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Sediment record from the Kamyshovoe Lake : history of vegetation during late Pleistocene and early Holocene (Kaliningrad District, Russia)

Olga Druzhinina, Dmitry Subetto, Miglė Stančikaitė, Giedrė Vaikutienė, Jury Kublitsky, Khikmatulla Arslanov

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Abstract Newly obtained pollen and diatom data from the Kamyshovoe Lake (previous Dobauen, Germ.), Vishtynets Highland, Baltic Uplands, analyzed by radiocarbon dating allowed to reconstruct the history of local vegetation during late Pleistocene and early Holocene. Pollen records show the formation of birch-predominating forest at ca. 13.4 ka cal. BP and the flourishing of pine towards the second half of the Allerød since about 13.2 ka cal. BP. The transition to the Younger Dryas around 12.7 ka cal. BP led to the development of sparse shrub tundra with Juniperus and communities of steppe herbs. Amelioration of the environmental regime enabled birch and pine woods to spread during the second part of the GS-1 event and the Preboreal. The late Preboreal time is marked by the appearance of Populus and an increase in the role of grasses in the vegetation cover, which can be correlated with similar open vegetation phases deduced from other pollen records in Europe (11.3–11.1 ka cal. BP). During the Boreal (since ca. 10.0 ka cal. BP) Corylus had its maximum value, Alnus, Tilia and Quercus appeared and spread while the birch-pine forests retreated.

Keywords *• pollen • diatoms • vegetation changes • Pleistocene • Holocene*

✉ *Olga Druzhinina (olga.alex.druzhinina@gmail.com), Immanuel Kant Baltic Federal University, A. Nevsky 14, Kaliningrad, 236038, and Vyshtynets Museum of Nature and History, Krasnoles`e, Kaliningrad Oblast, 238023, Russia; Dmitry Subetto, Northern Water Problems Institute, Karelian Research Centre, Russian Academy of Sciences, A. Nevsky 50, Petrozavodsk, 185030; Miglė Stančikaitė, Institute of Baltic Region History and Archaeology, Klaipėda University, Herkaus Manto 84, LT-92294 Klaipėda, Lithuania; Giedrė Vaikutienė, Vilnius University, M. K. Čiurlionio 21/27, LT-03101, Vilnius, Lithuania; Jury Kublitsky, A. Herzen State Pedagogical University, Nab. Moyki 48, St. Petersburg, 191186, Russia; Khikmatulla Arslanov, St. Petersburg State University, Institutsky 29-24, St. Petersburg, 194021, Russia*

INTRODUCTION

The transitional period from the late Pleistocene to the early Holocene is a time of natural history marked by major climatic and environmental changes. The high environmental dynamics of this period make it important for gaining insight into spatial patterns of natural climatic variability and environmental responses to it. A large amount of multi-proxy data obtained from terrestrial, marine and ice archives is already available for the late Pleistocene and early Holocene in northern Europe (Huntley, Birks 1983; Walker 1995; Subetto *et al.* 2002; Birks, Birks 2004; Latałowa, van der Knaap 2006; Lowe *et al.* 2008; Binney *et al.* 2009; Brooks, Langdon 2014; Seddon *et al.* 2015).

Recent research of the palaeoenvironment of the Eastern Baltic region, in which the multi-proxy approach has increasingly been used, addresses questions about the ice-recession pattern (Bitinas 2011; Guobytė, Satkūnas 2011; Kalm *et al.* 2011), vegetation history (Stančikaitė *et al.* 2008, 2009, 2015;

Šeirienė *et al.* 2006; Heikkila *et al.* 2009; Saarse *et al.* 2009; Amon, Saarse 2010; Gaidamavičius *et al.* 2011; Veski *et al.* 2012), the chronology of particular climatic and environmental events in the region (Rinterknecht *et al.* 2006, 2008), and the postglacial history of numerous lakes (Šeirienė *et al.* 2009; Gryguc *et al.* 2013; Balakauskas *et al.* 2013).

A significant amount of research aimed at the reconstruction of the natural environment of the late Pleistocene and early Holocene, and in particular on the processes of deglaciation, vegetation dynamics has been carried out in Poland (Ralska-Jasiewiczowa 1966; Kondracki 1972, 2000; Miotk-Szpiganowicz *et al.* 2004; P. de Klerk *et al.* 2007; Marks 2010; Pochocka-Szwarc 2010, 2013; Apolinarska *et al.* 2012; Karpińska-Kołaczek *et al.* 2013; Kołaczek *et al.* 2013, 2014).

By comparison with other palaeogeographic studies done in this part of the South-Eastern Baltic, the Kaliningrad District of Russia is almost unexplored area. Most of the palaeoenvironmental research here, in Ost-Preussen, was done before the II World War . The range of issues studied was quite broad: the reconstruction of late Pleistocene palaeobasins (Meyer 1919), vegetation history and palaeoclimate (Gams 1932; Gross 1937), and palaeogeomorphology (Körnke 1930; Lemke 1931). After the II World War, the attention of Kaliningrad researchers focused mainly on the study of palaeogeography issues in the Baltic Sea (Blazhchishin 1998; Yuspina 2001).

Targeted investigations of the palaeoenvironment began in this part of the Baltic region in 2005 (Druzhinina 2005, 2011; Arslanov *et al.* 2010; Druzhinina, Skhodnov 2011; Kublitsky *et al.* 2013, 2014). At the present time, in order to address a lack of data, multi-proxy palaeolimnological investigations of the lakes situated on the Vishtynets Highland are being carried out. The main objective of recent research in the area of the Kaliningrad District is to contribute to the understanding of the palaeoenvironmental changes on the Pleistocene / Holocene boundary in the context of regional and global ones. Bottom sediments of the Kamyshovoye Lake were investigated in order to reconstruct the history of vegetation and its response to climatic oscillations of the late Pleistocene and early Holocene in this part of the South-Eastern Baltic. The pollen and diatom survey with LOI (loss-on-ignition) and ^{14}C dating were applied to achieve the stated objective.

STUDY AREA

The Kamyshovoe Lake (54 ° 22 605` N, 22 ° 42 790` E, 189 m a.s.l.) is situated on the area of the Vishtynets Highland (part of the Baltic Uplands), which formation is related to the Baltija stage of the last glaciation (Weichselian) (Guobytė, Satkūnas 2011) (Fig. 1). The recent relief in the study area was formed as a result of intensive glacial accumulation in the marginal belt of the ice sheet. The Kamyshovoe Lake is located on the hypsometric level with a height of 180–230 m. The relief of the referenced area represents an alternation of single hills, ridges, inter-ridge troughs, and valleys. Sediments forming the relief are mosaic: fluvioglacial sands, gravel interlayers, boulder loams (till). Depressions between the hills are often swamped, the largest occupied by lakes. The origin of most lakes is associated with thawing of buried ‘dead ice’ blocks during deglaciation processes in this area (Zagorodnyh 1998; Litvin 1999*a*).

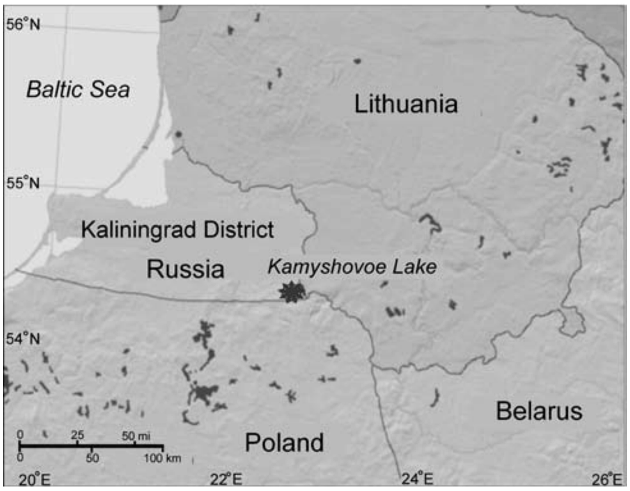

Fig. 1 Location of the investigated lake. Compiled by O. Druzhinina, 2014

The average annual precipitation is less than 700 mm on the study area. The average annual temperature is +6.5ºC, in January –4.5ºC, in July +17.5ºC. The predominant type of soil is podzol, under different types of forest vegetation are light pine forests, fir, and alder (Litvin 1999*b*). The Kamyshovoe Lake stretches from SW to NE and occupies an area of 0.32 km². The lake is surrounded by high hills (196–225 m a.s.l.). It is shallow with a maximum depth of 4.5 m, and measures 0.85 km long by 0.57 km wide. The complex investigation was carried out in the southern part of the lake.

METHODS

Drilling and sediment sampling

In order to reconstruct the history of vegetation and conditions of sedimentation in the Kamyshovoe Lake a borehole was drilled with the use of the ‘Russian’ corer (consists of a 100 cm long chamber (diameter 5 cm) and of 150 cm long rods; 8 rods were used to sample 1200 cm long sediment section). The materials obtained were sampled for lithological, palynological, and diatom studies, analyses of loss-on-ignition, as well as for radiocarbon dating. The samples for lithological, pollen and diatom analysis were spaced by 2 cm, and for LOI and radiocarbon dating by 10 cm. The article is devoted to the part of the section (700–1199 cm), composed by late Pleistocene and early Holocene deposits, which have been the main subject of the current study.

Pollen analysis

During the study 38 samples representing the lower part of the core were examined. The sub-samples of 1–3 cm^3 for pollen analysis were prepared and investigated using a standard chemical procedure (Erdtman 1936; Grichuk 1940), including treatment of the sediments with a heavy liquid (CdI_2+KI). *Lycopodium* spores were added in order to calculate pollen concentrations (Stockmarr 1971). Pollen identification was based on Moore *et al.* (1991). In the most of the samples number of counted terrestrial pollen grains exceeded 500 with exception of some samples where the number of pollen grains was extremely low. Taxa are presented as percentages of the sum of arboreal (AP) plus non-arboreal (NAP) taxa (AP+NAP=P). For calculation and presentation of both pollen and diatom data the programs *TILIA* and *TILIA-graph* (Grimm 2007) were applied. Along with the visual inspection, a stratigraphically constrained cluster analysis (CONISS – Constrained Incremental Sums of Squares cluster analysis; Grimm 1987) was used for the subdivision of above mentioned diagrams.

Diatom survey

The laboratory preparation of sediment samples for diatom analysis follows techniques presented in R. W. Battarbee (1986). Slides for microscopic analysis were prepared using the NAPHRAX mounting medium. Slides were studied under a NIKON light microscope (with a magnification of ×1000). Diatom species were identified mainly by using the taxonomic works of K. Krammer and H. Lange–Bertalot (1986–1991).

The succession of the most frequent and ecologically important taxa is presented as percentages of the total sum of identified diatoms. In order to describe the palaeoecological conditions of the water basin, diatom species are classified into ecological groups (Van Dam *et al.* 1994; Loseva 2000; Barinova *et al.* 2006). The first ecological group is defined by the tolerance of the diatoms to fresh water pH (van Dam 1994): 1) alkalibiontic − exclusively occurring at pH>7; 2) alkaliphilous − mainly occurring at pH.7; 3) circumneutral − mainly occurring at pH-values about 7 and 4) acidophilous − mainly occurring at pH<7. The next ecological group contains diatoms classified according to their habitats: 1) planktonic-free floating in water; 2) benthic diatoms-bottom living and 3) epiphytic-attached to various surfaces in the shallow zone of the lake.

The percentage composition of each diatom species is calculated from the total diatom sum in the sample. The diatom diagram shows selected species (which percentages are >1% of total diatom sum in the sample) and some ecologically important taxa. The solid (black) curves show actual percentages of species, and the adjacent (grey) curves are shown at a magnification of x10. Diatoms were analyzed in 50 sediment samples taken from the interval 1195–700 cm of the Kamyshovoe Lake sediment section.

Loss-on-ignition (LOI)

In order to estimate conditions of sedimentation in the Kamyshovoe Lake loss-on-ignition (LOI) method was applied (Heiri *et al.* 2001). LOI was conducted at the Laboratory of Geochronology, St. Petersburg State University, following standard procedure: to ascertain the LOI, sediments covering 10 cm interval were dried at 105° C for 24 h and combusted at 500°C (4 h). The content (in %) of total organic carbon (TOC) in 50 sediment samples was determined.

Radiocarbon (^{14}C) dating

The absolute age of sediments was determined by radioactive carbon (^{14}C) at the Laboratory of Geochronology, St. Petersburg State University, Russia (laboratory index LU-); 8 samples were taken for this analysis. AMS ^{14}C dating of 3 samples from the lower part of the section was conducted at Radiocarbon Dating Laboratory, Poznan, Poland (laboratory index Poz-). For the calibration of dates, OxCal v 4.2.4 (Bronk Ramsey, Lee 2013) was used.

RESULTS

Lithological composition, LOI and chronology of sediments

The investigated part of the sediment section from the Kamyshovoe Lake is described as seven layers, both late Pleistocene and Holocene (Table 1). Sediment classification was based on Subetto (2009). The section studied consists of lacustrine sediments represented by gyttja with interlayers of clayish silt underlain by clay without clearly marked stratification from a depth 1089 cm and lower.

The calibrated ages of all the samples are in stratigraphical order, except the (^{14}C) AMS date 13,720–13,577 cal yr BP at the 1011–1012 cm depth (Table 2, Fig. 2). The dating carried out on the sediments from

Table 1 Subdivision of the sediment section from the Kamyshovoe Lake. Compiled by J. Kublitsky, 2014

Depth from the water surface, cm	Layer	Lithology
700–853	7	Organic gyttja
853–932	6	Grey-brown clayish gyttja with interbedded dark brown organic matter at depths 8.95-8.97 and 9.29-9.32 m
932–950	5	Dark gray clayish silt
950–1061	4	Greenish-grey clay-silt gyttja with hydrotroilite (FeS·nH2O)
1061–1067	3	Greenish-brown organic gyttja
1067–1089	2	Dark grey clayish silt with hydrotroilite (FeS·nH2O)
1089–1199	1	Grey silty clay with separate inclusions of hydrotroilite (FeS·nH2O) and not clearly marked stratification

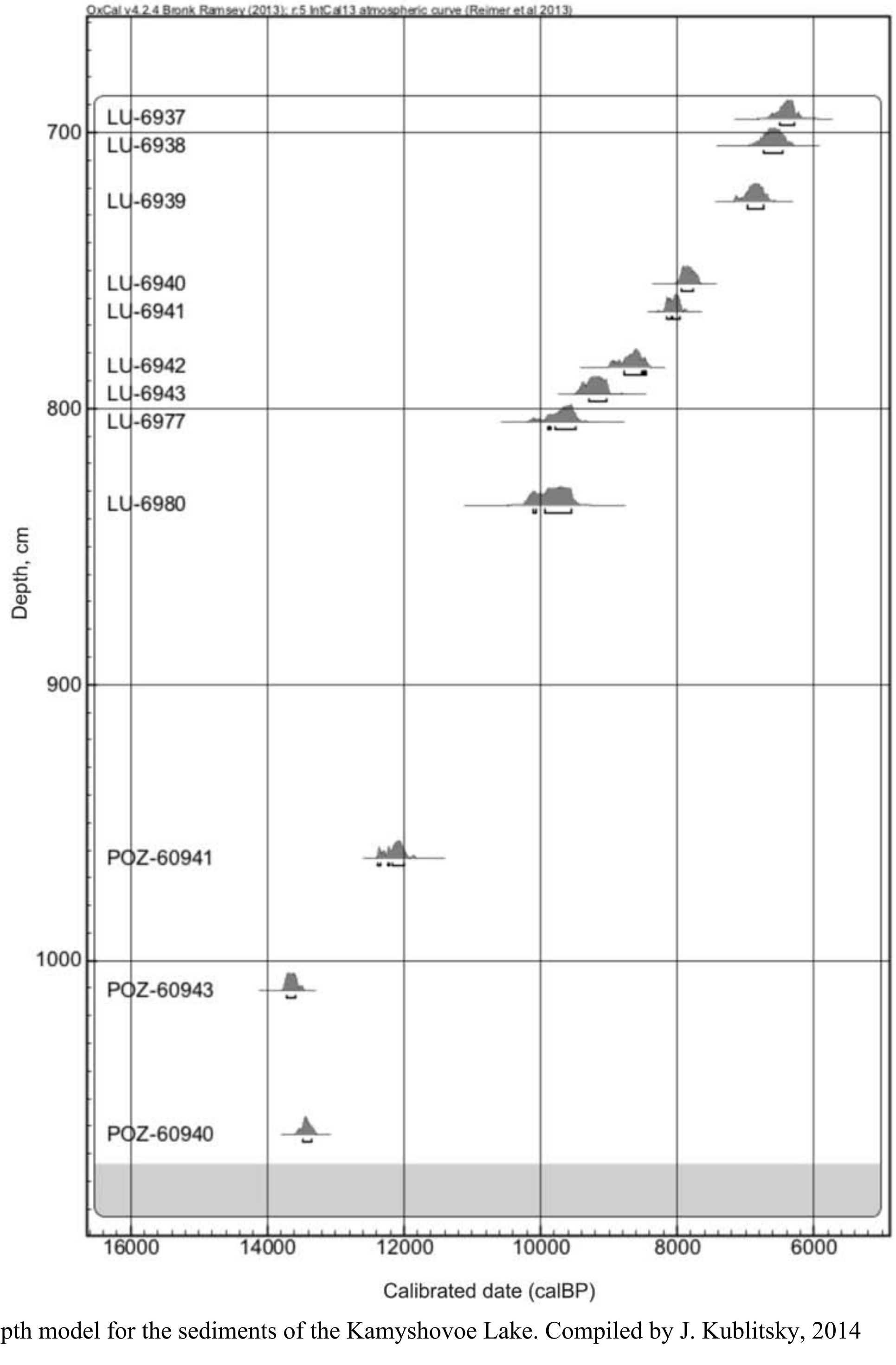

Fig. 2 Age-depth model for the sediments of the Kamyshovoe Lake. Compiled by J. Kublitsky, 2014

Table 2 Results of the radiocarbon (^{14}C) dating. Compiled by J. Kublitsky, 2014

Lab code	Type of sample	Depth, cm	^{14}C age (BP)	Cal. Age ranges 68,2% conf. intervals	Cal. Age ranges 95,4% conf. intervals
LU-6938	Organic gyttja	700–710	5790±120	6730–6453	6882–6319
LU-6939	Organic gyttja	720–730	6010±90	6967–6739	7156–6663
LU-6940	Organic gyttja	750–760	7010±90	7937–7757	7995–7675
LU-6941	Organic gyttja	760–770	7220±80	8157–7965	8194–7869
LU-6942	Organic gyttja	780–790	7830±90	8773–8463	8977–8430
LU-6943	Organic gyttja	790–800	8220±100	9300–9030	9465–8995
LU-6977	Organic gyttja	800–810	8630±130	9885–9486	10153–9427
LU-6980	Organic gyttja	830–840	8740±160	10117–9545	10201–9492
POZ-60941	Clay-silt gyttja	962–964	10310±50	12375–11992	12389–11845
POZ-60943	Clay-silt gyttja	1011–1012	11810±60	13720–13577	13758–13483
POZ-60940	Organic gyttja	1062–1063	11600±60	13483–13351	13557–13305

Table 3 Results of LOI analysis. Compiled by J. Kublitsky, 2014

Depth, cm	LOI, %	Depth, cm	LOI, %	Depth, cm	LOI, %
700-710	41,00106	870-880	13,22976	1040-1050	6,640858
710-720	39,33352	880-890	11,8004	1050-1060	7,778113
720-730	35,14644	890-900	11,57107	1060-1070	4,651163
730-740	35,12111	900-910	10,85316	1070-1080	7,387326
740-750	29,8713	910-920	12,09136	1080-1090	4,665162
750-760	30,80477	920-930	8,860759	1090-1100	4,864154
760-770	27,94402	930-940	8,297362	1100-1110	5,254963
770-780	29,29464	940-950	7,85039	1110-1120	4,998135
780-790	28,59589	950-960	7,705123	1120-1130	4,837703
790-800	25,31705	960-970	10,18719	1130-1140	5,059524
800-810	25,37917	970-980	7,043974	1140-1150	5,230386
810-820	24,60674	980-990	8,560477	1150-1160	5,212465
820-830	24,01961	990-1000	8,908361	1160-1170	5,178643
830-840	21,59144	1000-1010	6,362084	1170-1180	5,189341
840-850	14,77507	1010-1020	4,78332	1180-1190	3,833605
850-860	13,0365	1020-1030	5,05459	1190-1199	3,863988
860-870	13,47976	1030-1040	5,825243		

the Kamyshovoe section indicates that the deposition of the lacustrine sediments under consideration began during the late Pleistocene. The oldest date obtained from the lower part of the section (1061–1062 cm depth) places the deposition of the investigated sediments before 13,483–13,351 cal yr BP.

The estimated content of total organic carbon (TOC) indicated the biological productivity of the lake over time, which is directly dependent on climatic parameters, primarily on the temperature. Especially low representation of organic matter (less than 6%) was recorded throughout the strata at a depth of 1199–1010 cm (Table 3). A slight change in the TOC values from 6% to 9% was observed at a depth of 1010–1000 cm. Further gradual and smooth increase of TOC up to 13% continued to a depth of 840 cm, which is marked by rapid change of parameter up to 20% (840–830 cm). The upper part of profile (830–700 cm) demonstrated a further increase of organic constituent up to 41%.

Pollen analysis

Five local pollen assemblage zones (LPAZ) with subzones were established for the Kamyshovoe Lake pollen diagram, based on visual inspection and statistical analysis of the data (Fig. 3). In LPAZ I non-arboreal taxa, e. g. Cyperaceae (up to 20%) and Poaceae (up to 13%) predominate. The lowermost part of the section (LPAZ I) is marked by low pollen concentration. In fact, some samples are totally lacking in pollen grains. Furthermore, the proportion of corroded pollen grains is very high, indicating the reworking of older material and this is also confirmed by the presence of thermophilous trees (*Alnus*, *Corylus*, *Ulmus*) in the spectra.

LPAZ II is characterised by an increase in the presence of *Pinus* pollen. This zone can be sub-divided into three sections. Sub-zone II-a is marked by first maximum for *Betula* (up to 36%), whereas sub-zone II-b shows an increasing amount and a maximum for *Pinus* (up to 60%). *Juniperus* has its maximum

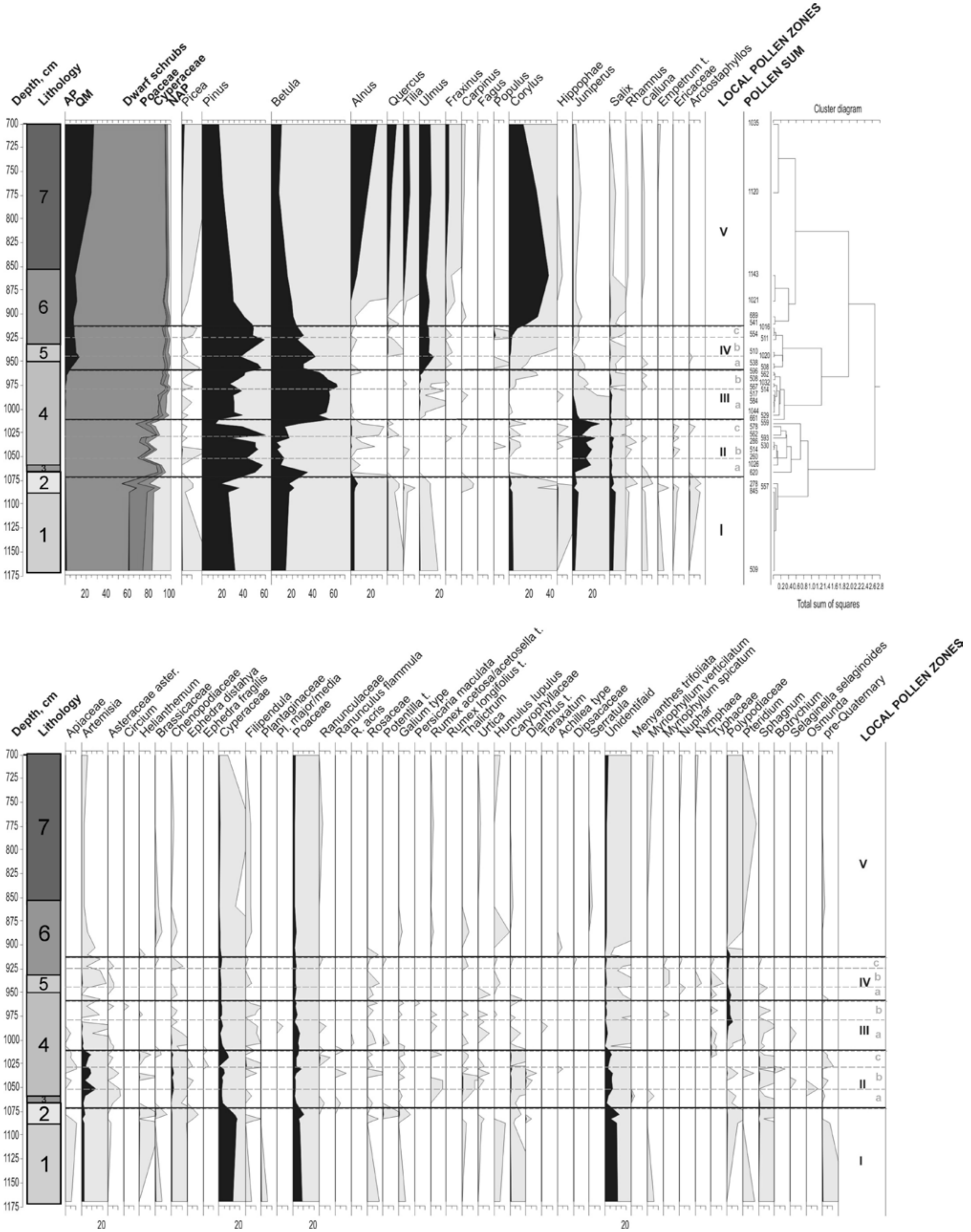

Fig. 3 Pollen diagram for the Kamyshovoe Lake sediment section. Compiled by M. Stančikaitė and O. Druzhinina, 2014

value (up to 26%) in sub-zone II-c and this coincides with a high value for *Artemisia* (up to 15%) and a decrease for both *Pinus* and *Betula* (to 12%). The values for Cyperaceae and Poaceae reach 10% and 7% respectively. *Ephedra* and *Helianthemum* both have their peaks in sub-zones II-b and II-c.

LPAZ III (sub-zone III-a) begins with rises in the amount of *Betula* (up to 62%) and the appearance of

Ulmus. This sub-zone is marked also by a peak for *Selaginella selagonoides.* In sub-zone III-b the amount of *Betula* decreases to 39% at the top of the zone corresponding with a peak for *Pinus* reaching 54%. Pollen grains of *Corylus* appear and the amount of Poaceae pollen increases.

The dynamic of the vegetation in LPAZ IV was reflected in the existence of three sub-zones. At the beginning of zone (sub-zone IV-a) after a peak for *Pinus* pollen (up to 59%) the value for this tree begins to decrease, corresponding with a rise in *Betula* pollen (up to 42%) and a maximum for *Ulmus* (up to 12%). Sub-zone IV-b shows a decrease in *Betula* and *Ulmus* and a new maximum for *Pinus* (up to 60%). The amount of *Corylus* grows slightly and *Quercus* appears. Sub-zone IV-c is marked by a decrease in *Pinus, Betula* and *Ulmus* which coincides with the rapid rise of *Corylus* (from 2% up to 9%) and a peak for *Populus* (up to 2.5%). In this sub-zone the percentage of herbaceous plants increases slightly.

In the upper part of the diagram, LPAZ V is represented by the rapid flourishing of *Corylus* (up to 38%) followed by a decreasing value for this taxa, and the appearance and spread of *Alnus, Tilia* and *Quercus* against a background of a decrease in *Pinus* and *Betula*.

Diatom analysis

In total 98 diatom species from 33 genera were identified in all investigated samples. Six bottom samples (1084–1195 cm) of the section are not included in the diatom diagram because the samples contain no diatoms or contain only single diatom frustules. Four local diatom assemblages zones (LDAZ) were identified according to changes in the composition of diatom species in the sediment section of the Kamyshovoe Lake (Fig. 4).

LDAZ I (depth 1024–985 cm) is related to the bottom of the section and includes only two samples. The predominant diatoms are freshwater alkaliphilous benthic (*Amphora ovalis*, *A. ovalis* var. *pediculus*) and epiphytic *Fragilaria construens*. LDAZ II (985–850 cm) is characterized by a higher diversity of diatom species. This zone is dominated by freshwater alkaliphilous epiphytic diatoms (*Fragilaria construens*, *F. brevistriata*, *F. lapponica*, *Martyana martyi*, *Achnanthes holsatica*) and benthic (*Amphora ovalis* var. *pediculus*, *Navicula scutelloides*, *N. schoenfeldii*, *Surirella biseriata* var. *bifrons*). The percentage of alkalibiontic diatoms gradually increases to 17 % higher up in the zone. Planktonic diatoms (*Campylodiscus hibernicus*, *Cyclostephanos dubius*, *Cyclotella ocellata*, *C. radiosa*) account for up to 5 %.

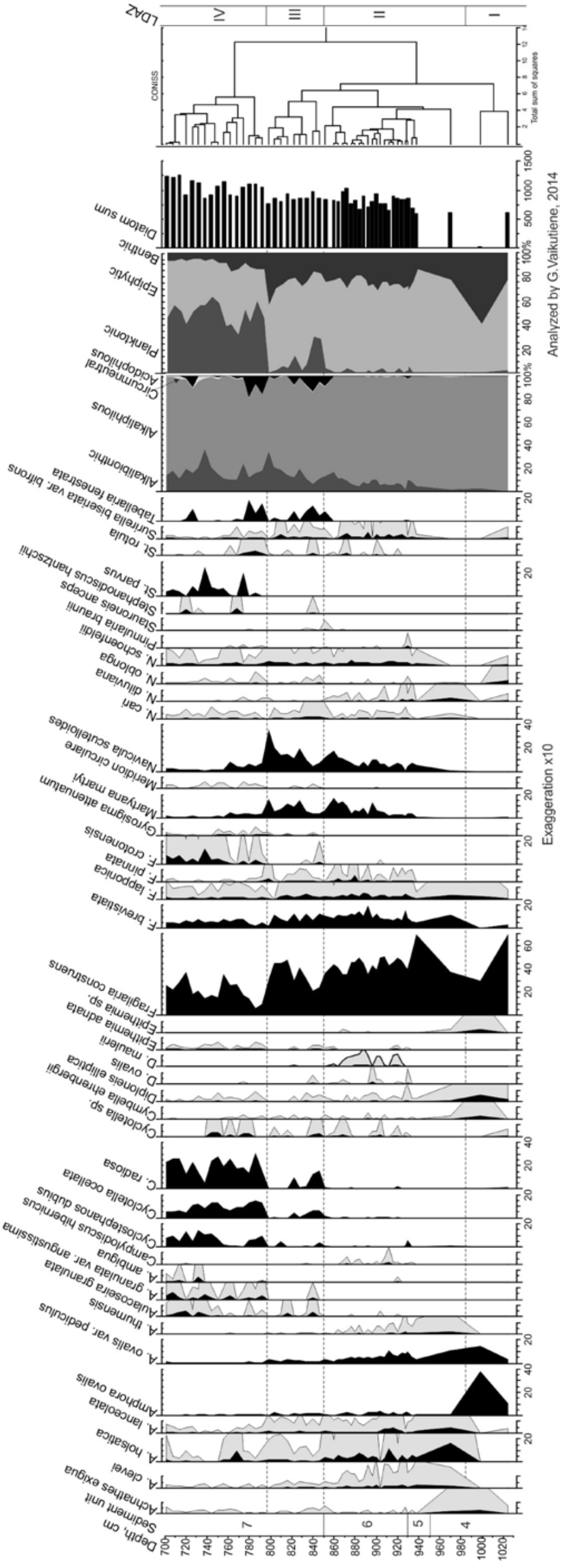

Fig. 4 Diatom diagram for the Kamyshovoe Lake sediment section. Compiled by G. Vaikutienė, 2014

LDAZ III (depth 850–795 cm). The number of freshwater alkalibionthic diatoms increases slightly and fluctuates between 7–34 %. The amount of acidophilous diatoms (epiphytic *Tabellaria fenestrata*) increases up to 13 % and planktonic (alkaliphilous *Cyclotella ocellata* and *C. radiosa*) up to 30 % at the bottom of the zone. Freshwater epiphytic *Fragilaria* sp. and benthic *Navicula scutelloides* still predominate in the alkaliphilous group.

LDAZ IV (depth 795–700 cm). The number of freshwater acidophilous (*Tabellaria fenestrata*) decreases from 16% to a few percent higher up the zone and the same is true for epiphytic and benthic diatoms. The previously predominant epiphytic *Fragilaria construens* decreases and the curve fluctuates around 20%. The amount of planktonic diatoms increases up to 63 % and the predominant species are *Cyclotella ocellata*, *C. radiosa*, *Cyclostephanos dubius*, *Stephanodiscus parvus*.

DISCUSSION

The study of pollen, diatom, LOI and radiocarbon dating carried out on the core section of the Kamyshovoe Lake made possible a reconstruction of the history of the terrestrial vegetation and lacutrine environment changes during the late Pleistocene and early Holocene. According to the results of the pollen analysis and radiocarbon dating, the accumulation of limnic sediments in the lake began before Allerød, which is quite common for other lakes investigated in the region (Gaidamavičius *et al.* 2011; Stančikaitė *et al.* 2009, 2015; Pochocka-Szwarc 2013; Stachowicz-Rybka, Obidowicz 2013; Zawiska *et al.* 2015). The calibrated ages of all the samples are in stratigraphical order, except the (^{14}C) AMS date 13,720–13,577 cal yr BP at the 1011–1012 cm depth. This sample appears to be too old probably owing to reworking.

Sediments lying at the bottom of the investigated section (1072–1199 cm) contain a low concentration of pollen which confirms the scarcity of the vegetation cover where non-arboreal taxa e.g., Cyperaceae (up to 20%) and Poaceae (up to 13%) (LPAZ I) predominate. Another possible explanation of the low concentration of pollen is high accumulation rate during this initial interval. While a pollen curve exceeding 25% (Huntley, Birks 1983) might indicate the presence locally of woodland dominated by birch, the values recorded in the Kamyshovoe Lake core suggest either a distant origin or the re-deposition of birch pollen during the initial stages of sediment formation.

With regard to the development of the *Pinus* curve, only pollen values exceeding 50% indicate local dominance of the plant (Huntley, Birks 1983) while the recorded number confirms long-transport of pollen grains. Other pollen grains, i.e. *Alnus*, *Picea* were presumably in-washed from the older interglacial deposits or have long-transport origin as is suggested by other LG records representing the Eastern Baltic (Veski *et al.* 2012; Stančikaitė *et al.* 2015). In general, the number and variety of plant micro remains indicates the re-deposition of this strata in the Kamyshovoe Lake. An intensive re-shaping of the landscape, which determined transportation and subsequent re-sedimentation of the older strata, was noted in the previously investigated beds representing the initial stages of the post-glacial sites around the Baltic (Iversen 1954; Veski *et al.* 2012, Stančikaitė *et al.* 2015).

Lithological changes occurred in the sedimentation of the lake at a depth of 1067–1062 cm and these are related to the formation of greenish-brown organic gyttja dated to 13,483–13,351 cal yr BP. Pollen analysis shows an increase in the *Betula* curve (up to 36%) which could be related to the formation of the birch-predominating forest, typical for the early part of the Allerød Interstadial in the Eastern Baltic (Kabailienė 2006; Šeirienė *et al.* 2006). At the same time the number of NAP pollen grains is small. Species requiring warmth, i.e. *Alnus*, *Ulmus*, *Corylus* diminished from the spectra, suggesting a stabilization of the sedimentation environment i.e. a decrease in the transportation of re-deposited material into the basin. Diatoms are absent in this part of section. Normally, a low pH of the water environment, indicated by inclusions of hydrotroilite in clay-silty gyttja at the bottom of the section, is unfavorable for the survival of diatom frustules during the sedimentation process.

The pollen record shows several signs indicating the formation of new vegetation cover in the area in the pollen sub-zone II-b. Although the total amount of AP pollen is low here as well, the increasing value for *Pinus* pollen (up to 60%) could be related to the local origin of the recorded pollen grains. The spread of pine forests in the second part of the Allerød (since about 13,200 cal yr BP) seems to be a reaction to an increased continentality in the climate (Hoek, Bohncke 2002), which was also reflected in the presence of *Ephedra* in the pollen diagram of the Kamyshovoe Lake.

At the transition of the Allerød to the Younger Dryas around 12,700 cal yr BP a major and abrupt change in the climate occurred (Hoek, Bohncke 2002; Feurdean *et al.* 2014; Brooks, Langdon 2014), leading to a diminishing of *Pinus* and *Betula* woods and the development of herbaceous plant communities. The pollen diagram from the Kamyshovoe Lake section shows an increasing number of particular NAP taxa i.e. *Artemisia*, *Juniperus* which suggests the development of patches of shrublands in which light-demanding species, such as juniper, flourished. *Helianthemum*, which is an indicator of dry climate conditions, is also present in the pollen spectra. PAZ II-c can be considered as being equivalent to the beginning of the Younger Dryas (GS-1), the 300-year-long time period with the most severe climate conditions (Hoek, Bohncke 2002; Lowe *et al.* 2008; Kołaczek 2013, 2014). Similar changes in vegetation, reflecting climate deterioration, have been observed throughout most of the neighboring territories: northern Poland (Apolinarska *et al.* 2012), Lithuania (Stančikaitė *et al.* 2008, 2009, 2015), Belarus (Makhnach *et al.* 2004; Zernitskaya *et al. in press*). Many records from all around the region indicate that amelioration of the environmental regime began during the second part of GS-1 event (Veski *et al.* 2012; Stančikaitė *et al.* 2008, 2009, 2015). A slight change in the TOC values from 6% to 9% observed at a depth of 1010–1000 cm of the sediment section of the Kamyshovoe Lake also reflects this trend. An increase in humidity and in mean annual temperature enabled birch-predominating forest to prevail in the area under discussion (PAZ III-a). Normally birch rapidly occupies open plots creating favorable conditions for the immigration of other trees. During the very end of the Younger Dryas (PAZ III-b) and the onset of the Holocene (PAZ IV-a) *Betula* was followed by an increase in *Pinus*.

Diatoms distinguished at a depth of 1024–985 cm of the section (LDAZ I) contain only two samples with prevailing alkaliphilous benthic (*Amphora ovalis*, *A. ovalis* var. *pediculus*) and epiphytic *Fragilaria construens* diatoms. The small variety of diatom species and the low number of diatom frustules in sediments indicate the existence of a cold environment and a shallow freshwater basin poor in nutrients during the Younger Dryas. An additional factor still inhibiting trophic increase was probably the inflow of cold waters caused by the melting of dead ice blocks. In the neigbouring areas lake sediment records indicate that this process could take place up to the Preboreal period (Pochocka-Szwarc 2013).

The transition of the Younger Dryas to the Preboreal was marked by changes in lithology at a depth of 950–932 cm, which possibly correlates with the draining of the Baltic Ice Lake around 11,600 cal yr BP (Stančikaitė 2006; Hyttinen *et al.* 2011). This part of the section is also marked by an exceptional high content of *Fragilaria construens* within the diagram (LDAZ II). Small size *Fragilaria* communities, with a high reproductive rate and large ecological amplitude, adapt well to changing environmental conditions and can be good indicators of high environmental stress, physical disturbance, and unstable transient conditions (Stančikaitė *et al.* 2015). The dominance of small *Fragilaria* sp. diatoms is mentioned in numerous papers summarized in Battarbee *et al.* (2010) as a characteristic feature of a changing cold postglacial environment.

It is probable that, whereas the Allerød implied an abrupt change for terrestrial vegetation, the warming prior to the Preboreal was a more subtile transition (Hoek, Bohncke 2002; Zawiska *et al.* 2015). The development of vegetation in the lake surroundings shows several trends, which are reflected in the subzones of PAZ IV.

In the sub-zone IV-a the number of *Pinus* pollen increased in the spectra indicating the formation of forest cover with a high participation of pine. At the same time, the number of NAP diminished suggesting the formation of dense vegetation cover with new deciduous taxa with higher thermal requirements. The sub-zone IV-b is characterized by an increasing amount of *Betula* in the woods and the appearance of *Ulmus*. According to pollen data, elm quickly took over in the local vegetation as the recorded number of pollen grains (up to 12%) significantly exceeds the pollen record typical for the regional development of the plant i.e. 2% (Huntley, Birks 1983). Immigration of this tree suggests the formation of fertile soils and increasing humidity (Grime *et al.* 1986). In North-Eastern Poland elm established as early as 9450 cal yr BP (Wacnik, 2009); shortly after 11,200 cal yr BP (Stivrins *et al.* 2014) this tree immigrated to the eastern Latvia and at about 10,300 cal yr BP pollen records suggest the establishment of this taxa in North-Eastern Lithuania (Stančikaitė, *pers. data*). About the same time *Corylus* became established on a regional scale as a pollen curve exceeding 2% is only related with the local presence of this taxa in Northern Europe (Miotk-Szpiganowicz *et al.* 2004). Regional establishment of the hazel varies from 10,000 cal yr BP to 9400 cal yr BP in the region (Wacnik 2009; Saarse 2009; Zernitskaya, Kolkovskij 2003; Novik *et al.* 2010). The sub-zone IV-c is notable for the appearance of *Populus* (up to 2,5%) and some increase in the role of grasses in the vegetation cover, which can be interpreted as representing an open vegetation phase during the Preboreal correlating to similar open vegetation phases deduced from other pollen records in Europe ('Preboreal Oscillation' ca. 11,300–11,150 cal yr BP, Björck *et al.* 1997; ca.11,270–11,210 cal yr BP, Bos *et al.* 2007; 'open vegetation phase during the Preboreal' 11,180–11,070 cal yr BP, P. de Klerk *et al.* 2007).

The biological productivity of the lake increased gradually and smoothly (TOC up to 20%) during the Preboreal and Boreal periods. The reservoir environment is characterized by a higher diversity of diatom species (LDAZ II) which indicates more suitable environmental conditions for diatoms spreading in the lake. Alkaliphilous epiphytic diatoms were still predominant within the zone. However, planktonic diatoms appear and account for up to 5%. The prevalence of *Fragilaria construens* indicates the littoral zone of the lake (muddy bottom) overgrown with aquatic plants *Phragmites* (Kuylenstierna 1990), but planktonic species indicate the very beginning of an increase in the depth of the basin. The fluctuation of planktonic and benthic diatoms within the described interval indicates short-term changes in water level and the changing conditions of sedimentation (some diatoms were found in a poor state of preservation). Variations in the water level were also observed in some lakes in Poland, Belarus, Germany during the Boreal chronozone (Novik *et al.* 2010; Galka *et al.* 2014; Kalis *et al.* 2003; Kolaczek *et al.* 2014).

The upper part of the pollen diagram (PAZ V) represents a further development of the terrestrial vegetation in the lake surroundings during the Boreal and the Atlantic. Pollen records which can be considered contemporary with the Boreal indicate the rapid spread and the highest content of *Corylus* (up to 38%) followed by a slight decrease, and the appearance and spread of *Alnus, Tilia* and *Quercus* together with the retreat of birch-pine forests. During the Atlantic the prospering of the broad-leaved thermophylous species suggest a flourishing of mixed deciduous forest and implies an amelioration of the climatic conditions. At the same time, the amount of organic content in the sediments began to increase as the deposition of organic brown gyttja was recorded.

The LOI study showed a rapid growth in the biological productivity of the lake 10,117–9545 cal yr BP. This was also reflected in the results of diatom analysis (LDAZ III). The number of alkali-bionthic diatoms increases slightly and fluctuates around 20 %. A sign of more intensive erosion of the soils around the lake, as a result of a warmer climate and increased precipitation, is the fact that the amount of acidophilous diatoms (epiphytic *Tabellaria fenestrata*) increases up to 13 %, while the planktonic (alkaliphilous *Cyclotella ocellata* and C. *radiosa*) increase up to 30 %, at the bottom of the zone. This indicates a rise in the water level in the lake. Epiphytic *Fragilaria* sp. and benthic *Navicula scutelloides* still predominate in the alkaliphilous group. Fluctuation of the alkalinity in the lake is typical for the beginning of the Holocene when climate, surrounding vegetation and soils in the area change significantly (Battarbee *et al.* 2010).

The lower part of the LDAZ IV could be correlated with the boundary of the Boreal-Atlantic chronozones, when acidity in the lakes started to increase again because of higher temperatures and precipitation which caused soil erosion. The large percentage of *Cyclotella* sp. would usually suggest a low trophic status for the lake (Sienkiewicz 2013). However, *Stepahanodiscus parvus* predominate in the early stage of eutrophication in shallow (<5 m) lakes and *Cyclostephanos dubius* spreads later. These *Stephanodiscus* and *Cyclostephanos* species are common in lakes with an increased amount of nitrogen (Bradshaw *et al.* 2003). The water level increased as did the amount of biogenic components in the lake, while eutrophication increased at the time of the Boreal–Atlantic chronozones.

CONCLUSIONS

Even though the vegetation history of the South-Eastern Baltic is well-recognized and supported by numerous studies of the pollen data, each new one such as of the Kamyshovoe Lake may provide with unique data on the development of vegetation and its response to climatic oscillations of the late Pleistocene and early Holocene. The data obtained during this study allowed to reconstruct the history of vegetation since 13,400 cal yr BP and up to ca. 7900 cal yr BP. The main trends of the changes in the vegetation cover during the mentioned period have been established. Also the results of the investigation indicate the linear vegetation response to the abrupt climate change at the transition of the Allerød to the Younger Dryas around 12,700 cal yr BP, meanwhile later, at the boundary of the Pleistocene / Holocene ca. 11,700–11,600 cal yr BP a more subtile pattern of the vegetation changes was observed.

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