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Influence of temperatures and precipitation on radial increment of Orlické hory Mts. spruce stands at altitudes over 800 m a.s.l.

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ABSTRACT: Research on the influence of temperatures and precipitation on radial increment was carried out in spruce stands over ninety years old in the surroundings of Anenský vrch in the Orlické hory Mts. at altitudes over 800 m above sea level. To model diameter increment in dependence on climatic conditions, the standard tree-ring and correlation analysis together with the analysis of negative pointer years were used. The diameter increment has a statistically significant correlation with temperatures in July of each year in question. The growth of spruce is also affected to a statistically significant degree by precipitation in July of the previous year and by precipitation in February and March of the year in question. The standard tree-ring chronology shows an obvious decrease in radial increments starting at the beginning of the 1970s and ending at the end of the 1980s. The lowest increments were recorded for 1974, 1980, 1984 and 1986. These years with low increments were also confirmed by the analysis of negative pointer years. In the following period there is an increase in increments, with slight decreases in 1996 and 2000, which, however, according to the analysis of negative pointer years do not demonstrate any significant reduction of increments. Another decrease was recorded starting in 2003 and this lasted until the studied period, i.e. 2007. The current condition of spruce stands is certainly the result of more stressors but it appears that with the current air pollution load the climatic conditions are the factor determining the resulting effect of the synergic influence of the stressors on the stands.

Keywords: Orlické hory Mts.; tree-ring analysis; spruce; climate; radial increments

Climatic conditions are the most important natural factors affecting the tree growth. These natural factors are permanently stored in the structure of the created biomass and so trees monitor the state of the environment in the structure of their rings (Fritts 1976). Therefore, it is possible to use the method of the dendrochronological analysis for modelling the climatic environment influence with success. The cornerstone of dendrochronological applications is the knowledge that trees growing in the same area, it means in the same conditions, have the same reaction expressed by the volume of created wood. Therefore, there is a similarity of changes in tree-ring width within a stand, especially as far as minimum and maximum values are concerned (Schweingruber 1996). These features then allow us to date favourable and unfavourable periods not only in recent years but also in distant past.

The most significant climatic factors that can even cause damage to wood are mainly extreme fluctuations of temperatures, insufficient precipitation, snow, wind and frost (Schweingruber 1996). Temperatures are the main factor limiting the wood growth in the mountains (Larcher 1988). The di-

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rect effect of the temperature on the growth is most frequent at the beginning of the vegetation season when low temperatures can result in postponing the start of cambial activity (Fritts 1976). The radial growth can be influenced by temperatures both above average and below average. High temperatures in the year before the tree-ring is created together with high radiation can increase the evaporation intensively and the following decrease in soil moisture in the top ground layer then reduces the creation of nutrients and also water availability during the following spring, especially if the precipitation of this period is below average. Similarly, also extremely low temperatures, especially in connection with drought, can negatively influence the increments, most significantly at the highest mountain altitudes (Čermák 2007). Mountain stands can be considerably damaged mainly during winter and at the beginning of spring as a result of 'physiological drought'. This damage is caused by long-term freezing of the soil surrounding the tree root system (Tranqullini 1979). Above-average temperatures during the vegetation season usually affect the radial growth positively. However, if they are too high, they can induce a decrease in the carbon balance and the consequence is a decrease in increments (Čermák 2007).

Water directly affects the activity of the cambium even though in some periods the cambium is more sensitive to the lack of water than in others. The main source of water in the system is atmospheric rainfall which affects the water balance in dependence on its amount, intensity and time distribution during the vegetation period (Horáček 1994). Precipitation is the main factor limiting the wood growth at lower altitudes (Larcher 1988). Tree radial growth can be influenced both by precipitation in the previous year and by precipitation in that particular year. Precipitation in spring of the previous year and precipitation in winter, spring and summer of that particular year are of the highest importance. The positive correlation between precipitation and growth, i.e. an increase in growth with the volume of precipitation, is supported with evidence mainly for lower and medium altitudes; the relation cannot often be supported with evidence for the highest altitudes. The negative correlation between the tree-ring width and precipitation, i.e. a decrease in increments consequent to above-average precipitation mainly during July and August, was only found in areas with exceedingly high precipitation, for example on the German side of the Krušné hory Mts. (Čermák 2007).

The aim of the paper is therefore to examine the effect of the most important climatic factors (temperature and precipitation) on the radial increment of selected spruce stands in the Orlické hory Mts.

MATERIAL AND METHODS

Research was carried out in a production forest in spruce stands over ninety years old in the surroundings of Anenský vrch (hill) in the Orlické hory Mts. at altitudes over 800 above sea level. Four stands were chosen (Table 1). The first, ninety years old stand (50°13'41"N, 16°28'30"E), was at the altitude of 830 m above sea level. The second, a hundred and twenty years old stand (50°13'49"N, 16°29'47"E), was at the altitude of 870 m a.s.l. The third, a hundred years old stand (50°14'07"N, 16°29'11"E), was at the altitude of 910 m a.s.l. The last stand (50°13'43"N, 16°29'17"E) was a hundred and forty years old and was also at the altitude of 910 m a.s.l. Twenty-two samples were taken in each stand.

Sample extraction, preparation and measurement

Samples were taken and processed in correspondence with the standard dendrochronological methodology (Cook, Kairiukstis 1990). The samples were taken using the Pressler borer. Bore holes were done at 1.3 m above the ground, one sample taken from each tree. The samples were fixed into wooden slats and their surface was ground off. The wood samples were then measured using a specialized measuring table equipped with an adjustable screw device and an impulse-meter 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 PAST 32 application. The annual wood increments were measured to the nearest 0.01 mm.

After measuring a comparison (cross-dating) of individual measured curves was made. Cross-dating is seeking the synchronous positions of two tree-ring series. Both series are compared at all possible mutual positions. The aim 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 (Vinař et al. 2005). The excellently correlating curves were used to create the average tree-ring curve. 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 curves was evaluated using the correlation coefficient and the parallelism coefficient (Gleichläufigkeit). These calculations facilitate the optical comparison of both curves, which is crucial for the final dating (Rybníček et al. 2007).

Removal of the age trend of tree-ring curves

Individual tree-ring series were exported from PAST 32 to the ARSTAN application (Grissino-Mayer et al. 1992), where they were detrended, autocorrelation was removed and the regional standard tree-ring chronology and the regional residual tree-ring chronology were created. The removal of the age trend was carried out using a two-step detrending method (Holmes et al. 1986). First, a negative exponential function or a linear regression curve, which best express the change in the growth trend with age, were used (Fritts 1963; 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, Peters 1981). The chosen length of the spline function was 67% of the detrended tree-ring curve length (Cook, Kairiukstis 1990).

From the tree-ring series detrended in this way the regional index residual tree-ring chronology was created in the ARSTAN application. The chronology has low values of autocorrelation. The standard regional tree-ring chronology was also established. The range of the created regional tree-ring chronologies is from 1888 to 2007.

Creation of the climatic time series for the Orlické hory Mts.

For the purposes of our research the climatic time series of temperatures and precipitation for the Orlické hory Mts. was created as the space average out of two available meteo stations. The first of them is a station in Rokytnice v Orlických horách (50°10'N, 16°28'E), which is about 5 km far from the studied stands and it is at the altitude of 580 m a.s.l. The second station is in Deštné v Orlických horách (50°18'N, 16°21'E) at the altitude of 649 m a.s.l. The resulting continual temperature series comprises the years 1956 up to 2005 and the precipitation series 1961 up to 2005.

Modelling of climatic influences

To model the diameter increments in dependence on the climatic characteristics the DendroClim application was used (Biondi, Waikul 2004). Before the modelling itself it was necessary to convert the output data from ARSTAN to the input format of DendroClim. 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 average monthly temperatures and precipitation for the Orlické hory Mts. were used to calculate the correlations of values of diameter increments with climatic factors. They were always calculated from May of the previous year till August of the year in question, i.e. the period of 16 months. It is the period that should have the highest influence on the radial increments in that particular year.

Analysis of negative pointer years

The statistical comparison of time series of diameter increments 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 is 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 was 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 four previous years; a strong increment reduction was found at least in 20% of the trees from the area (Kroupová 2002).

RESULTS

When comparing the average tree-ring curves of the individual stands, the statistical indicators show

Table 1. Description of stands

Stand number	Mark	GPS	Altitude (m a.s.l.)	Forest type	Slope orientation	Age	Species composition (%)	Stocking	Mean-tree volume
1	59A9	50°13'41"N 16°28'30"E	830	6K1	S	96	spruce 90 beech 10	8	1.21
2	42F12	50°13'49"N 16°29'47"E	870	6S1	NE	126	spruce 70 beech 30	7	1.32
3	41B10	50°14'07"N 16°29'11"E	910	7K1	E	105	spruce 98 beech 2	8	0.68
4	60C14	50°13'43"N 16°29'17"E	910	7K5	SE	141	spruce 65 beech 35	8	1.10

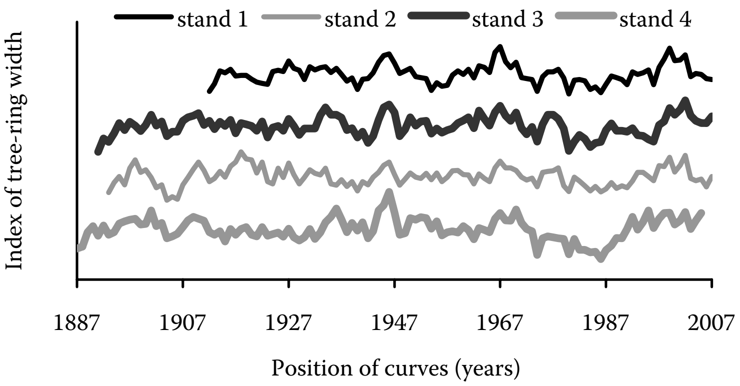

Fig. 1. Synchronization of average tree-ring curves of individual stands

Table 2. Synchronization of average tree-ring curves of individual stands

Compared curves	*T*-test		Synchronization of curves (%)
	(according to Baillie & Pilcher)	(according to Hollstein)	
Stand 1 × stand 2	11.66	9.36	77
Stand 1 × stand 3	12.63	11.06	82
Stand 1 × stand 4	7.85	10.02	83

high values. When the curves overlap by sixty rings at least, the critical value of Student's *t*-distribution with 0.1% level of significance is 3.46 (Šmelko, Wolf 1977). The values of our *t*-tests are much higher than 3.46, which shows high reliability of the synchronization (Table 2). The correctness of the synchronization is also proved by the agreement of the average tree-ring curves in most of the extreme values (Fig. 1). Thanks to these results, only one average tree-ring curve representing the radial increment of all four stands together could be created.

Correlation of the diameter increments with the average monthly temperatures and precipitation shows only positive statistically significant values. The diameter increments correlate to a statistically significant degree with the temperatures in July of the year in question (Fig. 2). Spruce growth is also influenced to a statistically significant degree by the precipitation in July of the previous year and by precipitation in February and March of the year in question (Fig. 3).

The standard regional tree-ring chronology shows a decrease in the radial increments starting at the beginning of the 1970s and ending at the end of the 1980s (Fig. 4). The lowest increments were recorded for 1974, 1980, 1984 and 1986. These years with low increments were also confirmed by the analysis of negative pointer years (Table 3). In the following period there is an increase in increments, with slight interruptions in 1996 and 2000. Another decrease was recorded starting in 2003 and this lasted until the studied period, i.e. 2007.

DISCUSSION AND CONCLUSIONS

The aim of the correlation analysis was to find out what climatic factors affect spruce growth in the

Table 3. Negative pointer years (highlighted in bold)

1956	**1973**	1990
1957	**1974**	1991
1958	1975	1992
1959	1976	1993
1960	1977	1994
1961	1978	1995
1962	**1979**	1996
1963	**1980**	1997
1964	**1981**	1998
1965	1982	1999
1966	1983	2000
1967	**1984**	2001
1968	1985	2002
1969	**1986**	**2003**
1970	1987	2004
1971	1988	2005
1972	1989	2006

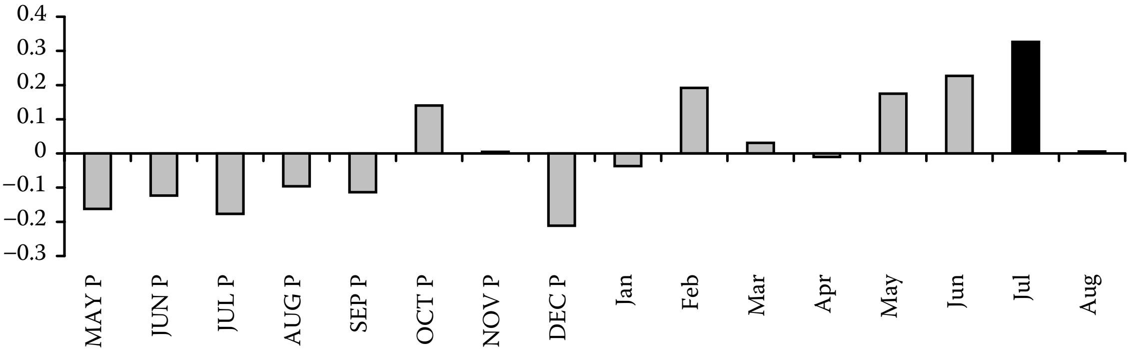

Fig. 2. The values of correlation coefficients of the regional residual index tree-ring chronology with the average monthly temperatures from May of the previous year (P) to August of the year in question in the period of 1956–2005. Values highlighted in black are statistically significant (α = 0.05)

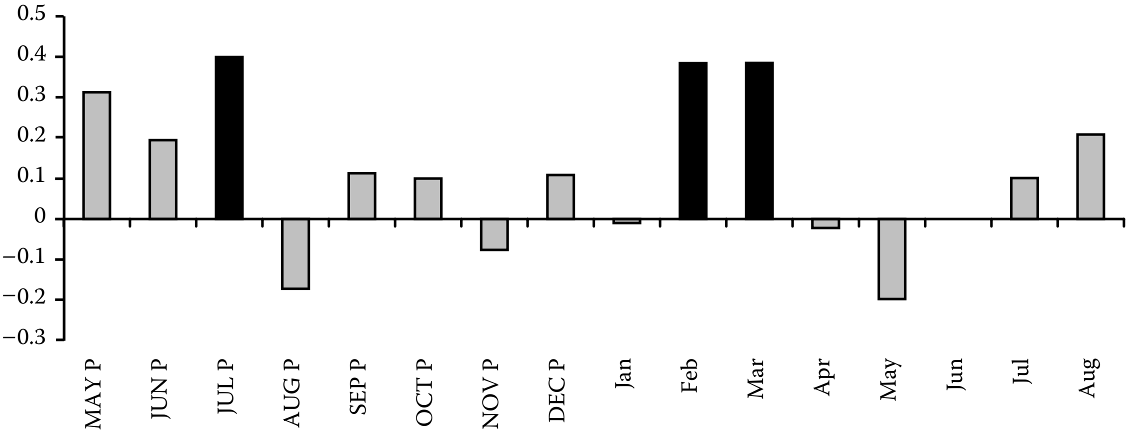

Fig. 3. The values of correlation coefficients of the regional residual index tree-ring chronology with the average monthly precipitation from May of the previous year (P) to August of the year in question in the period of 1961–2005. Values highlighted in black are statistically significant (α = 0.05)

selected area of the Orlické hory Mts. To calculate the correlations of diameter increment values with climatic factors the regional residual index tree-ring chronology and the climatic time series of average monthly temperatures and precipitation for the area of the Orlické hory Mts. were used. The length of the tree-ring chronology is 119 years (1888–2007), the temperature series comprises the years 1956 up to 2005 and the precipitation series 1961 up to 2005. The correlations of diameter increment values with average monthly temperatures and precipitation were always calculated from May of the previous year till August of the year in question.

The results show that the diameter increments demonstrate only positive statistically significant correlations. The diameter increments correlate to a statistically significant degree with the temperatures in July of the year in question and with the precipitation in July of the previous year, i.e. the months when a considerable part of annual increments is created. July has long been the warmest month of the year; it means that temperatures do not limit the growth of spruce if its water supply is not disrupted. If spruce water distribution is reduced, the stress is usually manifested a year later. Positive correlations of spruce growth with summer precipitation and temperatures were also found at lower altitudes of the French Alps (Desplanque et al. 1999) or the Polish Beskids (Feliksik et al. 1994). Similar results showing the positive effect of July temperatures on spruce growth were also seen in subalpine spruce forests of the Western Carpathians (Bednarz et al. 1997), in northern expositions of the Elbe valley in the Krkonoše Mts. (Sander et al. 1995) and in the Polish Tatras (Feliksik 1972). The positive influence of precipitation in July of the previous year was also found at lower altitudes of the Krušné hory Mts. (Kroupová 2002). The growth of spruce is also influenced to a statistically significant degree by the precipitation in February and March of the year in question. This dependence was found in the Polish part of the Beskids (Feliksik 1993). The positive correlation of the increments with

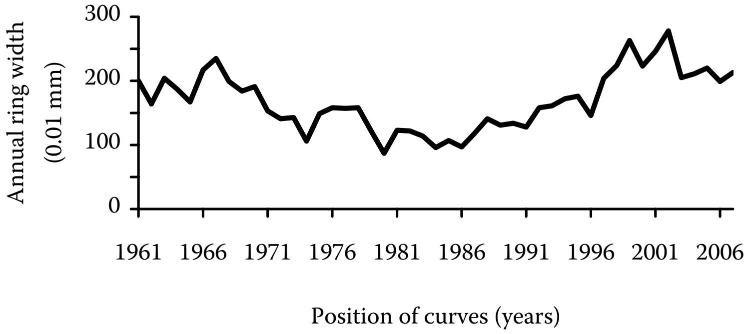

Fig. 4. Regional standard chronology from the Orlické hory Mts.

February and March precipitation can be explained by snowfalls. The snow cover protects the ground from being frozen through and thus the root system cannot be damaged as a cause of physiological drought at the beginning of spring.

The regional standard tree-ring chronology shows a decrease in the radial increments starting at the beginning of the 1970s and ending at the end of the 1980s. The lowest increments were recorded for 1974, 1980, 1984 and 1986. These years with low increments were also confirmed by the analysis of negative pointer years. The main cause of this significant decrease is most probably the heavy air pollution load, mainly SO_2 pollutants in the 1970s (Žid, Čermák 2008). This period was also critical for spruce forests in the Krušné hory Mts. and later for spruce forests in the Jizerské hory Mts. and the Krkonoše Mts. (Kroupová 2002). In the following period there is an increase in increments, with slight interruptions in 1996 and 2000, which, however, according to the analysis of negative pointer years do not demonstrate any significant reduction of increments. In this period winters were mild without any significant temperature extremes, high temperatures in the vegetation period and also lower air pollution (Kroupová 2002). The damaged spruce stands manifested their ability to regenerate by an increase in increments starting at the beginning of the 1990s. Another decrease was recorded starting in 2003 and this lasted until the studied period, i.e. 2007. The year 2003 was characterized by a dry and warm vegetation period. Similar results were recorded in the Silesian Beskids (Slezské Beskydy) (Šrámek et al. 2008).

The current condition of spruce stands is certainly the result of more stressors but it appears that with the current air pollution load the climatic conditions are the factor determining the resulting effect of the synergic influence of the stressors on the stands.

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Vliv teplot a srážek na radiální přírůst smrkových porostů Orlických hor v nadmořských výškách nad 800 m

ABSTRAKT: Výzkum vlivu teplot a srážek na radiální přírůst probíhal na smrkových porostech s věkem nad devadesát let v okolí Anenského vrchu v Orlických horách v nadmořských výškách nad 800 m. Pro modelování tloušťkového přírůstu v závislosti na klimatických charakteristikách byla použita standardní letokruhová a korelační analýza doplněná analýzou významných negativních let. Tloušťkový přírůst statisticky významně kladně koreluje s teplotami v měsíci červenci aktuálního roku. Růst smrku je také statisticky významně ovlivněn srážkami v červenci předchozího roku a srážkami v únoru a březnu aktuálního roku. Ze standardní letokruhové chronologie je patrný pokles radiálního přírůstu od počátku sedmdesátých let do konce osmdesátých let dvacátého století. Nejnižší přírůsty jsou zaznamenány v letech 1974, 1980, 1984 a v roce 1986. Tyto roky s nízkým přírůstem byly potvrzeny i analýzou negativních významných let. V následujícím období je patrné zvýšení přírůstu s mírným poklesem pouze v roce 1996 a 2000, které ovšem podle analýzy negativních významných let nevykazují žádnou významnou redukci přírůstu. Další pokles je zaznamenán v roce 2003 a trvá až do konce sledovaného období, tedy do roku 2007. Současný stav smrkových porostů je zcela jistě výsledkem působení více stresorů, ovšem ukazuje se, že při současné imisní zátěži jsou klimatické faktory činitelem, který rozhoduje o výsledném efektu synergického působení těchto stresorů na porosty.

Klíčová slova: Orlické hory; letokruhová analýza; smrk; klima; radiální přírůst

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