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Benthic diatom communities in Estonian rivers

Sirje Vilbaste

Institute of Zoology and Botany, Estonian Agricultural University, Riia 181, EE-51014 Tartu, Estonia (e-mail: sirje.vilbaste@zbi.ee)

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Epilithic, epiphytic and epipelic (soft bottom) diatom communities were studied in three rivers (Ahja, Selja and Valgejõgi). Although the total number of recorded diatom taxa was 165, the studied diatom assemblages consisted of 32, 26, or 28 constant taxa in the three studied rivers, respectively. The dominating diatoms were *Achnanthidium minutissimum*, *Cocconeis placentula*, *Amphora pediculus*, *Staurosirella pinnata*, *Planothidium lanceolatum,* and *Diatoma moniliformis*. The cluster analysis of three different diatom communities yielded different results. The clustering of the composition and structure of the epilithic diatom community brought out three principal groups of river reaches differing in the trophic status of water. Hence the epilithic community of diatoms can be recommended for the monitoring of Estonian running waters.

Introduction

The ecology and distribution of diatoms in Estonian running waters have been poorly investigated compared with analogous studies in lakes and coastal waters. Two surveys of the diatom flora of Estonia were completed: one by Mölder (1938), who used material from different water bodies (with only a few sampling sites in streams), and another by Pork (1961) who studied lakes. A floristical and ecological review of the diatoms of Lake Peipsi-Pihkva was published recently (Laugaste and Pork 1996). Intercalibration guides of the diatom species in the Baltic Sea (Snoeijs 1993, Snoeijs and Vilbaste 1994, Snoeijs and Potapova 1995, Snoeijs and Kasperovičené 1996, Snoeijs and Balashova 1998) include the distribution of diatom taxa in Estonian coastal waters. There are few data about diatoms on soft sediments of some rivers in the drainage basin of the Gulf of Finland (Vilbaste 1998). Information on several benthic diatom communities in Estonian rivers is lacking.

Diatoms can provide valuable information for the monitoring of running waters. Several European states use diatom-based indices (Whitton *et al.* 1991, Whitton and Rott 1996, Prygiel *et al.* 1999), however, methods developed for a particular region may not be appropriate for estimation of the quality of the environment in other regions.

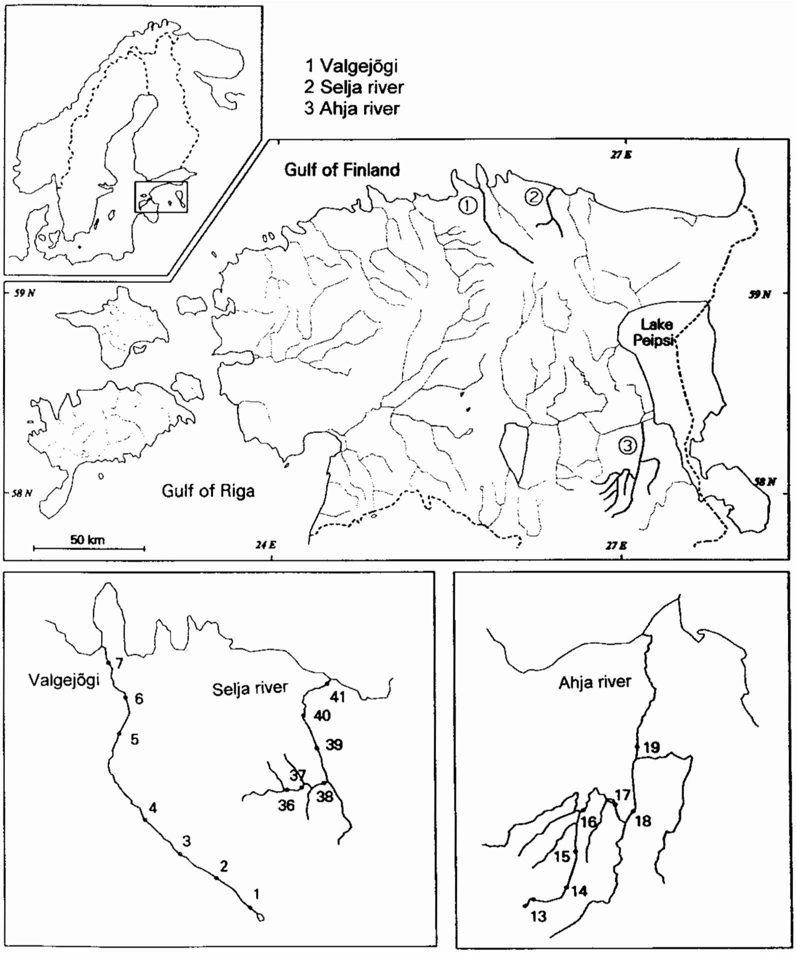

Fig. 1. Map of the studied rivers with location of sampling sites (1 — Valgejõgi, 2 — Selja river, 3 — Ahja river).

The goals of the present study were to describe different benthic diatom communities in rivers; to identify their differences and mutual affinities; to select the most suitable diatom community for the purpose of monitoring running waters in Estonia.

Materials and methods

Abbreviations

EPL	epilithic community,
EPH	epiphytic community,
EPP	epipelic community,
H′	Shannon-Weaver index,
I′	Pielou's evenness index,
RA	relative abundance,
Tot-N	total nitrogen,
NO_3-N	nitrate nitrogen,
NO_2-N	nitrite nitrogen,
NH_4-N	ammonium nitrogen,
Tot-P	total phosphorus,
PO_4-P	phosphate phosphorus.

Study area

Estonia is rich in running waters (Fig. 1). The density of the network of running waters is 0.72 km km^{-2} (Hang and Loopman 1995). The morphology and evolution of rivers differ between northern (Selja and Valgejõgi rivers) and southern Estonia (Ahja river) (Hang and Miidel 1987, Miidel and Raukas 1991). In their lower courses, the Selja and Valgejõgi rivers penetrate the Baltic Glint, a steep escarpment with a resistant carbonate rock cap, and flow in deep terraced valleys. Upstream of the Glint, valleys are shallow with no terraces. The Ahja river flows in a deep, V-shaped valley along the slope of the Otepää Upland and the south-east Estonian Plateau. The depth of the valley decreases gradually in the lower course in the Peipsi Depression.

The Valgejõgi rises from Lake Porkuni (41.5 ha) and smaller reservoirs occur in investigated rivers. The Ahja river includes a large reservoir (Saesaare, 54 ha) upstream of sampling site 17 (Fig. 1). In its upper and middle courses the Ahja river flows through cultivated land; around the lower course swamps and mires prevail. The upper and middle courses of the Selja river pass through densely inhabited territory, the lower course is surrounded by forests. Cultivated land borders the upper course of the Valgejõgi, while the middle and lower courses flow through forest. The riparian vegetation of the rivers is abundant; only in some places do cultivated fields extend to the riverbed and tree canopy is absent. Hydrological characteristics of the rivers are given in Table 1. All the rivers are moderately polluted by agricultural and domestic sewage. The most important source of point pollution affects the Selja river. Wastewater from the town of Rakvere enters the river via a brook between sampling sites 37 and 38 (Fig. 1). Although the population of Rakvere is not very large (ca. 20 000), the impact of the biggest meat-preserving factory in Estonia is considerable.

Sampling procedures

Samples were collected during hydrobiological expeditions of the Department of Hydrobiology of the Institute of Zoology and Botany. The Selja river was sampled at six sites on 17 and 18 July, 1995, the Valgejõgi, at seven sites on 9 July, 1998, and the Ahja river, at seven sites on 28 June, 1999. Water temperature, pH, and concentration of dissolved oxygen were measured and water samples were taken at each sampling site. The concentration of phosphorus and nitrogen compounds was determined in accordance with standard methods (Grasshoff *et al*. 1983) in the laboratory.

The material for studying diatom communities was collected from three different habitats: cobbles or boulders, macrophytes, and soft bottom. According to Round (1991), 'four habitats of river benthos and their community names associated with the underwater surfaces are (1) the aquatic plant surfaces supporting the *epiphyton*; (2) the stone surfaces supporting the *epilithon*; (3) the sand surfaces supporting the *epipsammon*; and (4) the silt surface supporting the *epipelon*'. However, in this study the last two habitats were treated together under epipelon, since it was hard to distinguish sandy habitats with and without silt in the rivers.

An epilithic microalgal sample (EPL) was obtained from 4–6 cobbles or boulders free of any visible filamentous macroalgal coating. Cobbles were gathered along a transect across the river. At deeper sites samples were only taken to a depth of 0.5 m. Diatom film was

Table 1. Hydrological characteristics of the rivers after Loopmann 1979.

River	Ahja	Selja	Valgejõgi
Length (km)	92	44	77
Catchment area (km^2)	1090	434	454
Altitudinal gradient (m km^{-1})	0.95	1.58	1.39
Width in lower part of water course (m)	4–72 (mean 35)	6–25 (mean 12)	6–50 (mean 15)
Depth in lower part of water course (m)	1.6–3.4 (mean 2.2)	0.2–1.5 (mean 0.4)	0.2–2.0 (mean 0.5)
Mean discharge in lower part of water course (m^3 s^{-1})	7.0–8.0	2.5–3.0	3.5–4.0

separated from the cobbles with a toothbrush. Algal suspension from all gathered cobbles was mixed to obtain a bulk sample.

To study the epiphytic diatom community (EPH), a mixed sample consisting of fragments of filamentous algae and aquatic mosses from stones was collected in the same fashion as epilithic samples — to a depth of 0.5 m. A pair of tweezers was used to detach algae and mosses from the stones. *Cladophora glomerata* and *Vaucheria* sp. and the water moss *Fontinalis antipyretica* were the most frequent species in the studied rivers. In some river reaches other macroalgae, such as *Batrachospermum* sp., *Spirogyra* sp., *Ulothrix zonata*, *Zygnema* sp., and the moss *Amblystegium riparium* also occurred.

An epipelic sample (EPP) was taken with a piston corer (i.d. 2.4 cm) from a depth of 0.5 m beyond the main water flow where soft sediments were present. Three different cores were taken and mixed to form one sample. All diatom samples were fixed with neutralised formaldehyde solution (2%–3%).

Diatom preparation

First the samples were processed with chloric acid to dissolve the calcareous compounds and washed three times with distilled water. Then the diatom slides were prepared using sulphuric acid treatment (Vilbaste *et al.* 2000). Hyrax (refractive index 1.65) was used as a mounting medium. On each slide a minimum of 500 valves were identified and counted under bright field microscopy MBL 2000 with a 100 times oil immersion objective. The basic counting unit was a single valve, a complete frustule being counted as two units. The absolute number of taxa counted was converted to relative abundance (RA, %). Altogether, 60 slides were analysed (20 from each community). Species were identified according to Krammer and Lange-Bertalot (1986-1991). The main habitat for each taxon is indicated as in Snoeijs (1993), Snoeijs and Vilbaste (1994), Snoeijs and Potapova (1995), Snoeijs and Kasperovičiené (1996), Snoeijs and Balashova (1998). Nomenclature was updated on the basis of Round *et al.* (1990).

Data analyses

Diversity and dominance in the diatom assemblages were measured by the Shannon-Weaver index (H') (log base = e) and Pielou's evenness index (I'), which were calculated from RA and species richness values. Ward's method of cluster analysis was applied to group diatom assemblages from different sampling sites according to the taxa RA. Before clustering, the data set of identified taxa was screened to remove the rare and sporadic taxa. If the numerical RA of a taxon in a single assemblage did not reach 2%, it was excluded from analysis. As a result 43 diatom species were included (Table 2). The Euclidean distances of species RA were used to draw up the dendrograms of the sampling sites. Distinction between the groups was subjective and based on linkage distance > 90. Three analyses were done, one for each studied diatom community (epilithic, epiphytic and epipelic). Differences in the median values of environmental variables for groups of sampling sites, as well as differences in the median values of H' were tested with the nonparametric Kruskal-Wallis ANOVA median test; p-value < 0.05 was accepted as significant. The software Statistica was used.

Results

Environmental variables and water analyses

Figure 2 shows the measured environmental variables and the results of the water sample analysis. All the rivers are largely spring-fed. At times of low flow, groundwater accounts for most of the discharge. Therefore, water temperature is relatively low in the headwaters of all rivers but rises downstream. In the Ahja river, the temperature gradient was the largest (12.0–21.3 °C), while in the Selja and Valgejõgi

Table 2. List of constant diatom species and their main habitats, with the frequency of occurrence of taxa (maximum value possible for each river shown below relevant river name).

Taxon	River			Habitat
	Ahja (21)	Selja (18)	Valgejõgi (21)	
Achnanthes flexella (Kützing) Brun			10	Epilithic + Epiphytic*
Achnanthidium minutissimum (Kützing) Czarnecki	21	18	21	Epiphytic
Amphora pediculus (Kützing) Grunow	19	18	20	Epipelic + Epilithic
Asterionella formosa Hassall	10			Pelagic
Aulacoseira granulata (Ehrenberg) Simonsen	11			Pelagic*
Caloneis bacillum (Grunow) Cleve	10			Epipelic
Cocconeis pediculus Ehrenberg		15	17	Epiphytic
Cocconeis placentula Ehrenberg	20	18	20	Epiphytic + Epilithic
Diatoma moniliformis Kützing	17	18	17	Epiphytic
Diatoma vulgaris Bory	5	12	13	Epiphytic
Encyonema silesiacum (Bleisch) D.G. Mann		13		Epiphytic + Epilithic
Fragilaria capucina Desmazières		14	15	Pelagic
Fragilaria crotonensis Kitton	11			Pelagic
Fragilaria cf. *famelica* (Kützing) Lange-Bertalot	18	14	15	Epiphytic + Epilithic*
Gomphonema olivaceum (Hornemann) Brébisson		17	14	Epiphytic + Epilithic
Gomphonema parvulum (Kützing) Kützing	17	18	21	Epiphytic + Epilithic
Gomphonemopsis exigua (Kützing) Medlin			16	Epiphytic
Martyana martyi (Héribaud) Round	20	17	15	Epipsammic
Melosira varians C.A. Agardh	16		8	Free living*
Meridion circulare (Greville) C.A. Agardh	18	18	18	Epilithic + Epiphytic
Navicula capitata Ehrenberg	19		15	Epipelic*
Navicula capitatoradiata Germain	16			Epipelic*
Navicula cryptocephala Kützing		12		Epipelic
Navicula cryptotenella Lange-Bertalot	21	17	21	Epipelic*
Navicula gregaria Donkin	20	16		Epipelic + Epilithic
Navicula lanceolata (C.A. Agardh) Ehrenberg	17	15		Epipelic
Navicula tripunctata (O.F. Müller) Bory	19	17	15	Epilithic
Nitzschia dissipata (Kützing) Grunow	17	16	14	Epipelic
Nitzschia inconspicua Grunow	3			Epilithic
Nitzschia palea (Kützing) W. Smith	20	18	8	Epipelic*
Nitzschia paleacea Grunow		18		Epilithic
Nitzschia recta Hantzsch	19	12		Epipelic
Nitzschia sigma (Kützing) W. Smith	15			Epipelic
Nitzschia sigmoidea (Nitzsch) W. Smith	12			Epipelic
Planothidium lanceolatum (Brébisson) Round & Bukhtiyarova	18	18	18	Epipsammic + Epilithic*
Rhoicosphenia curvata (Kützing) Grunow	11	14	10	Epiphytic + Epilithic
Staurosira construens Ehrenberg	15		7	Epipsammic
Staurosira cf. *construens* var. *venter* (Ehrenberg) Hamilton	21	15	15	Epipsammic
Staurosirella pinnata (Ehrenberg) Williams & Round	20	18	18	Epipsammic*
Surirella ovalis Brébisson	15			Epipelic*
Synedra acus Kützing			9	Epiphytic or Free-living
Synedra capitata Ehrenberg			5	Free-living*
Synedra ulna (Nitzch) Ehrenberg			14	Epiphytic or Free-living
Total	32	26	28	

* Author's own observations

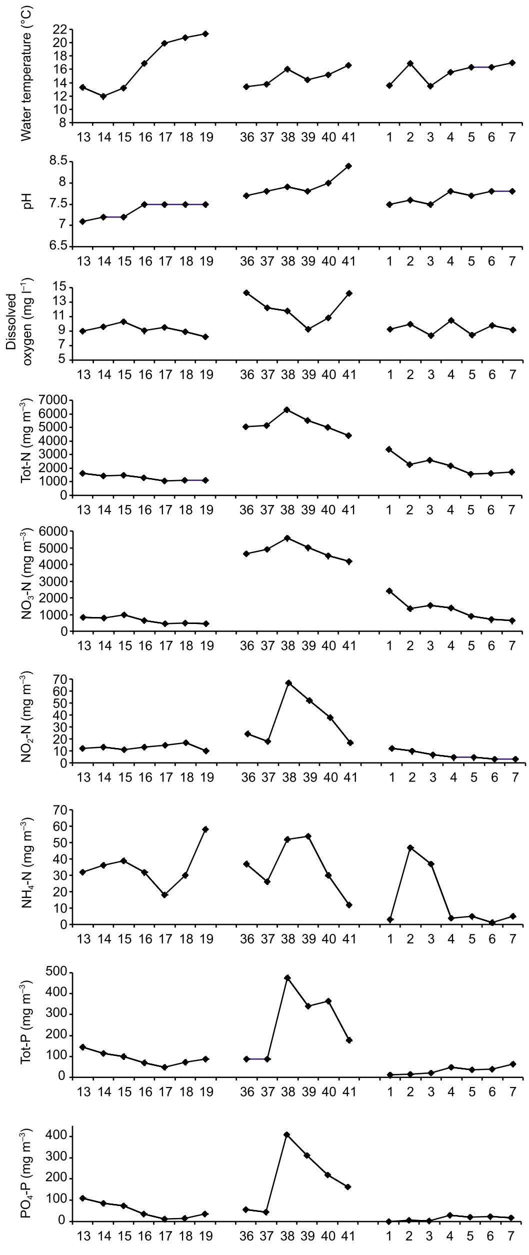

Fig. 2. Measured environmental variables and the results of water analysis. Numbers of sampling sites are the same as in Fig. 1 (13 to 19 — Ahja river, 36 to 41 — Selja river, 1 to 7 — Valgejõgi).

rivers it varied from 13.4 °C to 16.6 °C and from 13.5 °C to 17.0 °C, respectively. As a rule pH increases downstream. In the Ahja river pH fluctuated between 7.1 and 7.5 and in the Valgejõgi between 7.5 and 7.8. In the Selja river the mean value of pH and the range of changes (7.7–8.4) were the largest. The highest concentrations of dissolved oxygen were measured in the Selja river (9.3–14.3 mg l^{-1}); in the Ahja and Valgejõgi the amount of dissolved oxygen was lower, and fluctuated from 8.2 mg l^{-1} to 10.3 mg l^{-1} and from 8.4 mg l^{-1} to 10.5 mg l^{-1}, respectively.

In the northern rivers (Selja and Valgejõgi), the concentration of dissolved total nitrogen (Tot-N) as well as nitrate nitrogen (NO_3-N) was considerably higher than in the Ahja river (Fig. 2). Very strong and extensive nitrogen pollution is a characteristic feature of the rivers rising in the Pandivere Upland region where the concentration of nitrogen compounds in the water of spring-fed streams is high (Järvekülg and Viik 1994). Strongly elevated concentrations of Tot-N and NO_3-N were recorded in the Selja river, at site 38 (6300 mg m^{-3} and 5570 mg m^{-3}, respectively), downstream of the wastewater discharge. In general, the amount of Tot-N and NO_3-N as well as nitrite nitrogen (NO_2-N) decreased downstream, except in river reaches near a wastewater discharge where the concentration of nitrogen compounds was considerably higher. The content of ammonium nitrogen (NH_4-N) was different in different rivers and river reaches. The concentrations of this compound tended to be higher downstream of reservoirs and sites of wastewater discharge (Fig. 2).

The concentration of phosphorus compounds in water and its changes were different in each river. In general, the concentration of total phosphorus (Tot-P) followed changes in the concentration of phosphate phosphorus (PO_4-P) along a river (Fig. 2). In the Ahja and Selja rivers, the concentration of phosphorus compounds decreased downstream, but increased downstream of the reservoir (the Ahja river). A particularly drastic increase was evident downstream of wastewater discharge (Selja river). The maximum values of Tot-P and PO_4-P concentration were recorded at sampling site 38 in the Selja river, 477 mg m^{-3} and 409 mg m^{-3}, respectively. In the Valgejõgi the concentrations of Tot-P and PO_4-P were low and increased slightly downstream.

Dominance and diversity

A total of 165 diatom taxa were recorded: 120 in the Ahja river, 118 in the Selja river, and 105 in the Valgejõgi. Of the 165 taxa, 62 occurred in all three rivers. Several diatom species occurred in only one river: 12 in the Ahja river, 21 in the Selja river, and 10 in the Valgejõgi. The species composition of all diatom assemblages consisted of 32, 26, and 28 constant taxa in the three rivers, respectively (Table 2), accounting for up to 85% of the total cell count in each assemblage. Seventeen taxa were common in all rivers. The most frequent species were also the most abundant ones. The dominating (mean RA > 4%) diatoms were *Achnanthidium minutissimum* [occurred in all assemblages (n = 60) with mean RA = 20%], *Cocconeis placentula* (n = 58; mean RA = 9.2%), *Amphora pediculus* (n = 57; mean RA = 5.7%), *Staurosirella pinnata* (n = 56; mean RA = 5.8%), *Planothidium lanceolatum* (n = 54; mean RA = 4.3%) and *Diatoma moniliformis* (n = 52; mean RA = 6.3%). There were some other taxa which occasionally showed high RA values (≥ 12%) (Table 3). Among them were representatives from different habitats: pelagic — *Asterionella formosa* and *Fragilaria crotonensis*; epilithic — *Navicula tripunctata*; epipelic — *Nitzschia palea*; epiphytic — *Cocconeis pediculus* and *Diatoma vulgaris*; epipsammic — *Staurosira construens*.

The Shannon-Weaver diversity index (H')

Table 3. Showing the maximum RA of non-dominant taxa (RA ≥ 12%) in different assemblages (EPL — epilithic; EPP — epipelic; EPH — epiphytic community). For location of sites, *see* Fig. 1.

Taxon	RA (%)	Community	River	Site
Asterionella formosa	14	EPH	Ahja	18
	12	EPP	Ahja	18
Cocconeis pediculus	43	EPH	Selja	38
	37	EPH	Selja	39
	18	EPL	Selja	38
	16	EPL	Selja	41
	15	EPP	Selja	41
	14	EPH	Selja	41
	12	EPH	Selja	40
Diatoma vulgaris	26	EPH	Selja	40
	14	EPH	Valgejõgi	3
Fragilaria crotonensis	13	EPH	Ahja	17
Martyana martyi	16	EPP	Valgejõgi	1
Navicula tripunctata	15	EPH	Ahja	14
	14	EPL	Valgejõgi	5
	13	EPL	Ahja	14
	12	EPL	Selja	37
	12	EPH	Valgejõgi	4
Nitzschia palea	16	EPL	Selja	17
	15	EPP	Ahja	15
Rhoicosphenia curvata	34	EPH	Selja	41
	17	EPL	Selja	41
Staurosira construens	21	EPP	Ahja	17
	12	EPH	Ahja	17
Staurosira cf. *construens* var. *venter*	25	EPP	Ahja	14
	24	EPP	Valgejõgi	3
	22	EPP	Ahja	15
	17	EPP	Valgejõgi	1
	16	EPP	Ahja	13
	14	EPP	Ahja	17
	13	EPP	Ahja	18

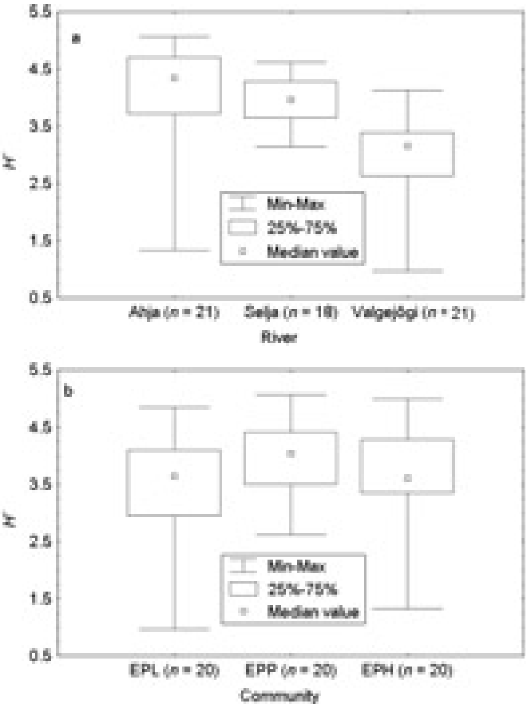

Fig. 3. Differences in the values of Shannon-Weaver diversity (H') shown as boxplots (**a**) by rivers, (**b**) by diatom communities (EPL — epilithic, EPP — epipelic, EPH — epiphytic).

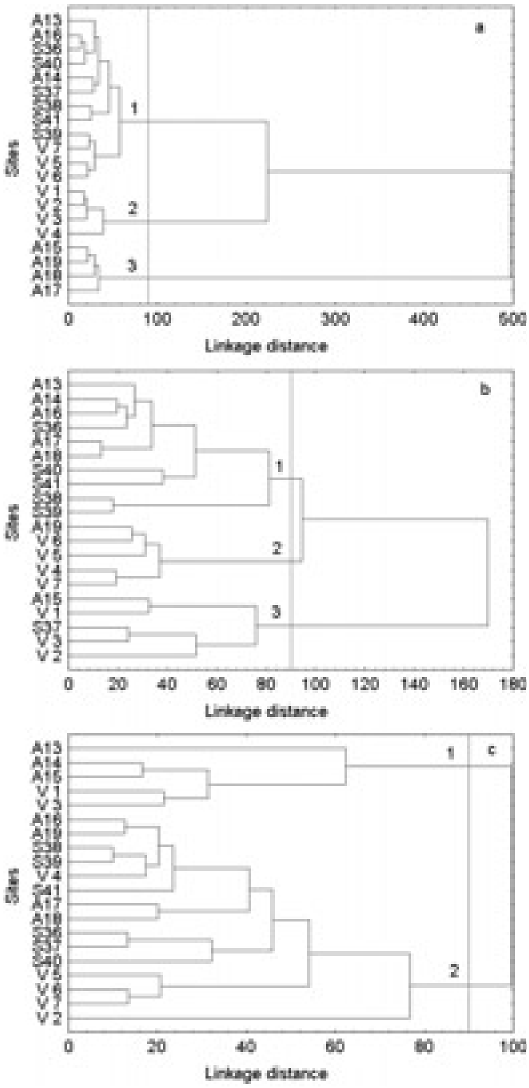

Fig. 4. Results of cluster analysis of (**a**) epilithic, (**b**) epiphytic, (**c**) epipelic diatom communities of studied rivers on the basis of relative abundance of constant diatom species. Numbers of sampling sites are the same as in Fig. 1 [13 to 19 — Ahja river (A), 36 to 41 — Selja river (S), 1 to 7 — Valgejõgi (V)].

varied on a large scale from 0.96 (an epilithic community (1 EPL) in the Valgejõgi) to 5.07 (an epipelic community (16 EPP) in the Ahja river) and correlated (Spearman $r = 0.93$; $p < 0.001$) with species richness which fluctuated from 12 (13 EPP) to 66 (16 EPP), and evenness (I') ($r = 0.80$; $p < 0.001$) which varied from 0.22 (1 EPL) to 0.94 (13 EPP). The variation of H'-values for diatom assemblages in the Selja river was smaller compared with the Ahja and Valgejõgi rivers (Fig. 3a). Median diversity was lower for the Valgejõgi (3.15) than for the Ahja (4.34) and Selja (3.96) rivers and tended to be higher (4.03) for epipelic than epilithic (3.64) and epiphytic (3.60) communities (Fig. 3b). However, neither of these trends was statistically significant. In the epipelic communities diversity index varied much less than in the epilithic and epiphytic communities (Fig. 3b).

Cluster analysis

The dendrograms of the sampling sites based on the RA of 43 diatom species are given in Fig. 4. Analysis of different diatom communities yielded different results (Table 4). Epilithic communities fell into three principal groups of sampling sites (Fig. 4a). Group 1 was the largest consisting of twelve river reaches and comprising the upper course of the Ahja river, the entire Selja river, and the lower course of the Valgejõgi. Four sampling sites of the upper and middle courses of the Valgejõgi belonged to group 2. Group 3 was formed of the middle and lower reaches ($n = 4$) of the Ahja river.

Cluster analysis of epiphytic diatom communities revealed two main groups of sampling sites, one of which was divided into two new clusters according to the selected linkage distance as 90 (Fig. 4b). The largest, group 1 ($n = 10$) was formed of the Selja river, excluding one (37) of its reaches, and the Ahja river, excluding two (15 and 19) of its reaches. Group 2 was formed of four middle and lower course sampling sites of the Valgejõgi and the most downstream river reach (19) of the Ahja river ($n = 5$). Group 3 consisted of three upper course reaches of the Valgejõgi plus one upper course sampling site (15 and 37) from both of the other two rivers ($n = 5$).

Cluster analysis of epipelic diatom communities revealed two main groups of river reaches (Fig. 4c). Group 1 consisted of two upper course sampling sites of the Valgejõgi and three upper course sampling sites of the Ahja river ($n = 5$). Group 2 included the other river reaches of the Ahja and Valgejõgi rivers and the entire Selja river ($n = 15$).

Grouping sampling sites by cluster analysis exposed dissimilarities in environmental variables between the groups (Table 4). Clustering by species composition of epilithic diatom communities revealed three different types of sites. (1) River reaches where the concentration of Tot-N indicated very strongly hypertrophic conditions and the concentration of Tot-P, of hypertrophic conditions (medians 3052 mg m^{-3} and 101 mg m^{-3}, respectively) according to Forsberg and Ryding (1980) for Tot-N and Järvekülg (1994) for Tot-P. (2) River reaches with Tot-N concentration displayed hypertrophic conditions (median 2427 mg m^{-3}) and Tot-P mesotrophic conditions (median 19 mg m^{-3}). (3) River reaches where the concentrations of both Tot-N and Tot-P pointed to eutrophic conditions (medians 1107 mg m^{-3} and 78 mg m^{-3}, respectively).

Groups of river reaches based on epiphytic

Table 4. Results of Kruskal-Wallis test between environmental variables of different groups of river reaches according to the cluster analysis (Fig. 4); *n* — number of river reaches within a group; EPL — epilithic; EPH — epiphytic; EPP — epipelic diatom community; median values of environmental variables are shown; ns — not significant.

	Community							
	EPL			EPH			EPP	
Group	1	2	3	1	2	3	1	2
n	12	4	4	10	5	5	5	15
Variable								
Temperature (°C)	ns	ns	ns	ns	ns	ns	13.3	16.3
pH	ns	ns	ns	ns	ns	ns	7.2	7.8
O_2 (mg l^{-1})	ns	ns	ns	ns	ns	ns	ns	ns
Tot-N (mg m^{-3})	3052	2427	1107	ns	ns	ns	ns	ns
NO_3-N (mg m^{-3})	2599	1472	487	ns	ns	ns	ns	ns
NO_2-N (mg m^{-3})	ns	ns	ns	17	5	11	ns	ns
NH_4-N (mg m^{-3})	ns	ns	ns	ns	ns	ns	ns	ns
Tot-P (mg m^{-3})	101	19	78	130	49	22	ns	ns
PO_4-P (mg m^{-3})	70	4	26	97	24	7	ns	ns

diatom communities clusters differed from each other in NO_2-N, Tot-P, and PO_4-P concentrations (Table 4). Water of the sampling sites of group 1 was characterised by high concentration of all these variables (medians 17 mg m^{-3}, 130 mg m^{-3} and 97 mg m^{-3}, respectively). For river reaches in group 2 low NO_2-N content (median 5 mg m^{-3}) and moderate phosphorus (medians 49 mg m^{-3} and 24 mg m^{-3} for Tot-P and PO_4-P, respectively) was typical. In group 3 the situation was opposite: a moderate NO_2-N (median 11 mg m^{-3}) and relatively low Tot-P and PO_4-P (medians 22 mg m^{-3} and 7 mg m^{-3}, respectively) occurred.

Clustering of river reaches according to the epipelic communities split them into two groups which differed from each other only in water temperature and pH. Sampling sites with relatively low water temperature and pH fell into the first group, while these values were higher (medians 13.3 °C and 7.2, and 16.3 °C and 7.8, respectively) for the second group.

Discussion

Diatom communities

The plankton community of river diatoms tends to be highly seasonal and can contaminated by species from reservoirs as well as by benthic microalgal communities (Round 1991). Planktonic species can also contaminate benthic diatom communities. In this study evident ‘pollution’ of benthic diatom communities by planktonic species was noted in the Ahja river. Downstream of the reservoir (sites 17 and 18) the amount of pelagic diatoms, such as *Asterionella formosa* and *Fragilaria crotonensis*, in the epiphytic and epipelic communities was remarkable (Table 3). Floating colonies of pelagic diatoms stuck to filamentous macrophytes or settled down in the riverbed. There was no marked contamination of any epilithic community with planktonic species.

Epilithic and epiphytic diatom cells washed away from their natural surface of habitat were often encountered among epipelon and epipsammon. Therefore the species composition of the epipelic community was made up of planktonic, epiphytic, epilithic, epipsammic, and epipelic algae: representatives of the whole river diatom flora had accumulated in it.

Separation of epiphytic samples would be reasonable when it based on different macrophyte taxa. In this study one diatom species sometimes strongly predominated over the others in the composition of epiphytic community (RA of *Diatoma moniliformis* at sampling site 15 in the Ahja river (15 EPH) was 83%; RA of *Cocconeis pediculus* at sampling site 38 in the Selja river (38 EPH) was 43%; RA of *Diatoma moniliformis* at sampling site 1 in the Valgejõgi (1 EPH) was 58% and RA of *Cocconeis placentula* at sampling site 7 in the same river (7 EPH) was 46%). It would be interesting to ascertain whether the species composition of the epiphytic diatom community is related to different host macrophyte species. However, species of filamentous algae are distributed unevenly in different river reaches along the river, and it is difficult to find a single macrophyte species that would provide comparable data for the whole river. In this study no any of the macrophytes, even the most widespread, occurred at all sites in a river.

Trophic status of water

As a result of the cluster analysis, the grouping of river reaches according to epilithic diatom community revealed a relationship with biogenous elements in the water. Main groups of river reaches differed from each other in Tot-N and NO_3-N as well as Tot-P and PO_4-P concentrations (Table 4). Since stratification is absent in shallow Estonian rivers and different compounds are distributed evenly in the flow, the species composition and structure of the epilithic diatom community reflect the ambient trophic status.

In Estonian rivers, autotrophic organisms cannot utilise most of the large supplies of biogenous elements. Even in midsummer, when photosynthesis is most intensive, the concentration of mineral nitrogen and phosphorus compounds remains considerably elevated (Järvekülg and Viik 1994). According to Järvekülg (2001) the concentration of Tot-N fluctuates considerably (from 115 mg m^{-3} to 9030 mg m^{-3}), being

< 3000 mg m^{-3} in 87% of the studied river reaches; Tot-P content varies from 4 mg m^{-3} to 2470 mg m^{-3} and is < 50 mg m^{-3} in 52% of the river reaches. Over 500 reaches of 238 rivers were studied in Estonia. For comparison, in Iceland Tot-P concentration does not exceed 50 mg m^{-3} in any of the streams (100%), while in Sweden the respective percentage is 70%, in Norway 87%, and in Finland 70%. However, in Denmark Tot-P is more than 50 mg m^{-3} in all streams (Indicators... 1997). In Estonia, river reaches 10–50 mg m^{-3} Tot-P in the water are considered mesotrophic (Järvekülg 1994), while in the United Kingdom mesotrophic rivers have 20–90 mg m^{-3} Tot-P (Kelly and Whitton 1998). Hence, it is evident that evaluative methods of trophic status developed for a specific region may not be applicable in other regions.

Annual differences

The species composition of diatom communities varies from season to season and from year to year. However, in this study seasonality was eliminated by collecting the material in midsummer. Cluster analysis did not reveal any annual differences — no cluster of sampling sites included samples of only one year (or one river) (Fig. 4). Consequently, differences between benthic diatom communities that were caused by environmental variables were more pronounced than any annual differences. Similar results were obtained by Stevenson and Hashim (1989) who claimed that the species composition of diatom communities varied more between habitats and streams than between years. Kelly *et al.* (1998) stressed that the investigation of aquatic biological communities at times of low flow yields comparable results. In Estonian rivers, midsummer is the period of low flow when stabilisation of the aquatic biological regime and maturation of the biota are complete, bioproduction is at a maximum, and water quality parameters are there most stable.

Dominance and diversity

The recorded composition of benthic diatom communities is typical of running waters. Many taxa which were abundant in our study are commonly found in rivers of Europe and North-America (Butcher 1940, Kawecka 1980, Stevenson and Hashim 1989, Eloranta 1995, Round and Bukhtiyarova 1996). The species such as *Achanthidium minutissimum* (*Achnanthes minutissima*), *Amphora pediculus* (*Amphora ovalis* var. *pediculus*), *Cocconeis placentula*, *Planothidium lanceolatum* (*Achnanthes lanceolata*) and *Staurosirella pinnata* (*Fragilaria pinnata*) appear to be widely distributed inhabitants of diatom communities on riverbeds.

The Shannon-Weaver diversity was high throughout the studied assemblages (median H' = 3.78). High values of diversity indices (> 4.5) have been reported earlier for benthic diatom communities of sandy streams in Michigan (Stevenson and Hashim 1989), however they have been considerably lower (1.40–2.43) in European mountain streams (Kawecka 1980).

Although the number of identified taxa was over 100 in each studied river and varied more than five times between different samples, the species composition of all 60 analysed individual diatom assemblages consisted of 26–32 constant species (Table 2). The number of rare and sporadic taxa was high in each assemblage. However, compared with epiphytic and epipelic communities the indices of species richness, diversity, and evenness tended to be lower for the epilithic community.

Conclusions

The benthic diatom flora of Estonian rivers can be characterised by a small number of species whose frequency and abundance are high, and by a large number of species which occur only occasionally and are always only represented by a few specimens. To a variable degree, all benthic diatom communities can be contaminated by planktonic species as well as by one another. Compared with the epiphytic and epilithic communities, the epipelic diatom community best expresses the entire natural diatom flora of a river. As the epilithic diatom community reflects water quality (trophic status) it can be recommended for monitoring running waters. Further research is required to test the usefulness and sensitivity of different diatom indices for Estonian rivers.

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