Hydrobiologia **506–509:** 519–524, 2003.

Littoral diatoms as indicators for the eutrophication of shallow lakes

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Key words: diatoms, eutrophication, epilithon, epiphyton, epipelon, fishponds, bioindication

Abstract

The littoral zone of shallow water bodies in the Czech Republic has been studied quite consistently at several fishponds. The use of algae, especially diatoms, for the monitoring of the state of lotic freshwater also has a long tradition. The main objective of the presented paper is to validate the feasibility of the use of littoral periphyton comunities for the biomonitoring of standing waters. At the investigated sites, littoral periphytic diatoms were studied together with selected enviromental variables (pH, conductivity, nutrients – especially total phosphorus) on three types of natural substrates (epilithon, epiphyton, epipelon). The evaluation of the diatom community was performed on the basis of the checklists of algal indicator species published by authors from the Czech Republic, Austria and the Netherlands. The data were subjected to statistical software NCCS 2000 (GLM Anova and "Ward's minimum" variance cluster analysis). Littoral periphytic diatoms appear to be good indicators of the fishpond water quality. The selected substrates show non-significant differences therefore the average values from all substrates were used. The best indicatory system for evaluation of Czech fishponds was van Dam's index.

Introduction

The sensitivity of algae, especially diatoms, to eutrophication has been proved and is commonly used in different ecological and paleoecological investigations (Stoermer & Smol, 1999; Ács et al., 2003). The composition of diatom communities reflects an entire complex of ecological parameters at a particular site (van Dam, 1982).

Phytoplankton of lakes and periphyton of running waters turned out to be reliable enviromental tools when estimating different levels of eutrophication. However, a possible use of periphyton for the assessment of the eutrophication degree in stagnant water bodies has not been verified sufficiently yet (Kiss et al., 2003).

This study aims (1) to verify the ability of littoral periphytic diatom assemblages to asses the trophic status of shallow lakes (fishponds); (2) to select the best sampling method and substrate for this type of monitoring (stones = epilithon, plants = epiphyton, sediments = epipelon); (3) to select the best indicatory system for this type of ecosystem – trophic diatom index (T_R) followed by Rott (1999), trophic diatom index (T_V) followed by van Dam et al. (1994) or saprobity index (S_S) followed by Sládeček & Sládečková (1996).

Methods

Altogether 15 localities (Central Moravia, Czech Republic) were investigated during the end of recreational season – september 2001. Table 1 summarizes the characters (Type 1–4) and enviromental variables of the sites.

In situ, we measured conductivity, and pH with mobile instruments (WTW Company). We took water samples for chemical analysis in 500 ml glass bottles 10 cm under the water surface using standard methods (Hindák, 1978). We analysed nutrient content by spectrophotometric methods using chemical sets of HACH company. At each site, we took one sample of water for chemical analysis and three samples of algae from three types of substrate (epilithon, epiphyton, epipelon), if available. Each sample represented a mixture from several stones, plant stems or places of the

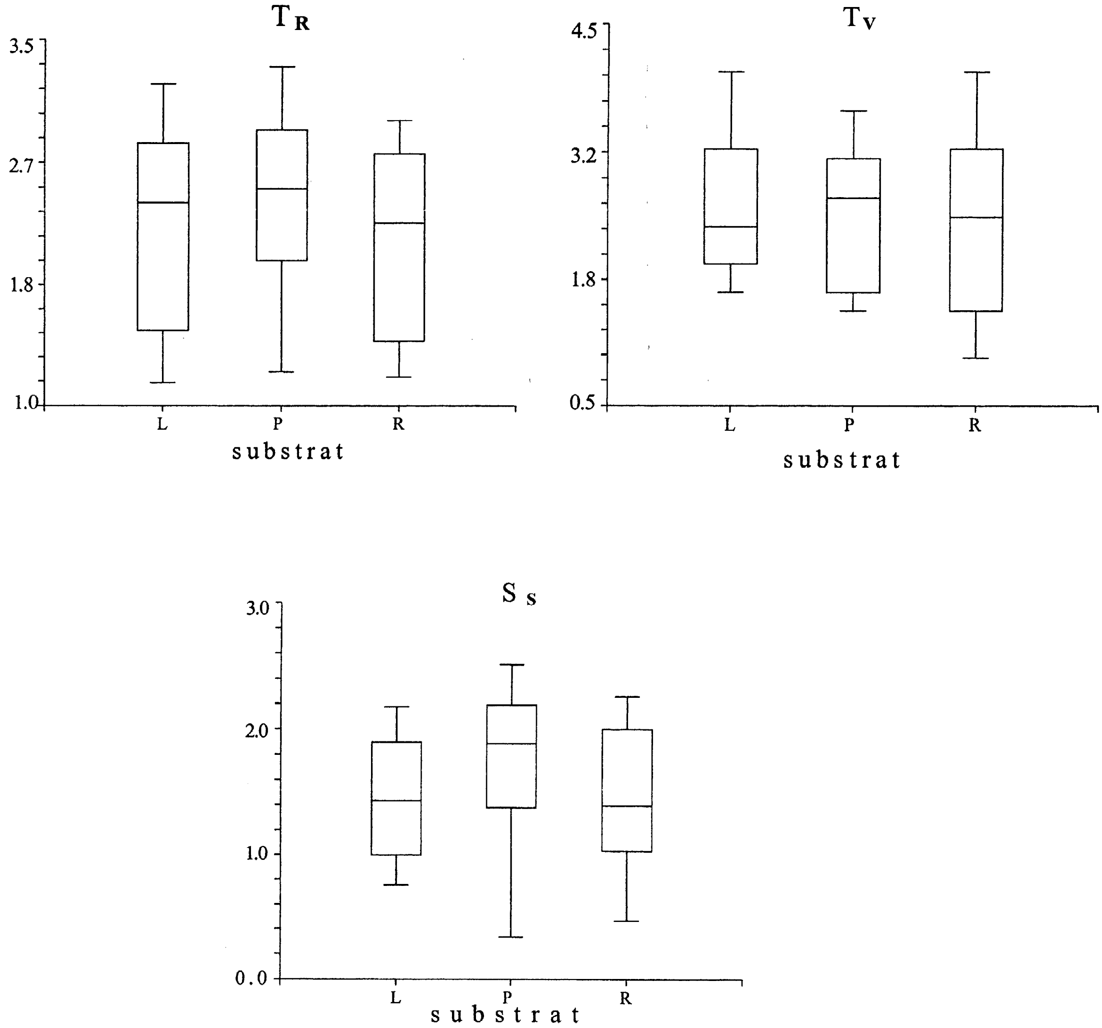


Figure 1. Differences in medians of used indices among substrates (T_R – trophic diatom index according to Rott (1999), T_V – diatom index according to van Dam et al. (1994), S_S – saprobity index according to Sládeček & Sládečková (1996); l – epilithon, p – epipelon, r - epiphyton). Number of samples per substrate: l = 11, p = 15, r = 11.

bottom. The methods complied with the claim for simplicity to enable their use for monitoring in different situations. The samples of epilithon were scraped off the stones with a toothbrush, epiphyton was obtained by cutting 10–20 cm long pieces of submerged plants into plastic bags and epipelon was pipetteed with an under-pressure system (Sládečková, 1962). Diatom frustules were mounted in pleurax and identified according to Krammer & Lange-Bertalot (1986, 1988, 1991a, b). Diatom species composition was estimated by counting 400 individuals from every pleurax mount. Results were expressed as relative abundance (%). We used three indicatory systems for the evaluation and estimation of the trophic state of sites – trophic diatom index (T_R) followed by Rott (1999), which represents arithmetic average of indicator values weighted by relative species abundance and fidelity; saprobity index (S_S) followed by Sládeček & Sládečková (1996), based on the same formula but different list of individual indices and trophic diatom index (T_V) followed by van Dam et al. (1994) differs in individual values and absence of indicator fidelity.

The obtained enviromental data, counted bioindices and number of identified taxa served as a base for statistical comparison of investigated localities using software NCCS 2001 (GLM Anova and "Ward's minimum" variance cluster analysis).

Table 1. The list of localities, the classification to types, enviromental variables (1 – forest-protected, 2 – meadow-recreational, 3 – field-recreational, 4 – field-fish-producting; TP – total phosphorus)

Locality	Coordinates	Type	Species richness	TP ($mg.l^{-1}$)	NO_3^- ($mg.l^{-1}$)	NH_4^+ ($mg.l^{-1}$)	pH	Conductivity ($\mu S.cm^{-1}$)
U třech krátkých	49° 29′ 32″ N; 16° 47′ 29″ E	1	24	0.160	0.000	0.857	6.920	105
Smolenská luka	49° 45′ 44″ N; 17° 40′ 58″ E	1	22	0.115	0.523	0.366	6.080	109
Černé jezero	50° 14′ 00″ N; 17° 24′ 49″ E	1	21	0.030	2.000	0.100	6.800	63
Obora	49° 27′45″ N; 16° 47′ 57″ E	2	25	0.164	0.477	0.735	7.640	150
Suchý 2	49° 28′47″ N; 16° 45′ 43″ E	2	20	0.615	0.452	1.02	7.290	132
Buková	49° 30′ 32″ N; 16° 49′ 47″ E	3	24	0.586	1.118	0.878	8.520	207
Suchý 1	49° 28′ 53″ N; 16° 45′ 22″ E	3	20	1.298	0.713	1.087	8.490	223
Pavlov	49° 31′ 00″ N; 16° 48′ 20″ E	3	32	0.427	0.467	0.663	8.290	206
Protivanov	49° 28′ 25″ N; 16° 49′ 01″ E	3	21	0.778	0.753	1.291	7.780	167
Drahany	49° 25′ 51″ N; 16° 53′ 33″ E	4	28	0.437	0.56	0.776	8.890	207
Tovačov	49° 25′ 56″ N; 17° 16′ 59″ E	4	17	0.664	0.778	1.204	7.770	342
Chropyně	49° 21′ 27″ N; 19° 21′ 39″ E	4	24	0.729	0.679	1.214	7.410	485
Záhlinice	49° 17′ 28″ N; 17° 28′ 54″ E	4	18	0.612	0.417	1.087	7.560	485
Hrdibořice 1	49° 28′ 43″ N; 16° 13′ 07″ E	4	29	0.674	0.541	0.852	7.160	677
Hrdibořice 2	49° 28′ 43″ N; 16° 13′ 10″ E	4	13	1.333	0.609	0.878	7.430	739

Results

The substrates evaluation

Altogether, we identified 119 diatom species, their list will be published elsewhere. Species richness per sample ranged from 5 to 19. The lowest species richnes was found for epiphyton (12.84 ± 4.23), the highest for epipelon (17.94 ± 4.63) and intermediate for epilithon (15.92 ± 5.39). The differences in species richness among substrates are significant (GLM ANOVA: F = 5.06; DF = 2; P = 0.10). The evaluation of diatom communities from different substrates and according to different indicatory system showed a wide variability (Fig. 1). Epipelon reached higher rates, than epilitic and epiphytic communities in all calculated indices. However, the GLM ANOVA median testing of all evaluated indices was not significant (T_R – epiphyton: 2.10 ± 0.18; epipelon: 2.36 ± 0.16; epilithon: 2.16 ± 0.18; F = 0.54; DF = 2; P = 0.585; S_S – epiphyton: 1.42 ± 0.15; epipelon: 1.72 ± 0.14; epilithon: 1.43 ± 0.15; F = 1.45; DF = 2; P = 0.246; T_V – epiphyton: 2.49 ± 0.19; epipelon: 2.52 ± 0.19; epilithon: 2.56 ± 0.21; F = 0.03; DF = 2; P = 0.969).

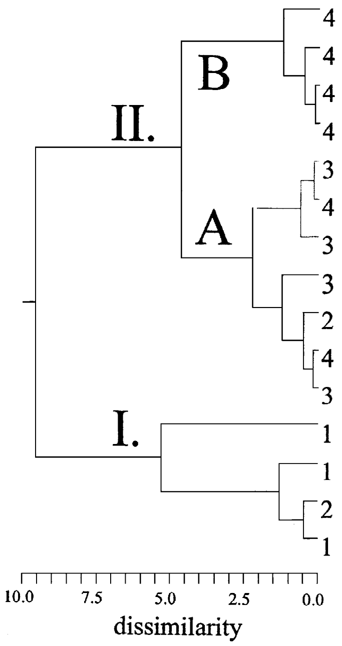
The sites evaluation

The averages from all three substrates were calculated for each of the three indices. Obtained "average indices" (T_{Ravg}, T_{Vavg}, S_{Savg}) and actual chemical data (Table 1) served as a basis for clustering analysis (Ward's minimum variance) of investigated ponds.

The analysis divided ponds into two groups (Fig. 2). The first one (I.) represents fishponds located usually in the protected areas – Types 1 and 2. The sites exhibited low conductivity (63–150 $\mu S.cm^{-1}$), and the concentrations of TP ranged from 0.03 to 0.164 $mg.l^{-1}$.

The second group (II.) contains a mixture of fishponds with different degrees of "exploitation". The isolation of the most loaded subgroup (II. B, Type 4) is evident. High fish and duck production, relatively high conductivity (485 – 739 $\mu S.cm^{-1}$) and nutrient concentrations (Table 1) are the characteristic features of this "dirty" cluster. This subgroup (B) is "out of scale" according to OECD (1982) trophy classification – heavily hypertrophic.

The central subgroup (A) contains a mixture of fish-producing, recreational and meadow ponds Types (2–4) with "halfway degree of exploitation". The conductivity ranged between 132 – 342 $\mu S.cm^{-1}$ and concentrations of TP varied from 0.437 to 1.298 $mg.l^{-1}$.



T_R	T_V	S_S
e	m	b
e	m	b
e-p	m	b
p	m-e	b
e	m	b
e-p	m	b
e-p	m-e	b
e	m-e	o
m-e	o-m	o
e-p	m-e	o
e-p	m-e	o
m	o-m	o
m-e	o-m	o
e-p	m	o
o	o-m	x-o

Figure 2. Results of cluster analysis (Ward's minimum variance) of the investigated ponds based on chemical data, and the classification of sites based on diatom communities from three substrates (average values of indices) according to different indicatory systems (1 – forest-protected, 2 – meadow-recreational, 3 – field-recreational, 4 – field-fish-producing ponds; x – xeno, o – oligo, b – beta, m – meso, e – eutrophic or saprobic, p – polytrophic). The sites from the top to the bottom of diagram: Hrdibořice 2, Hrdibořice 1, Chropyně, Záhlinice, Pavlov, Drahany, Buková, Suchý 1, Suchý 2, Tovačov, Protivanov, Černé jezero, Smolenská luka, Obora, U třech krátkých.

Discussion

The substrate evaluation

The variations in the colonization of different substrates by diatoms have been previously studied mainly in lotic systems (Albay & Akcaalan, 2003). Round (1991) described epilithon as the most suitable substrate for the monitoring of streams. Regardless of the availability of stones in rivers, they can be missing at fishponds and floodplain lakes, like at sites Oborský and Tovačovský fishponds. In addition, the contamination of epilithon by epipelon mentioned by Round (1991) can be more frequent in lentic waters then in streams. A great deal of planktonic species were present on stones and sediment during our investigations (*Aulacoseira ambigua* (GRUN.) SIMON., *Stephanodiscus hantzschii* GRUN., *Cyclostephanos dubius* (FRICKE) ROUND. While the stones are considered as inert surface for algae, epiphytic algae are more or less influenced by the plant surface, especially in infertile lakes (Eminson & Moss, 1980; Cattaneo, 1987). On the other hand, epiphytic assemblages are not encumbered by dead diatom frustules from the previous seasons, as in the case of bottom sediments (Round, 1991).

In summary, we can obtain more or less different estimation of trophic status by sampling different substrates. The differences were not significant: the only significant differences were found in the species richness. Several studies (e.g. Buczkó & Ács, 1994) did not prove significant differences in the algal composition developing on different hosts too. Therefore, we used average values from all substrates for further classification of the sites.

The site evaluation

Results can be compared with OECD (1982) classification, based on average TP values. This classification has following categories: oligotrophic = 0.01 mg.l^{-1}; mesotrophic 0.01–0.035 mg.l^{-1}; eutrophic 0.035–0.1 mg.l^{-1}; hypertrophic <0.1 mg.l^{-1}

Although the classification of the I. group of sites is, according to OECD (1982), inside the category meso-eutrophic, our experiences are not in agreement with this classification. Results, obtained in this study, can be sustained by published phytoplankton data as well. As an example we can use the fishpond U třech krátkých (group I.). Total abundances of phytoplankton per 1 ml ranged from 300 to 3000 cells during 1999 (Kitner & Poulíčková, 2000). The phytoplankton was represented mostly by Chrysophyceae and green algae, the proportion of Cyanophyta was low, with the occurrence of small species (*Merismopedia* sp.). The site was characterized by the occurrence of clear water species as *Bitrichia longispina* (J. W. G. Lund) Bourr., *Dinobryon divergens* Ihm., *Dicranochaete reniformis* Hieron. (Kitner et al., 2003). The T_V classification of this site (oligo-mesotrophic, Fig. 2) can be considered as the most correct assessment. On the other hand, the lowest classification xeno-oligosaprobic (S_S; Fig. 2) is too optimistic.

An interesting situation was observed in the case of Obora fishpond (group I., Type 2). Regardless of the position in cluster analysis and the occurrence of rare planktonic species *Rhizosolenia longiseta* Zach., *Entomoneis ornata* (Bailey) Reimer, high trophy was assessed using T_R. This result was influenced by the absence of epiphyton and by the dominance of *Aulaco-*

seira ambigua (58%). This species, similarly to all centric diatoms and other planktonic species, is not included in Rott's list of indicator species.

The most objective evaluation of sites inside this "clean" group I. were obtained with T_V classification; S_S is too optimistic and T_R is overestimating due to the absence of centric diatoms.

Another situation was observed at sites of group II.B. T_R classification corresponds more or less in this part of the trophic scale. The total abundances of phytoplankton reached up to 18 800 cells per 1 ml at Chropyňský fishpond, with dominance of green algae (44%) and centric diatoms (46%, unpublished data). The littoral community was characterized by the occurrence of eutrophic species (*Stephanodiscus hantzschii*, *Navicula cryptocephala* Kütz., *Fragilaria ulna* (Nitzsch) Lange-B.). Even polytrophic conditions were assessed at Záhlinice fishpond due to the dominance of *Amphora pediculus* (Kütz.) Grun., *Navicula veneta* Kütz., *N. phylepta* Kütz. and *Gomphonema parvulum*. Fishponds Drahany and Tovačov (Type 4) were found as the most eutrophic sites (eutrophic-polytrophic, according to T_R). This classification is in agreement with our experiences. Phytoplankton was dominated by Cyanophytes (*Aphanizomenon flos-aquae* Elenk. at Drahany fishpond, unpublished data) and littoral was dominated by eutrophic diatom species (*Stephanodiscus hantzschii)*. All these fishponds are out of the OECD scale.

The use of algae as bioindicators has been discussed for almost 100 years. The first indicator system were published by Kolkwitz & Marsson (1908). In spite of the hundred years old development of indicatory systems, two main questions remain open (1) selection of indicatory species and (2) evaluation of the results. We tried to use the periphytic littoral diatoms for the classification of shallow fishponds. Our method is applicable and surely is able to recognize the extremes (clear and dirty sites). The combination with the other methods (e.g. phytoplankton, chlorophyl *a*, nutrient concentrations) is necessary for the classification of halfway loaded sites. The methods of bioindication cannot replace physical or chemical analyses, but they can complement them. In any case these methods need and deserve further development to give more precise and reproducible results.

In summary: (1) littoral periphytic diatoms can be used for bioindication of fishpond trophic status. (2) We recommend careful unification of sampling methods and sampling of all available substrates at investigated fishpond. (3) As the best indicatory system for evaluation of Czech fishponds was found van Dam's index (T_V) (van Dam et al., 1994). Saprobity index (S_S) followed by Sládeček & Sládečková (1996) is too optimistic and trophic diatom index (T_R) followed by Rott (1999) is overestimating due to the absence of centric diatoms.

Acknowledgements

This work was supported by grant agency of the Ministry of Education of the Czech Republic "FRVŠ" No. 1248/2002 and "Kontakt" Czech Republic – Austria No. 2000/3.

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