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Impact of mine drainage on diatom communities of Orijärvi and Määrjärvi, lakes in SW Finland

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The top/bottom paleolimnological approach was used to assess (1) the spatial extent of the effect of acid mine-drainage from the Orijärvi mine tailings on diatom communities of Orijärvi and Määrjärvi, and (2) the change that occurred in these communities as compared with the pre-disturbance conditions. Altogether eight cores were retrieved from the lakes and examined for their diatom remains. The compositional change in the diatom communities was assessed by detrended correspondence analysis and changes in their diversity by the Shannon diversity index ($H´$). The metal pollution affected diatoms at community levels resulting in a shift in dominant taxa and an overall decrease in diversity (both lakes), and at the individual level causing alteration in valve morphology (Orijärvi). The proportion of benthic and tychoplanktonic diatoms increased while planktonic diatoms markedly decreased in abundance. This study demonstrates that the used approach is a useful tool in larger-scale assessments of recent change and ecological reference conditions of surface waters.

Introduction

Heavy metals occur naturally, and several of them are fundamental components of Earth's ecosystems. For example copper (Cu) and zinc (Zn) are essential to life but in high concentrations they can be toxic. Lead (Pb) and mercury (Hg), however, are not known to perform any useful biochemical function (Allan 1997). Heavy metals released to aquatic environments severely affect primary producers. Toxicity of heavy metals to algae primarily results from their binding to sulphydryl groups in proteins, disruption of protein structure, or displacement of an essential element (De Filippis and Pallaghy 1994). Metal pollutants also disturb the oxidative balance in algae, which leads to an unbalanced cellular redox status (Pinto *et al*. 2003). In addition, algae accumulate heavy metals and can pass them through the food chain up to the top predators.

Metal inputs from mining activities are in most cases a local issue. Mining involves removal, processing and disposal of vast volumes of rock and wastes, and therefore the main direct release of metals is from tailings and polishing ponds, and emissions later in the beneficiation stage (Allan 1997). Acid mine-drainage (AMD), generated by oxidation of iron-rich sulphide waste rocks and tailings, is one of the largest environmental problems caused by mining of sulphide-rich minerals (Cattaneo *et al*. 2004, Salonen *et al*. 2006, Cattaneo *et al*. 2008). This problem is extensive in Finland, where during the past centuries nearly 200 sulphide ores were

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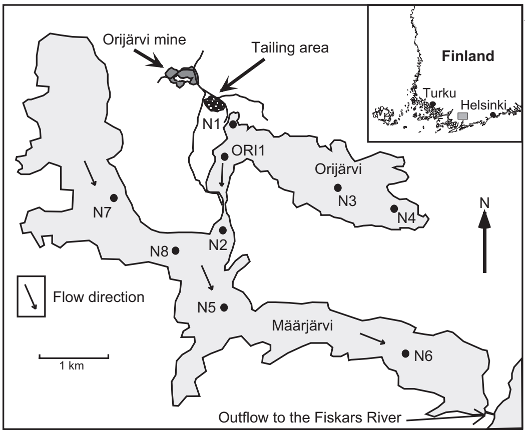

Fig. 1. Map of Orijärvi and Määrjärvi showing locations of the sampling sites, mine and tailing area.

actively mined (Puustinen 2003), yet assessments of the environmental impacts of sulphide tailings on aquatic communities in Finland are few (Kauppila 2006, Kauppila *et al*. 2006, Salonen *et al*. 2006, Kihlman and Kauppila 2009).

The AMD-derived metal impact of Orijärvi mine tailings on Orijärvi algal communities was found to be the strongest thus far recorded in Finland (Salonen *et al*. 2006). Concentrations of Cu, Pb and Zn in the sediments are two to three orders of magnitude higher than the background values in Finland, which are for Cu, Pb and Zn 5–35 mg kg^{-1}, 3.4–22 mg kg^{-1} and 20–140 mg kg^{-1}, respectively (Lahermo *et al*. 1996). Lake water still has elevated levels of heavy metals, indicating that the impact from the tailing area continues to affect the lake. Orijärvi is connected to Määrjärvi through a narrow inlet, which has led to elevated metal concentrations also in Määrjärvi. The previous study by Salonen *et al*. (2006) was based on a single core; hence this study will complement it by providing additional and important information on the spatial patterns and extent of the environmental impacts caused by the Orijärvi mine tailings.

In this study, we aim to assess the spatial extent of the AMD-derived metal impact on the diatom communities of Orijärvi and Määrjärvi by using the top/bottom paleolimnological approach. Further, we also define the extent of the departure from background conditions in the diatom communitites. The top/bottom analysis makes the assumption that the top sample represents the present day and the bottom sample reference or pre-industrial conditions prior to anthropogenic disturbance. The approach allows the assessment of change either in a large number of lakes, or at multiple sites in one lake, as it only involves the analysis of two samples from a sediment core per site (e.g. Cumming *et al*. 1992, Weckström *et al*. 2003). Due to the assumption the analysis makes about the bottom sample, this methodology can either be used in lakes where disturbance of sedimentation is low or, alternatively, when average sedimentation rates have previously been assessed. The European Water Framework Directive requires "good ecological status" of surface waters to be reached by 2015, allowing only a slight departure from the biological community structure, which would be expected in conditions of minimal anthropogenic impact (e.g. ecological reference conditions) (Anonymous 2000). In order to assess the present state and possible restoration needs of a given system, its ecological reference conditions have to be known. Hence, the focus of this study is timely and the results will be of importance to the WFD.

Study site

Orijärvi and Määrjärvi (60°14´N 23°35´E) are lakes located in southwestern Finland (Fig. 1). They are the two headwater lakes in the river system of the Fiskars river. The physical and chemical characteristics of the lakes are given in Table 1.

The concentrating plant and the tailing area, which contains ca. 400 000 tonnes of mine waste rich in metal sulphides, are directly connected to Orijärvi (Fig. 1). The mine environment was never restored, but open pits, gangue piles and tailings were left uncovered in the open air. It can be estimated that weathering of tailings affected on average the topmost 50 cm of the tailings, which equals about 100 000 tonnes of mine waste. The total metal load released to the lake can thus be estimated to equal 800 tonnes of Cu, 5400 tonnes of Zn and 300 tonnes of Pb (Salonen *et al*. 2006). The leachate water in the brook connecting the tailing area and the lake is typical AMD water (pH 5.1, Fe 0.71 mg l^{-1},

SO_4^{2-} 217 mg l^{-1}, Pb 40 μg l^{-1}, Cu 640 μg l^{-1}, Zn 14 300 μg l^{-1}) (Räisänen *et al*. 2005).

Water quality monitoring has been carried out in Orijärvi and Määrjärvi since the 1960s by the Finnish Environmental Institute (Vogt 1998), and the elevated concentrations of Cu, Pb, Cd and especially Zn (Table 2) in the lake are a 10- (Pb) to 100-fold (Cd, Zn, Cu) higher than average background concentrations in surface waters in Finland. Background concentrations for Zn are 1–8 μg l^{-1} (Mannio *et al*. 1993); for Cu and Pb 0.36 μg l^{-1} and 0.01–0.4 μg l^{-1}, respectively (Lahermo *et al*. 1996); and for Cd 0.04 μg l^{-1} (Tarvainen *et al*. 1997). However, there is a decreasing trend in the metal concentrations in Orijärvi. The chlorophyll-*a* concentrations are very low in both lakes (approx. 2.5 μg l^{-1}) indicating very low phytoplankton production; pH of the lakes is around seven (Table 1).

Table 1. Physical and chemical characteristics of Orijärvi and Määrjärvi. The values are averages from the data provided by the Finnish Environmental Institute.

	Orijärvi	Määrjärvi
Lake area (km²)	1.7	5.7
Maximum depth (m)	21.4	34.1
Average depth (m)	8.5	12.5
Lake volume (million m³)	14.8	71.7
Water residence time (years)	4	6
pH (units)	6.9	6.8
Secchi depth (m)	3.7	3.9
Chlorophyll *a* (μg l^{-1})	2.35	2.8
Total nitrogen (μg l^{-1})	650	616
Total phophorus (μg l^{-1})	8.3	6.5
Alkalinity (mmol l^{-1})	0.20	0.16

Material and methods

Sampling

Sampling was carried out in March 2000 with a Limnos gravity corer (Kansanen *et al*. 1991). Altogether eight cores where retrieved from the lakes; N1, N3 and N4 from Orijärvi and N2, N5, N6, N7 and N8 from Määrjärvi (Fig. 1 and Table 3). The top 5 cm and the 5-cm sequence from the bottom of each core were collected to represent post-mining and background conditions, respectively. Also previously published data from the ORI-1 core (Salonen *et al*. 2006) was used in the analyses. The sedimentation rate in the uppermost 15 cm in the ORI-1 core was

Table 2. Metal concentrations (Zn, Cd, Pb and Cu) of Orijärvi and Määrjärvi. Background values are from (Mannio *et al*. 1993), (Lahermo *et al*. 1996) and (Tarvainen *et al*. 1997).

Date	Zn (μg l^{-1})	Cd (μg l^{-1})	Pb (μg l^{-1})	Cu (μg l^{-1})	pH	EC (mS m^{-1})	SO_4 (μg l^{-1})	Fe (μg l^{-1})
Orijärvi								
5.XI.1974	1250	3.00	2	50	6.9	10.4		
24.III.1976	1200				6.7	13		
7.XI.1979	1250	3.00	3	24	6.5	11.6	30	93
26.X.1982	1000	2.10	1	27	7	11.3	28	79
14.XI.1985	950	1.45	1	27	7.2	10.5	28	120
1.IX.1993	810		0.63	27				
21.VII.1997	700		1.3	22	7.6	14.6	24	
2.VIII.2000	615	7.54	1.32	19.7	7.5	9.6	23	44
30.VII.2008	610	1.10	0.27	23	7.4	8.9	19.5	34
Background	1–8	0.04	0.01–0.04	0.36	6	2.6		190
Määrjärvi								
5.XI.1974	322		2	8				
7.XI.1979	400		1	7	6.5			
26.X.1982	300	0.7						
14.XI.1985	250		1	7	7	7	16.4	73
21.VII.1997					7.4	7	14	
2.VIII.2000	179	0.6	0.94	5.32	7.3	6.7	13.5	
30.VII.2008	170	0.3		5.8	7.3	6.8	14	22
Background	1–8	0.04	0.01–0.04	0.36	6	2.6		190

1.4 mm year^{-1}, thus the sediment below 15 cm represents layers from before the 1880s. Hence the bottom samples (Table 3) can be assumed to represent background conditions before the concentrating plant started to operate in the beginning of the 1900s.

Subfossil diatoms

Organic matter in the diatom samples was removed by oxidation with 30% H_2O_2 (Battarbee 1986). After rinsing with distilled water, the suitable dilutions of the diatom suspension were allowed to dry on cover slides and mounted using Naphrax® mounting medium. Identifications were carried out with a light microscope at 1250× magnification using phase contrast illumination. A minimum of 300 diatom valves were counted at each level. Diatom taxonomy was based on Cleve-Euler (1951–1955) and Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b). The assignment of diatom species to different life forms was done according to Krammer and Lange-Bertalot (1986–1991), Lowe (1974), van Dam *et al*. (1994) and Stevenson *et al*. (1991). Compositional changes in diatom assemblages were assessed with detrended correspondence analysis (DCA), which is a unimodal indirect ordination method (Hill and Gauch 1980). DCA was carried out with the programme Canoco ver. 4.0 for Windows (Ter Braak and Šmilauer 1998). Shannon's diversity index ($H' = -\sum P_i \ln P_i$, where P_i is the proportion of each species in the sample) was calculated using the PAST@ statistical software (Hammer *et al*. 2001). The proportion of the deformed *Achnanthidium minutissimum* valves was expressed as a percentage of the total *A. minutissimum* counted at each level.

Table 3. Depths of the samples and water depths of the sampling sites.

Core	Top (cm)	Bottom (cm)	Water depth (m)
Orijärvi			
N1	0–5	29–34	2.5
N3	0–5	37–42	19
N4	0–5	37–42	19
Määrjärvi			
N2	0–5	48–53	12.6
N5	0–5	32–37	35
N6	0–5	30–35	35
N7	0–5	32–37	27
N8	0–5	19–24	10

Results

The subfossil diatom flora consisted of 168 taxa belonging to 23 genera. The majority of diatom taxa found in this study were benthic. Maximum abundance of only 17 taxa was over 5% (Table 4), nonetheless all the species were used in the analysis. Although the taxa encountered were predominantly benthic, 9 out of the 17 most abundant taxa were planktonic. These abundant species were also generally frequent in the data set. Overall, the proportion of planktonic species, especially taxa belonging to the genus *Cyclotella*, decreased from the bottom to the top of the samples. At the same time, the proportion of benthic and tychoplantonic species increased (Fig. 2). The diversity of the diatom communities ranged between 0.42 and 3.50; higher values were systematically found in the bottom samples.

Orijärvi (N1, N3 and N4)

There was a clear change in the diatom assemblages from the bottom to the top samples (Table 4). In core N1, both the top and the bottom samples were dominated by benthic species. *Achnanthidium minutissimum* and *Brachysira vitrea* dominated in the top and bottom samples, respectively (*see* Table 4). Species diversity in the bottom sample was higher than in the top sample (Table 5).

The N3 and N4 top samples were dominated by the benthic species *Achnanthidium minutissimum* and *Brachysira vitrea* (*see* Table 4). In the bottom samples, the dominating species were the planktonic *Aulacoseira subarctica*, *Aulacoseira* sp. and the tychoplanktonic *Tabellaria flocculosa* (*see* Table 4). Also the planktonic *Cyclotella rossii* and *Cyclotella radiosa* were fairly abundant. The species diversity was considerably smaller in the N3 and N4 top samples (*see* Table 5).

Some deformed *A. minutissimum* valves were found in all the top samples from Orijärvi. As much as 10% of the *A. minutissimum* valves were deformed in the top sample N1, which is closest to the tailing area.

Määrjärvi (N2, N5–N8)

The changes in the top/bottom diatom assemblages in Määrjärvi were not as distinctive as in Orijärvi (Table 4). In the N2 top sample, the dominating species were the planktonic *Cyclotella rossii*, *Aulacoseira* sp., *A. subarctica* and *Achnanthidium minutissimum* (*see* Table 4). In the bottom sample, the most abundant species were *Aulacoseira* sp., *Cyclotella radiosa* and *Cyclotella tripartita* (*see* Table 4). The diversities in the top and bottom samples were similar (Table 5).

In the top samples of cores N5 and N6, the dominating species were *Fragilaria capucina* var. *gracilis*, *Brachysira vitrea* and *Achnanthidium minutissimum* (*see* Table 4). In the bottom samples, the dominating species were *Aulacoseira subarctica*, *Aulacoseira* sp., *Cyclotella pseudostelligera*, *C. rossii*, *Tabellaria flocculosa* and *Asterionella formosa* (*see* Table 4). The species diversities in the bottom samples were higher than in the top samples (*see* Table 5).

In the N7 top sample, the most abundant species were *Aulacoseira subarctica*, *Aulacoseira* sp., *Achnanthidium minutissimum*, *Fragilaria nanana* and *Brachysira vitrea* (*see* Table 4). In the bottom sample, the dominating species were *A. subarctica*, *Aulacoseira* sp., *Asterionella formosa*, *Tabellaria flocculosa* and *Cyclotella rossii* (*see* Table 4). The species diversity in the top sample of N7 was clearly lower than in the bottom sample (Table 5). In the N8 top sample, the dominating species were *Aulacoseira subarctica*, *Aulacoseira* sp., *Cyclotella rossii*, *Achnanthidium minutissimum* and *Brachysira vitrea*, whereas in the bottom sample the dominating species were *Aulacoseira subarctica* and *Cyclotella radiosa* (*see* Table 4). The species diversity in the top sample was slightly higher than in the bottom sample. The diatom valves in the bottom sample of N8 were eroded.

Table 4. Abundance (%) of diatom species in top and bottom samples (top/bottom). Only the most abundant diatom taxa (max. occurrence > 5%) are included.

	Cores							
	N1	N2	N3	N4	N5	N6	N7	N8
Benthic species								
Achnanthidium minutissimum	89.7/7.7	9.2/5.6	45.1/1.3	62.2/3.3	18.0/4.0	14.1/5.7	14.2/3.0	14.8/–
Brachysira vitrea	7.6/39.4	3.3/0.3	21.4/–	13.4/0.3	26.9/1.6	19.4/0.3	8.6/0.3	12.8/–
Navicula aboensis	–/–	–/5.6	–/2.6	–/2.7	–/1.6	–/1.7	–/4.0	0.3/3.0
Navicula begerii	0.3/11	–/–	–/–	–/–	–/–	–/–	–/–	–/–
Psammothidium helveticum	0.3/8.0	1.0/–	6.5/0.7	3.9/2.1	1.6/0.6	3.0/0.7	0.3/–	1.6/–
Tychoplanktonic species								
Fragilaria capucina var. *gracilis*	–/0.7	3.0/–	4.2/0.3	5.5/0.3	26.0/0.3	27.3/0.7	1.7/–	–/–
Fragilaria capucina var. *vaucheriae*	–/13.8	2.0/–	14.0/–	5.9/–	2.6/–	1.6/–	0.7/–	1.3/–
Tabellaria flocculosa	–/–	4.9/6.0	–/10.3	1.0/12.4	1.3/8.7	2.0/10.7	1.7/10.6	3.9/2.3
Planktonic species								
Asterionella formosa	–/–	–/0.3	–/–	–/3.9	–/6.2	0.3/9.4	–/10.5	–/–
Aulacoseira subarctica	–/–	11.2/3.0	–/11.6	–/8.2	5.1/13.0	11.8/14.4	32.5/12.8	15.7/8.6
Aulacoseira sp.	–/–	12.2/17.9	–/14.5	–/9.7	4.8/10.9	10.9/11.7	18.5/13.5	13.8/28.5
Cyclotella bodanica var. *lemanica*	–/–	4.0/4.0	–/6.1	–/7.3	–/4.0	–/3.0	–/–	–/–
Cyclotella pseudostelligera	–/0.3	4.3/1.3	–/–	–/0.9	–/12.4	–/5.7	–/7.6	–/1.0
Cyclotella radiosa	–/–	4.3/11.3	–/7.7	–/2.7	–/3.4	–/5.4	–/3.3	3.0/27.2
Cyclotella rossii	–/–	18.8/5.3	–/4.2	–/7.3	–/11.8	0.3/7.0	0.7/8.2	15.4/–
Cyclotella tripartita	–/–	–/9.3	–/1.6	–/0.3	–/–	–/–	–/–	–/–
Fragilaria nanana	–/–	–/–	–/–	–/0.9	1.6/0.6	–/1.3	9.9/0.3	1.0/–

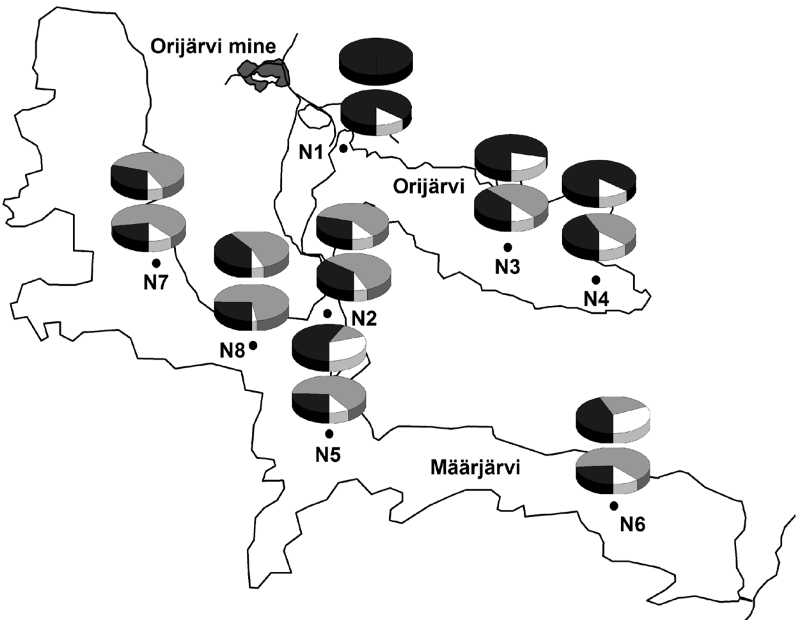

Fig. 2. Proportions of benthic (dark grey), planktonic (light grey) and tychoplanktonic (white) diatoms in the top and bottom samples.

DCA

DCA axes 1 (eigenvalue = 0.718) and 2 (eigenvalue = 0.173) together explained 40.5% of the total variance and revealed four separate clusters in the top/bottom samples (Fig. 3a). The first cluster consists of all the Orijärvi top samples, N5 and N6 top samples and the N1 bottom sample. The second cluster consists of the top samples N7, N8 and N2 and in the third and fourth clusters all bottom samples excluding bottom N1. The bottom samples show also some variation along the second DCA axis.

Table 5. Species diversity (Shannon diversity index *H´*) in the top and bottom samples, all the taxa are included.

	Top	Bottom
Orijärvi		
N1	0.42	2.04
N3	1.65	3.50
N4	1.53	3.44
Määrjärvi		
N2	2.94	3.12
N5	2.20	3.02
N6	2.25	3.04
N7	2.13	3.05
N8	2.63	2.38

The combined dataset produced very similar results. The bottom samples (excluding N1), top N2, top N7 and top N8 with the ORI-1 core samples below the 7-cm depth are plotted in one cluster at the same end of axis 1 with some variation along the second axis (Fig. 3b). The top samples of Orijärvi, ORI-1 core samples above 6 cm and the bottom N1 sample are at the left end of the first axis and the N5 and N6 top samples in between. The eigenvalue of axis 1 in the combined dataset is 0.732 and the first two axes explain 35.2% of the total variance.

Discussion

The top/bottom samples from multiple cores in Orijärvi showed similar marked changes in the diatom communities as those found earlier in the single core (Salonen *et al*. 2006). Despite the greater distance from the tailing area as compared with that of core ORI-1, the top samples of N3 and N4 show the same changes; they completely lack planktonic diatoms (Table 4 and Fig. 4) and a clear decrease in species diversity is evident. In contrast, the top and bottom assemblages in core N1 are both dominated by benthic species. This is most likely due to the fact that core N1 was taken from the littoral zone

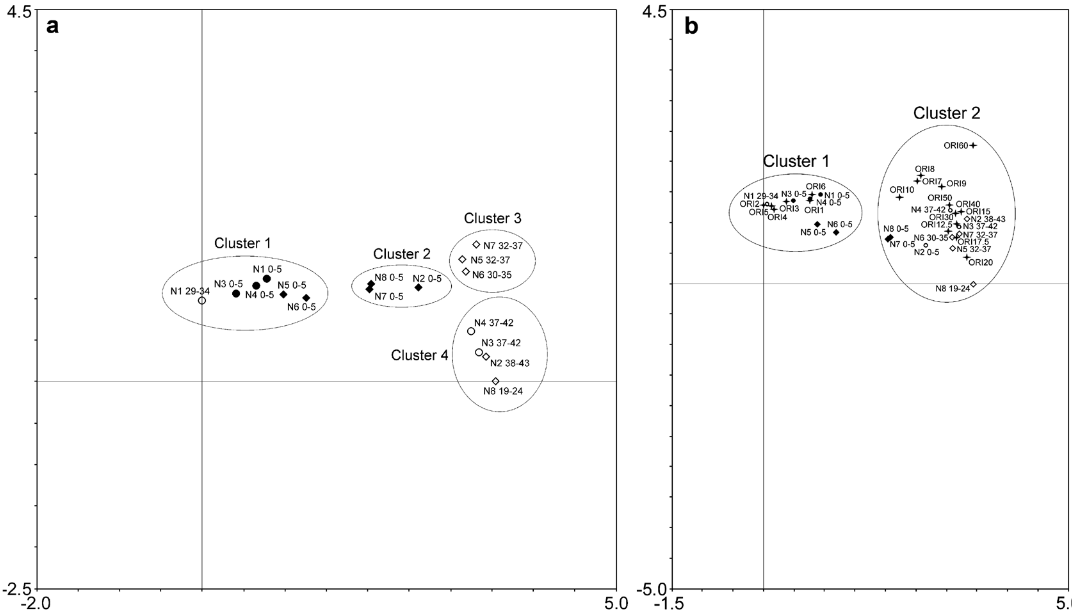

Fig. 3. (**a**) DCA results showing main patterns of variation in the diatom assemblages in the top/bottom samples. (**b**) DCA results showing main patterns of variation in the diatom assemblages for the combined dataset of the top/bottom samples and ORI-1 core. Filled circles: top samples of Orijärvi; filled diamonds: top samples of Määrjärvi; empty circles: bottom samples of Orijärvi; empty diamonds: bottom samples of Määrjärvi. ORI-1 subsamples are shown as crosses (numbers refer to depth of the sample in the Ori-1 core).

at a depth of 2.5 m (Table 2). Water in Orijärvi is very clear (Secchi depth mean value 3.7 m), which enables the benthic diatoms to grow at greater depths. Despite the dominance of benthic taxa in both samples of core N1, the changes in diatom assemblages to a near monoculture of *Achnanthidium minutissimum* accompanied by a marked drop in diversity in the top sample were clear.

The Määrjärvi diatom communities showed less drastic changes than the communities in Orijärvi. However, the AMD from the tailings still had a clear impact on the diatom communities of this lake, especially at sites N5 and N6. The proportions of the planktonic diatoms and the species diversity were both smaller indicating moderate contamination. Cores N7 and N8 were not so strongly affected by the current carrying contaminated water from Orijärvi, and therefore it is surprising that marked changes in the planktonic communities could also be found in core N7. Similar changes in diatom communities can occur due to acidification (Battarbee *et al*. 1999), but there are no signs of decreasing pH in the lakes (*see* Table 2). On the contrary, the diatom data, where acidophilic taxa gave way to more alkaliphilic species, indicate that pH increased due to the metal load (Salonen *et al*. 2006); the Orijärvi copper ore is associated with calcium-silicate rocks (Latvalahti 1979) and hence has a high neutralizing capacity. Due to the fact that pH levels stayed close to neutral in these two lakes, they provide a unique opportunity to study the effect of metals on diatom communities, since increased metal concentrations are usually accompanied by other perturbations like acidification or eutrophication (Davies *et al*. 2004, Reavie *et al*. 2005). Core N2 was taken from a slope where the accumulation of sediment due to the bottom topography and bottom currents may not have been continuous. Hence it can be that the top sample did not represent contemporary sedimentation.

Compositional changes in the diatom assemblages are also clearly seen in the results of the DCA analysis. The unaffected core-bottom samples are located at the right end of axis 1 and the most severely affected core-top samples from Orijärvi at the left end of the axis. The core-bottom sample of N1 is also located at the far left,

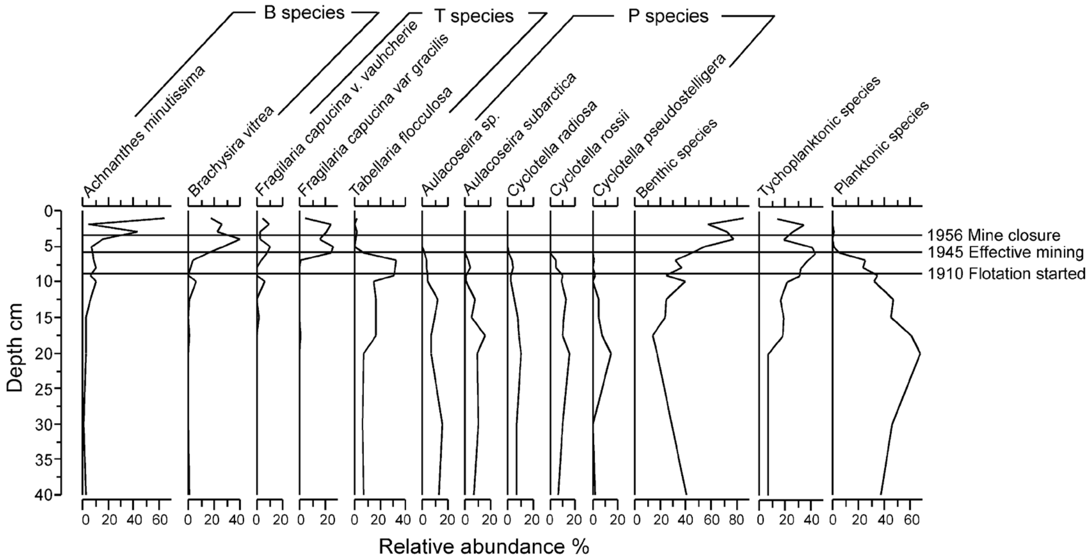

Fig. 4. Summary diagram of the ORI-1 core showing the most important diatom taxa, and the proportions of benthic (B species), tychoplanktonic (T species) and planktonic (P species) diatoms. (Modified from Salonen *et al.* 2006).

as it resembles the affected core-top communities due to the lack of a planktonic component. The samples with moderate contamination are located in between. This change along the 1st DCA axis — the axis which explains most of the variance in the diatom assemblages — is likely to represent the marked change in diatom life forms towards the dominance of benthic species.

According to this study, planktonic diatoms are more sensitive to the effects of metal contamination than benthic taxa. Especially species of the genus *Cyclotella* seem to be particularly sensitive (*C. rossii* more tolerant than *C. radiosa*). In several previous studies, as in the present study, *Achnanthidium minutissimum* and *Brachysira vitrea* appear to be the most tolerant species to metal contamination (Ruggiu *et al*. 1998, Salonen *et al*. 2006, Cattaneo *et al*. 2008). Cattaneo *et al*. (2008) reported very similar changes in plankton communities under severe metal contamination in a Canadian lake. *Achnanthidium minutissimum* is a cosmopolitan species which has on several occasions been reported to tolerate extreme metal pollution (e.g. Takamura 1989, Ruggiu *et al*. 1998, Cattaneo *et al*. 2004, Salonen *et al*. 2006). Also the *Fragilaria capucina* group seems to be tolerant of quite high metal concentrations. The higher stress tolerance of benthic taxa relative to planktonic ones could be based on the ability of benthic organisms to adapt better to living in a highly variable environment (Cattaneo *et al*. 2008). This could lead to the replacement of planktonic taxa by benthic ones under severe stress as documented, for example, in the industrially polluted Lago d'Orta (Italy) (Cattaneo *et al*. 1998) and in a British Columbia lake polluted by mining operations (Austin *et al*. 1985). Another explanation for the increase in benthic diatoms is that the contaminant transfer is slowed down by the benthic biofilms secreted by algae and bacteria (Ivorra *et al*. 2000). Biofilms are consortia of autotrophic and heterotrophic organisms imbedded in a matrix of polymers and particles, and according to Ivorra *et al*. (2000), they reduce the effects of metal exposure. This depends on the development stage of the biofilms, because an increased density of the biofilms can lead to increased recycling of nutrients within the biofilms (Riber & Wetzel 1987) thus reducing the dependence on external conditions outside the biofilms.

All the top samples from Orijärvi included some clearly deformed valves of *Achnanthidium minutissimum*; none deformed valves, however, were found in Määrjärvi. The amount of deformed valves was highest (ca. 10%) in the top sample of N1, which was located closest to the mine and the tailing area. Teratological valves have also been documented in other lakes polluted by heavy metals, such as in Lac Dufault, Quebec, Canada (Cattaneo *et al*. 2004) and Lake Orta, Italy (Ruggiu *et al*. 1998). These morphological changes may be related to some disturbance in silicon uptake. Fisher and Jones (1981) concluded that Cu can bind to sulphydral groups on the diatom cell membrane, impairing normal membrane function and reducing silica uptake, therefore mimicking conditions of silica limitation.

In the light of this study, the top/bottom approach is a very useful tool in larger-scale studies, particularly, where comparisons can be made with a detailed analysis from a dated sediment core. In environmental assessments this would be an optimal situation; however, for many management questions very detailed analyses are not always necessary. Especially for the WFD, this "before and after" type of sediment sampling method can provide a very time- and cost-effective tool for assessing background or ecological reference conditions of surface waters.

Conclusions

The AMD-derived metal impact of Orijärvi mine tailings has affected Orijärvi and Määrjärvi diatom communities in two ways. At the community level through a shift in dominant taxa and a decrease in species diversity, and at the individual level through an alteration in valve morphology. Orijärvi was clearly affected by metal impact, whereas the changes in Määrjärvi were less drastic. The Orijärvi diatom assemblages were completely dominated by benthic species. In Määrjärvi, the proportion of benthic and tychoplanktonic diatoms increased and the abundance of planktonic diatoms decreased. This study demonstrates that the top/bottom approach is an efficient tool for larger-scale studies, in particular for management purposes such as the WFD.

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