EXTREME RADIAL GROWTH REACTION OF NORWAY SPRUCE ALONG AN ALTITUDINAL GRADIENT IN THE ŠUMAVA MOUNTAINS

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Received 4 May 2009 Accepted 27 July 2009

Abstract: Extreme radial growth reactions were analyzed over a 79-year period (1922-2000) to compare response of Norway spruce (Picea abies [L.], Karst.) along an altitudinal gradient (376-1221 m a.s.l.) in the Šumava Mountains, the Czech Republic. Extreme growth events were defined as pointer years, when an average percentage of the site pointer years reached at least 50% strength observed at the relevant altitudinal zone (low < ca. 700 m; middle ca. 700-950 m, high > ca. 950 m). The comparison of the pointer years showed a specific pattern for altitudinal zones (Low: negative pointer years 2000, 1992, 1984, 1976, 1971 and positive 1997, 1975, 1960, 1949, 1932, 1926; middle: negative 2000, 1992, 1976 and positive 1997, 1975, 1960, 1949, 1932, 1926; high: negative 1996, 1980, 1974, 1965 and positive 1989, 1963, 1927). Negative pointer years were usually induced by summer drought at low elevations and by wet-cold summer at high altitudinal zone. These two main limiting factors were probably combined at the middle altitudinal zone. Detailed understanding of the extreme tree ring pattern along the altitudinal and geographical scale may be used as one of the additional indicators of dendrochronological dating and provenance identification of spruce sample among altitudinal zones in the Šumava Mountains.

Keywords: dendrochronology, Picea abies, pointer years, altitudinal gradient.

1. INTRODUCTION

The methods of dendrochronology are an effective tool for analyzing the ecological relationship among tree species and environment (e.g. Fritts, 1976; Schweingruber, 1996). Tree-ring series contain an aggregation of a finite number of signals that represent the sum of the environmental influences on a tree growth (Cook and Kairiukstis, 1990). Climate signal is considered as one of the main controlling factors for the tree growth, and the tree response is modified by tree species, provenience, competition, site conditions etc. (Fritts, 1976; Vitas, 2004; Spiecker, 2002). To understand the relationship between the tree growth and complex actions of climate, correlation and response function analyses have been developed (Fritts, 1976; Cook and Kairiukstis, 1990).

This approach ordinarily provides the concept about the average response of trees to the range of climate factors. Such information is very useful for studying climate reconstructions and climate changes over long periods (e.g. Rolland et al., 1998; Solberg et al., 2002; Esper et al., 2002; Wilson et al., 2005a; Wilson et al., 2005b). The above mentioned techniques have not revealed climatic forcing of single extreme years (e.g. Kienast et al., 1987). Analyses of extreme growth events and comparison with instrumental data serve for this purpose (Schweingruber et al., 1990) and could validate the temporal stability of the climate-growth relationship (Neuwirth et al., 2004). When such an event year is detected simultaneously in the majority of trees in the same population, it is named “pointer year”. Only these extreme growth changes common for relevant altitudinal zone are comprised in this study. To illustrate the behavioral differences of the Norway spruce to extreme climatic conditions, we analyzed 17 Norway spruce (Picea abies [L.] Karst.) popula-
2. MATERIAL AND METHODS

For this study, 17 sites of Norway spruce of relatively similar character were chosen along an altitudinal gradient in the Šumava Mountains and its foothills from ca. 375 to 1315 m a.s.l. (Table 1, Fig. 1). Most of the studied sites are plantations, particularly at low and middle elevations. In each stand, 20 dominant trees without visible signs of damage were selected as sample trees. Two increment cores were taken from each tree at the height of 1.3 m above ground.

Tree-ring widths were measured within 0.01 mm accuracy, using the measuring device (TimeTable) and the computer program Past32 (Knibbe, 2003). Tree-ring series with dissimilar growth were not used for the analysis of pointer years.

Pointer years for each stand were determined by the method of “Normalization in a moving window” (Crapper, 1979; this method was also described in Schweingruber et al., 1990 and Meyer, 1999). Extreme growth reaction within a sequence of an individual tree is called an event year, synchronous event years of one site are referred to as pointer years (Schweingruber et al., 1990).

In the first step, event years were calculated using a five-year moving window in each measured tree-ring width series following this formula:

\[
    z_i = \frac{x_i - \text{mean}[\text{window}]}{\text{stdev}[\text{window}]} 
\]  

\(z_i\) – index value in the year \(i\)

\(x_i\) – original value in the year \(i\)

mean [window] – arithmetic mean of the ring width within the window \(x_i, x_i-1, x_i-2, x_i+1, x_i+2\)

stdev [window] – standard deviation of the ring width within the window \(x_i, x_i-1, x_i-2, x_i+1, x_i+2\)

Negative and positive event years demand for threshold values of \(z_i\), which were \(z_i \geq -1\) and \(1\).

In the second step, the site pointer year was determined when the event value recurred in at least 50% of tree-ring width series per population.

The pointer years of the 17 site chronologies were analyzed along an altitudinal gradient for the common time span of 1922-2000. The whole period of individual chronologies is longer (from 83 to 275 years, Table 1), but the common interval with sufficient numbers of measurements for every stand started in 1922. In our previous study (Čejková and Kolář, 2005) we identified three categories of altitudinal zones (low < ca. 700 m; middle ca. 700-950 m, high > ca. 950 m). Common altitudinal pointer years were determined for each of these altitudinal zones, and they were recognized when the average percentage of site pointer years reached at least 50%.

For the climatic interpretation of pointer years meteorological data from České Budějovice (mean temperature and monthly sum of precipitation) were used. This series were used for its longer time period and relatively close distance of the study area.

3. RESULTS AND DISCUSSION

Pointer years on the altitudinal gradient


The highest tree responses to the changes of the environmental factors are often observed at low altitudes and particularly on the southern slopes (Rolland et al., 2000). The same trend was determined for populations of Norway spruces at the low altitudinal zone of the Šumava foothills where the trees reacted more frequently than at the high altitudinal zone. Spruces had extreme growth reactions along the whole altitudinal gradients only since the 1960s and eminent abrupt reductions were higher than positive increments (Fig. 2). It could be a consequence of the negative correlation between the tree age and its tree-ring width. Schweingruber (1986) demonstrated that younger trees were unable to react whereas the reactions of the mature individuals were obvious (Schweingruber, 1986). Another and probable explanation is the negative influence of air pollution (above all SO\(_2\)) in central Europe (e.g. Visser and Molenaar, 1992; Wilson and Elling, 2004 – Bavarian forest-Germany; Sander et al., 1995 – Giant Mountain-Czech Republic). In the first part
of the analyzed time span (1922-1960), the trees reacted only extremely positively in the low altitudinal zone, weakly in the high altitudinal zone and no reaction was found by means of this calculation method in the middle altitudinal zone. Most positive growth responses are stronger with the ecological limits of the species (Fritts, 1976). In this case, the abiotic ecological limit of the spruce is at low altitudes; the centre of the occurrence of Picea abies is the mountainous (750-1100 m a.s.l.) and above all the supramountainous zone (1000-1370 m) in the Czech Republic (Skalický and Skalická, 1988). Trees growing in average climatic conditions react in a weaker way to the changes of climatic factors and the relationship between radial increment and climatic conditions may be more complex in average conditions. The factors that affect radial increment may change from year-to-year (Mäkinen et al., 2003).

Climatic interpretation of pointer years and the large-scale comparison for Europe

In the low altitudinal zone, the expression of negative pointer years (years: 1971, 1976, 1984, 1992, 2000; 0

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Table 1. Climatic interpretation of pointer years: - negative, + positive pointer year, L – low altitudinal zone (< ca. 700 m), M – middle altitudinal zone (ca. 700-950 m), H – high altitudinal zone (> ca. 950 m).

<table>
<thead>
<tr>
<th>Altitudinal zone</th>
<th>Sand code</th>
<th>Location</th>
<th>Altitude (m)</th>
<th>Chronology time span</th>
<th>Mean age</th>
<th>No. of radii (trees)</th>
<th>Site description</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>001p</td>
<td>49°06 35,8' N 14°13 36,6' E</td>
<td>376</td>
<td>1908-2002</td>
<td>86</td>
<td>30 (17)</td>
<td>plain, mixed forest: Picea abies, Pinus sylvestris with Rubus sp.</td>
</tr>
<tr>
<td></td>
<td>003p</td>
<td>49°06 08,1' N 14°07 24,4' E</td>
<td>537</td>
<td>1900-2001</td>
<td>94</td>
<td>29 (20)</td>
<td>plain, spruce forest with Calamagrostis ephigejos</td>
</tr>
<tr>
<td></td>
<td>004p</td>
<td>49°04 26,1' N 14°11 24,9' E</td>
<td>480</td>
<td>1883-2002</td>
<td>105</td>
<td>27 (17)</td>
<td>plain, mixed forest: Picea abies, Pinus sylvestris with Avenella flexuosa</td>
</tr>
<tr>
<td></td>
<td>006p</td>
<td>49°09 03,8' N 14°00 29,0' E</td>
<td>624</td>
<td>1884-2002</td>
<td>91</td>
<td>27 (16)</td>
<td>west gentle slope (5°) mixed forest: Picea abies, Abies alba with Calamagrostis arundinacea</td>
</tr>
<tr>
<td></td>
<td>007p</td>
<td>49°05 11,4' N 14°01 07,9' E</td>
<td>520</td>
<td>1908-2002</td>
<td>81</td>
<td>23 (17)</td>
<td>plain, mixed forest: Picea abies, Pinus sylvestris, Larix decidua with Carex brizoides</td>
</tr>
<tr>
<td></td>
<td>008p</td>
<td>49°04 16,9' N 13°55 53,2' E</td>
<td>698</td>
<td>1910-2002</td>
<td>81</td>
<td>18 (14)</td>
<td>plain and gentle slope, mixed forest: Picea abies, Abies alba, Pinus sylvestris with Calamagrostis arundinacea</td>
</tr>
<tr>
<td>high</td>
<td>010p</td>
<td>48°58 45,2' N 13°33 02,7' E</td>
<td>1 313</td>
<td>1857-2002</td>
<td>118</td>
<td>26 (14)</td>
<td>summit site, spruce forest with Calamagrostis villosa</td>
</tr>
<tr>
<td></td>
<td>011p</td>
<td>48°58 38,2' N 13°33 29,0' E</td>
<td>1 255</td>
<td>1865-2002</td>
<td>111</td>
<td>23 (15)</td>
<td>small plain in east slope (10°), spruce forest with Calamagrostis villosa</td>
</tr>
<tr>
<td></td>
<td>012p</td>
<td>49°02 16,4' N 13°34 54,3' E</td>
<td>1 118</td>
<td>1839-2002</td>
<td>110</td>
<td>28 (17)</td>
<td>plain, spruce forest with Avenella flexuosa</td>
</tr>
<tr>
<td></td>
<td>013p</td>
<td>49°02 22,7' N 13°37 08,1' E</td>
<td>1 218</td>
<td>1837-2002</td>
<td>136</td>
<td>27 (15)</td>
<td>summit site, spruce forest with Calamagrostis villosa</td>
</tr>
<tr>
<td></td>
<td>014p</td>
<td>49°00 10,8' N 13°37 51,2' E</td>
<td>1 047</td>
<td>1858-2002</td>
<td>124</td>
<td>28 (16)</td>
<td>southwest slope (5°), spruce forest with Calamagrostis villosa</td>
</tr>
<tr>
<td></td>
<td>015p</td>
<td>49°00 10,8' N 13°37 51,2' E</td>
<td>1 221</td>
<td>1729-2002</td>
<td>177</td>
<td>32 (19)</td>
<td>plain in southwest slope (10°), spruce forest with Calamagrostis villosa</td>
</tr>
<tr>
<td></td>
<td>016p</td>
<td>49°03 12,8' N 13°39 54,7' E</td>
<td>979</td>
<td>1736-2002</td>
<td>190</td>
<td>30 (17)</td>
<td>plain, spruce forest with Calamagrostis villosa</td>
</tr>
<tr>
<td>middle</td>
<td>017p</td>
<td>49°03 32,2' N 13°42 54,9' E</td>
<td>946</td>
<td>1901-2002</td>
<td>93</td>
<td>29 (15)</td>
<td>southeast gentle slope (5°), spruce forest with Avenella flexuosa and Vaccinium myrtillus</td>
</tr>
<tr>
<td></td>
<td>020p</td>
<td>49°01 54,8' N 13°48 29,8' E</td>
<td>835</td>
<td>1910-2002</td>
<td>86</td>
<td>19 (10)</td>
<td>gentle slope and plain, spruce forest with Avenella flexuosa and Vaccinium myrtillus</td>
</tr>
<tr>
<td></td>
<td>021p</td>
<td>49°08 09,5' N 13°30 45,6' E</td>
<td>842</td>
<td>1879-2004</td>
<td>105</td>
<td>34 (19)</td>
<td>plain, mixed forest: Picea abies, Pinus sylvestris, Abies alba with Vaccinium myrtillus</td>
</tr>
<tr>
<td></td>
<td>022p</td>
<td>49°06 43,4' N 13°33 25,2' E</td>
<td>760</td>
<td>1849-2004</td>
<td>110</td>
<td>28 (18)</td>
<td>east gentle slope (5°), mixed forest: Picea abies, Abies alba, Fagus sylvestris, Tilia cordata with Calamagrostis villosa</td>
</tr>
</tbody>
</table>
Extreme radial growth reaction of Norway spruce along an altitudinal gradient in the Western Alps is probably connected with an insufficient amount of precipitation during the vegetation period (above all in May and June) and with the drought during a part of the vegetation period of the previous year. The lack of water usually interacts with warm temperatures in spring and summer that increase dehydration of the tree and result in a negative relationship between ring-width and temperature (Dittmar and Elling, 1999). The strong impact of drought coincided above all with the beginning of vegetation; mainly during tree-ring formation (Rolland et al., 1999; Vitas, 2001).

Positive pointer years are, to the contrary, connected with enough precipitation during the growing season (1926, 1932, 1949, 1960, 1975, 1997; Fig. 3a, Table 2). It corresponds with the findings that in central Europe the annual growth of the Norway spruce was mainly related to precipitation (e.g. Koprowski and Zielski, 2006; Mäkinen et al., 2002; Wilson and Hopfmueller, 2001), and dry summers were connected to lower growth rates (cf. Eckstein et al., 1989; Spiecker, 1991). A typical positive pointer year of low elevations was 1932. The initiation of tree-ring formation was positively influenced by high precipitation and below-average temperature above all in May; similar situation with a rainy but warmer than usual summer led to larger ring widths in Southern French and Italian Alps (Rolland et al., 2000) and the north foothill of the Alps in Switzerland (Schweingruber et al., 1991).

On the other hand, the drought period from May to August induced the highest growth reduction (Schweingruber, 1986). The Norway spruce is very sensitive to drought due to its superficial root system (Chmelař, 1986). This is the cause of the negative pointer year of 2000.

Table 2. Climatic interpretation of pointer years: - negative, + positive pointer year, L – low altitudinal zone (< ca. 700 m), M – middle altitudinal zone (ca. 700-950 m), H – high altitudinal zone (> ca. 950 m).

<table>
<thead>
<tr>
<th>Year</th>
<th>Sign</th>
<th>Zone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>-</td>
<td>L-M</td>
<td>dry and hot spring and early summer, dry previous spring to autumn (1999)</td>
</tr>
<tr>
<td>1997</td>
<td>+</td>
<td>L-M</td>
<td>rainy summer, warm and wet end winter and early spring</td>
</tr>
<tr>
<td>1996</td>
<td>-</td>
<td>H</td>
<td>severe winter, rainy spring and cold summer</td>
</tr>
<tr>
<td>1992</td>
<td>-</td>
<td>L-M</td>
<td>dry and hot spring and summer</td>
</tr>
<tr>
<td>1989</td>
<td>+</td>
<td>H-M</td>
<td>mild winter and early spring and relatively dry late spring and summer</td>
</tr>
<tr>
<td>1984</td>
<td>-</td>
<td>L</td>
<td>dry almost entire period - May 1983 to August 1984</td>
</tr>
<tr>
<td>1980</td>
<td>-</td>
<td>H</td>
<td>extremely cold growing season and after warm December cold January in combination with relatively small precipitation in this period</td>
</tr>
<tr>
<td>1978</td>
<td>+</td>
<td>M</td>
<td>cold vegetation season</td>
</tr>
<tr>
<td>1976</td>
<td>-</td>
<td>L-M</td>
<td>extremely dry late winter to early summer and relatively hot in summer, after warm January cold February and March</td>
</tr>
<tr>
<td>1975</td>
<td>+</td>
<td>L</td>
<td>wet summer and wet summer in previous year (1974) and mild winter</td>
</tr>
<tr>
<td>1974</td>
<td>-</td>
<td>H</td>
<td>cold and rainy growing season, dry autumn in previous year (1973) and dry and warm period at the winter</td>
</tr>
<tr>
<td>1971</td>
<td>-</td>
<td>L</td>
<td>relatively dry late spring and summer in previous year (1970), dry and cold January and May, dry July</td>
</tr>
<tr>
<td>1965</td>
<td>-</td>
<td>H</td>
<td>cold wet year</td>
</tr>
<tr>
<td>1963</td>
<td>+</td>
<td>H</td>
<td>relatively hot summer with low precipitation but severe winter – relationship unclear</td>
</tr>
<tr>
<td>1960</td>
<td>+</td>
<td>L</td>
<td>wet and relatively cold year, above all summer and rainy late spring and summer in previous year (1959)</td>
</tr>
<tr>
<td>1949</td>
<td>+</td>
<td>L</td>
<td>rainy spring and summer</td>
</tr>
<tr>
<td>1932</td>
<td>+</td>
<td>L</td>
<td>rainy May and July and warmer than usually in July and August</td>
</tr>
<tr>
<td>1927</td>
<td>+</td>
<td>H</td>
<td>mild winter and early summer, wet summer and autumn in previous year (1928)</td>
</tr>
<tr>
<td>1926</td>
<td>+</td>
<td>L</td>
<td>wet and cold late spring and summer, mild winter and wet previous summer (1925)</td>
</tr>
</tbody>
</table>
Fig. 3. Altitudinal variability of pointer years with temperature (T) and precipitation (P) data (mean long term data 1921-2000 and monthly values) for previous vegetation season and current year (from May of previous to September current year). Pie charts show in colored part the percentage of event years per population (The pointer year was determined, when event value was detected at least by 50% of tree-ring width series per population). a) Low altitudinal zone, b) high altitudinal zone, c) middle altitudinal zone.
1992 in the low and middle altitudinal zones in the Šumava Mountains. This drought year also had a negative impact on spruce growth in the southern French and Italian Alps (Desplanque et al., 1999, Rolland et al., 2000), in Swiss Alps (Neuwirth et al., 2004) or in the whole Lithuania on wet sites (Vitas, 2004). The most important negative year occurred in many regions of Europe in 1976, especially at lower elevations (Swiss, French and Italian Alps – Jepp, 1986; Schweingruber et al., 1991; Desplanque et al., 1999; Rolland et al., 2000, Neuwirth et al., 2004; Germany - Becker et al., 1990; Mäkinen et al., 2002; Southern Norway and Finland – Mäkinen et al., 2002). It was also detected at the elevation bellow 950 m a.s.l. in the Šumava Mountains and the foothills. 1976 was dry and warm, which prolonged the water deficit. This situation was repeated in the other sites in the Czech Republic, specifically in the Ore and Giant Mountains, but growth depression was detected in the trees bellow 800 m (Kroupová, 2002).

Generally, it is assumed that in the mountainous areas, the main driving factor of the tree growth is the temperature (Tranquillini, 1979; Rochefort et al., 1994; Rolland et al., 1998; Desplanque et al., 1999; Koprowski and Zieliski, 2006). At high elevations in southern Germany, spruce chronologies (>800-900 m) are more influenced by the temperature rather than precipitation (Dittmar and Elling, 1999). In the Czech part of the Šumava Mountains, the temperature could not be the main driving factor of ring-width formation, because this region does not reach the upper tree-line limit (Moravec, 1964; Skalický, 1998) and the trees from higher sites may not therefore demonstrate as strong response to the temperature as they would at a temperature of upper tree-line (Wilson and Hopfmüller, 2001). Positive pointer years are usually caused by low sums of precipitation and the average temperature or slightly higher temperature during the growing season (1927, 1963, 1989; Fig. 3b, Table 2) and negative pointer years with the cold especially in July and wet vegetation season (1965, 1974, 1980, 1996; Fig. 3b, Table 2). The intensive growth of the Norway spruce is connected with the summer months of June and July in the mountains (Kroupová, 2002, Savva et al., 2006) and the excessive June rainfall that are unfavorable for the ring formation at high elevations (Desplanque et al., 1999).

For instance, the stronger negative pointer year 1965 was very rainy and cold. This year was detected at the majority of sites and also in the other part of the Šumava Mountains (Trojmezná forest – Svoboda and Tichý, 2004), in Europe, for example in the French and Swiss Alps (Desplanque et al., 1999; Neuwirth et al., 2004). A similar response to extremely cold summer was observed in the high altitude zone in 1980, which is in a good agreement with the observations from Trojmezná (Svoboda and Tichý, 2004), the northern foothills of Swiss Alps (Schweingruber, 1986; Schweingruber et al., 1991) and wet sites in Lithuania (Vitas, 2004). Kroupová (2002) also connected the negative pointer year 1980 with the high concentration of air pollution during winter for localities above 1000 m in the Giant and Ore Mountains (Czech Republic).

Negative pointer year 1996 seems to be untypical; growth reduction was probably induced by a harsh winter in combination with a wet and cold vegetation season (Savva et al., 2006). Furthermore, the frozen soil may have prevented trees from absorbing soil water in March (Rolland et al., 1999). The same reduction was noted in the Ore Mountains (Kroupová, 2002), where it was connected with winter frosts and high SO2 concentrations. Frost resistance of Norway spruce is decreased by long-term high concentrations of SO2 during winter (e.g. Spalený, 1980). A relatively similar coincidence could also occur in the Šumava Mountains, because the highest SO2 concentrations in this decade was recorded for Prachatice region in 1996 (Hruška and Cienciala, 2003).

The occurrence of pointer years could be a consequence of other effects, e.g. defoliation caused by insect, mast year etc. (Schweingruber, 1996). In southern Finland, the low growth of the Norway spruce has often coincided with the production of a rich seed crop, which requires large amounts of photosynthetic products (Mäkinen et al., 2002). For example, negative pointer years 1974 or 1976, usually connected with dry years, and are also related with mast years (Selás et al., 2002). This is a probable explanation also for the negative pointer years 1980, 1971 and 1992 because they represented mast years of the Norway spruce for the whole Czech Republic.

ACKNOWLEDGEMENTS

The authors thank for anonymous reviewers for their critical and helpful comments on this paper and English-speaking friends for improving our English. This research was supported by Ministry of Education of the Czech Republic grants FRVS 1849/2003, FRVS 40/2006 and MSM6007665801.

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