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Benthic Diatom-Based Lake Types in Hungary

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Abstract

Hydromorphological and chemical properties of water bodies have pronounced influence on the occurrence and distribution of biological elements in the aquatic ecosystems. Based on a series of abiotic characteristics, seventeen lake types were established in Hungary for management purposes. Benthic diatom assemblages were studied in shallow standing water bodies in Hungary in order to provide a biological validation of these types. Species composition and abundance of the occurring taxa were analysed. By their diatom taxonomic composition five basic lake types could be distinguished; two calcareous lake types, which differ in size and in their trophic characteristics and three types within the group of high salinity lakes. In this latter group the astatic and perennial lakes showed considerable differences. These results have great practical importance, because biological validation of the hydromorphological lake typology is the first step for reliable assessment of the ecological status of water bodies.

Introduction

Aquatic ecosystems are the most threatened ecosystems world-wide (Revenga et al. 2000). For managing the preservation and restoration of aquatic ecosystems across Europe the European Commission implemented the Water Framework Directive (WFD, 2000/60/EC). The directive is considered to be the most ambitious and comprehensive document of European environmental legislation (Moss et al. 2003). WFD requires member states to monitor and assess the quality of surface waters in order to identify and reverse negative trends in the ecological state of water bodies. The WFD and the various supportive documents (Anonymous 2003) provide guidance to ensure its implementation in a consistent way across Europe; however, it is still a major challenge for the member states. Ecological state assessment of water bodies has to be based on the evaluation of the actual status in comparison to the type specific reference conditions (WFD, 2000/60/EC). Therefore, establishment of river and lake typologies is the first step in the assessment process. It has been known from the early decades of the last century that hydromorphological characteristics of lakes basically determine the composition of lake biota (Murray et al. 1910). Ecoregions, size, depth, altitude, hydrological regime and geology are considered as the most important variables influencing distribution and abundance of biological elements. By combining these variables, hundreds of lake types can be defined but forty-eight were proposed as “core types” (Moss et al. 2003). Besides these variables other biologically important type descriptor variables can also be applied in order to reach greater and clearer separation of the types. Type of the stratification, lake residence time, acid neutralizing capacity, water level fluctuation and several other properties were applied in the national typologies across Europe (Borics et al. 2014). The resulted types, so-called top–down types, have been created accordingly; while ecological similarities or dissimilarities of the types have not been considered. However, biological elements used in ecological state assessment are not sensitive to all the type descriptor variables and this makes possible the merging of the types, and thus, the simplification of the typologies (Zenker and Baier 2009). Phytobenthos is one of the biological elements that required by the WFD and included in ecological status assessments. Benthic diatoms, being a species-rich and ecologically diverse group of algae, are used increasingly in ecological monitoring as proxies for phytobenthos. Several diatom-based metrics have been developed (Coste in Cemagref 1982, Rott et al. 1997, 1999) and used for river quality assessment in European countries (Birk et al. 2012, Rimet et al. 2005, Van Dam et al. 2007, Várbíró et al. 2012) and usefulness of these metrics in lake quality assessment has been demonstrated (Ács et al. 2005, Bolla et al. 2010, Blanco 2004). A European scale comparison of the diatom-based national assessment methods has been done for three common European lake types (low, moderate and high alkalinity lakes) by Kelly et al. (2014). However the number of hydromorphological lake types within countries is much higher (Kolada et al. 2005, Borics et al. 2014), and only a few of them can be assigned to the common intercalibration types.

Based on hydromorphological characteristics seventeen lake types were established in Hungary (Szilágyi et al. 2008). As a result of the phytoplankton-based validation of these types the numbers have been reduced to four (Borics et al. 2014). However in that study the authors noted that there was no clear overlap between the biomass-based types and the types based on phytoplankton composition. The four types were distinguished by their trophic characteristics but in several types eutrophication may not be the key pressure (Hering et al. 2010). Large steppe lakes (Borics et al. 2014) and shallow, turbid soda lakes are characteristic elements of the landscape in the Carpathian Basin (Felföldi et al. 2009). The common feature of these lakes is that they are naturally eutrophic, or hypertrophic (Boros et al. 2006, Stenger-Kovács et al. 2014), but other characteristics such as pH, conductivity, and macrophyte composition show significant differences. However, it is still a question whether these differences appear in the composition of the benthic microflora. Diatom based methods are promising tools in lake quality assessment, but simplification of the top–down typologies and establishment of diatom-based lake types are required. Therefore, the aim of the study is to present a diatom-based bottom–up typology and simplification of the hydromorphology based top–down typology for the lakes in the Carpathian basin.

Materials end Methods

Database

Benthic diatom data derived from the Hungarian National Water quality monitoring survey and from the database of the Danube Research Institute. To avoid mis-grouping, only data for the least disturbed sites were considered during the analyses.

For selecting the least disturbed sites we applied type-dependent screening criteria. In case of those lakes where there is only one lake within one lake type (Lake Balaton, Lake Velencei and Fertő) we used data from last decade, because great improvement in lake quality could be observed in this period (Istvánovics and Somlyódy 2001; Ács et al. 2005).

The following criteria were applied to the other lake groups: no point source pollution, no intensive stocking of fish, no artificial modification of the shoreline, complete zonation of macrophytes. Since very shallow high alkalinity soda lakes are considered naturally hypertrophic (Boros et al. 2014) exclusion criteria for nutrients have not been applied in this lake group. Although high alkalinity calcareous lakes can also be considered naturally eutrophic (Borics et al. 2014), extreme values of nutrients unanimously refer to anthropogenic load. Therefore, for the lakes in this lake group the following screening criteria were applied: $P < 250\ \mu g\ l^{-1}$ and $N < 2000\ \mu g\ l^{-1}$ (lake mean values).

Land use is considered important screening criterion across Europe (Pardo et al. 2012; Kelly et al. 2014), but this criterion has not been applied in this study, because previously it was demonstrated that differences in land use appear not to be relevant for lake quality at this region, because the importance of land use is exceeded by that of lake use, i.e., intensity of fishing and fish stocking (Borics et al. 2013).

Sampling

Altogether six hundred thirty-nine samples were collected from one hundred forty-four sampling sites belonging to seventy-five water bodies in the middle of the vegetation period (from May to September) between 2010 and 2016. Benthic diatom samples were collected from five reed stalks per sampling site from the well illuminated littoral zones of lakes. Diatom samples were preserved with Lugol's solution and were stored in plastic containers until processing.

Sample processing

The frustules were cleaned with hydrochloric acid and hydrogen peroxide, subsequently washed in distilled water and mounted with Naphrax® mounting medium (MSZ EN 13946:2014). Identification was performed according to Krammer & Lange-Bertalot (1986–1991), Krammer (2003) and Hofmann et al. (2011).

Approaches of biological validation of the hydromorphological lake types

There are two options for establishing lake types in which both hydromorphological and biological characteristics of waters are considered (Fig. 1).

Option 1: during the implementation of the WFD one of the first steps is the establishment of a water body typology. The typology proposed by the WFD has to be based on the broad scale ecoregions, hydromorphological, physical and chemical characteristics of water bodies, and thus, it can be considered as a top–down typology (Zenker and Baier 2009). This typology can be simplified if biological characteristics of the hydromorphological types are compared directly and types with no significant differences are merged. The disadvantage of this approach is that biological homogeneity of the hydromorphological types is supposed *a priori* (Mykrä et al. 2009), thus splitting off the hydromorphological types is not possible.

Option 2: when this option is applied the top–down typology is ignored because comparison of the biological characteristics of lakes is done at lake (or site) level. During this process, the whole lake population is separated into smaller groups in which lakes sharing similar biological characteristics are pooled. This can be accomplished with a step by step process (clustering), or with ordination techniques. This approach results in a so-called bottom–up typology. These biological types have to be accommodated to the hydromorphological types. Splitting of the hydromorphological types is feasible as long as it is corroborated by biological evidences. During this study both options were combined.

Statistical analyses

Statistical analysis was based on species abundance data. Non-metric multidimensional scaling (NMDS), using Bray-Curtis similarities, was applied for grouping of the hydromorphological lake types (Option 1). In the second step this technique was applied to data from entire lakes (Option 2). Statistical differences between the groups obtained by the NMDS were tested by PERMANOVA (Anderson et al. 2008). Analysis was performed on site level. The proposed biologically validated lake types were characterised by the diatom species using Similarity percentage analysis (SIMPER; Clark 1993). SIMPER is a multivariate, exploratory method that assesses the contribution of each taxon to the Bray-Curtis dissimilarities between contrasted groups. Statistical analysis was performed using PAST package (Hammer et al. 2001).

Species diversity was calculated by the Shannon formula (1948). The trophic state of the proposed types was characterised by the trophic metric of the OMNIDIA software (Lecointe et al. 1993) using the range zero to twenty. The highest values indicate lower trophic conditions. The significance of the differences in diversity and TID values were tested by the Kruskal-Wallis test. Analysis was done on a sample level.

Results

Establishment of the biologically validated lake types

Ordination of the hydromorphological lake types resulted in two distinct groups (Fig. 2). The group of high salinity lakes (with Na^+ and Mg^{2+} dominance) and the moderate salinity (Ca^{2+} dominated) lakes clearly separated from each other according to diatom composition (Permanova of Bray-Curtis similarity $p < 0.05$). Further separation of the two subgroups was based on site level data (Option 2). The NMDS ordination of the site level data displays two groups in the moderate (Fig. 3) ($p < 0.05$), and three groups in the high salinity lakes (Fig. 4). Diatom assemblages of Lake Balaton differed significantly from that of the other Ca^{2+} dominated lakes (Fig. 3). Within the groups of high salinity lakes the following three groups could be distinguished: 1. large steppe lakes (Lake Velencei and Lake Fertő), 2. Na^+ dominated perennial saline lakes, and 3. Na^+ dominated astatic saline lakes (PERMANOVA $p < 0.05$) (Fig. 4). The proposed five bottom–up types could be accommodated to the hydromorphological lake types (Table 1 and 2). Species characteristics for the given lake types (identified by SIMPER analysis) are shown in Tables 3, 4 and 5. (Physical and chemical characteristics of the proposed lake types are shown in Table 6.)

Characterisation of the lake types

Significant differences were found in the Shannon diversity values between the astatic [4] and perennial [5] high salinity lakes (Fig. 5). The highest values were observed in the case of the perennial lakes, while the lowest ones in the group of astatic lakes. Diversity of the large steppe lakes Fertő and Lake Velencei (3rd biological type) did not show differences from the others, and the values fell in the middle range of diversity (Fig. 5). In the two groups of calcareous lakes (Balaton [1] and others [2]) differences in diversity could also be demonstrated ($p < 0.05$) (data not shown).

The low values of the trophic metrics indicate that lakes in the Carpathian basin are eutrophic or hypertrophic. Differences in the distribution of the trophic metric scores have also been shown both for the moderate and high salinity lakes (Fig. 6). In the group of moderate salinity calcareous lakes, metric scores calculated for Lake Balaton [1] samples were significantly higher than those characterised in the other [2] calcareous lakes.

Significant differences were also found in the trophic metric scores among the three proposed groups of high salinity lakes (Fig. 6). The lowest values were characteristic for the astatic saline lakes [4], while the highest scores were obtained for the large steppe lakes (Fertő and Lake Velencei [3]). Trophic scores of the perennial high salinity lakes [5] appeared to be between the values of the two above mentioned types.

Discussion

Establishment of the biologically validated lake types

NMDS ordination of the species abundance data resulted in a clear and consistent distinction between the highly saline sodium and magnesium dominated lakes and moderate salinity calcareous ones. This result is consistent with that obtained in a recent study which was based on the analysis of phytoplankton (Borics et al. 2014). Diatom flora of high salinity lakes consists of species with wide ecological valence that enables their survival in extreme environmental conditions (Hecky & Kilham 1973). In the highly saline lakes of the Carpathian Basin species are subject to various types of extremities, such as high salt content and high organic and inorganic load (Stenger-Kovács et al. 2014, Boros et al. 2006). However, we note that from the present analysis separation of these extremities cannot be made.

Separation of the two types of the moderate salinity calcareous lakes (Balaton and others) can be explained partly by the trophic differences and partly by the unique microflora of the Balaton (Bolla et al. 2010).

In the literature on saline lakes several halophilic species are mentioned such as *Nitzschia frustulum, Rophalodia brebissonii, Halamphora veneta* (Hecky & Kilham 1973, Silva et al. 2010, Stenger-Kovács et al. 2014) and these taxa were also characteristic in the studied high salinity lakes. However microflora of the lakes belonging to the highly saline lake group appeared to be similar but the abundance of these taxa was remarkably different in the three lake types (Table 5). These differences in abundance values are responsible for the separation of the lake groups rather than unique species that might occasionally occur in one of the lake groups.

Characterisation of the lake types

Although earlier it was believed that diversity of algae in eutrophic lakes is usually lower than that of oligotrophic ones (Moss 1973), experimental studies proved that diversity is influenced by the fluctuation of resources rather than the quantity of them (Sommer 1984). Both experimental (Carrick et al. 1988) and field studies (Leira et al. 2009) demonstrated that nutrient enrichment narrows the niche of some sensitive benthic diatom taxa, but simultaneously creates favourable conditions for many specialised species. However, low diversity values might be related to natural processes such as grazing or other disturbances (DeNicola and Kelly, 2014). This means that higher nutrient concentration does not necessarily coincide with decreasing species diversity. Therefore, the higher diversity observed in the case of Lake Balaton, as compared to other calcareous lakes, cannot be explained by its lower nutrient content. Results on the species/area relationship for algae revealed the importance of lake size as a control of diversity (Bolgovics et al. 2016, Borics et al. 2016), therefore the size differences between Lake Balaton and the other considerably smaller lakes may be responsible for the observed differences of diversity.

The astatic/perennial distinction which was observed for Shannon diversity within the group of saline lakes has also been demonstrated for the phytoplankton (Borics et al. 2014), which indicates that desiccation puts a stress on both planktonic and benthic algae and thus coincides with a decrease in diversity (Borics et al. 2013). In the group of high salinity lakes significant differences in diversity were attributable to the very low values found in the astatic lake group. In this group the biota is exposed to double stress i.e., desiccation of the lake basin, and the extremely large salt content. Both phenomena exert strong selective pressure on the species pool of the lakes, and results in very low Shannon diversity and species richness values in pristine soda pans (Stenger-Kovács et al. 2016).

Desiccation means that for a considerable period of time the lake bed becomes a terrestrial habitat where algae are subjected to heat and osmotic stress (Souffreau et al. 2010), and only those taxa can survive which have special adaptations (i.e., migration, production of extracellular polysaccharids) (McKew et al. 2011). Even in those periods when water is present in the lake basin diatoms are under strong selection to adapt to pressures that the high salinity and the dominance of sodium exert on them (Hecky & Kilham 1973).

The results of the characterisation of the nutrient status of lakes by trophic scores is in accordance with that of a previous study (Borics et al. 2014) which suggest, that lakes in the Carpathian Basin are in the mesotrophic – hypertrophic range. An elevated trophic state is especially common in this group of saline lakes, because these lakes are endorheic (without outlet). Their water cannot leave the lake basin and are continuously enriched with nutrients mostly because of the birds which use the lakes for feeding and roosting (Boros et al. 2006).

Conclusions

The remarkable floristic and compositional differences in the benthic diatom flora of the studied shallow lakes in Hungary enabled the separation of five bottom–up lake types. These types could be clearly assigned to hydromorphological types, and this resulted in a rational simplification of the hydromorphological typology. These results are in accordance with those of previous studies which were based on the analysis of phytoplankton (Borics et al. 2014) and of aquatic macrophytes (Lukács et al. 2015).

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Legends for figures and tables

Fig. 1 Scheme of the applied biological validation options. The upper arrow indicates how the 17 hydromorphological lake types were established using a top–down approach.

Fig. 2 Nonmetric multidimensional scaling (NMDS) ordination of the hydromorphological lake types (Ordination is based in the Bray-Curtis distances among the types).

Fig. 3 Nonmetric multidimensional scaling (NMDS) ordination of the sites belonging to the groups of moderate salinity calcareous lakes.

Fig. 4 Nonmetric multidimensional scaling (NMDS) ordination of the sites belonging to the groups of high salinity sodium and magnesium dominated lakes.

Fig. 5 Distribution of the Shannon diversity values in the five proposed biologically validated types.

Fig. 6 Distribution of the trophic metric scores in the five proposed biologically validated types.

Table 1 Hydromorphological lake types proposed for Hungary and the applied type descriptor variables.

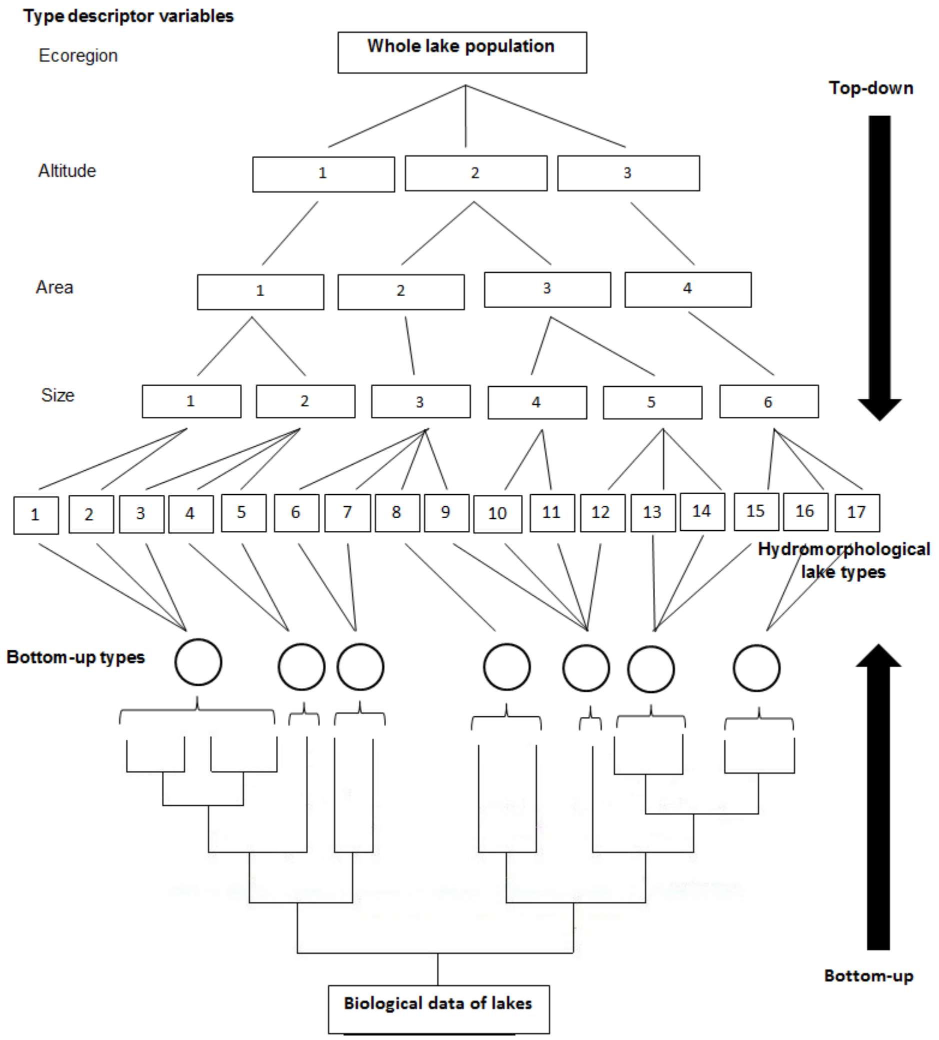
Table 2 Assignment of biological lake types to hydromorphological types.

Table 3 SIMPER analysis results showing taxa contributing to 25% of the total similarity within the groups of moderate and high salinity lakes.

Table 4 SIMPER analysis results showing taxa contributing to 25% of the total similarity within the groups of Balaton and other calcareous lakes.

Table 5 SIMPER analysis results showing taxa contributing to 25% of the total similarity within the three groups of high salinity lakes.

Table 6 Physical and chemical characteristics of proposed lake types.


Type descriptor variables
Ecoregion
Whole lake population
Top-down
Altitude
1
2
3
Area
1
2
3
4
Size
1
2
3
4
5
6
1
2
3
4
5
6
7
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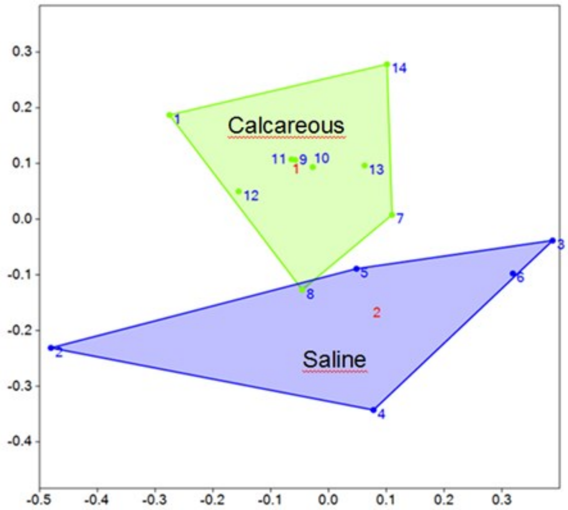
17
Hydromorphological lake types
Bottom-up types
Biological data of lakes
Bottom-up

Fig.1.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0.3
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12
7
3
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2
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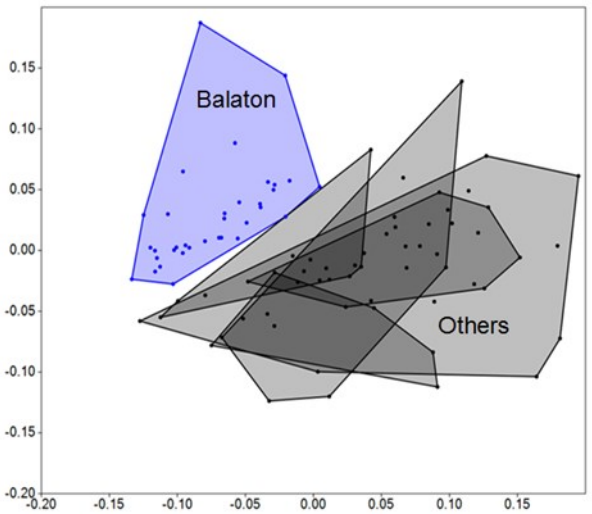
Saline
4

Fig.2.



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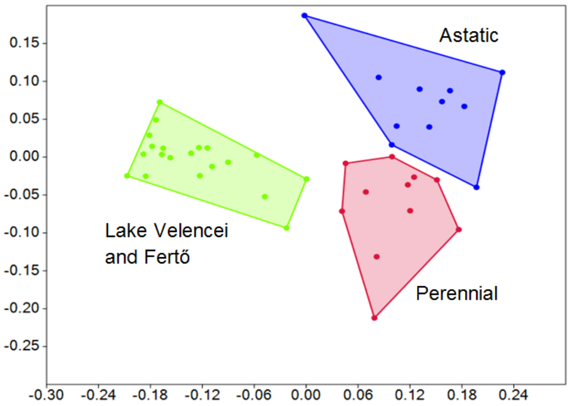

Fig.4.

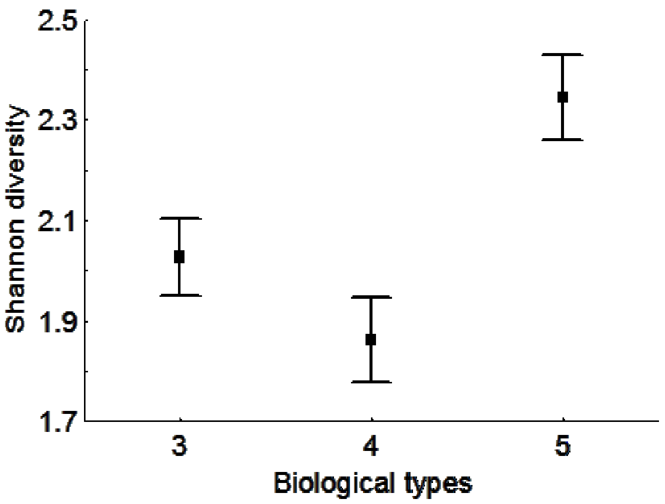

Fig.5.

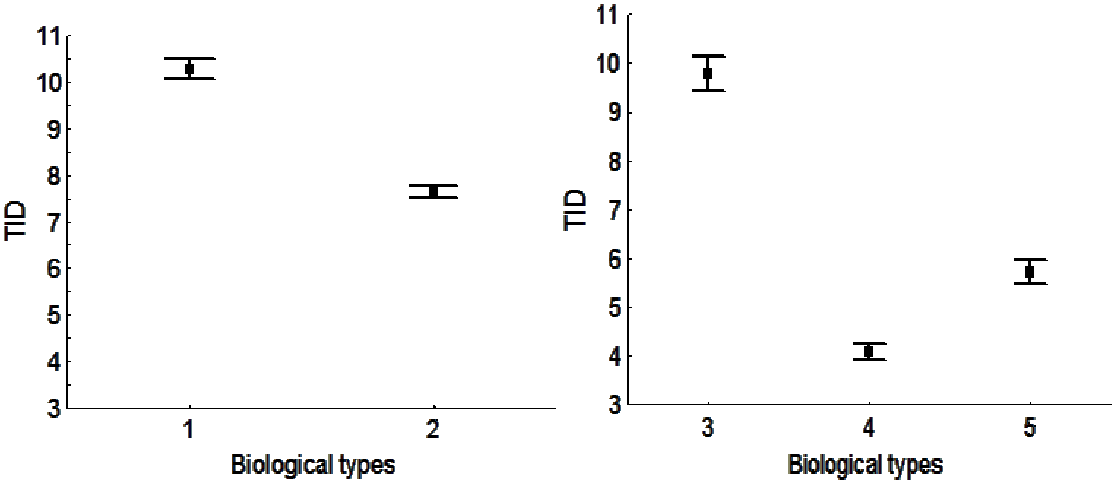

Fig.6.

Table 1

Type	Altitude (m)	Hydrochemical character	Size (km^2)	Average depth (m)	Water regime	Biological types
1	< 200 m (lowland)	moderate salinity	> 10 (km^2)	> 3-6 m	perennial	1
2	< 200 m (lowland)	high salinity	> 10 (km^2)	< 3m	perennial	3
3	< 200 m (lowland)	high salinity	1- 10 (km^2)	< 1m	astatic	5
4	< 200 m (lowland)	high salinity	1- 10 (km^2)	< 3m	perennial	4
5	< 200 m (lowland)	high salinity	< 1 (km^2)	< 3m	perennial	4
6	< 200 m (lowland)	high salinity	< 1 (km^2)	< 1m	astatic	5
7	< 200 m (lowland)	moderate salinity	1- 10 (km^2)	< 3m	perennial	2
8	< 200 m (lowland)	moderate salinity	< 1 (km^2)	< 3m	perennial	2
9	< 200 m (lowland)	moderate salinity	1- 10 (km^2)	< 3m	perennial	2
10	< 200 m (lowland)	moderate salinity	1- 10 (km^2)	3-6 m	perennial	2
11	< 200 m (lowland)	moderate salinity	< 1 (km^2)	< 3m	perennial	2
12	< 200 m (lowland)	moderate salinity	< 1 (km^2)	< 3m	perennial	2
13	< 200 m (lowland)	moderate salinity	> 10 (km^2)	< 3m	perennial	2
14	< 200 m (lowland)	moderate salinity	> 10 (km^2)	< 3m	perennial	2
15	> 200 m (hill country)	moderate salinity	> 10 (km^2)	< 3m	perennial	2
16	> 200 m (hill country)	moderate salinity	> 10 (km^2)	< 1m	astatic	2
17	< 200 m (lowland)	moderate salinity	<1; 1-10 (km^2)	< 3m	astatic	2

Table 2

Codes of the proposed biological lake types	**Names of the proposed biological lake types**	**Codes of the hydromorphological lake types**
1	Balaton	1
2	Others	7,8,9,10,11,12,13,14,15,16,17
3	Lake Velencei and Fertő	2
4	Perennial	3,6
5	Astatic	4,5

Table 3

Taxon	**DENOM**	**Av. dissim**	**Contribution (%)**	**Cumulative (%)**	**Moderate salinity**	**High salinity**
ADMI	*Achnanthidium minutissimum* (Kützing) Czarnecki 1994	1.786	2.532	2.532	12.1	9.87
NIS1	Nitzschia sp. Hassall 1845	1.726	2.446	4.978	6.32	7.93
EADN	*Epithemia adnata* (Kützing) Brébisson 1838	1.435	2.033	7.011	6.11	6.86
HVEN	*Halamphora veneta* (Kützing) Levkov 2009	1.381	1.958	8.969	2.24	10.8
RHOS	*Rhopalodia* species Müller 1895	1.24	1.757	10.73	0.561	7.87
NCLA	*Nitzschia clausii* Hantzsch 1860	1.182	1.675	12.4	0.284	8.19
NACI	*Nitzschia acicularis* (Kützing) W.Smith 1853	1.128	1.598	14	2.16	6.66
RBRE	*Rhopalodia brebissonii* Krammer in Lange-Bertalot & Krammer 1987	1.084	1.537	15.54	0.0606	7.89
NHAN	*Nitzschia hantzschiana* Rabenhorst 1860	0.8474	1.201	16.74	1.93	4.96
NLBT	*Nitzschia liebetruthii var.liebetruthii* Rabenhorst 1864	0.8303	1.177	17.91	1.45	6.98
CPLI	*Cocconeis placentula* Ehrenberg 1838	0.7983	1.131	19.05	3.48	5.33
ETUR	*Epithemia turgida* (Ehrenberg) Kützing 1844	0.7315	1.037	20.08	1.22	4.76
RGIB	*Rhopalodia gibba var. gibba* (Ehrenberg) Otto Müller 1895	0.7259	1.029	21.11	1.65	5.77
COCE	*Cyclotella ocellata* Pantocsek 1901	0.6806	0.9646	22.08	5.07	0.0436
SCON	*Staurosira construens* Ehrenberg 1843	0.6416	0.9094	22.99	3.36	3.73
AMIN	*Achnanthes minutissima* Kützing 1833	0.6384	0.9048	23.89	4.72	0
CPLA	*Cocconeis placentula var. placentula* Ehrenberg 1838	0.6314	0.8949	24.79	5.2	2.38
NIPU	*Nitzschia pusilla* Grunow 1862	0.6239	0.8842	25.67	0.467	4.48
APED	*Amphora pediculus* (Kützing) Grunow ex A.Schmidt 1875	0.6048	0.8572	26.53	5.94	2.4
GAFF	*Gomphonema affine* Kützing 1844	0.6013	0.8523	27.38	2.6	3.66
NDIS	*Nitzschia dissipata var.dissipata* (Hantzsch) Grunow in Van Heurck 1881	0.5676	0.8045	28.18	4.07	0.647
CYDE	*Cyclotella delicatula* Hustedt 1952	0.5664	0.8027	28.99	3.97	0
NPAL	*Nitzschia palea* (Kützing) W.Smith 1856	0.5085	0.7207	29.71	3.27	5.02
EBLU	*Eunotia bilunaris* (Ehrenberg) Schaarschmidt in Kanitz 1880	0.4995	0.708	30.41	2.28	3.17
LGOE	*Luticola goeppertiana* (Bleisch ex Rabenhorst) D.G.Mann in Round,	0.4962	0.7033	31.12	3.73	0.161
SHAN	*Stephanodiscus hantzschii* Grunow in Cleve & Grunow 1880	0.4768	0.6757	31.79	3.3	0.363
ESOR	*Epithemia sorex* Kützing 1844	0.4741	0.672	32.47	4.01	2.78
NISO	*Nitzschia solita* Hustedt 1953	0.4674	0.6625	33.13	0.234	3.4
AINA	*Amphora inariensis* Krammer 1980	0.4579	0.649	33.78	3.44	0.735
NRCS	*Navicula recens* (Lange-Bertalot) Lange-Bertalot in Krammer & Lange-Bertalot	0.4503	0.6382	34.42	0.593	3.21
NIPM	*Nitzschia perminuta* (Grunow) M.Peragallo 1903	0.4379	0.6207	35.04	1.19	3.85
GINS	*Gomphonema insigne* W.Gregory 1856	0.4373	0.6197	35.66	3.31	0.82
ADEU	*Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot 1999	0.4327	0.6133	36.27	1.35	2.67
NVEN	*Navicula veneta* Kützing 1844	0.4302	0.6097	36.88	1.16	3.87
MAAT	*Mayamaea atomus* (Kützing) Lange-Bertalot 1997	0.4149	0.5881	37.47	1.4	2.49
NAMP	*Nitzschia amphibia f.amphibia* Grunow 1862	0.4104	0.5816	38.05	2.47	4.7

Table 4

	Taxon	DENOM	Av. dissim	Contribution (%)	Cumulative (%)	Balaton	Others
1	ADMI	*Achnanthidium minutissimum* (Kützing) Czarnecki 1994	8.694	10.68	10.68	33.4	13.8
2	CEXI	*Cymbella exigua* Krammer 2002	2.367	2.907	13.58	7.1	0
3	APED	*Amphora pediculus* (Kützing) Grunow ex A.Schmidt 1875	2.068	2.54	16.12	2.13	7.12
4	NDIS	*Nitzschia dissipata* (Kützing) Rabenhorst 1860	1.585	1.946	18.07	5.07	1.71
5	GPUM	*Gomphonema pumilum* (Grunow) E.Reichardt & Lange-Bertalot 1991	1.364	1.675	19.74	4.22	0.481
6	COCE	*Cyclotella ocellata* Pantocsek 1901	1.326	1.628	21.37	1.41	3.22
7	ESOR	*Epithemia sorex* Kützing 1844	1.238	1.52	22.89	1.36	3.17
8	FHUN	*Fragilaria hungarica* Pantocsek 1901	1.223	1.502	24.39	4.05	0
9	CPLI	*Cocconeis placentula* Ehrenberg 1838		1.399	25.79	1.63	3.77
10	ECPM	*Encyonopsis minuta* Krammer & E.Reichardt in Krammer 1997	1.106	1.359	27.15	2.09	2.1
11	NCTE	*Navicula cryptotenella* Lange-Bertalot in Krammer & Lange-Bertalot 1985	1.046	1.285	28.44	3.11	3.75
12	ENCM	*Encyonopsis microcephala* (Grunow) Krammer 1997	0.9935	1.22	29.66	2.98	0
13	EADN	*Epithemia adnata* (Kützing) Brébisson 1838	0.9336	1.146	30.8	0.208	3.07
14	SGRI	*Staurosira grigorszkyi* Ács, Morales & Ector in Ács et al. 2009	0.8726	1.072	31.87	2.87	0
15	HVEN	*Halamphora veneta* (Kützing) Levkov 2009	0.8714	1.07	32.94	0.0442	2.61
16	DMON	*Diatoma moniliformis* (Kützing) D.M.Williams 2012	0.8519	1.046	33.99	2.71	0.305
17	SBRV	*Staurosira brevistriata* (Grunow) Grunow 1884	0.8301	1.019	35.01	1.48	1.35
18	GOMS	*Gomphonema* species Ehrenberg 1832	0.8287	1.018	36.03	2.69	0.332
19	GOST	*Gomphonema olivaceum var.staurophorum* Pantocsek 1889	0.7915	0.9719	37	2.42	0
20	UUAC	*Ulnaria ulna* (Nitzsch) Compère in Jahn et al. 2001	0.7913	0.9717	37.97	0.978	1.95

Table 5

	Taxon	DENOM	Av. dissim	Contribution (%)	Cumulative (%)	Velencei –Fertő	Small astatic	Small high salinity perennial
1	ADMI	*Achnanthidium minutissimum* (Kützing) Czarnecki 1994	7.935	8.91	8.91	176	6.46	15.3
2	HVEN	*Halamphora veneta* (Kützing) Levkov 2009	5.095	5.72	14.63	0.945	130	50.5
3	NCLA	*Nitzschia clausii* Hantzsch 1860	4.308	4.837	19.47	0	139	0.182
4	GPAR	*Gomphonema parvulum* (Kützing) Kützing 1849	3.573	4.011	23.48	1.46	89.4	35.3
5	CPLI	*Cocconeis placentula* Ehrenberg 1838	3.107	3.488	26.97	53.8	27	4.68
6	NPAL	*Nitzschia palea* (Kützing) W.Smith 1856	2.412	2.709	29.68	3.5	43.5	53.3
7	NLBT	*Nitzschia liebetruthii var.liebetruthii* Rabenhorst 1864	2.402	2.697	32.37	3.58	58.5	24.8
8	NIPU	*Nitzschia pusilla* Grunow 1862	2.142	2.405	34.78	0.2	72.8	2.05
9	RGIB	*Rhopalodia gibba* (Ehrenberg) Otto Müller 1895	2.081	2.337	37.11	12.4	2.85	56.4
10	EADN	*Epithemia adnata* (Kützing) Brébisson 1838	1.693	1.901	39.01	3.24	2.24	47.3
11	CMEN	*Cyclotella meneghiniana* Kützing 1844	1.625	1.824	40.84	1.17	20.5	36
12	ACHD	*Achnanthidium* F.T. Kützing	1.549	1.739	42.58	42.3	0	0
13	NIGR	*Nitzschia gracilis* Hantzsch 1860	1.545	1.735	44.31	1.88	1.33	52.1
14	NINC	*Nitzschia inconspicua* Grunow 1862	1.453	1.631	45.94	1.49	22.3	32.5
15	NAMP	*Nitzschia amphibia f.amphibia* Grunow 1862	1.367	1.535	47.48	6.71	14.7	31.7
16	NIFR	*Nitzschia frustulum var.frustulum* (Kützing) Grunow in Cleve & Grunow 1880	1.329	1.492	48.97	7.81	15.2	30.8
17	ESBM	*Eolimna subminuscula* (Manguin) Gerd Moser, Lange-Bertalot & Metzeltin 1998	1.325	1.487	50.46	0.275	5.94	33.3
18	ESOR	*Epithemia sorex* Kützing 1844	1.118	1.255	51.71	10.8	1.23	28.5
19	ADEU	*Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot 1999	1.087	1.22	52.93	2.05	46.4	0.727
20	NCRY	*Navicula cryptocephala* Kützing 1844	1.087	1.22	54.15	1.32	24.7	7.67

Table 6

Type	**1**			**2**			**3**			**4**			**5**		
	n	**mean**	**SE**	**n**	**mean**	**SE**	**n**	**mean**	**SE**	**n**	**mean**	**SE**	**n**	**mean**	**SE**
Conductivity (μS*cm^{-1})	21	718	6	157	647	25	27	2547	100	19	1930	142	38	5199	480
pH	24	8.5	0	139	8.02	0	6	8.56	0	19	8.63	0	37	9.13	0
Total phosphorus (μg*l^{-1})	24	48	3	152	175	18	30	71	4	19	695	243	38	4680	623
Total nitrogen (μg*l^{-1})	24	906	18	151	1583	96	30	2091	112	18	4719	992	38	10652	2058
Magnesium (mg*l^{-1})	24	61	1	35	37	4	30	214	11	18	64	7	30	23	4
Natrium (mg*l^{-1})	24	41	1	47	49	6	30	335	16	18	369	43	31	1222	127
Calcium (mg*l^{-1})	24	40	1	47	52	2	30	30	2	18	32	3	30	22	2
Potassium (mg*l^{-1})	24	8	1	47	7	1	30	48	2	18	20	3	31	17	3