POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	52	2	201–210	2004

Regular research paper

Adomas VITAS

Vytautas Magnus University, Faculty of Nature Sciences, Centre of Environmental Research, Group of Dendroclimatology and Radiometrics,
Ž.E. Žilibero 2, LT-46324 Kaunas, Lithuania,
e-mail: Adomas_Vitas@fc.vdu.lt

TREE RINGS OF NORWAY SPRUCE (*PICEA ABIES* (L.) KARSTEN) IN LITHUANIA AS DROUGHT INDICATORS: DENDROECOLOGICAL APPROACH

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; Rebetez 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; Stravinskienė 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 (Ozolinčius 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.

2. STUDY AREA

Territory of Lithuania is located between maritime and continental climate zones of middle latitude. Average year temperature in Lithuania is +6.1°C (-4.9°C in January and +17.0°C in July). Territory of Lithuania, according to the differences in climate character, is divided into four main regions (Fig. 1): Western, Northern (region of r. Mūša-Nevėžis), Southern (region of r. Nemunas lowland) and Eastern Lithuania (Bukantis 1994). The most important differences exist between the Western and other regions of Lithuania (Fig. 1).

The main differences of climate in mentioned four regions are as follows:

- Western region is characterized with the mildest. maritime climate conditions: highest amount of precipitation per year (up to 930 mm), warmest winters (temperature of January -2.8°C) and the longest period of vegetation (200–206 days).
- The smallest amount of precipitation (520–620 mm per year) is characteristic for the North Lithuania.
- Warmer winters and summers than those in the North and East are indicative for the South Lithuania.
- The most continental climate conditions with the shortest period of vegetation (185–192 days) and coldest winters (-5.0 to -6.8°C) are characteristic for the East Lithuania.

3. MATERIAL AND METHODS

For the purpose of research, 47 experimental plots of Norway spruce (*Picea abies* (L.) Karsten) in Lithuania were selected (Fig. 1). Dry stands of spruce (forest types – *Piceetum vaccinio-myrtillosum* and *Piceetum hepatico-oxalidosum*) represent 31 experimental plots and wet stands (forest types – *Piceetum myrtillosum, Piceetum myrtillo-oxalidosum* and *Piceetum aegopodiosum*) – 16 plots. Using increment borer, samples from 20 to 30 trees in each plot were taken at the breast height. Tree ring widths (earlywood and latewood separately) with preciseness of 0.01 mm were measured. For this purpose, LINTAB tree-ring measuring table and TSAP 3.12 computer program (F. Rinn Engineering Office and Distribution, Heidelberg) were used.

For the dating quality control (Eckstein 1987; Lovelius 1997), COFECHA 3.00P computer program (R.L. Holmes, Tucson) was applied. Using CHRONOL 6.00P program (R. L. Holmes, Tucson), the indexing of tree ring series in two stages was performed – according the methods, proposed by Holmes *et al.* (Holmes 1994). At first negative exponential curve or linear regression was used and after the polynomial function – spline (Formula 1), preserving 67% of variance at wavelength 21 years was fitted. Spline function consists of cubic polynomials, smoothly passing one into another at the crossing points and meeting conditions presented in Formula 2. Site chronologies were constructed as biweight robust means (Formula 3) (Cook 1985; Riitters 1990).

$$q_i(x) = a_i x^3 + b_i x^2 + c_i x + d \qquad (1)$$

Where: d – is the y – intercept,
a_i, b_i and c_i – slope coefficients,
x – time (years) from 1 to n.

$q_i(x_i) = q_{i+1}(x_i)$, functions should coincide at the crossing points (x_i), (2)

$q'_i(x_i) = q'_{i+1}(x_i)$, fluxion of functions should coincide at the crossing points,

$q''_i(x_i) = q''_{i+1}(x_i)$, curvature of smoothing curve should not change at the crossing points.

$$I_t=\sum_{j=1}^{m}W_tI_t \quad (3)$$

$$W_t=\left[1-\left[\frac{I_t-\bar{I}_t}{cS_t}\right]^2\right]^2, \text{ when } \left[\frac{I_t-\bar{I}_t}{cS_t}\right]^2<1,$$

otherwise – 0.

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

Where: $\bar{I}_t$ – biweight mean (index) for year t,
I_t – value of tree ring series (index) in year t,
W_t – 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).

$$W_i=\sum_{j=1}^{J}a_jT_{ij}+\sum_{k=1}^{K}b_kP_{ik}+\sum_{l=-m}^{-1}c_lw_l \quad (4)$$

Where:
W_i – ring width in year I (index),
i equals 1 to n years of the calibration period,
T_{ij} – data of temperature (monthly variable j in year i),
a_j – coefficient on the temperature variables,
P_{ik} – data of precipitation,
b_k – coefficient on the precipitation variables,
W_l – number of lagged ring widths for up to m previous years,
c_l – 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.

$$Z_i=\frac{x_i-mean\ [window]}{stdev\ [window]} \quad (5)$$

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

$P_i \leq T_i$	Extreme drought	(6)
$T_i < P_i \leq 2T_i$	Drought	
$2T_i < Pi \leq 3T_i$	Arid conditions	

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

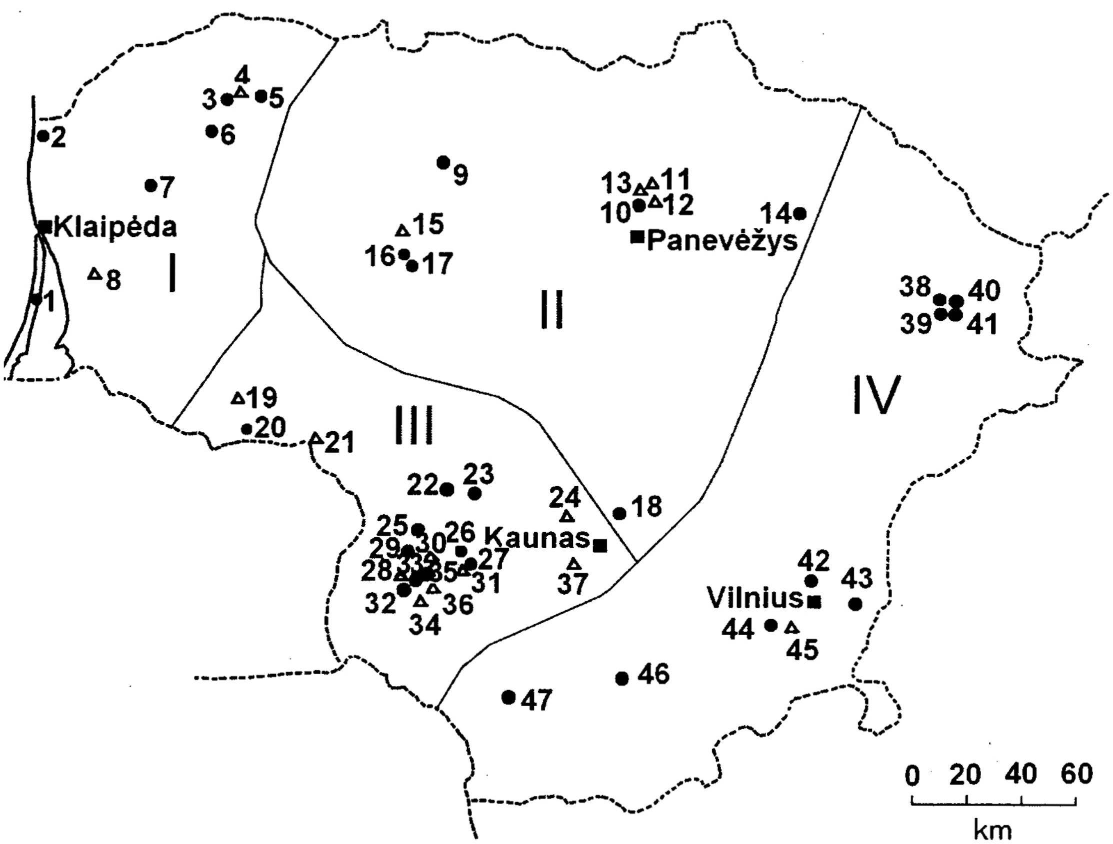

Fig. 1. A network of experimental plots on Norway spruce and climate regions of Lithuania. Numbers 1–47 indicates experimental plots and I–IV refers to climate regions of Lithuania: I – Western, II – Northern, III – Southern and IV – Eastern. Experimental plots on dry forest sites are marked with circles and on wet sites with triangles.

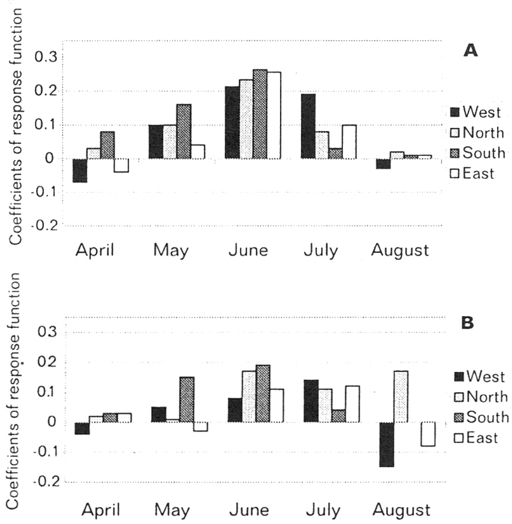

Fig. 2. Average coefficients of response functions between precipitation in April–August and the radial growth of Norway spruce on dry (A) and wet (B) forest sites in four regions of Lithuania (West, North, South and East, see Fig. 1).

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 ($P \leq 0.05$) (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

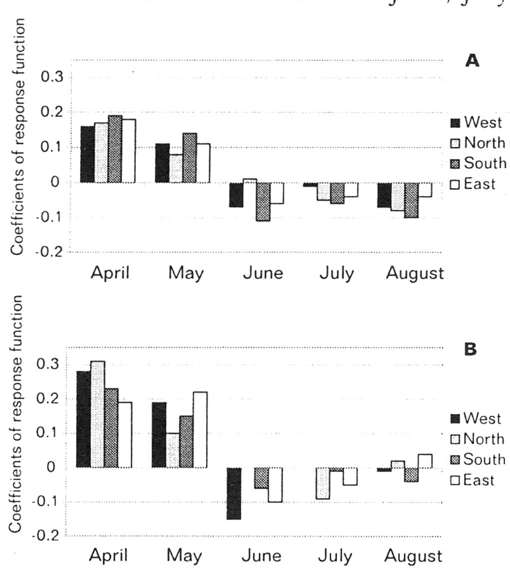

Fig. 3. Average coefficients of response functions between air temperature in April–August and the radial growth of Norway spruce on dry (A) and wet (B) forest sites in four regions of Lithuania (West, North, South and East, see Fig. 1).

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 20^{th} 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),
- 6 in the North (1941, 1954, 1964, 1979, 1980 and 1992),
- 7 in the South (1931, 1941, 1964, 1979, 1980, 1989 and 1992) and
- 5 in the East Lithuania (1910, 1941, 1971, 1980 and 1992).

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.

II. Pointer years observed in two regions: 1921, 1931, 1964, 1979 and 1989.

III. Pointer years detected in one region: 1910, 1914, 1917, 1934, 1954 and 1971.

These pointer years (i.e. years with narrow tree rings in the majority of trees) partly 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 tempe-

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.

Year	Number of trees (%)				Climate extremes				
	W	N	S	E	April	May	June	July	August
1910				58		D			
1914	50					A	D		A
1917		50			X	X	X	X	X
1921	48		57		X	X	X	X	X
1931			46		-2,6	D			
1934	47						ED		
1941		85	72	93	-3.7	A	A – D	D	
1954		52			-2,8	D			
1964		49	49			A	D	D – ED	A
1971				52		ED		D	D
1979		63	65			A – D	D		
1980		50	56	83		A	A		
1989	46		48			D			
1992	61	60	57	62		A	D – ED	A – D – ED	A

rature and droughts during May–August detected using formula 6 are presented with abbreviations: ED – extreme drought, D – drought and AP – aridity conditions.

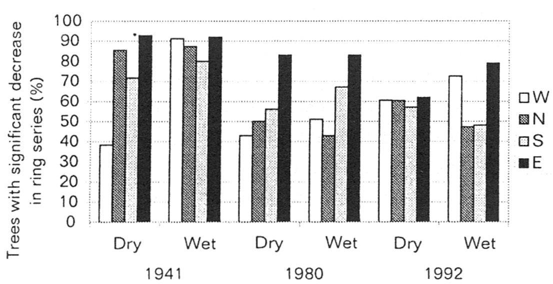

Fig. 4. Percentage of Norway spruce trees with detected event years (i.e. years with extremely narrow tree ring) in 1941, 1980 and 1992, expressed as medians in the West (W), North (N), South (S) and East (E) Lithuania (Fig. 1) on dry and wet forest sites.

From the Table 1 it is evident that droughts of May (11) and June (7) were more frequently related to pointer years than dry conditions in July (4) and August (6). Conditions of cool April were observed in 1931, 1941 and 1954.

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 temperature and summer precipitation and negative impact of precipitation in winter on tree ring widths of spruce was confirmed (Karpavičius *et al.* 1996).

Studies carried out in Germany, southern Sweden, Poland and Norway show that tree ring growth of Norway spruce is favoured by high spring temperature and cool wet summer (Alexandrowicz *et al.* 1997; Eckstein and Krause 1989; Linderson 1992). Recent research conducted on tree rings of Norway spruce in northeast Poland (Masurian Lakes district) has demonstrated that precipitation at the end of spring and summer (May–August) is of importance. Positive link with air temperature in March and negative impact of previous November and current June was ascertained too. Analysis of pointer years (i.e. years with narrow tree rings in the majority of trees) confirmed that trees negatively responded to spring and summer droughts, and cool springs. Spruce is determined to be resistant enough to cold winters in Baltic region (Zielski and Koprowski 2001; Koprowski and Zielski 2002). The number of pointer years detected during this research in different regions of Lithuania (from 4 to 7) that were induced by droughts is similar to number of pointer years detected in Poland (6 years during the 20th century).

Norway spruce is the second mostly spread coniferous species in Lithuania that is why its future perspectives of prosperity are important not only to scientists of different fields, but also to foresters. According to the results of Ruseckas (2002), during the severe summer droughts, humidity in the upper layer of soil reaches the humidity of drooping, which reduces the vitality of trees and reflects in the radial growth. During such droughts, the small roots in the upper layer of the soil are dried off (Ruseckas 2002). According to the opinion of Moosmayr (1988), decline of forests in Europe is strongly driven by unfavourable meteorological factors. Such droughts also decrease the resistance of spruce trees to invasions of Bark beetle (Ozolinčius 1998; Vaivada 1999). Looking on the other hand, Norway spruce in Lithuania grows near the southern limit of its habitat (Hanisch and Kilz 1990) and therefore is more sensitive to climate fluctuation than Scots pine is.

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

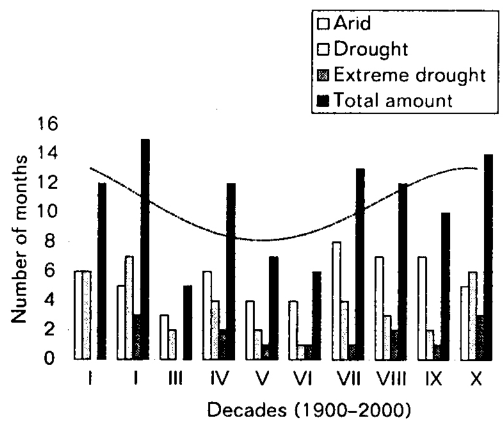

Fig. 5. Number and total amount of months with arid, drought and extreme drought conditions during May–August in ten decades of the 20th century (I – 1900–1910, II – 1911–1920, III – 1921–1930, IV – 1931–1940, V – 1941–1950, VI – 1951–1960, VII – 1961–1970, VIII – 1971–1980, IX – 1981–1990, X – 1991–2000) in Lithuania, according Vilnius Meteorological Station. Line indicates the polynomial trend of the total amount of droughts.

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 bigger 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.

7. REFERENCES

Alexandrowicz W. P., Krapiec M., Szychowska-Krapiec E. 1997 – Zmiany środowiska południowej Polski w okresie historycznym [Changes of the environment in southern Poland during a historical period] – Geologia, 23(4): 340–387. (in Polish)

Barbu I., Popa I. 2003 – Monitoringul secetei în pădurile din România [Monitoring of

droughts in Romanian forests] – Editura Tehnică Silvică, Câmpulung Moldovenesc, 128 pp. (in Romanian)
Beniston M. 2002 – Climate modelling at various spatial and temporal scales: where can dendrochronology help? – Dendrochronologia, 20 (1–2): 117–131.
Bitvinskas T. T. 1974 – Dendroklimaticheskie issledovania [Dendroclimatological research] – Gidrometeoizdat, Leningrad, 172 pp. (in Russian)
Bukantis A. 1994 – Lietuvos klimatas [Climate of Lithuania] – VU leidykla, Vilnius, 187 pp. (in Lithuanian)
Bukantis A. 1998 – Neįprasti gamtos reiškiniai Lietuvos žemėse XI–XX amžiuose [The unusual natural phenomena in the territory of Lithuania in 11th–20th centuries] – Geografijos institutas, Vilnius, 197 pp. (in Lithuanian)
Bukantis A., Gulbinas Z., Kazakevičius S., Kilkus K., Mikelinskienė A., Morkūnaitė R., Rimkus E., Samuila M., Stankūnavičius G., Valiuškevičius G., Žaromskis R. 2001 – Klimato svyravimų poveikis fiziniams geografiniams procesams Lietuvoje [The Influence of Climatic Variations on Physical Geographical Processes in Lithuania] – Vilniaus universitetas, Geografijos institutas, Vilnius, 280 pp. (in Lithuanian)
Cherubini P. 2000 – Tree-Ring research beyond the climate change: "Quo vadis?" – Dendrochronologia, 18: 91–93.
Corona E. 1986 – Dendrochronologia: Principi e applicazioni [Dendrochronology – principles and applications] – Thesis of the seminar held on 14–15th of November in Verona. Istituti italiano di dendrochronologia, Verona, p. 103. (in Italian)
Cook E. R. 1985 – A Time Series Analysis Approach to Tree-Ring Standardization – Ph. D. Dissertation. Tucson.
Cook E. R., Kablack M. A., Jacoby G. C. 1988 – The 1986 drought in Southeastern United States: how rare an evant was it? – Journal of geophysical research, 93: 257–260.
Čerškienė I. 1975 – Research on radial growth of spruce stands in Lithuanian SSR – Summary of Doctoral dissertation. Kaunas, Lithuanian Agricultural Academy, 23 pp. (in Russian)
Čerškienė I. 1978. Annual radial growth dynamic of spruce stands in Lithuania (In: Environment conditions and radial growth of trees, Ed. T. Bitvinskas) – Institute of Botany of Lithuanian SSR, Kaunas, p. 19–21. (in Russian)
Eckstein D. 1987 – Measurement and dating procedures in dendrochronology (In: Methods of Dendrochronology, Eds.: L. Kairiūkštis, Z. Bednarz, E. Feliksik) – IIASA, Warsaw, 3: 35–44.
Eckstein D., Krause C. 1989 – Dendrochronological studies on spruce trees to monitor environmental changes around Hamburg – IAWA bulletin, 10: 175–182.
Fritts H. 1987 – Tree Rings and Climate – IIASA, Polish Academy of Sciences Systems Research Institute, Warsaw, 1–2, 567 pp.
Fritts H. C., Dean J. S. 1992 – Dendrochronological modelling of the effects of climatic changes on the tree-ring width chronologies from Chaco Canyon and environs – Tree-Ring Bulletin, 52: 31–58.
Hanisch B., Kilz E. 1990 – Monitoring of forest damage – Ulmer, Stuttgart, 317 pp.
Holmes R. L. 1994 – Dendrochronology program library – Laboratory of Tree-ring Research, University of Arizona, Tucson.
Karazija S. 1997 – Eglynų džiūties priežastys ir auginimo perspektyvos [Causes of spruce drying and perspectives of growing] – Musū girios, 7: 4–6. (in Lithuanian)
Karpavičius J., Yadav R. R., Kairaitis J. 1996 – Radial Growth Response of Pine (*Pinus sylvestris* L.) and Spruce (*Picea abies* (L.) Karst.) to Climate and Geohydrological factors – Paleobotanist, 45: 148–151.
Koprowski M., Zielski A. 2002 – Lata wskaźnikowe u świerka pospolitego (*Picea abies* (L.) Karsten) na Pojezierzu Olsztyńskim [Pointer years of Norway spruce (*Picea abies* (L.) Karsten) in Olsztyn Lake District] – Sylwan, 11: 29–39. (in Polish)
Krause C. 1992 – Ganzbaumanalyse von Eiche, Buche, Kiefer und Fichte mit dendroökologischen Methoden [Complete analysis of Oak, Beech, Pine and Spruce using dendroecological methods] – Ph. D. dissertation. University of Hamburg, Hamburg, 163 pp. (in German)
Kuliešis A., Rutkauskas A., Butkus A. (Eds) 2001 – Lietuvos miškų valstybinė apskaita 2001 m. sausio 1 d. [State inventory of Lithuanian forests according 1st January of 2001] – LVMI, Kaunas, 76 pp. (in Lithuanian)
Linderson H. 1992 – Dendroclimatological investigation in Southern Sweden (In: Proceedings of the International Dendrochronology Symposium "Tree Rings and Environment", Ed. O. Eggertsson) – Lund University, Lund, p. 198–201.
Lovelius N. V. 1997 – Dendroindication of Natural Processes – World&Family-95, St. Petersburg, 316 pp.
Lamb H. 1995 – Climate History and Modern World – Routledge, London, 433 pp.
Meyer F. D. 1998–1999 – Pointer year analysis in dendroecology: a comparison of methods – Dendrochronologia, 16–17: 193–204.
Moosmayr H. U. 1988 – Stand der Forschung über das Waldsterben – Allgemeine Forstzeitung, 43: 1365–1373. (in German)

Parmesan C., Yohe G. 2003 – A globally coherent fingerprint of climate change impacts across natural systems – Nature, 421: 37–42.

Ozolinčius R. 1998 – Lietuvos spygliuočiai: morfologinės struktūros transformacijos bei jas indikuojantys veiksniai [Conifers in Lithuania: transformation of morphological structure and factors inducing them] – Lututė, Kaunas, 300 pp. (in Lithuanian)

Rebetez M. 2002 – La Suisse se réchauffe [Switzerland in Greenhouse] – Presses polytechniques romandes, 140 pp. (in French)

Riitters K. H. 1990 – Analysis of Biweight Site Chronologies: Relative Weights of Individual Trees Over Time – Tree-Ring Bulletin, 50: 11–19.

Roig F. A., Le-Quesne C., Boninsegna J. A., Briffa K. R., Lara A., Grudd H., Jones P. D., Villagran C. 2001 – Climate variability 50.000 years ago in mid-latitude Chile as reconstructed from tree rings – Nature, 410: 567–570.

Root T. L., Price J. T., Hall K. R., Schneider S. H., Rosenzweig C., Pounds A. J. 2003 – Fingerprints of global warming on wild animals and plants – Nature, 421: 57–60.

Ruseckas J. 2002 – Miško ir drėgmės sąveika [Interaction between forest and moisture] – Lututė, Kaunas, 200 pp. (in Lithuanian)

Schweingruber F. H. 1990 – Dendroecological Information in Pointer Years and Abrupt Growth Changes (In: Methods of Dendrochronology, applications in the Environmental Sciences, Eds.: E. Cook and L. Kairiukštis) – Kluwer, Dordrecht, pp. 277–283.

Schweingruber F. H. 1993 – Jahrringe und Umwelt dendroökologie [Tree Rings and the World of Dendroecology] – Lis, Vologda, 474 pp. (in German)

Schweingruber F. H., Eckstein D., Serre-Bachet F., Bräker O. U. 1990 – Identification, Presentation of Event Years and Pointer Years in Dendrochronology – Dendrochronologia, 8: 9–38.

Stravinskienė V. 2000 – Klimato veiksnių ir antropogeninių aplinkos pokyčių dendrochronologinė indikacija Lietuvoje [Dendrochronological indication of climatic factors and anthropogenic environmental trends] – Summary of Doctoral dissertation. Kaunas, 42 pp. (in Lithuanian)

Vaivada S. 1999 – Žievėgraužio tipografo (*Ips typograhus* L.) žiemojimo ypatumai [Peculiarities of wintering of bark beetle (*Ips typographus* L.)] (In: Proceedings of the Conference of Young Scientists "Forests and Environmental Sciences in the beginning of 3rd millennium", Ed. G. Marcinkevičiūtė) – Lututė, Kaunas, p. 136–140. (in Lithuanian)

Vitas A. 2001 – Drought of 1992 in Lithuania and consequences to Norway spruce – Baltic Forestry, 7 (2): 25–30.

Vitas A. 2002 – Klimato veiksnių įtaka paprastosios eglės (*Picea abies* (L.) Karsten) radialiajam prieaugiui [Impact of climate factors on the radial increment of Norway spruce (*Picea abies* (L.) Karsten)] – Doctoral dissertation. Kaunas, 114 pp. (in Lithuanian)

Walter H. 1974 – Vegetatia Pământului. – Stiintifică, Bucuresti. (in Romanian)

Yoo S. J., Wright B. D. 2000 – Persistence of Growth Variation in Tree-Ring Chronologies – Forest Science, 46 (4): 507–520.

Zielski A., Koprowski M. 2001 – Dendrochronologiczna analiza przyrostów rocznych świerka pospolitego na Pojezierzu Olsztyńskim [A dendrochronological analysis of annual rings in Norway spruce of the Olsztyn Lake District] – Sylwan, 7: 65–73. (in Polish)

(Received after revising November 2003)