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Holocene sediment record from Briaunis palaeolake, Eastern Lithuania: history of sedimentary environment and vegetation dynamics

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Abstract This paper presents new data describing the Holocene environmental history of the Briaunis palaeolake, Eastern Lithuania. Shortly before 9600 cal yr BP, sedimentation began in an oligotrophic deep-water basin, whereas the Early Holocene instability of the environmental regime caused the influx of detrital sediment into the basin. A birch forest dominated in the surrounding landscapes, and at ca. 9600 cal yr BP, the spread of *Ulmus, Alnus, Populus* and *Corylus* began, suggesting a short-lived climatic amelioration. A subsequent drop of the water table and increasing influx of the terrigenous material continued from 9600 to 9300–9200 cal yr BP. The ensuing climatic stability caused the formation of a deciduous forest and the regional spread of *Picea*. Some instability, i.e. a decline in the thermophilous species, as well as the appearance of boreal and northern alpine diatoms, could be associated with the so-called "8.2 ka event". This reversal was followed by amelioration and prospering of the water plants typical of the Holocene climatic optimum from 7900 to 7200–7100 cal yr BP. At aproximatelly 6600–6500 cal yr BP, a small rise of the water table was documented and bog-forming processes dominated until ca. 3600–3400 cal yr BP, when a small-scale deepening of the basin occured.

Keywords *Pollen • Plant macrofossils • Diatoms • Vegetation changes • Sedimentation history • Holocene • East Lithuania*

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INTRODUCTION

Based on multi-proxy records, the post-glacial history of vegetation and climate, and the sedimentary environment, have been investigated from the Eastern Baltic region and neighbouring countries (Ilves, Medne 1979; Ralska-Jasiewiczowa 1983, 1989; Heikkilä *et al.* 2009; Kupryjanowicz 2007; Niinemets, Saarse 2009; Szoszkiewicz *et al.* 2010). Similarly, recent studies of the palaeoenvironment and palaeoecosystems of Lithuania contribute to the solution of the issues of stratigraphy, palaeogeography and post-glacial evolution of the components of the ecosystem (Stančikaitė *et al.* 2002, 2003, 2004, 2008; Kabailienė 2006; Gaidamavičius *et al.* 2011; Balakauskas 2012). Despite the long-term investigations of this type conducted in many countries, detailed complex studies of the evolution of the Holocene palaeoecosystem are lacking in this region. The data on macrofossils as the natural signals of plant variability in the period under consideration are particularly poor, and a detailed chronology based on the absolute dates is missing in most cases. The results of biostratigraphy have played an important role in the chronostratigraphical subdivision of the post-glacial history in Lithuania. The existing biostratigraphical units were based on the vegetation dynamic established on a regional scale. However, no detailed data describing the migration pattern of a particular species or the local composition of terrestrial and aquatic vegetation were obtained previously. To obtain this information in this study, a plant macrofossil survey was applied that allowed a new approach for the reconstruction of the local vegetation history and correlation of the data sets in the context of the regional events (Kupryjanowicz 2007; Heikkilä 2009; Niinemets, Saarse 2009). The pollen, plant macrofossil and diatom survey with LOI (loss-on-ignition) and ^{14}C measurements were applied for the reconstruction of the palaeoecological setting in the investigated basin because similar investigations have shown important results describing the postglacial history of numerous lakes (Šeirienė *et al*. 2009; Stančikaitė *et al.* 2009; Gaidamavičius *et al.* 2011). The recorded fluctuations are discussed in a context of regional climatic variations established in the North Atlantic Climatic rim (Björck et *al*. 1996*,* Wohlfarth *et al.* 2002; Subetto *et al.* 2002). The new data can be considered as reliable markers of the palaeoenvironmental history of the post-glacial history in this area of Lithuania. The performed study supplemented the existing databases on the East Lithuanian region with data about post-glacial vegetation and changes of the palaeoecological conditions.

STUDY AREA

The complex investigation was carried out in the sediment section made in the eastern shore of Briaunis Lake (54°43′64″N, 24°36′51″E) situated in the East Lithuanian Elektrėnai District (Fig. 1). The lake occupies an area of 3.1 ha, stretching 102 m a.b.s. The reference area is a deep pothole in the distal slope of Baltijos Upland, Dzūkai Hill 2.5 km south-west of the Elektrėnai Pond (Fig. 1). The main features of relief in the reference area were sculptured by the Last (Weichselian) Glaciation (Guobytė 2001). The pothole is 25–30 m deep, 2.5 km long and 0.6–0.7 km wide. It is surrounded by small hilly morainic glacier formations composed of till sediments. The morainic hills are somewhere covered with a thin layer of glaciofluvial sand. The depressions between are filled with silty sand, deposited in small palaeobasins that must have existed in late glacial (Fig. 1). In the bottom of the depression, the lacustrine sediments are bedding at different absolute altitudes: the highest bedding point is situated at the north-western edge of the pothole (110–115 m a.s.l.); the lower scarp of the glaciolacustrine plain is mapped in the northern and southern parts of the pothole where the sandy glaciolacustrine plain is lying at 105–108 m a.s.l. Two scarps of glaciolacustrine plain are distinct in the centre of the pothole. They are situated at 100–103 and 95–100 m a.s.l. respectively. The central, deepest, part of the pothole is occupied by the boggy glaciolacustrine plain with Švenčius and Briaunis lakelets. It is surrounded by a glaciolacustrine plain (100–103 m a.s.l.) which is composed of sandy peat left by past bogging processes.

According to climatic classification of Lithuania's territory, the study area is included in the Aukštaičiai sub-region of the Lithuanian South-East Upland cli-

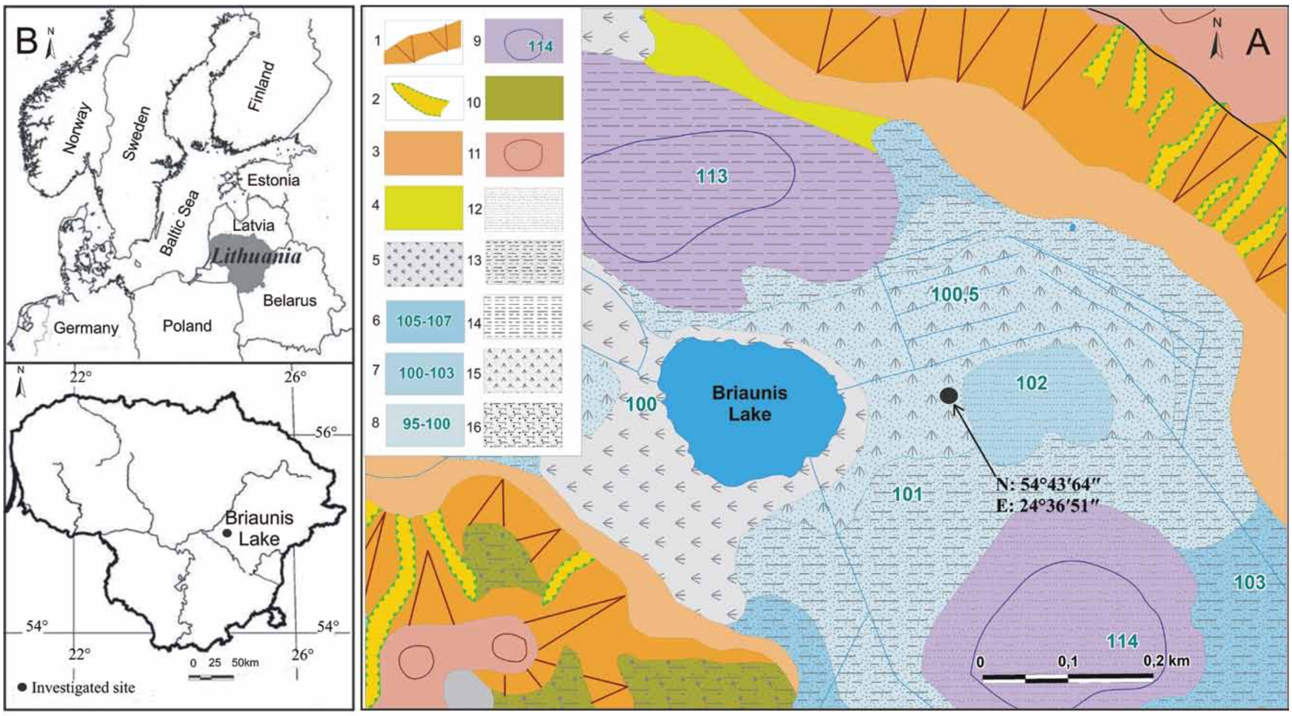


Fig. 1 A. Geological-geomorphological map (1:10 000) of the study area surrounding the Briaunis Lake, Eastern Lithuania (after R. Guobytė 2001). Legend: Holocene, lateglacial: 1) ice contact slopes; 2) ravines; 3) deposits of solifluction origin; 4) deposits of temporary flows; 5) peat (unidentified); teracces of the lacustrine plain: 6) the 3-rd (105–107 m a.s.l.), 7) the 2-nd (100–103 m a.s.l.), 8) the 1-st (95–100 m a.s.l.); 9) altitude of the surface. Upper Pleistocene, Upper Nemunas, Baltija Stage: 10) kames; 11) glaciofluvial hills. Lithology: 12) fine grained sand; 13) clayey-silty sand; 14) silty clay; 15) peaty sand; 16) clayey sand with sparse gravel. **B.** Insets show location of the reference site.

mate region. The average annual precipitation is about 600–700 mm and average annual air temperature 5.5 ºC (Bukantis 1994 a, b) here. Coniferous forests are dominant in the present Elektrėnai District. About two thirds of the stands are represented by pine forests, followed by birches, alders, aspen and grey alders. The Briaunis Lake is surrounded by cultivated fields.

METHODS

Drilling and sediment sampling. For determining the thickness and lithological composition of the sediments as well as for sampling of the deposited in the Briaunis lakeside, 4 parallel wells were drilled to a depth of 8 m. The core samples of lake sediments were taken using the "Russian" manual drill (length 100 cm; diameter 5 cm). The samples for pollen and diatom analysis were spaced 2 cm and for macrofossil analysis and radiocarbon dating 5 cm.

Pollen analysis. For isolation of pollen grains, V. Gritchuk's (Grichuk 1940) separation and G. Erdman's acetolysis (Erdtman 1936) methods were applied. The analysis was performed with NICON microscope using image expansion 400 x. 500 pollen grains of terrestrial plants were counted in each sample (Kabailienė 2006). K. Fægri and J. Iversen (1989) and Moore *et al.* (1991) pollen atlases were used for identification of pollen. Spores were identified using D. Moe's (1974) atlas. Percentage calculation of identified taxa is based on the sum of arboreal (ΣAP) plus non-arboreal (ΣNAP) taxa.

Analysis of plant macrofossils. Samples (230 cm^3) were taken from the core sample at intervals of 5 cm. The samples were rinsed using a percolator with mesh size (diameter) 0.25 mm. The isolated macrofossils of plants were identified using binocular microscope Nikon 1500 with expansion capacity 10–100 x, Beijerinck (1947), Cappers *et al.* (2006) and Grigas (1986) atlases and comparative collection of contemporary vegetation. The results in the diagram are given in absolute values, except the sums of plant groups (Trees, Aquatic plants, Wetland plants, Xeromesophytes, Indeterminate), those are given in percentages.

Diatom survey. The technical preparation of samples for diatom analysis was performed using the standard method (Battarbee 1986; Miller, Florin 1989). About 500 diatomic shells were counted in the central part of each slide. The diatoms were examined using biological microscope Nikon Eclipse with expansion magnitude 1000 x and immersion liquid. For identification of species and description of ecological conditions, Krammer and Lange-Bertalot (1988, 1991 a, b; 1997) were used. The obtained results are given in the percentage diagram including the most typical and stratigraphically and ecologically most significant species only. For construction of pollen, diatom and plant macrofossil diagrams the programs TILIA and TILIA-GRAPH (Grimm 1992) and CorelDRAW 7 were applied.

Statistical methods. Alongside with the visual inspection, stratigraphically constrained cluster analysis (CONISS) (Grimm 1987) was applied for the subdivision of the palaeobotanical diagrams.

Radiocarbon (^{14}C) dating. The absolute age of sediments was determined by radioactive carbon (^{14}C) dating at the Radioisotope Research Laboratory of the Institute of Geology and Geography, Nature Research Centre (NRC) in Vilnius, Lithuania. AMS ^{14}C dating of one sample of terrestrial macrofossils (*Alnus* seeds) was conducted at Beta Analytic Laboratory, United States. For calibration of dates, OxCal v3.10 software (Bronk Ramsey 2001) and IntCal2009 calibration curve (Reimer *et al.* 2009) were used. The age-depth model was developed using Bayesian sequence modelling, implemented in the OxCal v4.2.2 programme (Bronk Ramsey, Lee 2013).

Loss-on-ignition (LOI). In order to estimate sedimentation of conditions the Briaunis palaeolake loss-on-ignition (LOI) method was applied (Heiri *et al.* 2001). Loss-on-ignition method was based on dry (105°C) material combustion which established the organic material (550°C) and carbonate (900°C) content. In total, 46 samples were investigated.

RESULTS

Lithological composition of sediments

Four lithological types of sediments were distinguished in the Briaunis palaeolake sediment stratum (Table 1). The stratum is predominated by layers of biogenic and limnic origin. The changes of lithological composition of sediments are related to different development stages of the basin predetermined by climatic conditions, fluctuations of basin water level, changes of lake vegetation, etc.

Table 1 Lithology of Briaunis palaeolake sediments. Compiled by G. Gryguc, 2012.

Depth, cm	Lithological unit	Lithology
0–300	4	Black peat
300–373	3	Brownish peat with numerous remains of trees
373–718	2	Brownish grey gyttja
718–800	1	Sandy clayey gyttja

Loss-on-ignition (LOI)

Estimated proportions of organic matter carbonate and terrigenous material indicated changes of sedimentation regime in the basin. The lower part of the core (800–387 cm) consists of calcium carbonate (91.16–66.22%) with admixtures of organic (3.98–12.04%) and terrigenous matter (5.17–26.73%). Meanwhile the upper part (387–35 cm) consists of organic (73.13–88.79%) and terrigenous matter (4.28–21.22%) predominantly. Amount of calcium carbonate is minor in this interval (1.6–8.47%) (Fig. 3).

Pollen analysis

A pollen diagram was compiled based on the data obtained by analysis of 42 samples (Fig. 2). According to the dominant plant species, five (B_{p-1}–B_{p-5}) local pollen zones (LPAZ) reflecting development stages of vegetation in the reference area were distinguished (Table 2).

Table 2 Local pollen zones. Compiled by M. Stančikaitė, 2010.

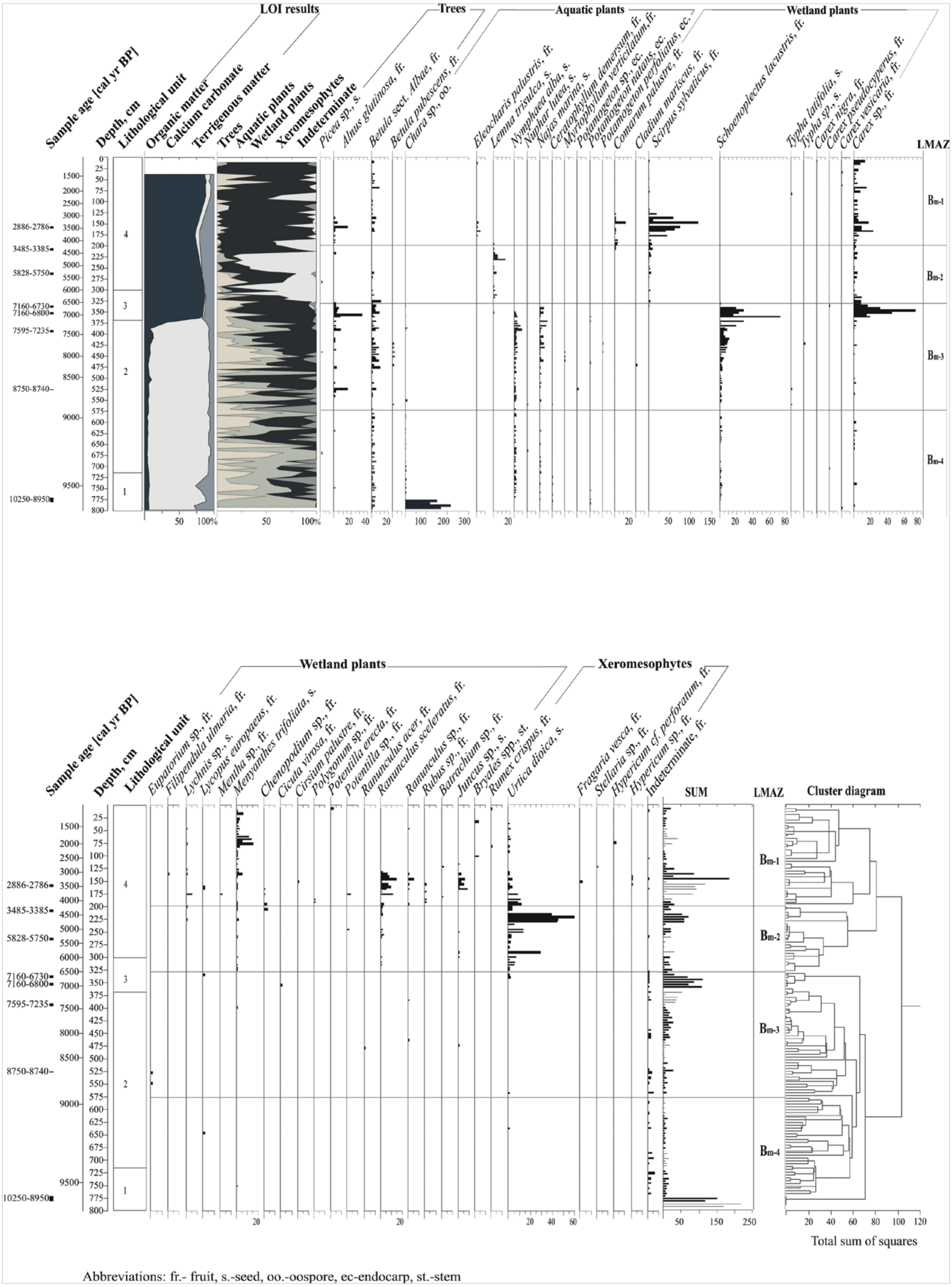
LPAZ	Depth, cm	Description
B_{p-5}	799–783	AP accounts for up to 88.5% with *Betula* reaching 58% and *Pinus* showing 43.7%. Cyperaceae (up to 5.1%) and Poaceae (up to 5.5%) are the best represented among NAP.
B_{p-4}	783–701	The number of *Betula* pollen decreases in comparison with the previous LPAZ whereas the number of *Pinus* (53.7%), *Ulmus* (3.8%), *Populus* (1.7%) and *Corylus* (1.0%) gradually increases. The number and variety of NAP is still low in this zone.
B_{p-3}	701–641	This zone is distinguished based on the immigration of new deciduous trees including the broad-leaved ones. *Alnus* reaches up to 2.4%, *Tilia* – 8.4%, *Quercus* – 2.2% and *Corylus* increases up to 14.4%. The number of *Betula* pollen decline drastically showing 15.9% in the upper part of the zone. NAP representation is negligible as well.
B_{p-2}	641–439	AP is dominated by *Pinus* (58%), *Alnus* (12.7%) and *Corylus* (16.9%) in the lowermost part of the zone. *Betula* reaches only 5.8% and scattered pollen grains of *Fraxinus* were recorded.
B_{p-1}	439–361	This zone is characterized by a decreasing representation of *Pinus* curve. Meanwhile, most of other trees, increased in representation and QM culminates (up to 17.0%) simultaneously. NAP are represented by Cyperaceae (up to 7.2%) mainly.

Plant macrofossils survey

In 150 samples, macrofossils belonging to 50 taxa were determined. 31 taxa are identified to species and 19 to genus. The macroflora complex from the analysed section was grouped into four (B_{m-1}- B_{m-4}) large local zones (Table 3). The identified species are attributed to trees and grasses and the latter are further subdivided into ecological groups: aquatic plants, wetland plants and xeromesophites (Fig. 3). In the group of arborous plants 4, in the group of aquatic plants 11, in the group of wetland plants 29, and in the group of xeromesophites -6 taxa were identified.

Table 3 Local macrofossil zones (LMAZ). Compiled by G. Gryguc and D. Kisielienė, 2011.

LMAZ	Depth (cm)	Description
B_{m-4}	800–575	Aquatic plants prevail. *Chara* sp. oospores are abundant in the lower part of the interval (780–800 cm) whereas in the upper part of the zone (575–780 cm) their amount considerably reduces; other species i.e. *Nymphaea alba*, *Najas marina*, *Ceratophyllum demersum*, and *Potamogeton natans* are dominant here. The littoral zone was overgrown with *Schoenoplectus lacustris* and the shores - with birch. Also *Picea* sp. fossils were identified.
B_{m-3}	575–330	The composition of flora in the water basin remains almost the same as well as the dominant plant species. Only *Nymphaea alba* and *Najas marina* are found in a greater abundance. *Myriophyllum verticillatum*, *Potamogeton perfoliatus* and small amount of *Lemna trisulca* appear. The number of wetland plants increases. *Schoenoplectus lacustris* and *Carex* sp. fossils are found in especially great abundance. Isolated *Cladium mariscus* fruits occur. This zone abounds in macrofossils of trees predominated by *Betula* sect. *Albae* and *Alnus glutinosa*.
B_{m-2}	330–200	Wetland plants i.e. *Scirpus sylvaticus, Carex* sp., *Ranunculus sceleratus* and *Menyanthes trifoliata* are dominant in this zone. Whereas *Urtica dioica* is most abundant among xeromezophytes. Only *Lemna trisulca* seeds are the single representatives of aquatic plants. Small amount of alder and birch macrofossils recorded.
B_{m-1}	200–5	Water plants are absent and wetland plants predominating in this zone. Furthermore richness of the recorded species is higher. *Scirpus sylvaticus*, *Ranunculus sceleratus, Menyanthes trifoliata* and *Carex* sp. are found in a greatest abundance. Species of plants growing in dryer habitats i.e. *Rumex crispus*, *Hypericum perforatum*, *Fragaria vesca*, *Urtica dioica* occur in a greater number.



Abbreviations: fr.- fruit, s.-seed, oo.-oospore, ec-endocarp, st.-stem

Fig. 3 Diagram of macrofossils found in the sediments of Briaunis palaeolake. Compiled by G. Gryguc and D. Kisielienė, 2011.

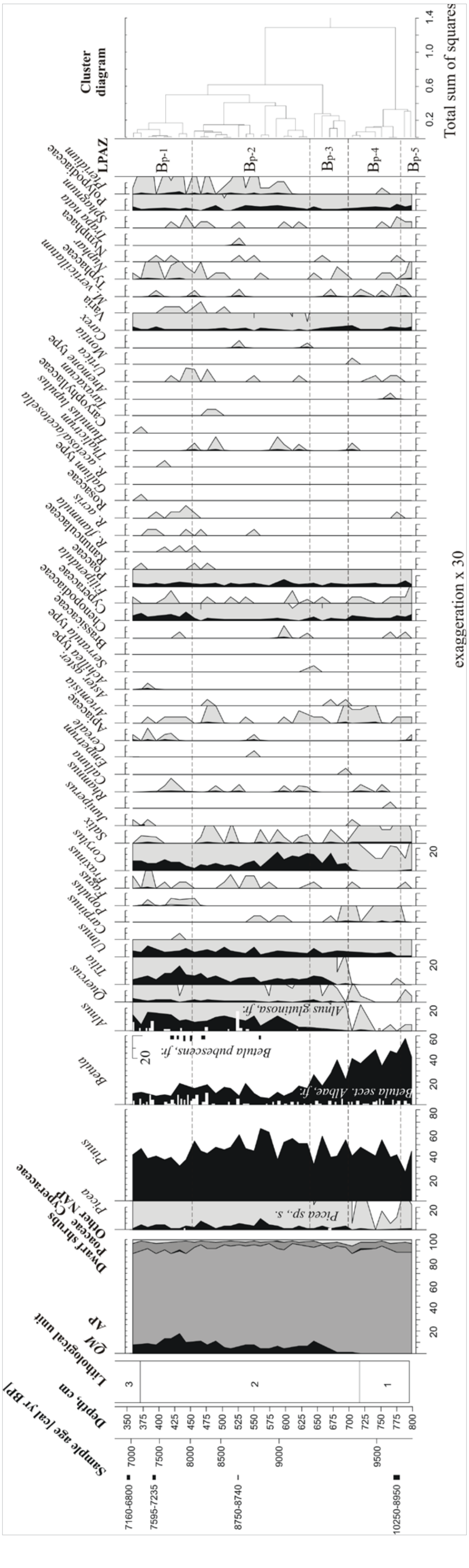


Fig. 2 Percentage pollen diagram for the Briaunis palaeolake. Compiled by M. Stančikaitė, 2010.

Diatom analysis

A rich complex of diatoms was identified in the investigated section. The complex includes 113 species and inter-species taxa (Fig. 4). Epiphytes, i.e. plants

Table 4 Local diatom assemblage zones (LDAZ). Compiled by V. Šeirienė, 2011.

LDAZ	Depth (cm)	Description
B_{d-6}	800–740	The number of planktonic species is highest (up to 50%) throughout the diagram. *Cyclotella radiosa* and *Cyclotella ocellata* are most dominant. The epiphytic species are predominated by *Fragilaria construens* with interspecies taxa and *Fragilaria pinnata*. *Navicula oblonga* is dominant among benthic ones.
B_{d-5}	740–700	The number of planktonic species decreases to 11% and benthic *Navicula oblonga* dropped down simultaneously. The species composition of the complex remains almost the same. Representatives of *Fragilaria* genus are still dominant.
B_{d-4}	700–605	Optimal conditions for the development of the diatom spectra existed in lake. Due to this reason number of the existed species was the highest throughout the section. The number of planktonic species increases up to 35% again; such taxa as *Cyclotella comensis* and *Cyclostephanos dubius* appeared. The number of epiphytic and benthic species increased considerably. Also the number of benthic species is the highest (35%) throughout the section. Along with *Navicula oblonga, N. menisculus, N. gastrum*, *Amphora ovalis, A. lybica, Stauroneis phoenicenteron* and other species occurred.
B_{d-3}	605–475	The diversity of diatom complex becomes poorer; epiphytic species are dominant. The number of plankton species decreases from 50% to 5% even. The number of benthic ones lowered as well (to 5%). Epiphytic species account for almost 90%. The most widespread is *Fragilaria construens* with varietes; other representatives of this genus are found in abundance: *F. brevistriata*, *F. pinnata*, *F. lapponica*.
B_{d-2}	475–350	The diatom flora resembles the former one yet the number of diatom species is even smaller. Representatives of *Fragilaria* genus are dominant, i.e. epiphytic species. Among the representatives of *Epithemia* genus (*E. adata, E. turgida*) the number of septum also increases. The number of boreal and north-alpine species increases simultaneously (*A. lanceolata, A. laterostrata* etc.).
B_{d-1}	350–250	The same species of diatoms are dominant in the sediments yet the species diversity is even poorer. Among the benthic ones, representatives of *Amphora* genus are found in greater abundance i.e. *A. libyca, A. pediculus* and *A. lapponica*. The number of *Cyclostephanos dubius* increases.

growing upon other plants, are dominants. The lower part of the section also contains many (up to 50% of the total number) planktonic species. Alkaliphilic diatoms, growing in alkaline environment when pH>7, are dominant, whereas the acidophilic species are hardly a few. According to species variation of diatom flora, six (B_{d-1} - B_{d-6}) local diatom assemblage zones (LDAZ) were distinguished (Table 4).

Sediments chronology

The chronological classification of the Briaunis section sediments was performed based on stratigraphic data and ^{14}C radioisotope dating of eight sediment samples (Table 5). Calibrated ages of the all samples are in stratigraphical order suggesting calm sedimentation regime predominated in the basin. Both the radiocarbon dates and biostratigraphic information indicate that the sediments under consideration were deposited during the Holocene (Ammann, Loter 1989; Kabailienė 2006).

According to ^{14}C, accumulation of limnic sediments started in lake at the beginning of Holocene – shortly before 9600 cal yr BP. Chronological attribution of the dated alder seeds (525–530 cm) suggests this tree established in area at ca. 8800–8700 cal yr BP. As deduced from obtained information major conversions in the sedimentation regime occurred at ca. 7200–7100 cal yr BP (onset of the lake overgrown, 373 cm depth), 6600–6500 cal yr BP (intensive bogging of the lake, 332 cm depth), ~ 3600 cal yr BP (insignificant rise of the water table in the lake, 167 cm depth) in the investigated basin. The average sedimentation rate was 0.55 mm a^{-1} for the gyttja part and about 1.7 mm a^{-1} for the peat-consisting interval.

DEVELOPMENT OF FLORA AND WATER BASIN

This detailed study of pollen, plant macrofossil, diatom, LOI and ^{14}C performed on a core sequence of the Briaunis palaeolake allowed to reconstruct the history of the terrestrial and aquatic vegetation during the Holocene.

Early Holocene (9600 – 7900 cal yr BP)

Deposition of the investigated sediments of the Briaunis palaeolake started during the early Holocene epoch, i.e. shortly before 9600 cal yr BP according to ^{14}C data (Fig. 5). Since the onset of the sediments formation,

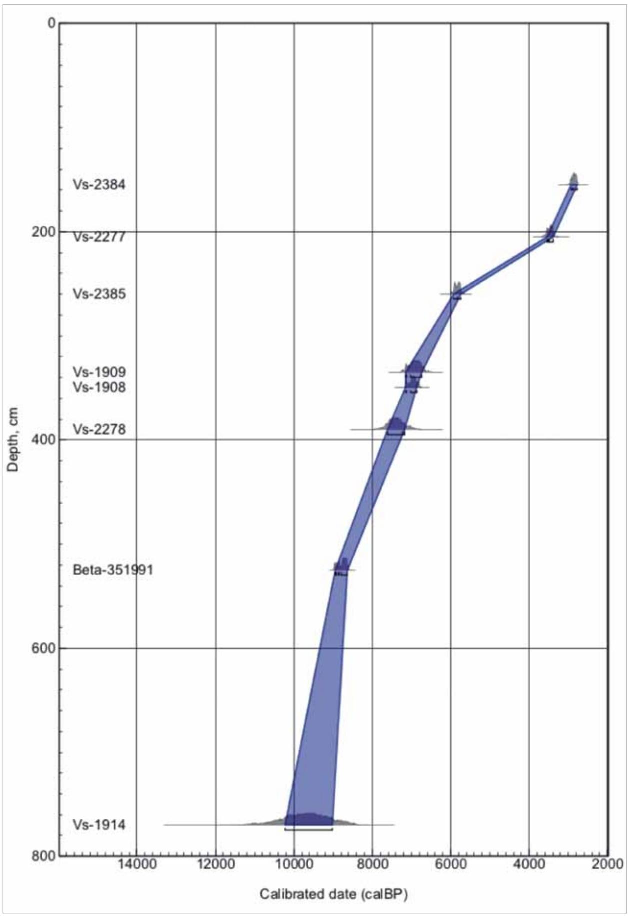


Fig. 5 Age-depth model for the sediments of Briaunis palaeolake. Compiled by Ž. Skuratovič, 2013.

Table 5 Radiocarbon ^{14}C (yr BP) and calibrated (cal yr BP) dates of Briaunis palaeolake sediments. Compiled by Ž. Skuratovič, 2012.

No.	Depth [cm]	^{14}C [yr BP]	Calibrated age [cal yr BP] (68.2%)	Laboratory code	Dated material
1	155–160	2760±50	2886–2786	Vs-2384	Total organic carbon
2	205–210	3235±65	3485–3385	Vs-2277	Total organic carbon
3	260–265	5100±60	5828–5750	Vs-2385	Total organic carbon
4	335–340	6040±120	7160–6730	Vs-1909	Total organic carbon
5	350–355	6090±120	7160–6800	Vs-1908	Total organic carbon
6	390–395	6510±220	7595–7235	Vs-2278	Total organic carbon
7	525–530	7920±40	8750–8740	Beta-351991	*Alnus* seeds
8	770–780	8600±470	10250–8950	Vs-1914	Total organic carbon

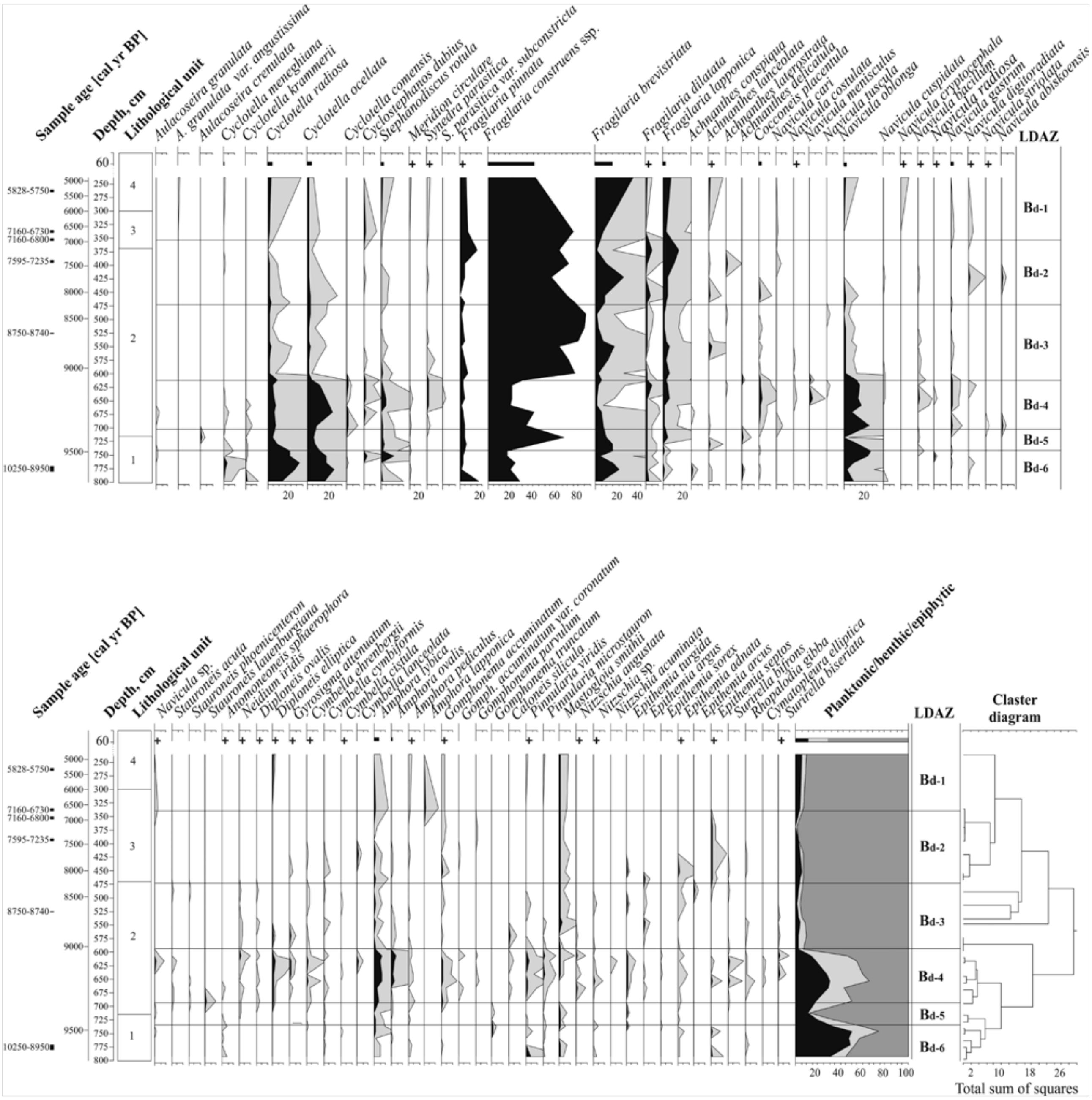


Fig. 4 Diagram of diatoms from the Briaunis palaeoake. Compiled by V. Šeirienė, 2011.

$CaCO_3$ predominated in the strata as is shown by the results of the LOI survey (Fig. 3), suggesting a higher pH in the basin at the identical time. Identification of a large amount of *Chara* sp. macrofossils indicates high-carbonate water saturation. At a high pH, this plant utilises carbon during photosynthesis, leading to the formation of endogenic calcium carbonate. *Chara* sp. flourishes in an oligotrophic water basin with low biogenic productivity (Velle *et al.* 2005), which is implied by the prevalence of *Cyclotella* genus diatoms and a slight variety of diatom species (Fig. 4). Simultaneously, the basin was dominated by planktonic diatoms, i.e. *C. ocellata* and *C. radiosa,* indicating a deep-water habitat (Sienkiewicz 2013) with a low nutrient supply because the pioneer genus *Cyclotella* sp. typical for such conditions (Rawlence 1988) was widely distributed. The input of the terrigenous matter usually related with environmental instability was higher during the initial stages of sediments formation, whereas the number of these particles dropped shortly before 9600 cal yr BP, suggesting stabilisation of the catchment.

The results from this study indicate that birch-predominating forests prevailed in this area before 9600 cal yr BP. The sediments of the Briaunis lake contain a high concentration of *Betula* pollen (> 57%) and *Betula* sect. *Albae* fruits (Fig. 2). Usually, birch rapidly occupies open plots, creating favourable conditions for the immigration of other trees. The predominance of birch in the local vegetation during the early Holocene epoch has been reported primarily from the surrounding regions (Kabailienė 1990). The representation of pine was negligible in the area because the amount of *Pinus* pollen is less than 25% in the particular spectra (Fig. 2), whereas only pollen values >50% indicate local dominance of this tree (Huntley, Birks 1983). A relatively low representation of this taxon in the Briaunis pollen record could be related to the lack of suitable sandy habitats that continue to predominate in the surrounding areas. Beginning in about 9600 cal yr BP, more soils that are fertile were gradually occupied by new deciduous taxa with higher thermal requirements. *Ulmus* was the first to appear in the area in about 9600 cal yr BP, according to the pollen data (Fig. 2). Elm was identified in southeast Lithuania (Stančikaitė *et al.* 2002) and other neighbouring regions (Ralska-Jasiewiczowa 1983; 1989; Punning *et al.* 2003; Saarse 2004; Kupryjanowicz 2007; Heikkilä *et al.* 2009; Niinemets, Saarse 2009), indicating climatic amelioration, the formation of fertile soils and increasing humidity. Simultaneously, pioneer stands of *Alnus glutinosa* might have been established in that area as fruit of this tree was discovered in the sediments (Fig. 3). A minor representation of *Corylus* pollen suggests a regional instead of local distribution of the taxa, although *Populus* stands could be represented locally as the amount of this pollen is relatively high in the pollen record. The persistent occurrence of different shrubs and herbs, i.e. *Salix*, *Artemisia*, and Chenopodiaceae, suggests that vegetation remained relatively open during the discussed time, which was common in the surrounding regions during the early Holocene epoch (Kupryjanowicz 2007, Stančikaitė et al., 2008; 2009; Novik *et al.*, 2010).

Further development of the diatom record shows that a new stage in the lake history started after 9600 cal yr BP. Decreasing representation of the planktonic taxa, i.e. *C. radiosa* and *C. ocellata,* coincides with a sharp negative excursion in the benthic *Navicula oblonga* curve (Fig. 4), suggesting a remarkable drop in the water table. The presence of *Typha* sp. indicates shallow water and the development of a littoral zone (Hannon, Gaillard 1997). Similar changes in the basin system dating to the earliest stages of the Holocene were recorded in Lithuania (Stančikaitė *et al.* 2008; 2009) and surrounding countries (Litt *et al.* 2001; Bos *et al.* 2007; Mortensen *et al.* 2011). Because of changes in the lake level, concentration of the dissolved salts in the basin might have increased, which is in agreement with the flourishing of *Cyclostephanos dubius* (Stoermer *et al.* 1987). Simultaneously, the eutrophication processes in the basin began as the macrofossils of *Najas marina* and *Nymphaea alba* occurred (Fig. 3). The presence of *Ceratophyllum demersum* shows that the basin was influenced by lime-enriched water (Kłosowski *et al.* 2011). The mentioned taxa suggest that the water depth could have been approximately 3 m (Hannon, Gaillard 1997). The elevated number of benthic diatoms is evidence of moderately transparent water and a high concentration of nutrients. The strong roots of *N. alba,* which is a strong competitor that shades out other submerged species, could recycle nutrients from deep in the mud, allowing an increase in the aquatic productivity (Birks 2000). The presence of *N. alba* seeds suggests that the average July temperature was ~ 12°C (Kolstrup 1979; 1980).

A recorded drop of the water table was accompanied by a rising input of terrigenous matter into the lake. The detrital sediment flux into the basin most likely increased, providing evidence of environmental instability, i.e. decay of the soil cover. This conclusion is in agreement with the pollen record, suggesting a simultaneous short-lasting spread of the pioneer taxa, i.e. *Artemisia* (Fig. 2). Most probably, the recorded instability of the environmental system was determined by the local conditions rather than by the regional features because other parts of the pollen record remain relatively stable. The *Pinus* and *Ulmus* curves are relatively steady, whereas the *Picea*, *Corylus* and *Alnus* curves increased shortly after the mentioned oscillation, suggesting an ongoing formation of the dense forest cover supplemented by the new taxa. Simultaneously, *Betula* and *Populus* declined most likely because of the ecological succession. The discussed environmental instability could be determined by the climatic fluctuations including the so-called "Preboreal oscillation" (Björck *et al.* 1996; 1997), widely recorded during the Early Holocene in northwestern Europe (Björck *et al.* 2001; Ralska-Jasiewiczowa *et al.* 2003; Bos *et al.* 2007; Bohncke, Hoek 2007). The chronological attribution of the indicated oscillations is relatively difficult to assess because of the existence of large radiocarbon plateaux at ca. 10.000–9900 and 9600–9500 ^{14}C BP (Björck *et al.* 1996; 1997). Discussing the environmental pattern of this time interval in the eastern Baltic, a regional delay in the response to the early Holocene climatic improvement must be taken into account (Wohlfarth *et al.* 2007; Stančikaitė *et al.* 2008; Lauterbach *et al.* 2011).

The environmental instability phase was followed by a period of increasing water level in the Briaunis palaeolake recorded around 9300–9200 cal yr BP. The high water table indicated at approximately the identical time in the lakes of northeast Poland (Zawisza, Szeroczynska 2007; Kupryjanowicz *et al.* 2009) was related to the intensive rainfall, "which was caused by the increased influence of warmer and moister air brought by the westerly winds from the Atlantic Ocean after the final decay of the ice sheet" (Yu, Harrison 1995; Gałka *et al.* 2013). The mean temperature gradually increased as indicated on the basis of the δ^{18}O data (Lauterbach *et al.* 2011). The increasing variety of the diatom species points to the rise of the nutrient supply, possibly from the catchment, as the rheophilous ("running water") species of the *Gomphonema* genus and the *Meridion circulare* are present. Fluctuations of the climatic parameters have been responsible for the formation of new terrestrial vegetation successions. New deciduous taxa, including the thermophylous broad-leaved species, started to expand forming a dense forest cover. The establishment of *Corylus,* which is tolerant of seasonal droughts, severe winters and cool summers (Huntley 1993), prior to other species suggests that pronounced continental climatic conditions (Lauterbach *et al.* 2011) existed in the surroundings at ca. 9400 cal yr BP. The presence of *Corylus* shows that the average July temperature was ~15°C (Hoffmann *et al.* 1998), and the presence of *Lycopus europaeus* fruits suggest that the average July temperature was no lower than 16°C (Bell 1970). Simultaneously, *Picea* pollen and then *Picea* seeds occurred in the sediments, confirming the immigration of this tree into the region. The data show that the density of this tree in the investigated area was relatively low at the beginning, and the local presence could be identified by the pollen data (up to 9–10%) around 8900–8700 cal yr BP. *Picea* is widely recorded in the beds deposited during the Late glacial/Holocene transition or the early Holocene epoch in eastern Lithuania (Stančikaitė *et al.* 2008; 2009), and this tree disappeared from the area and re-advanced into the eastern Baltic region (Gaidamavičius *et al.* 2011) around the so-called "8.2" climatic event dated to 8600–8000 cal yr BP (Seppä, Poska 2004). This amelioration of the climatic regime was responsible for the spread of the *Tilia* stands recorded from around 9200 cal yr BP. This tree prefers habitats with rich, mineral-humic soils that may have existed in the area at that time because movement of terrigenous matter into the basin was negligible according to the LOI record. Changes to the development of the humidity system of alder thickets were crucial because this tree is severely sensitive to drought. The gradual spread of *Alnus* in 9300–9400 cal yr BP suggests an increasing number of wet habitats in the area. The pollen data show that since about 9100 cal yr BP, the number of these trees in the area increased remarkably (Fig. 2). The explosive expansion of alder recorded all over Europe was triggered by climate change (Huntley, Birks 1983; Ralska-Jasiewiczowa, Latałowa 1996; Saarse *et al.* 1999), which might have coincided with the onset of the Holocene climatic maximum in about 9000 BP (Davis *et al.* 2003; Kalis *et al.* 2003). Development of the wet habitats in the Briaunis palaeolake catchment is assumed to have contributed to the recorded prosperity of alder. The formation of these areas might have been related to the decreasing water depth in the Briaunis palaeolake since about 9100 cal yr BP. The diatom record indicates a reduction of the water table and beginning of the overgrowing process: the planktonic diatom species as well as the benthic species were reduced to the minimum, and the epiphytic species dominate the sediments (Fig. 4). The data representing neighbouring regions contradicts that obtained from an investigated sequence suggesting a high water level a period started after 9100 cal yr BP (Gałka *et al.* 2013). Very few records, i.e. from lakes of the Vistula River valley, mark a considerable decline in water level (Starkel *et al.* 1996) at about the period in question. Substantially more data indicating the onset of the dry interval or low water level since about 9100–9000 cal yr BP is available from Central Europe (Jakab *et al.* 2004; Magny 2004; Magyari *et al.* 2009b). The indicated drop of the water level in the Briaunis palaeolake can be attributed to local factors, i.e. changes in the local hydrological situation. The results of former investigations of the different palaeolakes in the Lithuania region (Kabailienė 2006) indicated that a low water table period is in good correlation with that recorded in the Briaunis palaeolake. Despite these fluctuations, ongoing deposition of $CaCO_3$ is a clear indication of high lake productivity in response to a favourable climatic regime. Most probably, the influence of the Holocene cold phase, termed 9.1 ka (Boch *et al.* 2009), 9.2 ka (Fleitmann *et al.* 2008) or 9.3 ka events (von Grafenstein *et al.* 1999a; Rasmussen *et al.* 2007) in different records (Lauterbach 2011), was minor in this case as the detrital input into the lake remained negligible because of the existence of a stable environmental structure. This fact is shown by the ongoing presence of the number of broad-leaved taxa, which gradually increased with the approach of the onset of the Holocene thermal maximum around 8000–4500 cal yr BP (Seppä, Poska 2004) in the Eastern Baltic. Shortly before that, at about 7900–8200 cal yr BP, one more oscillation in the sedimentation regime of the Briaunis palaeolake is signalled by the increasing availability of the organic constituent in the LOI curve from about 453 cm (Fig. 3). Simultaneously, the number of aquatic taxa decreased in terms of wetland plants suggesting the increasing intensity of the overgrowing processes in the lake (Fig. 3). Most probably, the water level in the lake decreased forming a vast wet overgrowing rim stretching along the lakeshore and determining the deposition of organic enriched gyttja. Based on the chronological implications, the identified changes of the sedimentation regime could be correlated with "8.2 ka event", which has been detected in various palaeoclimate archives worldwide (von Grafenstein *et al.* 1999a; Kobashi *et al.* 2007; Rasmussen *et al.* 2007; Seppä *et al.* 2007; Boch *et al.* 2009). Representing the most significant Holocene climate anomaly during which a pronounced temperature drop (-2°C in comparison with the present temperature) was recorded in the northern Hemisphere (Klitgaard-Kristensen *et al.* 1998; Weninger *et al.* 2006; Magny *et al.* 2007), this event was determined by the outburst of the Agassiz-Ojibway meltwaters from the Wisconsin ice-sheet (Barber *et al.* 1999). With the widely recorded drop of the mean temperature, a considerable reduction of precipitation was suggested (Tindall, Valdes 2011; Ghilardy, O'Connell 2013) that might have influenced the hydrological regime as well. A simultaneous expansion of *Pinus* and *Betula,* as well as a decline in thermophylous *Corylus* and *Alnus* recorded in the Briaunis pollen diagram (Fig. 2), reflects a negative temperature excursion. This fact is supported by the appearance of boreal and north alpine diatoms, i.e. *Achnanthes lanceolata* (Fig. 4) in the sediments.

Middle Holocene (7900–3600 cal yr BP)

The period between 7900 and 7200–7100 cal yr BP was marked by relatively stable vegetation development in the surroundings of the Briaunis palaeolake. The short-lasting negative reversion of the vegetation structure was followed by the prospering of the broad-leaved thermophylous species that suggests the flourishing of a mixed deciduous forest and implies the amelioration of the climatic conditions. The warming at that time is shown by the increasing representation of *Cladium mariscus* and *N. marina* because these species are typical for the climatic optimum in Lithuania and the surrounding regions (Marek 1991, Tobolski *et al.* 1997; Lang 1994; Stančikaitė *et al.* 2004; Tobolski 2006; Brande 2008), whereas the lowering of the water level continued as the density of the wetland plants continued to increase (Fig. 3). The drop of the water level is confirmed by the diatom record in which a number of planktonic species decreased, whereas the presence of benthic species indicates high water turbidity. Simultaneously, the alkalinity of the basin was high as the epiphytic diatoms, i.e. *Fragilaria* taxa, typical of this type of sedimentation environment (Bigler *et al.* 2006) flourished. The high concentration of *N. marina*, *N. alba* and *Potamogeton perfoliatus* macrofossils suggests that the depth of the paleolake varied around 3 m (Hannon, Gaillard 1997; Preston, Croft 1997; Szoszkiewicz *et al.* 2010). Considering the predominance of *Myriophyllum verticillatum*, *Potamogeton natans*, *P. perfoliatus*, *N. marina*, and *N. alba* with the typical diatom species such as *Fragilaria pinnata, Fr. construens* spp., *Fr. brevistriata*, *Fr. dilatata*, *Navicula digitoradiata and N. oblonga,* it can be assumed that the basin pH was approximately 6.5–7.8 (Hannon, Gaillard 1997; Zarzycka *et al.* 2002) at the time under consideration and that eutrophic conditions predominated. *N. marina* (Ozola *et al.* 2010) is typical of carbonate-rich habitats, suggesting a high carbon content of the basin, which is shown by the LOI data as well.

Approaching the upper chronological limit of the 7200–7100 cal yr BP time period, the proportion of organic material in the sediments sharply increased (363 cm depth), suggesting that intensive overgrowing processes occurred at least in the investigated part of the lake. It appears that the water table lowered even more and the basin was distinguished for its high trophicity level, what is shown by the presence of species of the *Amphora* genus that require large amounts of nutrients (Van Dam *et al.* 1994) and representative species of *Cyclostephanos dubius*. Because of the overgrowing processes, the number of macrophyte remains (*Nymphaea alba*, *Najas marina*) has increased in the sediments. The flourishing of *Schoenoplectus lacustris and Carex* sp. shows the dominance of lake-side grasses. The high amounts of *Betula* sect. *Albae*, *Betula pubescens* and *Alnus glutinosa* macrofossils indicate an abundance of these plants very near the sedimentation plot. These trees might have spread on the wet plots along the water rim as a bed of brownish peat with numerous remains of trees was deposited at that time. The formation of the carbon-enriched beds most probably continued in the central part of the basin, whereas organogenic sedimentation prevailed in the peripheral parts. This hypothesis is supported by the presence of *Lemna trisulca* macrofossils typical of a eutrophic water basin rich in calcium (Szoszkiewicz *et al.* 2010). The recorded water level changes might have provoked some instability of the surface as terrigenous influx into the sediments started to increase.

The period around 6600–6500 cal yr BP was crucial for the development of the investigated basin. Though the water level slightly increased as plants typical of a shallow water basin, i.e. *Schoenoplectus lacustris* (Hannon, Gaillard 1997) disappeared from the spectra and thickets of birch and alder left the immediate vicinity of the coring point (no remains of these trees were discovered in the subsequent deposits), bogging processes took over. At the same time, xeromesophytic species spread at the expanse of the aquatic taxa, with *Urtica dioica* being the most abundant among them. Being a nitrophilous species, nettle characterises the edaphic conditions of the basin and suggests intensive soil leaching that is confirmed by the LOI record. A simultaneous period of increasing water level dated to 4400–4950 BC was distinguished in the lakes of central Europe (Magny 2004), which could approximately be correlated with the above described changes in the Briaunis lake. The simultaneous rise of *Lemna trisulca* (Fig. 3) indicates increasing water temperature, which is a key factor for the blooming and fruiting of these water plants. *Lemna* sp. blooms at air temperatures of 25–30 ºC remaining for at least 14 days (Szczepanek 1971; Stachowicz-Rybka 2009). Finding *Lemna triscula* indicates that the mean summer temperature was relatively high. Today, comparable summer temperatures in the Eastern part of Lithuania persist for 16–18 days on the average (Bukantis 1998). Such circumstantial evidence of a moderately warm climatic regime from the investigated record agrees favourably with the regional evidence, suggesting the Holocene thermal maximum around 8000–4500 cal yr BP in this part of Europe (Seppä, Poska 2004). The pollen data reflect progressively warmer and drier summers at that time that may be interpreted as indications of increasing climatic continentality (Seppä, Poska 2004).

Late Holocene (after 3600 cal yr BP)

The period of an especially low water regime continued until about 3600–3400 cal yr BP in the Briaunis palaeobasin. The later repeated rise of the water table is confirmed by the increasing representation of wetland plants in the plant macrofossil spectra (Fig. 3). The identified high number of *Scirpus sylvaticus* macrofossils and isolated *Typha latifolia* findings show that the sediments accumulated further from the shoreline though growing conditions that remained humid, which is shown by the presence of *Menyanthes trifoliata*, a typical semi aquatic plant and *Cirsium palustre*. Most probably, the areas surrounding the Briaunis Lake turned into the fens with abundant representation of sedges at that time. Yet the identified fossils of *Rumex crispus*, *Hypericum perforatum*, *Fragaria vesca* and *Urtica dioica* allow the assumption that dryer habitats existed on the slopes of the surrounding hills. The eutrophication process intensified as shown by the presence of *Ranunculus sceleratus* and other plants (Szoszkiewicz *et al.* 2010). *Betula* sect. *Albae* and *Alnus glutinosa* flourished in the area as macrofossils of these trees are represented in the sediments (Fig. 3). The recorded changes of the water table correspond well to the rise in the water level in most of central Europe (Magny 2004), Poland (Gałka *et al.* 2013), Finland (Heikkilä, Seppä 2003; Väliranta *et al.* 2007), the Estonian lakes (Punning *et al.* 2003) and Northern Ireland (Swindles *et al.* 2010). Climatic cooling and rising precipitation recorded since about 3300–3400 cal yr BP played a leading role in the history of numerous sedimentary basins. The mentioned fluctuations were determined by the increasing precipitation that was accompanied by the climatic cooling similarly recorded in the eastern Baltic region (Seppä, Poska 2004). The changing environmental situation is confirmed by the increasing input of terrigenous matter into the lake. The latter could be related with increasing human interference as a simultaneous activity of the Bronze Age population that was identified according to archaeological records.

CONCLUSIONS

The investigation results enabled us to distinguish the main periods in palaeobasin and palaeovegetation development and provided new data describing the Holocene history of the sedimentary environment. The initial stages of the Briaunis palaeolake formation (before 9600 cal yr BP) could be marked as a deep, transparent and oxygen-rich oligotrophic water basin with low nutrient supply and biogenic productivity. The surroundings of the lake were overgrown with a sparse birch-predominating forest. At about 9600 cal yr BP, climatic amelioration, formation of fertile soils and increasing humidity was fixed as the spread of new deciduous taxa – *Ulmus, Alnus* and *Populus* on the local scale and *Corylus* on the regional scale – begin, although the structure of vegetation remained relatively open. After 9600 cal yr BP, the remarkable drop of the water table, the eutrophication processes and the rising input of terrigenous matter into the lake began, as registered in the water flora composition. These changes could be related to the decay of the vegetation and soil layer that continued to 9300–9200 cal yr BP. Subsequent positive climate changes forced the formation of the thermophilous broad-leaved forest and the regional spread of *Picea*. Some instability of the water level and vegetation structure, i.e. a decline in the thermophilous species and the appearance of boreal and north alpine diatoms, could be associated with "8.2 ka event". A flourishing of mixed deciduous forests and an increase typical for the thermophilous species of this period marked the Holocene thermal optimum (from 7900 to 7200–7100 cal yr BP). The lowering of the water level in the eutrophic alkaline shallow basin with a high carbon content and pH varying from 6.5 to 7.8 remained until 6600–6500 cal yr BP when a small rise of the water table was fixed. Repeated increases in the water level were registered around 3600–3400 cal yr BP, and this finding has a good correlation with the regional pattern. The simultaneous instability of the environmental situation could be related to increasing human interference.

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