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Lithology and biostratigraphy of the Holocene succession of Lake Ķūži, Vidzeme Heights (Central Latvia)

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Holocene sediment profile from a paludified near-shore area of Lake Ķūži (Vidzeme Heights, Central Latvia) was investigated using lithological and palaeobotanical (pollen and macrofossil analysis) methods and accelerator mass spectrometry AMS ^{14}C dating. The results of this first comprehensive study of a Holocene sediment core from the Vidzeme Heights indicate that at the beginning of the Early and at the end of the Late Holocene the lake level was low and fen peat accumulated around the lake. From *ca*. 9000 BP up to 1500 BP the mire was flooded and gyttja with interlayers of sand and peat accumulated. The water level fluctuations are clearly represented in the lithological succession and pollen spectra. We compared the L. Ķūži pollen diagram with well-studied sites from the Haanja Heights, which have a similar genesis. The most obvious difference in these diagrams is the earlier appearance (9200 BP) of *Picea* pollen in the L. Ķūži profile and its dominance up to 1000 BP. Comparative analysis of the lithology and pollen spectra from L. Ķūži and reference profiles from the Haanja Heights indicate the importance of broad regional factors in influencing the pollen spectra.

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Key words: Vidzeme Heights, Haanja Heights, pollen analysis, lithological analysis, vegetation history, lake level fluctuations.

INTRODUCTION

During the last few decades, a number of studies have addressed the influence of environmental processes at various time and space scales on the development of vegetation, ecosystem and landscape (Delcourt and Delcourt, 1988; Punning *et al*., 1995; Laurent *et al*., 2008). The development of vegetation and the formation of pollen spectra is particularly complex on mosaic glacial landscapes where variable topography and soils and changeable microclimatic, aero- and hydrodynamic conditions limit the spatial-temporal resolution of pollen data for the reconstruction of palaeogeographic conditions. Many investigations dealing with lake deposits show that water level plays a crucial role in the formation of pollen spectra (e.g., Davis and Brubaker, 1973). The effects of local factors can be so dominant that few stratigraphic criteria proposed for the Holocene should be treated as synchronous. Therefore the study of such areas also gives valuable information in establishing constraints on palaeogeographic and biostratigraphic methods (Lynch, 1996; Sugita *et al*., 2006).

Long-term stratigraphical and palaeoclimatological studies have been carried out on the Haanja Heights in Estonia (Ilves and Mäemets, 1987; Saarse and Rajamäe, 1997; Punning *et al*., 2004, 2005; Veski *et al*., 2005; Niinemets and Saarse, 2007). The Haanja Heights is part of a well-developed ice-marginal zone ranging from the Leningrad region (Luga) to North Lithuania (Serebrjannyi and Raukas, 1966; Serebrjannyi *et al*., 1970; Raukas *et al*., 2004). During the formation of these landscapes a complicated proglacial fluvial network developed between the individual peripheral ice streams; processes caused by active and passive ice created mosaic topography and soils on which the biogenic processes developed (Zelcs and Markots, 2004).

Study of the vegetation history on the Haanja and Vidzeme Heights is also important in order to clarify the immigration of individual tree species into areas freed from continental ice cover. Eilart (1963) and Laasimer (1965) noted the importance of the southeastern part of Estonia with mosaic landscapes and rivers such as the Gauja River as migration routes for many species. Most recent syntheses of the palynological and climatostratigraphical data show that the vegetation dynamics

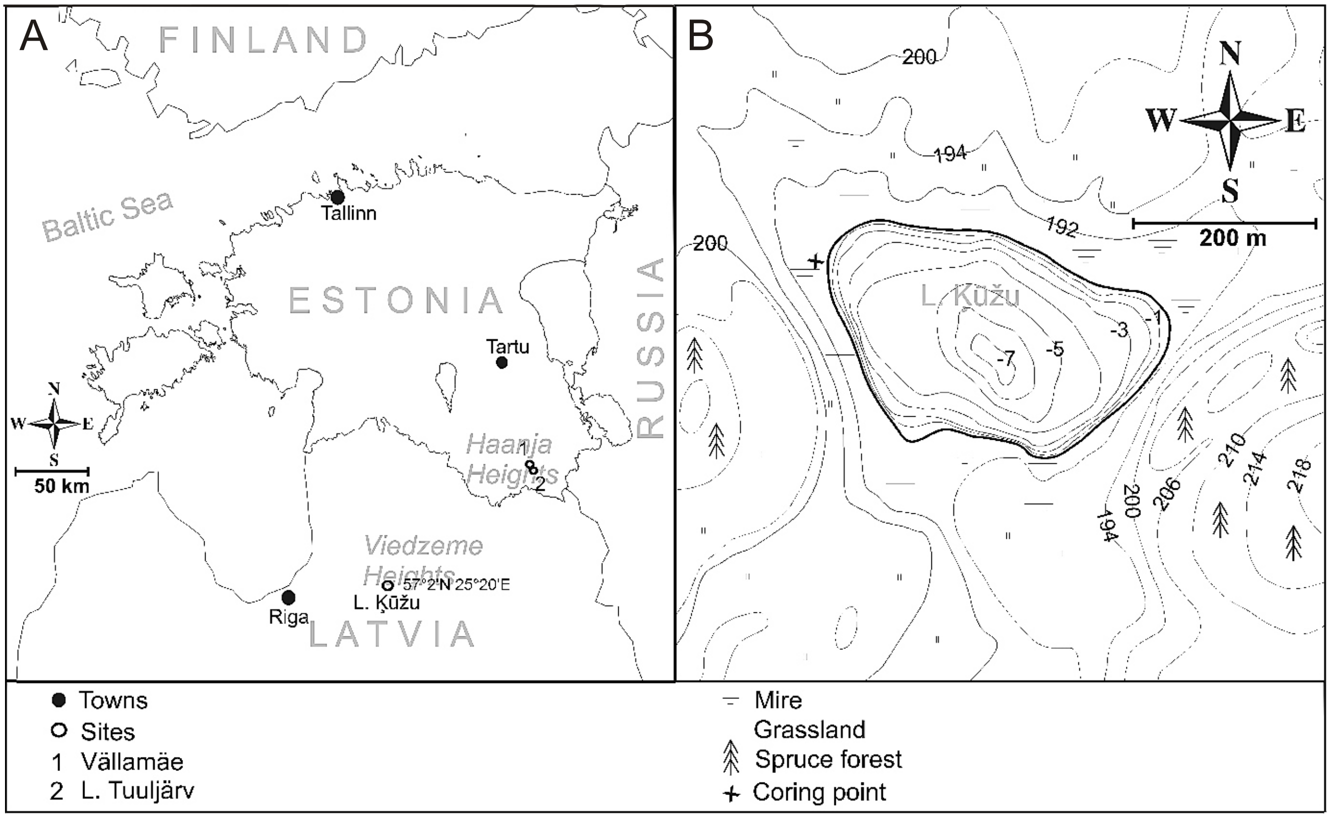

Fig. 1. Location of the study sites in the Haanja Heights and Vidzeme Heights (A); bathymetry of Lake Ķūži, topography and land cover of the lake catchment (B)

in SE Estonia was characterized by specific patterns, such as the early arrival of *Picea*, *Ulmus* and *Quercus* (Niinemets and Saarse, 2007). Essential differences in the individual pollen diagrams complicate the reconstruction of regional palaeoclimatic conditions but offer new possibilities for clarifying the mechanisms of the formation of local vegetation history and resultant pollen spectra (Ralska-Jasiewiczowa, 2006).

Detailed studies of three Holocene peat profiles within the small Vällamäe (Haanja Heights) kettle-hole (diameter of 150 m) showed that microclimatic variations produced differences in the pollen content of different profiles (Punning *et al*., 1995). The temporal distribution of solar radiation falling on the kettle-hole and the development of the hydrological regime in generating diverse peat sequences was highly significant in controlling the earliest stages of mire development.

Although the postglacial vegetation history of Latvia has been studied since the beginning of the 20th century, and pollen zones of Holocene deposits from many peat profiles from different regions have been used to compile a regional summary diagram for the whole of Latvia, palynological and climatostratigraphical information from the Holocene vegetation history in Northern and Central Latvia is rather poor. The only available palynological profiles from the Latvian part of the Haanja Heights (Alūksne Heights) are undated (Vanaga, 1970) and for the Vidzeme Heights are totally absent. Therefore, together with colleagues from the University of Latvia, we started a comprehensive study of the Holocene sediment profiles in this area.

In this paper we focus on the establishment of the development of environmental conditions of the Vidzeme Heights through pollen and macrofossil analyses of sediments from L. Ķūži combined with litho- and chronostratigraphy. This is the first site in this region with a well-established chronology, enabling discrimination of differences and similarities with the palaeoenvironmental development the Haanja Heights in Estonia.

STUDY AREA

Lake Ķūži is situated in Central Latvia in the western part of the Vidzeme Heights amongst the Piebalga hilly area (57°2'N and 25°20'E; absolute height 191.5 m a.s.l.; Fig. 1). The Vidzeme Heights is located distally from the ice-marginal deposits of the Luga (North Lithuanian) stage. The most impressive deposits of this ice advance form a wide belt of heights at about 13 200–13 000 BP (Raukas *et al*., 1995). The topography of the Vidzeme Heights is varied and complex, with a dominance of subglacial landforms. The elevation of the area varies from 180 to 240 m. Small depressions between hillocks were formed following the withdrawal of glaciers from marginal landforms. Many basins, such as L. Ķūži, have a glaciokarstic origin.

The Vidzeme Heights have a moist climate. The average annual precipitation is about 800 mm of which 550 mm falls during the warm season and 250 mm during the cold season. The mean temperature varies from –7.5°C in January to 16.5°C in June. The vegetation period lasts for 175–185 days. The frost-free period lasts for 120 days and the area is usually covered with snow from November to April. The thickness of the snow cover may reach 50 cm. The soils are extremely varied in the region because of the hilly topography. On the hills podzols dominate, which on the cultivated slopes are intensively eroded (Āboltiņš, 1997).

The Vidzeme Heights belongs to the Central Vidzeme geobotanical region. Only 25% of the heights are covered with forest; the rest of the territory is mainly cultivated. The most common are *Oxalidosa* and *Aegopodiosa* spruce forests, which make up 50.4% of all the forests in the area. A total of 1009 vascular plant species have been recorded, of which 167 occur in lakes (Kabucis, 1994).

Lake Ķūži is 6.3 ha in area (maximum length 380 m, width 210 m and depth up to 7 m) with a limited flow-through. It is situated in the hilly landscape and is surrounded in the NW part of the lake by a peaty area up to 100 m wide (Fig. 1B). The thickness of fen peat and lacustrine sediments in the surrounding area reaches 630 cm. The size of the lake's catchment area is 1.2 km^2 and it is covered with forests to the east and west of the lake. Meadows and agricultural land are situated to the north and south of the lake. A 2 m terrace around the lake is clearly visible.

METHODS

SAMPLING

A sediment core of 650 cm was taken in the summer of 2007 with a Belarussian (Russian) peat sampler from the paludified northwestern shore of L. Ķūži (Fig. 1B). A description of the core was recorded in the field. Then the sediment core was dissected into 50 cm long pieces, photographed and wrapped in plastic. A subsampling for the different analyses was made in the laboratory. At first macrofossils from layers of different composition were picked out for AMS ^{14}C dating performed in the Poznań radiocarbon dating laboratory, Poland. After that samples for lithological analyses (1 cm^3 samples from every 20 cm) and pollen analysis were taken. The sediment samples for macrofossil analyses, which require a larger amount of material, were collected from a 20 cm interval with a thickness of 5 cm.

ANALYSES

The lithological analyses were performed by the standard loss-on-ignition (LOI) method. To determine the water content, the samples were dried to constant weight at 105°C. The content of organic matter was measured after 3.5 hours of combustion at 550°C and expressed as the percentage of dry matter. The carbonate content was calculated from the loss of weight after burning the LOI residue at 950°C for 2.5 hours (Heiri *et al*., 2001). The siliclastic (minerogenic) component was calculated by subtracting from the dry mass the amount of LOI_{550} and LOI_{950}.

For macrofossil analyses 100 cm^3 samples were dispersed in water and washed gently through a 250 µm mesh sieve. Residues were dispersed in water and examined on a white plate under a stereo microscope. The general composition of each sample and the relative abundance of the components in percentages were estimated by using a 10 × 10 square grid graticule inserted into one of the microscope eyepieces and moving the specimen plate randomly to 10 different positions and averaging the results. The following components of the sediment fractions were separated: leaves and stems of mosses (mainly *Warnstorfia* spp.), amorphous herbaceous debris (limited to small roots of *Carex* spp. and epidermis of *Typha latifolia* L. and *Nuphar lutea* (L.) Sm) and a ligneous part (small pieces of wood or bark and so on). All seeds, fruits and other identifiable remains were identified with the aid of reference collections and descriptive manuals and the results were expressed as number of macrofossils per 100 cm^3.

For pollen analysis 1 cm^3 block samples were treated with a 10% KOH solution followed by a standard acetolysis according to Moore *et al*. (1991). In general, at least 500 arboreal pollen grains were determined under the microscope. The percentage pollen diagrams are based on total pollen sums. The diagrams were made using the *TILIA* program. Pollen and spore nomenclature follows Moore *et al.* (1991).

RESULTS

LITHOLOGY AND CHRONOSTRATIGRAPHY

The unconsolidated organic-rich deposits with high water content (80–90%) of L. Ķūži lie above on fine-grained silty sands. The Holocene sediment sequence was divided into four lithostratigraphic units (Table 1). Unit 1 consists of woody peat rich in wood remains. Unit 2 is detritic gyttja with interlayers of well-decomposed peat and sand; wood fragments are also present. Unit 3 consists of slightly decomposed fen peat characterized by a high content of wood remains. The topmost 30 cm of the sediments (unit 4) consists of well-decomposed peat layers under slightly decomposed *Sphagnum-Carex* peat.

Table 1

Lithological units of the Ķūži sediment sequence

Depth from the sediment surface [cm]	Unit	Lithological description	Organic matter [%]
0–30	4	slightly decomposed *Sphagnum-Carex* peat	80–90
31–150	3	slightly decomposed fen peat with pieces of wood remains	90–95
151–580	2	detritic gyttja, peaty sand interlayers	40–75
581–627	1	woody peat	75–85

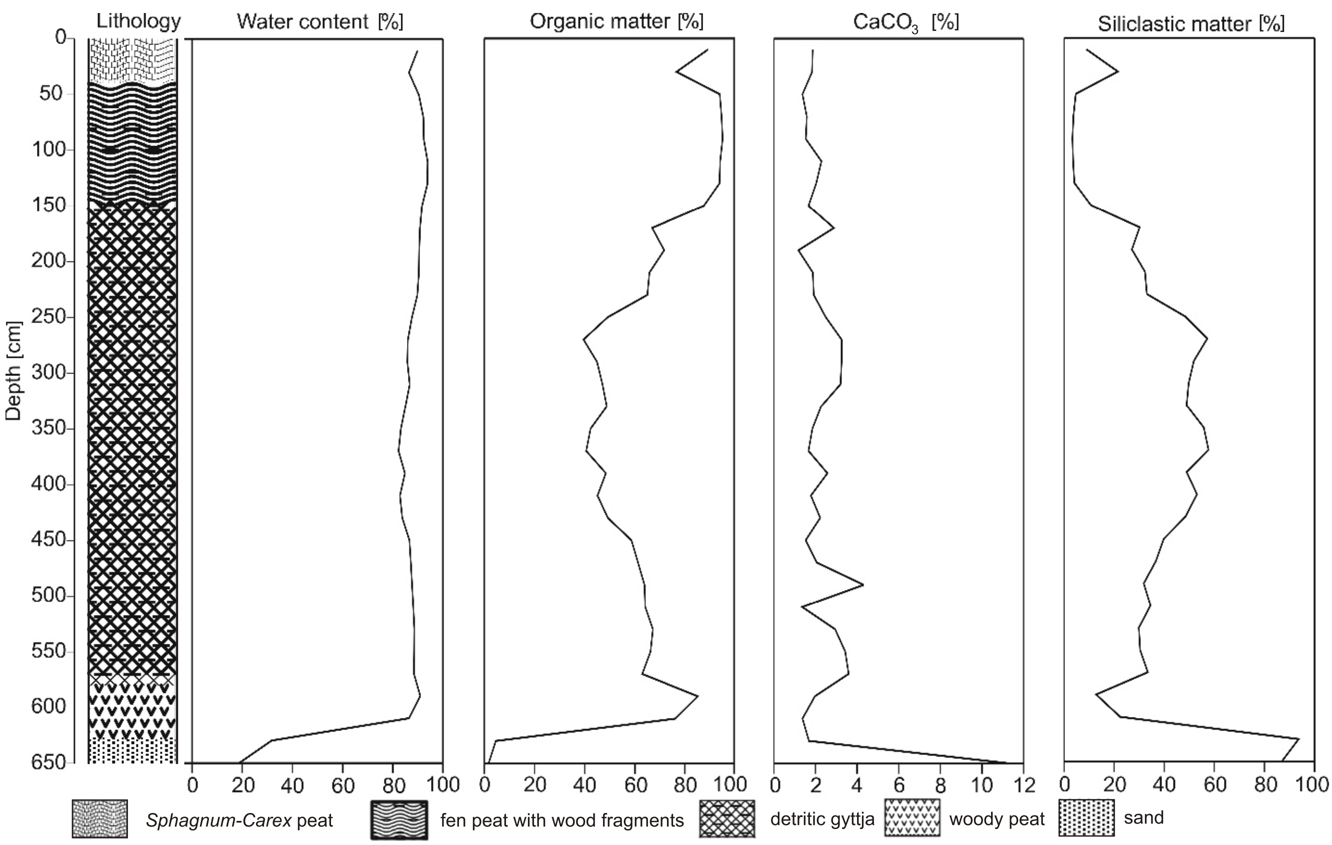

Fig. 2. Lithostratigraphy of the core studied; physical composition of sediments: water content, organic matter content in percentages from dry matter (LOI_{550}); carbonaceous matter (calculated on the basis of LOI_{950}) content in percentages from dry matter; siliclastic (minerogenic) component was calculated by subtracting from the dry matter the amount of organic matter and carbonaceous matter

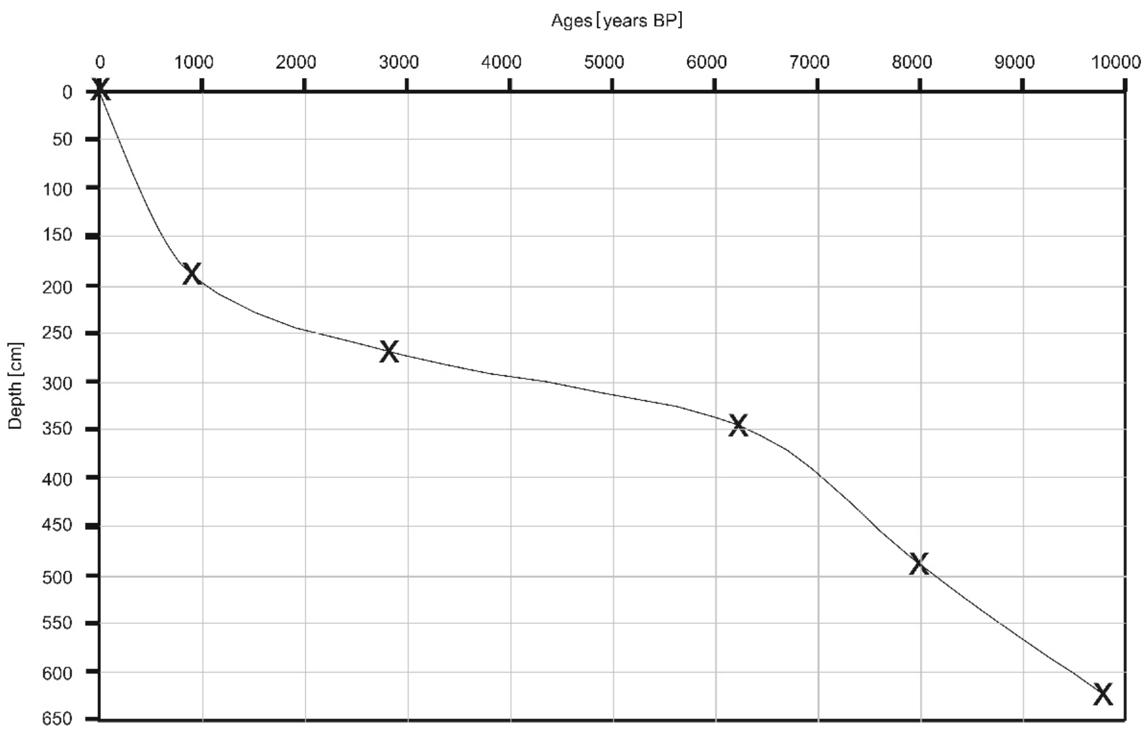

Fig. 3. Age-depth curve of the Lake Ķūži core based on five AMS ^{14}C dates shown in Table 2

Table 2

AMS ^{14}C data from the Ķūži sediment sequence

Sample depth [cm]	Lab. number	Macrofossils submitted	^{14}C age [yr BP]	Cal ^{14}C age [yr BP] 68% probability (Reimer *et al.*, 2004)
190	Poz-23170	plant remains	925 ±30	790–910
269	Poz-23171	plant remains	2825 ±35	2 870–2 965
345	Poz-23172	plant remains	6240 ±50	7 020–7 260
490	Poz-23174	plant remains	8030 ±50	8 770–9 020
625	Poz-23175	wood remains	9810 ±60	11 185–11 265

The lithology of the sediment profile is clearly represented in the composition of the sediments (Fig. 2), with a high content of organic matter (OM) in the woody peat (up to 85%). The OM content in unit 2 varies from 40 up to 75%, indicating a changeable sedimentary environment. In unit 3 the OM content is high and stable (*ca*. 95%). The content of carbonaceous matter is generally uniform through the core (2–3%).

The age-depth curve (Fig. 3) was compiled on the basis of five AMS ^{14}C dates (Table 2). The ^{14}C dates were also calculated in calendar years, but in order to compare different sequences in this paper we further apply only uncalibrated ^{14}C dates in years BP. Three sedimentation periods of different accumulation rates could be distinguished on the ^{14}C age-depth diagram. The accumulation rate was generally stable and high at the beginning of the Holocene (10 000 BP up to 7000 BP) and over the last few millennia (since *ca*. 1000 BP). There was a transition interval between these when the area studied was frequently flooded, and the sedimentation rate was much lower and more variable.

POLLEN AND MACROFOSSIL STRATIGRAPHY

The L. Ķūži pollen diagram is divided into five major LPAZ (Local Pollen Assemblage Zones; Fig. 4). These pollen zones largely correspond with the macrofossil zones (Fig. 5) and coincide with some lithological units (Table 1). The lowermost part of the pollen percentage diagram (10 000–9000 BP, LPAZ K-1; 650–560 cm) is characterized by high *Betula* and NAP frequencies, which decline upwards. The NAP consist mainly of Poaceae pollen and their frequency is fairly high (40%). The *Pinus* curve is irregular and its pollen content is below 20%. Polypodiaceae and *Sphagnum* spores are present in values of 10–20%. Among the macrofossils, only seeds and catkin scales of birch are represented among the remains of trees and seeds of *Carex* and *Menyanthes trifoliata* among the remains of herbal plants in zone KM1 (Fig. 5). The role of the ligneous fraction was higher in the lowermost layers. Lithologically these fit within unit 1.

A sharp increase in *Alnus*, *Corylus* (up to 20%) and *Ulmus* pollen is characteristic of LPAZ K-2 (9000–6500 BP; 559–375 cm). At the beginning of the zone there is a slight increase in *Picea* pollen began. Low percentage values of *Picea* pollen at

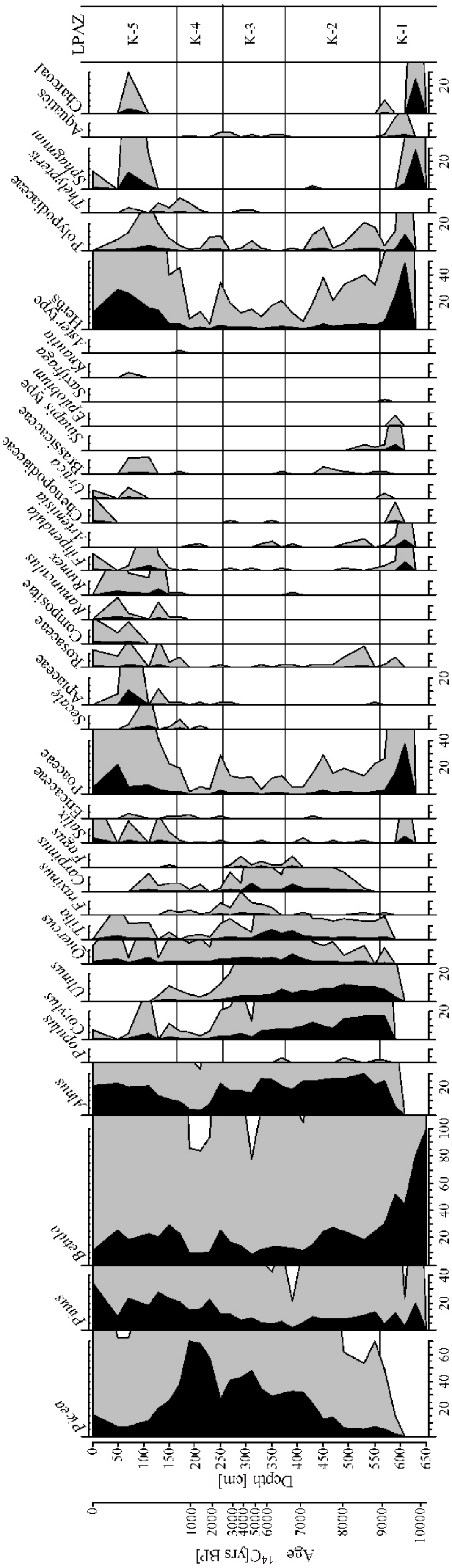

Fig. 4. Pollen percentage diagram from L. Ķūži

The chronological scale is provided by five AMS ^{14}C dates; the black areas on the diagram show the actual pollen in percentages, while the gray areas show the percentages multiplied by 10

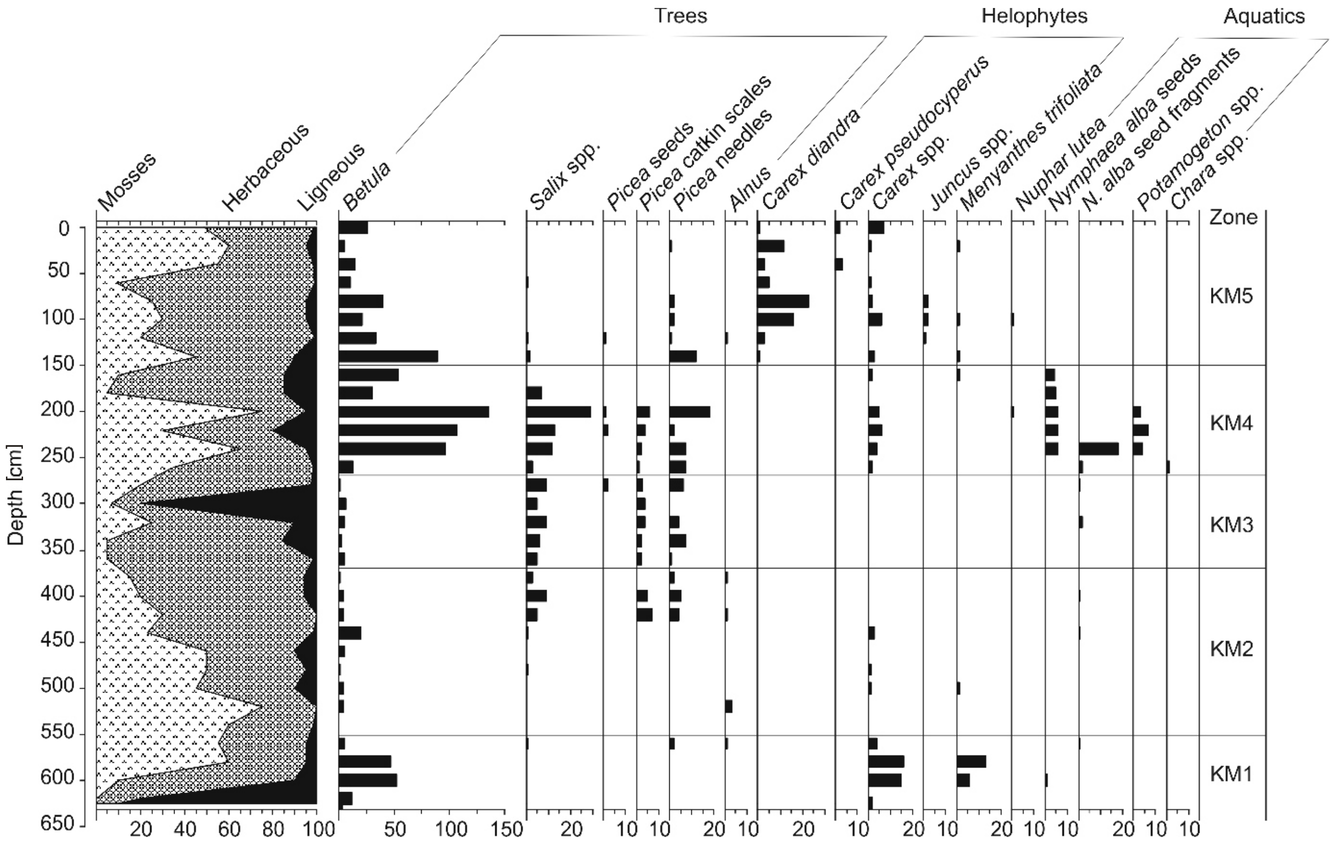

Fig. 5. Distribution of macrofossils in the L. Ķūži sediment core

The fractions of sediment types are given in percentages, macrofossils as the number of seeds per 100 cm^3 of the sediment

the beginning of the zone suggest that this most probably represents only scattered trees. Since 8000 BP the frequency of *Picea* pollen continuously increased. At the same time the percentage of *Pinus* remained low (less than 20%). By the end of LPAZ K-2 pollen of *Quercus* and *Tilia* began to increase. A few birch and alder seeds and individual *Carex* and *Menyanthes trifoliata* seeds were found from the macrofossils in zone KM2. The fraction of moss remains varied from 70 up to 15% (Fig. 5).

In LPAZ K-3 (6500–2500 BP; 374–250 cm) the content of *Picea* pollen reach a first maximum of 40%. The frequencies of *Betula* and *Alnus* are around 20%. *Tilia* had the maximum values at the beginning of the zone. By the end of the zone the amount of the pollen of *Quercetum mixtum* was steadily decreasing. Only macrofossils originating from trees and individual fragments of *Nymphaea alba* seeds were found in the sediments of zone KM3 (Fig. 5). The lithology of this LPAZ K-3, detritus gyttja with interlayers of well-decomposed peat and sandy peat and some pieces of wood remains, indicates a changeable sedimentary regime. The presence of spruce needles indicates that a spruce forest was growing around the lake with some birch, willow and alder trees near the shoreline. Around 2200 BP, at a depth of 250 cm, a short-term decrease in *Picea* pollen with a simultaneous increase in *Betula* pollen occurred. The increase in Poaceae pollen and Polypodiaceae spores suggests that there were changes in water level.

Zone LPAZ K-4 (2500–700 BP; 249–160 cm) is characterized by a maximum of *Picea* pollen (up to 70%). *Betula* and *Alnus* pollen frequencies were around 10–20%. A slight increase occurred in *Pinus* pollen content (up to 20%). The seeds and catkin scales of *Betula* were present in the highest values of up to 150 per 100 cm^3 of the sample in zone KM4 (Fig. 5). The number of the remains of other trees such as needles and seeds of *Salix* and *Picea* was high. For the first time the seeds of aquatic plants such as *Nymphaea alba*, *Potamogeton* spp. and individual *Chara* oospores appeared in these layers.

Zone LPAZ K-5 (700–0 BP; 159–0 cm) is characterized by a very sharp decrease in *Picea* pollen and an increase in *Betula*, *Pinus* and *Alnus* pollen. The former lake shore receded and the area around the lake became covered with fen peat where *Carex diandra* and other *Carex* species grew, as indicated by macrofossil data (Fig. 5).

DISCUSSION

The changeable lithology, sharp variations in the OM content and in the sedimentary accumulation rate in the L. Ķūži show that marked fluctuations of lake level and alternation of regressive-transgressive phases of the lake took place during the Holocene. The well-sorted fine-grained silty sands in the basal layers accumulated most probably in the ice-dammed lake that formed on the Vidzeme Heights during the Late Glacial. The woody peat rich in wood remains, lying on sands at depths of 627–625 cm, is dated to 9810 BP and indicates a relatively low water level at the beginning of the Holocene. This early postglacial regression was brief as from a depth of 610 cm (from *ca*. 9500 BP) upwards well-decomposed peat and further gyttja with sand and woody peat interlayers accumulated. Such lithologies suggest a continuous water level rise, which was frequently interrupted by short-term periods of water level lowering. The water level fluctuations are also vividly recorded in the OM values (Fig. 2). The decrease of OM values from a depth of 590 cm upwards is at first drastic and then rather smooth up to minimum values in layers from 400 up to 270 cm (accumulated since 7000 BP to 3500 BP). From that level onwards the organic matter content again starts to increase. The sediments of lowest organic matter content consist of homogeneous gyttja rich in mineral matter with scarce plant remains. Such sediments are characteristic of the deep and near-shore water environment. The upper contact between gyttja and well-decomposed fen peat at a depth of 150 cm is sharp and is characterized by a rapid increase in the OM content up to 95%.

Comparison of water level changes in L. Ķūži with the data obtained in our earlier studies on the botanical composition records in the Vällamäe kettle-hole in the Haanja Heights (Punning *et al*., 1995) and, with the lithology and geochemistry of sediments in the transect through Lake Juusa in the Otepää Heights (Punning *et al*., 2005) gives a possibility of estimating regional and local specific features of the hydrological balances of the lakes studied. It seems that a high water level dominated in all the lakes studied at the beginning of the Holocene somewhat before and around 10 000 BP. After that a rapid water level fall took place in L. Ķūži, but in the Vällamäe kettle-hole and especially in L. Juusa the water level was relatively high throughout the Early Holocene, at least up to 8200 BP. Then in L. Juusa a clearly represented regression followed and the water level was relatively low up to 6000 BP. Contrasting trends are recorded in the sediments of L. Ķūži and Vällamäe. During that time gyttja of low OM content accumulated in L. Ķūži and the presence of *Warnstorfia fluitans* in the Vällamäe kettle-hole indicates a high water level (Punning *et al*., 1995).

From 6000 BP a water level rise is recorded in all the profiles studied. The lithological composition of the sediments indicates that this process was not uniform; the amplitudes of fluctuations differed and were even at times opposite in phase. So in the Vällamäe peat profile the yellow interlayers indicate some water level rise about 3800, 2200, 1600 and 700 years ago (Punning *et al*., 1995). In L. Juusa the water level rose 4000 BP followed by a regression at 3200 BP (Punning *et al*., 2005) and in L. Ķūži the water level fluctuated around its maximum level from 7000 BP up to 3500 BP. A common feature of all the sites studied is the relative lowering of the water level since about 1000 BP.

Thus the lithological composition of the sequence studied clearly reflects two terrestrial periods (first from *ca*. 10 000 BP up to 9500 BP and then from 700 BP up to the present) when the water level was below or around the sediment surface and a lacustrine period between them when the water level was mainly above it. This conclusion is also supported by the pollen data (Fig. 4): the content of herb pollen is considerably higher in layers accumulated in the Early and Late Holocene.

The reconstructed variations in the changes of the sedimentation environment set additional constraints on the stratigraphical resolution and adequacy between pollen spectra and vegetation on the catchment. Therefore we provide characterization of pollen diagrams for comparison of the Ķūži site with the Vällamäe (Punning *et al*., 1995) and Tuuljärv (Ilves and Mäemets, 1987) sites within the Haanja Heights (Fig. 1A) on the basis of the ^{14}C data (Table 3). Lake Tuuljärv was chosen as it is approximately of the same size (3.6 ha) as L. Ķūži, and the core for palynological analyses was taken from the quagmire area. The sedimentary regime should therefore be comparable with that of L. Ķūži.

In sediments that accumulated in the reference sites on the Haanja Heights during the Early Holocene, *Pinus* and *Betula* pollen dominated (Table 3). On the Vidzeme Heights, Holocene woodland development started with scattered birch woods with individual pine trees. Most characteristic of the pollen diagram of L. Ķūži is a clear signs of *Picea* appearing already from 9000 BP (*ca*. 1000 years before its appearance in the Vällamäe section) and its continuously high proportion up to the Late Holocene. This difference in the distribution of spruce in pollen diagrams from the Haanja and Vidzeme heights might partly be explained by the characteristics of spruce pollen grains. These may be overrepresented in pollen spectra during the lacustrine phase of sedimentation in Ķūži site due to their saccate structure. This might also be one of the reasons why the content of *Picea* pollen reaches such high values (up to 70% of AP) in the lacustrine sediments and decreases rapidly in the fen peat layers. However, it should be mentioned here that at present the proportion of spruce-dominated forests in the Vidzeme Heights is around 50% while in the uppermost sample from the peat in the Ķūži site it is around 20%.

The successive immigration of the shade-tolerant and competitive broad-leaved forest trees — *Alnus, Ulmus* and *Corylus* — began in the area of L. Ķūži about at 9000 BP (Fig. 4). The change in the pollen assemblage suggests warming as well as increased precipitation accompanied by a rise in the water level. Earlier expansion of *Alnus* was also noticed in L. Tuuljärv (Ilves and Mäemets, 1987). In Poland the wide distribution of *Alnus* is dated to 8500–8000 BP (Ralska-Jasiewiczowa, 2006) and such a broad spread of moist woodland most probably suggests a period of greater rise of water levels. Simultaneously with an increase in the pollen of thermophilous trees a significant decline in *Betula* pollen is seen in the L. Ķūži diagram. In this diagram a modest (*ca*. 15–20% of AP) and almost constant content of *Pinus* pollen throughout the Holocene is common. By contrast in the sites from the Haanja Heights *Picea* pollen appears much later and its frequencies are highly variable. In L. Ķūži *Picea* pollen is dominant among the tree pollen (55–70%) in deposits accumulated from 4500 up to 700 BP. A short-term *Picea* pollen decline at *ca*. 2300 BP concurred with an increase in *Betula* and *Alnus* pollen. The lowering of the lake level and a change in the pollen source area might have caused this. The Vällamäe and Tuuljärv sites also demonstrate a boundary around 2500 BP but with an increase in *Betula* and *Pinus* and a reduction in *Alnus*. *Picea* is most variable having maximum values in

Table 3

Characterization and comparison of PAZ-s from Ķūži (Vidzeme Height), Vällamäe and Tuuljärv (Haanja Height) sites

Age, ^{14}C yrs BP	Ķūži	Characterization	Vällamäe III (Punning *et al.*, 1995)	Characterization	Tuuljärv (Ilves and Mäemets, 1987)	Characterization
0, 500, 1000	K-5 Pi-Be-NAP	Increase of *Pinus*, *Betula* and NAP. Regular record of *Secale*. Reduction of *Picea*.	V-III-3 Pc	Increase of *Betula* and *Pinus*. Regular records of *Secale*. Reduction of *Picea* and *QM*.	SA	Increase of *Betula* and *Pinus*. Maximum of *Picea*. Sharp decrease of *Alnus* and *QM*. Regular records of *Secale*.
1500, 2000, 2500	K-4 Pc	Maximum of *Picea*. Sharp decrease of *Alnus*. Reduction of *QM*.	V-III-2 Pc-Al-Co	Maximum of *Picea*. High share of *Alnus*, *Corylus* and *Ulmus*. Slight decrease of *Tilia*..	SB	High share of *Alnus*, *Corylus* and *Tilia*. Increase of *Picea* and *Quercus*. Low share of *Pinus*.
3000, 3500, 4000, 4500, 5000, 5500, 6000, 6500	K-3 Pc-Al-Ti-Q	First maximum of *Picea*. High share of *Alnus*. Maximum of *Tilia* and *Quercus*.			AT	High share of *Alnus*, *Corylus*, *Ulmus* and *Betula*. Appearance of *Tilia*. Reduction of *Pinus*.
7000, 7500, 8000, 8500, 9000	K-2 Al-Co-Ul	High share of *Alnus*, *Corylus* and *Ulmus*. Increase of *Picea*. Sharp reduction of *Betula*.	V-III-1 Pi-Be-Co-Ul	High share of *Pinus* and *Betula*. Increase of *Picea*, *Tilia*, *Corylus*, *Ulmus* and *Alnus*.	BO, PB	High share of *Pinus* and *Betula*. Appearance of *Ulmus*, *Quercus* and *Picea*.
9500, 10000	K-1 Be-NAP	High share of *Betula* and Poaceae.				

L. Ķūži at around 1000 BP, in Tuuljärv at 500 BP and in Vällamäe at 1500 BP (Table 3).

Comparative analysis of the pollen diagrams of the cores from L. Ķūži, the Vällamäe kettle-hole and L. Tuuljärv in the Haanja Heights (Table 3) indicates consistency in pollen composition. The main difference is that *Picea* pollen appears temporally earlier and is dominant in the deposits accumulated during the period of a high lake level. It is a clear evidence that spruce forests together with mixed pine-spruce forests dominated on the higher hills near the western and eastern slopes around L. Ķūži.

Sharp changes in the pollen composition during the last thousand years reflect changes in pollen transport and accumulation pathways. In the pollen diagram the content of *Alnus, Betula* and *Pinus* pollen increases together with herb pollen. These taxa grow in the nearest surroundings of the site studied on the northwestern paludified area of L. Ķūži and have played a dominant role due to the decrease of the water level.

Comparison of the L. Ķūži pollen diagram with the pollen diagrams from the mire sediments from the Vällamäe kettle-hole and L. Tuuljärv in the Haanja Heights demonstrates that the difference is not larger than the difference between the reference sites themselves. The most distinctive biostratigraphic units on a regional scale are the changes in the Early and Late Holocene. Frequent fluctuations in water level at the site studied in the Middle Holocene had marked impact on the composition of the pollen spectra and therefore the respective part of the pollen diagram only weakly reflects the changes in forest composition.

CONCLUSIONS

Results of comprehensive palaeoenvironmental studies of a sediment core from the shore of L. Ķūži have revealed significant changes in the hydrological regime on the northwestern area of the Vidzeme Heights during the Holocene. The lithological composition of the sequence studied clearly reflects two periods (first from *ca*. 10 000 BP up to 9500 BP and the second from 700 BP up to the present) when the water level was below or around the sediment surface, and a lacustrine period between them when the water level was mainly above the sediment surface. This conclusion is also supported by the pollen data: the content of herb pollen is considerably higher in the layers that accumulated in the Early and Late Holocene. These variations in the sedimentary environment set additional constraints to the stratigraphical resolution and the degree to which pollen spectra may be interpreted in terms of vegetation on the catchment.

The Holocene pioneer vegetation in the area studied consisted mainly of birch with some pine trees. The main difference between the composition of the L. Ķūži pollen diagram and those from of the Haanja Heights situated to the north-east (Vällamäe and Tuuljärv sites), which have been more thoroughly studied, is the early appearance of *Picea* pollen at 9000 BP and its dominance up to 700 BP. As to the composition of the remaining taxa, the L. Ķūži diagram is rather similar to the pollen diagrams from the Haanja Heights, showing similarity of vegetation history in the central part of the Luga–Haanja–North-Lithuania ice-marginal zone.

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