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Michal Rybníček, Petr Čermák, Tomáš Žid, Tomáš Kolář

Growth responses of *Picea abies* to climate in the central part of the Českomoravská Upland (Czech Republic)

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Abstract: The aims of the study were to determine the effect of temperatures and precipitation on the ring width and to compare the results with the results of previous studies conducted in other mountain ranges of the Czech Republic. The research was performed in the central part of the Českomoravská Upland in the vicinity of Herálec municipality in selected 70- up to 110-year-old spruce stands at altitudes from 680 m a.s.l. to 779 m a.s.l. Measuring of tree-ring widths and synchronization of individual ring series were conducted in PAST4. The age trend was removed by ARSTAN and climatic effects were modelled in DendroClim2002. The correlation of tree-ring width with monthly precipitation is positive and statistically significant for July of the previous year and for the entire summer period from June to September of the current year. The correlation of tree-ring width with mean monthly temperatures is negative and statistically significant for July and September and positive and statistically significant for October of the previous year. Negative correlation was also found for temperatures of the entire summer period from June to September of the previous year. The regional tree-ring chronology mainly shows two periods of highly reduced increment: from 1992 to 1996 and from 2003 to the end of the analysed period. The results thus confirm the hypothesis that the tree-ring width is in positive correlation with summer precipitation and negative correlation with summer temperatures. Also the results of the habitual diagnostics have shown a relatively low degree of crown transformation which indicates a weak or short-term stress load.

Additional key words: Norway spruce, precipitation, temperature, tree-ring width, habitual diagnostic, Českomoravská Upland

Addresses: M. Rybníček, P. Čermák, T. Žid, T. Kolář, Mendel University in Brno, Faculty of Forestry and Wood Technology, Zemědělská 3, 613 00 Brno, Czech Republic, e-mail: michalryb@email.cz, T. Kolář, Global Change Research Centre, Academy of Science of the Czech Republic, Bělidla 986/4a, 603 00 Brno, Czech Republic

Introduction

Factors of the environment are permanently deposited in the structure of the biomass created – in tree rings (Fritts 1976). The record consisting of tree-ring widths is a continuous temporal series of up to several hundred years providing us with a long-term view of tree growth variability. As the climatic signal is considered one of the main factors for the tree growth (Spiecker 2002), we can search for a relationship between tree rings and climatic records (Fritts 1976). The main usually meteorological monitored factors limiting growth of woody plants are temperature and precipitation. Temperature is limiting mainly in mountainous areas; precipitation is the main factor at lower altitudes (Larcher 1988). Radial growth of a tree is affected by temperatures and precipitation in the year of the growth as well as in the year preceding the formation of the tree ring (Čermák 2007). A direct influence of temperature on growth mainly occurs at the beginning of the growing season when a low temperature can postpone the beginning of cambial activity (Fritts 1976). Temperatures both above and below average may be significance. For example, an increase in average monthly temperature during the growing season by more than 3°C over the long-term average is considered highly risky (Grabařová, Martinková, 2000, 2001). Water affects cambium activity directly although at some development stages cambium is more sensitive to its lack than in others (Čermák 2007). The cornerstone of dendrochronological applications is the finding that trees growing in the same area, i.e. in the same conditions, display the same response expressed by the amount of formed wood. Therefore, the changes in tree-ring widths within a stand are parallel, especially concerning minimum and maximum values (Schweingruber 1996). Based on this, we can date favourable or unfavourable periods, not only recent but also those from distant past. Based on previous studies performed in the other mountain ranges of the Czech Republic (Rybníček et al. 2009, 2010, 2012a, b), we hypothesized that the ring width will be affected by summer precipitation and temperatures mainly. Especially the expected high temperatures and low precipitation in the second half of the growing season could negatively affect the ring width.

As has been stated, radial growth is a suitable indicator of tree vitality, mainly for longer periods, but the analysis of the radial growth is dependent on semi-destructive testing of the analysed trees. However, tree vitality can be observed by means of other, non-destructive, methods, one of which is for example habitual diagnostics (Cudlín et al. 2001). Habitual diagnostics combine tree condition assessment with evaluation of realized ability of regeneration (percentage of secondary shoots). The combination makes possible description of response history of trees and forest stands to multiple stress. The response of radial growth and defoliation (as one of main parameters of habitual diagnostics) may occur with different delays: in some cases, the first observable reaction to a factor is defoliation (e.g. when insects feed on the tree), while the response in the form of increment is delayed; in other cases (e.g. extreme drought) the reduction in growth is immediate whereas the reduction in foliage can be observed several months later (Rybníček et al. 2012a). Therefore, a combination of these two procedures is highly suitable.

The dominant tree species in the Českomoravská Upland (in Czech Českomoravská vrchovina) is Norway spruce (*Picea abies* (L.) Karst.), which is one of the most significant European woody plants and also a tree with the highest amount of various health and growth problems appearing in the past decades. It is relatively demanding concerning precipitation and also generally it is a relatively sensitive species (Rybníček et al. 2010). Recently, a number of publications have appeared dealing with the effect of climate on radial increment of spruce in various parts of Europe, e.g. Mäkinen et al. (2001), Vitas (2004), Koprowski and Zielski (2006), Savva et al. (2006), Bouriaud and Popa (2009), Affolter et al. (2010), Aakala and Kuuluvainen (2011), and in the Czech Republic Čejková and Kolář (2009), Kroupová (2002), Rybníček et al. (2009, 20010, 2012a, 2012b).

The aims of this study were to analyse the dynamics of radial growth of Norway spruce in the central part of the Českomoravská Upland mainly in the last fifty years, for which there are relevant climatic records available, and to identify the growth response to climate; also, to find connections between the results of the dendrochronological analysis and parallelly obtained results of the habitual diagnostics.

Methods

The research was conducted in ten selected forest stands with predominance of Norway spruce in the central part of the Českomoravská Upland near Herálec municipality in 2011

The stands were aged from 73 to 116 and were located at altitudes from 680 m a.s.l. to 779 m a.s.l. (Table 1). The region is relatively moist – the average annual precipitation is 785 mm (for the monitoring period 1961–2010). The average annual temperature is 6.2°C.

The cores were taken and processed in correspondence with the standard dendrochronological methodology (Cook and Kairiukstis 1990). The cores were taken using the Pressler borer at 1.3 m above ground. The cores were taken along the contour line so that increment was not influenced by the presence of compression wood. At each of the plots, 20 trees had selected and one core from each tree was taken for dendrochronological analyses (in total 200 trees and 200 cores). The cores were fixed into wooden slats and their surface was polished. The wood cores were then measured using a specialized measuring table equipped with an adjustable screw device and an impulsemeter recording the interval of table top shifting and in this way also the tree-ring width. Measuring and synchronizing of tree-ring sequences were carried out using the PAST4 (©Sciem) application. The annual wood increments were measured with 0.01 mm accuracy.

After measuring, a comparison (cross-dating) of individual measured curves was made. Cross-dating is finding the synchronous positions of two tree-ring

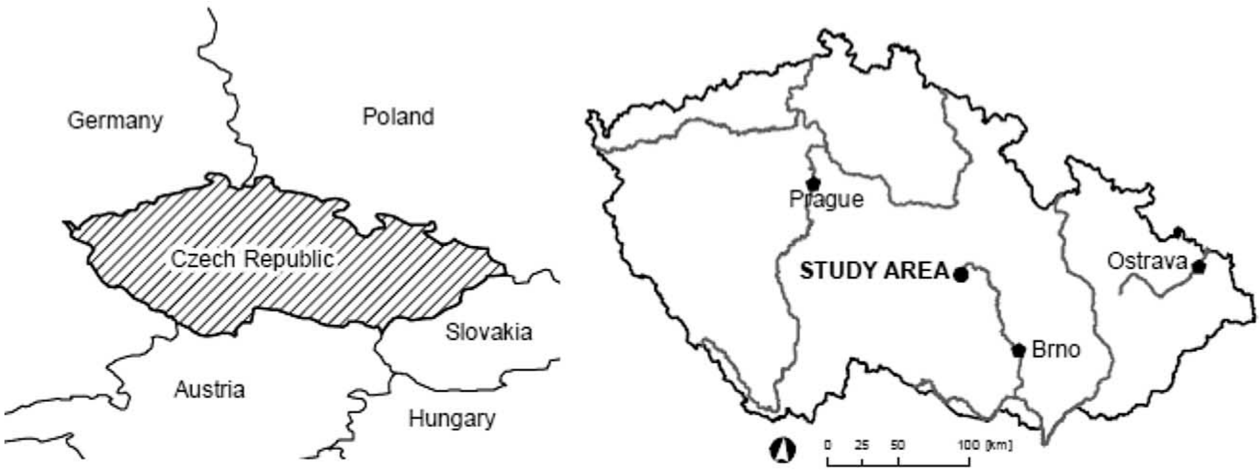

Fig. 1. Location of the study area

series. Both series are compared in all possible mutual positions. The objective is to identify the tree rings in each sample created in the same year. If there is a synchronous position, it is demonstrated by a sufficiently high similarity in the area where they overlap (Cook and Kairiukstis 1990). The excellently correlating series were used to create the average tree-ring curves. The curve sets off the common extremes related to climatic changes and reduces all the other oscillations caused by other factors. The degree of similarity between the tree-ring series was evaluated using the correlation coefficient and the coefficient of agreement (Gleichläufigkeit). These calculations facilitate the optical comparison of both curves, which is crucial for the final dating (Rybníček et al. 2010).

Individual tree-ring series were exported from PAST4 to ARSTAN (Grissino-Mayer et al. 1992), where they were detrended, autocorrelation was removed and the regional tree-ring chronology and the regional residual tree-ring chronology were created. The removal of the age trend was carried out using a

Table 1. A detailed overview of all areas

Title of plot	GPS	Altitude (m a.s.l.)	Slope orientation	Slope gradient	Forest vegetation zone	Edaphic category	Age (2011)	% of *P. abies*
V2	N49 40.719 E15 57.384	685	SW	3	5	variohumida acidophila	83	100
V7	N49 40.506 E15 57.530	692	SW	6	5	variohumida mesotrophica	111	100
V9	N49 40.198 E15 57.886	692	W	8	5	variohumida acidophila	111	100
V12	N49 40.471 E15 58.509	706	E	7	5	variohumida acidophila	73	96
V30	N49 40.247 E16 00.112	705	NW	7	5	variohumida mesotrophica	95	99
V36	N49 39.968 E16 01.581	779	S	8	5	lapidosa acidophila	116	99
V41	N49 39.610 E16 02.079	760	W	5	5	lapidosa acidophila	109	95
V34	N49 40.387 E16 01.068	768	NW	4	5	variohumida acidophila	90	99
V25	N49 40.893 E16 01.196	703	N	4	5	variohumida acidophila	77	97
V23	N49 41.766 E16 01.933	680	SE	2	5	acidophila	96	88

two-step detrending method (Holmes et al. 1986). First, a negative exponential function or a linear regression curve which best express the change of the growth trend with age were used (Fritts et al. 1969). Other potentially non-climatically conditioned fluctuations of values of diameter increments, brought about by e.g. competition or forester's interference, were balanced using the cubic spline function (Cook and Peters 1981). The chosen length of the spline function was 67% of the detrended tree-ring curve length (Cook and Kairiukstis 1990).

From the tree-ring series standardized in this way the regional index residual tree-ring chronology was created in the ARSTAN application. Also the regional tree-ring chronology was established. The range of the created regional tree-ring chronologies is from 1882 to 2010.

We used DendroClim2002 to model the tree-ring widths in dependence on the climatic characteristics (Biondi and Waikul 2004). Before the modelling itself it was necessary to convert the output data from ARSTAN to the input format of DendroClim2002. To convert the data the YUX application (web.utk.edu/~grissino/) was used.

The regional index residual tree-ring chronology and the climatic time series of monthly average temperatures and monthly precipitation for 1961–2010 were used to calculate the correlations of tree-ring widths with climatic factors. They were always calculated from April of the previous year till October of the year of tree ring formation, i.e. for the period of 19 months. It is the period that should be of the highest influence on the radial increment in each particular year.

Climatic data were derived for the location defined by geographic coordinates 49°40'22.522"N, 16°00'45.330"E and an altitude of 715 m a.s.l. based on spot monitoring and application of regression dependence of the quantity on the altitude. We used technical series of stations (268 meteorological and 787 precipitation stations in the area of the CR) for the calculation; the original station series were subjected to quality control and homogenization using ProClimDB (Štěpánek 2007) and the missing values of measurement were added. The calculated values were interpolated in area by the method of universal linear kriging (or linear kriging with possible selection of parameters of the method), while the dependence of a specific meteorological element on the altitude was respected (we applied local linear regression, radius of the circular surroundings of the spot was 20 km for precipitation and 40 km for temperature characteristics). The resulting grid of each climatologic feature was calculated as a weighted average where the weight coefficient was the value of the coefficient of determination R2 in each grid cell. The size of the grid was 500 m.

The statistical comparison of time series of tree-ring widths and the time series of climatic factors will enable us to find out what the average influence of the studied climatic parameters on the increments has been in the long term. The influences that occur with a low frequency and that also have a fundamental effect on the tree growth do not have to be demonstrated in the correlation analysis to a statistically significant degree (Kienast et al. 1987). To establish these effects the analysis of negative pointer years is used. The negative pointer year is defined as an extremely narrow tree ring with the growth reduction exceeding –40% in comparison with the average tree-ring width in the previous four years; strong increment reduction is found in at least 20% of the trees from the area (Kroupová 2002).

In the habitual diagnostics the following were especially evaluated: the total defoliation, the defoliation of the primary structure, the percentage of secondary shoots, the presence and extent of yellowing and browning, and the stem damage (Cudlín et al. 2001). The same trees as for dendrochronological analyses were used. Basic habitual characteristics according to Cudlín et al. (2001) were evaluated in a representative number of trees by means of binoculars. First, the growth habit of a tree was described, namely social position, type of branching, type of the tree top, crown form, the presence of stem, crown and top breaks. Crowns were visually divided into three parts: the upper juvenile part, the central production part and the lower saturation part. Then we evaluated the form of the juvenile part (according to a modified method by Lesinski and Landman 1995), and the total defoliation, the defoliation of the primary structure, the percentage of secondary shoots and the types of damage in the production part (Cudlín et al. 2001). Subsequently, discoloration was assessed, i.e. yellowing and browning of needles – the percentage of the total volume of an assimilatory apparatus with the presence of needles discoloration (in an interval of 5%) was estimated.

The final parameter of habitual diagnostics analyse was degree of crown structure transformation. Transformation of the tree crown is a process when the gradual substitution of original primary (proleptic) shoots by secondary shoots occurs. Transformation of the crown structure is a result of the tree response to changes in the spectrum or intensity of the effect of stress factors. This reaction can be manifested as a short-term physiological response or as long-term physiological, morphological and structural changes. Five degrees of crown structure transformation were distinguished (Cudlín et al. 2001) – from degree 1 with small defoliation and percentage of secondary shoots less than 20% to degree 5 with peripheral injury occurring by most of branches and percentage of secondary shoots 100%.

Results

The correlation of tree-ring width with monthly precipitation is positive and statistically significant for July of the previous year and for the entire summer period from June to September of the current year (Fig. 2). The correlation of tree-ring width with mean monthly temperatures is negative and statistically significant for July and September of the previous year and positive and statistically significant for October of the previous year. Negative correlation was also found for temperatures of the entire summer period from June to September of the previous year (Fig. 3).

When comparing the average tree-ring curves of the individual plot, the statistical indicators show high values. When the curves overlap by at least sixty rings, the critical value of Student's t-distribution with 0.1% level of significance is 3.46 (Šmelko and Wolf 1977). The values of our t-tests are much higher than 3.46 which shows high reliability of the synchronization (minimum value of t-test was higher than 5). The correctness of the synchronization is also proved by the agreement of the average tree-ring curves in most of the extreme values. Thanks to this, only one average tree-ring curve representing the radial increment of all plots together could be created (the mean tree ring width is 2.268 mm, the first-order autocorrelation is 0.798, the mean sensitivity is 0.135 and the standard deviation is 0.652). The regional tree-ring chronology shows two periods of strongly reduced increment: from 1992 to 1996 and from 2003 to the end of the analysed period. The lowest increments were found for years 1965, 1976, 1980, 1992, 1996, 2004, and 2006 (Fig. 4). These years with low

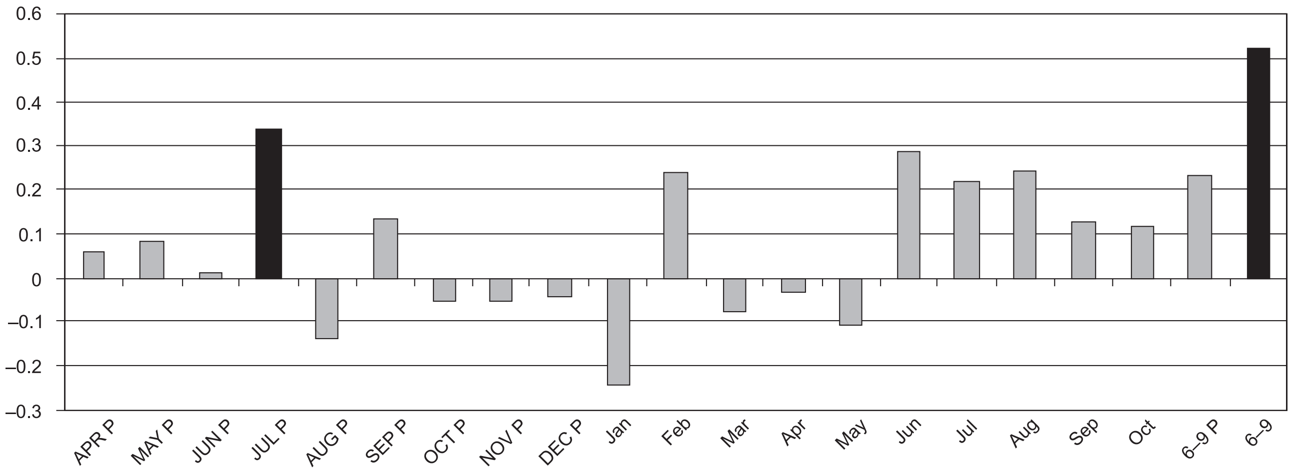

Fig. 2. The values of correlation coefficients of the regional residual index tree-ring chronology with the monthly precipitation from April of the previous year (P) to October of the current year; the period June-September (6–9) of both the previous (P) year and the current year for the period of 1961–2010. Values highlighted in black are statistically significant (α = 0.05)

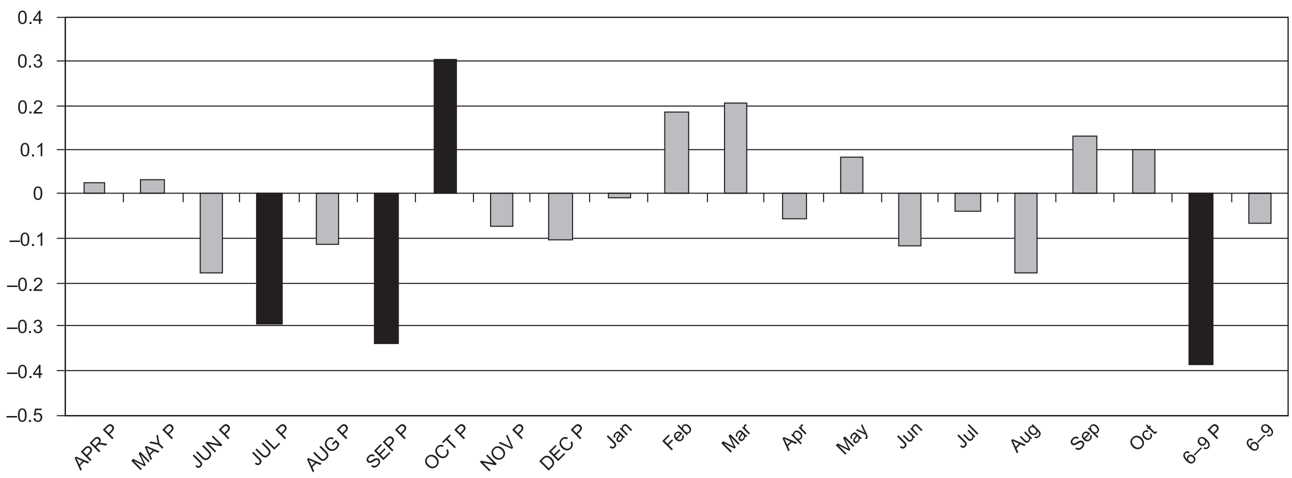

Fig. 3. The values of correlation coefficients of the regional residual index tree-ring chronology with the average monthly temperatures from April of the previous year (P) to October of the current year; moreover, the period June-September (6–9) of both the previous (P) year and the current year for the period of 1961–2010. Values highlighted in black are statistically significant (α = 0.05)

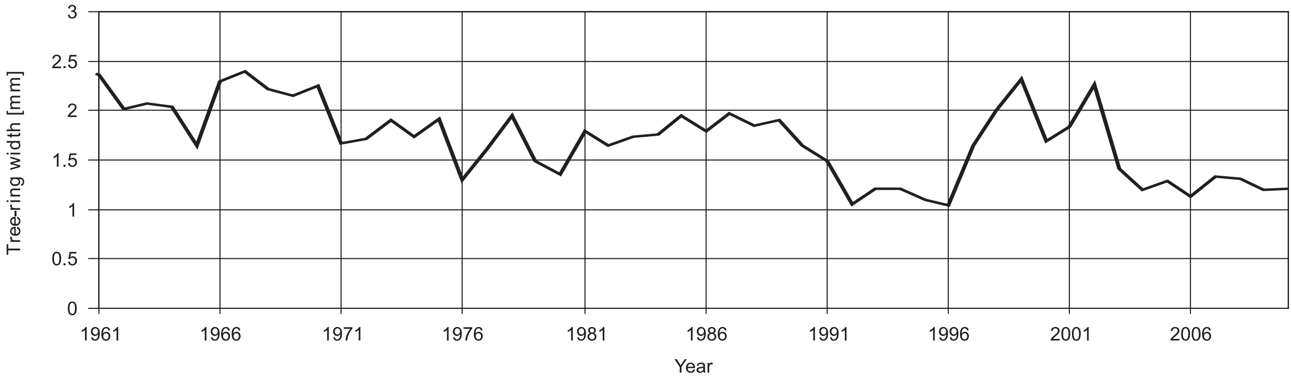

Fig. 4. Regional tree-ring chronology from the central part of the Českomoravská Upland

increments were also confirmed by the analysis of negative pointer years. During the most extreme years: 1992 and 2004, 71% and 63%, respectively, of trees forming the tree-ring chronology responded negatively (Table 2).

The results of the habitual diagnostics are presented in Table 3. The average defoliation of spruce was 34.8%. The values of the defoliation of the primary structure reached an average of 63.4% and the percentage of secondary shoots was 44.3% on average. Discolouration of needles was found to an insignificant degree only. The trees in the research plots were classified into categories based on their stress response to synergistic stress exposure (according Cudlín et al. 2001). The degree of crown structure transformation was 1 (148 trees), 2 (46 trees), 3 (5 trees) or 4 (1 tree), the average plots degrees were from 1.1 to 2.1 (Table 3), i. e. most of trees were only slightly damaged and slightly transformed. The findings indicate that stress exposure isn't heavy.

Discussion and conclusions

The radial increment manifested a positive and statistically significant correlation with precipitation in July of the previous year and also from June to September of the current year (Fig. 1). These correlations were also found through our previous studies in the Orlické Mts. (in Czech Orlické hory) (Rybníček et al. 2009) and the Silesian Beskids (Slezské Beskydy) (Rybníček et al. 2010), the same correlation has also been reported from the submontane and montane altitudes of the Swiss Alps (Affolter et al. 2010) and north-western Russia, the Archangelsk area (Aakala and Kuuluvainen 2011). A positive effect of precipitation from the growing season (April–September) of the year preceding tree ring formation in spruce was

Table 2. Negative pointer years and climatic characteristics which may be their interpretation

Negative pointer year	Abnormal climatic characteristics	Percent of trees sampled
1965	fluctuating precipitation in summer of previous year, subnormal precipitation in March	20–40
1971	subnormal precipitation from July to October, supernormal temperature in August	20–40
1972	subnormal precipitation in previous year, subnormal precipitation from January to March	20–40
1974	very low precipitation from February to April, supernormal temperature in March	20–40
1976	very low precipitation from February to April, subnormal precipitation from June to August, supernormal temperature in July	40–60
1980	very low precipitation in March and May, subnormal temperature from March to May	20–40
1991	subnormal precipitation in previous year, very low precipitation from January to March, very cold May, supernormal temperature in July	20–40
1992	very low precipitation in April and May, subnormal precipitation from July to September, hot July and August	60–80
1993	subnormal precipitation in previous year, very low precipitation in April	20–40
1995	hot July	20–40
1996	subnormal precipitation in January, cold January, February and March	20–40
2003	very low precipitation in February, March, June and August, hot summer (June–August)	40–60
2004	subnormal precipitation in previous year, subnormal precipitation in May	60–80
2005	subnormal precipitation in June	40–60
2006	subnormal precipitation in previous autumn, very low precipitation in July, hot July	40–60
2009	very low precipitation in January and April, very warm April, supernormal temperature in summer (July–September)	20–40

Table 3. The results of habitual diagnostics

Title of plot	Total defoliation (%)	Defoliation of primary structure (%)	% secondary shoots	Average degree of crown structure transformation	Yellowing of needles (%)	Browning of needles (%)	Stem damage
V2	33.0	60.0	40.0	1.2	0.1	0.0	0.2
V7	33.8	65.3	47.8	1.6	0.4	0.0	0.5
V9	33.3	62.0	42.3	1.1	0.0	0.0	0.3
V12	33.5	57.8	36.0	1.1	0.3	0.0	0.2
V30	33.8	59.0	38.3	1.2	0.8	0.5	0.6
V36	39.3	70.8	52.3	1.5	0.0	0.3	0.2
V41	41.8	78.3	65.8	2.1	4.0	0.3	0.5
V34	33.0	61.8	42.3	1.1	2.0	0.0	0.4
V25	33.0	59.5	38.8	1.1	1.8	0.0	0.7
V23	34.0	59.5	39.8	1.2	0.9	0.0	0.7
Mean	34.8	63.4	44.3	1.3	1.0	0.1	0.4

documented in Poland, forest district Bukowiec (Feliksik 1993); a positive effect of precipitation in June–July in the Alps (Pichler and Oberhuber 2007). Significant positive correlations with precipitation in August and September of the previous year were found in the Romanian Carpathians (Bouriaud and Popa 2009); and significant positive correlations with precipitation in May of the previous year were ascertained for the Drahanská Upland (Drahanská vrchovina) (Rybníček et al. 2012a).

Lack of precipitation in the growing season leads to a physiological stress determining the radial growth in the following year (Kozlowski and Pallardy 1997). On the contrary, sufficient precipitation has a positive effect on the overall tree vitality and nutrients which are used for the growth at the initial stage of ring formation. Precipitation in the growing season of the previous year may influence the distribution, biomass and vitality of roots and thus also production capacity of the plant in the following year; the volume of precipitation at the end of the season especially affects the volume of water available in the soil in spring of the following year. The reasons why July precipitation of the previous year was significant in this study whereas the precipitation from June to September was not significant (Fig. 2) are not clear. A possible (but highly speculative) explanation might be that July precipitation initiates the second period of root growth which takes place from August to September (Xu et al. 1997) and can considerably affect the production capacity of the tree in the following growing season.

A positive effect of summer precipitation (June–September) of the current year (Fig. 2) is one of the most frequently found correlation relationships concerning growth of spruce. Precipitation during the growing season is a limiting factor for spruce growth especially at lower and middle altitudes. Significant positive correlations with summer precipitation were also found for the Silesian Beskids (Rybníček et al. 2010), the Drahanská Upland (Rybníček et al. 2012a), the lowest altitudes of the south-eastern part of the Českomoravská Upland (hereinafter SE Českomoravská Upland) (Rybníček et al. 2012b) and a number of other European territories (Feliksik et al. 1994; Desplanque et al. 1999; Mäkinen et al. 2001; Vitas 2004; Andreassen et al. 2006; Koprowski and Zielski 2006; Bouriaud and Popa 2009; Affolter et al. 2010).

Temperatures during growing season were more often in a negative relationship to radial growth, mainly temperatures in the year preceding the ring formation. The negative correlations for July and September of the previous year and the entire summer period June–September of the previous year were significant (Fig. 2). July correlations were also found in our previous studies in the Drahanská Upland (Rybníček et al. 2012a) – together with August temperature – and in the SE Českomoravská Upland (Rybníček et al. 2012b) – together with June temperature. Negative correlations of temperatures with increments have also been observed at middle altitudes of the Swiss Alps for temperatures in August and September (Affolter et al. 2010), in Norway (Andreassen et al. 2006), Archangelsk (Aakala and Kuuluvainen 2011) and the Romanian Carpathians (Bouriaud and Popa 2009) for temperatures in July, August and September; also in southern Finland for temperatures during the entire summer period (Mäkinen et al. 2001). High summer temperatures negatively affect the availability of soil moisture through increased evapotranspiration (Miyamoto et al. 2010; Aakala and Kuuluvainen 2011). Such temperatures for some of the summer months were recorded in Herálec in 1983, 1992, 1994, 1995, 2003, 2006, and 2010. The negative relationship of summer temperatures in the previous year and growth is generally found at lower altitudes and in less cold middle locations. No significant or even a positive relationship is most often found in colder areas (Frank and Esper 2005).

The correlation of the tree-ring width with mean monthly temperatures is positive and statistically significant for October of the previous year (Fig. 3). The same finding was observed in the Silesian Beskids (Rybníček et al. 2010), the Drahanská Upland (Rybníček et al. 2012a) and the Polish Tatras (Savva et al. 2006). The transition from negative temperature correlations in September of the previous year to positive correlations in October of the previous year has been identified in all the studies we have conducted so far – although they were significant correlations in the above listed study areas only (Rybníček et al. 2009, 2010, 2012a, 2012b). The same transition was observed in Czech plots of the ICP Forests network (MZe ČR, VÚLHM 2004), Norwegian monitoring plots (Andreassen et al. 2006) and at lower and middle altitudes of the Eastern Tatras (Büntgen et al. 2007). While higher mean temperatures in September (mean temperature for Herálec 1961–2010 11.5°C) are related to quite high maximum temperatures and lead to soil drying, higher mean temperatures in October (mean temperature 1961–2010 6.8°C) enable a more gradual transition of spruce to dormancy and provide better conditions for allocation of assimilates and thus also cambium formation in the following year.

The results of the analysis of negative pointer years show two most marked drops of growth curves – in 1992 and 2004. The same drop in 1992, which was a very warm and dry year, has been observed in all our previous studies (Rybníček et al. 2010, 2012a, 2012b). However, the second most significant negative pointer year in the other analysed areas was 2003, which was very dry and hot (Rybníček et al. 2009, 2010, 2012a, 2012b). The fact that the second significant negative pointer year in the central part of the Českomoravská Upland was 2004, i.e. a year later, can be explained by the prevailing presence of water-affected sites and the fact that in 2002 the sum of precipitation was above average. The precipitation in July 2002 was 209 mm, the following months were average until the end of winter in 2003. Thus in 2003 spruces to a large extent profited from the water stored in the soil (especially in the first half of the growing season) and the water content probably decreased only in the second half of summer.

The results of tree condition assessment show a prevailing proportion of resistant trees (Table 3). This shows that mainly the static component of resistance – strain avoidance – is used in over a half of the trees (Levitt 1972). The total defoliation, the defoliation of the primary structure and the degree of transformation were average in the context of the Czech Republic (Table 3). The values ascertained were surprisingly similar to the values from a considerably warmer and drier part of the SE Českomoravská Upland investigated earlier (Rybníček et al. 2012b). The average total defoliation was the same; the defoliation of the primary structure (63%) and the percentage of secondary shoots (44%) were slightly higher in the central part compared to 58% defoliation of the primary structure and 37% of secondary shoots in the SE Českomoravská Upland. When comparing the habitual diagnostics with dendrochronological analysis, the difference between the two areas in the recent years (which tree condition assessment mainly reflects) was the dynamics of the development of the radial increment. The tree-ring width dropped to values between 1 mm and 1.5 mm in both areas after the extremely dry year 2003, but with considerably larger interannual fluctuations in the SE Českomoravská Upland dependent on the amount of summer precipitation. Spruces in the SE Českomoravská Upland face interannual precipitation fluctuation repeatedly – their assimilatory apparatus is adapted to a large extent and the defoliation (in contrast to drops in the radial increment) therefore occurs only when a longer or stronger precipitation deficit occurs.

The results have confirmed our hypotheses: we found mainly positive correlations of summer sums of precipitation with the ring width and negative correlations of summer temperatures with the ring width. Also the results of the habitual diagnostics have shown a relatively low degree of crown transformation which indicates a weak or short-term stress load.

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References

Aakala T., Kuuluvainen T. 2011. Summer droughts depress radial growth of Picea abies in pristine taiga of the Arkhangelsk province, northwestern Russia. Dendrochronologia 29: 67–75.

Affolter P., Büntgen U., Esper J., Rigling A., Weber P., Luterbacher J., Frank D. 2010. Inner Alpine conifer response to 20th century drought swings. European Journal of Forest Research 129: 289–298.

Andreassen K., Solberg S., Tveito O.E., Lystad S.L. 2006. Regional differences in climatic responses of Norway spruce (*Picea abies* L. Karst) growth in Norway. Forest Ecology and Management 222: 211–221.

Biondi F., Waikul K. 2004. DendroClim2002: AC++ program for statistical calibration of climate signals in tree ring chronologies. Computers and Geosciences 30: 303–311.

Bouriaud O., Popa I. 2009. Comparative dendroclimatic study of Scots pine, Norway spruce, and silver fir in the Vrancea Range, Eastern Carpathian Mountains. Trees 23: 95–106.

Büntgen U., Frank D.C., Kaczka R.J., Verstege A., Zwijacz-Kozina T., Esper J. 2007. Growth responses to climate in a multi-species tree-ring network in the Western Carpathian Tatra Mountains, Poland and Slovakia. Tree Physiology 27: 689–702.

Cook E.R., Peters K. 1981. The smoothing spline: a new approach to standardizing forest interior tree–ring width series for dendroclimatic studies. Tree Ring Bulletin 41: 45–53.

Cook E.R., Kairiukstis L.A. 1990. Methods of Dendrochronology – Applications in the Environmental Sciences. Kluwer Academic Publisher and International Institute for Applied Systems Analysis, Dordrecht, Boston, London, pp. 394.

Cudlín P., Novotný R., Moravec I., Chmelíková E. 2001. Retrospective evaluation of the response of montane forest ecosystems to multiple stress. Ekológia 20: 108–124.

Čejková A., Kolář T. 2009. Extreme Radial Growth Reaction of Norway Spruce along an Altitudinal Gradient in the Šumava Mountains. Geochronometria 33: 41–47.

Čermák P. 2007. Defoliace a radiální rùst jako ukazatelé vitality smrku ztepilého. Lesnická práce 86: 14–15.

Desplanque C., Rolland C., Schweingruber F.H. 1999. Influence of species and abiotic factors on extreme tree ring modulation: *Picea abies* and *Abies alba* in Tarentaise and Maurienne (French Alps). Trees 13: 218–227.

Feliksik E. 1993. Wpływ klimatu na wielkość przyrostów radialnych lasotwórczych gatunków, występujących na terenie leśnictwa Bukowiec. Acta Agraria et Silvestria, Series Silvestris 31: 39–46.

Feliksik E., Wilczyński S., Wałecka M. 1994. Klimatyczne uwarunkowania przyrostów kambialnych świerka pospolitego (*Picea abies* (L.) Karst.) w leśnictwe Pierściec. Acta Agraria et Silvestria. Series Silvestris 32: 53–59.

Frank D., Esper J. 2005. Characterization and climate response patterns of a high-elevation, multi-species tree-ring network in the European Alps. Dendrochronologia 22: 107–121.

Fritts H.C., Mosimann J.E., Bottorff C.P. 1969. A Revised Computer Program for Standardizing Tree – Ring Series. Tree Ring Bulletin 29: 15–20.

Fritts H.C. 1976. Tree ring and climate. Academic Press. London, New York, San Francisco, pp. 567.

Grabařová S., Martinková M. 2000. Changes of Norway spruce (*Picea abies* /L./ Karst.) growth characteristics under the impact of drought. Ekológia (Bratislava) 19, Supplement 1/2000: 81–103.

Grabařová S., Martinková M. 2001. Changes in mineral nutrition of Norway spruce (Picea abies /L./ Karst.) under the impact of drought. Ekológia (Bratislava) 20, Supplement 1/2001: 46–60.

Grissino-Mayer H.D., Holmes R., Fritts H.C. 1992. International tree–ring data bank program library. Version 1.1. Laboratory of Tree–Ring Research, University of Arizona, Tucson.

Holmes R.L., Adams R.K., Fritts H.C. 1986. Tree-Ring Chronologies of Western North America: California, Eastern Oregon and Northern Great Basin with Procedures Used in the Chronology Development Work Including Users Manuals for Computer programs Cofecha and Arstan. – Chronology Series VI. Laboratory of Tree – Ring Research, University of Arizona, Tuscon, AZ, USA: 50–56.

Kienast F., Schweingruber F.H., Bräker O.U., Schär E. 1987. Tree ring studies on conifers along ecological gradients and the potential of single-year analyses. Canadian Journal of Forest Research 17: 683–696.

Koprowski M., Zielski A. 2006. Dendrochronology of Norway spruce (*Picea abies* (L.) Karst.) from two range centres in lowland Poland. Trees 20: 383–390.

Kozlowski T.T., Pallardy S.G. 1997. Growth Control in Woody Plants. Academic Press, San Diego: pp. 641.

Kroupová M. 2002. Dendroecological study of spruce growth in regions under long-term air pollution load. Journal of Forest Science 48: 536–548.

Larcher W. 1988. Fyziologická ekologie rostlin. Academia, Praha: pp. 361.

Lesinski J.A., Landman G. 1995. Crown and branch malformation in conifers related to forest decline. In Cape, J.N., Mathy, P., (eds.) Scientific basis of forest decline symptomatology. Air Pollution Research Report 15: 95–105.

Levitt, J. 1972. Responses of plants to environmental stresses. Academic Press, New York: pp. 698.

Mäkinen H., Nöjd P., Mielikäinen K. 2001. Climatic signal in annual growth variation in damaged and healthy stands of Norway spruce [*Picea abies* (L.) Karst.] in southern Finland. Trees 15: 177–185.

Miyamoto Y., Griesbauer H.P., Green D.S. 2010. Growth responses of tree coexisting conifer species to climate Gross wide geographic and climate ranges in Yukon and British Columbia. Forest Ecology and Management 259: 514–523.

MZE ČR, VÚLHM 2004. Monitoring stavu lesa v České republice 1984–2003. MZe ČR, VÚLHM, Praha: pp. 432.

Pichler P., Oberhuber W. 2007. Radial growth response of coniferous forest trees in an inner Alpine environment to heat-wave in 2003. Forest Ecology and Management 242: 688–699.

Rybníček M., Čermák P., Kolář T., Přemyslovská E., Žid T. 2009. Influence of temperatures and precipitation on radial increment of Orlické hory Mts. spruce stands at altitudes over 800 m a.s.l. Journal of Forest Science 55: 257–263.

Rybníček M., Čermák P., Kolář T., Žid T. 2010. Radial Growth and Health Condition of Norway Spruce (*Picea abies* (L.) Karst.) Stands in Relation to Climate (Silesian Beskids, Czech Republic). Geochronometria 36: 9–16.

Rybníček M., Čermák P., Hadaš P., Žid T., Kolář T. 2012a. Dendrochronological Analysis and Habitual Stress Diagnostic Assessment of Norway Spruce (*Picea abies*) Stands in the Drahany Highlands. Wood research 57 (2), in press.

Rybníček M., Čermák P., Kolář T., Žid T. 2012b. Growth responses of *Picea abies* to climate in the south-east part of the Českomoravská vrchovina Upland (Czech Republic). Geochronometria 39: 149–157.

Savva Y., Oleksyn J., Reich P.B., Tjoelker M.G., Vaganov E.A., Modrzynski J. 2006. Interannual growth response of Norway spruce to climate along an altitudinal gradient in the Tatra Mountains, Poland. Trees 20: 735–746.

Schweingruber F.H. 1996. Tree Rings and Environment Dendroecology. Birmensdorf, Swiss Federal Institute for Forest, Snow and Landscape Research, Bern, Stuttgart, Vienna: pp. 609.

Spiecker H. 2002. Tree rings and forest management in Europe. Dendrochronologia 20: 191–202.

Šmelko Š., Wolf J. 1977. Štatistické metódy v lesníctve. Príroda, Bratislava: pp. 330.

Štěpánek P. 2007. ProClimDB – software for processing climatological datasets. CHMI, regional office Brno. http://www.climahom.eu/ProcData.html

Vitas A. 2004. Tree rings of Norway spruce (*Picea abies* (L.) Karsten) in Lithuania as drought indicators: dendroecological approach. Polish Journal of Ecology 52: 201–210.

Xu Y.J., Röhrig E., Fölster H. 1997. Reaction of root systems of grand fir (*Abies grandis* Lindl.) and Norway spruce (*Picea abies* Karst.) to seasonal waterlogging. Forest Ecology and Management 93: 9–19.