Reconstruction of palaeovegetation and sedimentation conditions in the area of ancient Lake Burtnieks, northern Latvia

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Received 12 November 2009, accepted 15 March 2010

Abstract. Palaeobotanical investigations were carried out with the aim of reconstructing the development of palaeovegetation and formation of sediments in the northeastern area of ancient Lake Burtnieks. Pollen and plant macroremain studies provide information on vegetation development in the surroundings of the lake, including Stone Age settlements of Braukšas I and Braukšas II. Results of the investigations indicate that the development of vegetation together with sedimentation conditions in the palaeolake have changed since the Younger Dryas until today. Vegetation composition varies in different parts of the ancient Lake Burtnieks area due to past changes in lake water level which reached different sites at different times. Data from the northern part of ancient Lake Burtnieks indicate its gradual overgrowing since the Preboreal. Deposition of minerogenic lacustrine sediments (silt, clayey silt and sand) lasted until the Boreal or the Atlantic time, depending on the water depth of the lake locality. Clastic sediments were overlain by gyttja, which in turn was later covered by well-decomposed fen (sedge, sedge–grass) peat that started to form at the end of Atlantic time.

Pollen and plant macroremain composition of lacustrine sediments and fen peat sequences suggests that people have inhabited the area since Preboreal–Boreal times. However, weak traces of possible presence of people are found already at the very end of the Younger Dryas. Fluctuating curves of broadleaved tree pollen, a significant amount of pollen of cultivated plants and charcoal dust in sediments indicate activities of an early man and refer to start of crop growing in the area in the second half of the Atlantic chronozone.

Key words: palaeovegetation, pollen analysis, plant macroremains, Palaeolake Burtnieks, northern Latvia.

INTRODUCTION

Lake Burtnieks (also historically known as Astijärv) is Latvia's fifth largest lake, located in northern Latvia (Fig. 1) in a depression within the extensive Burtnieks Drumlin Field. Lake Burtnieks is a very interesting object of study because of its geological development and the presence of the Europe-wide known Zvejnieki Stone Age archaeological complex on lake shores. The Zvejnieki Stone Age complex was well excavated already 30 years ago and described in the monograph by Francis Zagorskis (1987). Further multidisciplinary studies of this important geological and historical site, conducted by Ilga Zagorska and Lars Larsson in 2000–08, were expanded to the northeastern area of the ancient Lake Burtnieks basin. Eberhards (2006) provides new data on the geological development and changes in palaeo-ecology and palaeovegetation in the last 10 ka, and on the complicated course of development of the entire Palaeolake Burtnieks area. Based on geological, archaeo-logical and chronological (^{14}C datings) data, Eberhards et al. (2003a, 2003b), Eberhards (2006) and Kalniņa (2006) reconstructed water levels in the palaeolake and provided new evidence of the presence of a Stone Age man in the area. Pollen and plant macroremains preserved in the deposits may suggest a relationship between plants or groups of plants and climatic conditions and reflect palaeovegetation and environment during the formation of the deposits (Iversen 1949; Behre 1986). The palaeoecological data obtained from lake and mire deposits of ancient Lake Burtnieks enable us to reconstruct changes in palaeovegetation and to estimate human impact on vegetation throughout prehistoric time.

This paper presents a new reconstruction of environ-mental conditions and vegetation development in the northern area of Palaeolake Burtnieks during the first half of the Holocene. Another aim is to correlate local pollen assemblage zones (LPAZ) to those of the regional North Vidzeme palynostratigraphy, as well as to estimate the earliest detectable human impact in the pollen and plant macroremain data.

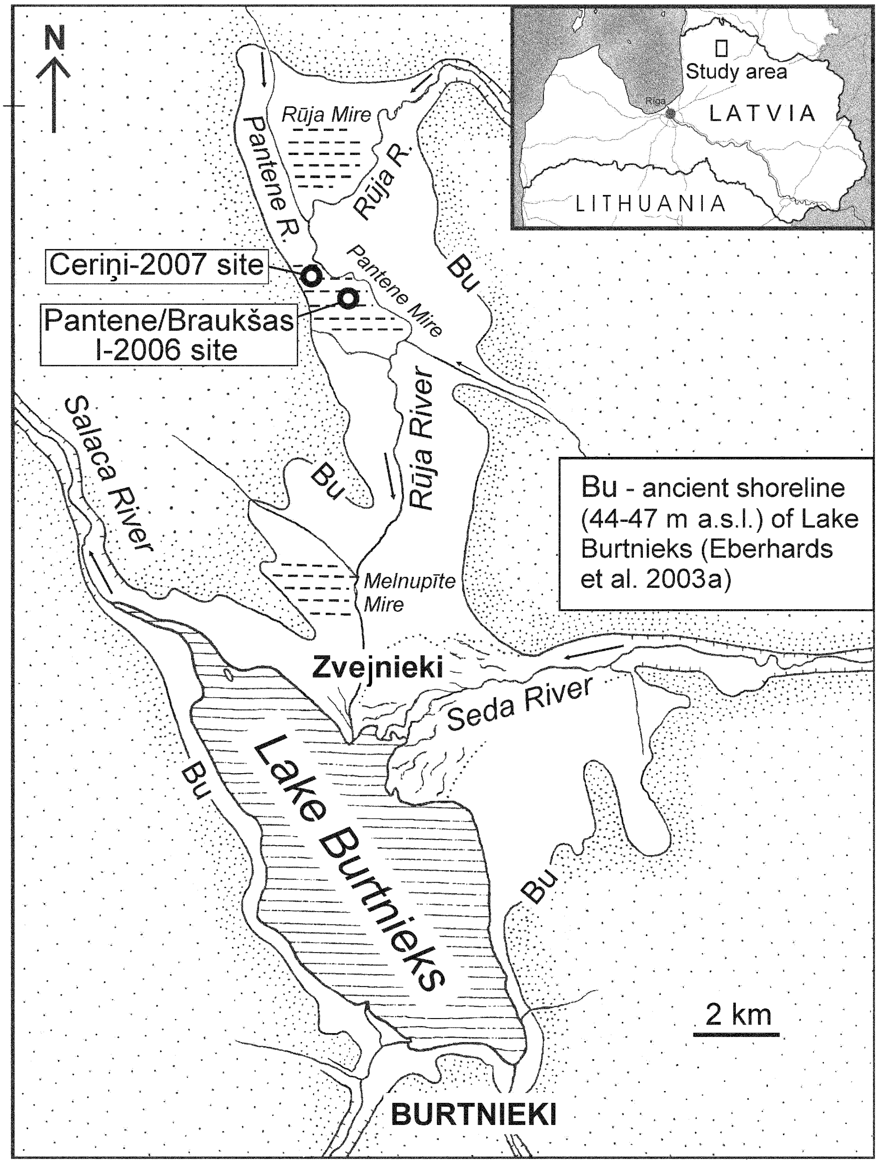

Fig. 1. Location of the research area and the sites studied.

GEOLOGICAL AND ARCHAEOLOGICAL BACKGROUND OF THE LAKE BURTNIEKS REGION

Lake Burtnieks with its ancient, for now overgrown and boggy part is located on the Northern Vidzeme Lowland, in the central part of the Burtnieks Drumlin Field (Zelčs & Dreimanis 1997). The drumlin field is one of the largest in the Baltic, measuring ca 83 km from north to south, with the width between 15 and 20 km at the Estonian border in the north, and 45 km at Valmiera in the south. The drumlin field has a fan-shaped configuration that broadens up to the southeast (Zelčs 1994). The Burtnieks Drumlin Field developed in the course of the final activity phases of the North Vidzeme Glacier Lobe (Zelčs & Dreimanis 1997). Single drumlins are normally 1000–2000 m long, 100–600 m wide and 6–12 m high and reach an elevation of 55–65 m a.s.l., which is ca 14–25 m above the present water level in Lake Burtnieks (Fig. 1). ^{10}Be ages of boulders from the drumlin field (13 495 ± 1178 and 13 328 ± 832 yr; Rinterknecht et al. 2006) indicate that the area was deglaciated by ca 13.5 cal yr BP at the latest (Zelčs & Markots 2003; Rinterknecht et al. 2006).

During the late glacial the lake depression was occupied by waters of Palaeolake Burtnieks, which was ca 20 km long with the maximum shoreline length (including islands) of >150 km (Eberhards 2006). The shoreline was sinuous, with many peninsulas and narrow bays (Fig. 1). Resulting from changes in climate and drainage conditions, the water level and extent of the palaeolake changed several times and thus predetermined the location of the Stone Age settlements. Many of the former lakes in depressions between drumlins have become overgrown and filled in by lake and mire deposits – gyttja, freshwater lime and peat. Present Lake Burtnieks occupies only the deepest and southernmost part of the ancient lake depression, covering ca 30% of the maximum area of the late glacial palaeolake.

The northeastern part of Palaeolake Burtnieks, named ‘Nordic Lake’ was shallow and therefore got rapidly overgrown. However, there were some deeper depressions in the area of the ‘Nordic Lake’, including the valleys of the lower reaches of the Rūja and Seda rivers, where the lakes preserved until the Atlantic times. Lakes in the areas of present Pantene, Rūja and Melnupīte Mires (Fig. 1), according to sediment characteristics, disappeared completely between 2000 and 4000 years ago (Eberhards 2006).

More than 300 graves, dated to Mesolithic and Neolithic times, were excavated at the Stone Age settlement site in Zvejnieki (Fig. 1). The artefacts, including skeletal material and grave goods of bone, teeth and antler, are very well preserved. These were discovered already during the first excavation in 1964–78, conducted by Dr Francis Zagorskis, when the Zvejnieki site gained its international reputation. Investigations at the Zvejnieki Stone Age site started again in 2000, including also a wider complex of palaeoenvironmental methods. This multidisciplinary study, conducted by Ilga Zagorska in collaboration with Lars Larsson, has already resulted in a book *Back to the Origin. New Research in the Mesolithic–Neolithic Zvejnieki Cemetery and Environment, Northern Latvia* (Larsson & Zagorska 2006).

Radiocarbon dates from the Zvejnieki Stone Age cemetery provide evidence that it was in use for several millennia (from 7480–7290 cal BC until 2890–2620 cal BC), extending the earlier known age of the burial ground by more than 1000 years back (Zagorska 2006). The oldest burial (No. 305) at the Zvejnieki site is dated back to Mesolithic settlement times (7480–7290 cal BC). A territorially monolithic group of the Late Mesolithic burials was found on the northwestern slope of the Zvejnieki–Borzoi drumlin. In addition also Early Neolithic burials were found, the age which covers almost a millennium (from 5480–5360 cal BC until 4540–4360 cal BC) (Zagorska 2006).

MATERIAL AND METHODS

Field works and pollen and plant macroremain analyses were carried out within the framework of the international multidisciplinary project ‘Archaeological complex Zvejnieki’ in 2005–08 with the aim of improving the knowledge of the development of Lake Burtnieks environs. Pollen and plant macroremains were analysed and the botanical composition and types of peat were identified at the Laboratory of the Quaternary Environment, Faculty of Geography and Earth Sciences, University of Latvia. Botanical composition and the type of peat were determined according to Tjuremnov’s (1976) methods. Most of the field works were done during the archaeological excavations conducted with the aim of locating the archaeological site Braukšas II. Samples for palaeobotanical studies were taken from two core sections: Pantene/Braukšas I-2006 and Ceriņi-2007.

Sediment description

Monoliths of sediment sequences 50 cm long were sampled from sediment cores, preliminarily described, packed in order to avoid loss of natural moisture and transported to the laboratory for sediment composition and palaeobotanical analysis. Sediment lithology of the studied profiles is presented in Tables 1 and 2.

In the core Pantene/Braukšas I-2006 ten sediment layers (lithological units) were recognized. The lowermost 10 cm (7.60–7.50 m) of the sequence is represented by reddish-brown clayey till, which is overlain by clay (7.50–7.30 m). The latter is covered by a 4.0 m thick layer of silty clay (7.30–3.30 m), followed by layers of silt (3.30–3.10 m) and gyttja (3.10–2.30 m). The uppermost part of the sequence (2.30–0.00 m) consists of medium- to well-decomposed (30–40%) grass–sedge, sedge and sedge–wood peat (Table 1).

Five lithological units were recognized in the core Ceriņi-2007 (Table 2). The lowermost part of the sequence (4.70–4.30 m) consists of different types of gyttja resting on sand at the bottom. Gyttja layers are overlain by peaty gyttja (4.30–2.70 m) and peat layers (2.70–0.00 m) with different characteristics.

Pollen analyses

The sampling interval was 5 cm. Altogether 239 samples from the two sediment cores were prepared for pollen analysis following standard techniques (Aaby 1986; Berglund & Ralska-Jasiewiczowa 1986; Faegri & Iversen 1989). Samples with a high amount of mineral matter were treated with fluoride acid and stored in glycerine. Pollen extraction and concentration was complicated due to a large amount of Fe hydroxides in the sediments.

Table 1. Lithology of the core from the Pantene/Braukšas I-2006 site

Depth, m	Lithology
0.00–0.35	Peat, medium- to well-decomposed (30–40%) grass–sedge, dark brown, dense
0.35–0.65	Peat, medium- to well-decomposed (30–40%) grass–sedge, dark brown, with plant remains and Fe hydroxide inclusions
0.65–1.45	Peat, well-decomposed (40–50%) sedge, dark brown, with sand admixture
1.45–1.80	Peat, medium- to well-decomposed (30–40%) sedge–wood, dark brown, with plant macroremains and fragments of wood
1.80–2.30	Peat, well-decomposed (40–50%) sedge–grass, dark brown, dense
2.30–3.10	Gyttja, homogeneous, greenish-grey
3.10–3.30	Silt, clayey, yellowish-brown
3.30–7.30	Clay, silty, brown
7.30–7.50	Clay, massive, reddish-brown
7.50–7.60	Till, clayey, reddish-brown

Table 2. Lithology of the core from the Ceriņi-2007 site

Depth, m	Lithology
0.00–2.00	Peat, medium- to well-decomposed (30–40%) sedge–grass, dark brown with wood fragments
2.00–2.70	Peat, medium- to well-decomposed (30–40%) sedge–wood, dark brown
2.70–4.30	Gyttja, peaty, dark brown
4.30–4.50	Gyttja, homogeneous, greenish-grey with admixture of wood fragments, leaves, detritus, rare charcoal
4.50–4.70	Gyttja, homogeneous, greenish-grey with shells of ostracods and molluscs
4.70–4.72	Sand, fine, greyish with organic matter

Quantitative and qualitative pollen analyses were made by using light microscopes Axiostar and Primostar with 400–1000 times magnification. Glycerine was used as the embedding medium to prepare slides. As a minimum 400 pollen grains, except aquatic herb pollen, were counted in each sample. Pollen and spores were identified by comparison with the available reference materials – pictures and descriptions (Moore & Webb 1978).

The TILIA 2.00 (Grimm 1991) and TGView software was used for constructing pollen diagrams and plotting the data. The percentage diagrams were prepared using basic sums that include all terrestrial pollen. Aquatic plant pollen and spores were calculated as a percentage of this sum. The pollen zones were determined as local pollen assemblage zones (LPAZ) and correlated with regional pollen zones (RPAZ) of eastern Latvia (Segliņš 2002) where the names are replaced by suffixes such as PB, BO1, BO2, etc., identical for the periods in the classical chronostratigraphical scheme (Berglund 1979).

Plant macroremain analyses

After sampling for pollen analysis rest of the material from the sediment sequence was divided into 83 subsamples and used for plant macroremain analysis. The volume of each subsample was approximately 200 mL. Preliminary processing of the plant macrofossil samples was conducted in the laboratory using flotation to separate the light fraction, collected on a 0.25 mm sieve, from the heavy fraction. The separated fractions were dried and an initial recovery and determination of the plant remains and other subfossils was undertaken. Samples for detailed plant macroremain analysis were prepared following standard techniques (Nikitin 1969; Yakubovskaya 1976; Warner 1990). Identification of plant macroremains was based on available reference materials (Rasiņš 1954; Katz et al. 1965; Rasiņš & Tauriņa 1983; Velichkevich & Zastawniak 2006, 2008) and their pictures and descriptions. In addition, carpoides were compared with the materials from the seed collection of the Laboratory of the Quaternary Environment, Faculty of Geography and Earth Sciences, University of Latvia. Computer programs TILIA 2.00 and TGView were used for constructing plant macroremain diagrams.

RESULTS

Sediment lithostratigraphy

The base of the studied sequence at the Pantene/Braukšas I-2006 site consists of reddish-brown clayey till overlain by brown clay and clayey silt. Minerogenic sediments are followed by gyttja and well- to medium-decomposed fen peat (Fig. 2). Deposition of clay and silt lasted until the end of the Boreal, gyttja deposited during the Atlantic chronozone. Well-decomposed fen (sedge, sedge–grass) peat started to accumulate at the end of the Atlantic.

In the Ceriņi-2007 site, the homogeneous, greenish-grey gyttja with shells of ostracods and molluscs, which covers fine sand at the bottom of the section, accumulated from the end of the Preboreal to the Boreal chronozones. Peaty gyttja started to accumulate during the second half of the Boreal and continued most of Atlantic time. Similarly to the Pantene/Braukšas I-2006 section, the sedge–wood peat started to accumulate at the end of the Atlantic chronozone and buried the gyttja layer.

Results of pollen analyses

On the basis of pollen analyses from sediments of the Pantene/Braukšas I-2006 site we determined 11 local pollen assemblages zones (P-LPAZ) (Fig. 2) that cover the time period from Younger Dryas (DR3) to current. In the section from the Ceriņi-2007 site seven pollen assemblages zones (C-LPAZ) were determined, which reflect vegetation development from the Preboreal until today.

Pantene/Braukšas I-2006 section

A total of 150 samples were analysed from the 7.6 m long sediment core taken from the Pantene/Braukšas I-2006 site. The following P-LPAZs were determined.

P-LPAZ-1, *Betula nana*–herbs (7.60–6.10 m, DR3, glaciolacustrine clay)

The glaciolacustrine sediment sequence has obviously deposited in periglacial conditions. The LPAZ is characterized by abundance of *Betula nana* and herb pollen that reach 18% of the total sum (Fig. 2). Clay contains a large number of different herbs (*Artemisia*, Chenopodiaceae, Poaceae, etc.), including *Dryas octopetala* pollen. *Pinus* and *Betula* dominate among tree pollen.

P-LPAZ-2, *Pinus–Betula* (6.10–5.50 m, PB1, silty clay)

Pollen of *Pinus*, *Betula* and herbs dominate in this LPAZ. The first maximum of *Pinus* (60%) can be observed in the upper part of the zone. Significant values of ruderals and meadow/pasture plant pollen, as well as Poaceae pollen, refer to relatively open landscape in the area. The abundance of pollen of periglacial plants has decreased in comparison with P-LPAZ-1, suggesting climate amelioration. From the given evidence the boundary between the Pleistocene and Holocene was determined at the base of P-LPAZ-2.

P-LPAZ-3, *Betula–Pinus* (5.50–4.20 m, PB2, silty clay)

The main components in the pollen spectra are *Pinus*, *Betula* and *Salix*, and herbs, represented by ruderals and undifferentiated herbs. The amounts of the ruderals and meadow/pasture plant pollen, as well as Poaceae pollen, have decreased compared to the previous LPAZ. The decreased quantity of pollen of aquatic plants and presence of *Equisetum* spores indicate shallow lacustrine conditions during accumulation of these silty clays.

P-LPAZ-4, *Pinus* (4.20–3.50 m, BO1, silty clay and silt)

Pinus reaches its second maximum (60%). The amounts of ruderals and undifferentiated herbs and meadow/pasture plant pollen increase. Pollen spectra in general reflect vegetation which is characteristic of the first half of the Boreal.

P-LPAZ-5, *Betula–Pinus–Alnus* (3.50–2.90 m, BO2, upper part of silt and lower part of gyttja)

Betula, *Pinus* and *Alnus* pollen are prevailing among the tree pollen and the amount of *Corylus* gradually increases to 5%. A sharp increase in the content of charcoal dust, rise in the pollen of ruderal plants (8%), maximum concentration of herb pollen together with a sharp decrease in tree and shrub pollen mark the occurrence of forest fires at the end of the Boreal and at the beginning of the Atlantic chronozone. Pitkänen & Huttunen (1999) show that mild surface fires leave most pine trees alive. This is in accordance with our data which show only insignificant decrease in *Pinus* and *Picea* pollen at the time of presumable forest fires in the environs of the Pantene/Braukšas site.

P-LPAZ-6, *Ulmus–Alnus–Corylus* (2.90–2.55 m, AT1, gyttja)

This LPAZ is characterized by a sharp increase in the quantity of *Alnus* (20%), *Corylus* (10%) and broad-leaved trees, and decrease in the amount of *Pinus* pollen. The concentration of aquatic plant pollen has increased compared to the previous LPAZ, while the amount of

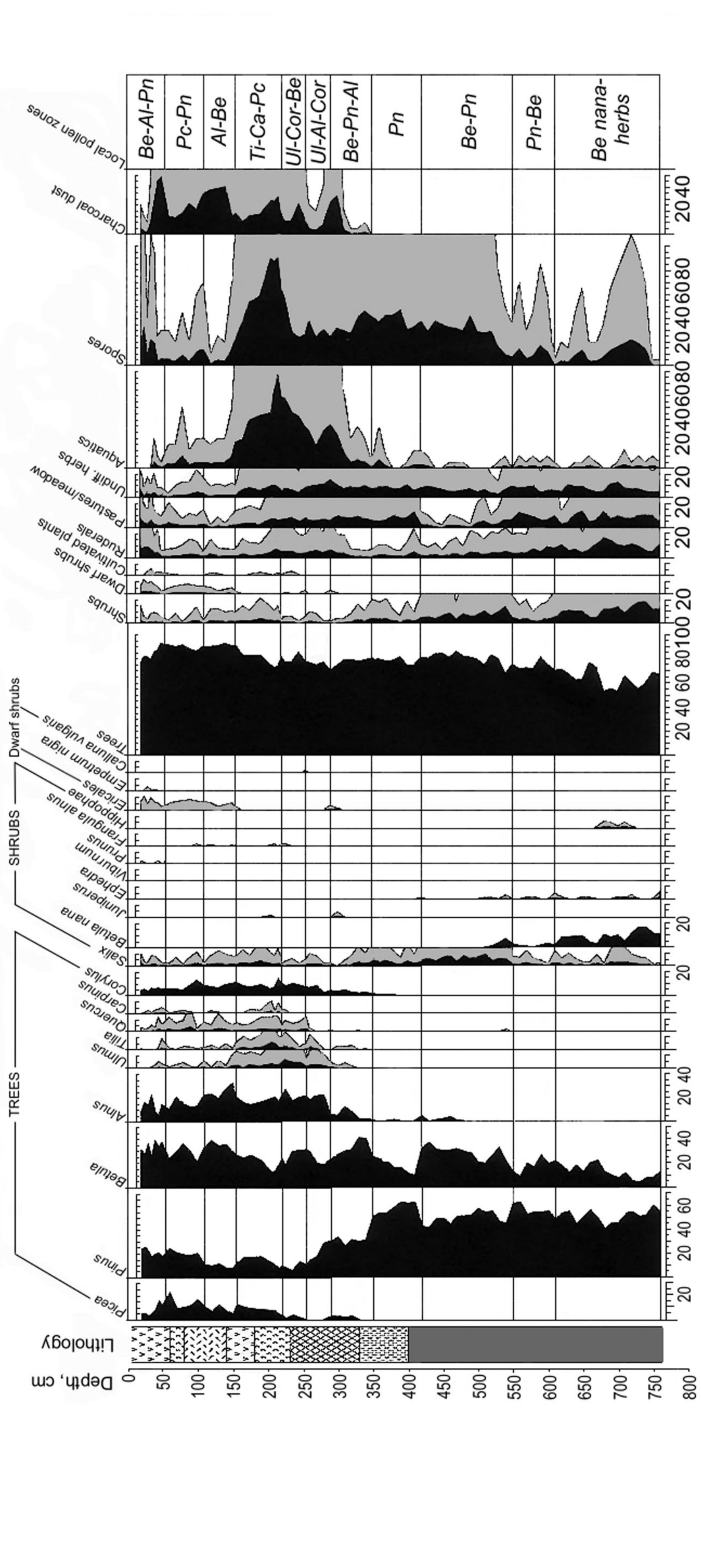

Fig. 2. Pollen percentage diagram of selected taxa from the Pantene/Braukšas I-2006 section.

charcoal dust has decreased in this LPAZ. Pollen spectra in general reflect vegetation change at the beginning of the Atlantic chronozone.

P-LPAZ-7, *Ulmus–Corylus–Betula* (2.55–2.15 m, AT2, upper part of gyttja and lower part of sandy peat)

Pollen of *Alnus*, *Corylus* and broadleaved trees have relatively high but fluctuating values. Some decrease in the pollen of ruderals and sharp increase in aquatics and spores was determined. Pollen of cultivated plants (*Cannabis*, *Hordeum*) appears and the amount of charcoal increases in this LPAZ. Relatively high amounts of *Betula* pollen and the character of the pollen spectra in general reflect vegetation of the middle part of the Atlantic chronozone.

P-LPAZ-8, *Tilia–Carpinus–Picea* (2.15–1.55 m, AT3, sandy peat and peat)

In this LPAZ the appearance of *Picea*, increase in *Pinus* (to 18%) and some decrease in *Alnus*, *Corylus* and broadleaved trees were observed. *Cannabis*-type, *Hordeum* and *Triticum* pollen and the presence of ruderal plants indicate human activity at the site. Charcoal values are modest and decreasing. Pollen spectra in general reflect vegetation during the latest part of the Atlantic chronozone.

P-LPAZ-9, *Alnus–Betula* (1.55–1.10 m, SB1, peat and peaty sand)

The spectra determined in this LPAZ pollen are completely different from those of the previous zone. Pollen of broadleaved trees has decreased (1–5%) and even disappeared from some intervals. Birch–alder–pine forests were spread in the area. The presence of *Cerealia* and *Cannabis/Humulus*-type pollen and ruderals, and sharp fluctuations in the quantity of charcoal dust prove human presence and activities in the area.

P-LPAZ-10, *Picea–Pinus* (1.10–0.55 m, SB2, peat, rich in Fe hydroxide)

Increase (10–25%) in the pollen of coniferous trees, including *Picea*, and decrease in *Betula* and *Alnus* and charcoal dust are characteristic of this LPAZ, indicating some deterioration of climate.

P-LPAZ-11, *Betula–Alnus–Pinus* (0.55–0.00 m, SA1–SA3, peat)

Sharp decrease in *Picea* pollen (15–25%) and fluctuations in *Pinus*, *Betula* and *Alnus* pollen, including anthropogenic indicators, are characteristic of this interval. Pollen data evidence some disturbances in the natural sediment sequence. The latest maximum of charcoal dust was recorded in this LPAZ. Fluctuations in modest quantities of herbs and *Cerealia* may point to low intensity of human activities in the area.

Ceriņi-2007 section

C-LPAZ-1, *Betula*–Poaceae (4.65–4.50 m, PB, gyttja)

This LPAZ is characterized by the first maximum (33%) of *Betula* and fluctuation in *Pinus* pollen (Fig. 3). Large amounts of shrubs and dwarf shrubs, particularly *Salix* and *Betula nana*, are present. High quantities of pollen of aquatic plants – Typhaceae, Nymphaeaceae and algae (*Cosmarium*), and mollusc subfossils refer to relatively shallow near-shore conditions. The presence of pollen of very typical reed-forming plants like Poaceae and Cyperaceae (Fig. 4) is also indicating shallow-water conditions at the site.

C-LPAZ-2, *Pinus–Betula* (4.50–3.75 m, BO1, gyttja and lower part of peaty gyttja)

The maximum of *Pinus* occurs together with high quantities (10–27%) of *Betula* pollen. Both, *Pinus* and *Betula* pollen curves fluctuate, indicating very changeable climate. Varying composition and amounts of spores, sedges and grasses refer also to variable sedimentation conditions. In general, increasing quantities of pollen of broadleaved trees (*Ulmus*, *Quercus* and *Corylus*) show that the climate became milder during this LPAZ. The distribution of pasture/meadow plants decreases as well, while pollen of different herbs increases. Compared to the previous LPAZ, pollen of aquatics and content of algae has sharply decreased. The presence of charcoal particles and ruderals (*Artemisia*, Chenopodiaceae and *Plantago*) refers to human occupation of the region.

C-LPAZ-3, *Corylus–Betula* (3.75–3.40 m, BO2, peaty gyttja)

Pollen spectra of this LPAZ suggest climate amelioration. Although the amount of birch pollen is lower in the middle of the zone, and that of pine is increasing, birch is prevailing among tree pollen. *Corylus* is at its maximum (15%), while *Picea* is present in low (<10%) quantities. The amounts of broadleaved trees and algae have increased and the quantity of herbs, aquatics and spore plants has decreased in this LPAZ.

C-LPAZ-4, *Pinus* (3.40–2.50 m, AT1, peaty gyttja and upper part of peat)

Pine reaches its second maximum (50%) and the amount of spruce increases, particularly in the upper part of the zone. With the appearance of charcoal dust in the middle of the zone the amount of tree (also coniferous trees), shrub and dwarf shrub pollen decreases. And vice versa, with the decrease in charcoal dust in the

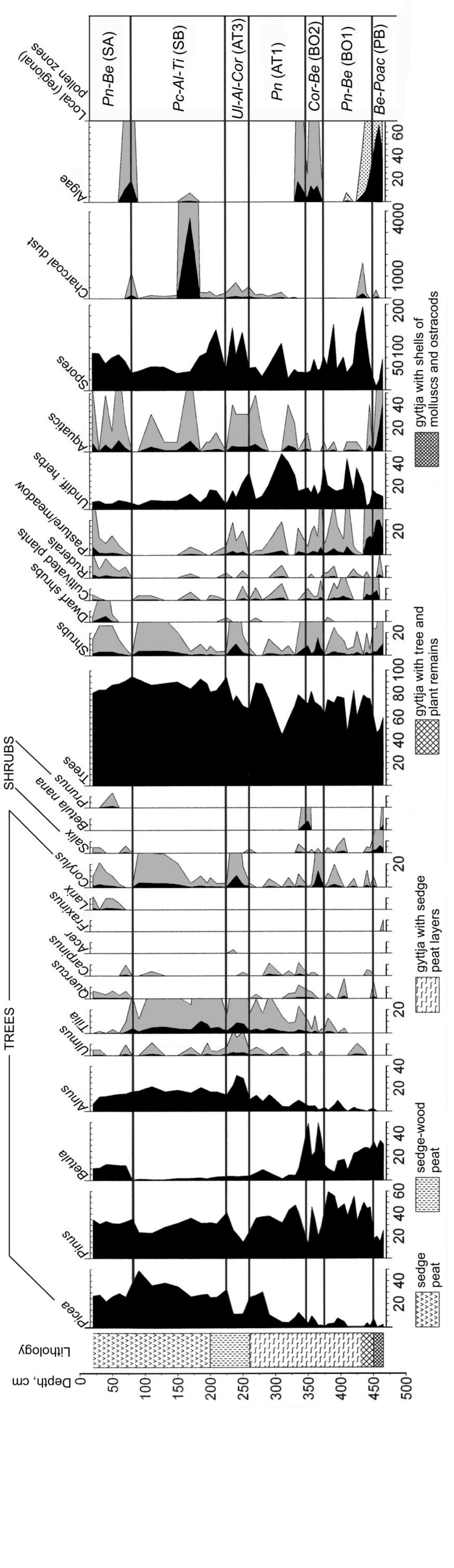

Fig. 3. Pollen percentage diagram of selected taxa from the Ceriņi-2007 section.

upper half of the zone, the quantity of tree pollen increases sharply. Different herbs, among which Cyperaceae is prevailing, have reached their maxima in this LPAZ. Decrease in *Betula* and gradual increase in *Alnus* and *Tilia* pollen point to warmer climatic conditions in the upper part of the zone. *Corylus* pollen decreases in this zone but the quantity of other broadleaved trees (*Ulmus*, *Tilia*) has increased in comparison with the previous LPAZ. Also pollen of the *Aster* family reaches its maximum in this LPAZ, while pollen of *Quercus* disappears in the second half of the zone.

C-LPAZ-5, *Ulmus–Alnus–Corylus* (2.50–2.25 m, AT3, sedge peat)

Pollen of broadleaved trees – *Ulmus*, *Alnus* and *Tilia* – reaches its maximum. Also the second maximum of *Corylus* pollen is apparent in this LPAZ. Conifers, represented by *Picea* and *Pinus*, are rare (10–30%) and the amount of birch pollen is gradually decreasing. The pollen spectra indicate climatic optimum in the region. Significant values of meadow/pasture (up to 6%) and aquatic plant pollen (8%) are characteristic of the LPAZ. However, in general the quantity of pollen of different herbs gradually decreases. The maximum in charcoal dust, decrease in tree pollen and increase in Polypodiaceae spores indicate the occurrence of forest fires in the middle of the zone. The decrease in charcoal quantity in the upper part of the zone is coeval with the increase in *Picea* and *Pinus* pollen.

C-LPAZ-6, *Picea–Alnus–Tilia* (2.25–0.80 m, SB, sedge peat)

The maximum of *Picea* pollen (up to 50%) and significant values (25–40%) of *Pinus* pollen are characteristic of this zone. *Alnus* pollen has reached its second maximum (20%) and concentrations of *Tilia* and *Corylus* pollen are also relatively high. The presence of aquatic plants, herbs and spore plants has decreased in this LPAZ. Also some algae are present. Clear increase in charcoal dust and pollen of cultivated land and pasture/meadow plants indicates human settlement in the area.

C-LPAZ-7, *Pinus–Betula* (0.80–0.20 m, SA, sedge peat)

The amount of *Betula* and *Pinus* pollen increases significantly but the quantity of *Picea*, *Alnus* and *Tilia* pollen decreases. Small increase in *Quercus* and *Corylus* pollen is noticeable. The presence of ruderals (*Plantago* and *Urtica*), wide distribution of pasture/meadow plants (grass and flax family (Linaceae)) and increase in cultivated land plant (*Cannabis/Humulus*) pollen is characteristic of this LPAZ. Pollen spectra suggest wide distribution of shrubs at that time. The amount of aquatic plant pollen and spores is increasing while that of algae is decreasing.

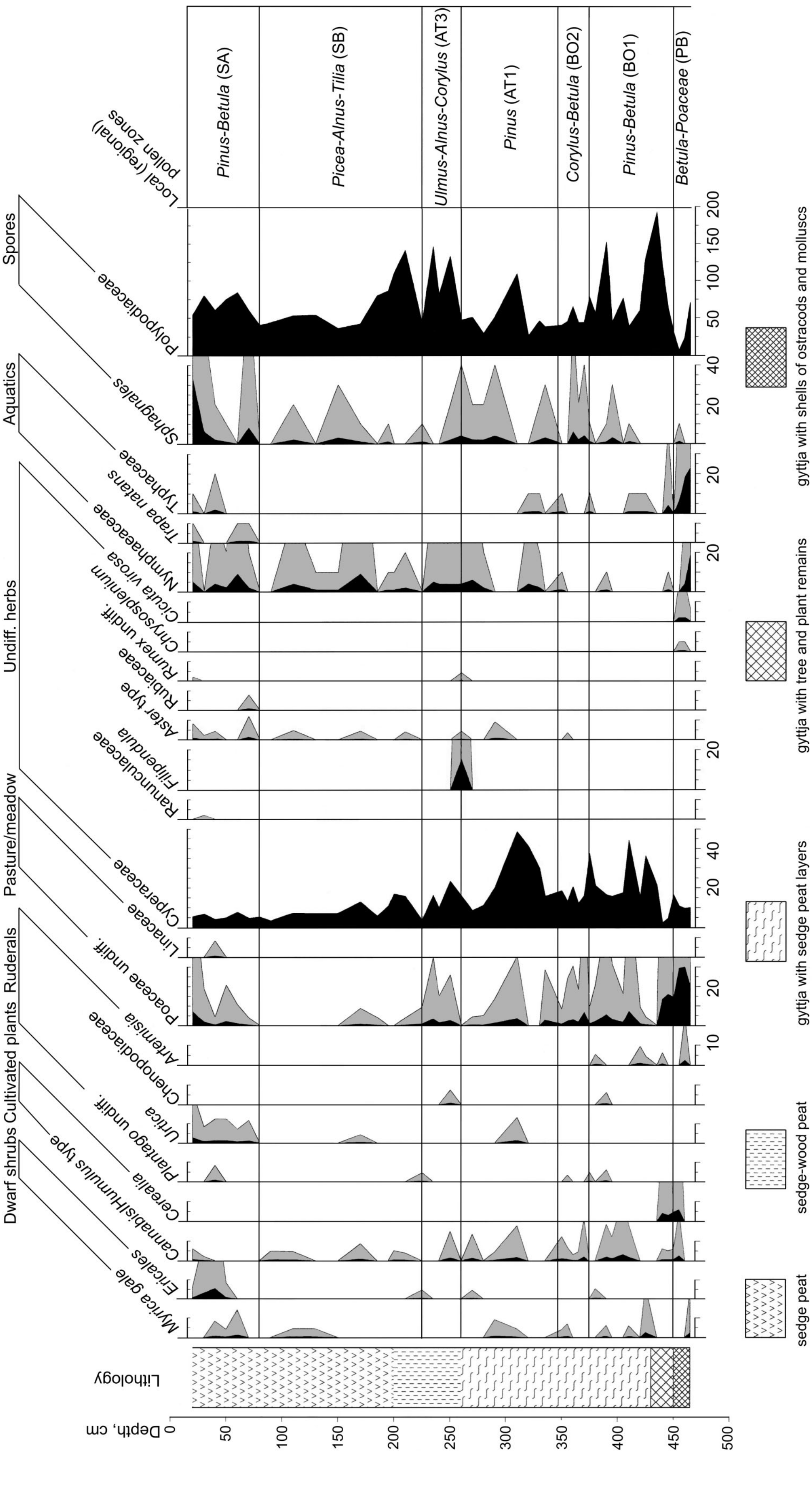

Fig. 4. Herb pollen percentage diagram of selected taxa from the Ceriņi-2007 section.

Plant macroremains

Pantene/Braukšas I-2006 section

Seven plant macroremain assemblages (PMA) were determined in this section (Fig. 5).

PMA-I (7.60–4.00 m, clay and silty clay)

A small number of Characeae oogonia is characteristic of this PMA. Ostracods and mollusc shells are present in this part of the sequence. According to few macroremains of *Betula nana* and *Dryas octopetala* determined at a depth of 5.25–5.00 m, silty clay was deposited in a late glacial oligotrophic lake.

PMA-II (4.00–2.30 m, silt and gyttja)

The quantity of Characeae oogonia is in its maximum. $CaCO_3$ incrustations of Characeae oogonia indicate that the lake became oligo-mesotrophic with carbonate-rich water. The number of macrophyte remains (*Nuphar*, *Nymphaea*, *Potamogeton*, *Scirpus* and *Najas*) has increased due to overgrowing of the coastal areas of the lake. The presence of seeds of *Najas marina* proves (Ellenberg 1996) that the lake water was carbonate-rich. Tiny mollusc shells were found in the lake sediments down from a depth of 2.30 m, however, the numbers of shells were the largest between 4.00 and 2.00 m.

PMA-III (2.30–1.50 m, peat)

The dominance of remains of aquatic plants, particularly those inhabiting coastal areas, fens and meadows, suggests that the site was near the shore and the lake continued to overgrow with macrophytes. Remains of *Trapa natans* were also found in sandy peat. Water chestnut favours nutrient-rich waters with a pH range between 6.7 and 8.2, and an alkalinity of 12 to 128 mg/L of calcium carbonate (Ellenberg 1996). During this interval the lake became mesotrophic, and fen slough was formed with *Menyanthes trifoliata* and *Lycopus europaeus* growing on it.

PMA-IV (1.50–1.40 m, sandy peat)

Only fen and wet meadow plant remains (*Lycopus europaeus*, *Menyanthes trifoliata*) are present in low quantities in this interval.

PMA-V (1.40–0.60 m, sandy peat)

Fragments of charred *Trapa* and *Corylus* nuts, small bones, charcoal, flint shreds and chips of magmatic rocks refer to a cultural layer in this depth interval. Plant macroremains were heavily decomposed in this layer. Larger mollusc fragments, possibly remains of *Unio* or *Anodonte* shells, were found in the depth interval 1.00–0.60 m.

PMA-VI (0.60–0.30 m, peat)

Due to high Fe hydroxide concentration plant macroremains are poorly preserved. Residue of Fe hydroxides in the sediments may be related to springs in the area and limonite formation in springs and mires around them (Danilans 1973). Most of the water chestnut and hazelnut shell fragments were found in the heavy fraction of the macrofossils, which probably can be explained by their larger weight because of Fe-mineralization. The most intense sedimentation of Fe hydroxides was noticed in the depth interval 0.60–0.30 m. Plant macroremains were apparently not preserved but fragments of animal bones were cemented like breccias in this interval. Bone remains and charcoal pieces suggest human activity during the formation of this layer. A find of a grain of wheat *Triticum aestivum/durum* indicates the presence of humans. However, as it was a single grain found very close to the surface, it may be occasional and not related to the original cultural layer.

PMA-VII (0.30–0.00 m, peat)

The uppermost layer of peat revealed the dominance of *Urtica dioica* and *Betula* sect. *Albae* represented by seeds, and nutlets and catkins, respectively. Deposits of this interval, similarly to the layer below, are rich in Fe hydroxides and charcoal. Fe hydroxides were observed in smaller or larger contents in the entire peat layer of the section. Charcoal of different sizes was found in the entire peaty layer, but the largest quantities of both visible charcoal and charcoal dust occurred in the depth interval from the surface to 1.40 m.

Ceriņi-2007 section

Three plant macroremain assemblages (PMA) were determined in this section (Fig. 6).

PMA-I (4.70–4.00 m, gyttja)

Seeds of aquatic plants (*Scirpus lacustris*, *S. maritima*, *Myriophyllum spicatum*, *Sparganium minimum*) at the bottom of the lower gyttja layers (depth 4.70–4.10 m) suggest that sediments were deposited in a shallow overgrown coastal area of the lake. Macroremains of birch are prevailing in this PMA, which probably were transported in by wind. In the depth interval 4.70–4.50 m a dwarf birch *Betula* sect. *Nanae* is present, which is a relict of tundra vegetation (Wahl & Kupffer 1911; Galenieks 1936). The presence of *Carex* nutlets and *Menyanthes trifoliata* seeds points to fen peat formation in a shallow coastal area of the lake.

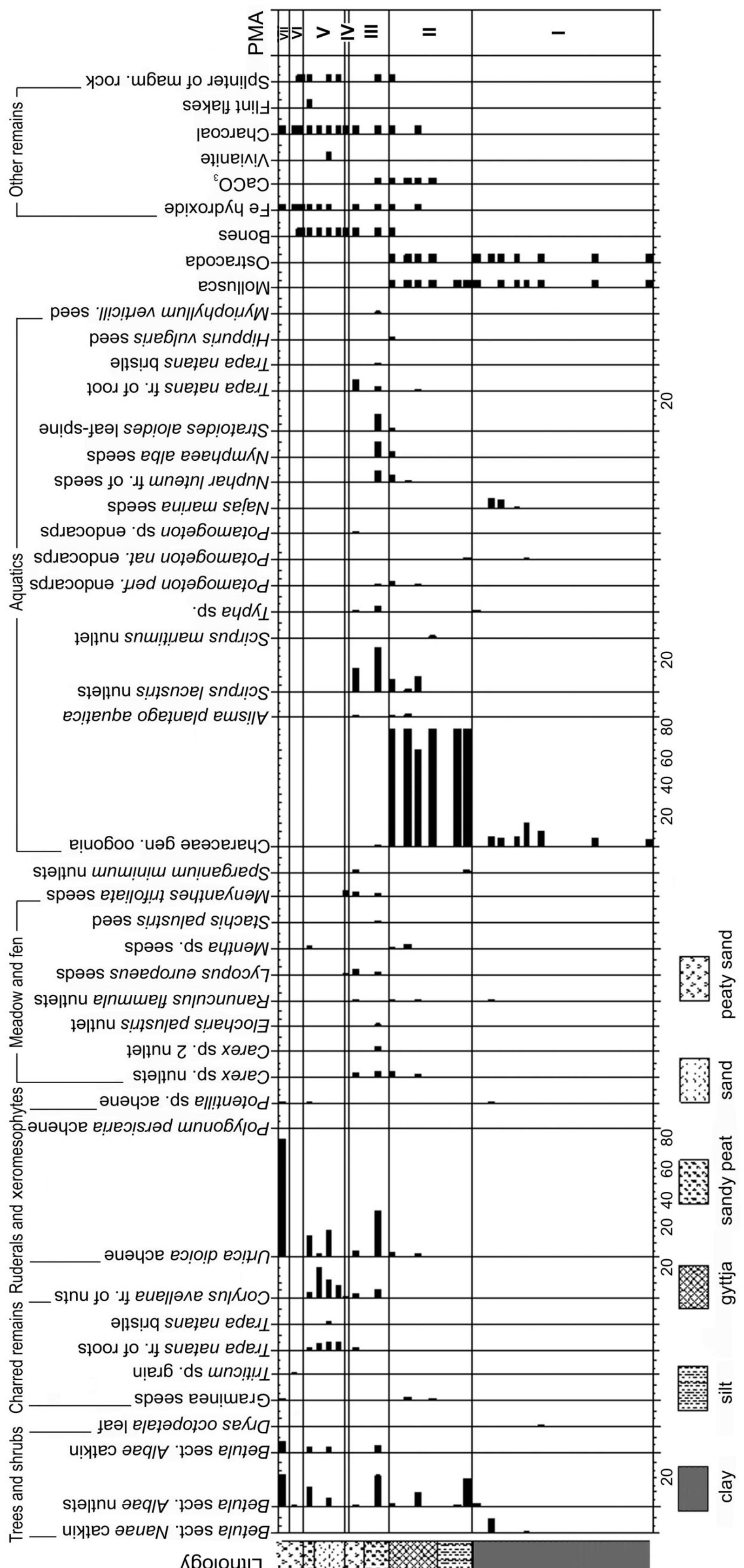

Fig. 5. Macroremain diagram from the Pantene/Braukšas I-2006 section.

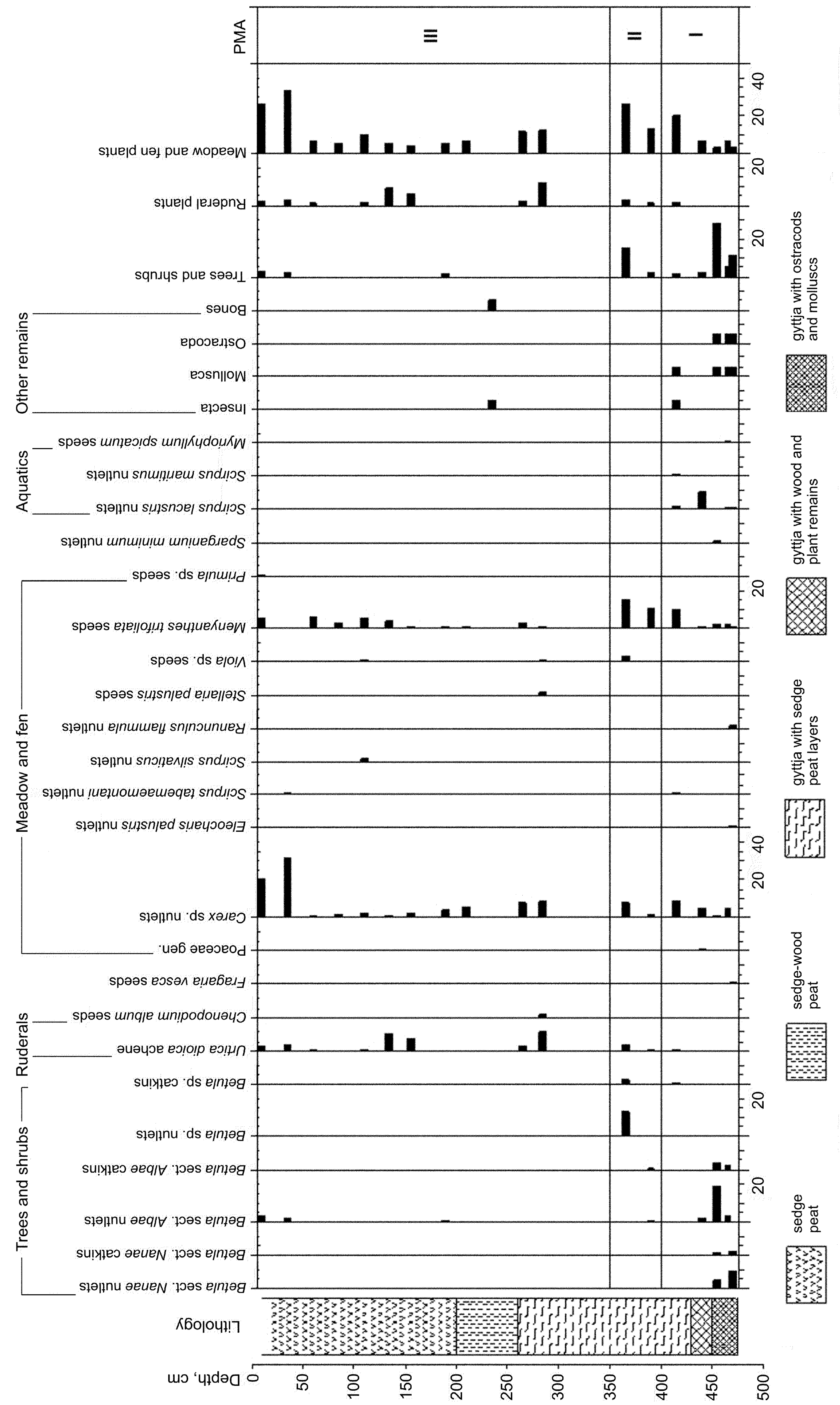

Fig. 6. Macroremain diagram from the Ceriņi-2007 section.

PMA-II (4.00–3.50 m, peaty gyttja)

Macroremains of plants from wet meadows and fens (*Menyanthes trifoliata*) are dominating in this zone. The presence of different wood remains (e.g. birch *Betula* sect. *Albae*) refers to intensive overgrowing of coastal areas and formation of a lake marsh during this interval.

PMA-III (3.50–0.00 m, peat)

Some remains of wet meadow and fen plants (*Carex*, *Menyanthes* and *Urtica dioica*) are present throughout the interval. Occasionally nutlets of *Betula* sect. *Albae* were found in the sediments.

DISCUSSION

Pollen data show vegetation dynamics in the Lake Burtnieks region since the Younger Dryas (DR3) until today. *Pinus*, *Betula*, *Salix*, *Betula nana*, Poaceae, Cyperaceae with some other subarctic species dominated in the landscape around the lake during the Younger Dryas. This observation correlates well with the data of Niinemets & Saarse (2006) from southeastern Estonia. Macrofossils – Characeae oogonia, shells of ostracods and molluscs – found in the lacustrine clay at the bottom of the Pantene/Braukšas I-2006 section, together with pollen of aquatic plants suggest that the clay was deposited in an oligotrophic lake during the late glacial.

Subarctic flora disappeared at the very beginning of the Holocene, during the first half of the Preboreal chronozone. Pollen data show the appearance and distribution of *Alnus* and *Corylus* in the birch–pine forest during the second half of the Preboreal (PB2). Vegetation development was similar in Estonia where *Ulmus* and *Corylus* appeared before 10 000 cal BP and *Alnus* later (Saarse et al. 1999; Saarse & Veski 2001). In the surroundings of Lake Burtnieks *Ulmus* appeared later (in the first half of the Boreal) than in the vicinity of Lake Verijärv in Estonia (Saarse & Veski 2001). *Equisetum* spores, algae, ostracods and molluscs refer to relatively shallow-water nearshore conditions during the Early Holocene.

Pinus and *Pinus–Betula* forest was characteristic of the Pantene site and the surroundings of Lake Burtnieks during the Boreal chronozone. The proportion of open areas, however, decreased.

Macroremains of plants from wet meadows and fens are prevailing in the Ceriņi-2007 site in the depth interval 4.50–3.40 m, which, according to pollen data, correlates with the first half of the Boreal. Different wood remains refer to intensive overgrowing of coastal areas and formation of lake marsh during this (BO) interval. Microscopic charcoal dust may be brought into the lake and bog by wind or by surface waters and the amount of these particles is expected to reflect the intensity of fires in the region. As indicated in the pollen diagrams, forest fires started in Boreal time, when coniferous species dominated in the vegetation. Thus, the curve of the charcoal dust reflects not only anthropogenic fires, but the sum of both, natural and anthropogenic fires. The largest quantities of charcoal and charcoal dust were found at a depth of ca 1.40 m, which is, according to pollen data, the first half of the Subboreal chronozone.

During the Atlantic chronozone the same tree species (*Ulmus*, *Tilia*, *Alnus*, *Corylus* and *Picea*) prevailed in the environs of Lake Burtnieks and in southeastern Estonia (Niinemets & Saarse 2009). During the first part of the Atlantic chronozone vegetation varied in different parts around the lake – pine forests were distributed at the Ceriņi-2007 site while *Ulmus*, *Alnus* and *Corylus* were dominating at the Pantene/Braukšas I-2006 site. This difference can be explained by changes in water level in ancient Lake Burtnieks. In the middle and at the end of the Atlantic chronozone (AT2) deciduous woodlands spread around the lake.

Fluctuating amounts of broadleaved tree pollen, together with increase in pollen of ruderal plants, charcoal dust and pollen of cultivated plants, indicate that ancient man not only inhabited the area, but also started farming activities during the Atlantic chronozone. A sharp peak in charcoal quantity at the end of the Atlantic chronozone suggests that the area suffered from fire that seems to have been a local event, because it did not leave traces into Lake Verijärv sediments in southeastern Estonia (Niinemets & Saarse 2006).

In comparison with southeastern Estonia where *Picea*, *Alnus*, *Quercus* and *Fraxinus* were distributed during the Subboreal (Niinemets & Saarse 2009), *Picea* and *Alnus* are prevailing in woodlands in the vicinity of Lake Burtnieks. Increase in the amount of *Picea* pollen and decrease in ruderals and cultivated plants indicate some deterioration of climate and less human impact during the Subboreal.

During the Subatlantic chronozone *Pinus* and *Betula* were dominating tree species in the area. At the same time the amount of ruderal plants (*Urtica*, *Artemisia*, Chenopodiaceae, Poaceae) increased while the distribution of *Picea* considerably decreased. Overall decrease in tree pollen quantity (from 90% to 80% at the Pantene/Braukšas I-2006 site and from 70% to 58% at the Ceriņi-2007 site) suggests a decline in woodland areas and expansion of fields, meadows and pastures. This conclusion is again in good correlation with the data from southeastern Estonia (Niinemets & Saarse 2006).

Pollen and plant macroremain data from ancient Lake Burtnieks evidence that gyttja started to accumulate in different places at different times. At the Ceriņi site gyttja accumulation started at the end of the Preboreal, whereas in the Pantene Mire it started around the Boreal–Atlantic boundary. In the Rūja Mire gyttja accumulation started at the beginning of the Atlantic period (AT1) (Kalniņa 2006). Fen peat started to form in the Pantene and Rūja mires at the end of the Atlantic period, but in the surroundings of the Pantene Drumlin at the beginning of the Boreal. This difference is explained by differences in sedimentation conditions between the two sites. For example, in the eastern part of the present Rūja Mire onset of peat accumulation occurred later due to the time needed for filling in the deepest parts of the palaeolake. The western part the lake was shallower and peat formation started earlier. The Ceriņi-2007 section is located close to the ancient coast of the lake and therefore the overgrowing of the site started significantly earlier (PB) than in the Rūja Mire (AT).

HUMAN IMPACT

Interpretation of pollen diagrams offers the potential for reconstructing human impact on the environment throughout prehistoric time (e.g. Iversen 1949; Behre 1986; Birks et al. 1988). The Stone Age people utilized the woodland surrounding their habitation sites by collecting wood for dwellings and fire. By opening up the forest and producing refuse, people created favourable conditions for the flourishing and spreading of light-demanding and nitrophilous herb taxa (Behre 1981, 1988; Berglund 1985, 1991; Chambers 1993).

Pollen of anthropogenic indicators like *Plantago major/media*, *Rumex acetosa/acetosella*, *Chenopodium alba* and *Urtica*, found at several sites in the northern part of the ancient Lake Burtnieks area, indicate the presence of Stone Age man in the region. Investigations of plant macroremains from the cultural layer of the Neolithic Zvejnieki settlement site revealed that seeds of *Chenopodium album* L. and charred fragments of *Corylus* nuts dominate in the studied material. Pollen data show pine forest during the Boreal in the surroundings of Lake Burtnieks, although significant quantities of herb pollen point to some open areas nearby. The presence of the latter may be explained by human activities – they opened the coastal area of the lake to make it suitable for living already during the Boreal chronozone.

Clear evidence of human presence in the area is available from the times when crop cultivation began. Into most of southern and central Europe, cereal cultivation was introduced by 5000 cal BC (Berglund et al. 1996; Haas 1996; Lang 1996). By about 4000 cal BC farming practices had reached northwestern and northern Europe (Andersen et al. 1996; Berglund et al. 1996). Crop cultivation was introduced in Latvia and northern Lithuania simultaneously with Estonia around 4000 cal BC (Lang 1999; Vasks et al. 1999; Stančikaite 2000), but considerably earlier than in southern Finland (ca 2500 cal BC; Vuorela & Hicks 1995). The first traces of crop cultivation in the Lake Burtnieks surroundings appear in the middle of the Atlantic chronozone (AT2) as the pollen of *Cerealia*, *Hordeum* and *Triticum* has been identified in the respective sediments. Thus the start of crop cultivation at Lake Burtnieks is approximately coeval with the Stone Age settlements in the Palaeolake Lubāns area in central Latvia.

Both wild gathered and cultivated plant remains, including charred nuts of *Corylus avellana* L. and *Trapa natans* L., were present in the sediments of the cultural layers of the studied sections. The charred *Triticum* grains were found in the upper part (0.50–0.30 m) of the cultural layer, which refers to later start (beginning of the Sub-atlantic chronozone) of crop-growing compared to the time seen from the pollen diagrams (middle of the Atlantic).

CONCLUSIONS

Pollen and macrofossil data from the northeastern area of ancient Lake Burtnieks indicate vegetation development since the Younger Dryas until today.

Minerogenic lacustrine sedimentation of sand, silt and clayey silt lasted until the Boreal or Atlantic chronozone, depending on the water depth at a particular locality in the ancient lake. Silt and clay were overlain by a layer of gyttja, while the latter is covered by well-decomposed fen (sedge, sedge–grass) peat which started accumulate at the end of the Atlantic.

The composition of pollen and plant macroremains suggests that the area was inhabited since the Preboreal–Boreal, but weak traces of possible presence of people are found already from the very end of the Younger Dryas.

The northern areas (Nordic Lake) of ancient Lake Burtnieks started to grow gradually in the Preboreal. Palaeobotanical data from the Braukšas 1 site reflect changes in lake trophy conditions from oligotrophic in the early Boreal (BO1) to mesotrophic in the middle Atlantic (AT2), and to complete fill-in and fen peat formation from the end of the Atlantic chronozone (AT2-SA).

Acknowledgements. The authors thank Sandijs Mešķis, Mārtiņš Kuzmins and Uldis Ozols who helped in field works. We thank Eliza Kušķe for her help in the laboratory. Many thanks go to anonymous referees for their helpful comments on the manuscript. The scholarship of the European Social Fund for doctoral studies to I. O. is greatly appreciated.

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Taimkatte arengu ja settetingimuste rekonstruktsioon Burtnieki järve ümbruses Põhja-Lätis

Ilze Ozola, Aija Ceriņa ja Laimdota Kalniņa

Paleobotaanilisi meetodeid (õietolmu- ja taimede makrojäänuste analüüs) kasutades rekonstrueeriti taimkatte arengu ning settekuhjumise olulisemad etapid Ürg-Burtnieki järve kunagises, nüüdseks kinnikasvanud põhjaosas. Taimestiku koosseis järve erinevates piirkondades varieerus sõltuvalt kliima, järve veetasemete, settekuhjumise ja inimmõju muutustest. Terrigeensete setete (liiv, aleuriit, savi) ladestumine kestis alates Hilis-Glatsiaalist kuni, sõltuvalt vee sügavusest, Boreaali või Atlantikumini. Järve põhjaosa hakkas järk-järgult kinni kasvama juba alates Preboreaalist. Inimmõju taimede õietolmu- ja makrojäänuste kooslusele on selgelt märgatav alates Preboreaalist.