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

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Abstract

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

Keywords: *air temperature, drought, Norway spruce, pointer year, precipitation and radial growth*

Introduction

Climate of the Earth is under increasing pressure of anthropogenic activity and likely to provoke the climate warming and forest decline [20]. The rapid rise of temperature, frequent droughts and other stresses decreases the stability of forest ecosystems [25, 27, 30]. Tree rings have proven to be a reliable climate archive for short and long-term scales [2, 3, 34], therefore a dendrochronological research for the analysis of climate changes could be applied [6, 29, 38].

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 [19]. Due to a surface root system, Norway spruce prefers stable moisture of the soil and is an excellent indicator of droughts [12, 16, 18, 26, 37]. Results of Lithuanian forest monitoring points to the biggest probability of Bark beetle invasions on dry stands of spruce, especially after droughty periods [15, 31]. 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 [26]. Dendroecological research, carried out in other countries have demonstrated that trees growing on dry forest sites are more sensitive to droughts [8, 13], therefore, the biggest part of research plots during this work on dry forest sites of spruce were selected.

Aim of the study was a dendroecological research on Norway spruce to estimate the impact of dry spring and summer climate conditions during 20th century with a respect to global climate change.

Material and methods

Territory of Lithuania is located between maritime and continental climate of middle latitude. Average year temperature in Lithuania is +6.1^{o}C (in January – -4.9^{o}C and in July –

+17.0ºC). 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 [4]. The most important differences exist between the western and other regions of Lithuania.

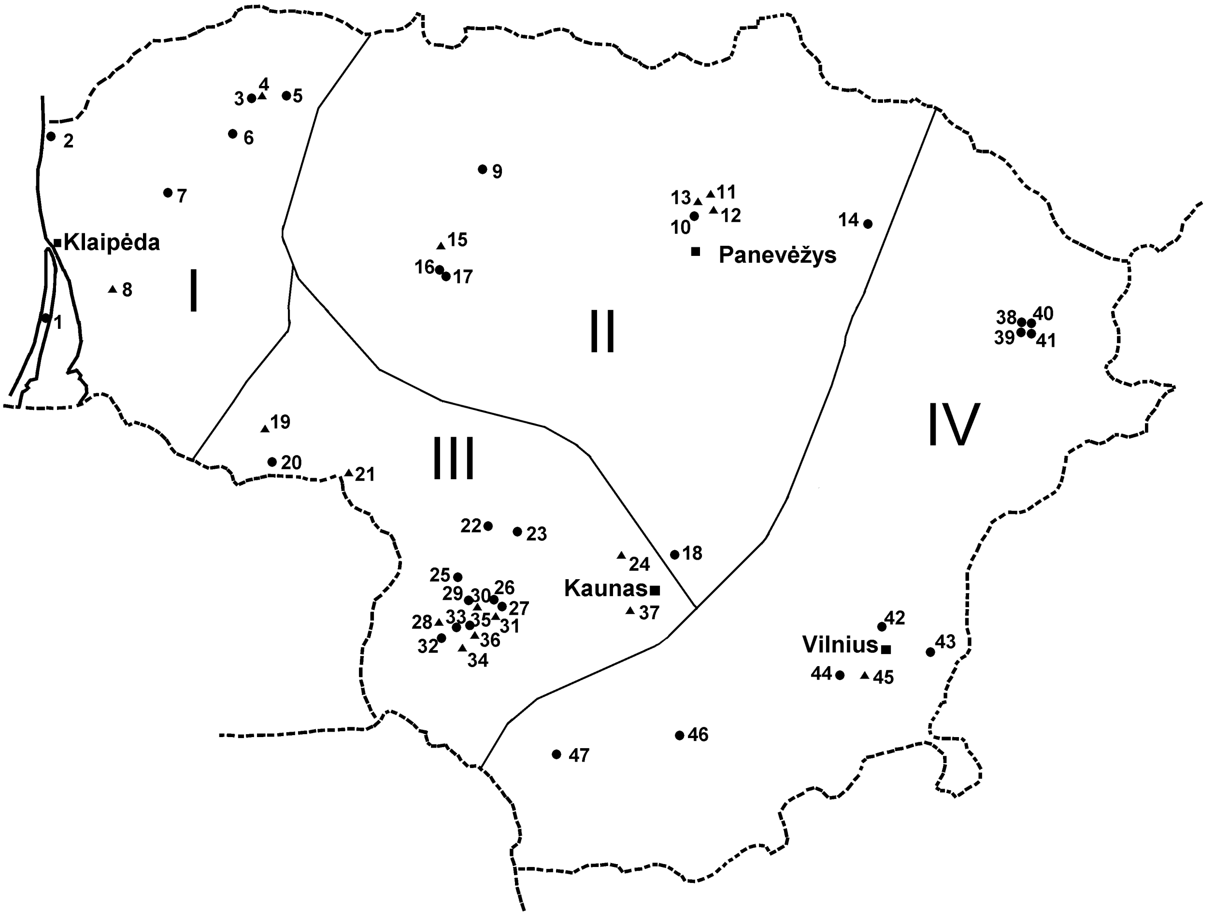

Fig. 1. A network of research plots on Norway spruce and climate regions of Lithuania. Number 1-47 indicates research plots and I-IV refers to climate regions of Lithuania: I – western, II – northern, III – southern and IV – eastern. Research plots on dry forest sites are marked with circles and on wet sites with triangles

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 – -2.8ºC) 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 in the north and east for the south Lithuania are indicative.
- The most continental climate conditions with the shortest period of vegetation (185-192 days) and coldest winters (-5.0 – -6.8ºC) for the east Lithuania are characteristic.

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 research 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 [11, 22], COFECHA 3.00P computer program (R.L. Holmes, Tucson) was applied. Using CHRONOL 6.00P program (R.L. Holmes, Tucson), the indexing in two stages was performed. At first negative exponential curve or linear regression was used and after the polynomial function – spline Eq. (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 Eq. (2). Site chronologies were constructed as biweight robust means Eq. (3) [29].

$$q_i(x) = a_ix^3+b_ix^2+c_ix + d \tag{1}$$

d – is the y-intercept, a_i, b_i and c_i – slope coefficients, x – time in years from 1 to n

$$q_i(x_i)=q_{i+1}(x_i)\ ;\ q'_i(x_i)=q'_{i+1}(x_i);\ q''_i(x_i)=q''_{i+1}(x_i) \tag{2}$$

where $q_i(x_i)$ - functions should coincide at the crossing points (x_i), $q'_i(x_i)$ - fluxion of functions should coincide at the crossing points, $q''_i(x_i)$- curvature of smoothing curve should not change at the crossing points.

$$\bar{I}_t = \sum_{j=1}^{m} w_tI_t \tag{3}$$

$$w_t = \left[1 - \left[\frac{I_t - \bar{I}_t}{cS_t}\right]^2\right]^2, \text{ when } \left[\frac{I_t - \bar{I}_t}{cS_t}\right]^2 <1, \text{ otherwise} - 0.$$

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

S_t is a 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 [32, 33].

The long-term link between air temperature, precipitation and the radial growth of Norway spruce using a multiple regression techniques with bootstrap method – a response function Eq. (4) was estimated [13, 14]:

$$W_i = \sum_{j=1}^{J} a_j T_{ij} + \sum_{k=1}^{K} b_k P_{ik} + \sum_{l=-m}^{-1} c_l W_l \tag{4}$$

i equals 1 to n years of the calibration period, W_i – indexed ring width in year i, T_{ij} – data of temperature (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 using PRECON 5.17B computer program (H. Fritts, Tucson) during 1930–1994 years from the prior October to current September was carried out. Climate data of monthly mean temperature and amount of precipitation from the nearest meteorological stations in Lithuania were selected. Obtained coefficients were used judging which climate extreme has had the strongest impact inducing the pointer year.

Several methods have been developed for event and pointer year detection [23]. A method called "normalisation in a mowing window", proposed by H.F. Schweingruber [32] was adapted. Index value for event year is calculated following Eq. (5).

$$Z_i = \frac{x_i - \text{mean}[\textit{window}]}{\text{stdev}[\textit{window}]} \tag{5}$$

Z_i – index value in year i, x_i – original value in year i, mean [window] – arithmetic mean of the ring width within the window x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2} and 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 is ≤ -0.75. Negative pointer years for experimental plots during 20th century were detected and summarized for four regions of Lithuania using a 50% threshold level.

For the climatologically 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 conditions of humidity in spring and summer months, a hydrothermal indicator proposed by T. Bitvinskas was adapted [3] Eq. (6):

$$H_i = \frac{T_i}{P_i} \tag{6}$$

H_i – hydrothermal indicator (bigger values of the coefficient indicates drier conditions), T_i – average temperature during the analysed month, P_i – amount of precipitation during the same month.

Results

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

A direct influence of air temperature in April for the radial growth of spruce on dry forest sites is weaker and mostly insignificant, comparing with precipitation in June. The coefficients that are higher on south and east Lithuania were discovered (Fig. 2). Link with spruce radial growth on wet sites is stronger considerably and reaches +0.43 ($p \leq 0.05$). Positive effect of air temperature in May prevails in all regions (Fig. 2), but, comparing with April, is weaker. The higher coefficients in south and east Lithuania were found. In June, July and August predominate weak negative link with temperature (the lowest coefficients in June reach -0.24, in July – -0.17 and in August – -0.19).

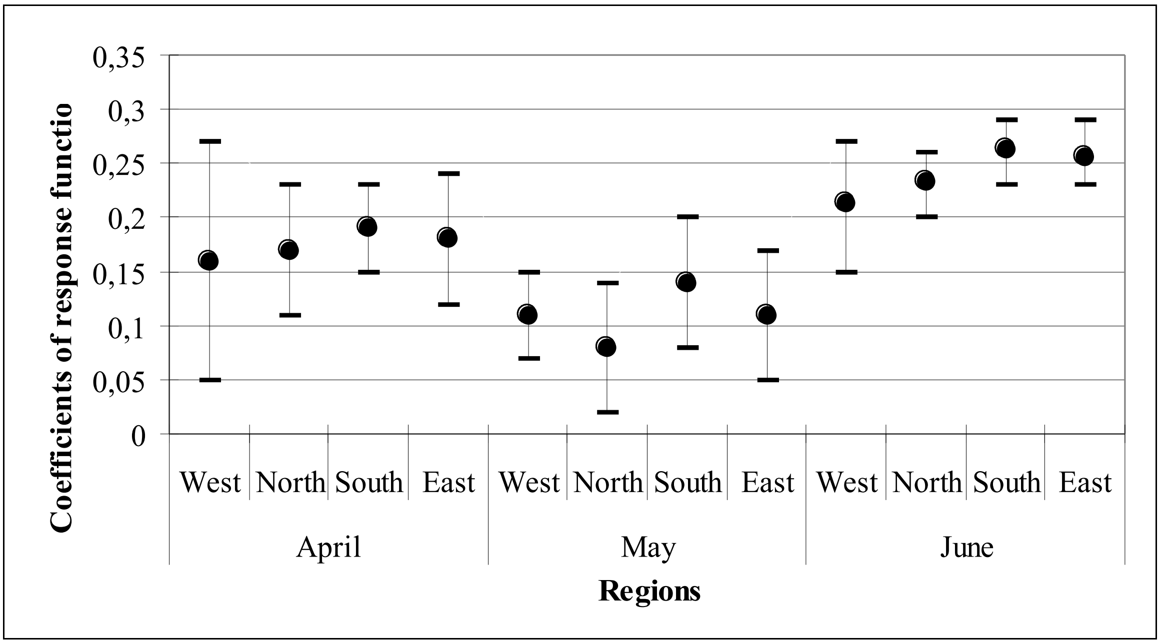

Fig. 2. Average coefficients of response functions between air temperature (April, May), amount of precipitation (June) and the radial growth of Norway spruce on dry forest sites in four regions of Lithuania (west, north, south and east)

Summarizing presented results it could be stated that for radial growth of Norway spruce (*Picea abies* (L.) Karsten) in Lithuania the most important is warm than average April and May and on the other hand – June with high amount of precipitation.

The total number of detected negative pointer years during 20^{th} century on dry forest sites varies from five to eight (5 in the west, 7 in the north, 8 in the south and 6 in the east Lithuania). Using hydrothermal indicator, four pointer years in western, five in northern, six in southern and five in eastern Lithuania possibly are attributed to dry climate conditions in late spring and summer. Exclusively to dry events, when no other extreme conditions, such as spring and winter colds were observed, these pointer years are assigned:

- 3 in the west (1914, 1934 and 1992),
- 4 in the north (1954, 1964, 1979 and 1992),
- 5 in the south (1931, 1964, 1979, 1989 and 1992) and
- 4 in the east Lithuania (1910, 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 Lithuania and rarer in the west Lithuania. These pointer years could be grouped, according to its spatial distribution, into three categories:

I. Pointer years, involving the biggest territory of Lithuania and detected in three or four regions: 1941 and 1992 (Fig 3). These pointer years were also observed on wet forest sites.

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

III. Pointer years detected in one region: 1910, 1914, 1931, 1934, 1954, 1971 and 1980.

These pointer years, partly or fully induced by droughts in Table 1 are presented. Number of trees with event years for each region is given. Cold April is shown in deviation from the long-term mean of temperature and droughts during May-August are expressed as percentage deviation of hydrothermal indicator.

From the Table 1 is evident that droughts of May (7) and June (7) are more frequently connected to pointer years than dry conditions in July (4) and August (2). Conditions of cool April (Δ -3.6 – -3.8˚C) in 1941 coincided with a summer drought.

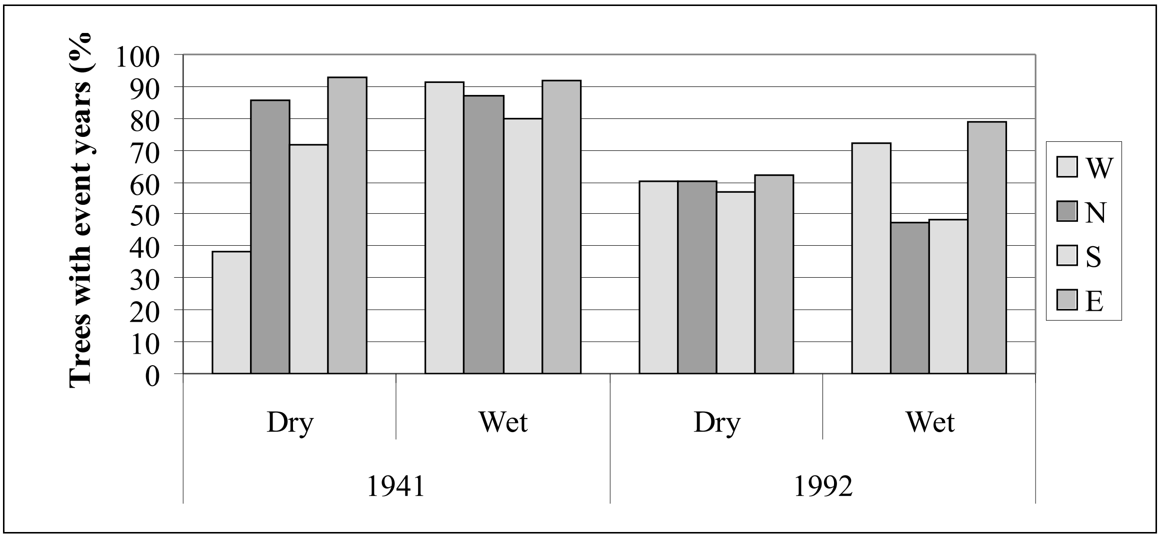

Fig. 3. Percentage of Norway spruce trees with detected event years in 1941 and 1992, expressed as medians in the west (W), north (N), south (S) and east (E) of Lithuania on dry and wet forest sites

Table 1. Pointer years of 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 are presented. Number of trees is given as average percentage of trees with event years. Cold April is shown in deviation (ºC) from the long-term mean of temperature and droughts during May-August are expressed as percentage deviation of hydrothermal indicator (higher values indicate drier conditions)

Year	Number of trees				Climate extremes				
	W	N	S	E	April	May	June	July	August
1910				58		57			
1914	50						71		
1931			46			129			
1934	47						249		
1941		85	72	93	-3.7		44-57	87	
1954		52				73			
1964		49	49				86-163	114-249	
1971				52		427		198	100
1979		63	65			33-68	93-95		
1980				83			69		
1989	46		48			55-87			
1992	61	60	57	62		31	97-225	124-277	13-22

Discussion and Conclusions

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 [7, 33].

Model of multiple regressions with air temperature and precipitation explain only up to 40% variation on the radial growth in 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 [2, 31, 33].

The first broadest research on tree rings of Norway spruce in Lithuania was conducted by Dr. I. Čerškienė. Using correlation coefficients, I. Čerškienė 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, years of the decrease of radial growth were detected in 1920-1921, 1930-1931, 1941-1942, 1954-1955 and 1964-1965 [9, 10]. 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 [16].

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 [1, 12, 21]. Recent research conducted on tree rings of Norway spruce in southeast Poland (Olsztyn Lakes district) has demonstrated that precipitation at the end of spring and summer (May-August) are 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 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 [17, 39]. The number of pointer years detected during this research in different regions of Lithuania (from 4 to 6) 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 coniferous species spread in Lithuania, that is why, its future perspectives of prosperity are important not only to scientists of different fields, but also to foresters too. According to the results of Prof. J. Ruseckas, during the severe summer droughts, humidity in the upper layer of soil falls up to 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 [31]. According to the opinion of H. Moosmayr, decline of forests in Europe is strongly driven by unfavourable meteorological factors [24]. Such droughts also decrease the resistance of spruce trees to invasions of Bark beetle [26, 35]. Looking on the other hand, Norway spruce in Lithuania grows near the southern limit of its habitat and therefore is more sensitive to climate fluctuation than Scots pine is.

Dry climate conditions were judged if the hydrothermal indicator [3] value is bigger than the standard deviation during the 20th century [5]. Two dry periods are established: the first one – in the beginning and the second one – in the last decade of the century. The beginning of the second dry period is marked with an extreme drought in 1992 [36]. It is also established that droughts in the last decades of 20th century lasted longer than observed before [5]. Unusual droughts at the end of 20th century were also observed in other continents [8].

Presented results on tree rings 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 [26, 31]. The latest analysis shows that the global average temperature has increased by 0.6°C during 20th century and is expected to continue rising at a rapid rate [30]. In spite of models of climate change are not reliable enough, an increase in frequency of summer droughts in Lithuania is predicted [31].

Impact of climate change on flora ecosystems are already noticeable in other countries: “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” [25].

Results obtained in this study have demonstrated that negative pointer years of the radial growth of spruce induced by droughts during 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 to a bigger deficiency of precipitation in mentioned region. Consequently, more optimum growing conditions in the west Lithuania and, looking on the other hand, more unfavourable conditions for spruce in the south Lithuania in the near future are expected.

References

[1] S.W. Alexandrowicz et al., Zmiany środowiska południowej Polski w okresie historycznym, Geologia. 23(4), 340–387 (1997).

[2] M. Beniston, Climate modelling at various spatial and temporal scales: where can dendrochronology help?, *Dendrochronologia*. **20** (1–2), 117–131 (2002).

[3] T.T. Bitvinskas, Dendroklimaticheskie issledovania (Gidrometeoizdat, Leningrad, 1974).

[4] A. Bukantis, Lietuvos klimatas (VU leidykla, Vilnius, 1994).

[5] A. Bukantis, Neįprasti gamtos reiškiniai Lietuvos žemėse XI–XX amžiuose (Geografijos institutas, Vilnius, 1998).

[6] P. Cherubini, Tree-Ring research beyond the climate change: „Quo vadis?“, *Dendrochronologia*. **18**, 91–93 (2000).

[7] E. Corona, Dendrochronologia: Principi e applicazioni, in: Thesis of the seminar held on 14–15th of November in Verona. (Istituti italiano di dendrochronologia, Verona, 1986), pp. 103.

[8] E. R. Cook, M. A. Kablack and G.C. Jacoby, The 1986 Drought in the Southeastern United States: How Rare an Event Was It?, J*ournal of geophysical research*. **93**, 257–260 (1988).

[9] I. Čerškienė, Research on radial growth of spruce stands in Lithuanian SSR, Summary of Doctoral dissertation (Lithuanian Agricultural Academy, Kaunas, 1975).

[10] I. Čerškienė, 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, 1978). pp. 19–21

[11] D. Eckstein, Measurement and dating procedures in dendrochronology, in: Methods of Dendrochronology, Vol. 3, eds. L. Kairiūkštis, Z. Bednarz and E. Feliksik (IIASA, Warsaw, 1987). pp. 35–44.

[12] D. Eckstein, C. Krause, Dendrochronological studies on spruce trees to monitor environmental changes around Hamburg, *IAWA bulletin.* **10**, 175–182 (1989).

[13] H. Fritts, Tree Rings and Climate, Vol. 1-2 (IIASA, Polish Academy of Sciences Systems Research Institute, Warsaw, 1987).

[14] H.C. Fritts, J.S. Dean, 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 (1992).

[15] S. Karazija, Eglynų džiūties priežastys ir auginimo perspektyvos, *Mūsų girios*. **7**, 4–6. (1997).

[16] J. Karpavičius, R.R. Yadav, J. Kairaitis, Radial Growth Response of Pine (*Pinus sylvestris* L.) and Spruce (*Picea abies* (L.) Karst.) to Climate and Geohydrological factors, *Paleobotanist*. **45**, 148–151 (1996).

[17] M. Koprowski, A. Zielski, Lata wskaźnikowe u świerka pospolitego (*Picea abies* (L.) Karsten) na Pojezierzu Olsztyńskim, Sylwan. **11**, 29–39 (2002).

[18] C. Krause, Ganzbaumanalyse von Eiche, Buche, Kiefer und Fichte mit dendroökologischen Methoden, Ph. D. dissertation (University of Hamburg, Hamburg, 1992).

[19] A. Kuliešis, A. Rutkauskas A. Butkus A. (eds.), Lietuvos miškų valstybinė apskaita 2001 m. sausio 1 d. (LVMI, Kaunas, 2001).

[20] H. Lamb, Climate History and Modern World (Routledge, London, 1995).

[21] H. Linderson, Dendroclimatological investigation in Southern Sweden, in: Proceedings of the International Dendrochronology Symposium „Tree Rings and Environment“, ed. Ó. Eggertsson (Lund University, Lund, 1992) pp. 198–201.

[22] N.V. Lovelius, Dendroindication of Natural Processes (World&Family-95, St. Petersburg, 1997).

[23] F.D. Meyer, Pointer year analysis in dendroecology: a comparison of methods, *Dendrochronologia*. **16–17**, 193–204 (1998–1999).

[24] H.U. Moosmayr, Stand der Forschung über das Waldsterben, Allgemeine Forstzeitung. **43**, 1365–1373 (1988).

[25] C. Parmesan, G. Yohe, A globally coherent fingerprint of climate change impacts across natural systems, *Nature*. **421**, 37–42 (2003).

[26] R. Ozolinčius, Lietuvos spygliuočiai: morfologinės struktūros transformacijos bei jas indikuojantys veiksniai (Lututė, Kaunas, 1998).

[27] M. Rebetez, La Suisse se réchauffe (Presses polytechniques romandes, 2002).

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

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

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

[31] J. Ruseckas, Miško ir drėgmės sąveika (Lututė, Kaunas, 2002).

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

[33] F.H. Schweingruber, Jahrringe und Umwelt dendroökologie (Lis, Vologda, 1993).

[34] V. Stravinskienė, Klimato veiksnių ir antropogeninių aplinkos pokyčių dendrochronologinė indikacija Lietuvoje, Summary of Doctoral dissertation (VDU, Kaunas, 2000).

[35] S. Vaivada, Žievėgraužio tipografo (*Ips typograhus* L.) žiemojimo ypatumai, in: *Proceedings of the Conference of Young Scientists „Forests and Environmental Sciences in the beginning of 3rd millennium*“, ed. G. Marcinkevičiūtė, (Lututė, Kaunas, 1999) pp. 136–140.

[36] A. Vitas. Drought of 1992 in Lithuania and consequences to Norway spruce, *Baltic forestry*, 7 (2), 25–30 (2001).

[37] A. Vitas, Klimato veiksnių įtaka paprastosios eglės (*Picea abies* (L.) Karsten) radialiajam prieaugiui, *Doctoral dissertation* (VDU, Kaunas, 2002).

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

[39] A. Zielski, M. Koprowski, Dendrochronologiczna analiza przyrostów rocznych świerka pospolitego na Pojezierzu Olsztyńskim, Sylwan, **7**: 65–73 (2001).