Dendrochronological Analysis of Subfossil *Fraxinus* and *Quercus* Wood Excavated from the Kegai Mire in Lithuania

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Abstract

Dendrochronological investigations on subfossil *Fraxinus* and *Quercus* wood found in the Kegai mire in Western Lithuania are discussed. Radiocarbon dating has revealed that the trees grew in the Middle and Late Holocene (*Fraxinus* approximately from 4700 BC to 1500 BC and *Quercus* from 3400 to 2300 BC). These trees were slow-growing (on average less than 1 mm per year) and usually with a less pronounced age trend in comparison to living trees. The subfossil *Fraxinus* lived longer (131 years) than modern ash trees (76 years). It is supposed that their growth was limited by humid periods. The rise of soil water induced a long downward trend in ring width of ash and oak. This was followed by an abrupt reduction (up to 51%) in ring width before the die-off of ash trees. Up to now, forest history in Lithuania relied mostly on palynological studies, thus our results extend the current knowledge on the distribution of deciduous trees in the Baltic region in different periods of the Holocene.

Key words: dendrochronology, *Fraxinus*, Holocene, mire, *Quercus*, radiocarbon, subfossil

Introduction

Dendrochronological data of subfossil wood preserved in mires have been widely used for the reconstruction of climate and ecological conditions during the Holocene (Baillie 1982, Eronen *et al*. 2003, Fritts 1991). The highest number of millennial-long chronologies used for the reconstruction of environmental conditions in Western Europe has been compiled using oaks (*Quercus* spp.) excavated from river sediments and mires (Brown and Baillie 1992, Leuschner and Delorme 1988, Leuschner and Sass-Klaassen 2003, Leuschner *et al*. 2002, Schmidt 1973). In contrast to it, *Fraxinus* wood was investigated in only the rare situation where it was mixed with oak wood (Baillie 1982, Leuschner *et al*. 2002). However, it was repeatedly confirmed that tree-ring series of *Fraxinus* are suitable for dendrochronological analysis (Sass-Klaassen *et al*. 2003).

Pollen analyses in mires and lakes (Kabailienė 2006) have shown that *Fraxinus* and *Quercus* grew from 8000 BC and spread widely in Lithuania in the Late Atlantic period (4700-3000 BC). The prevalence of broadleaved during the Holocene in Western Europe was determined by long-term (centennial and millennial) climate changes and human impact in the later period (Davis *et al*. 2003). The anthropogenic impact on forests and woodlands is mainly responsible for the decrease of area occupied by broadleaved as a consequence of conversion to arable land, building activity, and hardwood timber trade to Western Europe (Haneca *et al*. 2005, Kabailienė 2006, Wazny 2002). *Fraxinus* and *Quercus* prefer fertile but well drained soils (Karazija 1997, Wardle 1961). To date, *Fraxinus* and *Quercus* forests occupy about 2.5% and 1.7%, respectively, of the total forest area in Lithuania.

Dendrochronological investigations on subfossil wood in Lithuania are mostly based on *Pinus* and less on *Quercus* wood from mires and river deposits (Pukienė 1997, 2003, Битвинскас *et al*. 1978); *Fraxinus* wood from mires was not investigated up to the present.

The aim of this study was to assess the potential of tree-ring series of subfossil *Fraxinus* and *Quercus* found in the Kegai mire to document forest history in Lithuania during the Holocene.

Materials and methods

The sampling site of subfossil *Fraxinus* and *Quercus* wood is located in Western Lithuania – a region of Žemaičiai Uplands. This region is characterized by high amounts of annual precipitation (734 mm, average in Lithuania – 675 mm), mild winters (coldest month January -4.4ºC, average in Lithuania – -4.9ºC) and cool summers (warmest month July +16.7, average in Lithuania – +17.0ºC) (Bukantis 1994). The average vegetation period lasts for 188-194 days.

The Kegai fen (a mire rich in minerals with drainage from the surrounding area to the centre (Helms 1998)) is situated near Kegai village in the Telšiai administrative district of Lithuania (Fig. 1). The mire has an oblong shape, and it is approximately 40 m x 70 m in size, geographical coordinates of the mire are: 55º50' latitude (N) and 22º17' longitude (E). The peat layer is up to 3 m thick. The mire is overgrown by young trees

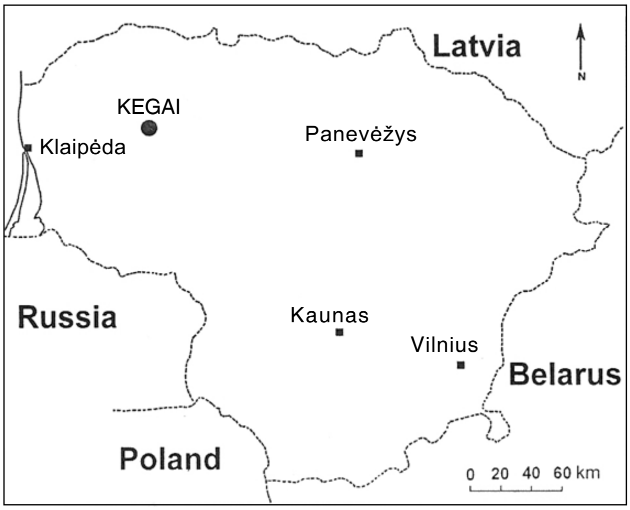


Figure 1. Location of the study site in Lithuania

and shrubs of *Salix*, *Alnus*, *Betula,* and *Populus*. Research was carried out expecting to find wood of *Quercus* for dendrochronological studies. During the investigation, 79 stem disks were collected. Investigations were performed after the peat excavations have revealed many wood remnants in the excavated peat. Thus, we could not study directly: (i) from what part of the mire, (ii) from what depth of peat layer the wood was extracted and (iii) what was the location (vertical or horizontal) of the stems preserved in peat.

Tree genera, among investigated samples were differentiated using microscopic anatomic analysis (Schweingruber 1990). Totally, eleven ash and three oak samples were identified.

Tree-ring widths of *Fraxinus* and *Quercus* samples were measured along at least two radii to the nearest 0.01 mm. For this purpose, a LINTAB tree-ring measuring table and the TSAP 3.14 computer program (F. Rinn Engineering Office and Distribution, Heidelberg) were used. The series were synchronized by visual comparison (Eckstein 1987) of ring-width graphs and checked statistically by TSAP 3.14. For this purpose, the coefficient of similarity (Gleichläufigkeit) (Eckstein and Bauch 1969) and standard t-value were used (Baillie and Pilcher 1973). Common statistics applied in dendrochronology, such as mean sensitivity and 1st order autocorrelation, were calculated for each tree-ring series. The values of mean sensitivity are divided into three classes: low sensitivity (complacent series) – <0.15, medium sensitivity – 0.16-0.29, and high sensitivity – > 0.30 (Till 1987). The frequencies of cycles expressed in the tree-ring series of *Fraxinus* and *Quercus* were assessed by using a single series Fourier (spectral) analysis. For this purpose, Statistica 6.0 (StatSoft Inc., *www.statsoft.com*) was applied.

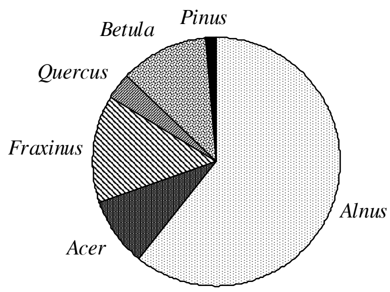
By measuring radiocarbon, five *Fraxinus*, three *Quercus*, and one *Alnus* sample were dated. This was done because dendrochronological synchronization has indicated that some *Fraxinus* and *Quercus* samples may perhaps be from different periods. Wood of *Alnus* was dated aiming to better understand the history of mire formation. This work was accomplished by using a high precision Liquid Scintillation Spectrometer – Counter LSC-1220 „Quantulus“ (PerkinElmer, Waltham). The radiocarbon calibration is a procedure used for converting radiocarbon ages to calendar years. Fluctuations in the atmospheric radiocarbon have been produced by changes in the solar magnetic field intensity. Radiocarbon dates were calibrated by using CALPAL program (B. Weninger, Köln University) (Weninger *et al.* 2003) with the INTCAL98 tree-ring calibration curve (Stuiver *et al.* 1998).

Results

Six tree genera among 79 wood samples from the Kegai mire were identified: *Alnus* (48 samples), *Fraxinus* (11), *Betula* (9), *Acer* (7), *Quercus* (3), and *Pinus* (1) (Fig. 2).

Ten from 11 *Fraxinus* samples and all three *Quercus* samples were suitable for dendrochronological analysis. Because of poor preservation, the *Acer*, *Bet-*

Figure 2. Tree species-related distribution of 79 wood samples found in the Kegai mire



ula and *Alnus* samples were not measured. The *Pinus* sample contained only 65 rings, and thus was unsuitable for dendrochronological investigation.

The radiocarbon dating of *Fraxinus*, *Quercus* and *Alnus* is presented in Table 1. The conventional radiocarbon dates of the *Fraxinus* samples ranged from 5753±34 to 3240±45 BP. The calibrated dates indicated that *Fraxinus* from the oldest period grew approximately from 4700-4600 BC. The other *Fraxinus* trees grew later by at least one millennium. *Fraxinus* from the youngest period grew approximately from 1600-1500 BC.

The conventional radiocarbon dates of *Quercus* samples ranged from 4599±47 to 3892±120 BP. The calibrated dates demonstrated that *Quercus* lived approximately between 3400 and 2300 BC.

The alder grew much earlier – in the Late Boreal period (conventional date - 7453±79 BP and calibrated date - 6320±60 BC).

The investigations have shown that the *Fraxinus* trees belong to different age categories: from 59 to 238 rings (Table 1) with waney edge missing in all samples. Tree-ring widths varied from 0.44 to 0.78 mm. The radial growth of *Fraxinus* is characterized by low or medium mean sensitivity (0.13-0.28). The standard deviation of the tree-ring series ranged from 0.15 to 0.21 and the 1st order autocorrelation from 0.46 to 0.85.

The dendrochronological synchronization of 10 *Fraxinus* samples enabled to construct four tree-ring mean curves spanning 98 to 246 years and including one to four samples (Fig. 3). They are radiocarbon dated to: 4688-4576 BC (Keu1 and Keu54), 3540-3295 BC (Keu2, Keu3 and Keu27), 2209-2112 BC (Keu36) and 1573-1471 BC (Keu43, Keu49, Keu50 and Keu52). The similarity between the tree-ring series used for the construction of the floating mean curves usually is very high: the coefficient of similarity varies from the 66 to 82% and t-value from 6.6 to 15.7.

Table 1. Radiocarbon dating and dendrochronological cross-dating characteristics of 14 tree-ring series of subfossil wood found in the Kegai mire

Sample	Species	C^{14} date (BP)	CalAge, p-68% (BC)	Span	Average ring width (mm)	Mean sensitivity	1st order auto-correlation
Keu 1	F	5753±34	4610±60	113	0.49	0.17	0.64
Keu 2	F	4590±32	3340±140	238	0.78	0.18	0.60
Keu 3	F	4593±54	3320±150	227	0.60	0.14	0.79
Keu 27	F			235	0.73	0.15	0.75
Keu 36	F	3753±51	2160±90	98	0.55	0.17	0.71
Keu 43	F	3240±45	1520±70	100	0.49	0.19	0.62
Keu 49	F			87	0.60	0.28	0.51
Keu 50	F			59	0.64	0.26	0.46
Keu 52	F			86	0.52	0.24	0.46
Keu 54	F			69	0.44	0.13	0.85
Keu 28	Q	3892±120	2370±170	86	0.28	0.26	0.13
Keu 37	Q	4267±105	2870±170	88	0.56	0.27	0.43
Keu 29	Q	4599±47	3350±140	116	0.75	0.22	0.68
Keu 35	A	7453±79	6320±80				

Abbreviations: F - *Fraxinus*, Q – *Quercus*, B – *Betula*, and A – *Alnus,* C^{14} date (BP) –radiocarbon dates before present (before 1950), CalAge, p-68% (BC) – calibrated radiocarbon dates (BC) within 1 σ (68%) confidence limit

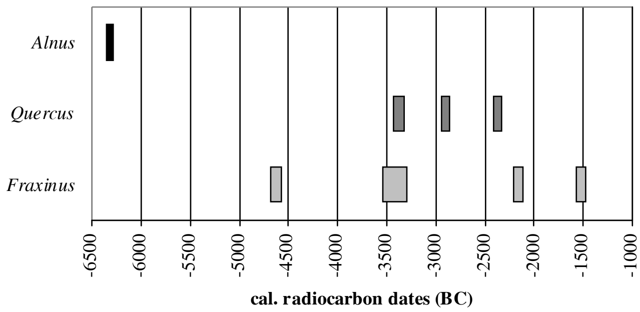


Figure 3. Radiocarbon dated and dendrochronologically cross-dated floating curves of *Alnus* (1), *Quercus* (3) and *Fraxinus* (4) from the Kegai mire

The three *Quercus* samples contain 86 to 116 years (Table 1) with missing outermost rings in all three samples. The tree-ring widths vary from 0.28 to 0.75 mm. The radial growth is characterized by medium mean sensitivity (0.22-0.27). The standard deviation of the tree-ring series ranges from 0.07 to 0.29, and the 1st order autocorrelation from 0.13 to 0.68. They are radiocarbon dated to: 3437-3322 BC (Keu29), 2943-2856 BC (Keu37) and 2412-2327 BC (Keu28).

Abrupt growth depressions occurring every 40-60 years, are common for two of the *Fraxinus* mean curves and one *Quercus* series dated to 3540-3295, 3437-3322 and 2209-2112 BC, respectively (Fig. 4 curves B and C, Fig. 5 curve A). Spectral analysis has confirmed the existence of 19, 29, 33, 41, 49, 58, 61, 82 and 98-year cyclic components in the patterns of these series (Fig. 6). No visible depressions are present in two *Fraxinus* and two *Quercus* chronologies dated to 4688-4576, 2943-2856, 2412-2327 and 1573-1471 BC, respectively (Fig. 4 curves A and D, Fig. 5 curves B and C). Spectral analysis has revealed shorter cycles for these chronologies: 2, 4, 5, 6, 7, 8, 11, 12, 14, 15, 19, 22, 28, 29, 34, 37, 43, 44 and 56-year cyclic components (Fig. 7) Most cycles, except the 58-year cycle, are not significant at p=0.05 level.

A long downward trend is typical of four mean curves: 4688-4576, 3540-3295, 2943-2856 and 1573-1471 BC (Fig. 4 curves A, B and D, Fig. 5 curve B). The *Fraxinus* trees in 4688-4576, 3540-3295 and 2209-2112 BC have indicated abrupt growth reduction before die-

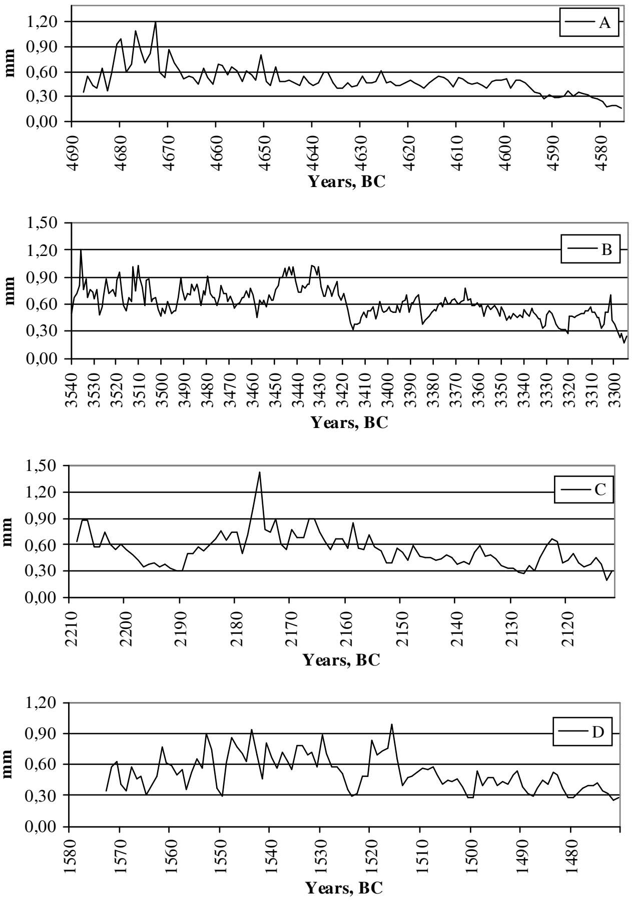


Figure 4. Floating tree-ring curves of *Fraxinus*: A – mean curve (made from two trees), dated to 4688-4576 BC; B – mean curve (three trees), dated to 3540-3295 BC; C – series (one tree), dated to 2209-2112 BC; D – mean curve (four trees), dated to 1573-1471 BC

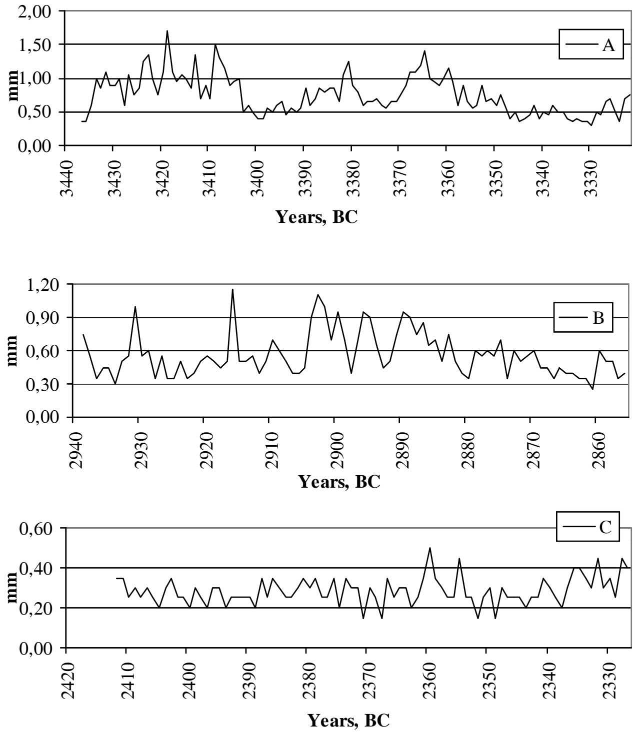


Figure 5. Floating tree-ring series of *Quercus*: A – series (one tree), dated to 3437-3322 BC; B – series (one tree), dated to 2943-2856 BC; C - series (one tree), dated to 2412-2327 BC

off: 39, 51 and 17% reductions during the five years in comparison to the five preceding years (Fig. 4 curves A, B and C).

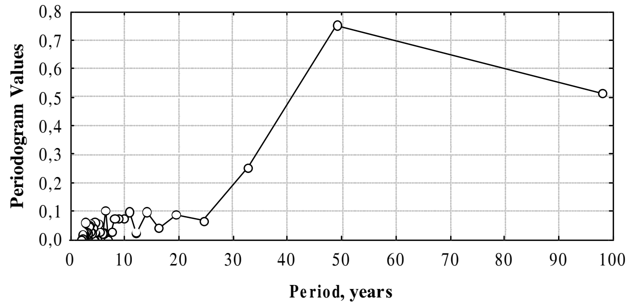


Figure 6. Spectral analysis (periodogram) of *Fraxinus* tree-ring series dated to 2209-2112 BC

Discussion

Fraxinus and Quercus samples comprise 18% of all investigated wood remnants (Fig. 2). They prefer fertile but well drained sites. However, needs in soil fertility for *Quercus* are less than for *Fraxinus* (Karazija 1997, Wardle 1961). *Fraxinus* is a common tree in waterlogged habitats, but the growth usually is poor (Wardle 1961), while *Quercus* is intolerant to long-lasting waterlogging (Новосельцев и Бугаев 1985). The studies have demonstrated that *Fraxinus* growth at waterlogged sites is negatively affected by high-amplitude and long-lasting floods (Tardif and Bergeron 1993). Wardle (1961) has shown that *Fraxinus* is intolerant to water shortage at waterlogged sites, where

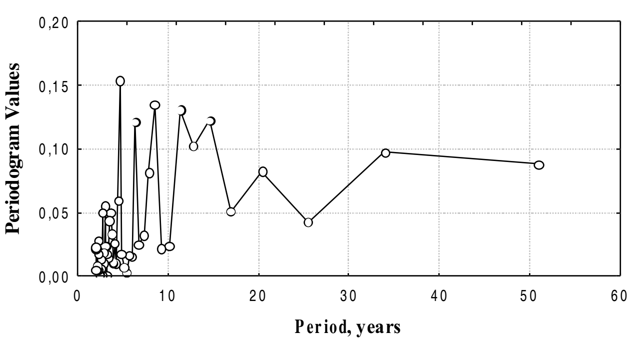


Figure 7. Spectral analysis (periodogram) of *Fraxinus* mean curve dated to 1573-1471 BC

the roots are unable to penetrate deep. This is in agreement with investigations of Karazija (1997), who described *Quercus* to be sensitive to high soil water fluctuations but tolerant to water shortage due to its deep root system (Погребняк и Мельник 1952).

The *Fraxinus* and *Quercus* trees grew on peat soil. At present, mires are not the typical sites for broadleaved in Europe. Therefore, it is impossible to study the growth of modern *Fraxinus* and *Quercus* in mires. Baillie (1982) hypothesized that such atypical vegetation on mires in the past may indicate drier geological periods.

The radial growth of living broadleaved is poorly investigated in Lithuania. This was mainly due to the prevalence of coniferous forests in Lithuania. Therefore, the number of the results published on tree rings of broadleaved in Lithuania is limited (Pukienė 2003, 2004, Vitas 2004, Битвинскас *et al*. 1978).

The narrow tree rings (on average 0.53-0.58 mm) are typical of the study trees (Table 1). They indicate poor growth conditions related to high water table of the mire. For example, the average tree-ring width of modern *Fraxinus* and *Quercus* trees is 2.08 mm and 1.60 mm, respectively (Karpavičius and Vitas 2006, Кайрайтис 1979) and for subfossil *Quercus* found in river deposits – 1.73 mm (Vitas 2004).

The autocorrelation of *Fraxinus* and *Quercus* tree-ring series is 0.64 and 0.41, respectively. It is slightly smaller than modern trees (0.73 and 0.53) (Karpavičius and Vitas 2006). This indicates a weaker overall trend in the growth patterns of *Fraxinus* and *Quercus* in comparison to living trees. This is in agreement with the investigations of subfossil *Pinus* carried out by Pukienė (1997) in an oligotrophic bog, where most trees did not show a downward age trend.

The history of the flora in Lithuania during the Holocene has been mainly reconstructed from palynological data (Kabailienė 1990, 2006). *Fraxinus* and *Quercus* pollen were found in sediments dated to 8000 BC (maximum number observed in the Atlantic period, 4700-3000 BC). Dates based on palynological investigations are only approximate, because pollen often is washed into deeper layers of the sediment and the quantitative reconstruction of the prevalence of species is complicated because different plants produce unequal quantities of pollen during the flowering period (Kabailienė 2006).

Radiocarbon dating confirms that at the initial stages of the mire (Late Boreal period) it was overgrown by *Alnus* (approximately 6300 BC). This is in accordance with studies on mire history in Western Europe (Leuschner and Sass-Klaassen 2003). *Fraxinus* and *Quercus* trees grew in the mire in the Late Atlantic and Sub-Boreal periods – approximately 4700-1500 BC and 3400-2300 BC, respectively. The Sub-Boreal period (3000-1000 BC) is characterized by flourishing of coniferous and broadleaved species (*Pinus*, *Betula*, *Picea*, *Alnus*) in Lithuania (Kabailienė 2006). Therefore, *Fraxinus* wood dated to the Sub-Boreal period extends the available palynological information on the forest history in the Baltic region.

Investigations on Stone Age pile-dwellings confirm that *Fraxinus* was a common tree. For example, investigations at the Žemaitiškės-2 pile-dwelling (Eastern Lithuania) have shown that *Fraxinus* posts predominate in wooden constructions (57%) (Pukienė 2004). These samples were radiocarbon dated to 4850-2500 BC. Because there are no forests with *Fraxinus* in this region of Lithuania at present, it might be supposed that *Fraxinus* was more widely spread in prehistoric times in comparison to the present time (Pukienė 2004). These findings are in agreement with investigations on prehistoric settlements in Slovenia (Čufar *et al*. 2005), where *Fraxinus* samples were dated to 3200-2500 BC. Our investigation on *Fraxinus* wood shows, that ash trees were quite common on the territory of Lithuania from approximately 5000 to 2000 BC.

The growth depressions in two *Fraxinus* tree-ring mean curves and one *Quercus* series occurred with a periodicity of 40-60 years and lasted from several to ten or more years (Fig. 4 curves B and C, Fig. 5 curve A). Spectral analysis has confirmed the presence of longer cycles (from 19 to 98 years). Leuschner *et al*. (2002) have attributed such growth depressions in *Quercus* to the rise in the soil water; later this was proven by other investigations (Sass-Klaassen and Hanraets 2006). A sharp reduction of the *Fraxinus* growth before die-off indicates a constant worsening of the growth conditions, connected to the hydrological regime of the mire – the rise of water level (Fig. 4 curves A, B and C). There are no visible persistent depressions in the oldest (4688-4576 BC) and youngest (1573-1471 BC) mean curves of *Fraxinus* (Fig. 4 curves A and D) and in two younger *Quercus* series dated to 2943-2856 and 2327-2412 BC (Fig. 5 curves B and C). The oldest *Fraxinus* and *Quercus* samples are also characterized by higher 1st order autocorrelation, which indicates a pronounced downward trend (Table 1).

This may be explained by: (i) less contrasting climate conditions in these periods or (ii) differences in site conditions. The second assumption is based on studies of bog oaks in Western Europe. It was established that there were two groups of trees: some rooted on mineral soil and overgrown by peat, while others rooted directly on peat soil (Leuschner *et al*. 1987). A visible downward trend (Fig. 4 curves A, B and D, Fig. 5 curve B) also confirms that some trees probably grew on mineral soil (Vitas and Erlickytė 2007). On the other hand, the growing time of the oldest *Fraxinus* coincides with an intensive formation of mires in Lithuania (Kabailienė 2006) triggered by humid Atlantic climate. Therefore, trees in this period probably grew on a thin peat layer and later were overgrown by the accumulation of peat. Because the roots of these *Fraxinus* were rotten and comprehensive soil examinations are missing, we cannot validate our hypothesis.

The lifetime of *Fraxinus* and *Quercus* in the Kegai mire, especially in 3540-3295 (*Fraxinus*), 2209-2112 (*Fraxinus*) and 3437-3322 BC (*Quercus*), corresponds to the phases of bog oaks prevalence in Western Europe (Leuschner and Sass-Klaassen 2003, Leuschner *et al.* 2002, Spurk *et al.* 2002). This indicates: (i) that the trees were under the control of large-scale climate changes, involving wide areas of Europe and (ii) that *Fraxinus* seems to be sensitive to the same climate extremes (cooling and increased humidity) as *Quercus* are. The results of the study are preliminary as they are limited by a small number of samples and therefore, more investigations are required in the future. Due to the small number of *Fraxinus* samples, there is no possibility to answer several questions related to the growth site of the trees: (i) did they grow on raised bog peat or on fen peat? (ii) did the trees grow on a slope of the bog and have accidentally fallen to the bog? In spite of these limitations, the current study extends our knowledge on the growth of *Fraxinus* in the Holocene pointing to the bigger age of trees in former times, and that they were perhaps more widely distributed in different periods of the Holocene than it was established by using palynological data.

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ДЕНДРОХРОНОЛОГИЧЕСКИЙ АНАЛИЗ СУБФОССИЛЬНОЙ ДРЕВЕСИНЫ ЯСЕНЯ И ДУБА, НАЙДЕНЫХ В БОЛОТЕ КЕГАЙ В ЛИТВЕ

А. Витас

Резюме

Представляются результаты дендрохронологических исследований субфоссильных находок древесины ясеня и дуба из болота Кегай, западной части Литвы. Радиоуглеродное датирование показало, что деревья росли в Среднем и Позднем Голоцене (ясени приблизительно с 4700 до 1500 г. до н. э., а дубы с 3400 до 2300 г. до н. э.). Исследованные деревья по диаметру росли медленно (в среднем меньше чем 1 мм за год) и обычно с менее выраженым возрастным трендом, чем ныне живущие деревья. Исследованные ясени жили дольше (131 лет) по сравнению с ныне живущими деревьями (76 лет). Предположительно, что рост деревьев в исследованном болоте было лимитировано влажными периодами. Повышение грунтовых вод индуцировало длительный понижающийся тренд, сопровождаемый резкими сокращениями (до 51%) в динамике радиального прироста перед гибелью ясеней.

До сих пор, история лесов в Литве главным образом основывалась на результатах палинологических исследований, таким образом, полученные результаты расширяют настоящее знание по распространению лиственных пород в Балтийском регионе в различные периоды Голоцена.

Ключевые слова: болото, Голоцен, дендрохронология, дуб, радиоуглерод, субфоссильная, ясень