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Lateglacial and Holocene environmental history in the area of Samogitian Upland (NW Lithuania)

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Abstract Pollen, plant macroscopic fossil and carbonate analyses supplemented with ^{14}C dating were applied for sediment sections of Lopaičiai Kettle and Pakastuva Lake. The new data obtained from two sediment cores were used to reconstruct vegetation cover and environmental changes during Lateglacial and Holocene in the Samogitian Upland (NW Lithuania). Different burial conditions of dead-ice blocks caused different times of lake sediment start in studied sites. The depositional and vegetation history is traced at the inception of pre-Allerød time in sediment section from the Lopaičiai core. However, sediment section from the Pakastuva core provides paleoenvironmental information starting only from the very beginning of Holocene. The study results shed more light on the environmental development during the Lateglacial and Holocene of the specific ice marginal area, which belongs to interlobate insular upland.

Keywords *• pollen • vegetation • environment • kettle hole*

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INTRODUCTION

Records from numerous paleobotanical, lithological and chronological investigations across Lithuania quite well unclose the vegetation cover and environmental variations during the last Lateglacial and Holocene (Kabailienė 1993, 2006*b*; Blažauskas *et al.* 1998; Stančikaitė *et al.* 2002, 2003, 2004, 2006, 2008, 2009, 2015; Gaidamavičius *et al.* 2011; Balakauskas *et al.* 2012; Gryguc *et al.* 2013). However, when dealing with marginal areas of the Late Weichselian Scandinavian ice sheet it faces many uncertainties related to the peculiarities of local environmental conditions and problems with stratigraphical subdivision of sediment layers (Satkūnas 2011; Šeirienė *et al.* 2015). The landform variety of insular-type Samogitian Upland (Guobytė 2004) situated in the north−western part of Lithuania provides such specific conditions. The upland was formed during the Pomeranian (Baltija) Stage of the Weichselian (locally named Nemunas) glaciation. However, the exact time of the Samogitian Upland deglaciation is under discussion. The ^{10}Be exposure age of erratic boulders in the area varies within 12.0−14.6 ka (Rinterknecht *et al.* 2006, 2008). Nevertheless, the data analysis show (Hughes *et al.* 2015; Stroeven *et al.* 2015), that at *c.* 16.0 ka at least the central part of Samogitian Upland was ice free. However, at the postglacial outset the remnants of down-wasting ice-sheet of the South Lithuanian Phase remained as dead-ice (Guobytė, Satkūnas 2011) throughout the whole upland, marking an asynchronous retreat of the ice margin. The melt out of dead-ice blocks caused the formation of lakes and kettle holes, the appearance time of which depended on the burial conditions of ice blocks and can be identified through lake sediment study.

The postglacial environmental conditions in the north−western part of Lithuania are less studied (Kabailienė 2006*b*; Stančikaitė *et al.* 2006, 2008, 2015; Šeirienė *et al.* 2006) in comparison with the rest part of Lithuania. Therefore two new cores have been obtained and investigated in the Samogitian Upland (NW Lithuania). The first core is drilled in a small Lopaičiai Kettle and the next one – in the Pakastuva Lake. Pollen, plant macroscopic fossil (macrofossil) and carbonate analyses supplemented with ^{14}C dating were applied for the investigation of new sites. The core from Lopaičiai Kettle revealed that lacustrine sedimentation started during the early Lateglacial. Deposition of the lacustrine sediments of the Pakastuva Lake started at the very beginning of Holocene. It is hoped that the obtained data will supplement a characteristic of the Lateglacial and Holocene environmental and vegetation changes in the north−western part of Lithuania.

STUDY AREA AND SITES

Two sediment sections representing north−western (Pakastuva) and central (Lopaičiai) parts of northwest–southeast stretching drainage divide area of the Samogitian Upland were selected as key sites to provide data to elucidate the pattern of the Lateglacial and Holocene environmental and vegetation change in this area. Data were obtained from the Lopaičiai Kettle (south-eastern part) and the Pakastuva Lake (north-western part) cores (Fig. 1).

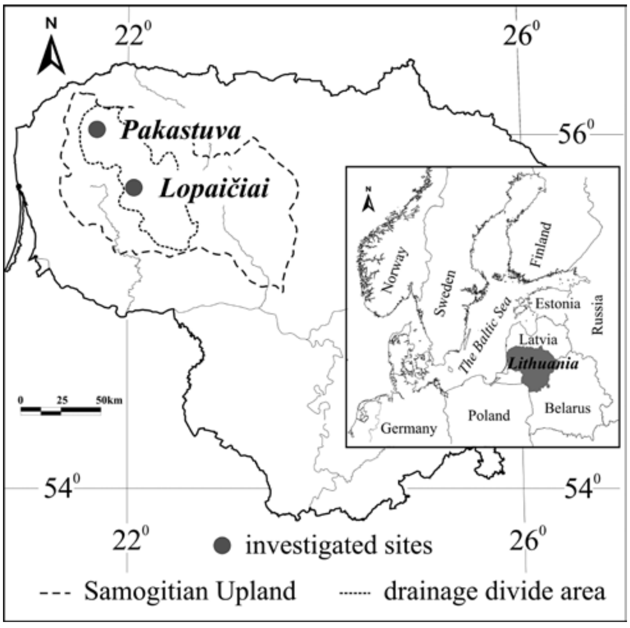

Fig. 1 Location of the Lopaičiai and Pakastuva study sites; compiled by P. Šinkūnas, 2015

Lopaičiai sediment core was taken from a small kettle hole (55°44’37.47’’ N, 22°11’34.28’’ E) located in the vicinities of the Tverai village at the hummocky moraine landscape (Fig. 2) formed during the Pomeranian (locally named – Baltija) Stage of the Late Weichselian Scandinavian ice sheet retreat (Guobytė 2004). The area of hummocky moraine, where the Lopaičiai Kettle is located, stretches in 30−35 km distance to the East from distal margin of the Last Glaciation ice retreat limit of the Middle Lithuanian Phase (Fig. 2). Small and rounded in its shape kettle hole is at 178.7 m a.s.l. The diameter of the hole is only 19 m, and its depth is of 2.5 m. Its bottom is usually wet, overgrown with herbal vegetation.

Other two parallel cores were taken from sediment section in a swampy depression occupied by a small overgrown Pakastuva Lake (56°04’22.62’’ N, 21°51’02.44’’ E). Pakastuva Lake is in about 40 km distance to the North−Northwest from the Lopaičiai Kettle. Hypsometrical position of the lake is 148.8 m a.s.l. The lake is located at the hilly landscape of the glaciofluvial origin in about 10 km distance to the East from distal margin of the Last Glaciation ice retreat limit of the Middle Lithuanian Phase (Fig. 2). The small Salupis River flows into the Pakastuva Lake from the north and again has the outlet to the south direction.

MATERIAL AND METHODS

Coring and sampling

The sediment cores were obtained using a *‘Russian corer’* (1 m long chamber with a 5 cm inner diameter). The core from the central part of the Lopaičiai kettle hole was visually described and sub-sampled in 3 cm interval for pollen, diatom, carbonate and ^{14}C analyses. The sediment core from the northern swampy part of the Pakastuva Lake was sub-sampled every 2 cm for pollen, diatom and carbonate analyses and a parallel core was sub-sampled every 4 cm for plant macroscopic fossil analysis.

Radiocarbon dating

Seven sediment samples from the section Lopaičiai and five from the section Pakastuva were dated by ^{14}C method in the Laboratory of Nuclear Geophysics and Radioecology, Nature Research Centre, Vilnius, Lithuania and Poznań Radiocarbon Laboratory, Poland (Table 1). All dates were calibrated to calendar years BP using IntCal2013 calibration curve (Reimer *et al.* 2013) within the calibration software OxCal 4.2 (Bronk Ramsey 2009). All ages in the paper are given as calibrated years before 1950 AD (cal yr BP).

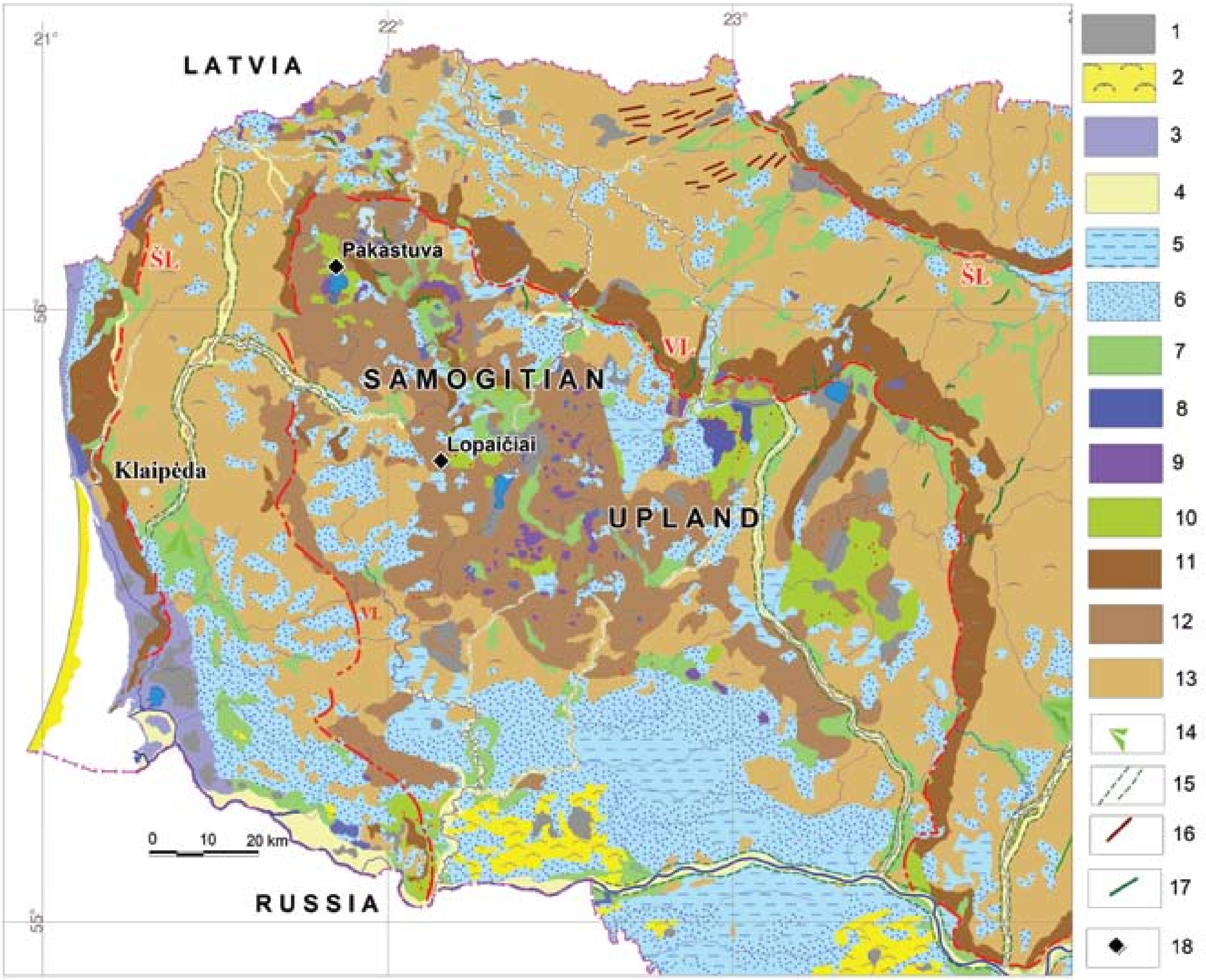

Fig. 2 Geomorphological map of the Samogitian Upland and surroundings with location of investigated sites; compiled by R. Guobytė, 2015. Legend: 1 – bog plains; 2 – aeolian topography; 3 – marine terraces of the Baltic Sea; 4 – river flood-plains; 5 – clayey glaciolacustrine plains; 6 – sandy glaciolacustrine plains; 7 – glaciofluvial plains; 8 – kame terraces; 9 – kames; 10 – glaciofluvial hills; 11 – end-moraine ridges; 12 – hummocky moraines; 13 – till plains; 14 – glaciofluvial delta; 15 – glaciofluvial valleys; 16 – drumlinoids; 17 – eskers; 18 – investigated sites. Limits of the phases of the Late Weichselian (Nemunas) Glaciation: ŠL – limit of the North Lithuanian Phase; VL – limit of the Middle Lithuanian Phase

Table 1 Radiocarbon (^{14}C) dating results from sediment sections Lopaičiai and Pakastuva; compiled by J. Mažeika, 2015

No.	Depth (m)	Dated material	Laboratory code	^{14}C, yr BP	Calibrated age, cal yr BP (1σ range)
Lopaičiai Kettle					
1	0.65	Peat	Vs–2114	3,940±70	4,445-4,287 (4,366±79) (54.5%)
2	1.10	Peat	Vs–2113	6,460±90	7,435 – 7,278 (7,357±79) (68.2%)
3	1.63	Tree trunk	Vs-1648	8,030±120	9,032 – 8,698 (8,865±167) (63.4%)
4	1.70	Peat	Vs–2111	8,520±90	9,560 – 9,430 (9,495±65) (67.5%)
5	2.25	Gyttja	Vs–2115	10,680±270	12,827 – 12,147 (12,487±340) (68.2%)
6	2.65	Gyttja	Vs–2116	11,030±200	13,062 – 12,738 (12,900±162) (68.2%)
7	2.95-2.98	Gyttja	Vs-1905	10,900±170	12,985 – 12,693 (12,839±146) (68.2%)
Pakastuva Lake					
1	1.59–1.60	Peat	Vs–2156	4,275±150	5,043 – 4,780 (4,912±132) (41.2%)
2	2.92–2.96	Peat	Vs–2158	4,950±110	5,757 – 5,590 (5,674±84) (53.8%)
3	3.95–3.96	Gyttja	Poz–44797	5,800±40	6,660-6,555 (6,607±53) (68.2%)
4	4.96–4.97	Gyttja	Poz–44799	7,180±50	8,027-7,950 (7,989±39) (68.2%)
5	5.98–5.99	Peat	Vs–2077	7,240±450	8,484 – 7,619 (8,052±433) (66.3%)

Pollen analysis

Sediment samples of 1−3 cm^3 for pollen analysis were prepared using a standard chemical procedures (Erdtman 1936; Grichiuk 1940) including treatment with a heavy liquid (CdI_2+KI). Tablets of spores *Lycopodium clavatum* were added during the preparation of sediment samples in order to calculate pollen concentration (Stockmarr 1971). 500 terrestrial pollen grains were counted for each sample. Pollen and spores identification was based on Moore *et al.* (1991) and Reille (1992). Taxa are presented as percentages of the sum of arboreal (∑AP) plus non-arboreal (∑NAP) taxa (∑AP + ∑NAP = ∑P). For calculation and presentation of pollen, diatom and plant macroscopic fossil data the programs TILIA and TILIA−GRAPH (Grimm 2000) were applied.

Chronostratigraphical subdivision into local pollen assemblages zones (LPAZ) of the diagrams is based according to characteristic taxa and a stratigraphically constrained cluster analysis (CONISS–Constrained Incremental Sums of Squares cluster analysis, Grimm 1987).

Diatom analysis

The laboratory preparation of sediment samples for diatom analysis follows techniques described by Battarbee (l986). Diatom species identification was made under a *'Nikon Eclipse E200'* microscope (magnification ×1000) using mainly the taxonomic works of Krammer and Lange–Benalot (l986–1991). The succession of the diatom species is presented as percentages of the total diatom sum. For description of paleoecological conditions, diatom species are classified into ecological groups according to their habitats: 1) benthic diatoms − bottom-living and 2) epiphytic − attached to various surfaces in the shallow zone of the lake (Van Dam *et al.* 1994; Barinova *et al.* 2006).

Plant macroscopic fossil analysis

108 samples, covering a 4 cm interval each, were collected for macrofossil survey. Plant remains were extracted from sediment samples (50 cm^3 in volume) by wet sieving on a screen with a mesh size of 0.2 mm. Plant macroscopic fossils (macrofossils) were separated and identified at a magnification ×20–100 using a binocular microscope. Identification of plant remains was based on Beijerinck (1947), Berggren (1969, 1981), Cappers *et al.* (2006), Grigas (1986) and the comparative collection of contemporary vegetation. Identified taxa are classified into groups (trees, aquatic plants, plants of wetland and shore), for the interpretation of surrounding vegetation and paleoenvironment. The plant macrofossils are presented as absolute values, plant groups are given in percentages.

Carbonate analysis

Carbonate analysis was applied for the 64 sediment samples from Lopaičiai core and 163 sediment samples from Pakastuva core. Results are given in dolomite and calcite percentages. CO_2 volume released from the deposits was determined by means of calcimeter (Shcherbina 1958). The CO_2 volume released after 30 seconds of reacting with 5 ml of 5% cold HCl with powdered sediment is treated as indicating calcite and volume released after further exposure to HCl and also after heating to 40°C for 3 minutes is treated as indicating dolomite. The percentage of the mentioned minerals was calculated by volume of CO_2 related to calcite and dolomite.

The sediment samples of 50 g for carbonate analysis were taken every 5 cm. The sediment was powdered and 0.2 g was used for the carbonate content measurement in calcimeter. Prior to carbonate analysis and after each 5 samples analysed, the content of CO_2 released from 0.2 g of pure calcite (2−3 control measurements) was determined. These measurements were used to calculate the calibration coefficient (k), which is temperature and atmospheric pressure dependent: $k = 44/x$, where x is CO_2 value from the pure calcite.

RESULTS

Lithology

The sediment sections Lopaičiai and Pakastuva were subdivided into the sediment layers after its visual inspection. The sediment section Lopaičiai of 400 cm length is subdivided into seven sediment layers (Fig. 3). Various sand with gravel admixture at the base (layer 1) of the Lopaičiai section was formed by the intensive input of minerogenic material into the basin most probably by ice meltwater during the last glacier retreat. The thin layer of gyttja (layer 2) represents the start of biogenic lacustrine sedimentation and synchronous increase of calcite precipitation (Fig. 4). Upwards, rather thick layers of clay with admixture of organic and interlayers of gyttja (layers 3 and 5) characterize intensive lacustrine sedimentation. Only very thin (263−264 cm) interlayer of fine sand (layer 4) shows a short-lasting interruption of clay sedimentation, probably related with increased erosion. Higher content of calcite and stable amount of dolomite are characteristic both of the clay and overlying silty clay (layer 6) layers. Overlying peat (layer 7) indicates lowering of the lake level by infilling and rapid overgrowth of the small lake. The beginning of peat formation is marked by distinct decrease of calcite and dolomite content. It is supposed, that tree trunk in the peat layer (147−163 cm) is autochtonous and have been dated by radiocarbon. The obtained radiocarbon date of 8,865±167 cal yr BP suggests that the peat layer formation began at the end of Boreal. At present the bottom of the Lopaičiai kettle hole is almost dry.

The length of the sediment section Pakastuva is 630 cm and it is subdivided into five sediment layers (Fig. 5). The lowermost part of the core consists of gravel and sandy loam (layers 1 and 2) which probably is of glacigenic origin. Amount of calcite and dolomite in the sediments is very low and do not exceed 10 % (Fig. 6). Upwards, the thin layer (595−600 cm) of peat (layer 3) is overlaid by gyttja with remnants of mollusc shells (layer 4). The calcite content in sediments abruptly increases up to 88 % (Fig. 6). At the upper part of the sediment layer the calcite content varies around 50 %. The sharp upper contact between the gyttja and the covering peat layer (layer 5) may reflect a hiatus in sedimentation. The peat contains very low content (about 10 %) of carbonates. An increase of carbonate content up to 46 % is observed only at the depth of 48−57 cm.

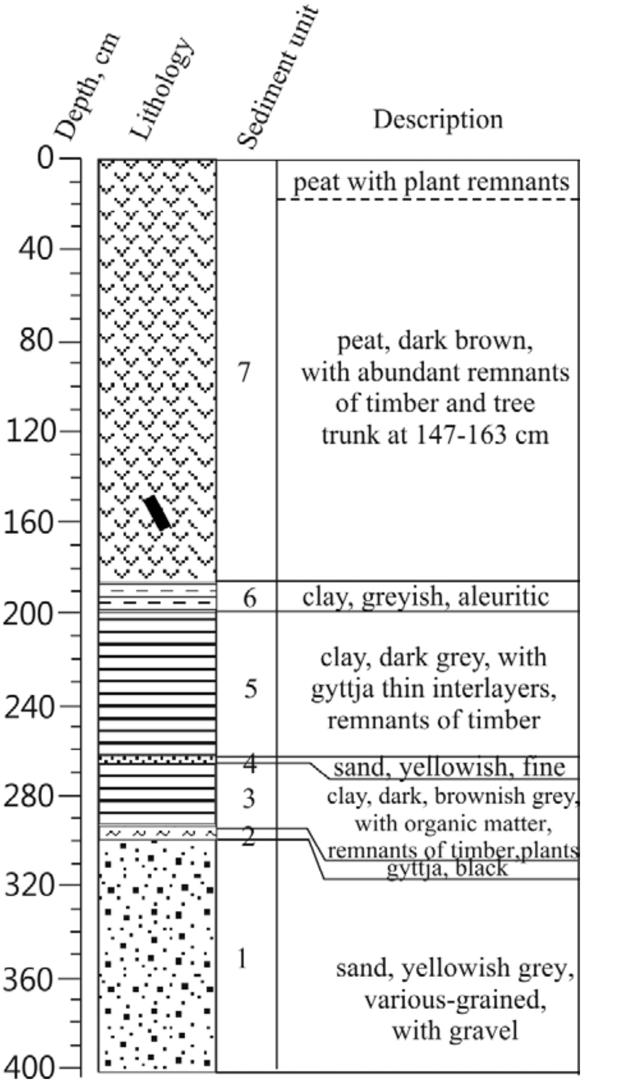

Fig. 3 Lithological description of the studied section from Lopaičiai kettle hole; compiled by G. Motuza, 2011

Pollen

Lopaičiai. The palynological analysis data have been described in terms of local pollen assemblages zones (LPAZ) based on visual and statistical evaluations of the pollen spectra. Seven LPAZ were established for the sediment section Lopaičiai (Fig. 7) and described in Table 2.

Pakastuva. Four LPAZ were established for the section Pakastuva (Fig. 8) and described in Table 3.

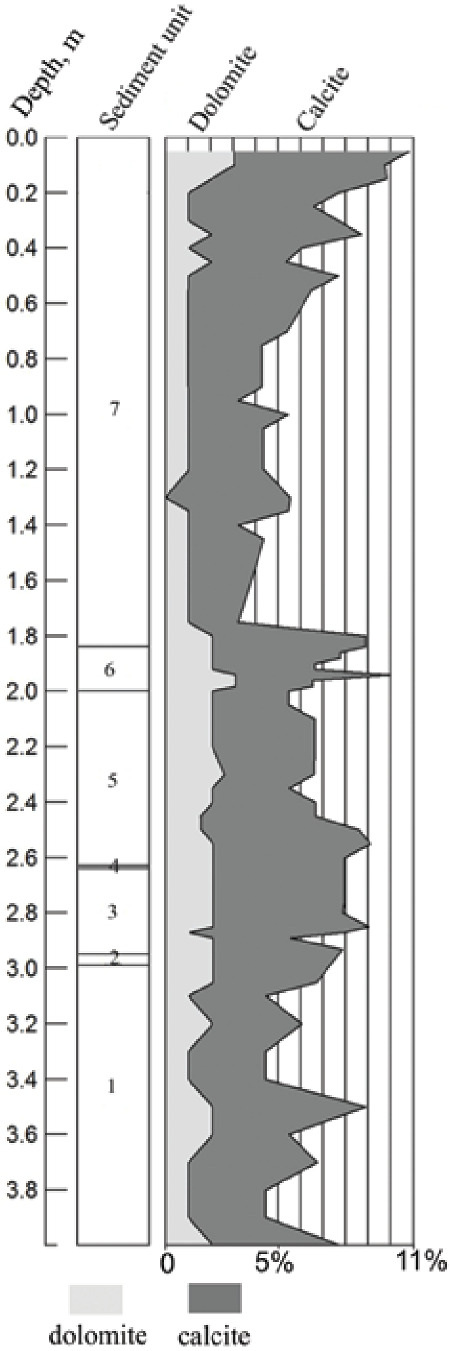

Fig. 4 Diagram of carbonate content of the sediment section Lopaičiai; compiled by E. Rudnickaitė 2013. Description of the sediment layers see in Fig. 3

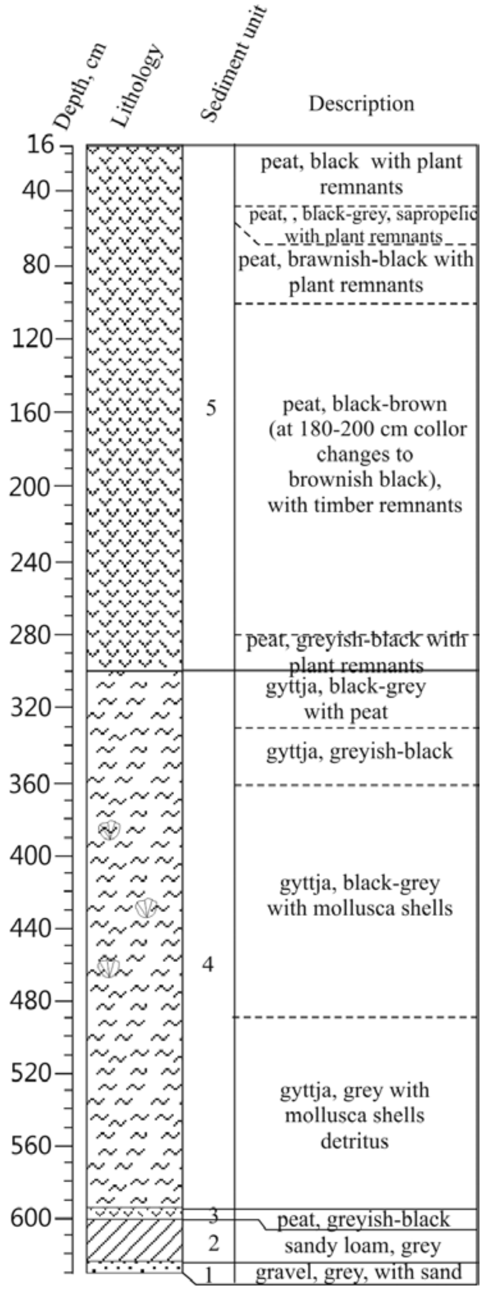

Fig. 5 Lithological description of the studied section from Pakastuva Lake; compiled by P. Šinkūnas, 2012

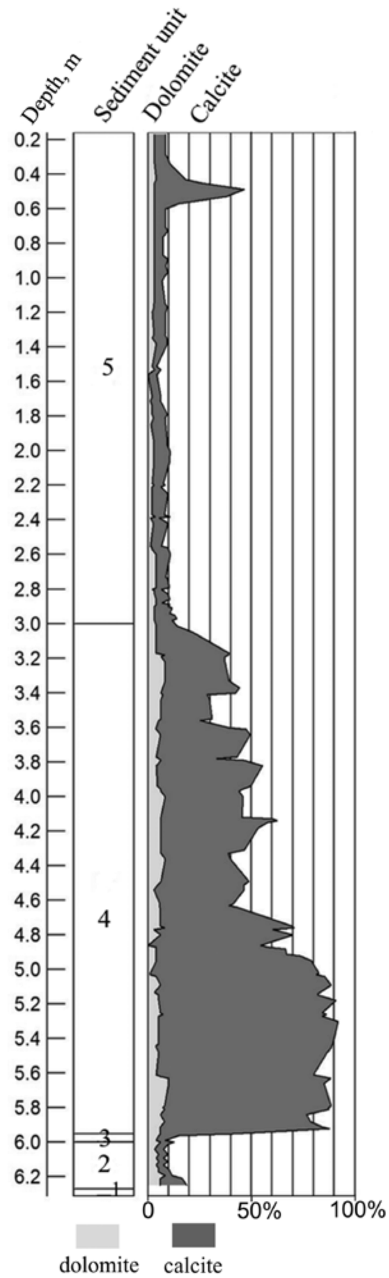

Fig. 6 Diagram of carbonate content of the sediment section Pakastuva; compiled by E. Rudnickaitė, 2013. Description of the sediment layers see in Fig. 5

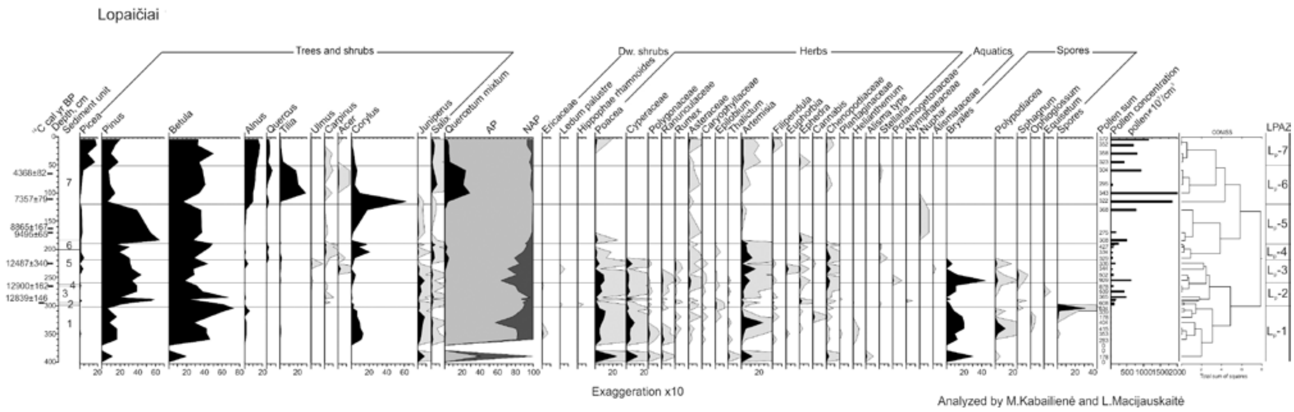

Fig. 7 Pollen diagram of the sediment section Lopaičiai; compiled by M. Kabailienė and L. Macijauskaitė, 2012. Description of the sediment layers see in Fig. 3

Table 2 Description of the local pollen assemblage zones (LPAZ) at the Lopaičiai site; compiled by M. Kabailienė and L. Macijauskaitė, 2012

LPAZ	Depth, cm	Description
L_p–7	5-50	Amount of *Pinus* varies about 15 %, *Betula* – 40 %. *Quercetum mixtum* decreases to 5 %, *Tilia* and *Quercus* make up only a few percent. Value of *Alnus* reaches 17 %. *Picea* curve culminates up to 20 % at the bottom and the top of the zone. Amount of NAP increases up to 10 % (mainly Poaceae, *Artemisia*, *Filipendula* and Asteraceae).
L_p–6	50–120	This zone is characterized by distinct increase in *Quercetum mixtum* percentage – *Tilia* reaches 30 %, *Quercus* – 8 %, *Alnus* – 15 %. *Pinus* percentage reduces to 7 %. The peak (62 %) of *Cory-lus* was observed at the bottom of the zone. Amount of *Betula* remains about 40 %. NAP values are very low. The highest pollen concentration was found at the bottom of the zone.
L_p–5	120–190	*Pinus* curve rises up to 62 %, *Betula* – 37 %. NAP values drop down significantly and are repre-sented mainly by Poaceae (4 %), *Ephedra* (4%) at the bottom of the zone and *Artemisia* (2 %) in the topmost part.
L_p–4	190–220	This zone is characterised by increase in arboreal species. Amount of NAP decreases to 7 %. Value of *Betula* percentage reaches 50 %, *Pinus* – 30 %, *Salix* – 5 % and *Corylus* – 20 %. A few percent of *Quercus* and *Carinus* were detected. Amount of *Artemisia* reaches 5 %, Poaceae – 4 %, *Ephedra* – 2 % and these taxa prevail in the group of NAP.
L_p–3	220–260	Increased percentage of NAP (Poaceae – up to 10 %, Cyperaceae – 8 %, *Artemisia* – 15 %, Che-nopodiaceae – up to 6 %) is characteristic for the lower part of the zone. Percentage of *Juniperus* slightly increases (up to 7 %) at the bottom of the zone. Single samples contain negligible amount of deciduous (*Alnus*, *Ulmus* and *Acer*). Content of *Pinus* and *Betula* decrease within this zone.
L_p–2	260-300	Pollen concentration increases up to 500×10^3 pollen/cm^3. This zone is characterized by decrease in herbal taxa and increase in AP species, especially *Pinus* – up to 60 % and *Betula* – 57 %. De-ciduous are represented by *Juniperus* (4 %) and *Salix* (2 %).
L_p–1	300–400	Pollen concentration is low within this zone. At the bottom of the zone (370–400 cm) sediments are empty of pollen grains but one sample represents high amount (up to 60 %) of herbs, espe-cially Poaceae (up to 25 %), Cyperaceae (18 %) and *Artemisia* (13 %). Arboreal taxa variety is very low: *Betula* reaches 22 %, Juniperus 8 % and *Pinus* varies around 12 %. The upper part of the zone is characterized by high percentage (80-60 %) of AP, represented by *Betula* (30–70 %) and *Pinus* (17 %). Sediments contain a small amount of *Alnus*, *Juniperus* and *Salix*, except of *Corylus* which makes up to 14 %. At the depth of 330 cm was observed distinct increase (to 40 %) of NAP, especially *Artemisia* (24 %).

Table 3 Description of the local pollen assemblage zones (LPAZ) at the Pakastuva site; compiled by M. Kabailienė and L. Macijauskaitė, 2013

LPAZ	Depth, cm	Description
P_p–4	18–190	*Picea* culmination (up to 38 %) is characteristic for this zone. *Betula* reaches 40 % and *Pinus* makes up to 50 % at the top of the zone. Amount of *Alnus* decreases and varies between 5 % and 15 %. Percentage of NAP increases and varies about 30 %. Curve of *Ephedra* reaches 45 % at the bottom of the zone. Percentages of Poaceae and Cyperaceae reach 20 %, Polypodisceae – 60 %.
P_p–3	190–300	This zone is characterized by two peaks of *Alnus* (up to 52 %). Enlarged amount of *Picea* (15 %) and *Pinus* (20 %) were observed at the bottom and topmost parts of the zone. Deciduous species decreased (*Corylus* to 15 %, *Quercus* – 3 %, *Tilia* – 8 %). A slight increase in NAP was observed (especially Poaceae up to 12 %, Cyperaceae –7 %, Ranunculaceae – 8 %). Sharp increase of Polypodiaceae (82 %) was detected at the bottom of the zone.
P_p–2	300–540	Increase of *Quercetum mixtum* taxa (up to 23 %) is characteristic for this zone. *Alnus* makes up to 35 %, *Tilia* – 10 %, *Ulmus* – 15 %, *Quercus* – 5 %, *Fraxinus* – 5 % and *Corylus* varies around 20 %. *Pinus* and *Betula* percentage decreases and varies about 10 %. Content of NAP is rela-tively low (5–10 %), most common are Poaceae (8 %), Cyperaceae (2 %) and *Ephedra* (3 %) at the bottom of the zone.
P_p–1	540–602	This zone is characterized by prevalence of *Betula* (up to 50 %) and *Pinus* (up to 40 %) pollen. Curve of *Corylus* makes up to 4 % at the bottom of the zone but reaches 15–34 % at the topmost part. Amount of herbs varies from 10 % to 22 %, dominate Poaceae (16 %), Cyperaceae (8 %) and *Artemisia* (2 %).

Diatoms

Diatom analysis was applied for the several sediment samples from the sediment section of Lopaičiai kettle hole but diatom frustules have not been observed there. Diatoms were analyzed in 46 sediment samples from the sediment section of Pakastuva Lake. Major part of the samples were empty of diatoms but at the depth of 34–102 cm diatom frustules were detected (Fig. 9). All identified diatom species are assigned to the benthic and epiphytic ecological groups. At the depth of 62–102 cm (peat) only single benthic–epiphytic diatoms of *Anomoeoneis sphaerophora*, *Amphora ovalis*, *Fragilaria* sp. were observed.

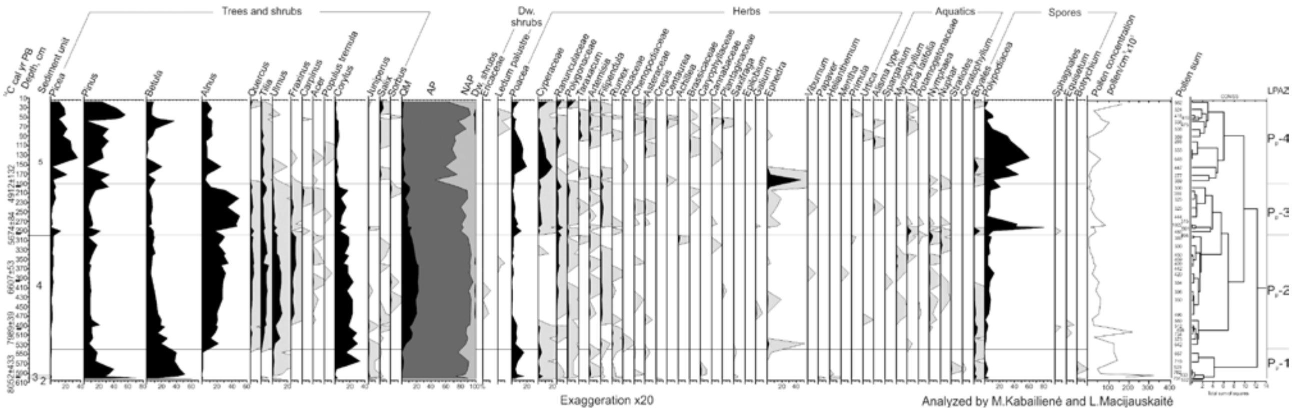

Fig. 8 Pollen diagram of the sediment section Pakastuva; compiled by M. Kabailienė and L. Macijauskaitė, 2013. Description of the sediment layers see in Fig. 5

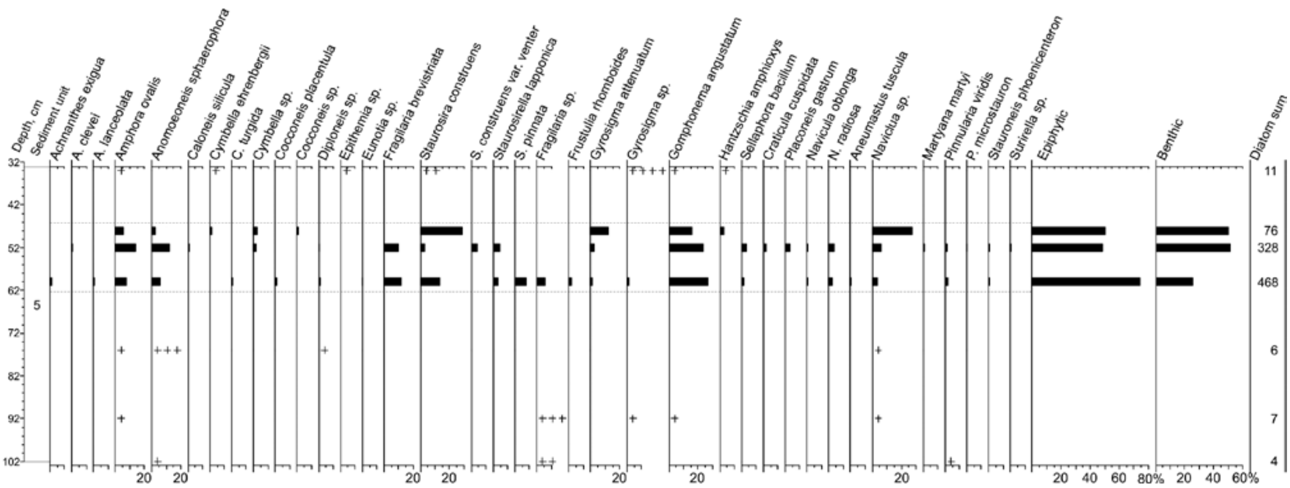

Fig. 9 Abbreviated diatom diagram of the sediment section Pakastuva at 32–102 cm depth; compiled by G. Vaikutienė, 2013. Description of the sediment layers see in Fig. 5

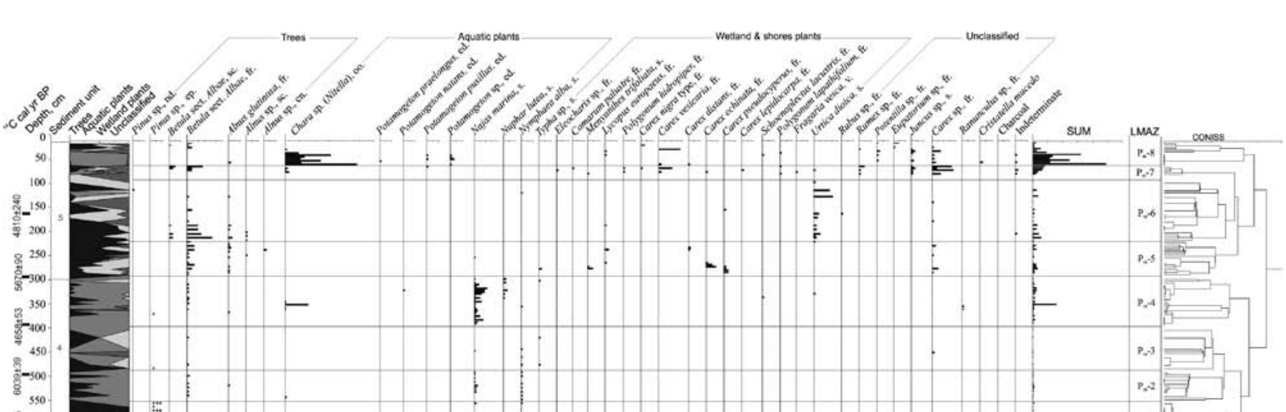

Fig. 10 Plant macrofossils diagram of the sediment section Pakastuva; compiled by D. Kisielienė and G. Gryguc, 2013. Description of the sediment layers see in Fig. 5

The diatom number increases at the depth of 46–62 cm where the peat became sapropelic. Epiphytic diatoms characteristic of shallow, overgrown freshwater lake environment *Staurosira construens* (up to 28 %), *Fragilaria brevistriata* (13 %), benthic *Amphora ovalis* (15 %), and *Anomoeoneis sphaerophora* (12 %) prevail. The increased number of epiphytic-reophilous *Gomphonema angustatum* (up to 27 %), which habitat usually is estuary (Kuylenstierna, 1990) was found. At the depth of 32–46 cm only single diatoms were found, mainly benthic *Gyrosigma* sp. and epiphytic *Staurosira construens*.

Plant macrofossils

Macrofossil analysis was applied only for the sediment section of Pakastuva Lake. 35 taxa have been defined: 21 taxa identified to species and 14 − to genus level. The macroflora complex was grouped into eight local macrofossil assemblage zones (LMAZ) and described in detail in the Table 4. Four taxa were identified in the group of trees, 8 taxa − in the group of aquatic plants, 16 taxa − in the group of wetland and shore plants (Fig. 10). Some taxa identified up to the genus level were attributed to the group of unclassified taxa.

Chronology

The chronology of environmental variation is based on the results of sediment ^{14}C dating and biostratigraphical information obtained at both investigated sites. An age/depth plot (Fig. 11) was compiled in order to demonstrate the differences of the sediment accumulation rates in two palaeolake with particular environmental situation.

According to the age/depth plot the accumulation of sediments was rather intensive in the small Lopaičiai palaeolake during the Lateglacial. According to pollen and carbonate analysis various sand with gravel at the bottom of the sediment section was deposited probably in the pre-Allerød time of the Lateglacial. The oldest date of sediment sample has been recorded in the sediment section Lopaičiai. The results of radiocarbon dating of gyttja indicate sedimentation during the latest stages of the Lateglacial. Two dates in the sediment section Lopaičiai are related to the Allerød chronozone pollen spectra: 12,839±146 cal yr BP and 12,900±162 cal yr BP (Fig. 7). Culminated curve of *Pinus*, decreased herbal taxa and increased pollen concentration (LPAZ L_p−2) are characteristic of the Allerød warming (Kabailienė 1993). The date 12,487±340 cal yr BP in the section Lopaičiai correlates well with the Allerød/Younger Dryas biostratigraphical boundary dated back to ca. 12,600 cal yr BP in the different parts of Lithuania (Stančikaitė *et al.* 2008, 2009). Increased number of herbal species and percentage of *Betula* pollen, decreased amount of *Corylus* and *Juniperus* in LPAZ L_p−3 (Fig. 7) characterize climate deterioration during the Younger Dryas at the end of Lateglacial.

According to the age/depth plot at the onset of Holocene the sedimentation rates in the Lopaičiai palaeolake decreased (Fig. 11). However, the intensive accumulation of biogenic sediments in the Pakastuva palaeolake continued throughout the Holocene. The obtained data at the lowermost part of the sediment section Pakastuva 8,052±433 cal yr BP (dated peat at the depth

Table 4 Description of the local plant macrofossil assemblage zones (LMAZ) for the Pakastuva site; compiled by D. Kisielienė and G. Gryguc, 2013

LMAZ	Depth, cm	Description
P_m–8	18–62	This zone is characterized by sudden increased amount of water plants (*Chara* sp., *Potamogeton* sp., *P. pusillus*, *P. praelongus*.) which poins to regeneration of water basin.
P_m–7	62–98	Variety of wetland plants (*Carex* sp., *C. vesicaria*, *C.echinata*, *C.nigra*, *C. lepidocarpa, Polygonum hidropiper*, *P. lapatifolium* et al.) indicates overgrowth of strand. Birch was dominant in the vicinities of the palaeobasin.
P_m–6	98–218	Plants of wetland and shore prevail. Finds of *Urtica dioica* are especially numerous. Amount of birch and alder drops down at the top of this zone. The seed of pine was found at the depth of 112–124 cm .
P_m–5	218–298	Plants of wetland and shores predominate in this zone. Remains of different species of sedges (*Carex* sp., *C. echinata*, *C. pseudocyperus*, *C. distans*), *Menyanthes trifoliata, Lycopus europaeus* and *Typha latifolia* represent this group. Water plants disappear. Significantly increased number of tree finds (alder and birch).
P_m–4	298–400	The zone is dominated by aquatic plants such as *Nuphar lutea*, *Chara* sp., *Potamogeton natans*, *Nymphaea alba*, but *Najas marina* makes a majority. Group of wetland and shore plants is represented by single *Schoenoplectus lacistris*, *Ranunculu*s sp., *Typha* sp. and *Urtica dioica* macroremains. Birch and alder were the most common trees in the vicinities of palaeolake.
P_m–3	400–490	The plant assemblage of this zone is very poor. Only single finds of *Pinus* and *Betula* are detected in the group of trees. Sharp reduction of *Najas marina* and scattered finds of *Nymphaea alba* characterize vegetation of water basin in this zone. The shore vegetation, represented by *Typha* sp. and *Carex* sp. is very sparse.
P_m–2	490–556	Variety of plant species is poor in this zone, dominate finds of *Nympheae alba* and *Najas marina*. Vegetation of shore is represented by several remains of *Typha latifolia* and *Carex* sp. Remains of *Betula* sect. *Albae* prevail over trees. Macroremais of *Pinus* nearly dissapear in this zone.
P_m–1	556–630	The zone is characterized by low number of plant macroremains. Pieces of *Pinus* epidermis dominate among remains of trees. Single fruits of *Alnus glutinosa* and *Betula* sect. *Albae* occur as well. *Nympheae alba* and *Najas marina* represent group of water plants, *Carex vesicaria* and *Menyanthes trifoliata* represent vegetation of wetland. Some particles of charcoal were found in the middle of this zone.

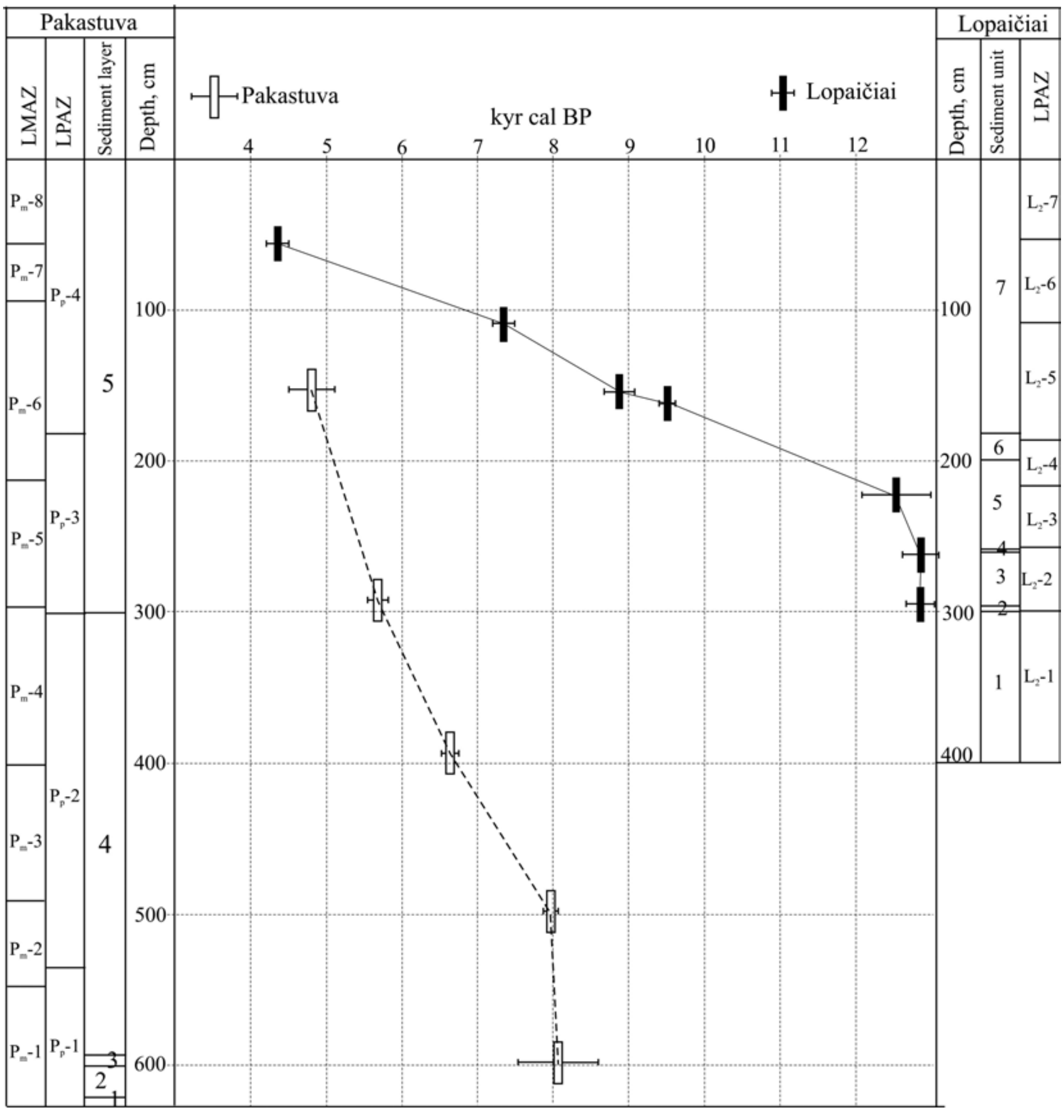

Fig. 11 Age/depth plot for the sediment sections Lopaičiai and Pakastuva; compiled by G. Vaikutienė, 2014. Description of the sediment layers see in Figs 3 and 5, details of radiocarbon dating see in Table 1

of 598−599 cm) seems to be too young, comparing to the pollen and macrofossils data. The possible reason of discrepancy between the radiocarbon and biostratigraphical data can be very small amount of dated organic matter. The beginning of Holocene warming can be observed in AP/NAP ratio changes in pollen diagram of the sediment section Lopaičiai (decreased number of herbal taxa and increased percentages of *Pinus*, *Betula* and *Corylus*, LPAZ L_p−4). Estimated age of the zone onset with increased account of deciduous *Alnus*, *Quercus*, *Ulmus* and *Corylus* is 7,989±39 cal yr BP.

The peat formation in the Lopaičiai site started before 9,495±65 cal yr BP. The age of pine trunk at the depth of 147−163 cm is 8,865±167 cal yr BP. Prevalence of *Pinus* is characteristic of relatively dry environment and correlates with the Boreal chronozone (LPAZ L_p–5).

Intensive increase of the *Tilia*, *Quecus* and *Alnus* curves in the sediment section Lopaičiai (LPAZ L_p−6) is dated by 7,357±79 cal yr BP and coincides with the beginning of Holocene climatic optimum (Fig. 7). The pollen spectrum in the sediment section Pakastuva (LPAZ P_p−2) dated back to 6,607±53 cal yr BP is also characteristic to the Atlantic chronozone.

The dates 5,674±84 cal yr BP, 4,912±132 cal yr BP in the sediment section Pakastuva and 4366±79 cal yr BP in sediment section Lopaičiai are from the uppermost dated sediments from studied sections. Decreased content of deciduous taxa and increased percentage of *Picea* in the diagrams (LPAZ P_p−3 and P_p−4, L_p−7) are characteristic of the end of Atlantic and the beginning of Subboreal chronozones (Kabailienė 1993).

VARIATION OF THE ENVIRONMENTAL CONDITIONS

Results of pollen, macrofossil and carbonate analyses and radiocarbon dating have been used for the description of vegetation and environmental conditions in the surroundings of Lopaičiai and Pakastuva coring sites during the Lateglacial and Holocene. The lacustrine sedimentation in the palaeolake started at some different time of the postglacial. Therefore the obtained data show their distinct development in the area of Samogitian Upland.

Lateglacial

Sediments composed of various grained sand (layer 1) at the bottom part of the sediment section Lopaičiai were accumulated most probably during the earliest stages of the Lateglacial. Presence of gravel in the various-grained sand is probably due to intensive surface erosion and inflow of terrigenous material into the palaeolake. Variation of carbonate content indicates the pulsating character of water flow possibly from the nearby melting glacier. The early Lateglacial development of small Lopaičiai kettle hole and start of lacustrine sedimentation in it can be explained by very shallow burial conditions of dead-ice block. Scarce number of pollen grains accumulated in the lowermost part of the sediment section Lopaičiai with relatively large amount of *Corylus* and *Juniperus* (see Fig. 7) most probably is due to re-deposition by intensive water flows. However, the appearance of *Salix* pollen at the base of sediment section (LPAZ L_p−1) may indicate the slight pre-Allerød warming which was identified in some other sites in the territory of Lithuania (Balakauskas 2012). Presence of *Betula*, *Pinus* and large number of herbs in the sediments seems to be characteristic of the early Lateglacial similar as in the northern part of Lithuania (Stančikaitė *et al.* 2015). *Betula* macrofossils found in the western part of Lithuania (Stančikaitė *et al.* 2008) confirm growth of birch trees in the area at that time. *Pinus* macrofossils, dated by 14,050−13,400 cal yr BP, were found in the southern part of Lithuania (Stančikaitė *et al.* 2008). Cold climate prevailed in the Northern Europe and soil formation process was still very weak (Iversen 1973; Birks 1986; Kabailienė 2006*a*; Ralska-Jasiewiczowa *et al.* 2004). Trees hardly could grow and biogenic sedimentation probably was very sparse in Lithuania during the pre-Allerød period. The start of biogenic sedimentation in many lakes of NW Poland is related to the Bølling period and is confirmed by pollen data in many cases (Gałka *et al.* 2013). Both, coarse sediments and low pollen concentration suggests that the Lopaičiai palaeolake was formed during the pre-Allerød time.

The thin gyttja interlayer (layer 2, Fig. 3) and overlaying clay (layer 3) in the sediment section Lopaičiai show that accumulation rate in the palaeolake was low and deposition of clay prevailed at the beginning of lacustrine sedimentation. Mentioned thin gyttja interlayers are characteristic pattern of the beginning of Allerød lacustrine sedimentation in the territory of Lithuania (Kabailienė 1993). Climate condition characteristic of the Allerød interstadial are reflected by the increase of pollen concentration at the base of the sediment layer 3 (clay with organic matter) of the sediment section Lopaičiai, significant decrease of NAP taxa (especially Poaceae, Cyperaceae and *Artemisia*), higher percentages of *Betula* and *Pinus* observed within the LPAZ L_p−2. The Allerød interstadial is indicated not only by presence of organic matter in the sediments and pollen composition characteristic of warmer climate, but also by increased amount of carbonates (see Fig. 4) in LPAZ L_p−2. Increased temperature and humidity, developed denser vegetation and more intensive soil formation occurred *c.* 13,000−13,100 cal yr BP in the area of Northern Europe (Mangerud *et al.* 1974; Walker *et al.* 1999; Gałka *et al.* 2014). The obtained ^{14}C dates from this zone are 12,839±146 and 12,900±162 cal yr BP. The pollen data obtained from the sediment section Lopaičiai support previous interpretations of researches, that during the Allerød interstadial the pine was dominant tree throughout Lithuania, but the birch was more common in the forests of NW Lithuania (Kabailienė 2006*b*; Stančikaitė *et al.* 2008; Balakauskas 2012).

Sedimentation of very thin fine-grained sand interlayer (layer 4) in the sediment section Lopaičiai indicates intensification of erosion or water level decrease in the basin. Change of AP/NAP ratio in LPAZ L_p−3 means the increase of herbal taxa content and decrease of tree species. Together with slight decrease of *Betula* comparing to the zone below (Fig. 7) the changes of pollen composition after the age of 12900±162 cal yr BP are characteristic of the Younger Dryas climate cooling, which correlates with the onset of cold GS-1 event in Greenland characteristic for Central and Eastern Europe around 12700 cal yr PB (Feurdean *et al.* 2014).

Decrease of *Pinus* and *Betula* due to climate deterioration at the onset of Younger Dryas is indicated southward from study area, i.e. in NE Poland (Gałka *et al.* 2014). According to the results from different investigated sites, the birch was more common in the north−western part, the spruce − in the eastern part of Lithuania (Gaidamavičius *et al.* 2011), while in the rest of territory the pine has prevailed (Balakauskas 2012). Earlier predominated pine−birch forest became less dense and finally the more tundra-like vegetation prevailed at the very end of the Lateglacial in the area of Samogitian Upland.

Holocene

Subsequent development of pollen spectra of the sediment section Lopaičiai, particularly increase of content of AP and decrease of NAP pollen, indicate significant changes of vegetation cover in the investigated area. Similar changes of vegetation are dated back to 11,500 cal yr BP and coincide with the Younger Dryas/Preboreal boundary according to palynological data and correspond to the climate warming in the North Atlantic region (Björck *et al.* 1996, 2002).

The change of clay (layer 5) to coarse sediments composed of silty clay (layer 6) in sediment section of Lopaičiai kettle hole probably is due to the water level lowering, which is characteristic of warmer climate at the beginning of Preboreal. Evidently decreased amount of NAP (especially Poaceae and Cyperaceae) observed in LPAZ L_p−4 reflects significant climate changes, which caused an alteration of vegetation composition in the catchment area. It probably had a significant influence on sedimentation pattern in the small basin at the beginning of Holocene. The peat layer (layer 7) occurring above, indicates continuing significant drop of water level and overgrowth of the Lopaičiai palaeolake.

Probably the Preboreal warming has triggered the melt out of the dead-ice block and Pakastuva Lake appearance. Pollen of *Betula* is dominant and makes up to 50 % in the lowermost part of the sediment section Pakastuva (LPAZ P_p−1) as well as in LPAZ L_p−4 of Lopaičiai one. Such a large percentage of *Betula* is typical for the Preboreal sediments of the Northern Lithuania (Stančikaitė *et al.* 2008) and also is recorded in Poland and Germany (Litt *et al.* 2001). Amount of *Corylus* pollen increases up to 34% at the top of the zone in Pakastuva. Increase of *Corylus* pollen amount is characteristic of the Preboreal chronozone of the sediment section Lopaičiai. *Corylus* started to spread in the northern part of the Central Europe after the age of 11,200 cal yr BP (Theuerkauf *et al.* 2014) and appeared in the eastern part of Lithuania at 10,200−10,000 cal yr BP and predominated in sandy habitats (Gaidamavičius *et al.* 2011). The peak of *Corylus* (20 %) pollen in the Lopaičiai section is defined approximately before 11,000 cal yr BP (see Fig. 7). Possibly, the immigration of *Corylus* was somewhat earlier in the north−western part of Lithuania because of the route of migration − from south−west and west (Saarse 2004). Hazel is not very sensitive for the lower temperatures, likes more wet background and spreads earlier than other deciduous (Theuerkauf *et al.* 2014). Because of favourable conditions *Corylus* appeared and was spread in the local areas of Samogitian Upland slightly earlier than in other areas of Lithuania. According to pollen data, birch forest with admixture of pine and hazel prevailed in the vicinities of Lopaičiai and Pakastuva palaeolakes at the beginning of Holocene.

Increase of *Pinus* percentage (up to 65 %) in the sediment section Lopaičiai indicates local pine forest growth (Huntley, Birks 1983). Decrease of *Betula* percentage and low amount of deciduous species (LPAZ L_p−5) was observed before 9,495±65 cal yr BP. The tree trunk at the depth of 163 cm was dated by 8,865±167 cal yr BP. Predominance of pine was characteristic of the forest in NW Lithuania and imply to warm climate with low precipitation at the first half of Boreal (Kabailienė 2006*b*). Decreased amount of calcite at the base of sediment layer 7 in the section Lopaičiai (see Fig. 4) support palynological data of dryer climate during the mentioned time period.

Significant changes of pollen composition are determined in the section Lopaičiai despite of low sedimentation rate in the palaeolake. Abrupt decrease of percentage of *Pinus* pollen is determined in LPAZ L_p−6. However, *Corylus* reaches the peak of 62 % at the base of the zone, amount of deciduous trees *Alnus* and *Tilia* increases. Such variation of pollen composition is dated by 7,357±79 cal yr BP. Accumulation of sediments was more intensive entire the Holocene in the Pakastuva palaeolake (Fig. 11). The highest percentage of *Tilia*, *Alnus* and *Quercus* is clearly observed in the section Lopaičiai (LPAZ L_p−6) as well as in the Pakastuva (LPAZ P_p−2). The highest percentages of *Tilia*, *Ulmus*, *Quercus* and *Fraxinus* are recorded in the gyttja layer of the section Pakastuva dated by 7989±39 and 6607±53 cal yr BP (Fig. 8). Identified macrofossils *Nuphar lutea*, *Najas marina*, *Typha* sp. in LMAZ P_m−4 suggest climate warming as well. The depth of the alkaline, close to neutral, Pakastuva palaeolake was about 3 m according to macrofossils of aquatic plants *Najas marina*, *Nymphaea alba* (Hannon, Gaillard 1997; Słowiński 2010). Increased content of pollen of mentioned deciduous trees is characteristic of the Atlantic chronozone over the Lithuania and indicate the highest temperature and precipitation during the Holocene (Kabailienė 2006*b*). Alder and hazel kept on flourishing in moist soils of the western−north western part of Lithuania (Stančikaitė *et al.* 2002). Spruce was growing abundantly since 8,000 cal yr BP (Stančikaitė *et al.* 2003) in the northern part of Lithuania and further spread to the central part during the Atlantic (Balakauskas 2012). Though, percentages of *Picea* in the sections Lopaičiai and Pakastuva were small in the sediments of Atlantic period.

Lower precipitation and air temperature have been observed after the Atlantic period climatic optimum throughout the NW Europe (Birks 1981; Seppä, Birks 2002). Decreased percentages of *Tilia*, *Quercus* and *Corylus* in the sections Lopaičiai (LPAZ L_p−7) and Pakastuva (LPAZ P_p−3) indicate lower temperature of the Subboreal period. According to pollen data variation of the percentage of *Alnus* was insignificant in the section Lopaičiai. However, *Alnus* percentage increased (up to 52%) before 5,674±84 cal yr BP in the section Pakastuva (LPAZ L_p−3).

Forests composed of pine, birch, alder and spruce with admixture of oak prevailed in the area of Samogitian Upland at the end of Holocene. Spruce and alder remained widespread in the western–north western part of Lithuania (Balakauskas 2012). *Alnus* decreases in the LPAZ P_p–4 in the section Pakastuva. Macrofossils of *Urtica dioica* indicate drier, enriched with nitrogen soils around the Pakastuva palaeolake (LMAZ P_m–6). Predominance of plant marcofossils of wetland and shore (LMAZ from P_m–5 to P_m–7) could be related with drop of the water level and overgrowth of the palaeolake. Vegetation, characteristic of the drier Subboreal climate was widespread before 4,912±132 cal yr BP.

Abrupt increase of percentage of aquatic plants macroffossils (*Chara* sp., *Potamogeton* sp.) occurs approximately before 1,500 cal yr PB in the sediment section Pakastuva (LMAZ P_m–8). Finds of *Potamogeton pusillus* and *P. praelongus* indicate that the depth of the palaeolake could be about 3 m again (Hannon, Gaillard 1997). Increase of diatom number at the depth of 62–46 cm (Fig. 9) coincides with dominance of aquatic plant macrofossils. Large amount of *Chara* sp. macrofossils indicates high water saturation in carbonates. Sudden increase of calcite percentage is observed also (Fig. 6). Numerous epiphytic–reophilous *Gomphonema angustatum* diatoms indicate water inflow into the lake. The water level of the Pakastuva palaeolake slightly increased probably for a short time, as general lithological composition of the sediments did not change. The peat formation continued but increased deposition of carbonates. Similar small-scale water level changes were recorded in the lakes of eastern Lithuania (Gryguc *et al.* 2013), NE Poland (Gałka *et al.* 2013) and were associated with climate cooling and raised precipitation before 3,300–3,400 cal yr BP. The water level increase in the Pakastuva palaeolake happened later and probably was caused by local environmental changes. Increased percentages of herbal taxa indicate enlarged areas of grassland and can be related with intensifying human agricultural activity. Such changes of pollen composition are recorded in the section Pakastuva (LPAZ P_p–4) like in the different sites of Lithuania (Stančikaitė *et al.* 2002; Stančikaitė *et al.* 2004; Kabailienė 2006b). Possibly, the short-time Pakastuva palaeolake regeneration occurred because of some local human economic activity (such as ductless formation), though pollen analysis did not reveal clear indications (like *Cerealia* pollen) of agricultural activity.

CONCLUSIONS

The lacustrine sediment study results show that the postglacial time of some lake and kettle hole formation depend on burial conditions of dead-ice blocks what had determined the beginning of lacustrine sedimentation. In the Lopaičiai palaeolake the lacustrine sedimentation started during the Allerød warming approximately before 12,900 cal yr BP. Birch and pine scarce forest was common in the north–western part of Lithuania during this time interval.

Hazel was widespread in the area of NW Lithuania before ~11,000 cal yr BP, probably about 1,000 years earlier than in the southern Lithuania. More favourable sites for growth of hazel are the wet soils with loamy background which are widespread in the Samogitian Upland.

Macrofossils, diatom and carbonate analysis revealed the local short-lasting regeneration (water level increase) of the Pakastuva palaeolake at the end of Subatlantic, whereas regional climate conditions according to pollen analysis remained stable. Clear human agricultural activity was not fixed in pollen records of the section Pakastuva, but macrofossils, diatom and carbonate analysis data revealed water level rise which could be caused by human economic activity.

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REFERENCES

Balakauskas, L., Taminskas, J., Mažeika, J., Stančikaitė, M., 2012. Lateglacial and Early Holocene palaeohydrological changes in the upper reaches of the Ūla river: an example from south eastern Lithuania. *The Holocene 23 (1)*, 117–126. http://doi.org/10.1177/0959683612455552

Balakauskas, L., 2012. *Development of the Late Glacial and Holocene forest vegetation in Lithuania, according to LRA (Landscape Reconstruction Algorithm) modelling data*. Ph. D. Thesis, Vilnius University, Vilnius, 53 pp.

Barinova, S. S., Medvedeva, L. A., Anissimova, O. V., 2006. *Diversity of algal indicators in environmental assessment.* Pilies Studio, Tel–Aviv, 498 pp. [In Russian].

Battarbee, R. W., 1986. Diatom analysis. *In* B. Berglund (Ed.), *Handbook of Holocene Paleoecology and Paleohydrology*, 527–570.

Beijerinck, W., 1947. *Zadenatlas der Nederlandsche Flora*. Wageningen, H.Weenman, 316 pp.

Berggren, G., 1969. *Atlas of seeds and small fruits of northwest-European plant species with morphological descriptions. Part 2, Cyperaceae*. Swedish Museum of Natural History, Stockholm, 107 pp.

Berggren, G., 1981. *Atlas of seeds and small fruits of northwest−European plant species with morphological descriptions. Part 3, Salicaceae–Cruciferae*. Swedish Museum of Natural History, Stockholm, 260 pp.

Birks, H. J. B., 1981. The use of pollen analysis in the reconstruction of past climates: a review. *In* T. M. Wigley, L. M. Ingram, J. G. Farmer (eds), *Climate and History*, Cambridge University Press, Cambridge, 111–138.

Birks, H. J. B., 1986. Late–Quaternary biotic changes in terrestrial and lacustrine environments with particular reference to North–Western Europe. *In* B. E. Berglund (Ed.), *Handbook of Holocene Palaeoecology and Palaeohydrology,* Johns Willey and Sons, Chichester, 3–67.

Björck, S., Kromer, B., Johnsen, S., Bennike, O., Hammarland, D., Lemdahl, G., Possnert, G., Rasmussen, T. L., Wohlfarth, B., Hammer, C. U., Spurk M., 1996. Synchronized terrestrial-atmospheric deglacial records around the North Atlantic. *Science 274*, 1155−1160.

Björck, S., Andrén, T., Wastergård, S., Possnert, G., Schoning, K., 2002. An event stratigraphy for the Last Glacial−Holocene transition in eastern middle Sweden: results from investigations of varved clay and terrestrial sequences. *Quaternary Science Reviews 21*, 1489−1501.

Blažauskas, N., Kisielienė, D., Kučinskaitė, V., Stančikaitė, M., Šeirienė, V., Šinkūnas, P., 1998. Late Glacial and Holocene sedimentary environment in the region of the Ūla River. *Geologija 25*, 20–30.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon 51 (1)*, 337–360.

Cappers, R. T. J., Bekker, R. M., Jans, J. E. A., 2006**.** *Digital seed atlas of the Netherlands*. Barkhius Publishing and Groningen University Library, Groningen.

Erdtman, G., 1936. New method in pollen analysis. *Svensk Botanisk Tidskrift 30*, 154−164.

Gaidamavičius, A., Stančikaitė, M., Kisielienė, D., Mažeika, J., Gryguc, G., 2011. Post−glacial vegetation and environment of the Labanoras Region, East Lithuania: implications for regional history. *Geological Quarterly 55(3)*, 269−284.

Gałka, M., Tobolski, K., Zawisza, E., Goslar, T., 2013. Postglacial history of vegetation, human activity and lake-level changes at Jezioro Linówek in northeast Poland, based on multi-proxy data. *Vegetation History and Archeobotany 23 (2)*, 123−152. http://doi.org/10.1007/s00334-013-0401-7

Gałka, M., Tobolski, K., Bubak, I., 2014. Late Glacial and Early Holocene lake level fluctuations in NE Poland tracked by macro-fossil, pollen and diatom records. *Quaternary International*. http://dx.doi.org/10.1016/j.quaint.2014.03.009

Grichiuk, A. I., 1940. *The preparation methodology of the organic poor sediments for the pollen analysis*. Problems of Physical Geography, Moscow, 'Nauka', 40 pp.

Grigas, A., 1986. *Fruits and seads of Lithuanian* plants. Vilnius, 'Mokslas', 606 pp. [In Lithuanian].

Gryguc, G., Kisielienė, D., Stančikaitė, M., Šeirienė, V., Skuratovič, Ž., Vaitkevičius, V., Gaidamavičius, A., 2013. Holocene sediment record from Briaunis paleolake, eastern Lithuania: history of sedimentary environment and vegetation dynamics. *Baltica 26*, 121−136. http://doi.org/10.5200/baltica.2013.26.13

Grimm, E. C., 1987. CONISS: a fortran 77 programm for stratigraphically constrained cluster analysis by method of incremental sum of squares. *Computer and Geosciences 13*, 13−35. http://doi.org/10.1016/0098-3004-(87)90022-7

Grimm, E. C., 2000. TILIA and TILIA.GRAPH; PC spread sheet and graphic software for pollen data. INQUA Commision for the Study of the Holocene, Working Group on Data−Handling Methods, *Newsletter 4*, 5−7.

Guobytė R., 2004. Geology and geomorphology of the northern part of the Samogitian Highland. *In* M. Iršėnas (compiler), Evolutions of cultural landscape in the Samogitian Highland, *Acta Academiae Artum Vilnensis*, 9−22. http://doi.org/10.1016/b978-0-444-53447-7.00019-2

Guobytė, R., Satkūnas, J., 2011. Pleistocene Glaciations in Lithuania. *In* J. Ehlers, P. L. Gibbard, P. D. Hughes (eds), *Developments in Quaternary Science 15*, Elsevier, Amsterdam, 231−246. http://doi.org/10.1016/b978-0-444-53447-7.00019-2

Hannon, G. E., Gaillard, M. J., 1997. The plant-macrofossil record of past lake−level changes. *Journal of Paleolimnology 18*, 15–28. http://doi.org/10.1023/A:1007958511729

Hughes, A. L. C., Gyllencreutz, R., Lohne, Ø. S., Mangerud, J., Svendsen, J. I., 2015. The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1. *Boreas,* 10.1111/bor.12142. http://doi.org/10.1111/bor.12142

Huntley, J., Birks, H. J. B., 1983. *An atlas of past and present pollen maps for Europe: 0-13,000 years ago*. Cambridge University Press, Cambridge.

Iversen, J., 1973. The development of Denmark's nature since the last glacial. *Denmarks Geologiske Undersøgelse Vrækkle 7C*, 1−126.

Kabailienė, M., 1993. The problems of stratigraphy and environmental history during Late Glacial and Holocene in Lithuania. *Geologija 14 (2)*, 208−222.

Kabailienė, M., 2006a. Late Glacial and Holocene stratigraphy of Lithuania based on pollen and diatom data. *Geologija 54*, 42−48.

Kabailienė, M., 2006b. *The development of the natural environment in Lithuania through 14000 years*. Vilnius University Press, Vilnius, 471 pp. [In Lithuanian].

Krammer, K., Lange–Bertalot, H., 1986–1991. Süßwasserflora von Mitteleuropa. 2 (Teil 1–4). *In* H. Ettl, J. Gerloff, H. Heynig, D. Mollenhauer (eds), *Bacillariophyceae*. VEB Gustav Fischer Verlag, Stuttgart/Jena, Germany.

Kuylenstierna, M., 1990. *Benthic algal vegetation in the Norde Älv Estuary (Swedish west coast).* Ph. D. Thesis, Vol. 1, Gothenburg University, Sweden, 57−143.

Litt, T., Brauer, A., Goslar, T., Merkt, J., Bałaga, K., Müller, H., Ralska−Jesiewiczowa, M., Stebich, M., Negendank, J. F. W., 2001. Correlation and synchronisation of Lateglacial continental sequences in northern central Europe based on annually laminated lacustrine sediments. *Quaternary Science Review 20*, 1233−1249. http://doi.org/10.1016/S0277-3791(00)00149-9

Mangerud, J., Andersen, S. T., Berglund, E. B., Donner, J. J., 1974. Quaternary stratigraphy of Norden: a proposal for terminology and classification. *Boreas 3*, 109−128. http://doi.org/10.1111/j.1502-3885.1974.tb00669.x

Moore, P. D., Webb, J. A., Collinson, M. E., 1991. *Pollen analysis*. *Second edition*. Blackwell, Oxford, 216 pp.

Ralska−Jasiewiczowa, M., Latałowa, M., Wasylikowa, K., Tobolski, K., Madeyska, E., Wright, H. E., Turner, C. (eds), 2004. *Late Glacial and Holocene history of vegetation in Poland based on isopolen maps*. Krakow, Poland, W. Szafer Institute of Botany, Polish Academy of Sciences, 444 pp.

Reille, M., 1992. *Pollen et spores D'Europe et D'Afrique du Nord*. Laboratorie de Botanique historique et Palynologie, Marseille, 543 pp.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Cheng, H., Edwards, L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., van der Plicht, J., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years cal BP. *Radiocarbon 55 (4)*, 1869−1887. http://doi.org/10.2458/azu_js_rc.55.16947

Rinterknecht, V. R., Clark, P. U. M., Raisbeck, G. M., Yiou, F., Bitinas, A., Brook, E. J., Marks, L., Zelčs, V., Lunkka, J.-P., Pavlovskaya, I. E., Piotrowski, J. A., Raukas, A., 2006. The last deglaciation of the south-eastern sector of the Scandinavian Ice Sheet. *Science 311*, 1449–1452. http://doi.org/10.1126/science.1120702

Rinterknecht, V. R., Bitinas, A., Clark, P. U., Raisbeck, G. M., Yiou, F., Brook, E. J., 2008. Timing of the last deglaciation in Lithuania. *Boreas 37*, 426–433. http://doi.org/10.1111/j.1502-3885.2008.00027.x

Saarse, L., 2004. Holocene isochrone maps and patterns of tree spreading in Estonia. *Proceedings, International Symposium on Earth System Sciences, Kelebek and Grafika Group*, Istanbul, 115−129.

Seppä, H., Birks, H. J. B., 2002. Holocene climate reconstructions from the Fennoscandian tree-line area based on pollen data from Toskaljarvi. *Quaternary Research 57*, 191−199. http://doi.org/10.1006/qres.2001.2313

Shcherbina, V. N., 1958. About the method of mass measurement of carbonates in sedimentary rocks. *Proceedings of Institute of Geological Science of Belarus Academy of Science 1*, Minsk, 1–144. [In Russian].

Słowiński, M., 2010. *Macrofossil reconstruction* of *preboreal wetland formed* on *dead ice block*: a *case study* of the *Borzechowo mire* in *East Pomerania*, *Poland*. *Studia Quaternaria 27*, 3–10.

Satkūnas, J., 2011. Sequence of climatostratigraphical events during the Middle Nemunas (Weichselian). *Baltica 24,* Special Issue, 113−116. [In Lithuanian, sum. English].

Stančikaitė, M., Šeirienė, V., Šinkūnas, P., 1998. New results of the Pamerkys outcrop, southern Lithuania, investigations. *Geologija 23*, 127−147.

Stančikaitė, M., Kabailienė, M., Ostrauskas, T., Guobytė, R., 2002. Environment and man in the vicinity of the Lake Dūba and Pelesa, SE Lithuania, during the Late Glacial and Holocene. *Geological Quarterly 46 (4)*, 391−409.

Stančikaitė, M., Milkevičius, M., Kisielienė, D., 2003. Palaeoenvironmental changes in the environs of Žadeikiai bog, NW Lithuania, during Late Glacial and Holocene, according to palaeobotanical and ^{14}C data. *Geologija 43 (3)*, 47−60.

Stančikaitė, M., Kisielienė, D., Strimaitienė, A., 2004. Vegetation response to the climatic and human impact changes during the Late Glacial and Holocene: case study of the marginal area of Baltija Upland, NE Lithuania. *Baltica 17 (1)*, 17−33.

Stančikaitė, M., Baltrūnas, V., Šinkūnas, P., Kisielienė, D., Ostrauskas, T., 2006. Human response to the Holocene environmental changes in Biržulis Lake region, NW Lithuania. *Quaternary International 150*, 113−129. http://doi.org/10.1016/j.quaint.2006.01.010

Stančikaitė, M., Šinkūnas, P., Šeirienė, V., Kisielienė, D., 2008. Patterns and chronology of the Lateglacial environmental development at Pamerkiai and Kašučiai, Lithuania. *Quaternary Sciences Reviews 27*, 127−147. http://doi.org/10.1016/j.quascirev.2007.01.014

Stančikaitė, M., Kisielienė, D., Moe, D., Vaikutienė, G., 2009. Lateglacial and early Holocene environmental changes in northeastern Lithuania. *Quaternary International 207*, 80−92. http://doi.org/10.1016/j.quaint.2008.10.009

Stančikaitė M., Šeirienė, V., Kisielienė, D., Martma T., Gryguc G., Zinkutė R., Mažeika J., Šinkūnas, P., 2015. Lateglacial and early Holocene environmental dynamics in northern Lithuania: a multy−proxy record from Ginkūnai Lake. *Quaternary International 357*, 44−57.

Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores 13*, 615−621.

Stroeven, A. P., Hättestrand, C., Kleman, J., Heyman, J., Fabel, D., Fredin, O., Goodfellow, B. W., Harbor, J. M., Jansen, J. D., Olsen, L., Caffee, M. W., Fink, D., Lundqvist, J., Rosqvist, G. C., Strömberg, B., Jansson, K. N., 2015. Deglaciation of Fennoscandia, *Quaternary Science Reviews*. http://dx.doi.org/10.1016/j.quascirev.2015.09.016

Šeirienė, V., Stančikaitė, M., Kisielienė, D., Šinkūnas, P., 2006. Lateglacial environment inferred from paleobotanical and ^{14}C data of sediment sequence from Lake Kašučiai, West Lithuania. *Baltica 19*, 80−90.

Šeirienė, V., Karabanov, A., Rylova, T., Baltrūnas, V., Savchenko, I., 2015. The Pleistocene stratigraphy of the south‒eastern sector of the Scandinavian glaciation (Belarus and Lithuania): a review. *Baltica 28*, 51‒60.

Theuerkauf, M., Boss, J. A. A., Jahns, S., Janke, W., Kuparinen, A., Stebich, M., Joosten, H., 2014**.** Corylus expansion and persistent openness in the early Holocene vegetation of northern central Europe. *Quaternary Science Reviews 90*, 183‒198. http://doi.org/10.1016/j.quascirev.2014.03.002

Van Dam, H., Mertens, A., Sinkeldam, J., 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Journal of Aquatic Ecology 28*, 117–133.

Walker, M. J. C., Björck, S., Lowe, J. J., Cwynar, L. C., Johnsen, S., Knudsen, K.‒L., Wohlfarth, M. J. C., INTIMATE Group, 1999. Isotopic "events" in the GRIP ice core: a stratotype for the Late Pleistocene. *Quaternary Sciences Reviews 18*, 1143‒1150. http://doi.org/10.1016/S0277-3791(99)00023-2