ABSTRACT: Dendroecological research on the radial growth of Norway spruce in Lithuania during the 20th century has been conducted. Hypothesis of the study is following: intensity of droughts during the 20th century is the main factor determining the state of spruce forests in Lithuania. Aim of the study was to estimate the impact of dry spring and summer climate conditions on Norway spruce during the 20th century with a respect to global climate change. Climate impact on the radial growth of spruce using multivariate regression techniques and detection of pointer years (i.e. years with narrow tree rings in the majority of trees) was investigated. The results show that for radial growth of spruce the most important factor is humid beginning of summer and that from four to six pointer years to droughts during the 20th century are attributed.

KEY WORDS: air temperature, drought, global climate change, Norway spruce, pointer year, precipitation and radial growth

1. INTRODUCTION

Climate of the Earth is under increasing pressure of anthropogenic activity that is likely to provoke the climate warming and forest decline (Lamb 1995). The rapid rise of temperature, frequent droughts and other stresses decreases the stability of forest ecosystems (Parmesan and Yohe 2003; Rebetz 2002; Root et al. 2003). Tree rings have proven to be a reliable climate archive for short and long-term scales (Beniston 2002; Bitvinskas 1974; Stravinskiene 2000), therefore a dendrochronological research for the analysis of climate changes could be applied (Cherubini 2000; Roig et al. 2001; Yoo and Wright 2000).

According to the data of National forest inventory on 1st January 2001, stands of Norway spruce (Picea abies (L.) Karsten) occupy 23.1% of forest area in Lithuania (Kuliešis et al. 2001). Due to a shallow root system, Norway spruce prefers stable moisture of the soil and is an excellent indicator of droughts (Eckstein and Krause 1989; Karpavičius et al. 1996; Krause 1992; Ozolinčius 1998; Vitas 2002). Results of Lithuanian forest monitoring points to the biggest probability of Bark beetle invasions on dry stands of spruce, especially after drought periods (Karazija 1997; Ruseckas 2002). For example, due
to a catastrophic invasion of Bark beetle (*Ips typographus* L.), 3.3% of spruce stands (18.3–18.6% of mature stands) during 1993–1996 were cut off (Ozoliņš 1998). Dendroecological research carried out in other countries has demonstrated that trees growing on dry forest sites are more sensitive to droughts (Cook et al. 1988; Fritts 1987), therefore, the biggest part of experimental plots during this work were selected on dry forest sites of spruce.

Hypothesis of the study is following: intensity of droughts during the 20th century is the main factor determining the state of spruce forests in Lithuania. Aim of the study was to estimate the impact of dry spring and summer climate conditions on Norway spruce during the 20th century with a respect to global climate change.
\[ I_t = \sum_{j=1}^{m} W_j I_j \]  

\[ W_i = \begin{cases} 1 - \left( \frac{I_i - \bar{I}_t}{cS_t} \right)^2, & \text{when } \left( \frac{I_i - \bar{I}_t}{cS_t} \right)^2 < 1, \\ 0, & \text{otherwise} \end{cases} \]

\[ S_t = \text{median}\{ |I_t - \bar{I}_t| \} \]

Where: \( I_t \) – biweight mean (index) for year \( t \),
\( I_t \) – value of tree ring series (index) in year \( t \),
\( W_i \) – weight function,
\( S_t \) – robust measure of the standard deviation of frequency distribution, which will be the median absolute deviation,
\( c \) – constant is equal to nine and determines the point at which a discordant value is given a weight of zero. The outlier is totally discounted computing the mean and has no influence on the estimation of the mean index.

Two main methods for the investigation of climate – tree radial growth relationships are generally applied: the long-term correlation or regression analysis and the short-term analysis, well known as detection of event and pointer years (Schweingruber et al. 1990; Schweingruber 1990, 1993).

The long-term link between the radial growth of Norway spruce, air temperature and precipitation using a multiple regression techniques with bootstrap method – a response function (Formula 4) was estimated (Fritts 1987; Fritts and Dean 1992).

\[ W_i = \sum_{j=1}^{J} a_{ij} T_{ij} + \sum_{k=1}^{K} b_{ik} P_{ik} + \sum_{l=m}^{n} c_{il} W_l \]  

Where:
\( W_i \) – ring width in year \( I \) (index),
\( i \) equals I to n years of the calibration period,
\( T_{ij} \) – data of temperature (monthly variable \( j \) in year \( i \)),
\( a_{ij} \) – coefficient on the temperature variables,
\( P_{ik} \) – data of precipitation,
\( b_{ik} \) – coefficient on the precipitation variables,
\( W_l \) – number of lagged ring widths for up to \( m \) previous years,
\( c_{il} \) – coefficient of the \( W_l \).

Calculations of response function applying PRECON 5.17B computer program (H. Fritts, Tucson) using climatic variables from prior October to current September during 1930–1994 years was carried out. Climate data of monthly mean temperature and amount of precipitation from the nearest meteorological stations in Lithuania was selected. Obtained coefficients were used judging which climate extreme had the strongest impact inducing the pointer year in tree ring series.

The long-term regression analysis seldom permits to evaluate the information contained in conspicuous single growth rings. Year with a conspicuous feature (extreme narrow rings) within a limited section of tree ring sequence is named as "event year". The term "event year" is related to single tree-ring sample. "Pointer year" refers to a group of trees and means that many of them display an event year (narrow ring) in the same year (Schweingruber et al. 1990). Several methods have been developed for event and pointer year detection (Meyer 1998–1999). A method called "normalisation in a mowing window", proposed by H. F. Schweingruber (Schweingruber et al. 1990) was adapted. Index value for event year (i.e. year with extremely narrow ring) is calculated following Formula 5.

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

Where:
\( Z_i \) – index value in year \( i \),
\( x_i \) – original value (mm) in year \( i \),
\( \text{mean [window]} \) – arithmetic mean (mm) of the ring width within the window \( x_i, x_{i+1}, x_{i+2}, x_{i+3} \),
\( \text{stdev [window]} \) – standard deviation of the ring width within the window \( x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2} \).

The threshold value of \( Z_i \) for negative event years (i.e. years with extremely narrow ring) is \( \leq -0.75 \). Negative pointer years for each experimental plot during the 20th century were detected using a 50% threshold level of event years (i.e. years with extremely narrow ring). If pointer year (i.e. year with narrow tree rings in the majority of trees) was detected in more than half of experimental plots, this year was classified as negative pointer year for mentioned region (i.e. West, North, South or East Lithuania).
For the climatological interpretation of detected negative pointer years, data of four meteorological stations, located in Western (Klaipėda), Northern (Panevėžys), Southern (Kaunas) and Eastern (Vilnius) Lithuania was used (see Figure 1). For the estimation of droughts in spring and summer months, a slightly modified method (Formula 6) proposed by Walter (1974) was used.

\[
\begin{align*}
    P_i & \leq T_i & \text{Extreme drought} \quad (6) \\
    T_i & < P_i \leq 2T_i & \text{Drought} \\
    2T_i & < P_i \leq 3T_i & \text{Arid conditions}
\end{align*}
\]

Where:
- \( P_i \) – amount of precipitation (mm) during the month,
- \( T_i \) – average temperature (°C) during the analysed month

4. RESULTS

The long-term analysis shows the strong positive link \( (P \leq 0.05) \) between precipitation of June and the radial growth of spruce on dry forest sites (Fig. 2A). The lowest coefficients in Western and the highest in Southern Lithuania have been ascertained (Fig. 2A). Comparing with June, impact of precipitation in July and August is weaker. The highest and significant coefficients with precipitation in July were obtained only in the West Lithuania (Fig. 2A). Coefficients on wet sites are lower and insignificant (Fig. 2B).

A direct influence of air temperature in April for the radial growth of spruce on dry forest sites is weaker and mostly insignificant (Fig. 3A), comparing with precipitation in June. The coefficients that are

Fig. 1. A network of experimental plots on Norway spruce and climate regions of Lithuania. Numbers 1–47 indicates experimental plots and I–IV refers to climate regions of Lithuania: I – Western, II – Northern, III – Southern and IV – Eastern. Experimental plots on dry forest sites are marked with circles and on wet sites with triangles.
higher on south and east of Lithuania were discovered of April temperature (Fig. 3A). Link with spruce radial growth is considerably stronger on wet sites and reaches +0.30 (P £ 0.05) (Fig. 3B). Positive effect of air temperature in May prevails in all regions (Fig. 3A, 3B), but, comparing with April, is weaker. The lowest coefficients in North Lithuania were found. In June, July and August weak negative link with temperature predominate: the lowest average coefficients reach: -0.15 in June, -0.09 in July and -0.10 in August.

Summarizing presented results it could be stated that for radial growth of Norway spruce in Lithuania the most important is warmer than average April and May and on the other hand – June with high amount of precipitation.

The total number of detected negative pointer years (i.e. years with narrow tree rings in the majority of trees) during the 20th century varies from five to eight on dry forest sites (5 in the West, 7 in the North, 8 in the South and 6 in the East Lithuania). Two pointer years in 1917 and 1921 (North and West Lithuania) could not be interpreted climatologically, because of missing climate data in these years (Table 1). Four pointer years in Western, six in Northern, seven in Southern and five in Eastern Lithuania are likely attributed to droughts or arid conditions in late spring and summer:

- 4 in the West (1914, 1934, 1989 and 1992),
- 7 in the South (1931, 1941, 1964, 1979, 1980, 1989 and 1992) and

The results presented above points out, that dry climate conditions, strongly negatively affecting the radial growth of spruce, were more frequent in the South and rarer in the West Lithuania. These pointer years (i.e. years with narrow tree rings in the majority of trees) could be grouped, according to its spatial distribution, into three categories:

I. Pointer years covered the largest territory of Lithuania and detected in three or four regions: 1941, 1980 and 1992 (Fig. 4). These pointer years were also observed on wet forest sites.


These pointer years (i.e. years with narrow tree rings in the majority of trees) partially or fully induced by droughts are presented in Table 1. Number of trees with event years recorded in tree ring series is given for each region. Cold April is shown in deviation from the long-term mean of air tempera-
Table 1. Pointer years (i.e., years with narrow tree rings in the majority of trees) in the radial growth of Norway spruce on dry forest sites, partly or fully explained by dry spring and summer conditions in the West (W), North (N), South (S) and East (E) Lithuania (see Fig. 1). Number of trees is given as average percentage of trees with event years (i.e., years with extremely narrow ring). Cold April is shown as deviation (°C) from the long-term mean of temperature and droughts during May–August are expressed with abbreviations: extreme drought (ED), drought (D), arid conditions (A) and climate data gap (X). Empty cells indicate that climate conditions in these years were around the long-term mean.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of trees (%)</th>
<th>Climate extremes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>N</td>
</tr>
<tr>
<td>1910</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>1914</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>1917</td>
<td>48</td>
<td>46</td>
</tr>
<tr>
<td>1931</td>
<td>47</td>
<td>32</td>
</tr>
<tr>
<td>1934</td>
<td>46</td>
<td>50</td>
</tr>
<tr>
<td>1944</td>
<td>43</td>
<td>65</td>
</tr>
<tr>
<td>1954</td>
<td>46</td>
<td>46</td>
</tr>
</tbody>
</table>

5. DISCUSSION

The negative influence of droughts during spring and summer was already observed in 16th century by Leonardo da Vinci and validated by scientists in later times (Corona 1986; Schweingruber 1993).

Analyse of the multiple regression have shown that with a model of air temperature and precipitation it is possible to explain only up to 40% variation of the radial growth in middle latitudes of Europe. Research carried out on radial growth in extreme years is valuable for ecological analysis, because extremes and not changes in means generally have the strongest coherence with environment (Beniston 2002, Ruseckas 2002; Schweingruber 1993).

The first broadest research on tree rings of Norway spruce in Lithuania was conducted by Čerškienė (1975, 1978). Using correlation coefficients it was established that climate factors during the vegetation period, especially moisture, play the most significant role for tree rings of Norway spruce on dry sites. Besides, these years of the decrease of annual radial growth were detected in 1920–1921, 1930–1931, 1941–1942, 1954–1955 and 1964–1965. In later works, the direct influence of spring
Norway spruce and a global climate change

For the climatologically interpretation of detected negative pointer years (i.e. years with narrow tree rings in the majority of trees) data of four meteorological stations, located in Western (Klaipėda), Northern (Panevėžys), Southern (Kaunas) and Eastern (Vilnius) Lithuania was used (see Figure 1). For the estimation of droughts in spring and summer months, a slightly modified method proposed by Walter (1974) was used.

The number of May–August months with arid, drought and extreme drought climate conditions during 20th century is presented in Figure 5. Droughts were ascertained according to formula 6. Two dry periods are established: the first one – in the beginning and the second one – in the second half (beginning from 7th decade) of the


century (Fig. 5). The end of the 20th century is marked with the frequent extreme droughts (Bukantis et al. 2001; Vitas 2001).

It is also established that droughts in the last decades of 20th century lasted longer than observed in the beginning of the century (Bukantis 1998). Unusual droughts at the end of 20th century were also observed in other continents (Barbu and Popa 2003; Cook et al. 1988).
Presented results on tree ring research in other countries and in Lithuania points out that the state of spruce forests in Lithuania will be highly dependent on the frequency and intensity of droughts in the near future and closely related to climate change. Frequent unusual droughts, manifested in the last decade of the 20th century in Lithuania, according to the opinion of scientists, have been attributed to climate change (Ozolinčius 1998; Ruseckas 2002). The latest analysis shows that the global average temperature has increased by 0.6°C during the 20th century and is expected to continue rising at a rapid rate (Root et al. 2003). In spite of the fact, the models of climate change are not reliable enough; an increase in frequency of summer droughts in Lithuania is predicted (Ruseckas 2002).

Impact of climate change on vegetation is already noticeable in other countries. Parmesan and Yohe (2003) stated that: "Scientists during discussion in the Intergovernmental Panel of Climate Change (IPCC) conclude that distribution and phenological shifts of flora species are attributed to global climate change with confidence".

Results obtained in this study have demonstrated that negative pointer years (i.e. years with narrow tree rings in the majority of trees) of the radial growth of spruce induced by droughts during the 20th century were more frequent in the South than in the West Lithuania. The highest positive coefficients of response function between the radial growth of spruce and precipitation in June in Southern Lithuania indicates the biggest deficiency of precipitation in mentioned region. Consequently, more favourable growing conditions in the West Lithuania and, on the other hand, more unfavourable conditions for spruce in the South Lithuania are expected in the near future.

6. SUMMARY

Aim of the study was to estimate the impact of dry spring and summer climate conditions on Norway spruce during the 20th century with respect to global climate change. For this purpose, 47 experimental plots of spruce in four main climate regions of Lithuania were selected (Fig. 1). Thirty-one plots represent dry stands of spruce and 16 plots – wet sites. Fieldwork and measurements of tree ring width were performed according the standard methods used in dendrochronological research. A link between climate (air temperature and precipitation) and the radial growth of spruce was ascertained using multiple regression techniques (Fritts 1987; Fritts and Dean 1992) and pointer year (i.e. year with narrow tree rings in the majority of trees) analysis (Schweingruber et al. 1990). For the detection of droughts, a method proposed by Walter (1974) was adapted.

The long-term analysis of response function showed that precipitation in June (Fig. 2A) and air temperature in April (Fig. 3A) directly stimulates the radial growth of spruce on dry forest sites. The radial growth on wet sites is directly connected with high temperature in April (Fig. 3B), while coefficients with precipitation are insignificant (Fig. 2B).

The number of negative pointer years (i.e. years with narrow tree rings in the majority of trees) on dry forest sites connected to dry climate conditions in late spring and summer during the 20th century changes from four in Western to seven in Southern Lithuania. The number of trees indicating event years and climate extremes during these pointer years is given in Table 1. Empty cells in the Table 1 indicate that climate conditions were around the long-term mean.

Droughts in May and June were more frequently connected to pointer years than dry conditions in July and August. Pointer years in 1941, 1980 and 1992 have covered the biggest territory of Lithuania and observed on wet forest sites too (Fig. 4).

The end of the 20th century is recognised as one of the driest periods of the century (Fig. 5). The longer lasting and more frequent droughts may be attributed to global climate change (Ozolinčius 1998; Ruseckas 2002).

Models of climate change forecast an increase in frequency of summer droughts in Lithuania (Ruseckas 2002). Therefore, if this tendency proves out in the future, it will highly affect the state of spruce forests in Lithuania. Because the negative pointer years induced by droughts are more frequent in south of Lithuania, recurrent unfavourable growing conditions in this region and, on the other hand, favourable growing conditions are predicted in the West Lithuania.

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