

Halophilic diatom taxa are sensitive indicators of even short term changes in lowland lotic systems

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Abstract – The occurrence and spread of halophilic diatom taxa in freshwater lotic ecosystems are influenced both by natural processes and anthropogenic pollution. Diatom assemblages were regularly monitored in lowland lotic systems in Hungary (Central Europe) during the unusually dry year of 2012. Highly pronounced changes in diatom composition were observed from spring to autumn. Halophilic taxa (especially *Nitzschia sensu lato* species) appeared in the dry autumn. In addition, the total relative abundances of halophilic species also increased up to autumn. Abundance of *Nitzschia* cf. *lorenziana* and *Nitzschia tryblionella* showed a positive correlation with chloride and phosphate concentration, while that of other taxa like *Tryblionella apiculata* or *Tryblionella calida* showed a positive correlation with the concentration of nitrate. Our findings clearly demonstrated that these halophilic and mesohalophilic diatom taxa were sensitive indicators of even short-term changes in lowland lotic ecosystems, such as the increasing salt concentration from spring to autumn caused by the lack of rainfall and/or environmental loads.

Keywords: cell size, dry year, freshwater river, nutrient load, salt concentration, taxa number, temporal dynamics

Introduction

Diversity, expressed often as the number of taxa, has an essential role in ecosystem processes and functioning, food chains, and ecosystem integrity (COTTINGHAM et al. 2001,

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FRANCE and DUFFY 2006, SMUCKER and VIS 2011, BORICS et al. 2014). The structure and functioning of ecosystems can be altered by changes in species diversity (PORTER et al. 2013). Biodiversity is influenced by biotic- (VASAS et al. 2013), or abiotic- (ÁCS et al. 2006), natural- (LOTTER et al. 1997, BUCZKÓ et al. 2013, CATALAN et al. 2013) or human induced processes (BÁCSI et al. 2013). Numerous anthropogenic factors cause short- or long-term changes in biodiversity (e.g. eutrophication, changes in some land-use processes, mining, and industry – TILMAN 1999, HOOPER et al. 2005, SMUCKER and VIS 2011). It is important to stress that aquatic assemblages respond much more sensitively to natural or anthropogenic disturbances than terrestrial communities (to changes in water flow conditions, precipitation, to the increase of nutrient concentrations or salinity – SMUCKER and VIS 2011, PORTER et al. 2013).

Benthic diatoms have a decisive structural and functional role in freshwater ecosystems (BOLLA et al. 2010, SMUCKER and VIS 2011). They are often the dominant photosynthetic algal group in the biofilm (PASSY 2002, ANTONIADES et al. 2004, KIRETA et al. 2012) and they have a crucial role in primary production (e.g. KIRETA et al. 2012). They are routinely used in biomonitoring assessments (e.g. BERTHON et al. 2011, VÁRBÍRÓ et al. 2012), because they respond sensitively to the changes in the physical and chemical parameters of freshwater habitats (flow conditions, conductivity, ion composition, and nutrient conditions – ÁCS et al. 2003, BERTHON et al. 2011, SMUCKER and VIS 2011, RUSANOV et al. 2012, STENGER-KOVÁCS et al. 2013, B-BÉRES et al. 2014). Increased nutrient load or conductivity induce changes of species composition in diatom assemblages (e.g. ZIEMANN et al. 2001, STENGER-KOVÁCS et al. 2013, B-BÉRES et al. 2014) via the frequent appearance of new taxa (e.g. some halophilic, mesohalophilic eutraphenic taxa) while the abundance of some others decreases (e.g. ZIEMANN et al. 2001). Structural parameters of diatom assemblages (i.e. the composition of size classes – BERTHON et al. 2011) can also change considerably, because of the increased interspecific competition caused by the immigrants.

The occurrence and spread of halophilic and mesohalophilic diatom taxa in freshwater lotic ecosystems are caused both by natural processes (e.g. by the increase of nutrient concentrations caused by a decreased water discharge in lack of rainfall) and/or by anthropogenic pollution (e.g. fertiliser run off, atmospheric sedimentation, mining).

In the spring of 2012 there was high precipitation, while the summer and autumn period was unusually dry in Hungary, as revealed by the data of the Hungarian Meteorological Service and the General Directorate of Water Management. Decreased water flow conditions occurred mainly because of the low precipitation input in the dry months in lowland rivers and channels (B-BÉRES et al. 2014, KÓKAI et al. 2014).

Diatom assemblages of 15 Hungarian lowland small to large rivers and channels were studied during the humid spring and dry autumn period of 2012. In the present study we have focused on the changes in taxa composition, taxa number, cell size classes and the evenness of diatom assemblages with a special emphasis on halophilic/mesohalophilic taxa. We hypothesised the following: (i) taxa number and abundance of halophilic and mesohalophilic taxa increase from spring to autumn with the increase of conductivity and nutrient content; (ii) the ratio of small disturbance-tolerant taxa and large halophilic/mesohalophilic taxa increases from spring to autumn according to augmented conductivity and nutrient content and (iii) due to the increasing conductivity, the evenness of species diversity decreases from spring to autumn.

Materials and methods

Sampling setup

Samples were collected from 15 channels and small to large rivers of the Trans-Tisza Region of Hungary in 2012 (Fig. 1). Altogether, 10 environmental factors were measured. Conductivity (COND), concentration of dissolved oxygen (DO), pH and water temperature (T)

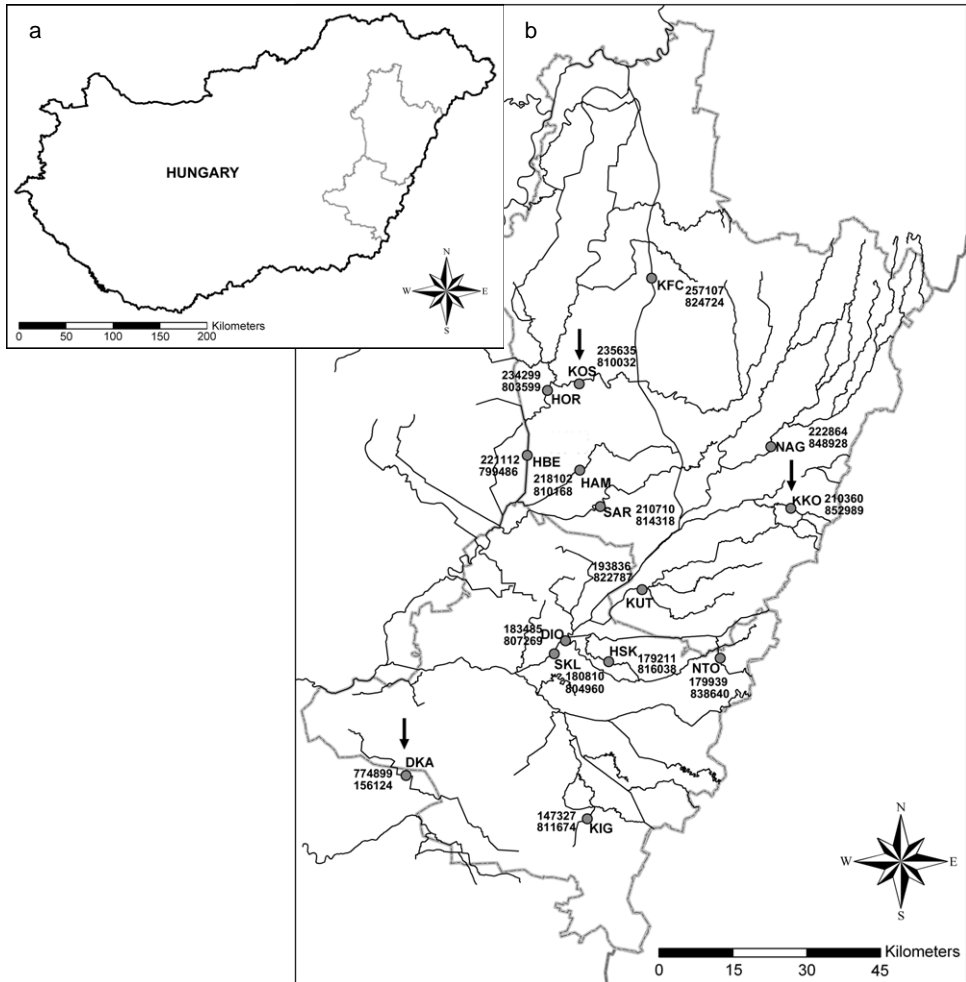


Fig. 1. The study area on Trans-Tisza region of Hungary: (a) localization of the study area (marked with grey borders); (b) sampling sites on the rivers and channels with EOVS coordinates, grey lines: borders of the study area, black lines: the rivers and channels. The abbreviations of the watercourses are the following: Dióéri-főcsatorna (DIO), Dögös-Kákafoki-főcsatorna (DKA), Hamvas-csatorna (HAM), Holt-Sebes-Körös (HSK), Hortobágy (HOR), Hortobágy-Berettyó (HBE), Keleti-főcsatorna (KFC), Kígyósi-főcsatorna (KIG), Kis-Körös-főcsatorna (KKO), Kösely (KOS), Kutas-főcsatorna (KUT), Nagy-ér (NAG), Nagytóti-Toprongyos-csatorna (NTO), Sárréti-csatorna (SAR), Sebes-Körös (SKL). Arrows indicate three representative sampling sites shown on Fig. 2.

were measured in the field with a portable multiparameter digital meter (Multi 350i-WTW, Germany). Water samples were kept at 4 °C in cooler bags during transportation to the laboratory for the measurement of the concentrations of hydrogen carbonate (HCO_3^- – titrimetric method; MSZ 1987), chloride (Cl^- – argentometric method; MSZ 2009a), ammonium (NH_4^+ – spectrophotometric method; MSZ ISO 1992), nitrite (NO_2^-), nitrate (NO_3^- – spectrophotometric method; MSZ 2009b), and phosphate (PO_4^{3-} – spectrophotometric method; MSZ EN ISO 2004). The year of 2012, especially the autumn period, was very dry, according to the data of the Hungarian Meteorological Service. The amount of precipitation was only 427 mm in this year, which was 25% less than the hundred-year average (569 mm).

Sample collection and preparation

Benthic diatom samples were collected from macrophytes, samples were fixed in Lugol's solution in the field. Diatom valves were prepared using the hot hydrogen-peroxide method (MSZ EN 2003). Naphrax synthetic resin was used for embedding (MSZ EN 2003). A Leica DMRB research microscope with Leica PL FLUOTAR objective with 100× magnification and 1.30–0.60 aperture was used for the identification of diatom taxa. At least 400 valves were counted (MSZ EN 2004). KRAMMER and LANGE-BERTALOT (1986, 1988, 1997a, b), KRAMMER and LANGE-BERTALOT (1991a, b, 2004a, b), and POTAPOVA and HAMILTON (2007) were used during diatom identification. The OMNIDIA version 5.2 software package (LECOINTE et al. 1993) and Algaebase (GUIRY and GUIRY 2014) were used for naming the diatom taxa. In each site three independent samples were collected.

Data processing and analyses

Diatoms were classified into halophilic/mesohalophilic and non-halophilic taxa groups according to ZIEMANN et al. 2001. Diatom taxa were assigned to five size classes (Tab. 1) according to BERTHON et al. 2011. The biovolume of diatom taxa was calculated by using the OMNIDIA version 5.2 software package (LECOINTE et al. 1993). To compare the taxa number of each size class with the total taxa number, we calculated the size class ratio (based on taxa numbers) using the following simple equation:

$$\begin{aligned} \text{size class ratio (based on taxa numbers)} &= \\ &= \text{taxa number in a size class} \times \text{total taxa number}^{-1} \end{aligned}$$

Furthermore, comparing halophilic taxa number of each size classes to the total halophilic taxa number, we calculated the size class ratio (based on halophilic taxa numbers) using the following simple equation:

Tab. 1. Diatom size classes according to BERTHON et al. 2011.

| Diatom size classes | Biovolume (μm^3) |
|---------------------|-------------------------------|
| S1 | 5 – 99 |
| S2 | 100 – 299 |
| S3 | 300 – 599 |
| S4 | 600 – 1499 |
| S5 | ≥ 1500 |

$$\begin{aligned} & \text{size class ratio (based on halophilic taxa numbers)} = \\ & = \text{halophilic taxa number in a size class} \times \text{total halophilic taxa number}^{-1} \end{aligned}$$

Principal component analysis (PCA) was used to validate the importance of environmental factors according to LEPŠ and ŠMILAUER (2003) and STENGER-KOVÁCS et al. (2013). To analyse the relationship between diatom taxa composition and validated environmental factors a detrended correspondence analysis (DCA) was used, in which environmental factors were added by weighted averaging (LEPŠ and ŠMILAUER 2003, B-BÉRES et al. 2014).

Results

Changes in environmental variables

All of the 10 measured environmental variables were included into the PCA (DO, COND, pH, T and concentrations of HCO_3^- , Cl^- , NH_4^+ , PO_4^{3-} , NO_2^- , NO_3^-). The first three axes of PCA explained 93% of the total of species variance. The PCA revealed that the factors with the highest correlation were with the first axis conductivity (0.8627), concentrations of HCO_3^- (0.7718), Cl^- (0.8469), and PO_4^{3-} (0.9569), with the second axis DO (0.6450), and with the third axis the concentration of NO_3^- (0.5022). Conductivity showed a very high correlation with the concentration of HCO_3^- (0.9033), Cl^- (0.9419), and PO_4^{3-} (0.9870), and HCO_3^- and Cl^- both with PO_4^{3-} (0.8036 and 0.8744, respectively). Thus, in the DCA only the following validated factors were included: concentrations of NO_3^- , HCO_3^- , Cl^- , and DO. The gradient lengths for the first and second axis in DCA were 4.186 and 3.026, while the cumulative percentage variances of species data were 21.6 and 28.9 for the first and second axis, respectively.

Changes in total and halophilic taxa number – size classes and size class ratio (taxa number)

Highly pronounced changes in diatom composition were observed from the humid spring to the dry autumn. For better clarity, changes are plotted in figure 2 only for three representative sites: Dögös-Kákafoki-főcsatorna (DKA), Kis-Körös-főcsatorna (KKO) and Kösely (KOS) (marked with arrows on Fig. 1B). Taxa number increased up to autumn almost in all cases (Fig. 2A), a lot of taxa appeared only in the dry autumn period (Tab. 2).

When size class ratios in spring were compared to those in autumn, there were clear increases only in the case of large taxa (S5 size class – 80% of all sampling sites; each representative site in Fig. 2A) and small taxa (S1 or/and S2 size classes – 73% of all sampling sites; KOS on Fig. 2A).

Similar changes occurred also in halophilic taxa numbers. They increased from spring to autumn in two thirds of the sampling sites (each representative site in Fig. 2B). From the identified 31 halophilic and mesohalophilic diatom taxa, 13 taxa appeared only in the samples collected in autumn. The most important difference between the changes of total taxa number and the changes of halophilic taxa number was the distribution of changes in the size classes. While total taxa number increased in all size classes almost in all sites, a clear increase was detectable in halophilic taxa number only in cases of S2 (60%), S4 (80%) and S5 (53.3%) size classes. Moreover, the increase of taxa numbers in the different size classes did not definitely mean the increase of the size class ratio. It increased only in the cases of

S2 and S4 and/or S5 size classes (73% and 53% of all sampling sites, respectively; S2: each representative site, S4 and S5: DKA and KOS on Fig. 2B).

Changes in total and halophilic taxon abundance – size classes

Increasing relative abundances of small taxa (S1 and/or S2 size classes) were observed from spring to autumn in almost every site (DKA and KKO on Fig. 2C; Tab. 3). Nevertheless, not only the abundances of small taxa, but also the abundances of large taxa (S5 or/and S4 size classes) were increased (S4: DKA and KOS, S5: KKO and KOS on Fig. 2C). However, the contribution of halophilic taxa to the increasing abundance of S4 size classes was

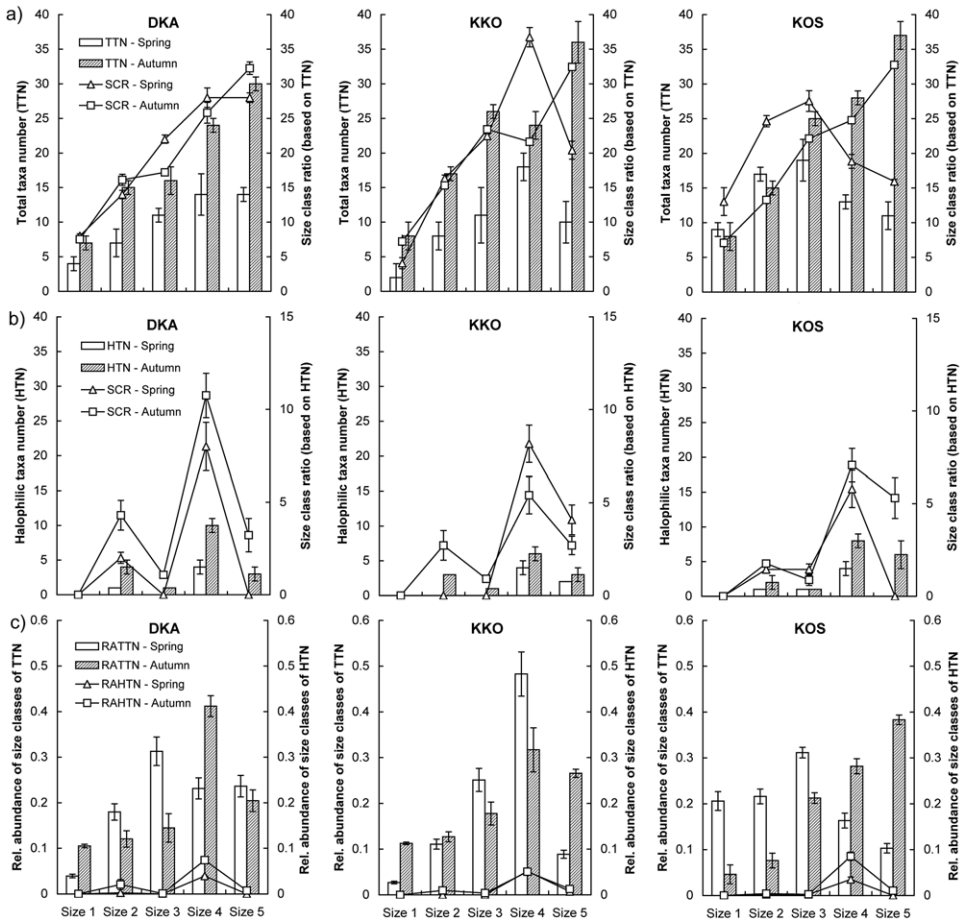


Fig. 2. (a) The total taxa number of different cell size classes and size class ratios based on total taxa number; (b) number of halophilic taxa of different cell size classes and size class ratios based on number of halophilic taxa; (c) relative abundances of different cell size classes and relative abundances of halophilic taxa of different cell size classes in spring and in autumn at three representative sampling sites. DKA – Dögös-Kákafoki-főcsatorna, KKO – Kis-Körös-főcsatorna, KOS – Köselly; TTN – total taxa number, HTN – halophilic taxa number, SCR – size class ratio and RA – relative abundances.

Tab. 2. Diatom taxa appearing only in the dry autumn period. For explanation of size class types see Tab. 1.

| Taxa name | Type of size class |
|---------------------------------|--------------------|
| <i>Fistulifera saprophila</i> | S1 |
| <i>Nitzschia microcephala</i> | S1 |
| <i>Sellaphora seminulum</i> | S1 |
| <i>Nitzschia angustatula</i> | S2 |
| <i>Cocconeis neodiminuta</i> | S2 |
| <i>Encyonema minutum</i> | S2 |
| <i>Navicula cf. kotschyi</i> | S2 |
| <i>Nitzschia clausii</i> | S2 |
| <i>Denticula tenuis</i> | S3 |
| <i>Hippodonta</i> | S3 |
| <i>Karayevia clevei</i> | S3 |
| <i>Kolbesia ploenensis</i> | S3 |
| <i>Encyonema caespitosum</i> | S4 |
| <i>Luticola goeppertiana</i> | S4 |
| <i>Nitzschia cf. lorenziana</i> | S4 |
| <i>Nitzschia prolongata</i> | S4 |
| <i>Surirella suecica</i> | S4 |
| <i>Anomoeoneis sphaerophora</i> | S5 |
| <i>Caloneis amphisbaena</i> | S5 |
| <i>Cymbella lanceolata</i> | S5 |
| <i>Craticula cuspidata</i> | S5 |
| <i>Ctenophora pulchella</i> | S5 |
| <i>Eunotia formica</i> | S5 |
| <i>Gomphonema spp.</i> | S5 |
| <i>Gyrosigma scalproides</i> | S5 |
| <i>Nitzschia angustata</i> | S5 |
| <i>Tryblionella calida</i> | S5 |

Tab. 3. Relative abundance of those small sized taxa the abundance of which increased from spring to autumn. For explanation of size class types see Tab. 1.

| Taxa name | Type of size class |
|-------------------------------------|--------------------|
| <i>Achnanthydium eutrophilum</i> | S1 |
| <i>Eolimna minima</i> | S1 |
| <i>Mayamaea permissis</i> | S1 |
| <i>Eolimna subminuscula</i> | S2 |
| <i>Mayamaea atomus</i> | S2 |
| <i>Nitzschia paleacea</i> | S2 |
| <i>Nitzschia pusilla</i> | S2 |
| <i>Planothidium frequentissimum</i> | S2 |

much more pronounced (maximum 84%; each representative site in Fig. 2C), while halophilic taxa only slightly (maximum 17%) contributed to the increasing abundance of small taxa in autumn. Overall, relative abundances of halophilic taxa increased at 53% of all sampling sites from spring to autumn (each representative site on Fig. 2C).

While abundances of certain halophilic and mesohalophilic taxa (Tab. 4) showed positive correlations with chloride and hydrogen carbonate concentrations, other taxa (Tab. 5) correlated positively with nitrate (Fig. 3).

Tab. 4. Halophilic diatom taxa correlating positively with chloride and hydrogen carbonate concentration. For explanation of size class types see Tab. 1.

| Taxa name | Type of size class |
|---------------------------------|--------------------|
| <i>Diatoma tenuis</i> | S4 |
| <i>Nitzschia cf. lorenziana</i> | S4 |
| <i>Craticula buderii</i> | S5 |
| <i>Craticula halophila</i> | S5 |
| <i>Nitzschia tryblionella</i> | S5 |

Tab. 5. Halophilic diatom taxa correlating positively with nitrate. For explanation of size class types see Tab. 1.

| Taxa name | Type of size class |
|--|--------------------|
| <i>Nitzschia microcephala</i> | S1 |
| <i>Nitzschia angustatula</i> | S2 |
| <i>Nitzschia clausii</i> | S2 |
| <i>Nitzschia frustulum</i> | S2 |
| <i>Navicula schroeteri</i> | S4 |
| <i>Nitzschia filiformis</i> | S4 |
| <i>Nitzschia prolongata</i> | S4 |
| <i>Surirella suecica</i> | S4 |
| <i>Anomoeoneis sphaerophora</i> | S5 |
| <i>Caloneis amphisbaena f. subsalina</i> | S5 |
| <i>Nitzschia angustata</i> | S5 |

Changes in evenness

Evenness of diatom assemblages also changed from spring to autumn, but inversely to the taxa number: the latter increased almost in every site, while in contrast, evenness decreased from spring to autumn (Fig. 4A). The number and/or ratio of those taxa the relative abundances of which were under 0.01 clearly increased in autumn relative to total taxa number (Fig. 4A). This was also observed in the case of halophilic taxa (Fig. 4B). Evenness decreased from spring to autumn at 73.3% of the sampling sites (Fig. 4B). The taxa number and the ratio of those halophilic taxa the abundances of which were under 0.01

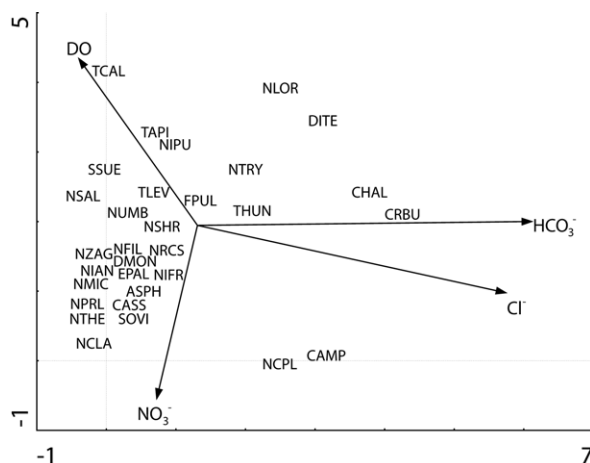


Fig. 3. The relationship among halophilic diatom taxa composition and environmental factors displayed by a detrended correspondence analysis (DCA). Cumulative percentage variance of species data are 21.6 and 28.9, while gradient lengths are 4.186 and 3.026 for the first and second axis, respectively. The concentrations of Cl^- , NO_3^- and HCO_3^- , and dissolved oxygen (DO) are added as environmental variables using weighted averaging. Halophilic species abbreviations are the followings: *Anomoeoneis sphaerophora* – ASPH, *Caloneis amphisbaena* fo. *amphisbaena* – CAMP, *Caloneis amphisbaena* f. *subsalina* – CASS, *Craticula buderi* – CRBU, *Craticula halophila* – CHAL, *Diatoma moniliformis* – DMON, *Diatoma tenuis* – DITE, *Entomoneis paludosa* – EPAL, *Fragilaria pulchella* – FPUL, *Navicula recens* – NRCS, *Navicula salinarum* – NSAL, *Navicula schroeteri* – NSHR, *Nitzschia angustata* – NIAN, *Nitzschia angustatula* – NZAG, *Nitzschia capitellata* – NCPL, *Nitzschia clausii* – NCLA, *Nitzschia filiformis* – NFIL, *Nitzschia frustulum* – NIFR, *Nitzschia lorenziana* – NLOR, *Nitzschia microcephala* – NMIC, *Nitzschia prolongata* – NPRL, *Nitzschia pusilla* – NIPU, *Nitzschia thermaloides* – NTHE, *Nitzschia tryblionella* – NTRY, *Nitzschia umbonata* – NUMB, *Surirella ovalis* – SOVI, *Surirella suecica* – SSUE, *Tryblionella apiculata* – TAPI, *Tryblionella calida* – TCAL, *Tryblionella hungarica* – THUN, *Tryblionella levidensis* – TLEV.

(e.g. *Anomoeoneis sphaerophora*, *Ctenophora pulchella*, *Caloneis amphisbaena* f. *subsalina*, *Tryblionella calida*), increased (87% and 73.3%, respectively) in autumn relative to total halophilic taxa number.

Discussion

Changes in total and halophilic taxa number

In spring there was a high amount of precipitation, while the summer and autumn was unusually dry in 2012 in Hungary. Decreasing water flow conditions were thus caused in these dry months in Hungarian lowland rivers and channels (B-BÉRES et al. 2014, KÓKAI et al. 2014). We assumed that taxa number was primarily influenced by increase of conductivity (strongly connected with decreasing water flow conditions and increasing nutrient concentration and/or Cl^- content), because it has been found that there is a correlation between taxa number and certain ecological parameters (e.g. Cl^- , total nitrogen, chemical oxygen demand, conductivity) in small Hungarian rivers (STENGER-KOVÁCS et al. 2013). We hypoth-

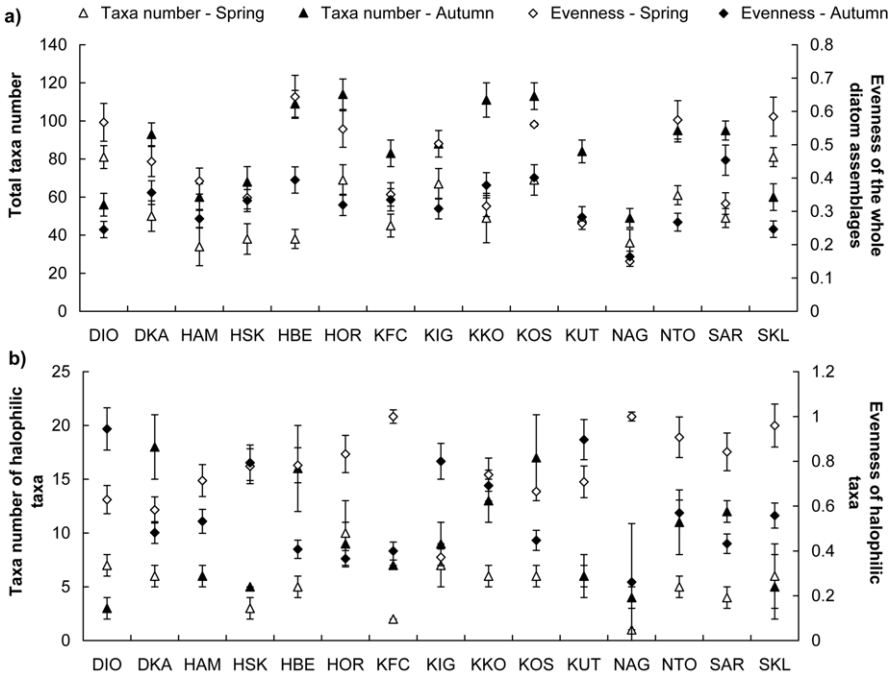


Fig. 4. (a) Taxa number and evenness of whole diatom assemblages in spring and autumn; (b) taxa number and evenness of halophilic taxa in spring and autumn. The abbreviations of the sampling sites are the following Dióéri-főcsatorna (DIO), Dögös-Kákafoki-főcsatorna (DKA), Hamvas-csatorna (HAM), Holt-Sebes-Körös (HSK), Hortobágy (HOR), Hortobágy-Berettyó (HBE), Keleti-főcsatorna (KFC), Kígyósi-főcsatorna (KIG), Kis-Körös-főcsatorna (KKO), Kösely (KOS), Kutas-főcsatorna (KUT), Nagy-ér (NAG), Nagytóti-Toprongyos-csatorna (NTO), Sárréti-csatorna (SAR), Sebes-Körös (SKL).

aised that the number of those taxa that prefer higher nutrient concentration and/or conductivity would be higher in autumn than in spring. This first hypothesis was confirmed: in the samples collected in autumn just such new taxa appeared, those that prefer high nutrient concentrations or high levels of conductivity (e.g. *Anomoeoneis sphaerophora*, *Caloneis amphisbaena* f. *subsalina*, *Craticula* spp., *Encyonema caespitosum*, *Eolimna minima*, *Fistulifera saprophila*, *Gyrosigma scalproides*, *Nitzschia clausii*, *Nitzschia lorenziana*, *Sellaphora seminulum* – ZIEMANN et al. 2001, ZALAT 2002, BOLLA et al. 2010, RIMET 2012). However, increased ratio of taxa number in different size classes was pronounced only in the cases of small taxa (S1 and S2 classes) and large taxa (S5 class). New taxa appeared in autumn in small size classes (e.g. *Eolimna minima*, *Fistulifera saprophila*), are frequent in polluted water (BELTRAMI et al. 2012, KELLY and ECTOR 2012, RIMET 2012). In contrast, a high number of newly-appeared taxa of the S5 size class were halophilic or mesohalophilic (e.g. *Anomoeoneis sphaerophora*, *Caloneis amphisbaena* f. *subsalina*, *Nitzschia angustata*, *Tryblionella calida* – ZIEMANN et al. 2001, ZALAT 2002). The number of mesohalophilic and halophilic taxa also showed a considerable increase in S4 size class (e. g. *Nitzschia* cf. *lorenziana*, *Nitzschia prolongata* – ZALAT 2002, CARTER and BELCHER 2010).

Changes in total and halophilic taxon abundance

We hypothesised that the abundance of diatom taxa preferring or tolerating high nutrient contents would increase from spring to autumn, since nutrient concentration has a key role in shaping diatom assemblages (e.g. STEVENSON et al. 2008, STENGER-KOVÁCS et al. 2013). We observed that the abundances of mobile and/or stalked taxa like *Planothidium frequentissimum*, *Cocconeis placentula* ssp., *Mayamaea permitis*, *Cymbella lanceolata*, *Encyonema caespitosum*, *Eolimna minima*, *Eolimna subminuscula*, *Gomphonema* spp., *Nitzschia paleacea* highly increased from spring to autumn. These taxa can be frequent in water with high nutrient load and conductivity (RIMET 2012, B-BÉRES et al. 2014).

The results supported our assumptions; an increase of conductivity is followed by the increase of the abundance of mesohalophilic and halophilic taxa (ZIEMANN et al. 2001). Most of the studied channels and rivers belonged to freshwater type ($\text{Cl}^- < 100 \text{ mg L}^{-1}$), according to the classification of waters on the basis of Cl^- concentration (VAN DAM et al. 2003). Exceptions were the sampling sites Hamvas-csatorna in spring and autumn (HAM: fresh-brackish water, Cl^- concentration 274 mg L^{-1} and 223 mg L^{-1} respectively) and Nagy-ér in autumn (NAG: brackish-fresh water, Cl^- concentration 557 mg L^{-1}). In these sampling sites diatom species of the kind known as halophilic taxa, preferring or tolerating high conductivity and nutrient contents were abundant (*Nitzschia frustulum*, *Nitzschia filiformis* – Hamvas-csatorna (HAM) in spring; and *Craticula buderi* – Nagy-ér (NAG) in autumn, respectively; BLIN and BAILEY 2001, ZIEMANN et al. 2001, ZALAT 2002, BONA et al. 2007, RIMET 2012). In other sampling sites, belonging to freshwater types, increasing abundance of other halophilic taxa (e.g. *Tryblionella* species, *Nitzschia* cf. *lorenziana*, *Nitzschia pusilla* and *Navicula schroeteri*) occurred with increasing conductivity/ Cl^- concentration and/or increasing nutrient content, confirming the observations of KAŠTOVSKÝ et al. (2010) and STENGER-KOVÁCS et al. (2013).

The composition of cell size classes in diatom assemblages includes useful information about the structure of the given assemblages and also about the pollution level and thereby about the physical and chemical composition of the water (BERTHON et al. 2011). We hypothesised that increasing nutrient content and/or conductivity cause conspicuous changes in composition of size classes; namely, the ratio of small disturbance-tolerant taxa and large halophilic/mesohalophilic taxa increases from spring to autumn. Our results confirmed this second hypothesis, the distribution of small size (S1 and/or S2 classes) and large size (S5 class) classes clearly changed. In accordance with BERTHON et al. (2011), an increasing abundance of S5 class was observed in relation to increasing nitrate and/or phosphate concentration and decreasing ammonium content. However, a clear increase in S1 size class was also observed in autumn, related to the increased nutrient contents and/or conductivity. We suggest that the reason for this was the composition of this size class, namely, 71% of the taxa were mobile (*Navicula* and *Nitzschia* spp.) or ruderal species (*Staurosira* and *Pseudostaurosira* spp.). Generally, mobile taxa prefer enriched habitats, and their abundance and taxa number increase with increasing nutrient contents (FAIRCHILD et al. 1985, VAN DER GRINTEN et al. 2004, BERTHON et al. 2011). Moreover, ruderal strategists prefer habitats with high amounts of nutrients (PADISÁK 2001, PASSY 2007)

Changes in evenness

The studied rivers and channels were exposed to both natural and anthropogenic impacts (lack of rainfall, agricultural pollution in the form of nutrient loads). These events caused an increased conductivity, and/or Cl^- and/or nutrient concentration in almost all sampling sites. The results supported our third hypothesis, that evenness of diatom assemblages decreases with increasing conductivity and/or nutrient content (NH_4^+ , PO_4^{3-}), according to ZALAT (2002), NDIRITU et al. (2006) and STENGER-KOVÁCS et al. (2013). Confirming our findings, they observed a decreasing diversity in diatom assemblages parallel to increasing salinity/conductivity, and/or nutrient (especially phosphate) contents. Number of taxa with low abundances (under 0.01%) increased remarkably from spring to autumn. This was primarily due to the increasing number of halophilic taxa with low abundances and decreasing abundances of other taxa, which were sensitive to high conductivity or nutrient content (e.g. *Achnantheidium minutissimum*, *Encyonopsis microcephala* – DE FABRICIUS et al. 2003, ÁCS et al. 2006, RUSANOV et al. 2009, RIMET 2012, STENGER-KOVÁCS et al. 2013).

Conclusions

Our results showed that even a one-year study can demonstrate such important changes in benthic diatom assemblages as decreasing diversity, loss of taxa, and increasing appearance of halophilic and mesohalophilic species caused by increasing conductivity and/or nutrient content. Our results pointed out those diatom assemblages sensitively indicate short-term changes in lowland lotic ecosystem; we found that studying changes in the ratio of halophilic and mesohalophilic taxa is especially useful for detection of environmental changes caused by either anthropogenic or natural effects. Knowledge based on such results provides an opportunity e.g. for rapid intervention for environmental protection (e.g. water supply in the case of smaller rivers or channels). Our results could form a basis for a forthcoming comprehensive study on the primary or secondary salinisation in Hungarian lowland medium or small rivers and channels.

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References

- ÁCS, É., SZABÓ, K., KISS, K. T., HINDÁK, F., 2003: Benthic algal investigations in the Danube river and some of its main tributaries from Germany to Hungary. *Biologia* 58, 545–554.
- ÁCS, É., SZABÓ, K., KISS, Á. K., TÓTH, B., ZÁRAY, G. Y., KISS, K. T., 2006: Investigation of epilithic algae on the River Danube from Germany to Hungary and the effect of a very dry year on the algae of the River Danube. *Archiv für Hydrobiologie, Supplementband* 158, 389–417.
- ANTONIADES, D., DOUGLAS, M. S. V., SMOL, J. P. 2004: Diatom species–environment relationships and inference models from Isachsen, Ellef Ringnes Island, Canadian High Arctic. *Hydrobiologia* 529, 1–18.
- BÁCSI, I., TÖRÖK, T., B-BÉRES, V., TÖRÖK, P., TÓTHMÉRÉSZ, B., NAGY, S. A., VASAS, G., 2013: Laboratory and microcosm experiments testing the toxicity of chlorinated hydrocarbons on a cyanobacterium strain (*Synechococcus* PCC 6301) and on natural phytoplankton assemblages. *Hydrobiologia* 710, 189–203.
- BELTRAMI, M. E., CIUTTI, F., CAPPELLETTI, C., LÖSCH, B., ALBER, R., ECTOR, L., 2012: Diatoms from Alto Adige/Südtirol (Northern Italy): characterization of assemblages and their application for biological quality assessment in the context of the Water Framework Directive. *Hydrobiologia* 695, 153–170.
- BERTHON, V., BOUCHEZ, A., RIMET, F., 2011: Using diatom life-forms and ecological guilds to assess organic pollution and trophic level in rivers: a case study of rivers in south-eastern France. *Hydrobiologia* 673, 259–271.
- B-BÉRES, V., TÖRÖK, P., KÓKAI, ZS., T-KRASZNAI, E., TÓTHMÉRÉSZ, B., BÁCSI, I., 2014: Ecological behaviour of diatom guilds during an extremely changing water regime: empirical evidences from a lowland river of Central-Europe. *Hydrobiologia* 738, 191–204.
- BLIN, D. W., BAILEY, P. C. E., 2001: Land-use influence on stream water quality and diatom communities in Victoria, Australia: a response to secondary salinization. *Hydrobiologia* 466, 231–244.
- BOLLA, B., BORICS, G., KISS, K. T., RESKÓNÉ, N. M., VÁRBÍRÓ, G., ÁCS, É., 2010: Recommendations for ecological status assessment of lake Balaton (largest shallow lake of central Europe), based on benthic diatom communities. *Vie Milieu* 60, 1–12.
- BONA, F., FALASCO, E., FASSINA, S., GRISELLI, B., BADINO, G., 2007: Characterization of diatom assemblages in mid-altitude streams of NW Italy. *Hydrobiologia* 583, 265–274.
- BORICS, G., GÖRGÉNYI, J., GRIGORSZKY, I., LÁSZLÓ-NAGY, ZS., TÓTHMÉRÉSZ, B., KRASZNAI, E., VÁRBÍRÓ, G., 2014: The role of phytoplankton diversity metrics in shallow lake and river quality assessment. *Ecological Indicators* 45, 28–36.
- BUCKÓ, K., MAGYARI, E. K., BRAUN, M., BÁLINT, M., 2013: Diatom-inferred lateglacial and Holocene climatic variability in the South Carpathian Mountains (Romania). *Quaternary International* 271, 123–135.
- CARTER, C. F., BELCHER, H., 2010: A UK record of *Entomoneis ornata* (J. W. Bailey) Reimer in R. M. Patrick et Reimer 1975. *Diatom Research* 25, 217–222.
- CATALAN, J., PLA-RABÉS, S., WOLFE, A. P., SMOL, J. P., RÜHLAND, K. M., ANDERSON, N. J., KOPÁČEK, J., STUHLÍK, E., SCHMIDT, R., KOINIG, K. A., CAMARERO, L., FLOWER, R. J., HEIRI, O., KAMENIK, C., LEAVITT, P. R., PSENNER, R., RENBERG, I., 2013: Global change

- revealed by palaeolimnological records from remote lakes: a review. *Journal of Paleolimnology* 49, 513–535.
- COTTINGHAM, K. L., BROWN, B. L., LENNON, J. T., 2001: Biodiversity may regulate the temporal variability of ecological systems. *Ecology Letters* 4, 72–85.
- DE FABRICIUS, A. L. M., MAIDANA, N., GÓMEZ, N., SABATER, S., 2003: Distribution patterns of benthic diatoms in a Pampean river exposed to seasonal floods: the Cuarto River (Argentina). *Biodiversity and Conservation* 12, 2443–2454.
- FAIRCHILD, G. W., LOWE, R. L., RICHARDSON, W. B., 1985: Algal periphyton growth on nutrient-diffusing substrates: an in situ bioassay. *Ecology* 66, 465–472.
- FRANCE, K. E., DUFFY, J. E., 2006: Diversity and dispersal interactively affect predictability of ecosystem function. *Nature* 441, 1139–1143.
- GUIRY, M. D., GUIRY, G. M., 2014: AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. <http://www.algaebase.org>.
- HOOPER, D. U., CHAPIN, F. S. III., EWEL, J. J., HECTOR, A., INCHAUSTI, P., LAVOREL, S., LAWTON, J. H., LODGE, D. M., LOREAU, M., NAEEM, S., SCHMID, B., SETALA, H., SYMSTAD, A. J., VANDERMEER, J., WARDLE, D. A., 2005: Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs* 75, 3–35.
- KAŠTOVSKÝ, J., HAUER, T., MAREŠ, J., KRAUTOVÁ, M., BEŠTA, T., KOMÁREK, J., DESORTOVÁ, B., HETEŠA, J., HINDÁKOVÁ, A., HOUK, V., JANEČEK, E., KOPP, R., MARVAN, P., PUMANN, P., SKÁCELOVÁ, O., ZAPOMĚLOVÁ, E., 2010: A review of the alien and expansive species of freshwater cyanobacteria and algae in the Czech Republic. *Biological Invasions* 12, 3599–3625.
- KELLY, M. G., ECTOR, L., 2012: Effect of streamlining taxa lists on diatom-based indices: implications for intercalibrating ecological status. *Hydrobiologia* 695, 253–263.
- KIRETA, A. R., REAVIE, E. D., SGRO, G. V., ANGRADI, T. R., BOLGRIEN, D. W., HILL B. H., JICHA, T. M., 2012: Planktonic and periphytic diatoms as indicators of stress on great rivers of the United States: Testing water quality and disturbance models. *Ecological Indicators* 13, 222–231.
- KÓKAI, ZS., TÖRÖK, P., BÁCSI, I., T-KRASZNAI, E., B-BÉRES, V., 2014: Effects of extremely dry weather on the individual number of *Achnanthydium minutissimum* and *Achnanthydium eutrophylum* in the River Sebes-Körös at Körösszakál – Az extrém száraz időjárás hatása az *Achnanthydium minutissimum* és *Achnanthydium eutrophylum* egyedszámára (Sebes-Körös, Körösszakál). *Hidrológiai Közöny* 94, 46–49.
- KRAMMER, K. LANGE-BERTALOT, H., 1986: Bacillariophyceae 1. Teil: Naviculaceae. In: Ettl, H., Gerloff, J., Heynig H., Mollenhauer, D. (eds.), *Süßwasserflora von Mitteleuropa*. Band 2/1. Gustav Fischer Verlag, Stuttgart, New York.
- KRAMMER, K. LANGE-BERTALOT, H., 1988: Bacillariophyceae 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In: Ettl, H., Gerloff, J., Heynig H., Mollenhauer, D. (eds.), *Süßwasserflora von Mitteleuropa*. Band 2/2. VEB Gustav Fischer Verlag, Jena.
- KRAMMER, K. LANGE-BERTALOT, H., 1991a: Bacillariophyceae 3. Teil: Centrales Fragilariaceae, Eunotiaceae. In: Ettl, H., Gerloff, J., Heynig H., Mollenhauer, D. (eds.), *Die Süßwasserflora von Mitteleuropa*, Band 2/3. Gustav Fischer Verlag, Stuttgart, Jena.
- KRAMMER, K. LANGE-BERTALOT, H., 1991b: Bacillariophyceae 4. Teil: Achnanthaceae. Kritische Ergänzungen zu Navicula (Lineolatae) und Gomphonema. *Gesamtliteraturver-*

- zeichnis Teil 1–4. In: Ettl, H., Gartner, G., Gerloff, J., Heynig, H., Mollenhauer, D. (eds.), Süßwasserflora von Mitteleuropa. Gustav Fischer Verlag, Stuttgart, Jena.
- KRAMMER, K. LANGE-BERTALOT, H., 1997a: Bacillariophyceae 1. Teil: Naviculaceae. In: Ettl, H., Gerloff, J., Heynig, H., Mollenhauer, D. (eds.), Süßwasserflora von Mitteleuropa. Elsevier, Heidelberg.
- KRAMMER, K. LANGE-BERTALOT, H., 1997b: Bacillariophyceae 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In: Ettl, H., Gerloff, J., Heynig, H., Mollenhauer, D. (eds.), Süßwasserflora von Mitteleuropa. Elsevier, Heidelberg.
- KRAMMER, K. LANGE-BERTALOT, H., 2004a: Bacillariophyceae 3. Teil: Centrales Fragilariaceae, Eunotiaceae. In: Ettl, H., Gerloff, J., Heynig, H., Mollenhauer, D. (eds.), Die Süßwasserflora von Mitteleuropa, Spektrum Akademischer Verlag, Heidelberg, Berlin.
- KRAMMER, K. LANGE-BERTALOT, H., 2004b: Bacillariophyceae 4. Teil: Achnanthes s. l., Navicula s. str., Gomphonema. Gesamtliteraturverzeichnis Teil 1–4. In: Ettl, H., Gartner, G., Gerloff, J., Heynig, H., Mollenhauer, D. (eds.), Süßwasserflora von Mitteleuropa. Spektrum Akademischer Verlag, Heidelberg, Berlin.
- LECOINTE, C., COSTE M., PRYGIEL, J., 1993: »Omnidia«: software for taxonomy, calculation of diatom indices and inventories management. *Hydrobiologia* 269/270, 509–513.
- LEPŠ, J., ŠMILAUER, P., 2003: Multivariate analysis of ecological data using CANOCO. Cambridge University Press, Cambridge, UK.
- LOTTER, A. F., BIRKS, H. J., HOFMANN, W., MARCHETTO, A., 1997: Modern diatom, cladocera, chironomid and chrysophyte cyst assemblages as quantitative indicators for the reconstructions of past environmental conditions in the Alps I. Climate. *Journal of Paleolimnology* 18, 395–420.
- NDIRITU, G. G., GICHUKI, N. N., TRIEST, L., 2006: Distribution of epilithic diatoms in response to environmental conditions in an urban tropical stream, Central Kenya. *Biodiversity and Conservation* 15, 3267–3293.
- PADISÁK, J., 2001: Phytoplankton, In: O’Sullivan, P. E., Reynolds, C. S. (eds.), *The lakes handbook, limnology and limnetic ecology*, 251–308. Blackwell Publishing, USA.
- PASSY, S. I., 2002: Environmental randomness underlies morphological complexity of colonial diatoms. *Functional Ecology* 16, 690–695.
- PASSY, S. I., 2007: Diatom ecological guilds display distinct and predictable behavior along nutrient and disturbance gradients in running waters. *Aquatic Botany* 86, 171–178.
- PORTER, E. M., BOWMAN, W. D., CLARK, C. M., COMPTON, J. E., PARDO, L. H., SOONG, J. L., 2013: Interactive effects of anthropogenic nitrogen enrichment and climate change on terrestrial and aquatic biodiversity. *Biogeochemistry* 114, 93–120.
- POTAPOVA, M., HAMILTON, P. B., 2007: Morphological and ecological variation within the *Achnantheidium minutissimum* (Bacillariophyceae) species complex. *Journal of Phycology* 43, 561–575.
- RIMET, F., 2012: Diatoms: an ecoregional indicator of nutrients, organic matter and micro-pollutants pollution Thesis, University of Grenoble, INRA-Thonon, France.
- RUSANOV, A. G., STANISLAVSKAYA, E. V., ÁCS, É., 2009: Distribution of periphytic diatoms in the rivers of the Lake Ladoga basin (Northwestern Russia). *Acta Botanica Croatica* 68, 301–312.

- RUSANOV, A. G., STANISLAVSKAYA, E. V., ÁCS, É., 2012: Periphytic algal assemblages along environmental gradients in the rivers of the Lake Ladoga basin, Northwestern Russia: implication for the water quality assessment. *Hydrobiologia* 695, 305–327.
- SMUCKER, N. J., VIS, M. L., 2011: Contributions of habitat sampling and alkalinity to diatom diversity and distributional patterns in streams: implications for conservation. *Biodiversity and Conservation* 20, 643–661.
- STENGER-KOVÁCS, CS., LENGYEL, E., CROSSETTI, L. O., ÜVEGES, V., PADISÁK, J., 2013: Diatom ecological guilds as indicators of temporally changing stressors and disturbances in the small Torna-stream, Hungary. *Ecological Indicators* 24, 138–147.
- STEVENSON, R. J., HILL, B. E., HERLIHY, A. T., YUAN, L. L., NORTON, S. B., 2008: Algal-P relationships, thresholds and frequency distribution guide nutrient criterion development. *Journal of the North American Benthological Society* 27, 783–799.
- TILMAN, D., 1999: Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences of the United States of America* 96, 5995–6000.
- VAN DAM, H., MERTENS, A., SINKELDAM, J., 2003: A coded checklist and ecological indicator values of freshwater diatoms from The Netherlands. *Netherlands Journal of Aquatic Ecology* 28, 117–133.
- VAN DER GRINTEN, E., JANSSEN, M., SIMIS, S. G. H., BARRANGUET, C., ADMIRAAL, W., 2004: Phosphate regime structures species composition in cultured phototrophic biofilms. *Freshwater Biology* 49, 369–381.
- VÁRBÍRÓ, G., BORICS, G., CSÁNYI, B., FEHÉR, G., GRIGORSZKY, I., KISS, K. T., TÓTH, A., ÁCS, É., 2012: Improvement of the ecological water qualification system of rivers based on first results of the Hungarian phytobenthos surveillance monitoring. *Hydrobiologia* 695, 125–135.
- VASAS, G., FARKAS, O., BORICS, G., FELFÖLDI, T., SRAMKÓ, G., BATA, G., BÁCSI, I., GONDA, S., 2013: Appearance of *Planktothrix rubescens* bloom with [D-Asp3, Mdha7]MC-RR in gravel pit pond of a shallow lake-dominated area. *Toxins (Basel)* 5, 2434–2455.
- ZALAT, A. A., 2002: Distribution and origin of diatoms in the bottom sediments of the Suez canal lakes and adjacent areas, Egypt. *Diatom Research* 17, 243–266.
- ZIEMANN, H., KIES, L., SCHULZ, C., 2001: Desalinization of running waters III. Changes in the structure of diatom assemblages caused by a decreasing salt load and changing ion spectra in the River Wipper (Thuringia, Germany). *Limnologia* 31, 257–280.