A radical shift from soft-water to hard-water lake: palaeolimnological evidence from Lake Kooraste Kõverjärv, southern Estonia

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Abstract. The Water Framework Directive (WFD) of the European Union requires the quality of all European water bodies to be examined, and aims to achieve good status by 2015. This study was initiated to assess whether a potential reference lake for identifying lake-type specific reference conditions meets the WFD requirements, of being minimally impacted by human activity during the last centuries. The sediments of Lake Kooraste Kõverjärv were analysed for diatom assemblages and sediment composition; past changes in the lake-water pH and total phosphorus were reconstructed, using quantitative models on sedimentary diatoms. The chronology of sediments was established, using spheroidal fly-ash particles stratigraphy. Palaeolimnological investigations, supported by information from historical maps, revealed that man-made changes around the lake have severely influenced its ecological conditions. The lake, which had been oligotrophic with soft and clear water before the mid-17th century, has been transformed into a hard-water lake by modifications to the inflow and outflow. The lake water quality has also been altered by the infiltration of nutrients from a nearby hypertrophic lake that was used for flax retting since the 19th century. Although the ecological status of the lake has remained good despite all these changes, it is still questionable whether to nominate it as a reference lake for stratified hard-water lake types.

Key words: palaeolimnology, lake sediment, diatoms, reference lakes, Water Framework Directive, Lake Kooraste Kõverjärv, Estonia.

INTRODUCTION

Eutrophication and pollution of aquatic ecosystems has been an environmental problem already for several decades (Laws 1993). Due to the need for action to avoid long-term deterioration of freshwater quality and quantity, as well as for sustainable management and protection of water resources, the Water Framework Directive (WFD) of the European Union (EU) was implemented (EU 2000). This directive aims at maintaining and improving the aquatic environment in EU countries and ensuring a good quality of all water bodies by the year 2015. A good quality means that the values of the biological quality elements for the aquatic ecosystem show low levels of distortion resulting from human activity, deviating only slightly from those normally associated with the surface water body type under undisturbed conditions. To achieve the goals set by the directive, the ecological quality of all water bodies should be determined, the water bodies should be divided into quality classes and all this should be carried out for individual lake types. What makes the implementation of the WFD complicated is the question of how to define and determine the ecological quality of a water body. The WFD stipulates that the quality classes are defined by the degree to which present-day conditions, biological and chemical indicators, deviate from those uninfluenced by anthropogenic activities, i.e. reference conditions. Several different approaches can be used to determine reference conditions. It can be performed by using modelled and historical data (Nielsen et al. 2003), via palaeolimnological reconstruction (Heinsalu & Alliksaar 2009b; Bennion et al. 2011) or by studying unimpacted water bodies. However, lakes that are minimally impacted and qualify for use as reference sites are difficult to find (Bennion et al. 2004; Bjerring et al. 2008).

Reference conditions of lakes are expected to vary across the EU as a result of geographical differences between catchments (geology and altitude), due to individual lake factors (e.g. depth, area, water colour) and also because different lakes can respond differently to human impact (Søndergaard et al. 2005; Carvalho et al. 2009). Therefore, according to the WFD, the surface water bodies should be differentiated into types from which type-specific biological or chemical reference conditions could be derived (EU 2000). The lake typology is mainly based on characteristics such as altitude, alkalinity, mean depth, lake area and colour, which are all important factors in determining the composition and abundance of biological communities (Kolada et al. 2005). Each country classes its water bodies individually. In Estonia lakes are divided into eight types. Two large lakes, Peipsi and Võrtsjärv, form separate classes, while small lakes make up six classes, namely alkalitrophic, not stratified with medium alkalinity, stratified with medium alkalinity, dark-coloured soft-water, light-coloured soft-water and coastal lakes (Ott 2006; ME 2009). In order to determine type-specific reference conditions, each lake typology class should have reference sites. The reference lakes need not be pristine; however, their state should indicate low anthropogenic pressure, i.e. minor effects of industrialization, urbanization and intensification of agriculture in their catchment (EC 2003). In Estonia the list of water bodies with their WFD typology and the rules for establishing their states with quality classes and the values of quality indicators corresponding to the state classes are enacted with an Order of the Minister of the Environment (ME 2009).

In the Central/Baltic geographical inter-calibration region, where Estonia belongs, a similar order document has been implemented in Belgium. Several other countries, e.g. Germany, UK, Ireland, Netherlands, Poland, Denmark, are about to confirm their rules. Latvia and Lithuania are still waiting for the inter-calibration results. The northern region, e.g. Scandinavia and Finland, has been successful with inter-calibration and the method used there has been confirmed. Since 2007 the countries have initiated national monitoring programmes of water bodies, following WFD requirements. Searching for potential reference lakes is included in the monitoring programme of Estonia.

Lake Kooraste Kõverjärv in southern Estonia was proposed as a candidate reference lake for the stratified, medium-alkalinity lake type. Among the EU member states in the Central/Baltic geographical region it belongs to the LCB1 lake type (Ott 2008; Poikāne et al. 2010). Some other reference sites are available for this lake type in Estonia, but they vary for different biotic groups. In numerous studies the palaeolimnological approach has played an important role in confirming whether the selected reference sites are indeed pristine or minimally impacted (Leira et al. 2006). The aim of the present study was to identify if the status of Lake Kooraste Kõverjärv has remained close to semi-natural during the last centuries and whether the water body meets the requirements set for reference lakes. For these purposes we utilized palaeolimnological techniques on dated sediment cores. We analysed the main constituents in the sediments, established the floristic composition of the lake in the past on the basis of the sediment microfossil diatom assemblages and employed the lake sediment diatom-based transfer functions to reconstruct quantitatively the total phosphorus (TP) concentrations and pH values of the lake water in the past.

STUDY AREA

Lake Kooraste Kõverjärv is located in southern Estonia, on the southeastern border of the Otepää Upland (57°57′55″N; 26°39′45″E), which is the meeting point of several primeval valleys abundant in lakes (Fig. 1).

Fig. 1. Location map of Lake Kooraste Kõverjärv and its surroundings. The coring site is indicated with a black asterisk and the catchment border with a dashed line. Modified fragment of the map from Land Information Web Map Application of the Estonian Land Board (http://xgis.maaamet.ee/xGIS/Xgis).

It is a small (10.9 ha) strongly stratified hard-water lake with clear water. A peninsula on the southern shore of the lake divides it into a deeper eastern part (max depth 10.1 m) and a shallower western part. The catchment area of this headwater lake (116 m a.s.l.) is very small, only 0.47 km^2 (Loopmann 1984), and restricted to the nearest vicinity of the lake (Fig. 1). Many other lakes lie nearby: Lake Mutsina (115.3 m a.s.l.) about 150 m northeast, Lake Kooraste Linajärv (117.5 m a.s.l.) 100 m south and Lake Kooraste Suurjärv (114 m a.s.l.) about 400 m southwest. A small outflow from Lake Kooraste Kõverjärv carries drainage water into Lake Mutsina. A ditch between lakes Kooraste Kõverjärv and Suurjärv is dry and has almost disappeared. The catchment area of Lake Kooraste Kõverjärv consists of sandy kames and sandurs covered with pine forest. The shores are mainly steep, while the western shore is swampy.

Lake Kooraste Kõverjärv was the subject of sporadic hydrochemical and limnological studies in 1954, 1972 (Mäemets 1977) and 1981 (Milius 1992). Over this period it changed from slightly eutrophic to mesotrophic (Lill 1988). All aspects of the lake ecosystem were investigated during the summer months in 2005 and 2006 in the framework of the Estonian national monitoring programme (http://eelis.ic.envir.ee:88/ seireveeb/). According to these latest surveys, the water in the lake is slightly alkaline (pH 8.1–8.4), and the water column is strongly stratified. The water transparency is 2.3–3 m, in 1972, however, it was 3.8 m. The TP concentration in the epilimnion and metalimnion varies from 15 to 20 μg L^{-1}, while the total nitrogen (TN) content is about 500 μg L^{-1}.

METHODS

Sediment samples from Lake Kooraste Kõverjärv were collected at 8.8 m water depth from the ice-cover in the eastern side of the lake in March 2005. A 54 cm long sediment sequence was taken with a Willner sampler. The core was sectioned at 1 cm intervals in the field and samples were packed into plastic bags. A Russian-type peat corer was used to sample lower sediments down to a depth of 2.2 m. One metre long cores were placed into half-cut plastic tubes and wrapped tightly in plastic film. All samples were stored at 4 °C in a laboratory cold room prior to analyses.

The chronology of upper sediments was established, using the sediment distribution of spheroidal fly-ash particles (SFAP). These are high-temperature combustion products of fossil fuels, which are distributed and well preserved in the environment and are often successfully used as an indirect method of dating sediments when compared with the fuel-burning history of the region (Renberg & Wik 1985; Rose et al. 1995; Alliksaar et al. 1998). In Estonia this method has repeatedly been applied together with other dating methods (e.g. ^{210}Pb radiometric dating, varvochronology, marker horizons of artificial radionuclides ^{137}Cs, ^{241}Am; Punning et al. 2004; Alliksaar et al. 2005; Veski et al. 2005; Nõges et al. 2006; Heinsalu et al. 2007, 2008; Leeben et al. 2008; Heinsalu & Alliksaar 2009a), therefore, the SFAP distribution chronology is very well established. For the SFAP analysis the sediment subsamples were treated with 30% H_2O_2, 3 M HCl and 0.3 M NaOH to remove organic, calcareous and biogenic siliceous material (Renberg & Wik 1985; Rose 1990). Next commercially available *Lycopodium* marker-spores were added for concentration calculations. The SFAP were counted at ×250 magnification under a light microscope. For two lower sediment horizons conventional radiocarbon analysis on 6 cm thick bulk sediment samples was applied. Radiocarbon dates were calibrated, using the Calib Rev 6.0.1 software (Reimer et al. 2009).

The basic properties of sediments were measured with standard methods: the water content was determined by drying the samples to constant weight at 105 °C; the organic matter (OM) and carbonate contents were measured as loss on ignition after heating dried samples at 550 °C for 4 h and at 950 °C for 2 h, respectively (Heiri et al. 2001). The combustion residue is regarded as primarily terrigenous matter of sediments.

For diatom analysis pre-weighted samples were treated with 30% H_2O_2 to remove OM (Battarbee et al. 2001). Diatom concentrations were also determined by *Lycopodium* marker-spores. Slides were mounted with Naphrax and analysed for microfossils under a Zeiss Axiolab microscope (oil immersion, phase contrast, ×1000 magnification, numerical aperture 1.30). At least 400 diatom valves were counted from each sediment sample. Diatom-inferred lake epilimnetic TP concentrations (DI-TP) were reconstructed using the weighted averaging partial least squares regression model (ter Braak & Juggins 1993) and the northwestern European TP dataset of the European Diatom Database (EDDI) calibration training set (Battarbee et al. 2000). Diatom-inferred lake pH (DI-pH) was modelled using the locally-weighted weighted averaging regression (Juggins 2001) and the EDDI combined pH dataset. The modelling was performed online (http://craticula.ncl.ac.uk/Eddi/jsp/).

RESULTS

A 2.2 m long sediment core consisted of homogeneous gyttja. The top 64 cm was brownish dark green and poorly compacted, the rest was dark brown-coloured. Sediment composition changed notably at a depth of 125 cm, showing sharp variations in the profiles of water content and both OM and terrigenous matter (Fig. 2). At a core depth of 125–210 cm, all sediment characteristics had stable values, the water content was around 92%, the majority of the sediment was formed from OM (60–80%), to a lesser extent from terrigenous matter (15–35%) and carbonate content was low (1–2%). At a depth of 125 cm, the terrigenous matter content suddenly doubled and the OM percentage decreased to about 30%. In the upper 50 cm, the sediment OM content increased to 50%; the carbonate content also gradually increased, but was still below 3% and terrigenous matter dropped from 60% to 45%.

The stratigraphy of SFAP coincides with the well-documented history of fossil fuel burning in Estonia (Fig. 3A). Some characteristic features are observed in the distribution of SFAP. A small and steady rise in particle concentration changed to a sharp increase after the Second World War, when energy demand rose

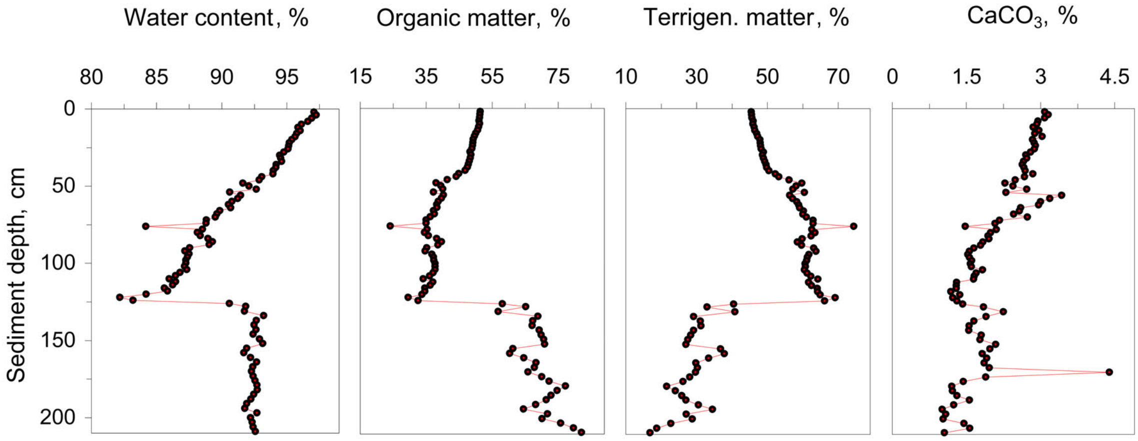

Fig. 2. Depth profiles of major sediment constituents of Lake Kooraste Kõverjärv. Water content is given as percentage of fresh sediment; organic, terrigenous and $CaCO_3$ matters are expressed as percentages of dried sediment weight.

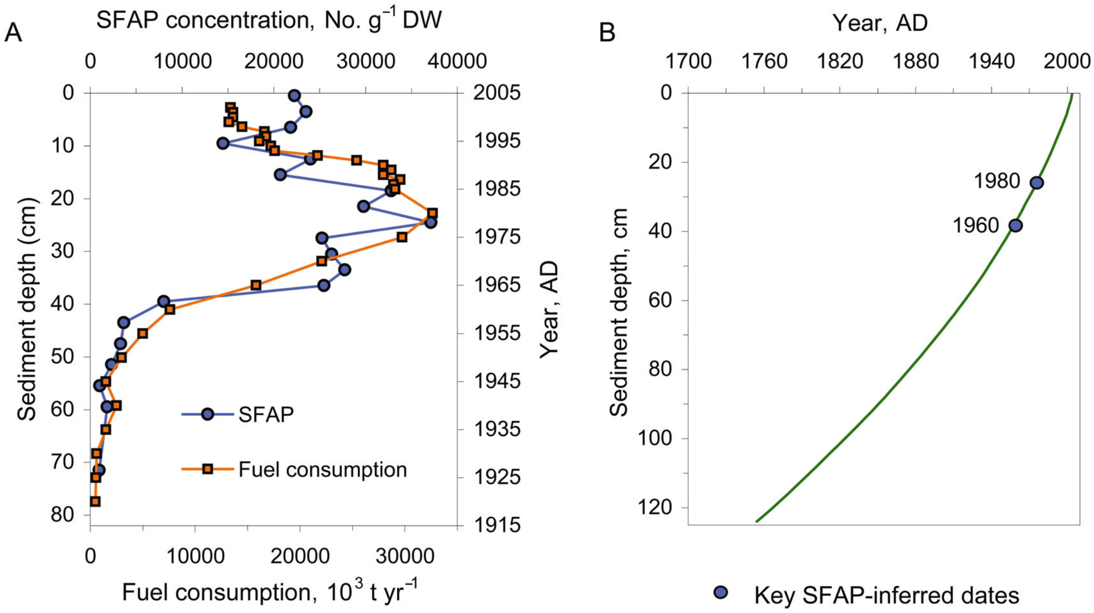

Fig. 3. Chronology of the Lake Kooraste Kõverjärv sediment core. **A**, the distribution profile of spheroidal fly-ash particles (SFAP) in sediment dry weight (DW) plotted against the data of fossil fuel consumption history in Estonia. **B**, the age-depth curve of sediments up to a depth of 125 cm, obtained by extrapolating the SFAP age-scale to deeper layers. Key SFAP-inferred dates are shown.

considerably and huge power plants using oil shale were established in northeastern Estonia (Nõges et al. 2006). The increase in SFAP at a core depth of 45 cm corresponds to the early 1950s when power plants were erected in Kohtla-Järve and Ahtme. The ^{210}Pb dates for sediment cores of other lakes confirm this age (e.g. Heinsalu et al. 2007). The following rise in SFAP abundance coincides with the establishment of two large power plants in Narva in 1960 and 1969. The combustion of fossil fuels, mainly oil shale, reached its peak in the 1980s. With the collapse of the Soviet Union in the early 1990s, energy production was sharply reduced. The removal of fly-ash also improved considerably, and the emission loads decreased. This is clearly visible in the sediment SFAP distribution curve of Lake Kooraste Kõverjärv, where particle concentration decreases substantially in the uppermost 16 cm of the core. The top sediment layer is estimated to have formed since the 1990s according to ^{210}Pb dates (Heinsalu et al. 2007; Heinsalu & Alliksaar 2009a).

Radiocarbon age estimations of two horizons resulted in ca AD 450 for the sediment depth of 64–70 cm and ca BC 250 for 110–116 cm (Table 1). When compared with the SFAP dates, the calibrated radiocarbon ages are older than expected. A probable reason for such old ages could be the well-known phenomenon of reservoir effect, which is common in hard-water lakes rich in bicarbonate ions, where plants can assimilate old carbon in the process of photosynthesis (Björck & Wohlfarth 2001). This results in much older radiocarbon dates compared to the actual time of sediment accumulation (Rajamäe et al. 1997). The use of such radiocarbon measurements on bulk sediments of hard-water lakes can be problematic, and consequently, we regarded the results obtained as unreliable and decided to omit them from the age-scale. Therefore, the age of the sediments below 45 cm was not estimated. However, the accumulation rate for the lower sediments was estimated by extrapolating the SFAP age-scale to deeper layers. The relatively constant OM deposition rate was taken as a basis for these calculations. The assumption of constant OM influx was valid only to a sediment depth of 125 cm. Below this level the sediment composition changed significantly, rendering the analogous extrapolation in the age estimations of older sediments impossible. According to the SFAP dating results, the average OM accumulation rate during the last 50 years has been 0.0183 g cm^{-2} yr^{-1}. Assuming that it has been constant to a depth of 125 cm, the dates for the intervening levels were calculated. Extrapolated sediment accumulation rates suggest that sediments at 125 cm formed in the middle of the 18th century (Fig. 3B). These calculations, however, should be taken with caution, as in this interval the OM content is not constant but rises slowly towards the surface (Fig. 2), and therefore the sediments are likely older than modelled.

Diatom analyses were carried out on 18 stratigraphic levels. A total of 164 diatom taxa of 36 genera were identified. The diatom stratigraphy (Fig. 4) was divided into four diatom assemblage zones (DAZ): depths of 175–200 cm (DAZ-1), 125–175 cm (DAZ-2), 85–125 cm (DAZ-3, estimated date AD 1750–1860) and 0–85 cm (DAZ-4, AD 1860–2004).

The composition of diatoms observed in DAZ-1 was subdominated by epipelic *Frustulia rhomboides*, *Navicula heimansii*, *N. subminuscula*, *Pinnularia interrupta* and epiphytic *Eunotia pectinalis* var. *minor*. Planktonic species *Asterionella ralfsii* and *Aulacoseira perglabra* were present. This diatom composition is characteristic of soft-water lakes. At the top of DAZ-1, *Synedra tenera* and *Tabellaria flocculosa* agg. increased. DI-TP was stable and low, <10 µg L^{-1}, and DI-pH was 6 for that period.

A sharp change in the diatom composition occurred at a core depth of 175 cm (DAZ-2), when soft-water taxa declined and hard-water diatoms appeared. Relative abundance of planktonic diatoms, namely *Asterionella formosa* and *Aulacoseira ambigua*, increased, small-sized epipsammic fragilarioid diatoms became visible and overall diatom composition fluctuated. The DI-TP estimates showed a sudden increase to approximately 20 µg L^{-1}, whereas DI-pH was enhanced over 7.

In DAZ-3 (estimated date AD 1750−1860) the diatom assemblage stabilized, periphytic diatoms dominated over planktonic taxa and small-sized fragilarioid diatoms as well as epiphytic *Achnanthes minutissima* increased. The DI-TP increased to above 30 µg L^{-1} and suggested slightly eutrophic conditions.

Table 1. Radiocarbon dates (yr BP) and calibrated ages (AD/BC) of sediment samples from the Lake Kooraste Kõverjärv core

Depth from the sediment surface, cm	Laboratory code	^{14}C date, yr BP	Calibrated age, 68.2% probability	Calibrated age, 95.4% probability
64–70	Tln-2862	1610 ± 90	AD 340–560	AD 240–640
110–116	Tln-2861	2180 ± 70	BC 370–160	BC 390–50

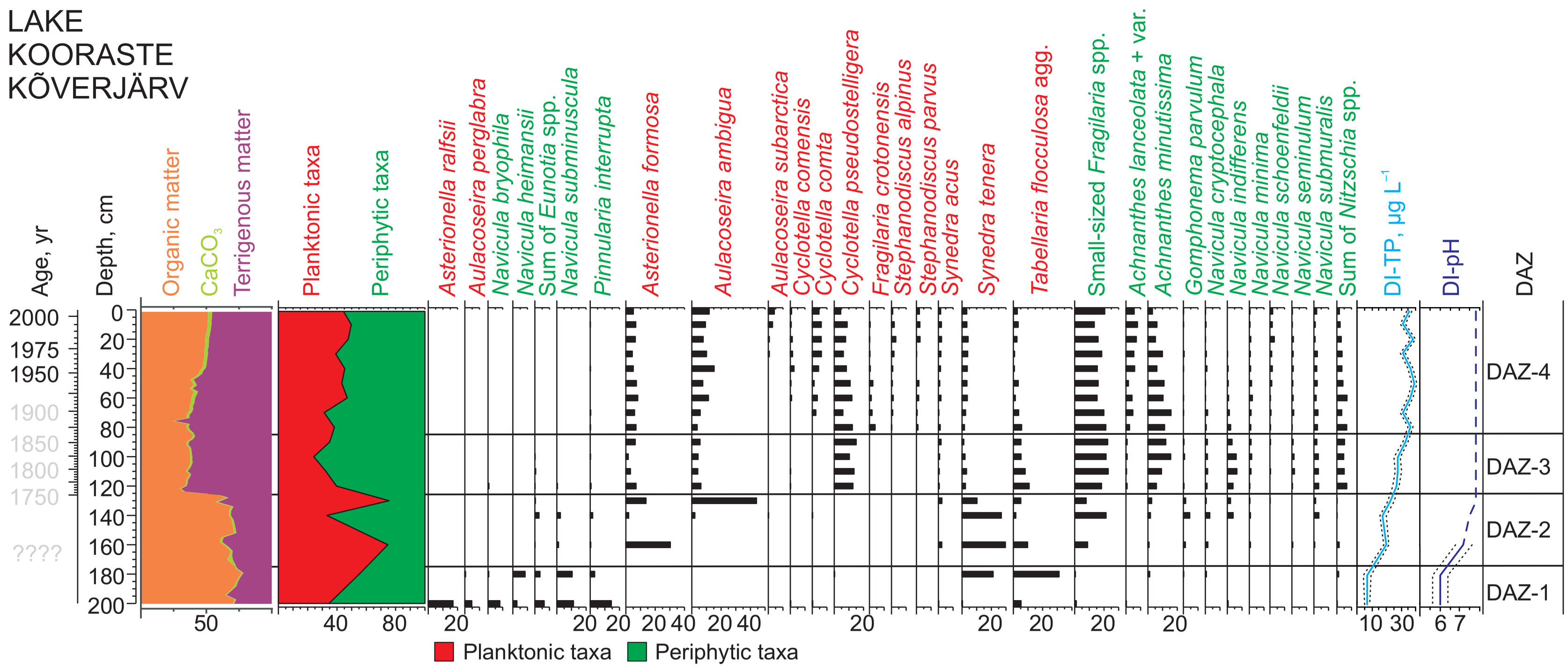

Fig. 4. Relative abundance of selected diatom taxa, diatom-inferred epilimnetic total phosphorus concentration (DI-TP) and diatom-based reconstruction of lake water pH (DI-pH) with standard errors of prediction (dotted lines). As a small number of modern analogues were found between the modern training set and sediment samples above 160 cm, the DI-pH (dashed line) is tentative. Due to a distinct change in sediment composition at a depth of 125 cm, downward temporal extrapolation of the age-scale was not performed. DAZ – diatom assemblage zone.

The zone DAZ-4 (AD 1860–2004) was characterized by the appearance of planktonic diatoms that tolerate high nutrient concentrations, such as *Cyclostephanos dubius*, *Fragilaria crotonensis*, *Diatoma tenuis*, S*tephanodiscus alpinus* and *S. parvus*. The DI-TP reconstruction suggests further nutrient enrichment.

DISCUSSION

The floristic composition of diatoms in the deepest sediment interval between 180 and 200 cm was completely different from that of the overlying sediments. The diatoms represented here prefer soft- and clear-water lakes. The abundant periphytic diatoms are markers of a well-illuminated water column. The reconstructed DI-pH suggests slightly acidic lake water with values around 6, and calculated epilimnetic DI-TP below 10 μg L^{-1} implies an oligotrophic environment. It is possible that these diatom assemblages represent natural baseline conditions for the lake. In addition, the OM content is high (70–80%), as typical of soft-water lakes that have no major inflows.

Diatom composition changes from a depth of 160 cm. Diatoms typical of soft-water lakes disappear and planktonic species characteristic of mesotrophic or slightly eutrophic hard-water lakes prevail, namely *Asterionella formosa*, *Aulacoseira ambigua* and *Synedra tenera*. The diatom abundance in this sediment interval is quite variable, indicating unstable conditions in the lake ecosystem. Moreover, the sediment composition revealed changes towards higher allochthonous terrigenous matter input. The diatom-based reconstruction of pH implied changes in the lake water from slightly acidic to neutral and later on to slightly alkaline conditions. The DI-TP concentration estimates increased to about 20 μg L^{-1}, referring to a mesotrophic environment.

The historical maps available in the Estonian Historical Archives suggest man-made changes in the Lake Kooraste Kõverjärv hydrological network (Fig. 5). Kanepi Parish in the historical Võrumaa County has been an important settlement area for a long time. Prior to the Livonian War, the land around Lake Kooraste Kõverjärv belonged to two manors – Kooraste (*Korast*) Manor (since AD 1511) and Erastvere (*Errestfer*) Manor (since AD 1452), which were both acquired by the von Ungern-Sternberg family in AD 1656. Around that time, AD 1582, Valgjärve (*Weissensee*) Manor was also formed. The manors established several water mills on nearby streams and rivers, the oldest and the most famous one being the Jõksi Watermill, which was first inventoried AD 1582–1591 and is still on the Võhandu River some kilometres northeast from Lake Kooraste Kõverjärv. Kooraste Manor had at least three watermills on the streams Lokuoja, Alopi and Sillaotsa, all flowing to Lake Kooraste Suurjärv (Fig. 1). Kokle Stream that flows through Lake Mutsina to the Võhandu River (Fig. 1) also had several watermills, e.g. at Kurvitsa, causing the formation of a lake of the same name. A map of parishes from AD 1685 shows a connection between Lake Kooraste Kõverjärv and Lake Mutsina (Fig. 5A). This could be an excavated ditch or a connection caused by the rise in the water level of Lake Mutsina, induced by the construction of milldams on its outflow. Mutsina is a hard-water lake with intensive through-flow and a very large catchment area (ca 2200 ha) of soils on carbonate-rich moraine. Therefore we suggest that the inferred shift from soft-water to hard-water lake was the result of Lake Mutsina supplying high-alkalinity water to Lake Kooraste Kõverjärv. This supposition must be treated with caution as only a few samples were analysed from this period and no chronology was established.

Our palaeolimnological record reveals a notable increase in allochthonous terrigenous matter at a core depth of 125 cm (ca the mid-1700s), which is a likely indication of further reorganization of the hydrological network of the lake. This assumption is supported by the historical map. On the plan of Karste (*Karstemois*) Manor from AD 1903, lakes Kooraste Kõverjärv, Suurjärv and Mutsina are all connected with ditches (Fig. 5B) and Lake Kooraste Kõverjärv has artificial inflow and outflow. The construction of milldams on Kokle Stream probably caused the rise in the water level of Lake Mutsina, and there was a need to re-route some of the water through lakes Kooraste Kõverjärv and Kooraste Suurjärv to the Võhandu River (Fig. 1). According to the extrapolated timescale, this work was obviously done about the mid-18th century. The appearance of the rheophilic component, including *Meridion circulare* and *Ceratoneis arcus*, in the sediment diatom record is further evidence that might be related to Lake Kooraste Kõverjärv being supplied by an inflowing artificial ditch. Otherwise the diatom composition stabilized, becoming typical of a stratified hard-water lake. However, the DI-TP concentration had risen to about 30 μg L^{-1}, probably due to increased inflow and nutrient supply.

During the period from around the 1850s to the present a number of species tolerating high nutrient levels have appeared in the assemblage, although their relative abundance is low. The occurrence of eutrophic diatom species has most likely resulted from the infiltration of nutrients from Lake Kooraste Linajärv. This small lake only a hundred metres southwards is exceptionally hypertrophic due to flax retting (Rakko et al. 2008). In addition, higher DI-TP estimates (40–50 μg L^{-1}) imply an increase in phosphorus concentration. How-

A

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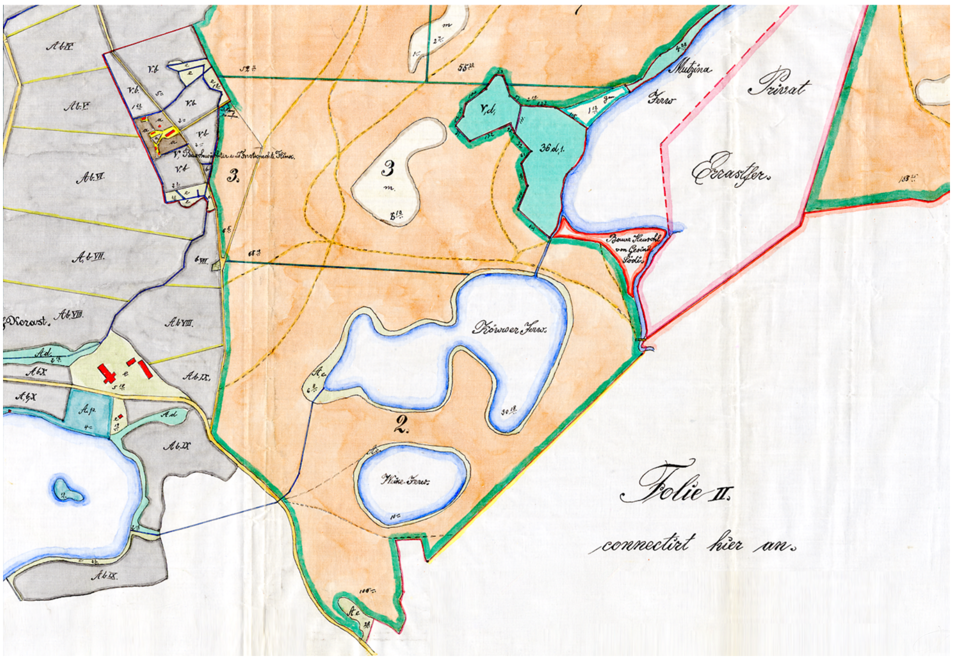

Fig. 5. Historical maps of Lake Kooraste Kõverjärv and its surroundings from the Estonian Historical Archives. **A**, the map of parishes from AD 1685, a connection between Lake Kooraste Kõverjärv and Lake Mutsina is seen. **B**, the plan of Karste Manor from AD 1903 shows that lakes Kooraste Kõverjärv, Suurjärv and Mutsina are all connected by ditches.

ever, the surface sediment diatom composition and DI-TP suggest that modern lake conditions can be regarded as 'good' water quality (ME 2009, Supplement 5).

Transfer functions have been successfully employed for inferring DI-TP in numerous regions in the world (e.g. Hall & Smol 1999) and most models predict DI-TP with reasonable precision. However, differences between instrumentally measured TP values and diatom predicted TP can be apparent and DI-TP reconstructions have at times over-estimated the measured values (e.g. Bennion et al. 2005; Bennion & Battarbee 2007). Model errors have often been attributed to non-planktonic diatoms formerly classified in the genus *Fragilaria* (Sayer 2001). At Lake Kooraste Kõverjärv the DI-TP value 35 μg L^{-1} for the surface sediment sample exceeds the instrumentally measured mean (ca 20 μg L^{-1}). However, even though DI-TP estimates are slightly larger than those associated with measured values, and the relatively high proportion of non-planktonic diatoms that are often insensitive to changes in the epilimnetic TP concentration is likely the major problem with the accuracy of the diatom inference model, we imply that the onset and overall trend in the nutrient enrichment are accurate and match well with the other palaeolimnological evidence.

The purpose of our investigation was to determine whether Lake Kooraste Kõverjärv remained in a semi-natural state during the last centuries when human impact on water bodies increased. In case of minimal change the lake would meet the requirements of the WFD and qualify for use as a reference site. The palaeolimnological study, primarily the diatom-based reconstruction of the sediment record of Lake Kooraste Kõverjärv, revealed substantial changes in the environmental history of the lake. Due to the manipulation of the hydrological network, the lake was once a closed soft-water oligotrophic system and is now an alkaline slightly eutrophic water body. Therefore it cannot be considered as an appropriate reference lake for deep stratified alkaline lakes.

Our earlier research (Heinsalu & Alliksaar 2009) has shown that the history of human impact varies significantly in its timing and intensity between individual lakes and between different kinds of human activity. The current study gave another salutary lesson how the real lake reference conditions may be unexpected if the lake hydrology has been irrecoverably transformed by man in the past and indicated the role and importance of palaeolimnology in establishing the development of the lake. This study highlights the importance of the applied role of sediment studies for lake management activities and illustrates that realistic restoration targets for lakes are sometimes difficult to define.

CONCLUSIONS

Palaeolimnological investigations of sediments of Lake Kooraste Kõverjärv and examination of the historical maps of the region suggest several distinct periods in the development of the lake. Before the second half of the 17th century, the lake was oligotrophic, slightly acidic, with soft and clear water. The construction of milldams on Kokle Stream caused the water level rise in Lake Mutsina and formation of a connection with Lake Kooraste Kõverjärv, which consequently induced a change in the lake type from an oligotrophic soft-water to a mesotrophic hard-water lake. During the 18th century connections between lakes Kooraste Kõverjärv, Kooraste Suurjärv and Mutsina were excavated and as a result Lake Kooraste Kõverjärv had an artificial inflow and outflow for a period. In the 19th century, the nearby Lake Kooraste Linajärv was utilized for the purpose of flax retting, the lake became hypertrophic and some of its nutrient-rich water filtered into Lake Kooraste Kõverjärv. Despite all these man-made changes, the ecological status of the lake, estimated via sediment diatom composition and modelled DI-TP, has remained good. However, the nomination of Lake Kooraste Kõverjärv as a reference lake for stratified hard-water lake types is not appropriate.

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Paleolimnoloogiline uuring Kooraste Kõverjärvest – veekogu muutumine pehmeveelisest kalgiveeliseks järveks

Tiiu Alliksaar ja Atko Heinsalu

Kooraste Kõverjärve setteläbilõikest analüüsiti ränivetikad ja sette koostis; veekeskkonna muutuste selgitamiseks rekonstrueeriti setete ränivetikakoosluse alusel järvevee üldfosfori ning pH väärtused. Paleolimnoloogilised uuringud ja vanad ajaloolised kaardid näitavad, et inimene on järve ökoloogilist seisundit tugevalt mõjutanud. Järv, mis enne 17. sajandi teist poolt oli pehme veega heledaveeline umbjärv, muutus veskitammide ja kraavide rajamisega algul sissevoolu-, hiljem ajutiselt läbivoolujärveks. See tõi kaasa järvetüübi muutuse – pehmeveelisest järvest sai kalgiveeline mesotroofne järv. Samuti on järve veekvaliteeti mõjutanud toitainerikkad infiltreeruvad pinnaseveed naabruses paiknevast liigrohketoitelisest Linajärvest, mis 19. sajandil võeti kasutusele linaleotamisveekoguna. Vaatamata sellele et inimene on Kõverjärve seisundit kõigi nende protsessidega muutnud, on järve ökoloogiline seisund nii ränivetikakoosluse kui ka modelleeritud fosforisisalduste põhjal hea. Kooraste Kõverjärve määratlemine kalgiveeliste kihistunud järvede fooniveekoguks on siiski küsitav.