Wałbrzyskie Foothills, at altitudes of between 340 and 595 m asl. Four wild service tree plots are situated at lower altitudes, from 160 to 386 m asl, in the Kaczawskie Foothills, Kłodzko Valley, Lubin Plateau, and Opole Plain (Fig. 1, Table 1). Apart from documentation of the plots and trees investigated, the field work encompassed taking samples with a Pressler increment borer, at the level of 1.3 m above the ground (two cores per tree). The samples were taken from 200 trees (115 yew ones and 85 wild service trees), resulting in a total of 347 samples (Table 1). The sampling points were protected with Lac-Balsam – a fungicide and antibacterial mean. In the laboratory the sampled cores were glued into wooden mounts and their surfaces were cut with knives in order to get legible images of the tree rings. In the case of the wild service tree, on account of the very weak visibility of borders between the annual growth rings, the measurements were carried out using an aqueous filter. Measurements of the annual growth widths were made with an accuracy of 0.01 mm, using a stereoscopic binocular microscope, movable measurement table connected with a counter, and the Dendrometer software (Mindur, 2000). 37,890 annual growth rings were measured (Table 1). Samples were cross-dated and chronology quality was evaluated using the Cofecha program (Holmes, 1983, 1994). Then, for the species *Sorbus torminalis* (ST) based on 37 trees and *Taxus baccata* (TB) based on 51 trees regional chronologies were constructed. The RES chronology (de-trended, autocorrelation removed) thus constructed was subjected to 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 & Holmes, 1986). The expressed population signal (EPS) analysis was used to

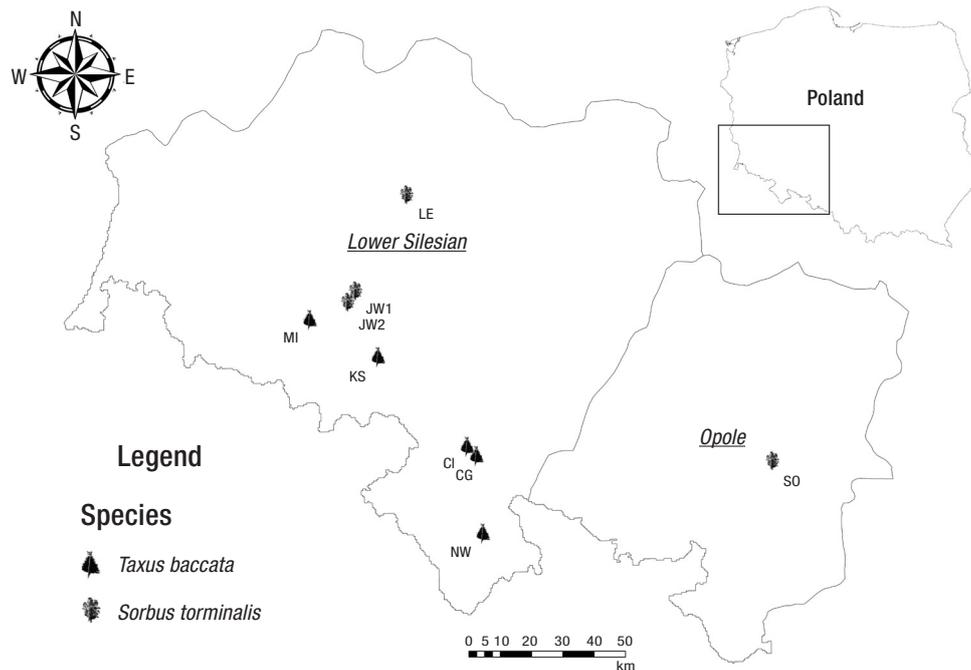


Figure 1. Location of study plots.

assess the degree, to which chronologies of each plot portrayed the perfect hypothetical chronology (Wigley *et al.*, 1984). The constructed chronologies were used as a base for dendroclimatological studies: analyses of correlation, response function and pointer years. The response function analysis was performed for a 16-month-long period (from June of the year preceding growth to September of the year of growth) using RESPO programme (Holmes, 1983, 1994). Climatic data were obtained from the nearest meteorological stations in Legnica (for 1949-2013 period), in Kłodzko (for 1948-2008 period), in Opole (for 1948-2013 period), and in Jelenia Góra (for 1948-2008 period).

Pointer years are concentrations of cross-dated event years within a group of trees (Kaennel & Schwiengruber, 1995). As pointer years were recognized such years, which exhibited the same growth tendency with respect to the neighbouring years (year with consistently narrow and occasionally large rings), calculated in the TCS program (Walanus, 2002) from minimum of 10 trees, with the minimum threshold of unanimity of the incremental reactions at 90%. A year characterized by increasing widths of the annual growth rings was a positive year (+), whereas a negative year (-) was marked by a reduction in the tree-ring widths (Meyer, 1997-1998).

Table 1. List and basic information on study plots surveyed.

No.	Lab. code	Species	Region	Geographic coordinates		Habitat	Altitude a.s.l. [m]	No. of trees	No. of samples	No. of tree-rings
				φ (N)	λ (E)					
1	MI	Tb	Kaczawskie Mountains	50°56'	15°56'	Mo	550-595	15	22	2947
2	KS	Tb	Wałbrzyskie Foothills	50°50'	16°15'	CM, M, hl	340-433	25	49	5552
3	CG	Tb	Bardzkie Mountains	50°35'	16°40'	M, Mo	395-550	25	48	5642
4	CI	Tb	Bardzkie Mountains	50°35'	16°40'	M, Mo, h	375-485	25	50	6845
5	NW	Tb	Kłodzko Valley	50°20'	16°45'	M, Mo, h	560-615	25	39	4918
6	LE	St	Lubin Plateau	51°18'	16°21'	Fh	160	18	36	2614
7	JW1	St	Kaczawskie Foothills	51°01'	16°08'	M, hl, h	300-367	19	31	2806
8	JW2	St	Kaczawskie Foothills	50°59'	16°06'	M, hl, h	310-386	28	51	4402
9	SO	St	Opole Plain	50°33'	18°04'	M	185	20	21	2164
Sum								200	347	37890

Legend to symbols: F, forest; C, coniferous forest; M, mixed forest; Mo, mountain forest; h, humid; hl, highland.

Results

Local chronologies

Five local chronologies were produced for *Taxus baccata*. The length of the chronologies spanned from 219 years (1790-2007) for Cisowa Góra Reserve in the Bystrzyckie Mts, to 171 years (1837-2007) for Cisy Reserve (Table 2, Cedro, 2012). Mean tree-ring width for the population fluctuated from 0.27 mm (the lowest value recorded in Poland, Cedro, 2012) up to 0.58 mm. The Expressed Population Signal (EPS) values are above the applied threshold of 0.85: from 0.87 for MI chronology to 0.97 for CI chronology (Table 2, Wigley *et al.*, 1984).

Four local chronologies were worked out for *Sorbus torminalis*. The length of the chronologies spanned from 96 years (1918-2013) for Brekinia Reserve in the Lubin Plateau to 173 years (1841-2013) for Kamień Śląski Reserve in the Opole Plain, the biggest specimens of the wild service trees in Poland. The tree-ring width varied from 0.52 mm up to 0.69 mm (Table 2). The Expressed Population Signal (EPS) values are above the applied threshold of 0.85: from 0.86 for LE and SO chronologies to 0.89 for JW2 chronology (Table 2, Wigley *et al.*, 1984).

Regional chronologies

A regional 219-year long yew chronology (TB) comprising 51 trees was constructed for south-western Poland for the 1790-2008 period. Regional chronology has an average ring width of 0.61 mm, mean

sensitivity of 0.3, and first order autocorrelation of 0.8 (Table 2, Fig. 2).

A regional 173-year long wild service tree chronology (ST) comprising 37 trees was constructed for the 1841-2013 period. The average width of the tree rings, mean sensitivity, and first order autocorrelation achieved similar values as in the case of the yew chronology, amounting to, appropriately: 0.60 mm, 0.3 and 0.7 (Table 2, Fig. 2). Both chronologies had low statistical and graphical similarity: $t = 4.27$, $r = 0.38$, $GL = 52\%$ (Fig. 3). The Expressed Population Signal (EPS) values are above the applied threshold of 0.85: 0.94 for yew chronology and 0.88 for wild service tree chronology (Table 2, Wigley *et al.*, 1984).

Dendroclimatological analyses

Statistical analysis (correlation and response function) pointed to thermal conditions of the winter period as the dominating factor ($r^2 = 64\%$) in the process of development of the annual growths at yew trees in SW Poland (Fig. 4). Higher than average air temperatures from December of the year preceding growth till February and March of the year of the growth formation were positively associated to higher secondary growth. An additional factor proved to be temperatures in the summer period (June-August), for which positive values of the correlation and regression coefficients were noted as well. The impact of precipitations on secondary growth was lower, only positive significant correlations could be noted for the growing season (Fig. 4). Also for the wild service trees higher determination rates were obtained for the air temperatures (38% in

Table 2. Selected statistics of measured and indexed local and regional chronologies.

No.	Lab. code	No. of years	Time span	No. of samples	Mean tree-ring width (mm)	Measured chronology			Residual chronology			EPS
						SD	1AC	MST	SD	1AC	MST	
1	MI	203	1806-2008	11	0.27	0.208	0.709	0.368	0.248	-0.0058	0.297	0.87
2	KS	205	1803-2007	15	0.47	0.329	0.726	0.314	0.2024	0.0203	0.2332	0.91
3	CG	218	1790-2007	15	0.58	0.453	0.763	0.325	0.2153	0,00	0.2424	0.95
4	CI	171	1837-2007	17	0.52	0.322	0.726	0.301	0.1951	0.0073	0.217	0.97
5	NW	201	1807-2007	15	0.4	0.242	0.706	0.291	0.1994	0.0208	0.245	0.90
6	LE	96	1918-2013	11	0.52	0.314	0.622	0.376	0.253	0.001	0.303	0.86
7	JW1	121	1893-2013	13	0.64	0.308	0.621	0.317	0.220	0.122	0.251	0.87
8	JW2	129	1885-2013	15	0.55	0.308	0.679	0.321	0.354	-0.025	0.255	0.89
9	SO	173	1841-2013	12	0.69	0.312	0.614	0.327	0.231	0.155	0.253	0.86
I	TB	219	1790-2008	51	0.61	0.408	0.756	0.303	0.159	0.002	0.187	0.94
II	ST	173	1841-2013	37	0.60	0.337	0.669	0.329	0.208	0.084	0.233	0.88

Legend to symbols: SD, standard deviation; 1AC, first order autocorrelation; MST, mean sensitivity.

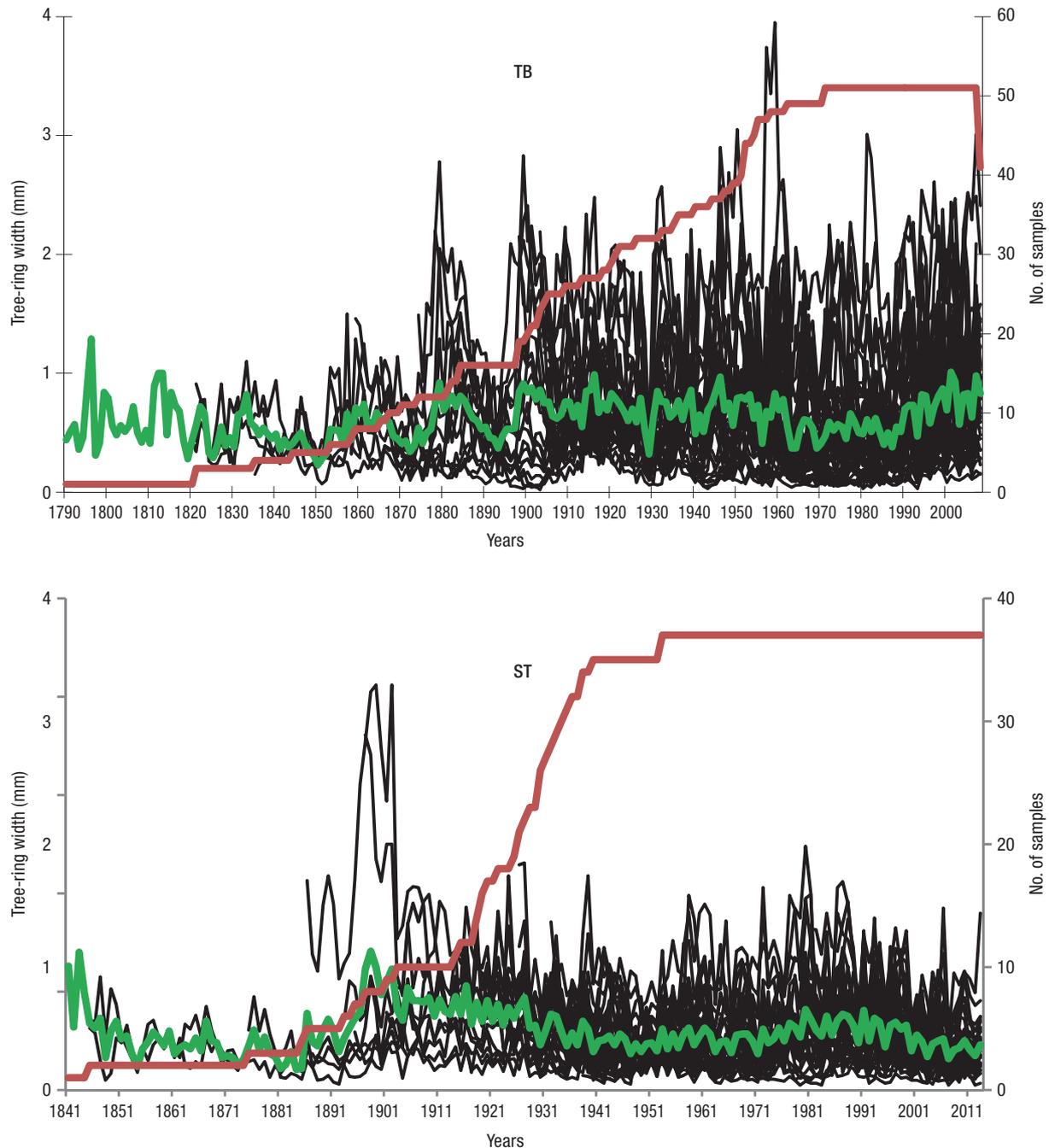


Figure 2. Tree-ring series of yews (TB) and wild service trees (ST). Black lines – individual tree-ring series, green line – regional chronology, red line – number of samples in regional chronology.

comparison to 17% for precipitations), however, substantially lower than in the case of the yew (Fig. 4). For the air temperatures negative values of correlation and regression could be generally noted, above all for the current and previous growth seasons, whereas for the precipitations these values could be positive (December, April and July) or negative (January and February).

18 pointer years could be identified for the regional yew TB chronology, including 13 negative (-) and 5

positive (+) (Table 3). Positive pointer years at yew trees were associated with mild and short winters and early springs, preceding mild, warm periods of the annual growth formation. Negative pointer years were characterized by long and frosty winters and late springs, subsequent summer droughts could be an additional factor favouring incremental reductions. 33 pointer years could be identified for the regional wild service tree ST chronology, including 21 negative (-) and 12 positive (+) (Table 3). Negative pointer intervals

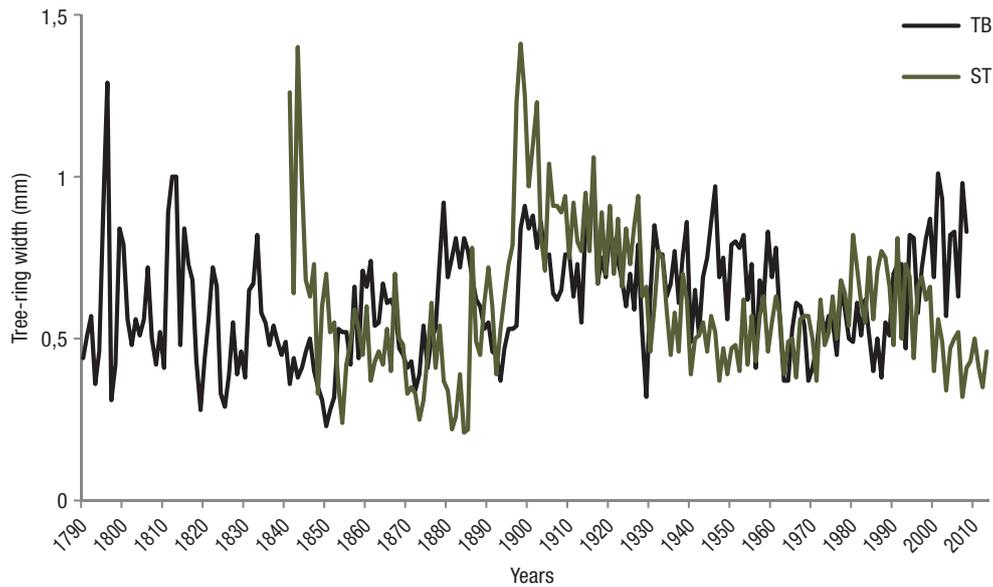


Figure 3. Comparison of regional chronology for yew (TB – black line) and wild service tree (ST – green line).

Table 3. Pointer years in regional chronologies: (–) negative pointer year, (+) positive pointer year.

Year	TB	ST	Year	TB	ST
1872	–		1959		–
1875	–		1963		–
1880	–		1967		+
1913	–		1969	–	
1916		+	1971		–
1917	–	–	1976		–
1919		–	1977	+	
1921		–	1980		+
1928	–		1984		+
1930		–	1990		–
1935		–	1991		+
1936		+	1992		–
1937		–	1993	–	
1938		+	1994	+	
1940	–	–	1995		–
1942	–		1996		+
1947	–	–	2000		–
1952		–	2001	+	+
1954		–	2003	–	–
1955		+	2004		+
1956	–	–	2007	+	–
1957	+		2013		+

for wild service trees were related to a deficiency in precipitation in the growth season, particularly in the summer months, cambium activity could be additionally weakened by high summer temperatures combined

with droughts. Positive pointers were years with humid summer periods. Only six pointer years were common, with the same incremental tendency, for both species: five negative years (1917, 1940, 1947, 1956 and 2003) and one positive – 2001 (Table 3). Negative years were marked by long and frosty winters (the year 1947 being an exception), and often with deficiency of precipitations in the summer period. Positive pointer 2001 is a year, in which winter temperatures were higher than average, early starting spring was mild, and also rainfall was above the average, particularly in the growth season any deficiency of rain was not registered.

Discussion

The tree species examined exhibit completely different relations growth-climate, which results from different evolutionary adaptation of trees to the environmental conditions. The yew, a coniferous species preserving its assimilatory apparatus in winter, developed considerable tolerance and adaptation processes for retaining conifer needles in that disadvantageous period. It is, however, sensitive to low winter temperatures as well as cool and late starting spring. The wild service tree, a species reconstructing its assimilatory apparatus every year, is not sensitive to thermal and humid conditions of the resting period, but it is very demanding, as to the humidity in particular, in the vegetation season. Different adaptive potential is also expressed in the incremental patterns (Fig. 3), displaying low similarity. This, in turn, is a result of variable cambium activity in response to the environmental

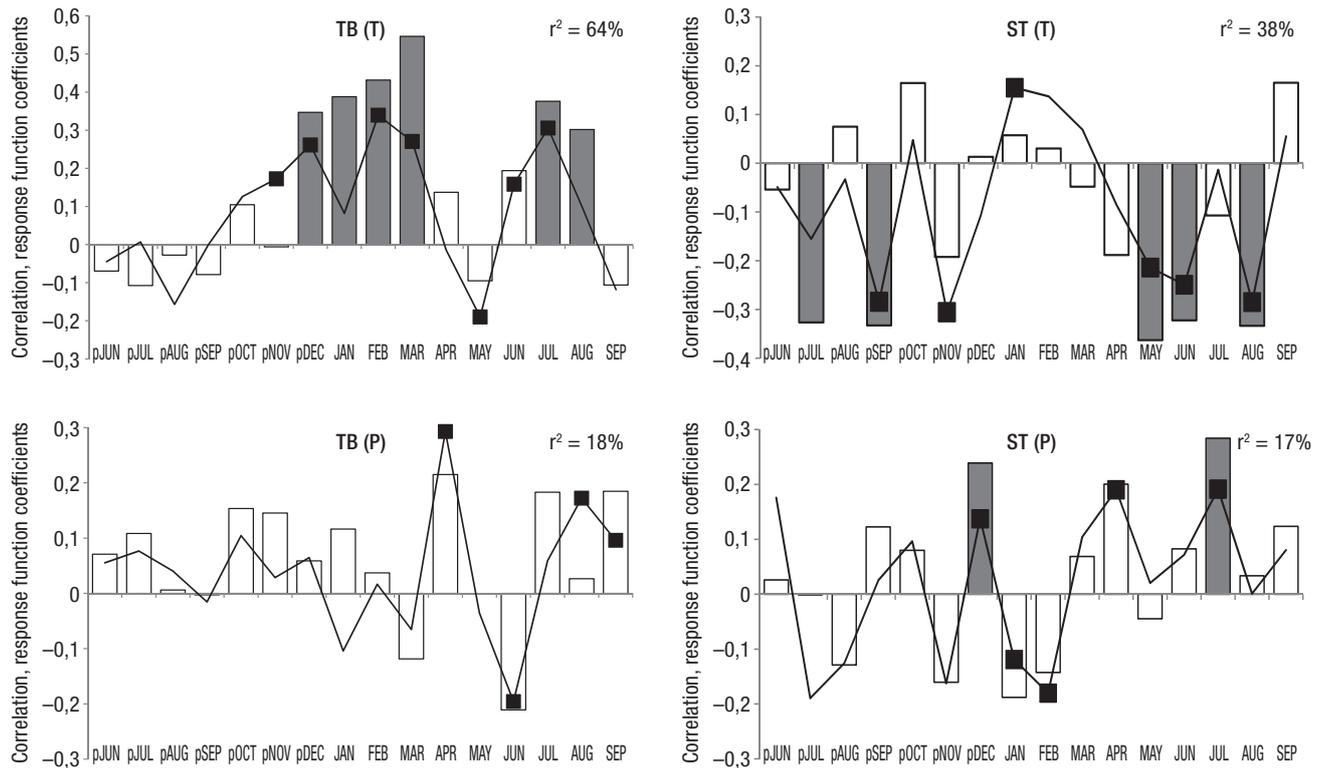


Figure 4. Results of correlation and response function analyses for regional chronologies and air temperature (T) and precipitation (P); bars denote correlation coefficients; line represents response function coefficient; significant values ($\alpha = 0.05$) marked as black squares and gray bars; p, previous year.

conditions, amongst which climatic conditions are marked by the highest changeability.

The yew has already been the subject of dendrochronological and dendroclimatological studies in Poland (Cedro, 2004, 2005, 2012, Cedro & Iszkuło, 2011, Cedro & Cedro, 2012). These analyses indicated that the predominating factors affecting the annual growth width of this tree species are the thermal conditions of the winter months and beginning of spring. An additional factor may be the amount of precipitation in the growth season – particularly important in dry locations and some mountain areas. The study of Cedro & Iszkuło (2011) revealed very interesting, different incremental reactions to the changing meteorological conditions for both sexes of yew. Based on five research plots in western Poland (altogether 10 patterns, 5 ones for every sex) it was demonstrated: differences in the annual growth widths (higher in males, however, divergences appeared after achieving sexual maturity, depending on, among others, the amount of light available for the trees); sensitivity of males on the amount of rainfall in the year preceding growth, particularly in October, and females on temperature of the previous summer (negative correlations) and amount of rainfall in the current growth season (positive correlations). Such differences could result from a different physiology between the sexes; different periods of the incre-

ment formation and development, as well as the energy expense for the development of flowers and seeds (Cedro & Iszkuło, 2011). Female specimens also exhibited higher numbers of sapwood rings, and in chronologies for both sexes these values did not depend on the dendroclimatic region, but on the age of trees – the younger the population, the less sapwood rings (Cedro, 2012). Around 0.8% of the growth rings at Polish yew trees are touched by frost deformations – damages brought about by sudden and sharp falls of temperature at the beginning of the cambium activity period (Cedro, 2012). Frost rings, particularly frequent in juvenile wood and relatively rare in subsequent years of the life of trees, are connected with strong reductions of the annual growth rings, therefore, they could also be used for reconstructions of thermal conditions. Relatively few studies on yew trees from other countries have been carried out in other countries, primarily in Great Britain (Moir, 1999, Moir & Leroy, manuscript), Iran (Parsapajouh *et al.*, 1986a,b), and Ukraine (Iszkuło *et al.*, 2011, Cedro, 2012). They point out similar determinants of the annual growth: the amount of precipitations in the period February–July and air temperatures in January and February. At one of the richest in yew trees posts of this species in Europe, Kniaźdworze in Ukraine, Iszkuło *et al.* (2011) and Cedro (2012) obtained similar results, additionally

pointing to the thermal conditions of July and September of the previous growth season as a factor conditioning the cambium activity.

Until now the wild service tree has not been the subject of dendrochronological or dendroclimatological analyses on the eastern boundary of its range in Europe. Only a few dendrochronological papers have been dedicated to this species from other areas of its natural range in Europe (Rasmussen, 2007, Pyttel *et al.*, 2011, 2013). Populations of wild service trees from the northern border of its range in Germany and Denmark proved to be responding negatively to temperatures in the previous growth season and to precipitations – both positive and negative values of correlation could be noted, also for the season preceding growth. The forest management was also pointed out as an important factor shaping the incremental dynamics (Rasmussen, 2007).

Taking into account relative scarcity of scientific studies on the wild service tree (mostly related to the areas of its natural range, morphological variability of leaves, fruits and seeds, and genetic testing), every piece of new information presents a valuable contribution to the state of our knowledge of this rare and disappearing species (Roper, 1993, Boratyński *et al.*, 1995, Rasmussen & Kollmann, 2004, Paganova, 2007, Szeszycki, 2008, Bednorz, 2004, 2007, 2010).

In this present time of climate change, manifested primarily by a rapid rise in temperature and a higher frequency of extreme events, for example droughts and heat waves, the study of species on the edge of their range may carry a lot of interesting information about these taxa and their adaptative potential. Species on the border of their range are very sensitive to changes in climatic conditions, and analysis of the growth-climate relationships allows to trace these changes and reactions of trees in time. The information obtained about the tree-ring width and adaptation of species to changes may be used in other climate zones to predict the dynamics of cambial activity and sensitivity to harmful factors. Therefore, dendroclimatic studies on the eastern limit of the range of yew and wild service tree are important not only for local populations. These species ‘niché’ may eventually expand their ranges, increasing the biodiversity of forest habitats, and even gain economic importance.

The yew and wild service trees are very rare components of Polish forests. In spite of legal protection and reintroduction programmes, their state of health, populations, renewal rates, and incremental dynamics are not always improving. Therefore, new programmes and scientific studies are essential, including these of a dendrochronological character, broadening the state of knowledge on these valuable trees enriching the

biodiversity of our forests. It is of particular importance in times of the current climatic changes and intensive farming and forest management, additionally threatening so small and dispersed populations of both these tree species.

References

- Bednorz L, 2004. Rozmieszczenie i zasoby *Sorbus torminalis* (Rosaceae: Maloideae) w Polsce. *Fragm Flor Geobot Polonica* 11: 105-121.
- Bednorz L, 2007. The wild service tree *Sorbus torminalis* (L.) Crantz in plant communities of Poland. *Dendrobiology* 57: 49-54.
- Bednorz L, 2010. Jarzab brekinia *Sorbus torminalis* (L.) Crantz w Polsce. Bogucki Wydawnictwo Nakowe, Poznań.
- Boratyński A, Kosiński P, Kwiatkowski P, Szlachetka A, 1995. Chronione i godne ochrony drzewa i krzewy polskiej części Sudetów, Pogórza i Przedgórze Sudeckiego. 8. *Sorbus torminalis* (L.) Crantz. *Arboretum Kórnickie, Rocznik* 40: 11-35.
- Boratyński A, Kmiecik M, Kosiński P, Kwiatkowski P, Szczęśniak E, 1997. Chronione i godne ochrony drzewa i krzewy polskiej części Sudetów, Pogórza i Przedgórze Sudeckiego. 9. *Taxus baccata* L. *Arboretum Kórnickie, Rocznik* 42: 111-147.
- Cedro A, 2004. Wpływ warunków klimatycznych na kształtowanie się przyrostów radialnych cisa pospolitego (*Taxus baccata* L.) w Rezerwacie Cisy Staropolskie w Wierchlesie. *Prace Geograficzne* 200: Rekonstrukcja i prognoza zmian środowiska przyrodniczego w badaniach geograficznych (Eds. Błaszkiwicz M & Gierszewski P): 47-57.
- Cedro A, 2005. Czynniki wpływające na szerokość przyrostów rocznych cisa (*Taxus baccata* L.) ze stanowisk Pomorza Zachodniego. W: *Hydrograficzne i meteorologiczne aspekty badań wybrzeża Bałtyku i wybranych obszarów Polski* (Eds. Gierjatowicz J & Koźmiński C) Szczecin: 8-13.
- Cedro A, 2012. Dendrochronologia cisa pospolitego w Polsce i na zachodniej Ukrainie. PPH Zapol, Szczecin: 1-230.
- Cedro A, Cedro B, 2012. Przyrosty roczne sosny zwyczajnej (*Pinus sylvestris* L.) i cisa pospolitego (*Taxus baccata* L.) w rezerwacie “Cisy Staropolskie im. Leona Wyczółkowskiego” i ich dendroklimatologiczna analiza. In: Pająkowski J, (Eds.) *Rezerwat przyrody “Cisy Staropolskie im. Leona Wyczółkowskiego” w Wierchlesie. Świecie: 84-88.*
- Cedro A, Iszkuło G, 2011. Do females differ from males of European Yew (*Taxus baccata* L.) in dendrochronological analysis? *Tree-Ring Research*, Vol. 67(1): 3-11. <http://dx.doi.org/10.3959/2009-9.1>
- Cook ER, Holmes RL, 1986. Arstan. Guide for computer program Arstan. The University of Arizona: 50-65.
- Giertych P, 2000. Factors determining natural regeneration of Yew (*Taxus baccata* L.) in the Kórnik Arboretum. *Dendrobiology* 45: 31-40.

- Holmes RJ, 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bull* 43: 69-78.
- Holmes RJ, 1994. *Dendrochronology Program Library. Users Manual*. University of Arizona, Tucson, USA.
- Iszkuło G, Boratyński A, 2005. Different age and spatial structure of two spontaneous subpopulations of *Taxus baccata* as a result of various intensity of colonization process. *Flora* 200: 195-206. <http://dx.doi.org/10.1016/j.flora.2004.03.001>
- Iszkuło G, Jasińska AK, Sobierajska K, 2011. Dendroecological differences between *Taxus baccata* males and females in comparison with monoecious *Abies alba*. *Dendrobiology* 65: 55-61.
- Kaennel M, Schweingruber FH, 1995. *Multilingual Glossary of Dendrochronology*. WSL FNP, Haupt.
- Król S, 1975. Zarys ekologii. W: *Cis pospolity. Taxus baccata* L. Red. Białobok S. PWN, Warszawa-Poznań: 78-103.
- Kruszelnicki J, 2001. *Taxus baccata* L. Cis pospolity. W: *Polska Czerwona Księga Roślin. Paprotniki i rośliny kwiatowe*. Red. Kaźmierczakowa R. i Zarzycki K. Instytut Botaniki im. W. Szafera, Instytut Ochrony Przyrody, Kraków, (Poland): 68-70.
- Linares JC, 2013. Shifting limiting factors for population dynamics and conservation status of the endangered English yew (*Taxus baccata* L., Taxaceae). *Forest Ecol Manag* 291: 119-127. <http://dx.doi.org/10.1016/j.foreco.2012.11.009>
- Meyer FD, 1997-1998. Pointer years analysis in dendrochronology: a comparison of methods. *Dendrochronologia* 16-17: 193-204.
- Mindur B, 2000. *Dendrometer 1.0*. Kraków, Poland.
- Mitchell A, 1996. *Alan Mitchell's Trees of Britain*. Harper Collins Publishers, London, UK.
- Moir AK, 1999. The dendrochronological potential of modern yew (*Taxus baccata*) with special reference to yew from Hampton Court Palace, UK. *New Phytol* 144: 479-488. <http://dx.doi.org/10.1046/j.1469-8137.1999.00545.x>
- Moir AK, Leroy S.A.G. Manuscript. The age and growth-climate relationship of yew (*Taxus baccata* L.) in south-eastern England.
- Paganova V, 2007. Ecology and distribution of *Sorbus torminalis* (L.) Crantz. In Slovakia. *Hort Sci (Prague)*, 34 (4): 138-151.
- Parsapajouh D, Schär E, Habibi H, Bräker OU, 1986a. Etude radiodensitométrique du bois de *Taxus baccata* du nord de l'Iran. Manuskript eingereicht bei R.F.F./Ann.sci. forest.F.
- Parsapajouh D, Bräker OU, Habib H, Schär E, 1986b. Etude dendroclimatique du bois de *Taxus baccata* du nord de l'Iran. *Schweiz Z Forstwes* 137(1986), 10: 853 - 868.
- Pyttel P, Kunz J, Bauhus J, 2011. Age and growth of wild service tree (*Sorbus torminalis* (L.) Cranz) in former oak coppice forests in southwest Germany. In: Maaten-Theunissen M., Spiecker H., Gartner H., Helle G., Heinrich I. (Eds.) (2011): *TRACE – Tree Rings in Archeology, Climatology and Ecology*, Vol. 9. GFZ Potsdam, Scientific Technical Report STR 11/07, Potsdam, pp. 64-70.
- Pyttel P, Kunz J, Bauhus J, 2013. Growth, regeneration and shade tolerance of the Wild Service Tree (*Sorbus torminalis* (L.) Cranz) in aged oak coppice forests. *Trees* 27: 1609-1619. <http://dx.doi.org/10.1007/s00468-013-0908-7>
- Rasmussen KK, 2007. Dendroecological analysis of a rare sub-canopy tree: Effects of climate, latitude, habitat conditions and forest history. *Dendrochronologia* 25: 3-17. <http://dx.doi.org/10.1016/j.dendro.2007.01.002>
- Rasmussen KK, Kollmann J, 2004. Poor sexual reproduction on the distribution limit of the rare tree *Sorbus torminalis*. *Acta Oecologica* 25: 211-218. <http://dx.doi.org/10.1016/j.actao.2004.02.001>
- Roper P, 1993. The distribution of the Wild Service Tree, *Sorbus torminalis* (L.) Crantz, in the British Isles. *Watsonia* 19: 209-229.
- Spjut RW, 2007. A phytogeographical analysis of *Taxus* (Taxaceae) based on leaf anatomical characters. *J Bot Inst Teras* 1(1): 291-332.
- Szeszycki T, 2007. Cis pospolity - *Taxus baccata*, przeszłość, ochrona, hodowla, przyszłość. *Soft Vision*. Wydanie II: 1-234.
- Szeszycki T, 2008. Jarzab brekinia – *Sorbus torminalis*, historia, hodowla, ochrona, przyszłość. *Soft Vision*: 1-138.
- Thomas PA, Polwart A, 2003. *Taxus baccata* L. *J Ecology* 91: 489-524. <http://dx.doi.org/10.1046/j.1365-2745.2003.00783.x>
- Walanus A, 2002. *Instrukcja obsługi programu TCS. Program TCS do obliczania lat wskaźnikowych*. Kraków, Poland.
- Wigley TML, Briffa KR, Jones PD, 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *J Clim App Meteorol* 23: 201-213.
- Zajac M, Zajac A, (Eds.), 1997. *Atlas rozmieszczenia roślin naczyniowych chronionych w Polsce*. Nakładem Pracowni Chorologii Komputerowej Instytutu Botaniki Uniwersytetu Jagiellońskiego, Kraków (Mapa rozmieszczenia *Sorbus torminalis* w Polsce).
- Zajac M, Zajac A, (Eds.), 2001. *Atlas rozmieszczenia roślin naczyniowych w Polsce*. Nakładem Pracowni Chorologii Komputerowej Instytutu Botaniki Uniwersytetu Jagiellońskiego, Kraków (Mapa rozmieszczenia *Sorbus torminalis* w Polsce).
- Zembrzusi J, 1975. Cis (*Taxus baccata*). *Studia Ośrodka Dokumentacji Fizjograficznej*, t. IV: 169-193.
- Zwijacz T, 2005. Stan aktualny stanowisk cisa pospolitego *Taxus baccata* L. w Tatrzańskim Parku Narodowym. *Chrońmy Przyrodę Ojczyzn*. Zeszyt 6(61): 25-38.