Dendroclimatological Research of Scots Pine (*Pinus sylvestris* L.) in the Baltic Coastal Zone of Lithuania

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Dendroclimatological research on living Scots pine (*Pinus sylvestris* L.) trees in the northern part of the Baltic coastal zone in Lithuania has been conducted. Climate impact on the radial growth of Scots pine using multiple regression techniques and detection of pointer years has been investigated. The results have shown that the most important factor for the radial growth of pine is warm February and September. Analysis on pointer years carried out during 1816-2002 has demonstrated that cold winters and summer droughts are the main factors in the formation of narrow tree rings for pine.

Key words: climate, coastal zone, event year, Lithuania, pointer year, radial growth, Scots pine

Introduction

The dynamics of annual radial growth of a tree is closely related to fluctuations of climate and other ecological factors, which encompasses dendroclimatology – a subfield of dendroecology (Kaennel and Schweingruber 1995). Tree ring research is widely applied in modern studies on forest dynamics, changes in climate and forest monitoring (Beniston 2002, Kairiūkštis 1995). Tree rings of Scots pine have been successfully used in dendroclimatological research and are one of the main sources for the long-term millennial chronologies used in climate reconstruction (Grudd *et al*. 2002, Helama *et al.* 2002, Pukienė 1997). According to the data of Forest Inventory and Management Institute, pine stands in Lithuanian forests occupy 36.6% of the forest area (http://www.lvmi.lt/lmis/engl_pagr.htm).

The coastal zone of the Baltic Sea in Lithuania is characterized by sensitive ecosystems and unique landscapes (Stauskas 2001). Pines of several centuries old as relicts of ancient forests have survived there. Until now only a few chronologies of pine from the Baltic coastal zone of Lithuania were presented in 1981-1983. These pine chronologies were not applied in dendroclimatological analysis using modern methods.

The aim of the research was a dendroclimatological research on Scots pine growing in the northern part of the Baltic coastal zone in northwestern Lithuania.

Material and methods

For the purpose of research, an experimental plot of Scots pine in the northern part of the Baltic coastal zone in Lithuania was selected. The experimental plot is located in the region of Kunigiškiai village. Forest type of the pine stand is *Pinetum vaccinio-myrtillosum*. The terrain is located on sandy soil, approximately 200 m from the Baltic Sea and 12 m above sea level. Geographical coordinates of the experimental plot are: 55°58’34” latitude (North) and 21°04’48” longitude (East). Using increment borer, samples from 20 dominant and codominant trees were taken at the breast height: two cores from each tree by inserting an increment borer perpendicularly to tree declination. Tree ring widths 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. Synchronisation of pine series was performed using visual and statistical (COFECHA 3.00P computer program by R.L. Holmes, Tucson) dating techniques (Eckstein 1987).

Using CHRONOL 6.00P program (R.L. Holmes, Tucson), the indexing of tree ring series at two stages was performed – according to the methods, proposed by Holmes et al. (Holmes 1994). At first a 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).

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

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

$$\bar{I}_t=\sum_{j=1}^{m} W_t I_t \qquad (3)$$

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

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

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.

The constructed chronology was compared with ten unpublished modern pine chronologies (distance from 10 to 317 km) compiled by the author and Dr. Rūtilė Pukienė and three chronologies from Palanga (distance <10 km) and Kuršių Nerija (distance >48 km) presented by T. Bitvinskas (Битвинскас 1981), L. Kairiūkštis and V. Stravinskienė (Кайрюкштис and Стравинскене 1987).

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).

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

where: *W_i – ring width in year I (index),*
i equals 1 to n years of the calibration period,
T_{ij} – data on temperature (monthly variable j in year i),
a_j – coefficient of the temperature variables,
P_{ik} – data on precipitation,
b_k – coefficient of 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 by applying PRECON 5.17B computer program (H. Fritts, Tucson) by using climatic variables from prior April to current September during 1904-2002 were carried out. Climate data on monthly mean temperature and amount of precipitation from Klaipėda, Kretinga, Palanga and Šventoji – the nearest meteorological stations from the experimental plot were selected. Coefficients of the response function are judged significant at the 95% level (p=0.05) if ratio regression coefficient/standard deviation is not lower than 2.00 (i.e. coefficients are twice bigger than standard deviation) (Fritts and Dean 1992, Garfi 2000).

The long-term regression analysis seldom permits to evaluate the information contained in conspicuous single growth rings. Year with a conspicuous feature (extreme narrow or wide rings) within 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 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 moving window", proposed by H.F. Schweingruber (Schweingruber *et al.* 1990) was adapted. Index value Z_i for event year is calculated following Formula 5. Calculations of event and pointer years applying WEISER 1.0 computer program (I.G. Gonzales, Lugo) were performed.

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

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 window x_{i-2}, x_{i-1}, x_i, x_{i+1}, x_{i+2},
stdev [window] – standard deviation of the ring width within 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 and for positive event years – =0.75. Pointer years during 1816-2002 were detected using a 50% threshold level of event years. Detected pointer years according to its significance were grouped into 3 categories: insignificant (detected in 50-64% of trees), moderate by significant (in 65-79% of trees) and important (in >80% of trees). Measurements of air temperature in Klaipėda Meteorological Station were begun in 1888 and of precipitation in 1881. For the interpretation of pointer years from 1819 to 1887 data on air temperature from Vilnius meteorological station were used. Because measurements of precipitation in Lithuania were begun only in 1887, earlier data of droughts were taken from chronicles, collected by A. Bukantis (1998).

Results

Synchronisation of measured pine series was very complicated but possible and the chronology containing 34 series from 18 trees was compiled. Nine absent tree rings were detected in 1968 (4 series), 1969 (1 series), 1979 (1 series), 1982 (1 series), 1988 (1 series) and 1997 (1 series). Similarity between series, expressed as inter-correlation, is +0.51. The chronology extends from 2002 to 1816 with time span of 187 years. The average ring width is 1.69 mm and the mean sensitivity of chronology – 0.14. Graph of chronology in indices is presented in Figure 1.

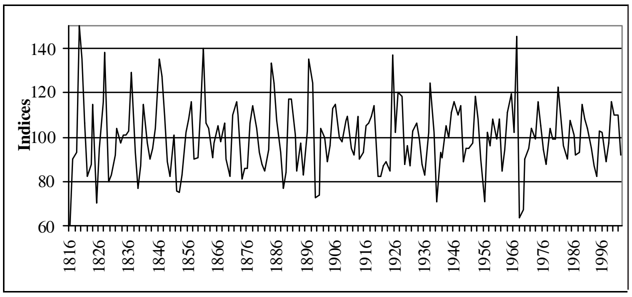

Figure 1. Chronology (indices) of Scots pine growing in the coastal zone of the Baltic Sea in Lithuania

Coefficients of response function are presented in Table 1. The coefficients are judged significant (p=0.05) if ratio regression coefficient/standard deviation is bigger than 2.00. The results have demonstrated (Fig. 2) that only air temperature in February and September of the current year has significant (p=0.05) direct connection to the radial growth of pine. Positive but insignificant coefficients were found with precipitation in June-August. The long-term impact of climate in previous year is insignificant.

Table 1. Coefficients of response function between the radial growth of Scots pine and climate data (air temperature and precipitation) from previous year April to current September. Ratio of regression coefficient / standard deviation indicates significance (p=0.05)

Months	Temperature	Ratio	Precipitation	Ratio
Pr_4	-0.06	-0.8	0.01	0.1
Pr_5	-0.11	-1.3	-0.10	-1.1
Pr_6	0.03	0.3	-0.02	-0.2
Pr_7	0.16	1.6	0.01	0.2
Pr_8	-0.1	-1.0	0.04	0.4
Pr_9	-0.05	-0.6	-0.06	-0.8
Pr_10	0.02	0.2	0.08	0.9
Pr_11	-0.00	-0.1	0.05	0.6
Pr_12	-0.02	-0.2	-0.12	-1.3
1	0.08	0.9	-0.05	-0.7
2	0.18	2.1	-0.10	-1.3
3	0.14	1.5	-0.01	-0.1
4	0.04	0.5	-0.07	-0.7
5	-0.13	-1.4	-0.08	-0.9
6	0.02	0.2	0.12	1.4
7	-0.12	-1.0	0.07	0.9
8	0.04	0.5	0.13	1.6
9	0.20	2.3	0.06	0.7

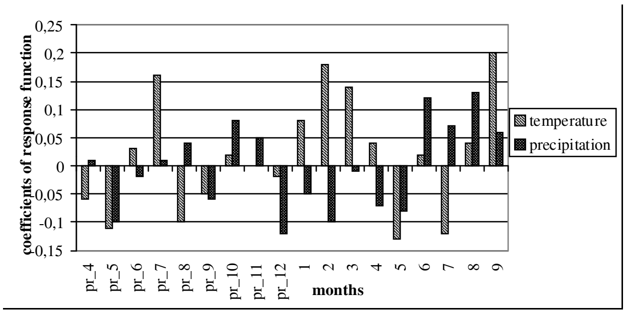

Fig. 2. Coefficients of response function between the radial growth of Scots pine and climate data (air temperature and precipitation) from previous year April to current September. Asterisk (*) – indicates significance (p=0.05)

Negative and positive pointer years of Scots pine are presented in Figure 3. Its significance is expressed with number of trees (%) with event years. Using this criterion, pointer years were grouped into three categories:

Negative pointer years:

- Insignificant pointer years (50-64% of trees) – 1829, 1839, 1852, 1853, 1874, 1888, 1893, 1895, 1920, 1929, 1962, 1969, 1977, 1994 and 1997.

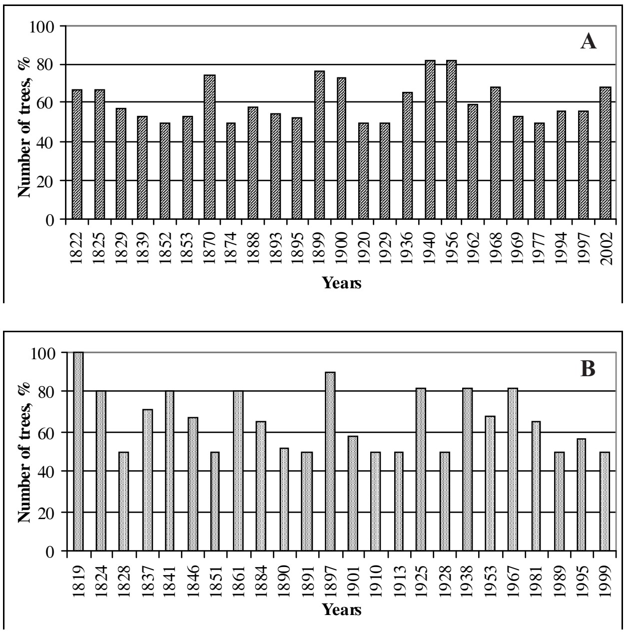

Figure 3. Negative (A) and positive (B) pointer years of Scots pine

- Moderately significant pointer years (65-79% of trees) – 1822, 1825, 1870, 1899, 1900, 1936, 1968 and 2002.
- Important pointer years (>80% of trees) – 1940 and 1956.

Positive pointer years:

- Insignificant pointer years (50-64% of trees) – 1828, 1851, 1890, 1891, 1901, 1910, 1913, 1928, 1989, 1995 and 1999.
- Moderately significant pointer years (65-79% of trees) – 1837, 1846, 1884, 1953 and 1981.
- Important pointer years (>80% of trees) – 1819, 1824, 1841, 1861, 1897, 1925, 1938 and 1967.

Climate events, suspected as a probable cause of pointer years for Scots pine are presented in Table 2. Deviations of air temperature (˛t) are shown as departure (°C) from the long-term mean in 1819-2002 and deviations of precipitation (˛p) are presented as departure (mm) from the long-term mean in 1887-2002.

Table 2. Negative and positive pointer years and climate characteristics, expressed as deviations from the long-term mean

Year	Number of trees with pointer year, %		Climate events
	Negative	Positive	
1819		100	Warm February Δt=+1.5°C and September Δt=+1.0°C
1822	67		Cool June Δt=-2.1°C and September Δt=-1.0°C, dry spring and summer
1824		80	Warm winter, spring Δt=+1.1°C and September Δt=-2.6°C
1825	67		Cold spring Δt=-1.2°C and September Δt=-0.8°C
1828		50	Humid summer
1829	57		Cold winter and spring Δt=-4.1°C, dry summer
1837		71	*Unidentified*
1839	53		Cold spring Δt=-2.4°C
1841		81	Warm spring and summer Δt=+1.3°C
1846		67	Warm spring Δt=+1.8°C
1851		50	Warm September Δt=+0.6°C
1852	50		Cold spring Δt=-2.3°C
1853	53		Cold spring Δt=-2.0°C and September Δt=-1.1°C, dry summer
1861		80	Warm February Δt=+2.3°C
1870	74		Cold February Δt=-8.5°C and September Δt=-2.7°C
1874	50		Cold May Δt=-3.5°C
1884		65	Warm winter Δt=+4.6°C and September Δt=+1.4°C
1888	58		Cold spring and summer Δt=-2.2°C, dry summer Δp=-70 mm
1890		52	Warm winter Δt=+3.2°C and spring Δt=+2.8°C
1891		50	Warm February Δt=+3.0°C and September Δt=+1.3°C
1893	54		Dry spring Δp=-65 mm and summer Δp=-69 mm
1895	52		Cold February Δt=-3.6°C
1897		90	Warm spring Δt=+1.4°C and summer Δt=+1.3°C
1899	76		Dry July Δp=-36 mm and August Δp=-54 mm
1900	73		Cold spring Δt=-1.5°C, dry May and June Δp=-56 mm
1901		58	Warm summer Δt=+1.6°C, wet June Δp=+55 mm
1910		50	Warm winter Δt=+4.8°C
1913		50	Warm February and March Δt=+3.8°C
1920	50		*Unidentified*
1925		82	Warm February Δt=+6.1°C
1928		50	Humid June, Δp=+30 mm
1929	50		Cold February Δt=-9.7°C and spring Δt=-2.3°C, dry summer Δp=-91 mm
1936	65		Dry summer in 1935 Δp=-78 mm
1938		82	Warm February and March Δt=+3.9°C
1940	82		Cold winter Δt=-7.4°C and March Δt=-3.1°C, dry June Δp=-29 mm
1953		68	*Unidentified*
1956	82		Cold February Δt=-7.2°C and spring Δt=-2.3°C
1962	59		Cold March, Δt=-3.0°C
1967		82	Warm February and March Δt=+3.3°C and September Δt=+2.8°C
1968	68		Dry spring and summer Δp=-114 mm
1969	53		Cold winter Δt=-2.6°C and spring Δt=-1.5°C, dry June Δp=-48 mm
1977	50		Dry summer in 1976 Δp=-124 mm
1981		65	Warm winter Δt=+2.4°C and humid summer Δp=+138 mm
1989		50	Warm winter Δt=+7.3°C and March Δt=+4.8°C, humid summer Δp=+197 mm
1994	56		Dry summer Δp=-107 mm
1995		56	Warm February Δt=+6.2°C
1997	56		Dry summer Δp=-125 mm
1999		50	Warm March Δt=+3.7°C and September Δt=+1.9°C, humid June Δp=+41 mm
2002	68		Dry August Δp=-84 mm (amount of precipitation – 0 mm)

As seen from Table 2, probable causes of negative pointer years, detected during short-term analysis are the following:

- Impact of droughts in spring and summer of the current or previous year (32% of events): 1893, 1899, 1936, 1968, 1977, 1994, 1997 and 2002.
- Colds in winter, spring and September (32% of events): 1825, 1839, 1852, 1870, 1874, 1895, 1956 and 1962.
- Complex effect of colds in winter, spring, summer and September, spring and summer droughts (32% of events): 1822, 1829, 1853, 1888, 1900, 1929, 1940 and 1969.
- Unidentified cause (4% of events): 1920.

As seen from presented above, negative pointer years were with equal frequency related to colds and droughts. With the same intensity pointer years were related to complex effect of colds and droughts. The very important fact is that already from 1970, four pointer years in 1977, 1994, 1997 and 2002 are attributed only to the effect of droughts.

Positive pointer years (Table 2) were induced by:

- Warm winter, spring, summer and September conditions (67% of events): 1819, 1824, 1841, 1846, 1851, 1861, 1884, 1890, 1891, 1897, 1910, 1913, 1925, 1938, 1967 and 1995.
- Humid summer (8% of events): 1828 and 1928.
- Complex effect of warm winter, spring, September and humid summer (17% of events): 1901, 1981, 1989 and 1999.
- Unidentified cause (8% of events): 1837 and 1953.

It could be stated that the main factor inducing positive pointer years is warm winter, spring and summer. Humid summer or complex effect of warm winter, spring and humid summer has probably caused only ¼ of pointer years. On the other hand, the more frequent latter mentioned years were recorded in the last two decades of the 20th century (1981, 1989 and 1999).

Discussion and conclusions

Experimental plot was selected in the oldest pine stand between Palanga and Būtingė – the northern part of the Baltic seaside in Lithuania. The forest planting works in the sandy soils of coastal zone have been accomplished until 1811 and firstly were performed in the southern part of the coastal zone – Kuršių Nerija (Daujotas 2001). Therefore we can conclude that analysed pine stand grows naturally from approximately 1800 and was not planted.

Synchronisation work of measured pine series was very complicated due to often found missing, double rings and reaction wood – anomalous xylem (Kaennel and Schweingruber 1995), formed due to strong seaside winds. Totally, 34 series from 18 trees were averaged into chronology.

The constructed chronology was compared with ten modern pine chronologies constructed by the author and Dr. Rūtilė Pukienė. Tree rings of them generally were measured within 0.01 mm accuracy. The distance between chronologies varies from 10 to 317 km. A significant similarity was found up to the distance of 200-250 km (Fig. 4).

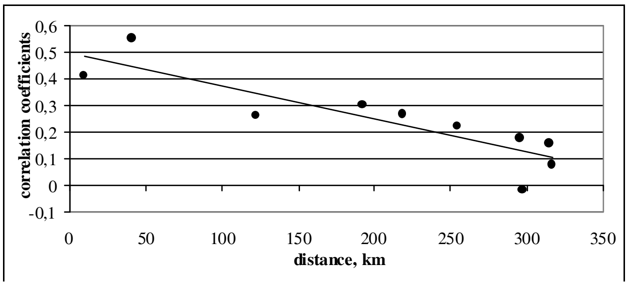

Figure 4. Similarity (coefficients of the correlation) and a linear trend line between the compiled chronology of Scots pine and other chronologies from Lithuania

The chronology has been also compared with three pine chronologies from Palanga (distance <10 km) and Kuršių Nerija (distance >48 km) presented by T. Bitvinskas (Битвинскас 1981), L. Kairiūkštis and V. Stravinskienė (Кайрюкштис and Стравинскене 1987). Similarity (coefficients of the correlation) with these chronologies in 1816-1959 varies from +0.24 to +0.34. It has been also discovered that an earlier chronology from Palanga in *Pinetum myrtillo-oxalidosum* forest type contains a missing ring in 1940.

The sensitivity of Scots pine tree rings to cold winters in Lithuania was proved earlier by T. Bitvinskas (Битвинскас 1974). Later results have proved that tree ring widths of pine are connected to high temperature in winter (Yadav *et al*. 1991), spring and summer (Stravinskienė 2002, Yadav *et al*. 1991). Impact of precipitation is less important. The authors have noticed the impact of precipitation in winter, spring and summer (Karpavičius *et al*. 1996, Stravinskienė 2002, Vitas and Bitvinskas 1998, Yadav *et al*. 1991). Different results could be explained not only by different forest types and geographical regions, but partly also by different methods used to identify the long-term impact of climate (Schweingruber 1993).

From the results of multiple regression it is evident that pine is sensitive to colds in February and March. Research carried out in Poland, Estonia and southern Sweden has also revealed that pine is sensitive to cold winters and springs (Krąpiec *et al*. 2003, Läänelaid 2001, Linderson 1992). However, negative pointer years for

Scots pine detected in Poland (1928, 1940, 1952 and 1976) by Krąpiec *et al*. (2003) are different than these found in this research. Scientists also point out that the effect of precipitation to tree ring widths of pine is insignificant (Läänelaid 2001, Linderson 1992).

Significant link between air temperature in September and the radial growth of pine in Lithuania was not mentioned in the scientific literature before. Residuals of inter-correlation between climate variables normally do not cause significant correlation. A possible explanation of this link is longer lasting vegetation season as an impact of the Baltic Sea. This hypothesis could be validated or denied only by further research on Scots pine in the Baltic coastal zone.

My results on pointer years of Scots pine show the important role of droughts in forming narrow tree rings. Extreme droughts (as in 1994) or long lasting dry periods (as in 1893) cause narrow rings in the majority of Scots pine trees. On the other hand, such effect of droughts was not validated by the long-term response function analysis.

Probable causes of negative pointer years from 1977 to 2002 are attributed only to dry summers, because winters during this period were mild (Bukantis, 1998). It points to a climate change: more frequent dry conditions in spring and summer during the last decades of the 20th century and "lack" of cold winters. The impact of climate change on vegetation is also noticeable in other countries. Parmesan, 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*". Recent results from climate modelling also add evidence to the idea that extreme temperature events are set to rise in Europe. Christoph Schär of the Swiss Federal Institute of Technology, Zurich, and his colleagues using a regional climate simulation have shown that that extreme temperatures will be more common in the future (Hopkin 2004).

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ДЕНДРОКЛИМАТОЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) В БАЛТИЙСКОЙ ПРИБРЕЖНОЙ ЗОНЕ ЛИТВЫ

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Резюме

Дендроэкологическое исследование растущих деревьев сосны обыкновенной (*Pinus sylvestris* L.) было проведено в Балтийской прибрежной зоне в северо-западной части Литвы в районе деревни Кунигишкей. Влияние климата на радиальный прирост сосны выявлено при помощи анализа множественной регрессии и выявлением т.н. особых лет.

Полученные результаты показывают, что главными факторами, влияющими на радиальный прирост сосны в Балтийской прибрежной зоне Литвы, являются теплые февраль и сентябрь. Анализ метеорологических данных особых лет в периоде 1816-2002 показал, что холодные зимы и летние засухи являются более вероятными факторами для формирования узких годичных колец сосны.

Ключевые слова: прибрежная зона, климат, год произшествия, Литва, особый год, радиальный прирост, сосна обыкновенная.