Dendrochronological Investigation on Scots Pine Timber Extracted from Lake Stirniai, Northeastern Lithuania

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Stasytytė, I., Pakalnis, R. and Vitas, A. 2005. Dendrochronological Investigation on Scots Pine Timber Extracted from Lake Stirniai, Northeastern Lithuania. *Baltic Forestry,* 11 (1): 46–53.

Abstract

Dendrochronological research has been carried out on subfossil pine timber found in Lake Stirniai, northeastern Lithuania. As a result, the tree ring width floating chronology spanning 213 years was compiled. Radiocarbon dating of the samples has shown that pines lived in the transition between Medieval Warm Period and Little Ice Age (from 1103±80AD to 1315±80AD). Research has revealed that pines grew on the peat soil, likely on *Pinetum carico-sphagnosum* forest type. It was discovered that the water level of Lake Stirniai in the Medieval Warm Period probably was bellow for about 1.0 m than nowadays. Analysis on cyclic recurrence of the annual radial growth fluctuations of pinewood growing on boggy soil along Stirniai lakeside in the 12^{th}-14^{th} centuries enabled to determine at least 6 cycles longer than 10 years.

Keywords: climate, Little Ice Age, Medieval Warm Period, radial growth, radiocarbon dating, Scots pine, subfossil timber

Introduction

Tree rings have proven to be a reliable climate archive for short and long-term scales (Beniston 2002, Stravinskienė 2000, Битвинскас 1974). 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 dating and climate reconstructions (Grudd *et al*. 2002, Helama *et al*. 2002, Pukienė 1997). The research conducted on Scots pine timber extracted from the lake water and lake sediments in Finnish and Swedish Lapland enabled to compile the long-term millennial chronologies and to apply them successfully for climate reconstruction (Eronen *et al*. 2002, Helama *et al*. 2004).

Dendrochronological research in Lithuania was mainly concentrated on living pine trees (Stravinskienė 2000, Битвинскас 1974 etc.), while the comprehensive investigations on subfossil pine timber were carried out only in two peatbogs: Užpelkių tyrelis (Pukienė 1997) and Aukštoji plynia (Karpavičius 1998). Dendrohydrological investigations on fluctuations of lake water level in Lithuania were started in the 8^{th} decade of the 20^{th} century (Пакальнис 1972, 1975). For the research work we used subfossil Scots pine (*Pinus sylvestris* L.) annual radial growth floating chronology and several chronologies from pine growing on lakesides. Novel research methods were applied to ascertain the distinct cycles of perennial water level fluctuation in closed lakes, average duration of which reach 25-27 years. The cyclicity of this length is characteristic of the majority of closed lakes in Lithuania (Пакальнис 1978a, б). It was determined that cyclic water level fluctuation is also typical of bogs characterized with the closed hydrological basin. For the precise mathematical identification of cyclicity and duration of cycles, a formant analysis was used (Kriukelis and Pakalnis 1994). Investigation on subfossil wood extracted from lake water has been conducted for the first time in Lithuania.

The aim of the research is investigation on subfossil pine timber extracted from Lake Stirniai, northeastern Lithuania applying dendrochronological and radiocarbon dating techniques and dendroecological analysis.

Materials and methods

Lake Stirniai is located 9 km east of Molėtai and occupies the area of 862 ha. Seven islands in the lake territory occupy the area of 53 ha. The lake is completely water running: several streams inflow and Stirnė, a small river outflows. The very twisty (33.7 km) and swampy coasts are the main features of the Lake. Stumps with root remnants of subfossil pines were found in the southern part of the lake: in the gulf by Peninsular Vieštauto ragas. The wood was found in the water at 1.16 m depth. Geographical coordinates of the research object established using a GPS device are: between latitude (North) 55°15'04" and longitude (East) 25°38'49" (Fig. 1).

For the purpose of the research cross-sections from 14 stumps were collected. After air-drying, the discs were sanded with progressively finer grades of sand paper (80 to 320 grid). Samples containing fewer than 50 tree rings were rejected as not suitable for reliable cross-dating (Eronen *et al.* 2002, Pukienė 1997).

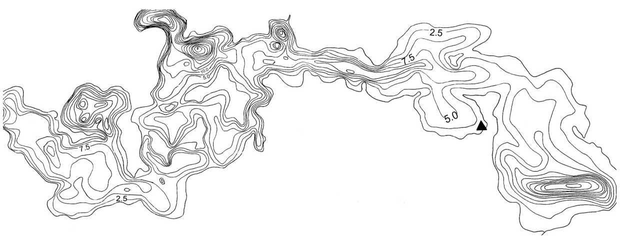

Figure 1. The bathymetric diagram of Lake Stirniai. The triangle shows the location of the research object

The tree ring widths of ten remaining samples were measured to the nearest 0.001 mm. For this purpose, LINTAB tree-ring measuring table and TSAPWin 0.30 computer program (F. Rinn Engineering Office and Distribution, Heidelberg) were used. The intervals of missing rings were observed at young age of subfossil trees. Such uncertain periods were not measured and not applied in the further investigations. The measured series were cross-dated by visual comparison (Eckstein 1987) of ring-width graphs. The positions of the best overlap were selected by using coefficients of similarity and t-value (Formula 1, 2, 3) – widely used in dendrochronological dating procedures (Pukienė 1997, Rinn 1996, Schweingruber 1988). Statistically significant t-values are bigger than 3.5, $p \leq 0.01$ (Baillie, Pilcher 1973).

$$GLK = \Sigma(y_i = x_i) \qquad (1)$$

where: GLK – coefficient of similarity (Gleichläufigkeit), $\Sigma(y_i = x_i)$ – sum of the equal slope intervals in %

Statistical significance of the coefficient of similarity is calculated at three levels of significance (95%, 99% and 99,5%) according to the formula (Rinn 1996).

$$\text{Significance of 95 \%} = 50 + \frac{1,654 * 50}{\sqrt{points}} \qquad (2)$$

$$\text{Significance of 99 \%} = 50 + \frac{2,326 * 50}{\sqrt{points}}$$

$$\text{Significance of 99.5 \%} = 50 + \frac{3,090 * 50}{\sqrt{points}}$$

$$t = \frac{cc * \sqrt{n-2}}{1 - cc^2} \qquad (3)$$

where: t – t value, cc – cross-correlation, n – number of overlapping points

The floating chronology was constructed as biweight robust means (Riitters 1990) and includes tree ring width of nine samples. 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, preserving 67% of variance at wavelength 21 years was fitted.

Because the dating attempts of floating chronology against the constructed long-term pine chronology (1487-2002) were unsuccessful, wood from two samples was submitted for radiocarbon (C^{14}) dating. Chemical preparation (benzene extraction) of the wood was accomplished at the Radioisotope Laboratory of Lithuanian Geology and Geography Institute. Radiocarbon dating was performed at the Group of Dendroclimatology and Radiometrics of Environmental Research Centre. For this purpose a highly precise Liquid Scintillation Spectrometer LSC-1220 (Quantulus) was used. For the calibration of obtained dates CALPAL program (B. Weninger *et al.*, Köln University) (Weninger *et al.* 2003) with tree ring calibration curve INTCAL98 (Stuiver *et al.* 1998) was used.

The tree ring pattern and age curve of floating chronology were compared to the chronologies from living pine trees. This approach enabled to reconstruct reliably enough the growing conditions of subfossil pines and the Lake water level. The first research plot is located in the vicinity of Lake Stirniai (forest type *Pinetum myrtillosum*) and the second - EŠPI 10-12 is situated at 32.1 km distance in the Aukštaitija National Park (forest type – *Pinetum carico-sphagnosum*). The main feature of the research plot EŠPI 10-12 is a thick peat soil.

The main climate factors influencing the radial growth of living pines by using response function analysis (Fritts and Dean 1992) were investigated. Calculations of response function were carried out by applying PRECON 5.17B computer program (H. Fritts, Tucson) by using climatic variables from prior September to current August during 1903-2002. Climate data on monthly mean temperature and amount of precipitation from Utena – the nearest meteorological station (about 30 km) from the experimental plot were selected.

We used computer program FORMANT 1.0 (V. Slivinskas *et al.*, Vilnius) for the analysis of the radial growth fluctuations (Slivinskas et al. 1991). Formant is an interactive program to develop the mathematical models of signal data. The main goal of FORMANT is to express the data as the minimal sum of formants and to get the numerical of their parameters. The data are considered to be a finite sequence of equidistant samples of investigated signal (Slivinskas and Šimonytė 1992).

Results

Several cross-dating characteristics between the radial growths of 9 samples are shown in Table 1. As seen from the table, the statistical similarity between samples is not always high and significant: coefficients of similarity ranged from 44 to 66 and the Student's criterion from 0.2 to 7.2 respectively. Statistically significant are judged from 10 (by t-value) to 11 (by coefficients of similarity) overlapping positions from the total 36 dating positions.

Table 1. Similarity between the tree ring widths of subfossil pine samples (in numerator – coefficient of similarity, denominator – Student's criterion), significance of the coefficient of similarity: * - 95%, ** - 99%*** 99.5%

Sample	2	3	4	7	9	11	12	13
3	54 2.9							
4	51 0.4	55 0.5						
7	65*** 4.7	62** 2.2	44 0.4					
9	46 1.7	60** 1.2	66*** 7.0	50 2.4				
11	46 1.3	56 2,3	54 3.9	54 2.9	61* 1.9			
12	52 2.2	58* 4.1	51 0.7	61** 2.2	54 2.1	64** 7.2		
13	55 2.2	53 1.0	59* 4.0	46 3.4	60* 7.2	57 1.1	52 1.2	
14	48 0.2	49 1.1	65** 5.7	46 1.1	62** 6.4	58 2.5	57 3.2	66*** 5.4

Table 2. Several characteristics of radiocarbon dating: laboratory inventory numbers of the sample, radiocarbon age and calibrated dates

Lab. No.	Sample No.	Age, ^{14}C conventional years	^{14}C calibrated dates (p=68%), years AD	Calibrated period, (p= 95%), years AD
VDU-173	7	710 ± 98	1280 ± 80	1120-1440
VDU-175	14	865 ± 52	1140 ± 80	980-1300

The radiocarbon dating of two subfossil pines (No. 7 and No. 14) has shown close ^{14}C dates (Table 2).

Radiocarbon age of two samples ranges from 710±98 to 865±52 conventional years. The calibration of radiocarbon dates has shown that pines grew in the 12-14th centuries and the chronology is placed between 1103±80AD and 1315±80AD. The 213 years length floating chronology of subfossil pines is presented in Figure 2. The trend line of the age curve shows very narrow tree rings (less than 1 mm) at young age of trees. The increment of trees has increased up to 3-10 mm after 40 years, but after ≈1270±80 years AD, i.e. when trees were approximately 180 years old, the sharp decrease in tree ring widths (less than 1 mm) is noticeable. The average tree ring width for subfossil pines is 1.12 mm and the mean sensitivity of the chronology – 0.30.

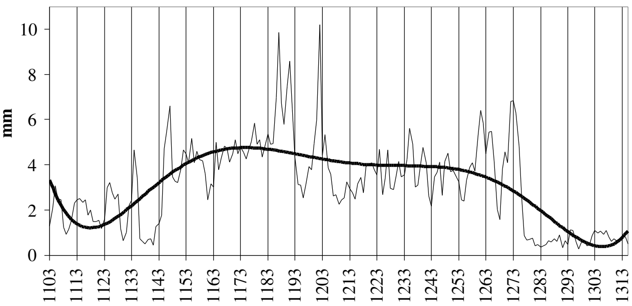

Figure 2. Floating chronology of subfossil pines (mm) from lake Stirniai and polynomial trend

Discussion and conclusions

Wood in anaerobic conditions can be preserved for centuries and by using dendrochronological methods applied for the reconstruction of growing conditions in the past and stand dynamics (Grudd *et al*. 2002, Renner 1982, Shär and Schweingruber 1988).

However, the accurate cross-dating of subfossil pine tree rings is not always possible due to irregular growth patterns and individuality in the radial growth of certain trees. Studies in Finland have revealed that 10-15% of pine samples cannot be reliably cross-dated (Eronen *et al*. 2002). Investigation on subfossil pines extracted from Lithuanian peatbogs has shown that the strong relationships between the radial growth series are characteristic only of a minor part of trees (Pukienė 1997, Карпавичюс 1994) and only up to 50% of them could be cross-dated reliably (Pukienė 1997). The cross-dating positions of less than 50 years overlap increase the probability of errors due to a pseudo-similarity (Mills 1992, Pukienė 1997). Because the cross-sections were taken from the basal area of stems, the eccentricity is common for all samples, e.g., diameter of sample No. 12 in one direction is 9 cm and in 90º direction already 23 cm.

It was corroborated once more that the visual comparison of the overlapping series should be used as the main method in the synchronization of pines. Statistical correlation could serve only as a tool facilitating selection of the best overlapping positions.

The uniformitarian principle of dendrochronology states that processes influencing current patterns of tree growth must have been in operation in the past. Using the relationship between the tree growth and present climate it is possible to reconstruct the nature of the past climate (Fritts 1987). In our study we have reconstructed the certain growing conditions of subfossil pines, e.g., forest type, soil type together with the main climate limiting factors.

The main feature of the constructed subfossil pines chronology is a poor increment at young age of trees, which increases with tree age (Figure 2). According to the scientific literature it indicates that studied trees grew on the deep peat soil (Karpavičius 1998). The age curves of two compared pine chronologies (Figure 3) shows that the curve of chronology (b) is more similar to the studied trees. The curve on graph (a) has a different character and represents a pine stand growing on mineral soil. We can conclude that the most likely pines grew on *Pinetum carico-sphagnosum* forest type, according the forest typology by S. Karazija (Karazija, 1988). This forest type in our research is represented by the research plot EŠPI 10-12, which is situated in the peatbog between two lakes – Žiegžmaris and Ešerinis of the Aukštaitija National Park. The stand consists of pure pine forest. *Betula pubescens* Ehrh. and *Picea abies* (L.) Karsten. comprise the underwood. The herby cover consists of *Sphagnum spp.* (80%), *Polytrichum commune* Herw., *Pleurozium schreberi* (Brid.) Mitt., *Vaccinium myrtillus* L., *Ledum palustre* L., *Eriophorum spp.*, *Vaccinium vitis-idaea* L., *Vaccinium uliginosum* L.

The long-term climate link between climate and the radial growth of pines in EŠPI 10-12 research plot shows that the radial growth of pines in such unfavourable growing conditions is limited by low July air temperature ($p \leq 0.05$), while the influence of precipitation is insignificant (Figure 4).

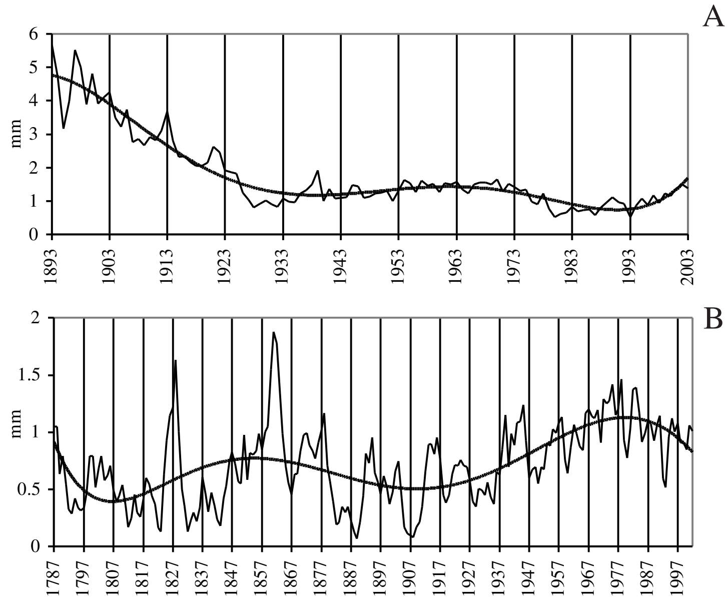

Figure 3. Tree ring width chronologies of living pines: A – Stirniai lakeside (*Pinetum myrtillosum*), B – EŠPI 10-12 (*Pinetum carico-sphagnosum*)

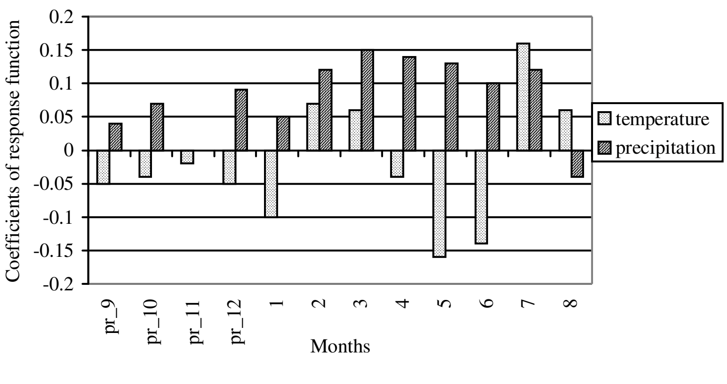

Figure 4. Coefficients of the response function between the pines radial growth at the research plot EŠPI 10-12 and climate (air temperature and precipitation) during September of previous year to current August. Asterisk (*) – indicates significance ($p \leq 0.05$)

The growth period of subfossil pine trees have coincided with two climate phases established in Europe: unusually warm Medieval Warm Period, which occurred in the tenth and eleventh centuries and followed by the long cold period Little Ice Age (Bukantis 1998, Hiller *et al*. 2001, Hughes and Diaz 1994, Soon and Baliunas 2003). Research conducted on subfossil pine trees in Scandinavia demonstrated that the climate cooling in the twelfth century led to a high mortality of pine trees (Gunnarson and Linderholm 2002).

The longest part of subfossil pines growing coincided with the Medieval Warm Period but the growing conditions suddenly became unfavourable in ~1270±80AD. This could be seen from the sharp decrease in ring width from 2.0-6.0 mm to 0.5-1.0 mm (Figure 2).

According to the data of pinewood growth dynamics reconstructed from Užpelkių tyrelis peatbog, the outspread phase of pinewood in the 12th - 15th centuries (Pukienė 1997) coincides with the flourishing of pines in the Stirniai lakeside (the 12th - 14th centuries). According to the results of other scientists, a sudden decrease in the increment could be connected to the low temperatures and abundant precipitation (Eronen *et al*. 2002, Kriukelis 1995), which resulted in the rise of the lake water level (Kriukelis 1995). Consequently, growing pines have died and the conditions of reforestation became critically unfavourable (McNally and Doyle 1984).

The long-term observations on the fluctuations of groundwater in the peatbog between Lakes Žiegžmaris and Ešerinis have been carrying out since 1997 (Figure 5) by Group of Dendroclimatology and Radiometrics (formerly Laboratory of Dendrochronology). The ground water fluctuates usually from 20-25 to 35-40 cm depth during the vegetation season. During the period of the long lasting droughts, e.g., 1997, 1999 and 2002 ground water level falls up to 60-70 cm depth.

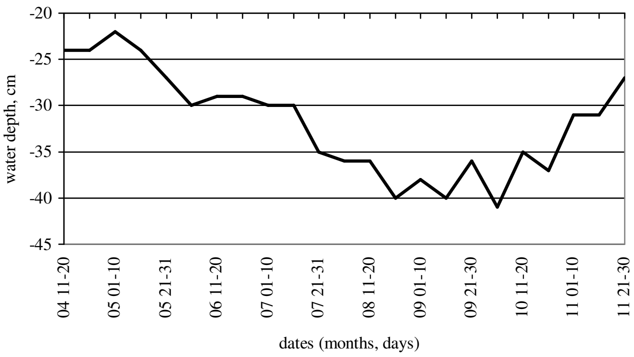

Figure 5. Average depth of the water level at the research plot EŠPI 10-12 in 1997-2003

Remnants of subfossil pines were found waterlogged with 1.16 m layer of water, while the stumps in a peat soil remained at 0.5-0.6 m depth. Our investigations on the research plot EŠPI 10-12 have shown that the water level diminishes up to 60-70 cm depth during the summer droughts. It means that in time of Medieval Warm Period, the ground water level in the growing place of subfossil pines, probably was bellow for about 1.0 m. than nowadays lake water level. According to the scientific literature, the water level in the water running lakes (like Lake Stirniai) fluctuates only insignificantly (Barysas and Kilkus 1977, Kilkus and Pumputytė 2001). A great abatement of lake water level in Medieval Warm Period could be connected only to the long-lasting dry period and unusually warm climate conditions.

Analysis on the cyclic recurrence of annual radial growth fluctuations of the pinewood growing on boggy soil along Stirniai lakeside in the 12th-14th centuries enabled us to determine at least 6 cycles longer than 10 years (Table 3). Comparison of the radial growth cycles of subfossil pines along Stirniai lakeside with pines growing alongside closed (Kreivasis, Molėtai district) and running water (Duobulis, Molėtai district) Lakes during the 20th century revealed that the cyclicity was more similar to that of pines growing on the banks of closed lakes. Probably it might be related to much lower overflow of Lake Stirniai in the 12th-14th centuries comparing with the present times.

Conclusions

1. By using dendrochronological and radiocarbon dating it was established that subfossil pines, which remnants had been found in lake Stirniai grew between 1103±80AD and 1315±80AD.

2. The research has revealed that subfossil pines grew on the peat soil, likely in *Pinetum carico-sphagnosum* forest type.

3. The water level of Lake Stirniai in the Medieval Warm Period was bellow nowadays lake water level probably about 1.0 m. and the cyclicity of the radial growth shows much lower overflow of Lake Stirniai in the 12th-14th centuries in comparison to the present times.

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Table 3. Results of formant analysis on annual radial increment

Lake	Number	Amplitude	Damping	Frequency	Period	Phase	Degree of t
Stirniai	1	0.189081	0.01518	0.50000	2.0	-90.00	0
	2	69.970197	-0.86502	0.50000	2.0	-90.00	0
	3	97.619339	0.00011	0.00000	0.0	90.00	0
	4	1.677041	-0.00890	0.01889	52.9	-58.49	0
	5	33.121595	-0.04692	0.03301	30.3	-73.67	0
	6	141.898150	-0.10231	0.04745	21.1	83.77	0
	7	28.510558	-0.01000	0.05702	17.5	-177.04	0
	8	10.329781	0.00103	0.06681	15.0	-169.75	0
	9	53.352259	-0.01749	0.08946	11.2	167.67	0
	10	3.187303	0.00503	0.10054	9.9	102.62	0
	11	56.104428	-0.04847	0.10581	9.5	-60.29	0
	12	3.430222	-0.00354	0.13213	7.6	57.81	0
	13	21.394553	-0.01910	0.15084	6.6	-87.03	0
	14	1.151704	0.00765	0.16016	6.2	113.16	0
	15	16.292767	-0.02146	0.17089	5.9	-10.70	0
	16	5.897412	-0.00130	0.17969	5.6	-165.90	0
	17	9.193364	-0.01238	0.19249	5.2	95.57	0
	18	5.315851	0.00151	0.20458	4.9	28.85	0
	19	0.422116	0.00849	0.21194	4.7	106.07	0
	20	15.657542	-0.01827	0.22381	4.5	-171.80	0
	21	30.299096	-0.00477	0.24761	4.0	172.51	0
	22	142.129492	-0.00173	0.25736	3.9	-173.68	0
	23	246.679447	0.00156	0.26886	3.7	-139.97	0
	24	600.314434	0.00865	0.27932	3.6	-173.10	0
	25	962.500465	-0.00125	0.29522	3.4	-140.98	0
	26	1203.859837	-0.01970	0.30270	3.3	-78.22	0
	27	4874.198054	0.01542	0.31578	3.2	-53.38	0
	28	4192.673238	-0.00146	0.32342	3.1	-23.93	0
	29	10872.288785	-0.03436	0.33481	3.0	21.30	0
	30	12624.921294	-0.00405	0.34617	2.9	32.82	0
	31	15788.963855	0.01263	0.35650	2.8	79.53	0
	32	29200.841162	0.00141	0.36958	2.7	141.47	0
	33	66334.756794	-0.01290	0.38414	2.6	146.93	0
	34	100964.308941	0.00974	0.39373	2.6	-159.22	0
	35	65871.722909	-0.00796	0.40157	2.5	-139.32	0
	36	155897.555889	0.01634	0.41453	2.4	-112.05	0
	37	591655.266692	0.00138	0.42232	2.4	-0.86	0
	38	2088738.339224	0.01109	0.44218	2.3	-173.63	0
	39	2104274.824684	0.01109	0.44218	2.3	-3.41	0
	40	4149394.762463	-0.00165	0.45418	2.2	163.74	0
	41	27988427.168030	-0.01138	0.47424	2.1	85.44	0
	42	31193237.432495	-0.00157	0.48995	2.0	-38.68	0
Kreivasis	1	44.366816	-0.16699	0.50000	2.0	90.00	0
	2	102.407394	-0.00213	0.00000	0.0	90.00	0
	3	9.816629	0.02449	0.03344	29.9	-109.34	0
	4	2.540052	0.02845	0.05982	16.7	-153.37	0
	5	8.119884	0.00752	0.07681	13.0	53.50	0
	6	19.771719	-0.02410	0.10242	9.8	-110.28	0
	7	3.174710	0.01806	0.12401	8.1	-28.32	0
	8	104.030036	-0.08888	0.14649	6.8	-15.98	0
	9	2.390926	0.02508	0.17693	5.7	-154.89	0
	10	23.228003	-0.03614	0.21887	4.6	32.89	0
	11	12.727086	-0.02916	0.26348	3.8	-3.84	0
	12	1.499989	0.01446	0.31982	3.1	175.28	0
	13	8.192062	-0.00717	0.35153	2.8	75.10	0
	14	11.406533	-0.01652	0.36891	2.7	41.89	0
	15	5.368405	-0.00975	0.42748	2.3	-8.89	0
	16	50.448155	-0.11215	0.45957	2.2	33.96	0
	17	0.427325	0.03210	0.47217	2.1	103.68	0
Duobulis	1	34.005311	-0.13476	0.50000	2.0	-90.00	0
	2	102.738804	0.00019	0.00000	0.0	90.00	0
	3	126.157678	-0.08142	0.03759	26.6	163.40	0
	4	4.640233	0.02632	0.07602	13.2	82.24	0
	5	2.375199	0.03748	0.08828	11.3	-29.39	0
	6	12.988869	-0.01528	0.11917	8.4	157.24	0
	7	16.565669	-0.01874	0.14467	6.9	16.49	0
	8	33.773021	-0.06530	0.16357	6.1	156.96	0
	9	31.533816	-0.04727	0.19321	5.2	-171.31	0
	10	2.061629	0.01788	0.23936	4.2	53.03	0
	11	22.447806	-0.06586	0.25281	4.0	-133.50	0
	12	1.467603	0.01077	0.27778	3.6	83.06	0
	13	10.545943	-0.00197	0.33865	3.0	135.84	0
	14	17.099902	-0.05904	0.36280	2.8	148.29	0
	15	12.224801	-0.02283	0.38981	2.6	-167.46	0
	16	22.415167	-0.02636	0.43076	2.3	-175.23	0
	17	23.213821	-0.04339	0.45520	2.2	-124.57	0

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Received 29 August 2004

ДЕНДРОХРОНОЛОГИЧЕСКОЕ ИССЛЕДОВАНИЕ ДРЕВЕСИНЫ СОСНЫ ОБЫКНОВЕННОЙ, ИЗВЛЕЧЛННОЙ ИЗ ОЗЕРА СТИРНЕЙ СЕВЕРОВОСТОЧНОЙ ЛИТВЫ

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Резюме

Дендрохронологические исследования было проведено на древесине субфосильной сосны найденной в озере Стирней северовосточной Литвы. Создана плавающая хронология радиального прироста, охватывающая 213 лет. Радиокарбонное датирование показало, что сосны росли в переходном периоде между Средневековой Эпохе Потепления и Малым Оледенением (1103±80–1315±80 н.э.). Исследование показало, что сосны росли на торфенной почве, возможно в *Pinetum carico-sphagnosum* типе леса. Установлено, что уровень воды в озере Стирней в Средневековой Эпохе Потепления вероятно был ниже теперешнего около 1.0 м. Анализ циклических колебании радиального прироста сосняков, произраставших на торфенной почве в побережьях оз. Стирней в 12-14 столетиях, позволило определить не менее 6 циклов, длина которых превышает 10 лет.

Ключевые слова: климат, Малое Оледенение, Средневековая Эпоха Потепления, радиальный прирост, радиокарбонное датирование, сосна обыкновенная, субфосильная древесина