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Records of the anthropogenic influence on different origin small lake sediments of Latvia

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Abstract Sediments in lakes have been formed under the conditions of sensitive ecosystem functions as historical records of micro- and macrocomponents. Besides others, lake sediments preserve macroremain and chemical evidence reflecting environmental changes and human impact. During the last centuries, sediment composition has been influenced by inconsistent urban and industrial developments. This article presents the multi-proxy data obtained from studies of lake sediment composition, chemical analysis and macroremain signatures in the upper sediment layer from tree small lakes of different origin: Lake Lilaste (lagoonal), Lake Velnezers (glaciokarstic), and Lake Veveri (glacial). The studies of lake sediments revealed that human impact is recognisable in the upper sediment layer of all investigated lakes, but at different depth from the sediment surface. The most recognisable traces of anthropogenic influence can be attributed to the increase of lead (Pb), cadmium (Cd) concentration, number of plant macroremains and charcoal particles in all investigated lake sediments.

Keywords *• gyttja • heavy metals • loss-on-ignition • plant macroremains • organic matter*

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INTRODUCTION

Sediment accumulation conditions in lake ecosystems are sensitive to the influence human of both, natural environmental conditions and anthropogenic activities, which can cause changes in sediment composition (Punning *et al* 2004; Smol 2008). According to the numerous studies of lake sediments, there were recognized conspicuous environmental changes during the last centuries. Through the field and laboratory investigations of lake sediments it is possible to strive for a better understanding of the processes how anthropogenic influence can affect ecosystems and sedimentation conditions. The major patterns of biostratigraphical and geochemical changes are detected by a range of multidisciplinary studies investigating recent environmental changes (Birks *et al.* 2004; Rose *et al.* 2004; Smol *et al.* 2005; Stivrins *et al.* 2014; Kalnina *et al.* 2015).

Documenting, understanding and responding to the present and future challenges posed by the recent environmental changes in the relationship between humans and surrounding environments have become as an essential for the modern human society. Several scientists support a new kind of stratigraphy or technostratigraphy, marked by the geologically accelerated evolution and diversification of technofossils driven by human purpose (Haff 2014; Zalasiewicz *et al.* 2014). This leads to the understanding of anthropogenic influence which can be characterized mainly as the result of urban and industrial inconsistent development over the last several decades affecting sediment composition and sedimentation conditions (Steffen *et al.* 2011; Cai *et al.* 2011; Wolfe *et al.* 2013). Chemical composition of lake sediments usually has been discussed from the viewpoint of pollution, but attention to the character of other changes in sediment composition caused by anthropogenic impact was not so strongly highlighted. Attention to the presence and values of heavy metals in lake sediments has been given under exploration and evaluation of sapropel (gyttja) as mineral resource in lakes of Latvia (Alksnitis 1992; Sicovs 1998). Although these data show only average values of and do not give understanding of their fluctuation during sediment accumulation. Relevancies of content and distribution of trace and major elements in the Latvian topsoils have been investigated by A. Gilucis (Gilucis 2007). Values of heavy metal accumulation in the mosses and soil have been carried out by Nikodemus and Brumelis (1998) and the highest concentrations of heavy metals (Cu, Pb, Ni, Co and Fe) have been determined in the Riga and Rezekne region (Pujāte 2015; Stankevica *et al.* 2015). According earlier studies of lake sediments the metal concentrations in sediments of lakes in Latvia are at a background levels (Klavins *et al.* 1995, 2011).

In Latvia currently is available a small number of multidisciplinary studies of lake sediment profile, which includes both chemical and macroremain analysis. Klavins *et al.* (1995, 2011) analysed trace element concentration in sediments of lakes in Latvia of different origin according to the factors influencing element availability. It was found that the concentration of metallic elements in sediments of lakes in Latvia is low (Burton 2002; Klavins *et al.* 2011).

The aim of this study is to try to find out the traces of anthropogenic impact on lake sediments. Small lakes compared to large lakes are more sensitive to changes in environmental conditions in the lake and its catchment area, thus they are well reflected in the lake sediments (Wetzel 2001; Meyers 2003; Punning *et al.* 2004). It was important to find out how records of anthropogenic impact are reflected in lakes of different origin.

BACKGROUND

Lakes and lake sediments represent a subject of studies on ecosystem dynamics focussing on the interaction between biological, chemical and physical processes, as determined by many different factors: the geological structure and topography of the drainage basin, the amount of precipitation, the inflow and composition of groundwater, human economic activities, biological processes etc. (Last, Smol 2001; Berglund 2003). Nowadays lakes in Latvia occupy about 1.6% of the territory. The largest part of lakes is of glacial origin, and their total area was significantly larger during the end of Late Weichselian, when depressions were filled by glacier melting waters. Over the time the shallowest and smallest lakes became fill-in and gradually overgrown. Other significant type of lakes within the territory of Latvia are lagoonal lakes located along the coasts of the Baltic Sea and the Gulf of Riga, Lagoonal lakes constitute young and dynamic systems (c. 3000–4000 years old), which, through a fall in sea level, have been completely separated from the sea, becoming freshwater basins (Eberhards, Saltupe 2002; Rosentau *et al.* 2012).

The major patterns of changes in geochemistry and biostratigraphy which can be suggested as anthropogenic influence in small lake sediments of Latvia are detected in multidisciplinary studies on recent environmental changes. There are several possible factors that may have influenced the recent geochemical and biostratigraphical changes recorded in studied lake sediments. However, in the current study the main attention is given to the modifications and fluctuations of major and trace element composition of sediment layers accompanied by the results of loss on ignition analysis and macroremain investigations (Lepane *et al.* 2007). Sedimentation rate is one of the most important parameters of the lakes dynamics, which are conditioned by various factors of natural and anthropogenic origin (Håkanson, Jansson 2002a) and can be various in different lakes.

These shallower lakes more intensive accumulate organogenic sediments and will overgrow faster. Only a few lakes in Latvia have remained in a mesotrophic state in the result of natural overgrowing and anthropogenic impact (Spriņģe *et al.* 2011). In the territory of Latvia humans lived near the lakes already since the Stone Age, somehow influencing lake ecosystems and leaving traces in the lake sediments (Murniece *et al.* 1999; Bērziņš 2008; Ozola *et al.* 2010). However, ancient human impact on lakes was local and did not strongly influenced whole lake ecosystems. Human impact increased gradually along the growing number of population in the surrounding of lakes and their catchment areas. Lake ecosystems became affected by prolonged human economic activity in the Early Metal Age and the Iron Age (Roberts 1998; Kalnina *et al.* 2004; Staškova *et al.* 2013; Brown, Pluskowski 2014; Stivrins *et al.* 2015). During the Medieval Age denudation in the lake catchments areas, erosion and terrestrial material transport and accumulation on lake bottoms were caused by deforestation and agricultural activities (Hoffman 2014). The cooling and humidification of the climate during the Little Ice Age also have contributed to the acceleration of the agrotechnical denudation.

It is important to determine the changes in lake sediments by using multiproxy data and to prove how lake sediments are vulnerable to anthropogenic impacts (Stumm, Baccini 1978; Davies *et al.* 2005; Plater *et al.* 2006). Investigation of sediment composition from lakes can reveal fluctuations of water level and climatic changes. Only complex multiproxy data help to make a reconstruction of environment and to assess natural and human impact with certainty. This is particularly significant for the studies of lake sediments accumulated during the last centuries, because result of these studies can determine evidence of rapid recent environmental changes in lakes of Latvia (Alksnitis 1992; Klavins *et al.* 2011) including increase of metal, particularly lead, concentration in the upper layers of lake sediments.

Analysis of trace element accumulation in sedimentary phases of lakes may reflect the overall regional pollution level, but analysis of trace element accumulation patterns in sediment profiles can help to reconstruct history of anthropogenic impacts, and provide information about trends of recent accumulation (within last 300 years) and balance between natural and human induced accumulation processes (Klavins *et al.* 2012). It is stated that the main mechanism of heavy metal dispersion in the environment is atmospheric transport; therefore, anthropogenic Cu and Pb contamination is widely distributed (Renberg *et al.* 1994; Planchon *et al.* 2002: Pujāte 2015) and has been detected in remote areas, including polar ice caps (Hong *et al.* 1994).

DESCRIPTION OF STUDY SITES

Within this investigation selected tree small lakes of different origin (Lake Lilaste has lagoonal, Lake Velnezers glaciokarstic, and Lake Veveri glacial origin), located close to highway or railway (Fig. 1) and containing rich organic sediment layers.

Lake Lilaste is of lagoonal origin and is very sensitive to the environmental changes. Lake Velnezers is smallest from studied lakes and has glaciokarstic origin (for general characteristics see Table 1). Lake Veveri has glacial origin, is located in the Latgale Upland at the eastern Latvia and has been included in the study with aim to find out peculiarities of anthropogenic influence in different nature regions.

Lake Lilaste

Lake Lilaste (Fig. 1A) occupies the former lagoonal area at the eastern coast of the Gulf of Riga, in the eastern part of the Rigava Plain of the Coastal Lowland (Turlajs 1999). Shores of the lake are flat, sandy, surrounded by dunes. The sandy bottom of Lake Lilaste is covered by gyttja and mud. At the southern part the lake is connected with the Lake Dunezers, but from the east there is the inflow of the River Melnupe. Along the western shore of the lake runs A1 motorway Riga–Tallinn, named as 'VIA Baltica', and railway at the distance of 100 m.

Lake Velnezers

Lake Velnezers (Fig. 1B) is located in the Rigava Plain of the Coastal Lowland within the accumulation-abrasion plain of the Baltic Ice Lake and the Littorina Sea Plain, traversed by the former valley of the Daugava and the valleys of other hydrographic networks and streams, in addition to which it is complicated by dune massifs and wetland areas (Brangulis *et al.* 2000). Lake Velnezers is formed in a glaciokarstic depression between the ancient dunes. Lake

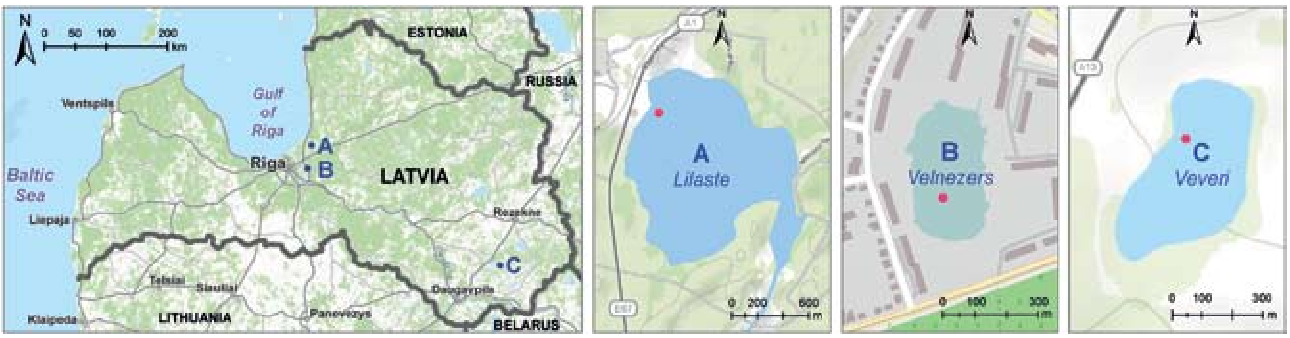

Fig. 1 Location of investigated lakes and sampling sites (marked with red points): A – Lake Lilaste, B – Lake Velnezers, C – Lake Veveri. Compiled by K. Stankevica, 2015

Table 1 General characteristic of the studied lakes Compiled by A. Pujate and K. Stankevica, 2015

Lake characteristics	Lake Lilaste	Lake Velnezers	Lake Veveri
Water surface area, km^2	1.87	0.04	0.075
Max. water depth, m	3.2	6.0	1.9
Origin	Lagoonal	Glaciokarstic	Glacial
Character of hydrological regime	Outflow/inflow	Closed basin	Outflow
Trophic degree	Eutrophic	Dystrophic	Eutrophic
Catchment basin landscape	Green area, pine forest with meadows, nearby railway and highway	Urban, intensively built-up area	Rural area with mixed forests and meadows, highway in 100 m distance

is without any outlet, fed mainly by groundwater. It has flat shores and sandy bottom (Lūmane 1998) and brown-coloured water characteristic for dystrophic lake. The colour of water results from high concentrations of humic substances and organic acids suspended in the water from peat layer underlayed gyttja at the bottom. Lake Velnezers is surrounded by many residential buildings which construction started in 1960 when the ambient pine forest was cut down, but more intensive construction activities were carried out in 1980s (Lūmane 1998).

Lake Veveri

Lake Veveri (Fig. 1C) has glacial origin and is located in the morainic interhill depression in the Feimani Hilly area of the Latgale Upland, eastern Latvia. Nowadays it has flat overgrowing shores. At the eastern shore the lake has outflow by ditch flowing to the Lake Kovaliski. Lake Veveri is located close to motorway A13 Daugavpils–Rezekne which runs at 0.2 km from the north-west shore of the lake.

METHODOLOGY

Chemical, loss on ignition (LOI) and palaeobotanical investigations of lake sediments using instrumental analytical methods can help reveal the processes and impacts influencing lake development and human pressures, especially during the last centuries (Renberg *et al.* 2001). This study includes the field research, sediment sampling and consequent laboratory analysis in all three lakes. Sediment sampling was carried out during 2010–2014 by coring from ice and boat. Coring points in all three investigated lakes were selected after the analysis of topographic maps and taking into account characteristics of lake and it surroundings. Sediment coring was carried out closer to the possible pollution sources (highways). Among the anthropogenic impacts the traffic intensity and vehicles exhaust can be mentioned. The oils and grease are leaked onto road surfaces from car and truck engines and can be carried into lakes and accumulated in lake sediments (Walraven *et al.* 2013). The data presented by Rose *et al.* (2004) suggests that the impact of fossil-fuel combustion sources can be observed within a radius of approximately 60–80 km, thus affecting a large area.

Coring has been done by a 10-cm-diameter Russian-type peat sampler with 1.0 m long camera. Parallel overlapping sediment cores from each studied lake were taken and documented according to the requirements for sediment sampling for physical and chemical analysis; samples were packed into film-wrapped plastic semi-tubes and transported to the laboratory.

The collected sediments were subsampled in laboratory and prepared for analysis according to the certain methodology. The main attention has been given for upper 50 cm layer of sediments in Lake Lilaste and Lake Velnezers. For Lake Veveri it was analysed 200 cm of upper part of 800 cm thick gyttja layer taking into account ^{14}C dating results. It was expected that human impact in sediments could appear 3000 cal yr BP when during Greek and Roman civilization flourishing Pb/Ag mining and smelting activities took a place 2700–1700 cal yr BP (Candelone *et al.* 1995). For the sediments from each lake the major and trace element quantitative analysis was performed, as well as LOI and plant macrofossils was done with the aim to obtain complex data.

The data from studies on the concentrations and levels of heavy metals in lake sediments can serve as indicators of the levels of environmental pollution in the drainage basins of water-bodies (Salomons, Förstner 1984). However, these data need to be interpreted very carefully, because the sediment composition may also include metals of natural origin and atmospheric pollution. Concentration of major and trace elements (Cu, Zn, Pb, Cd, Cr, Co, Ni, Na, Mg, K, Ca, Fe and Mn) were determined for sediments from three freshwater lakes of Latvia (13 samples for Lake Lilaste, 13 samples for Lake Velnezers and 15 samples for Lake Veveri) after acid digestion of samples (Csuros, Csuros 2002).

The sample pre-treatment procedure involved following steps. Air-dried lake sediment samples were poured into glass beaker and dissolved in 25 ml of concentrated HNO_3 and 5 ml of H_2O_2. The samples were digested by heating on a hotplate (Biosan) until the evaporation of the liquid. Then dissolution was repeated with 25 ml of concentrated HNO_3 and heating was accelerated to boiling. The sample solutions were cooled and filtered; the remains on the filter were washed with deionised water until the filtrate volume of 50 ml. Quantitative content of elements was measured by atomic absorption spectrometry (AAS) using *'AAnalyst 503'* (Perkin Elmer).

Loss on ignition (LOI) method was applied for sediment analysis in order to estimate the moisture level and content of organic matter, carbonates and mineral matter in the sediment 1 cm interval (Håkanson, Jansson 2002b; Heiri *et al.* 2001). Fluctuations in values of these sediment characteristics point on changes in sedimentation conditions and give additional information for data interpretation. Moisture of sediments was determined after drying samples at 105°C in drying oven. Content of organic and carbonate matter was analysed by incinerating the samples sequentially at 550°C for 4 h and at 900°C for 2 h.

The results of plant macroremain analysis provide information about the quantity and composition of aquatic plants during the deposition of a particular sediment layer, making possible to reconstruct conditions in the basin during it development (Hannon, Gailard 1997; Birks 2001). Plant remains, for example, seeds tend not to be transported in large distance (Dieffenbacher-Krall 2007), therefore provide a basis for assessing local changes in the lake palaeoenvironment. Sediments for plant macrofossil analysis were subsampled with interval 5 cm for Lake Lilaste and Velnezers, 10 cm for Lake Veveri section and prepared in accordance with standard method (Warner 1990; Birks 2001), wet-sieving them with a 250-micron sieve.

Macrofossils were examined systematically under a Stemi 2000-C stereomicroscope at about 10–40× magnification and identified by comparison with atlases (Katz *et al.* 1965, 1977; Cappers *et al.* 2006; Velichkevich, Zastawniak 2006, 2008) and herbarium collection reference materials (Laboratory of Quaternary Environment of the Faculty of Geography and Earth Sciences, University of Latvia; Latvian Museum of Natural History), counted and tabulated (Birks, Birks 1980).

The obtained data were treated and visualised by several methods. The obtained radiocarbon dates for sediments of Lake Velnezers (5 samples) have been done at the Scottish Universities Environmental Research Centre – SUERC (GU) and for Lake Veveri (5 samples) sediments at the Institute of Geology, Tallinn University of Technology (Tln), Estonia. Obtained ^{14}C data were converted to calibrated age (cal yr BP), and, by means of Clam v.2.1 (Blaauw 2010) and R v.2.1.2 software (R Development Core Team 2010). Sediment profiles were visualised using Tilia v.1.5.12 software (Grimm 2012). In this study, selected statistical methods were used to determine major and trace element accumulation intensity and its' affecting factors. The results were processed by the Microsoft Excel 2010 Data analyses correlation; data were plotted and visualised using Adobe Illustrator CS6.

RESULTS AND INTERPRETATION

Lake Lilaste

The LOI analysis show changes of metal accumulation in Lake Lilaste sediments during the sediment formation at the depth of 5 cm from surface and also in the layer of 35–45 cm, where obtained values of mineral matter content increased (Fig. 2A). Most likely that it is related to the soil erosion in catchment area. The land cover in this region is very sensitive because of sandy soils.

Data of chemical analysis of the upper layer of Lake Lilaste sediments (50 cm) revealed that Cr concentration is tended to increase (16.5–22.6 mg/kg) and accelerating changes have occurred at the depth of 35–10 cm. As well as other heavy elements, also concentration of Co and Ni has tendency to increase evenly from the lower sediment layers to the top. Concentration of Cu and Zn also has tendency to increase but with more considerable fluctuations, for example, value of Cu and Zn concentration at the depth of 34 cm were 4.9 mg/kg and 31 mg/kg, respectively, while the values rise up at upper sediment layers.

The sediments of Lake Lilaste contain high Fe concentration (up to 52 583 mg/kg, on average 43 813 mg/kg) in whole sediment section. It is not a characteristic for lake sediments in Latvia, where usually Fe concentration is around 20 000 mg/kg (Klavins *et al.* 1995; Jankēvica *et al.* 2012; Stankevica *et al.* 2012).

Pb concentration in average is 8.6 mg/kg, for studied Lake Lilaste sediments at the depth interval 34–50 cm, while from the depth of 34 cm upwards to top Pb concentration increase from 18.5 mg/kg to 35.7 mg/kg. In generally Pb concentration in sediment section fluctuate similarly as for Zn, from the depth of 30 cm to the top layer of sediments.

It was expected that the changes in metal composition of sediments will appear at the depth of 40 cm (thin silty gyttja layer) because of changes in sediment composition detected by loss on ignition method. However, obvious changes in analysed element concentration values were observed at the depth of 34 cm, when concentration dropped and then increased rapidly, except for Cd. Concentration of Cd on average was high (about 3.0 mg/kg) at the depth of 22–29 cm compared to the Cd average value of background which was only 0.3 mg/kg. Such rapid changes of Cd concentration may be an indicator for human activities in the catchment area of the lake.

Positive correlations were observed for Cr-Co-Ni-Cu-Zn-Fe-K-Mg after Lake Lilaste sediment analysis at depth 0–50 cm (Fig. 2A). It is supposed, that carbonates positive correlate with Ni, Co, Mn, K and Mg, but negative correlate with mineral matter. Cd has no correlation. Ca has positive correlation with Na and Mn. Pb has positive correlation only with Ni. Element correlation analysis revealed that Lake Lilaste sediments are influenced by anthropogenic impact and it can be assessed as the zone of natural geochemical barriers for input waters from the River Melnupe and the Lake Dunezers to the Baltic Sea.

Plant macrofossil analysis was carried out from the sediments sampled close to the lakeshore (Fig. 3), where submergent and floating aquatic plants characteristic of eutrophic lakes nowadays occur (Eņģele, Sniedze-Kretalova 2013). In the upper 10 cm of the lake sedi-

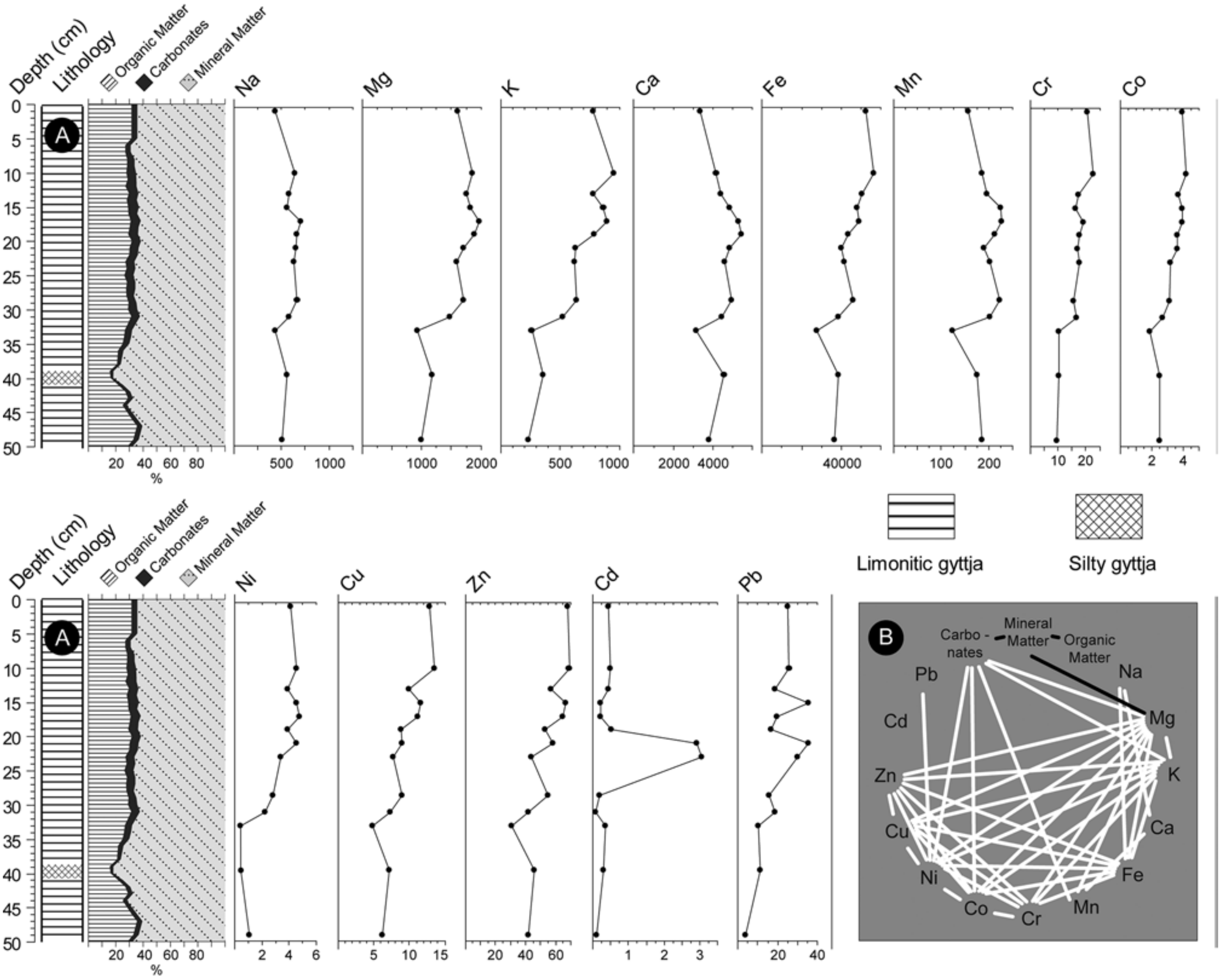

Fig. 2 (A) Sediment composition according Loss on Ignition analysis and major and trace element concentration (mg/kg) diagrams from Lake Lilaste upper 50 cm sediment layer; (B) Significant element correlations (P > 0.01; N=15). Black lines negative correlation, white lines – positive. Compiled by A. Pujate and K. Stankevica, 2015

ments idioblasts of water lily *Nymphaea* were identified, indicating that water lilies grew in the lake, even though no seeds were found (Fig. 3). Sediments in the depth interval 55–15 cm are rich in aquatic fauna, particularly with Cladocera, while at the depth of 15 cm they almost disappear. Charcoal fragments – one of the indicators of human impact – were found in small amounts already at 55 cm depth, and were present in greater quantity starting from 45 cm. This boundary coincides with the disappearance of pine bark fragments in the sediments (Fig. 3).

Lake Velnezers

Chemical analysis of Lake Velnezers sediments (Fig. 4A) showed that the highest concentration of heavy metals was detected for Pb, reaching 75.5 mg/kg. That can be related mainly to the air and surface water transport and car internal combustion engine activities. Lake Velnezers is located in the area where the road enters the catchment area of the lake; therefore, Pb pollution by airborne particles may appear (as the result of the movement of air masses). Concentration of Cd in Lake Velnezers sediments was found in a small amount, 2.14 mg/kg. Cd may release into environment from burning diesel fuel and subsequently may air-assimilate in sediments (Fig. 4A).

Metal concentration in the lake sediments increased from the depth of 15 cm and above, but the largest values reached at the depth of 5 cm where Ni concentration was 15.1 mg/kg, Co 3.9 mg/kg and Cr 25.7 mg/kg. These elements in the environmental samples usually are found incorporated in chemical compounds, which, like Pb and Cd, may be harmful and probably point on anthropogenic impact, because background values are significantly lower. The diagram created according to the data of chemical analysis of Lake Velnezers sediments (Fig. 4A) revealed that concentration of elements is significantly greater in the very upper sediment layer in comparison with lower ones at the depth of 25–50cm. It points on strong increase

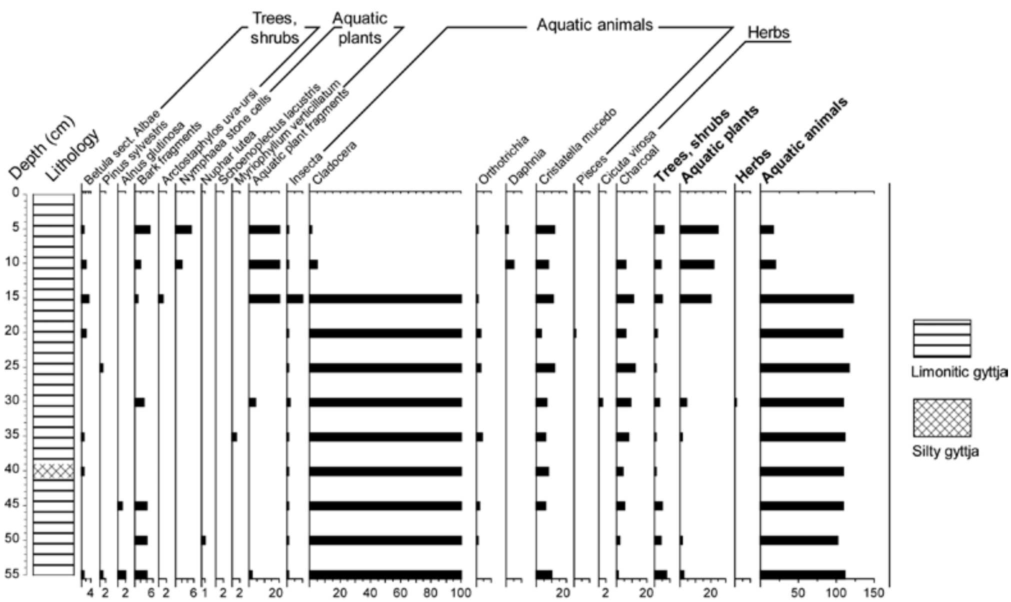

Fig. 3 Plant macrofossil diagram from upper sediment layer from Lake Lilaste sediments. Compiled by A. Pujate and K. Stankevica, 2015

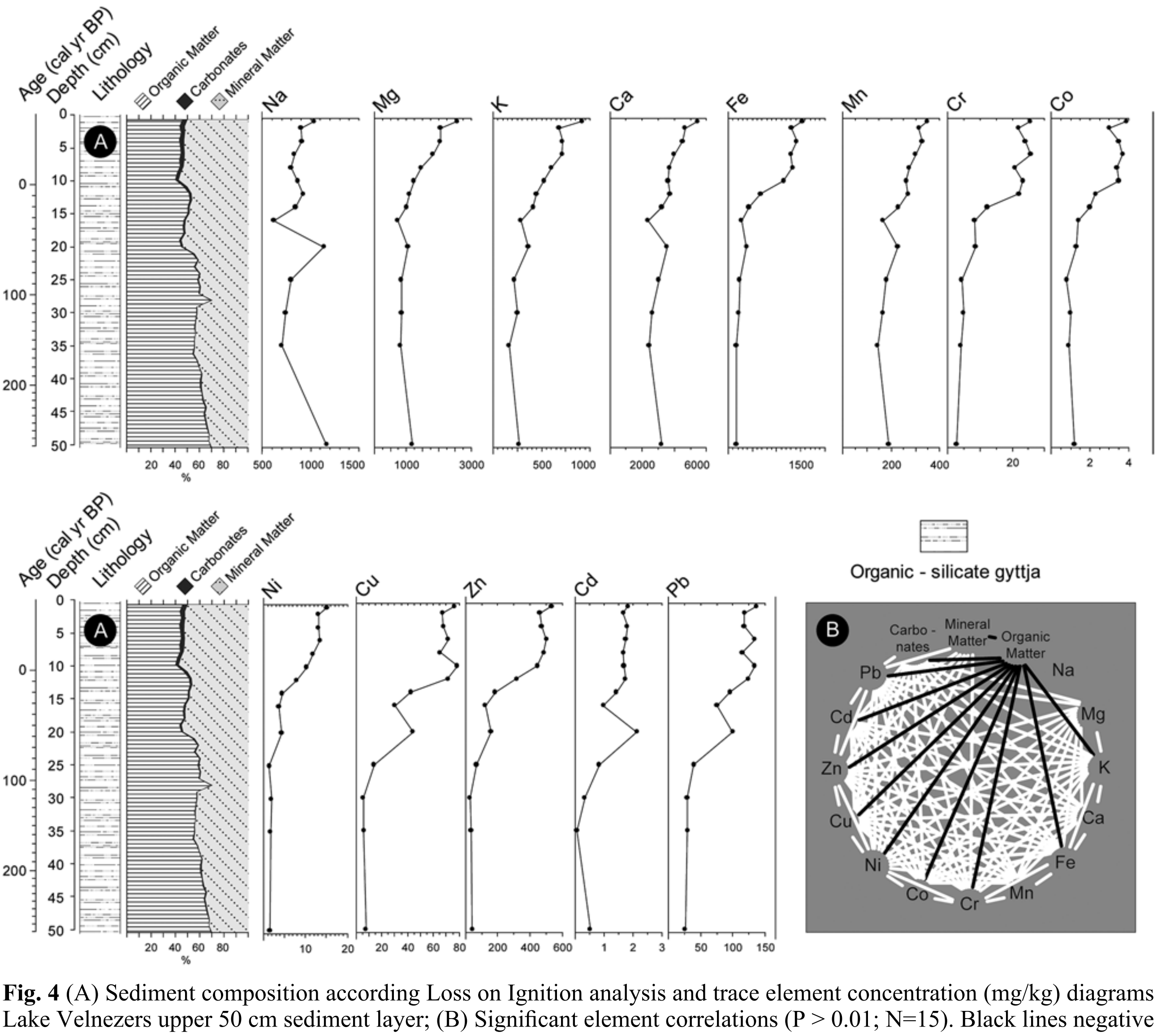

Fig. 4 (A) Sediment composition according Loss on Ignition analysis and trace element concentration (mg/kg) diagrams Lake Velnezers upper 50 cm sediment layer; (B) Significant element correlations (P > 0.01; N=15). Black lines negative correlation, white lines – positive. Compiled by A. Pujate and K. Stankevica, 2015

of anthropogenic influence characterised by intensive metal accumulation (Zerbe *et al.* 1999).Results of chemical analysis of Lake Velnezers sediments reflect that in the upper layer of sediments accumulated metals concentration was three times higher than in the sediments at the lake bottom.

The range of concentration of Cu, Pb and Zn displayed great spatial variability of elements in the lake sediments which suggests anthropogenic origin of these elements. Chemical analysis of Lake Velnezers sediments (Fig. 4A) showed strong influence level that can be explained by its location in an urban environment, as well as the fact that the lake is waterless, i.e., accumulated elements assimilate and do not distribute.

Statistically significant analyse of Lake Velnezers sediments (Fig. 4B) shows that only Na has no any correlation. All other elements Mg-K-Ca-Fe-Mn-Cr-Co-Ni-Cu-Zn-Cd-Pb-Carbonates and Mineral matter has negative correlation with organic matter and positive links to each other. It is supposed that metallic elements are carried in lake with mineral matter and carbonates including air pollution and inflow waters from the lake catchment basin. Lake Velnezers is situated in urban area with apartment buildings, roads and streets. Local people use the lake for recreation over the year especially at summer; municipality regularly reap grass, bushes and remove biomass from the lake catchment area which is natural barrier zone for anthropogenic contamination.

According plant macroremain analysis of lower lake sediment layer (20–50 cm) is represented by peaty gyttja rich in macroremains containing different species of plant remains (Fig.5). In the upper layer of sediments (upper 20 cm) of Lake Velnezers there were not found seeds, possibly it was due to the sedimentation density. Fragments of pine (*Pinus sylvestris*) needles were found in lightly decomposed in two layers (20–25 cm depth), while birch (*Betula sect. Albae*) nutlets were found almost in all plant macrofossil records of the sediments (Fig. 5).

From terrestrial plants in the upper layer remains of reeds were found, but they were not detected in the lower lake sediment layers; such species as common spike-rush *Eleocharis palustris*, hare's-tail cottongrass *Eriophorum angustifolium*, toad rush *Juncus bufonius*, compact rush *Juncus conglomeratus*, thread rush *Juncus filiformis* were recognized. From aquatic plants stone-fruits were found belonging to least Burreed *Sparganium minimum* (at the depth of 40 and 55 cm) which usually is growing in shallow marshes, ponds and streams (Kaul 2000).

In this upper layer also spore-bearing were found, dominating by moss leaves *Sphagnum* (*Sph. angustifolium*, *Sph. magellanicum*, *Sph. subsecundum*) (mainly in the upper layer of 30 cm) and *Hypnum* (*Drepanocladus*). In the lake sediments moss leaves enter with flushing from the steep shores of the lake. Increased amount of *Hypnum* and *Sphagnum* moss in this area may be a sign of bogging of the lake shore. Increased number of charcoal was detected in the upper layers of sediments in comparison to the lower lake sediment layers (not shown in the diagram). However, the charcoal appears throughout all lake sediment record. In the upper sediment layer large number and variety of terrestrial plant remains were found. This can indicate the inflow of nutrients, the base of plant nutrition, promoting the growth conditions, leading to the eutrophication of lakes and overgrowing processes.

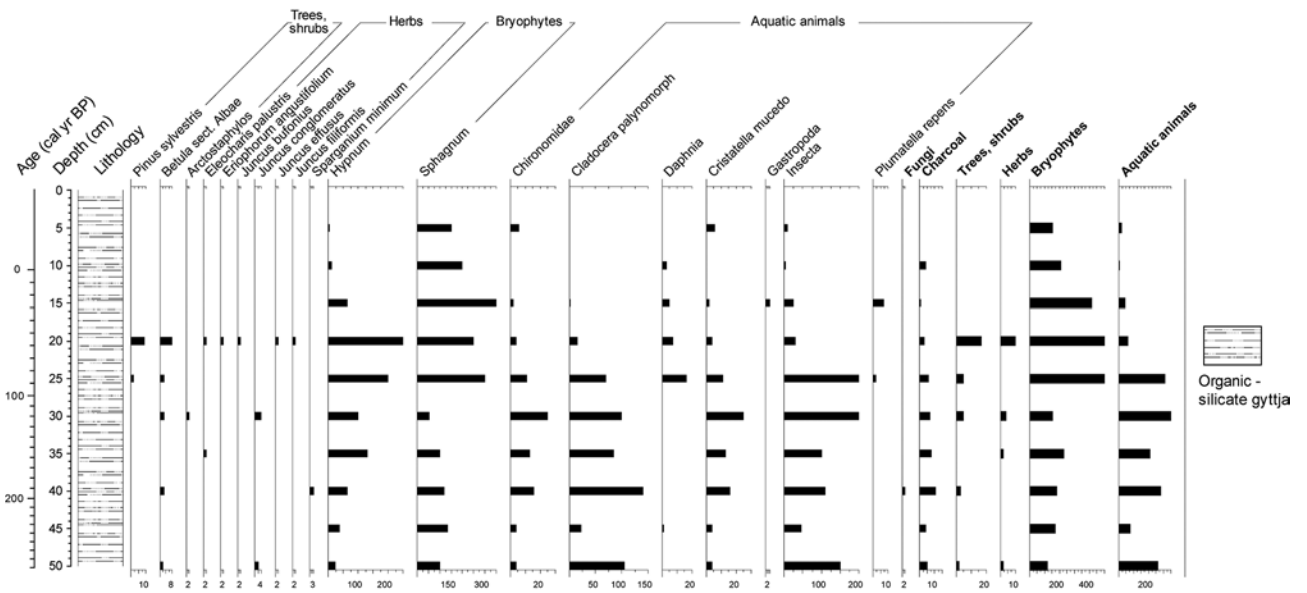

Fig. 5 Plant macrofossil diagram from Lake Velnezers sediments. 0 cal yr BP=1950 AD. Compiled by A. Pujate and K. Stankevica, 2015

Lake Veveri

The data derived by LOI from Lake Veveri show that in the lake sediment composition organic matter dominates, while carbonates are almost absent (Fig. 6A) Chemical analysis of Lake Veveri sediments revealed almost constant concentration of metals (Cr, Co, Ni, Cu) in the upper 50 cm of sediments. Accelerated changes of Cr, Co, Ni, Cu concentration were observed at the depth of 75 cm when the measured values were almost two times higher. The proportion of sediment components at this depth varied, the amount of mineral particles increased to 30%.

Cd and Pb concentration can be assessed as low (on average 0.25 and 3.00 mg/kg, respectively), but starting at the depth of 60 cm and above the concentration increased rapidly (on average 1.29 and 18.7 mg/kg, respectively). In the Lake Veveri values of Cd concentration rise up rapidly at the time dated by ~590 cal yr BP, and then 300 cal yr BP values fall back to natural level, as it was observed also in the case of Lake Lilaste. Cd during last 300 years has tendency to slow increase in all studied lakes.

Statistically significant element correlations from the sediment analysis of Lake Veveri which is situated in the rural area shows two groups of elements that have no links to each other. The characteristics of positive correlation among Na, Mn and Fe (Fig. 6B) provide that these elements are of natural origin. Positive correlation was observed also for Mg-K pair that can be explain as an influence of use of fertilizers in the lake catchment area. Pb has negative correlation with organic matter and positive links with mineral matter, Co and Cu. These data provide that heavy metals in the lake sediments could be runoff from the pollution induced by traffic on the motorway A13 Daugavpils–Rezekne. The motorway lays in the

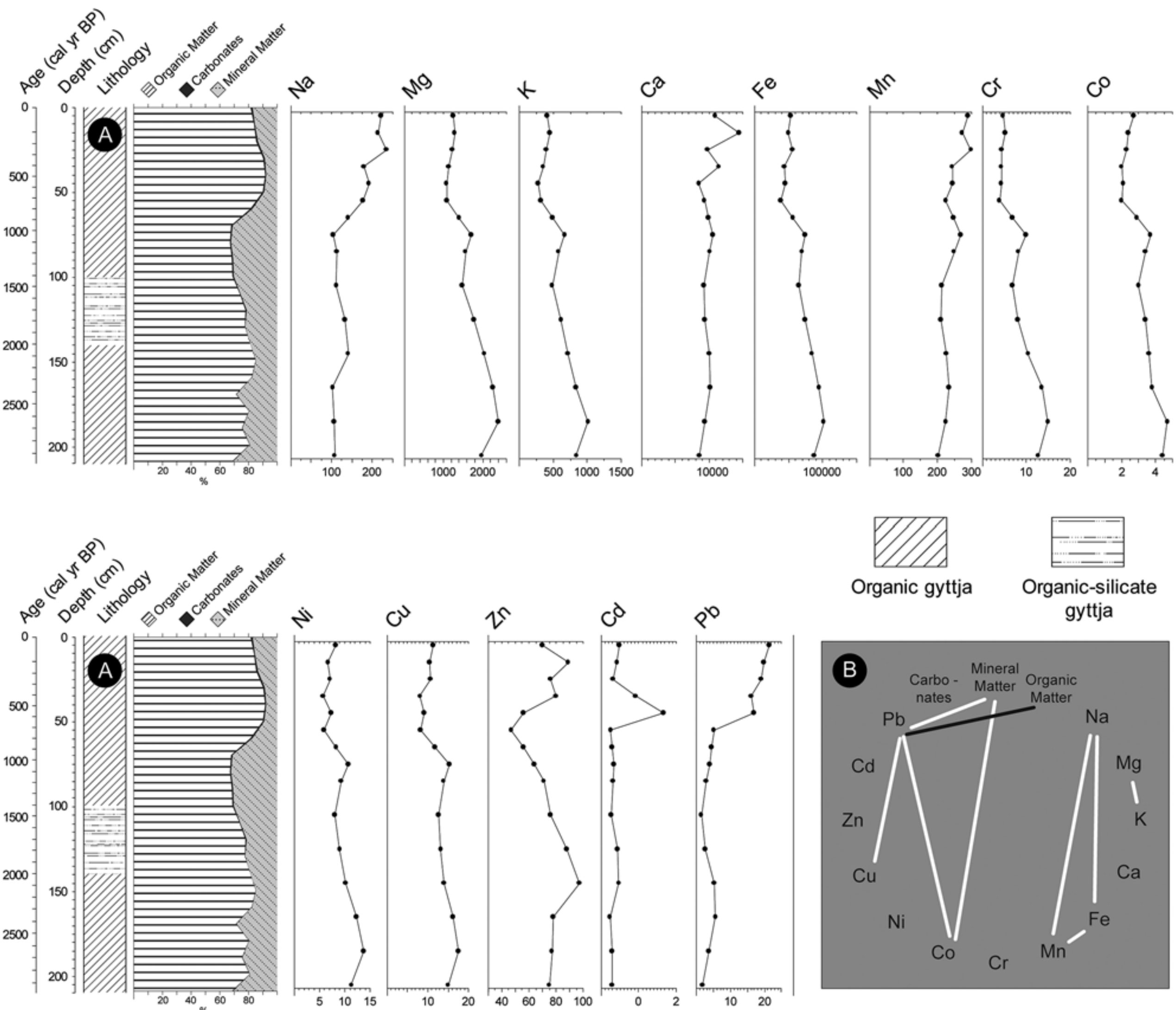

Fig. 6 (A) Sediment composition according Loss on Ignition analysis and major and trace element concentrations (mg/kg) diagrams Lake Veveri upper 200 cm sediment; (B) Significant element correlations (P > 0.01; N=15). Black lines negative correlation, white lines – positive. Compiled by K. Stankevica, 2015

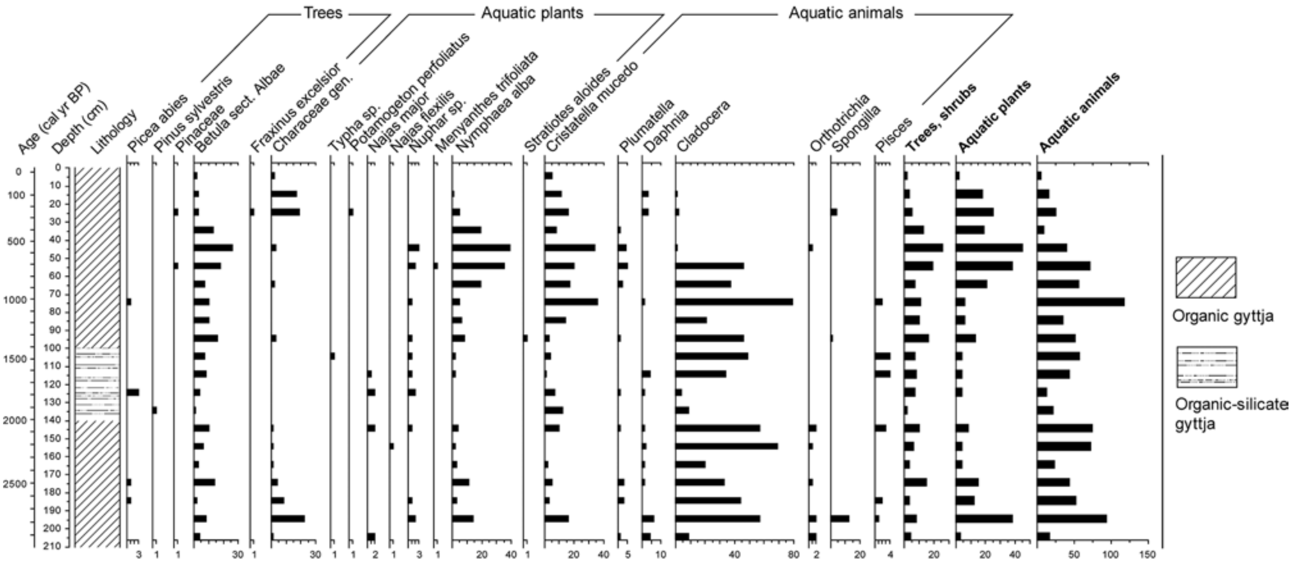

Fig. 7 Plant macrofossil diagram from Lake Veveri sediments. Compiled by A. Cerina and K. Stankevica, 2015

lake catchment area, only 200 m to the west part of the lake shore.

The results of macrofossil analysis discovered the dominance of birch plant macroremain (Fig. 7) in the upper layer of the lake sediments, indicating the presence of birch in the surrounding area. There were also found macroremains of pine and spruce trees. Directly in the upper 50 cm of the lake sediments only three species of limnic plants were found, i.e., Characeae (oogonium), consisting of *Chara* sp. and *Nitella* sp., perfoliate pondweed *Potamogeton perfoliatus* and *Numphaea alba*. *Chara* usually grows in mesothropic lakes in Latvia. These plants are forming extensive underwater carpets of up to 4 m deep in lakes. This aspect can be observed that there were more tops *Chara* remains (oogonia), aquatic plants reduce remains (at the depth of 0–30 cm and 165–210 cm). Perhaps it shows the water level fluctuations in Lake Veveri. In comparison, in other lakes it is possible to detect that with the increase of *Chara* also the number of cladocerans macroremains is increasing in lake sediments (Pujate 2015). *Chara* and perfoliate pondweed *Potamogeton perfoliatus* can be found in brackish water habitats and calcareous ponds (Godfrey, Wooten 1979). Perfoliate pondweed *Potamogeton perfoliatus* is among very tolerant species, known to persist in very nutrient-rich lakes (Sand-Jensen *et al.* 2008) and coverage in shallow water areas (Lu *et al.* 2012).

Perfoliate pondweed *Potamogeton perfoliatus* is the one of most common species of pondweed in Latvia (Stankevica *et al*. 2015) and Lithuania (Gryguc *et al.* 2013). The sediments of Lake Veveri are rich in *Cladocera* remains up to 50 cm, but they almost disapear in the upper sediment layers. In deeper part of the lake sediments have been found remains of bulrush *Typha* sp., holly-leaved naiad *Najas major*, slender naiad *Najas flexilis*, water-lily *Nuphar* sp., bogbean *Menyanthes trifoliata* and water-soldier *Stratiotes aloides*. Water-soldier *Stratiotes aloides* are characteristic species for standing, eutrophic waters.

DISCUSSION

Lake sediments have a high potential for accumulating pollutants, because in the hydrological cycle less than 1% of metals actually occur in dissolved form in the lake water; more than 99.9% occur in the sediments (Salomons 1998). The lakes chosen for study are of different origin, however the results obtained from sediment analysis show that changes in composition of the lake partly caused be human activity. As a result of human impact, changes have taken place in the superficial sediments, which is connected with the intensification of wind transport and dune migration, as a result of the levelling of dunes (at Lake Velnezers, Lake Lilaste), changes of lake catchment area sizes for all studied lakes.

The results of LOI analysis show that organic and mineral matter varies 40–60% in the composition of upper layer sediments in studied lakes, while values of carbonates very low, but with tendency to slightly increase in the very upper sediment layer. In general the significant amount of carbonates in lake sediments expands along with an increase of quantity of *Chara* (Apolinarskaa *et al.* 2011). But in our study amount of *Chara* is increasing in Lake Veveri in the upper layer of sediments (0–25 cm) without increase of carbonates. This is probably due to another parameter such as the depth of water in the lake, the chemical composition of lake water and lake bed sediment character or some other parameters.

Plant macrofossil analysis provides a clear indication of lake overgrowing, reflected in an increase in the quantity and species diversity of seeds of plants growing in shallow, slowly flowing, nutrient-rich waters, along with an increase in the quantity of seeds of damp-loving plants. These trends are observable in the change in macrofossil composition in the sediments of Lake Velnezers, where remains of damp-loving and wetland plants are identifiable in the 70–0cm interval, including sedges, common spike-rush, common cotton-grass, toad rush etc. Aquatic plants, on the other hand, are represented only by least bur-reed, which generally grows in wetlands, ponds and streams; this indicates intensive overgrowing of the lake. The presence of *Nitzschia acicularis* in the superficial sediment layers indicates eutrophication, which was found in uppermost layers of Lake Lilaste (10–0 cm) sediments and in Lake Ummis (Staskova *et al.* 2014; Pujate 2015).

It should be mentioned that in the upper 40 cm layers of Lake Lilaste and Lake Velnezers sediments appear wood charcoal. A greater concentration of charcoal fragments occurs in this interval of the sediments, testifying to human activities in the drainage basin of the lake, possibly with tree-cutting and burning or forest fires. According radiocarbon dating of sediments containing higher concentration of charcoal in Lake Velnezers was accumulated during 80–180 cal yr BP. It can be caused by changes in the lake catchment area, such as forest fires and anthropogenic activities like forest clearance and agriculture, typically increase and enlarge the general rate of erosion and sediment transportation into the lakes (Staškova *et al.* 2014).

One of the most easily traceable indicators is the pronounced increase in the concentration of heavy metals within the superficial sediment layer, testifying to an increase in human impact during the last century. Content of heavy metals in the upper 25 cm of the Lake Velnezers sediments significantly increase (Pb 137 mg/kg, Ni 15.1 mg/kg, Cu 78.6 mg/kg, Zn 535 g/kg, Cr 25.6 mg/kg) which point on industrial pollution. Likewise, research on the sediments of Lake Nommerjarv in Estonia has shown an increase in heavy metal quantity in the result of human impact (Marzecová *et al*. 2011). Values of chrome increase in upper part (0–20 cm) of the Lake Lilaste sediments but the maximal values of chrome have been found at the depth interval 12–14 cm reaching 22.6 mg/kg. In the Lake Lilaste sediment section iron values is very high in the upper 15cm and reach more than 50,000 mg/kg. High iron concentration has been found also in the upper sediment layer of the Lake Velnezers – 15,000 mg/kg.

Many investigations and observations lead to the consideration that traffic is one of the main sources of lead (Pb) pollution. As a result, traces from possible pollution caused by traffic appear to be as one of the most important markers of anthropogenic impact revealed in lake sediments. Traffic development in Latvia started in the beginning of the 20th century with the first cars appearing in 1901. Number of cars increased gradually during the first half of the 20th century; for example, in 1956 intensive road building development was accomplished and 53 asphalt factories were operating. One of the most clearly recognisable signs of human impact is the pronounced increase in the concentration of heavy metals, including Pb, in the superficial layers of all of the lakes under study, which in the sediments of Lake Velnezers is dated to back ~100 cal yr BP. According to data from research on Lake Velnezers, the reflection of human activities is pronounced in sediments accumulating 60–50 years ago, when intensive construction and road traffic began in the area around Lake Velnezers (Pujāte *et al*. 2014).

Due to the location of studied lakes the presence of trace metals in sediments can come from anthropogenic sources and relatively higher concentration of elements is not likely to be of natural environmental origin. Use of fertilizers in the catchment areas of lakes could contaminate a lake with minor trace element concentrations typically as detected in the study. In early 1990'ies, dramatic reduction in industrial and agricultural activities had taken place due to socio-economic and political crisis of former Soviet Union (Klavins *et al.* 2001). Thus, e.g., in Lake Veveri catchment area pollution by agricultural fertilizers has decreased. Recent socio-economic recovery has increased anthropogenic pressure, but still it is lower than before 1990's. Other potential anthropogenic sources of trace elements include runoff of surface water in the urban environment, like in the case of Lake Velnezers.

Heavy metals can come from some natural sources such as minerals in rocks, vegetation, sand, and salt. However significant increase of heavy metals in sediments, especially Pb and Cd is caused by long distance atmospheric transportation (Pacyna 1987; Braennvall *et al.* 1999). This study has shown that sediments of the studied lakes are polluted with heavy metals. The comparison of data shows the highest major and trace element concentration (mg/kg) concentrations are in Lake Velnezers sediments, which is located in the urban area. For example lead values in Lake Velnezers sediments reach 137 mg/kg, which is significantly higher than in Lake Lilaste (18.5 mg/kg to 35.7 mg/kg) and Lake Veveri (18.7 mg/kg). However, even the highest Pb concentrations in comparison with detected metal concentration in the West European countries (de Boer *et al.* 2001; Martin 2004; Wildi *et al.* 2004; Thevenon *et al.* 2011; Ong *et al.* 2013) in studied lake sediments is low.

CONCLUSIONS

The results of research on the composition of the small lake sediments, applying a set of multidisciplinary research methods, allow to make assessment of environmental changes and the character of human impact during the time of deposition of the superficial sediments in studied lakes of different origin. Composition and changes in macroremain analysis reflect intensification of the overgrowing and eutrophication processes in the lakes and supplemented with data on the chemical analysis point on anthropogenic influence on sediment composition. Increase of macroremain amount in lake superficial sediments indicates that the lakes under study have a tendency of increased eutrophication, which has intensified in recent centuries due to human activities.

Independently of the location and origin of studied lakes, an increased concentration of heavy metals, in particular Pb and Cd, has been found in the composition of superficial sediments, possibly connected with the inflow of surface waters containing Pb into the lake and with regional atmospheric emissions. However the several times higher concentration and more expressed increase of heavy metal has been found in Lake Velnezers located in the urban area.

The obtained data has provided evidence of increasing anthropogenic influence in the sediments of all the lakes under study, regardless of whether they are located in a rural or an urban environment. The most recognisable traces of anthropogenic influence can be attributed to the sharp increase of the amount of lead (Pb), macroremains and charcoal presence in analysed lake sediments.

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