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The Late Glacial and Early Holocene environmental history of shallow lakes in Estonia, revealed from subfossil ostracod data

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The Late Glacial and Early Holocene shallow lake history in Estonia is documented from the freshwater ostracod subfossil record. Three cores studied consist of Late Glacial and Holocene sediments: gyttja, calcareous mud and peat, with ostracod subfossils being well preserved in the calcareous mud. 18 freshwater ostracod species were recorded in the cores: the most common species are *Metacypris cordata*, *Limnocythere inopinata*, *Cyclocypris ovum*, *Cypridopsis vidua*, and *Candona candida*. Changes in the ostracod succession of the lakes can be interpreted in the context of environmental changes that were not contemporaneous but were related to the evolution of particular water bodies. *Darwinula stevensoni* and *Metacypris cordata* do not appear together in the Late Glacial and Early Holocene lacustrine sediment records of Estonia. *M. cordata* appears as the water body evolves or by lowering of the water level. The appearance of *Scottia pseudobrowniana* in the sediments refers to the stage of an overgrown lacustrine system. *M. cordata* appeared in southeastern Estonia at the end of the Late Glacial (~12 800 cal. BP), when the calcareous mud started to form. The earliest subfossil record of *M. cordata* from southwestern Estonia is from the Early Holocene.

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Key words: Estonia, Late Glacial, Early Holocene, ostracods, shallow lakes.

INTRODUCTION

Ostracods, well-known aquatic meiobenthic bivalved crustaceans, are widespread in all types of water bodies: lakes, ponds, streams, rivers, seas and oceans. The occurrence of ostracods in marine and nonmarine environments is controlled by a wide range of factors. In nonmarine environments, water depth, turbulence (energy level), size and hydrological regime of a water body, water temperature, concentration of dissolved oxygen and water chemistry are the principal factors controlling the assemblage structure and the population size of a particular species.

Ostracods may effectively serve as palaeoecological indicators of freshwater habitats. This is particularly true for lacustrine environments with a well-preserved sedimentary record (Holmes and Horne, 1999). Ostracod valves, 0.50–2.00 mm in size on average, are often well preserved in Quaternary deposits (Griffith and Holmes, 2000). For about thirty years, the distribution of subfossil ostracods in lacustrine environments has been an important component of palaeoecological observations (Löffler, 1997), with studies carried out world wide, (e.g., Griffith and Evans, 1995; Scharf, 1998; Krzymińska and Przeździecki, 2001). The ostracod record may shed light on the evolution of lakes, as regards changes in the trophic parameters, water level and temperature, and the development of the aquatic vegetation. Interpretation of the ostracod record is based on the well-known ecological preferences of recent species, which may be recorded in a subfossil state in lacustrine sediment cores. Species such as *Cytherissa lacustris* (known as an indicator of oligo- to mesotrophic lakes), *Metacypris cordata* (an indicator of high trophic status of a lake), *Cypridopsis vidua* (a phytophilic species) are particularly common in lacustrine sediment cores. Documentation of the distribution of these listed and other taxa can also be interpreted in the context of evolution of regional climate. Today, many palaeolimnological and palaeoenvironmental studies are based on the interpretation of changes in the ostracod fauna in lacustrine successions (e.g., Namiotko, 1998; Scharf, 1998; Belis *et al*., 1999).

In Estonia, recent ostracod faunas in freshwater bodies and in the brackish eastern Baltic Sea are relatively well documented. Altogether 73 freshwater, 12 marine and 7 brackish water ostracod species are recognized in the area (Järvekülg, 1995) and some data on their ecology can be found in Järvekülg (1959, 1961).

Compared to the data on recent faunas, the ostracod record from Holocene deposits is remarkably poor. The only available data comes from Lake Peipsi (Niinemets, 1999), the fourth biggest lake in Europe, which is the subject of several monographic papers (Miidel and Raukas, 1999; Pihu and Haberman, 2001; Nõges, 2001). Although the subfossil ostracod record from Lake Peipsi shows low diversity (only eight species have been identified in total), changes in the ostracod assemblage structure can still be interpreted in the context of water level and temperature changes (Hang *et al*., 2001).

The data from Lake Peipsi are difficult to compare with the new evidence from smaller water bodies in Estonia. In smaller lakes, the ostracod assemblages appear to be more variable. This material could potentially be better interpreted in a palaeoecological context, but its potential has not been exploited up to now. The present study aims to analyse the shallow lake history using data on ostracod distribution in the Late Glacial and Holocene deposits of two lakes in Eastern Estonia and one lake in southwestern Estonia.

GEOLOGIC HISTORY OF THE LAKES STUDIED

Material of the present study comes from three sites: Lake Elistvere in the Saadjärve Drumlin Field, Laeva Bog (formerly the area of Lake Big Võtrtsjärv) in Eastern Estonia and Lake Ermistu in south-western Estonia (Fig.1).

The Quaternary glacial deposits overlie early to middle Palaeozoic rocks in Estonia, being mostly deposited on Ordovician and Silurian limestones or on Middle Devonian sandstones. The glacial activities are responsible for the undulating bedrock topography under a Quaternary cover with an average thickness of about 20 m (Pirrus, 2001). The postglacial sediments in Estonia are partly redeposited, comprising of marine and dune sands but also riverine deposits. In addition, calcareous mud, gyttja and peat are also typical of the local Holocene (Pirrus, 2001).

About 1500 lakes in Estonia are smaller than 10 km^2 and are termed “the small lakes” (Mäemets and Saarse, 1995). Lakes in the Saadjärve Drumlin Field are of glacial origin. They have an elongated shape, pointing in the NW–SE direction of ice movement, and their basins are partly filled with Late Glacial sand and silt. The glacial deposits are overlain by postglacial organic and calcareous deposits storing information on vegetation history and climate change (Saarse, 1997).

Because of infilling and overgrowth, the number and area of lakes are generally decreasing. However, new water bodies become isolated from the Baltic Sea because of crustal uplift in western and northwestern Estonia. The development of the residual coastal lakes in northwestern and western Estonia began at the end of the Late Glacial, after the area had emerged from the Baltic Ice Lake, and is still in progress. The basal glacial and glaciolacustrine deposits in the lake depressions are covered by clayey lacustrine sediments, calcareous mud and gyttja (Saarse, 1997).

The highly eutrophic Lake Võtrtsjärv is the second largest lake in Estonia (Fig.1) with an area of nearly 270 km^2; average and maximum depths are 2.8 and 6 m, respectively, and the water level is at 30 m a.s.l. (Järvet *et al*., 2004). Lake Võtrtsjärv derives nutrients and water via the four main rivers from the catchment areas; the pH of the water varies between 7.5 and 8.6 (Tuvikene *et al*., 2004). The Võtrtsjärv depression is of pre-Quaternary origin and has later been reshaped by glaciers. In the Early Holocene, the westward outflow was reduced due to crustal uplift giving birth to a transgressive basin termed the Big Võtrtsjärv (Moora *et al*., 2002). At ~8340 cal. BP the outflow to the west terminated and the eastward connection opened, causing a continuous lowering of the lake level until it acquired its present outline. The bottom sediments of Lake Võtrtsjärv consist mainly of fine-grained sand and silt, gyttja and calcareous mud (Moora *et al*., 2002).

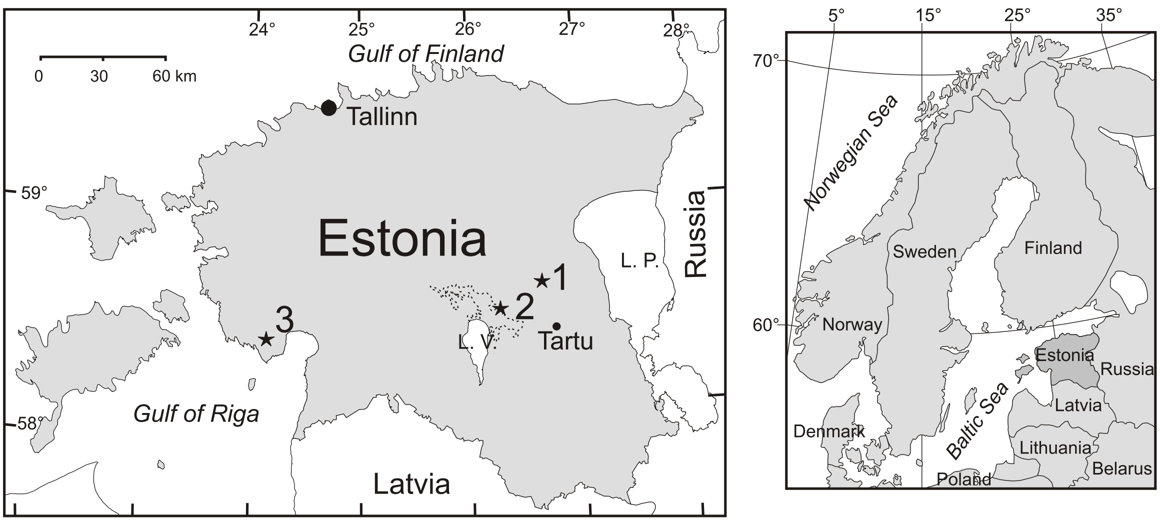

Fig. 1. Location of the study sites

1 — Elistvere, 2 — Pedja, 3 — Ermistu; lakes: L. V. — L. Võtrtsjärv, L. P. — L. Peipsi; dotted line shows the extent of Lake Big Võtrtsjärv in the Early Holocene (after Moora and Raukas, 2004)

DESCRIPTION OF THE SECTIONS STUDIED AND THE CORES OBTAINED

The eutrophic Lake Elistvere (18.3 km^2, maximum depth 3.50 m, average depth 1.95 m, and 50 m a.s.l.) is located in the Saadjärve Drumlin Field. The alkaline (pH 8.4) lake is fed by rivers, ditches and some bottom springs in its northeastern part (Mäemets, 1977). The Holocene sediments in this lake are mostly represented by calcareous mud. In the overgrown part of the lake, the Holocene sediments overlie terrigenous Late Glacial deposits (Pirrus, 1983).

The Elistvere drill core (58°35'12''N, 26°40'54''E) (Fig. 1) was taken in the northern part of the Lake Elistvere basin, in a wetland area about 350 m north-west of the coastline of lake. The clayey and organic-rich silt is overlain by a thin layer of greenish gyttja (interval 325–321 cm), (Fig. 2) covered by calcareous mud with a thickness of 82 cm (321–239 cm). The lower part of the latter unit has a pinkish tinge and is detritus-poor; the upper part (289–239 cm) is of greenish-grey colour and is detritus-rich. The upper part (239 cm) of the profile is formed by dark brown moderately decomposed peat with macrophyte remains.

The Pedja drill core of (58°30'22''N, 26°16'2''E) (Fig. 1) was taken from Laeva bog in the Võtrtsjärv Lowland. The interval studied of the Lake Võtrtsjärv deposits was 550–750 cm. The deepest 16 cm of the profile comprises dark grey homogenous sand (Fig. 2) overlain by grey silt devoid of organic matter (734–730 cm). A thin layer of dark brown calcareous mud (730–726 cm) formed above the silt is overlain by a light-coloured beige calcareous mud unit (726–583 cm interval). In the upper part the latter unit contains macrophyte remains and fine organic flakes, and also fragmented mollusc shells. The upper, main part of the section comprises dark brown moderately decomposed peat.

The mesotrophic Lake Ermistu (4.8 km^2, maximum depth 2.9 m, average depth 1.3 m, and 17 m a.s.l.) is located in a north-south oriented bedrock depression between the megadrumlins in the southwestern part of the Estonian mainland. The lake is surrounded by mires on all sides, except from the east. The coastal deposits of Ancylus Lake and the Littorina Sea are developed south of the modern lake. Lake Ermistu is overgrown with a

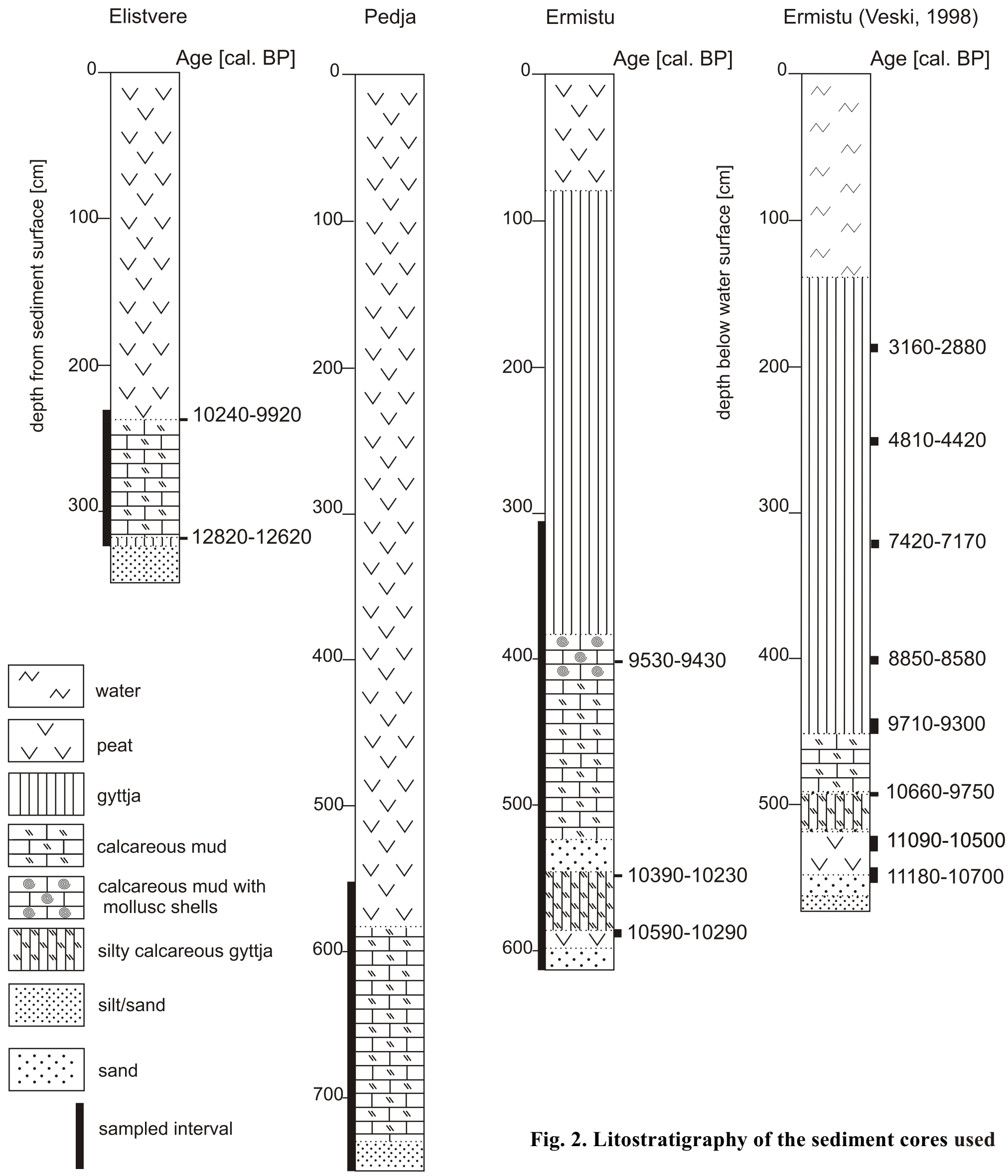

Fig. 2. Litostratigraphy of the sediment cores used

floating mat of vegetation in its western part. The bottom sediments of the lake are mainly represented by gyttja (Veski, 1998). Inflow to the lake comes from some small springs, from the bog and from some bottom springs (Mäemets, 1977).

The Ermistu drill core (58°21'18''N, 23°58'45''E) (Fig. 1) was taken from the southern shore of Lake Ermistu. The deepest part of the section studied consists of sand which is overlain by dark brown peat (598–588 cm interval; Fig. 2). The peat was considered as being of Early Holocene age by Veski (1998), as it apparently indicates a considerable lowering of water level. The dark brown silty calcareous gyttja unit lies over the peat (interval 588–546 cm). A layer of grey sand (at 546–523 cm) on the silty gyttja interval probably reflects a short-time rise of water level in the Early Holocene (Veski, 1998). The sand is overlain by calcareous mud. In the 523–418 cm interval, the calcareous mud contains macrophyte remains. The 418–384 cm interval is represented by coarse detrital calcareous mud, with bivalve and gastropod shells. The dark greenish-brown gyttja (304 cm thick) lies over the coarse calcareous mud. The upper 80 cm of the section is composed of peat (Fig. 2).

METHODS

The drilling was performed with a Russian-type corer and sampling was made on lake shores and bogs. The sampled intervals of the drill cores were sliced every 2 cm and distilled water was poured on the samples. The samples (~5 cm^3 in size) were soaked for a few weeks and then sieved with tap water through a 50 μm sieve. The sieved samples were dried at room temperature and studied under a low-power binocular microscope. Ostracod shells and valves were picked with a fine wet brush. Selected specimens were figured under the scanning electron microscope (SEM) at the Centre of Material Research at Tallinn University of Technology, Estonia and at the Natural History Museum, London, UK. SEM images of ostracods are represented in Figures 4 and 5. 18 ostracod species were identified altogether whereas the specimens identified as Candonidae spp. are probably juveniles and may belong to several species. For the ostracod assemblage diversity the Shannon-Wiener diversity index H´ (Hammer and Harper, 2006 for details) was calculated (Fig. 3).

Two samples from Lake Elistvere and four samples from Lake Ermistu were dated by means of ^{14}C radiocarbon accelerator mass spectrometry (AMS) in the Poznań Radiocarbon Laboratory, Poland. The OxCal v3.10 programme (Bronk Ramsey, 1995, 2001) was used for the calibration. Table 1 lists the AMS ^{14}C datings; in Lake Elistvere the ages are in agreement with the stratigraphic order of the samples, while deposition of the calcareous mud started earlier than stated by Pirrus (1983) according to the pollen and radiocarbon datings. The AMS ^{14}C dates from Lake Ermistu are generally in a good agreement with these of Veski (1998), except for one date (8700–8460 cal. BP) which clearly "falls out" of the row and was therefore excluded. The summary of our investigation and of previous dating (Veski, 1998) suggests that the paludal period ended around 10 500 cal. BP. The transgression (marked by a sand layer on the silty calcareous gyttja in both sections) is dated at about 10 250 cal. BP. The accumulation of gyttja started ~9500 cal. BP. The chronology of the Pedja section used herein is based on pollen data and age constraints from Orviku (1973) and Moora *et al*. (2002).

RESULTS

Subfossil ostracods are well preserved in calcareous mud; in the pure gyttja the fossil material is rare, probably due to the influence of aggressive pore water in the organic sediments. Altogether 5864 subfossil ostracod specimens were collected and attributed to 18 ostracod species (Table 2). Palaeoenvironmental reconstructions of lake histories are based on the ecological preferences of the species, as summarized by Meisch (2000).

The Elistvere section yielded 9 ostracod species (Fig. 3A). The dominant species is *Metacypris cordata* (Fig. 4N, O), while *C. ovum* (Fig. 4L, M) and *C. vidua* (Fig. 4A, B) are common. The subfossil ostracod material is well preserved, both shells and valves of juvenile and adult specimens occurring. The ostracods were recorded from the calcareous mud. In the gyttja-calcareous mud transition beds, ostracods are rare, while higher up the diversity increases rapidly. Throughout the fossiliferous calcareous mud unit, the relative abundance of *M. cordata* gradually increases, whilst the diversity of the assemblages decreases in the upper part of the unit.

The Pedja section showed 12 freshwater ostracod species in total (Fig. 3B). The ostracods occur in the interval from the topmost part of the silt and sand up to the base of the peat unit. In the lower part of the calcareous mud unit (the interval of 730–720 cm), *C. ovum*, *C. vidua, L. inopinata* (Fig. 4J, K) and *C. candida* (Fig. 5B–D) are dominant, but this interval also contains *Darwinula stevensoni* (Fig. 5K) and *Herpetocypris reptans* (Fig. 5R). Higher up, *D. stevensoni* and *H. reptans* disappear and the next unit (690–720 cm) shows low ostracod abundances whereas *C. vidua* is more common. Higher up, a gradual increase in the abundance of *M. cordata* was recognized and the species becomes dominant in the assemblage. In the topmost part of the fossiliferous interval, *M. cordat*a is accompanied by *Scottia pseudobrowniana* (Fig. 5O–Q).

The Ermistu section was taken from Western Estonia. The profile investigated yielded 12 ostracod species in the calcareous mud and silty calcareous gyttja (Fig. 3C). Ostracods were lacking in several samples of the calcareous mud and the *M. cordata* specimens were poorly preserved in the ostracod-containing samples. In the lowermost part of the fossiliferous interval, rare specimens of *Fabaeformiscandona holzkampfi* (Fig. 5E–I), *Ilyocypris* cf. *bradyi* (Fig. 4E–H) and juveniles of Candonidae spp. (Fig. 4R) were recorded. The upper part of the silty calcareous mud interval shows a dominance of *D. stevensoni*. This unit is overlain by a sand interbed, interpreted as evidence of a transgression (Veski, 1998). Uniquely for this section, *Limnocytherina sanctipatricii* (Fig. 4I) was recorded in this terrigenous layer. Upwards, the assemblage is dominated by *M. cordata,* with its relative abundance increasing upwards in the section again. In the depth interval 470–460 cm *M. cordata* is accompanied by *Pseudocandona sucki* (Fig. 5L–N), and *Candona neglecta* (Fig. 5A). In the middle part of the calcareous mud unit most of the valves recorded are attributed to *M. cordata.* The depth interval 384–418 cm reveals a concentration of shells of bivalves and gastropods, but no ostracod remains.

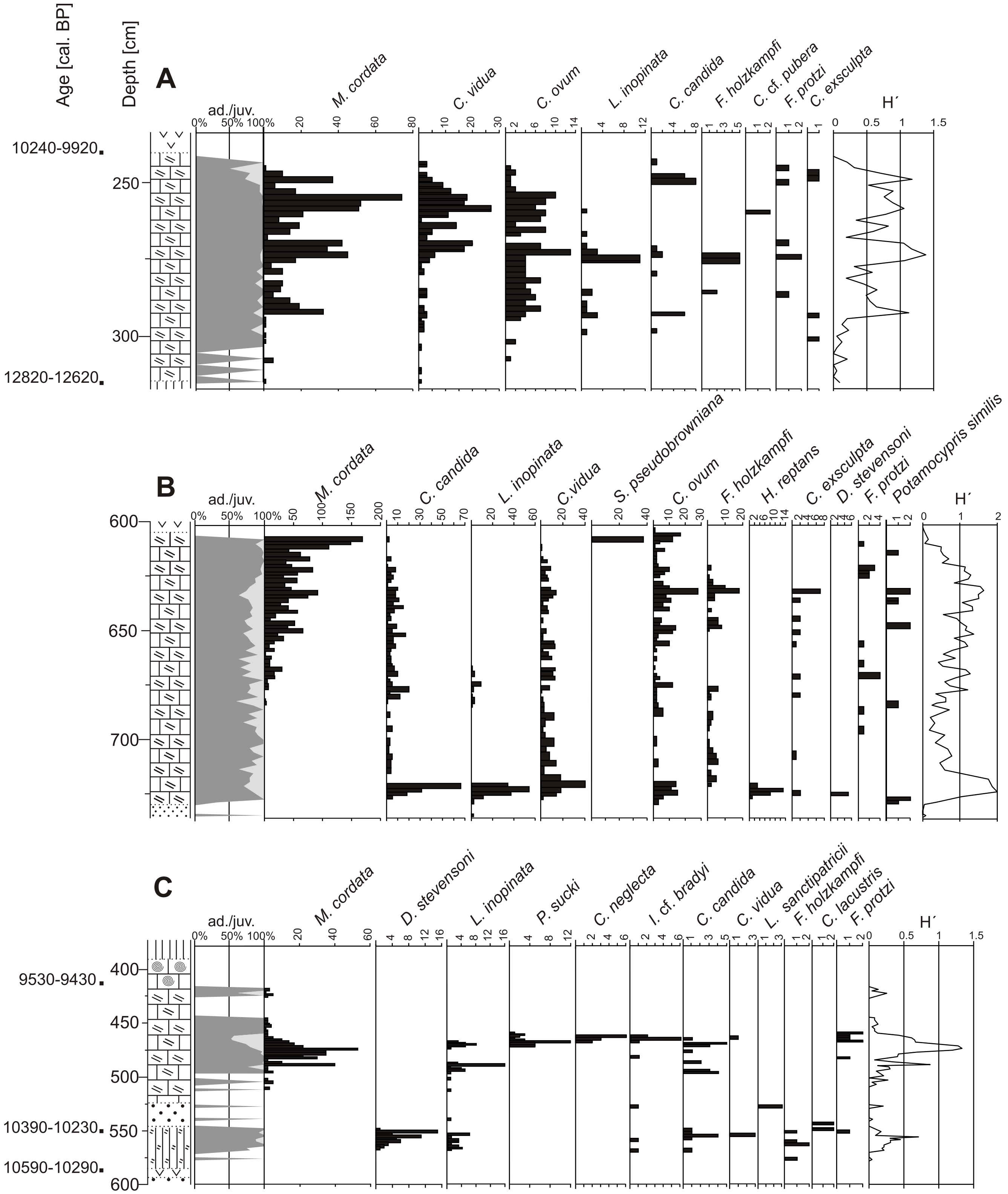

Fig. 3. Chronology, stratigraphic log, ostracod adult/juvenile ratios (ad/juv — dark grey adult/light grey juvenile), distribution and number of specimens (in ~5 cm³ of wet sediment), diversity index (H`) in the cores studied

A — Elistvere, **B** — Pedja, **C** — Ermistu; for explanations see Figure 2

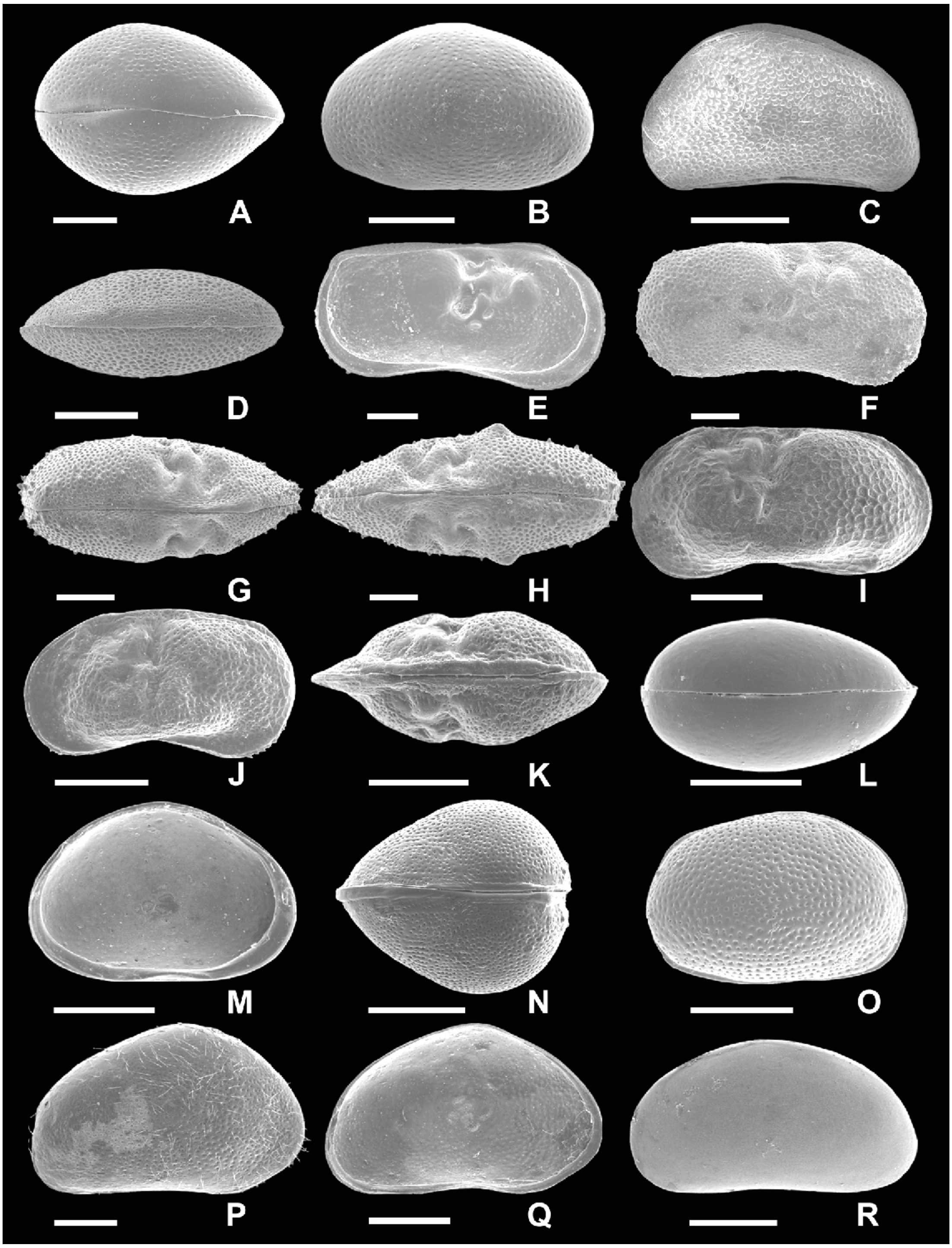

Fig. 4. Subfossil ostracods from the material studied (scale 0.2 mm)

A — *Cypridopsis vidua*, carapace, dorsal view; **B** — *Cypridopsis vidua*, left valve, external view; **C** — *Potamocypris similis*, carapace, lateral view; **D** — *Potamocypris similis*, carapace, dorsal view; **E** — *Ilyocypris* cf. *bradyi*, left valve, internal view; **F** — *Ilyocypris* cf. *bradyi*, right valve, external view; **G** — *Ilyocypris* cf. *bradyi*; carapace, dorsal view; **H** — *Ilyocypris* cf. *bradyi*, carapace, dorsal view; **I** — *Limnocytherina sanctipatricii*, left valve, external view; **J** — *Limnocythere inopinata*, left valve, external view; **K** — *Limnocythere inopinata*, carapace, dorsal view; **L** — *Cyclocypris ovum*, carapace, dorsal view; **M** — *Cyclocypris ovum*, left valve, internal view; **N** — *Metacypris cordata,* carapace, dorsal view, female; **O** — *Metacypris cordata,* carapace, left valve, external view; **P** — Cypris cf. *pubera*, left valve, external view; **Q** — *Cypris* cf. *pubera*, right valve, internal view; **R** — Candonidae spp., right valve, external view

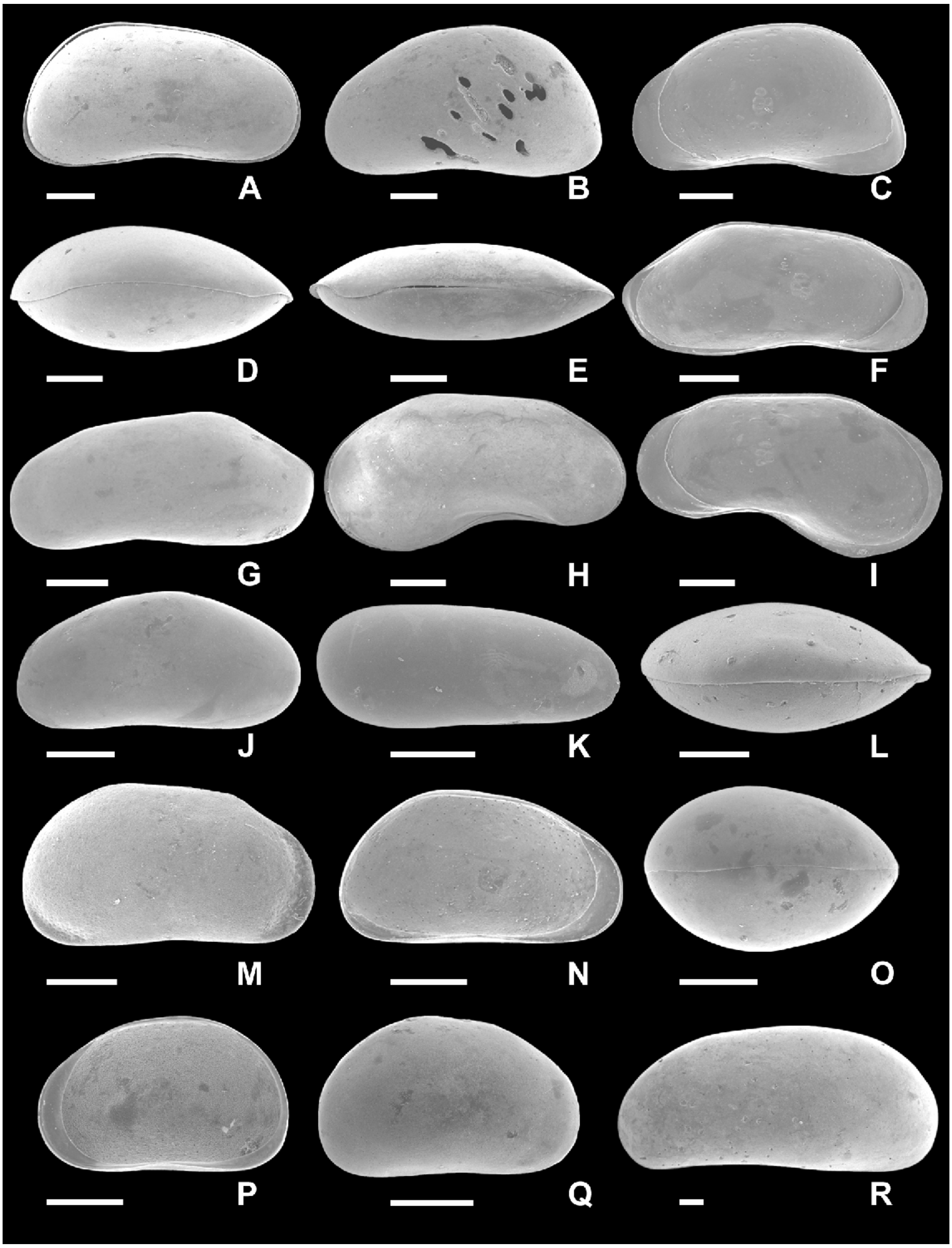

Fig. 5. Subfossil ostracods from the material studied (scale 0.2 mm)

A — *Candona neglecta*, carapace, lateral view; **B** — *Candonda candida*, left valve, external view; **C** — *Candonda candida*, right valve, internal view; **D** — *Candonda candida*, carapace, dorsal view; **E** — *Fabaeformiscandona holzkampfi,* carapace, dorsal view, female; **F** — *Fabaeformiscandona holzkampfi*, left valve, internal view, female; **G** — *Fabaeformiscandona holzkampfi*, left valve, external view, female; **H** — *Fabaeformiscandona holzkampfi*, carapace, lateral view, male; **I** — *Fabaeformiscandona holzkampfi*, right valve, internal view; **J** — *Fabaeformiscandona protzi*, left valve, external view; **K** — *Darwinula stevensoni*, right valve, external view; **L** — *Pseudocandona sucki*, carapace, dorsal view; **M** — *Pseudocandona sucki*, right valve, external view; **N** — *Pseudocandona sucki*, left valve, internal view; **O** — *Scottia pseudobrowniana*, carapace dorsal view; **P** — *Scottia pseudobrowniana*, right valve, internal view; **Q** — *Scottia pseudobrowniana*, right valve, external view; **R** — *Herpetocypris reptans*, left valve, external view

Table 1

AMS ^{14}C dates from Lake Elistvere and Lake Ermistu

Depth [cm] on sediment core	Dated material	$\delta^{13}C$ [‰]	^{14}C AMS age BP	Lab. no.	Cal. BP, 1σ
Lake Elistvere					
239	peat	–29.80	9000 ±50	Poz-24222	10240–9920
321	gyttja	–13.00	10690 ±60	Poz-24262	12820–12620
Lake Ermistu					
407	organics from calc. mud	–27.80	8490 ±50	Poz-24232	9530–9430
520	organics from calc. mud	–28.30	7840 ±50	Poz-24231	8700–8460
549	gyttja	–29.80	9160 ±50	Poz-24223	10390–10230
588	peat	–19.60	9310 ±50	Poz-24224	10590–10290

Calibrated using OxCal v3.10

In the Ermistu, Elistvere and Pedja sections the numerically dominant ostracod species is *M. cordata*. *D. stevensoni* seems to be confined to the lower parts of the sections (Pedja, Ermistu). None of the profiles studied shows *D. stevensoni* co-existing with *M. cordata*.

The Elistvere AMS ^{14}C ages show that the calcareous mud started to accumulate at ~12 800 cal. BP, at the end of the Late Glacial, and lasted until ~10 200 cal. BP in the Early Holocene. The estimated accumulation rate of the calcareous mud in Lake Elistvere was ~0.32 mm per year. In Lake Ermistu calcareous sedimentation took place from ~10 500 cal. BP until ~9 500; the average accumulation rate in the Early Holocene was ~1.54 mm per year.

OSTRACOD EVIDENCE IN LAKE HISTORY

The overall ostracod composition in the Holocene deposits of Estonia is generally similar to the Central European Holocene ostracod fauna (e.g., Absolon, 1973; Günther, 1986; Scharf, 1998; Viehberg, 2004). It is generally accepted that changes in Holocene ostracod faunas reflect changes in their habitat and the environmental history of the water body they inhabited. The ecological preferences of the ostracod taxa recorded have not been sufficiently investigated within the study area but the data available from Meisch (2000, and references therein) can serve as the basic information source in this respect.

LAKE ELISTVERE

The previous reconstruction of the history of Lake Elistvere is based on palynological data from the overgrown northwestern part of the lake (Pirrus, 1983). In the early development stage, the lake was shallow and relatively small; the lower part of the calcareous mud accumulated in the deepest part of the depression only, whereas the water level was not less than 3 m below the present water level. According to Pirrus (1983), accumulation of the calcareous mud started in the Early Holocene but our study shows the Late Glacial age of the basal beds of calcareous mud (~12 800 cal. BP). At this time, the retreat of proglacial lakes from the Saadjärve Drumlin Field had left only small isolated lakes in the inter-drumlin depressions (Rosentau *et al*., 2007). According to Pirrus (1983) the overgrowth of in the mar-

Table 2

Ecological preferences of ostracod species recorded in the lakes studied (after Meisch, 2000)

Ecological preferences	*Cytherissa lacustris* (Sars, 1863)	*Limnocytherina sanctipatricii* (Brady and Robertson, 1869)	*Fabaeformiscandona protzi* (Hartwig, 1898)	*Candona neglecta* Sars, 1887	*Candona candida* (O. F. Müller, 1776)	*Ilyocypris* cf. *bradyi* Sars, 1890	*Pseudocandona sucki* (Hartwig, 1901)	*Herpetocypris reptans* (Baird, 1835)	*Potamocypris similis* G. W. Müller, 1912	*Darwinula stevensoni* (Brady and Robertson, 1870)	*Cyclocypris ovum* (Jurine, 1820)	*Fabaeformiscandona holzkampfi* (Hartwig, 1900)	*Limnocythere inopinata* (Baird, 1843)	*Cypridopsis vidua* (O. F. Müller, 1776)	*Cypris* cf. *pubera* O. F. Müller, 1776	*Cypria exsculpta* (Fischer, 1855)	*Metacypris cordata* Brady and Robertson, 1870	*Scottia pseudobrowniana* Kempf, 1971
Oligotrophic	x	x	x															
Eutrophic																	x	
Coldstenothermal						x												
Oligothermophilic				x	x													
Polythermophilic									x				x	x				
Thermoeuryplast								x		x	x					x	x	
Freshwater															x	x	x	
Oligohaline					x	x	x											
Mesohaline				x				x		x	x	x	x					
Phytophilic							x	x	x			x		x				x
Littoral		x	x	x	x		x	x	x		x						x	x
Sublittoral	x	x	x	x	x													
Profundal	x	x	x	x	x													

ginal parts of Lake Elistvere started in the mid-Holocene but this estimate must be revised also. Our dates suggest that the water level had lowered and the marginal zone of the lake had become paludal already in the Early Holocene (~10 200 cal. BP).

LAKE VÕTRTSJÄRV

The ostracod assemblage in the fossiliferous part of the Pedja section (735–721 cm; Fig. 3B) is characterized by abundant *C. ovum, C. vidua, C. candida, H. reptans* and *D. stevensoni*. This assemblage is indicative of a shallow warm lake with dense vegetation and shows the highest diversity of ostracods in the material studied. According to Orviku (1973) this interval may be dated to the Early Holocene. Changes in the ostracod assemblage (Fig. 3B) in the 721–690 cm interval may be related to rising water level as suggested by Orviku (1973), but the relative increase in abundance of the phytophilic *C. vidua* may also suggest a more extensive development of vegetation in the littoral zone. Along with the water level lowering documented by Moora *et al*. (2002), *M. cordata* made its appearance. The gradual increase of abundance of the latter species indicates a progressive eutrophication of the water body, the ancient Big Võtrtsjärv. In the topmost part of the lake sediments, *M. cordata* has a very high population density and is accompanied by *S. pseudobrowniana.* The latter species is known to prefer swampy conditions (Meisch, 2000). As the peat accumulation started just above this level, the appearance of *S. pseudobrowniana* is apparently related to the transition of the marginal parts of the lake from the lacustrine to the wetland (peat-bog) stage. The ^{14}C data from the bog at the north-east margin of the contemporary lake sediments indicate a pronounced water level decrease at ~7700 cal. BP (Moora *et al*., 2002).

LAKE ERMISTU

Lake Ermistu was thoroughly studied and the pollen record carefully analysed by Veski (1998). The calcareous mud unit below the sand layer in the lower part of the section revealed a shallow freshwater littoral ostracod fauna consisting mainly of *D. stevensoni, C. candida, L. inopinata,* with a few shells of *I.* cf. *bradyi.* This assemblage is comparable to the assemblage in the lower part of the Pedja section although the water may have been cooler (*I. bradyi* is known as a cold-stenothermal species according to Meisch, 2000). It is noteworthy that *L. sanctipatricii* and *C. lacustris,* two species typical of oligotrophic cold-stenothermal environments, occur in the same transgressive interval. The particular ostracod assemblage in the sand layer is similar to that of the Holocene deposits of Lake Peipsi (see Niinemets, 1999).

A new water level lowering in the Early Holocene led to on increase in the population density of *M. cordata* and the disappearance of *D. stevensoni*, as has also been recorded in the Pedja section. This ostracod assemblage is probably related to the shallowest water levels and to high productivity. The ostracod fauna does not reflect the overgrowth of the area which has been noted in the penecontemporaneous sediments of the Elistvere and Pedja sections. Changes in the Early Holocene in Lake Ermistu took place much faster than in the other shallow water bodies studied and the sedimentation rate was also higher than in Lake Elistvere. The proximity of the sea has not influenced the lake, because only a freshwater ostracod fauna is documented from the Early Holocene, as in the shallow water bodies of southeastern Estonia.

CLUES TO ENVIRONMENTAL CHANGES IN THE OSTRACOD RECORD FROM ESTONIAN LAKES

The ostracod record from the lakes of Estonia studied is quite obviously environmentally controlled. Such an environmental signal can be revealed from the following features: 1) cold oligotrophic conditions are characteristic of the early development stage of the lakes in the Late Glacial and Early Holocene; this is shown by the lack or scarcity of the phytophilic taxa (first of all, *C. vidua*) and eutrophic indication (*M. cordata*) in the ostracod record, but also by the fact that *D. stevensoni* seems to be confined only to the lower parts of the sections; 2) the subsequent dominance of *M. cordata,* which progressively increases in the upper parts of the section, clearly carries a eutrophication signal in the Late Glacial and Early Holocene. This assumption is supported by the fact that in one section *S. pseudobrowniana* accompanies *M. cordata* in the topmost part of the calcareous unit, just before peat formation started in the area.

Absolon (1973) makes a distinction between the Late Glacial "*candida* fauna" and the Holocene "*cordata* fauna". He also states that one of the typical components of the "*cordata* fauna" is *D. stevensoni*. In the Estonian lake sediments we did not recognize *D. stevensoni* and *M. cordata* occurring together. *D. stevensoni* seems to be characteristic of a muddy and shallow lake, with a rough depth estimate of about 2.5–3.0 m. Such an association is characteristic of the lowermost parts of the Ermistu and Pedja sections. The typical "*cordata* fauna" *sensu stricto* occurs in the upper parts of the Elistvere, Pedja and Ermistu sections, as a specific indication of lake eutrophication and overgrowth.

The idea that the progressive blooming of *M. cordata* can be interpreted as an environmental signal gains additional support from the timing of this particular event in different lakes. The interval with an assemblage rich in *M. cordata* is older in eastern Estonia, compared to its age in the western near-coastal area (Lake Ermistu). A transgression-related shift back towards colder and oligotrophic conditions, revealed from the Ermistu section, is in good agreement with this interpretation and shows that the eutrophication trend can also be reversed.

The ostracod fauna in the calcareous mud intervals of the lakes studied is roughly similar; the dominant species are *L. inopinata* and *M. cordata*. This assemblage differs from that in the calcareous Holocene sediments of Lake Peipsi, which includes a distinct interval of cold oligotrophic conditions, in agreement with the hypothesis of groundwater feeding of Lake Peipsi during this period (Niinemets, 1999).

CONCLUSIONS

The occurrence of ostracods in sediments of shallow lakes in Estonia depends on the sediment composition. The highest ostracod diversity is related to the calcareous sediments while peat and pure gyttja are characterized by the lack of subfossil ostracod material. The ostracod succession in the three lakes studied follows a distinct pattern of changes that are not contemporaneous but are obviously related to the evolution of the water bodies. *D. stevensoni* and *M. cordata* do not co-occur but are related to succeeding ostracod assemblages.

The patterns in the distribution of indicator species among ostracods allow characterization of the development of small lacustrine systems in Estonia as follows:

1. A Late Glacial and Early Holocene cool and oligotrophic lacustrine system, where *D. stevensoni* colonized muddy and shallow lakes; few (or no) phytophilic taxa;

2. The appearance of *M. cordata* and a gradual increase in its population density in the course of water body ageing, lowering of the water level and/or change of the trophic status of a lake. The first appearance of *M. cordata* can be dated to the end of the Late Glacial in Lake Elistvere, contemporaneously with the beginning of accumulation of calcareous sediments.

3. The occurrence of *S. pseudobrowniana* in the uppermost part of the ostracod succession (recorded in former Lake Big Võtrtsjärv) indicates at the overgrowth stage of a lake.

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