Acta Botanica Hungarica 47 (3–4), pp. 211–223, 2005

APPLICATION OF EPIPHYTIC DIATOMS IN WATER QUALITY MONITORING OF LAKE VELENCE – RECOMMENDATIONS AND ASSIGNMENTS

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(Received 20 March, 2005)

The suitability of benthic diatoms in the biological monitoring program of the water quality of Lake Velence was tested. Diatom indices were calculated with the aid of the software Omnidia based on reed periphyton samples collected between 1988 and 1990, and 1999 to 2004. We have pointed out which indices are appropriate for indicating the water quality changes of Lake Velence. The correlation between the indices IBD, IPS, IDG, and the total nitrogen, total phosphorus content of the water and chlorophyll-a content of the periphyton was calculated. Significant negative correlation was found between the indices and the total phosphorus content of the water. Moreover, we concluded that the chlorophyll-a content of the periphyton related to surface area can also provide information about the water quality. Based on these results the index IBD seems to be the most suitable for the water quality analysis of Lake Velence. Recommendations are provided here concerning the ecological status classification of Lake Velence based on epiphytic diatoms; unaccounted questions and future assignments are also outlined in connection with this.

Key words: biological monitoring, chlorophyll-a, diatom indices, epiphyton, shallow lake

INTRODUCTION

Lake Velence is the third biggest natural lake in Hungary. The shallow water of the lake (mean water depth is 1.2 m) is dark from humic acids. It is a sodic lake, rich in sodium, magnesium, hydrogen-carbonate and sulphates. Because of its large open water areas the lake is an important recreational centre. Its surface area is 24.5 km^2, its catchment area is 602 km^2. The water level of the lake is regulated by the Zámoly and Pátka reservoirs. The southwestern part of the lake is a nature conservation area with a wide reed belt. The central part and the northeastern part are the so-called open water areas serving for recreational activities and water sports (Reskóné 1999, Reskóné *et al.* 2001).

0236–6495/$ 20.00

Reeds (*Scirpo-Phragmitetum*) are the most important plant association of Lake Velence. In the water quality regulating function of the reeds, periphyton coating on the reed stems plays a crucial role (Neely and Wetzel 1995). In Lake Velence, reed stems also constitute the largest available substrate area for periphyton.

Reed periphyton of Lake Velence was first investigated by Zsuzsanna Bartha in 1978 (Lakatos and Bartha 1989). These investigations were started again – after a longer interval – in 1988 (Lakatos and Ács 1990, Lakatos *et al.* 1991, Ács *et al.* 1991, 1994, 2001, Ács and Buczkó 1994, Buczkó and Ács 1997, 1998) with the aim of surveying the quantitative and qualitative composition of epiphytic algae of the different lake parts, furthermore to analyse the changes of the reed periphyton in the last 20 years from an algological viewpoint. In order to gain a more complex picture about the functioning of the periphyton, algological investigations were supplemented by analyses of bacteriological and elemental composition (Ács *et al.* 2003, Kröpfl *et al.* 2003*a*, *b*, Záray *et al.* 2004). Experiments on the degradation of certain pollutants (acetochlor and athrazine) – in which periphytic microbes play a primary role – have also been started (Bohuss *et al.* 2004).

Besides, there is an urgent need to include periphytic algae into studies on the ecological state and water quality of lakes. This is of utmost importance since in littoral regions of shallow lakes primary production of benthic algae can exceed that of the planktonic ones (Vörös *et al.* 2004).

Nowadays, benthic diatoms are considered to be key organisms in ecological quality monitoring of streams and rivers (flowing waters) in the investigations concerning the Water Framework Directive (WFD, European Parliament (2000), directive 2000/60/EC) in several European (EU) countries. Survey of benthic diatoms builds also a part in the National Water Quality Assessment Program (NAWQA) of the United States, in the course of which more than 1500 rivers have been monitored since the beginning of the 1990s (Hambrook Berkman and Porter 2004). However, periphyton research of lakes lags a lot behind, although Hoffman (1994) wrote down the principles of the use of periphytic algae in lakes as trophic and saprobic indicators. Later on, she also prepared a diatom index to create a more correct ecological classification (Hoffman 1999), drawing the attention at the same time to its limits. This index cannot be used for instance in the case of samples where the ratio of tolerant taxa considerably overrides that of indicator taxa. In summer periods, abundance of the tolerant *Achnanthidium minutissimum* often far exceeds that of indicator taxa in Lake Velence (Ács and Buczkó 1994, Ács *et al.* 1994, 2003), hence, this index is not appropriate for water quality analysis of this lake.

Kitner and Poulíčková (2003) examined the indicator role of diatoms in the littoral regions of eutrophic shallow lakes in the Czech Republic and in

Austrian alpine lakes (Pouličková *et al.* 2004). Blanco *et al.* (2004) studied the indicator role of diatoms for the determination of trophic and saprobic state of six Spanish lakes of different water quality.

The aim of this study was to clarify how suitable epiphytic diatoms are for the ecological state and water quality analysis of Lake Velence. In the course of the analysis we made use of our own long-term data and the data of Bartha from 1978 (Lakatos and Bartha 1989).

MATERIAL AND METHODS

Epiphytic diatoms were collected from the open water side of reed stems between 1988–1990 and 1998–2004 from different parts of the lake (F = Fürdető, H = Hosszú-tisztás, K = Kajak-kenu pálya, L = Lángi-tisztás, N = Német-tisztás, and in 2001 also from Cs = Császár-öböl) in summer, in 2000 also in spring, in 2001 also in autumn, finally in 2003 in spring, summer and autumn as well (Fig. 1). On each occasion, 5 green and 5 old reed stems were collected – 5 to 20 cm long pieces from below the water level – at each sampling point. In

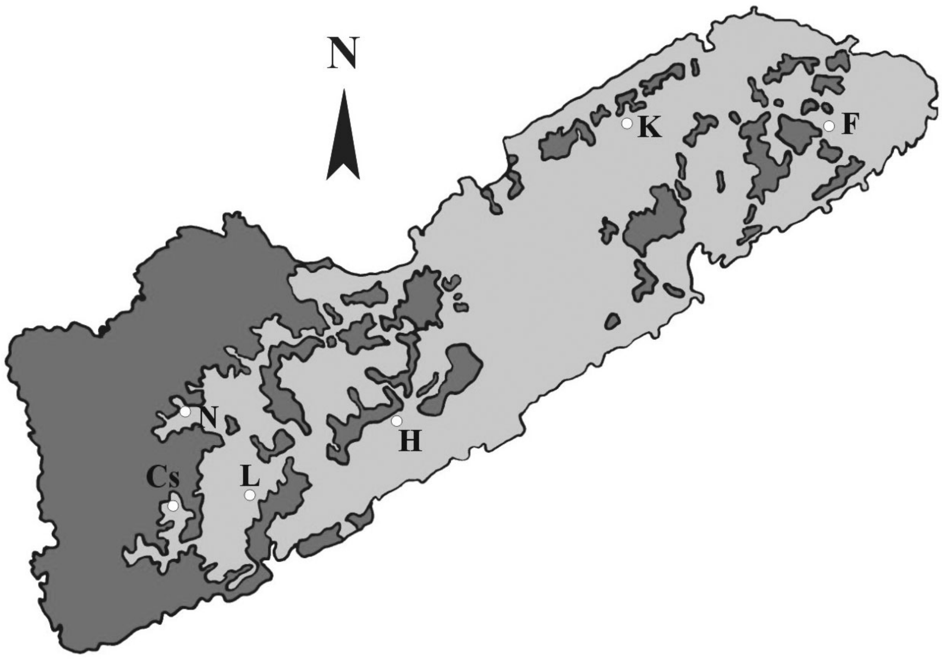

Fig. 1. Sampling points. Cs = Császár-öböl, F = Fürdető, H = Hosszú-tisztás, K = Kajak-kenu pálya, L = Lángi-tisztás, N = Német-tisztás

the laboratory, the periphyton was washed into tap water of known volume. One part of this sample was used for Utermöhl (1958) analysis of algological composition according to the instructions of Lund *et al.* (1958), the other part of the sample was used to determine chlorophyll-a content according to the Hungarian National standard (MSz ISO 10260:1993). Diatoms were identified and counted from treated (with H_2O_2) samples according to standard European protocol (CEN 2002), counting up to 400 valves. Diatom indices were calculated using Omnidia V4. software (Lecointe *et al.* 1993, 1999), which is presented in details in Ács *et al.* (2004). (The software Omnidia is primarily designed for the water quality analysis of flowing waters, we made an attempt to apply it for a standing water, too. The reason for this is that on one hand – as already pointed out in the introduction – diatom index based water quality analysis of standing waters is rather neglected compared to that of flowing waters. On the other hand, the Omnidia indices have already been applied for water quality analysis of some Spanish lakes and some of the indices gave satisfactory results (Blanco *et al.* 2004)).

Chemical parameters of the water were measured by Central Transdanubian Inspectorate for Environmental, Nature Protection and Water, chlorophyll-a content of the water was measured by the same institution until 2001, since then this parameter was measured by our laboratory.

Since 1999 these investigations have been carried out as part of Lake Velence biological monitoring project.

RESULTS AND DISCUSSION

Dominance of diatoms – both in respect to species numbers and abundance values – is characteristic of the periphyton of Lake Velence at nearly all sampling points and nearly any investigated period of time. In the summer, strong dominance of *Achnanthidium minutissimum* is characteristic of the reed periphyton except for the sampling point "Császár-öböl" (where *Amphora pediculus* is the most dominant diatom). An exception was the year 2003 – marked by an unusual low water level – when nitrogen-fixing Cyanobacteria-symbiont Epithemiaceae species gained ground. In the southwestern part of the lake, in the so-called protected area, the water retained a more or less bog-like character. In this part, especially in the area of "Német-tisztás", more Cyanobacteria can be found in the periphyton in respect to the relative abundance and individual number values than in the rest of the lake. However, diatoms even in this bog-like part of the lake mostly dominate in periphyton. Following the reconstruction of Lake Velence in 1987, water quality – based on chlorophyll-a content of the phytoplankton (OECD 1982) – is as a rule mesotrophic in summer. Nevertheless, in 2003 and 2004 our data often showed eutrophic water quality at the time of sampling. The epiphytic diatom based water quality classification of the program Omnidia was absolutely in line with this: according to Omnidia indices, water quality was generally good, in 2003 and 2004 moderate at most sampling points (Fig. 2). When highlighting the water quality values of summer samplings, it is clear that the index IBD (Indice Biologique Diatomées, Biological Diatom Index) closely follows the changes of the lake's state very well. The area "Fürdető" was subject to planktonic eutrophication in 1978; based on the chlorophyll-a content the water was of hypertrophic quality. IBD indicated moderate water quality (Fig. 2). Between the years 1998 and 2002 IBD indicated good water quality, whereas in 2003, during the extraordinarily low water level period this index showed moderate water quality. In 2004 the quality of the water improved slightly, nonetheless, IBD still showed moderate quality.

Water quality of the area "Császár-öböl", the recipient of Császár-víz, is heavily loaded by the nutrient-rich, hypertrophic water of two reservoirs constructed in the catchment area. Based on benthic diatoms, the water quality of this area can be characterised as moderate since 2001.

Water quality of the area "Lángi-tisztás" was good in 1978, 1988–1999, 2001–2002 and 2004, excellent in 1998, moderate in 2003 in the middle of the summer period. Water quality of "Német-tisztás" was good in 1988, 1989 and 1990. In the subsequent years, it deteriorated to moderate level. However, the strong degradation of water quality in 2003, caused by the extraordinarily low water level, was detectable on the index values (Fig. 2).

In "Hosszú-tisztás", water quality was good in 1978, 1988–1990, 1999 and 2001, it was excellent in 1998, and moderate in 2002–2004. IBD index displayed its lowest value in 2003. In the area of the "Kajak-kenu pálya" water quality was good in 1978, 1988–1989 and 2001, excellent in 1999, whereas it was moderate in 2002–2004. IBD showed the lowest value again in 2003. As come from our results, the scale of water quality based on phytoplankton and that of epiphyton necessary to harmonise in the future.

Comparing the species stocks of the different Omnidia indices with the species stock of Lake Velence we concluded that the indices IBD and IPS (Specific Pollution Sensitivity index) displayed the best correspondence with it, because they work with 80–95% of the species of our samples. That was the reason for us to choose these two indices, furthermore the generic index IDG (Generic Diatom Index) for further analysis. Since all of these three indices function based on a theoretical correlation between the available inorganic nutrient pool and diatom species composition, we subjected the correlation of total phosphorus content and total nitrogen content of Lake Velence with the index values to further investigation. Total phosphorus content of the water showed

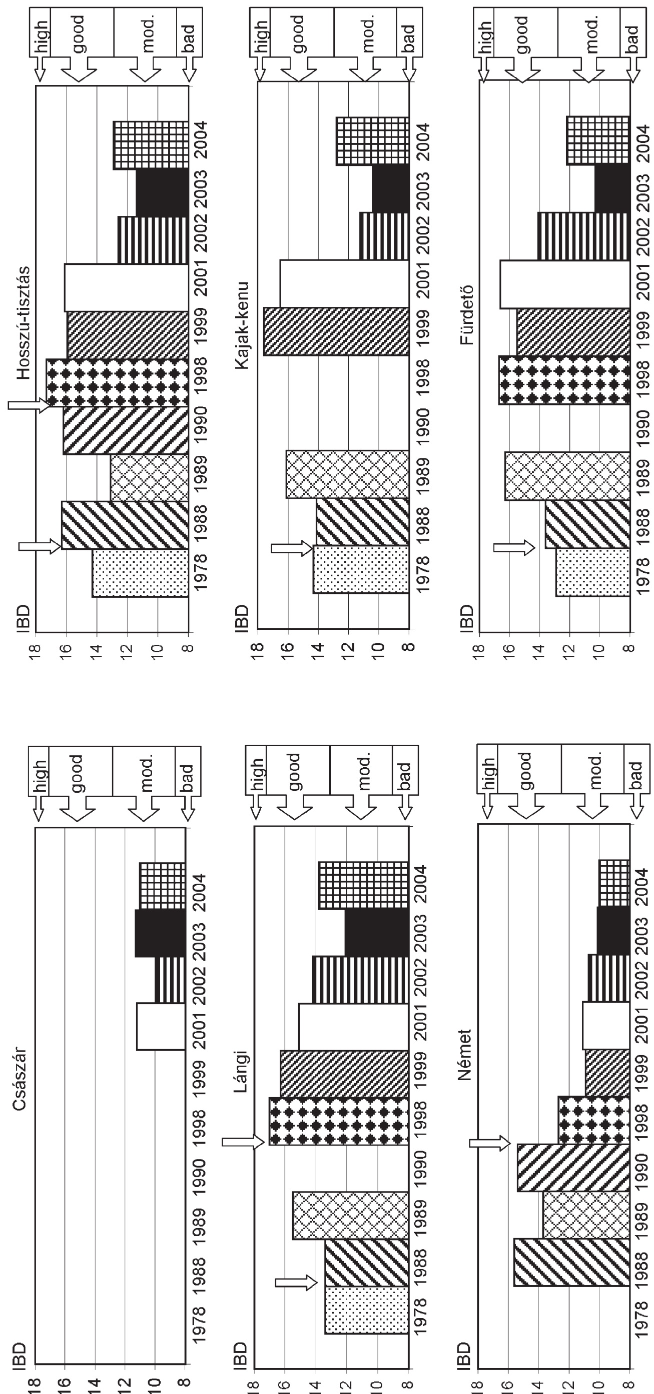

Fig. 2. Change of the index IBD in the investigated years at the different sampling points. Arrows stay for longer temporal gaps of sampling. Mod. = moderate

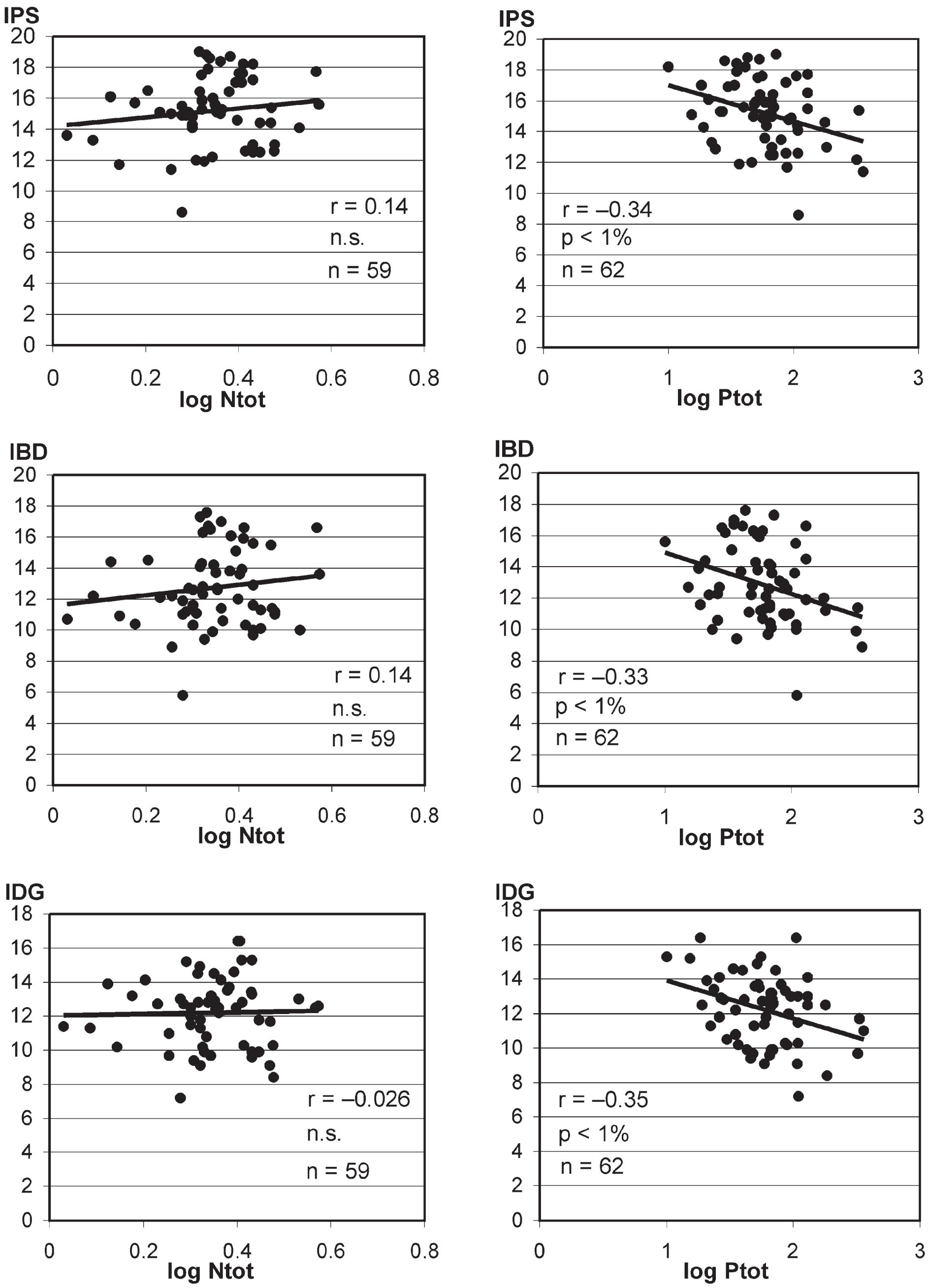

Fig. 3. Correlation of the indices IPS, IBD and IDG with the logarithm of the total phosphorus and total nitrogen content. r = correlation coefficient, *p* = level of significance, n = number of samples, n.s. = non-significant

significant ($p < 1\%$) negative correlation with the three indices (Fig. 3), which means that a better phosphorus supply was coupled with lower index values thus with worse water quality. With the total nitrogen content, the indices did not show significant correlation. A plausible reason for this is that in the periphyton of Lake Velence nitrogen cycle is more or less independent from the nitrogen cycle of the water. It was also clearly shown by Ács *et al.* (2003) that periphytic bacteria of Lake Velence produce nitrogen forms that can be readily taken up by algae. Blanco *et al.* (2004) found negative correlation between total phosphorus and total nitrogen content and diatom indices in the case of some shallow Spanish lakes; however, they found a stronger correlation between the total nitrogen content and the indices than between the total phosphorus content and the indices. The smaller N/P ratio of the Spanish lakes compared to Lake Velence could partly be in the background of this difference. Then again the results and conclusions of the Spanish lakes' investigations are based on merely 6 samples, whereas in our study 62 samples were considered when analysing the correlation with the total phosphorus, and 59 when analysing the correlation with the total nitrogen. Moreover, limiting inorganic nutrient of Lake Velence is phosphorus. Thus, perspicuously, indices show a stronger correlation with it than with nitrogen content.

Negative correlation was found between the chlorophyll-a content of the periphyton and the different index values (Fig. 4). Although the correlation was not significant, the negative coefficient signals, that thickness of the periphyton could also serve with information concerning the water quality. At the same time, this (the non-significant negative correlation) draws attention to the fact that chlorophyll-a content has to be handled with care when drawing conclusions about the water quality. Namely, chlorophyll-a content of the periphyton depends on several other parameters such as the shade of the sampling point, amount of green algae or filamentous algae. Notwithstanding, there are water qualification scales based on chlorophyll-a content of periphyton (Dodds *et al.* 1998), but it must be stressed that chlorophyll-a content has to be related to unit surface area.

Among the three analysed indices, IDG showed the best correlation with the total phosphorus content of the water, and with the chlorophyll-a content of the periphyton. Since IDG is a generic index, thus only considers the genera but not the species of a sample, we are of the opinion that its water quality analysis might be less exact. For benthic diatom based water quality analysis of Lake Velence the index IBD is the best suitable tool according to our study. This index uses more than 80% of Lake Velence's diatom species stock for its calculation and gives reliable results of water quality changes of the lake.

Standards for water quality analysis of flowing waters (e.g. CEN 2002) recommend one sampling a year (in the vegetation period; in the case of water

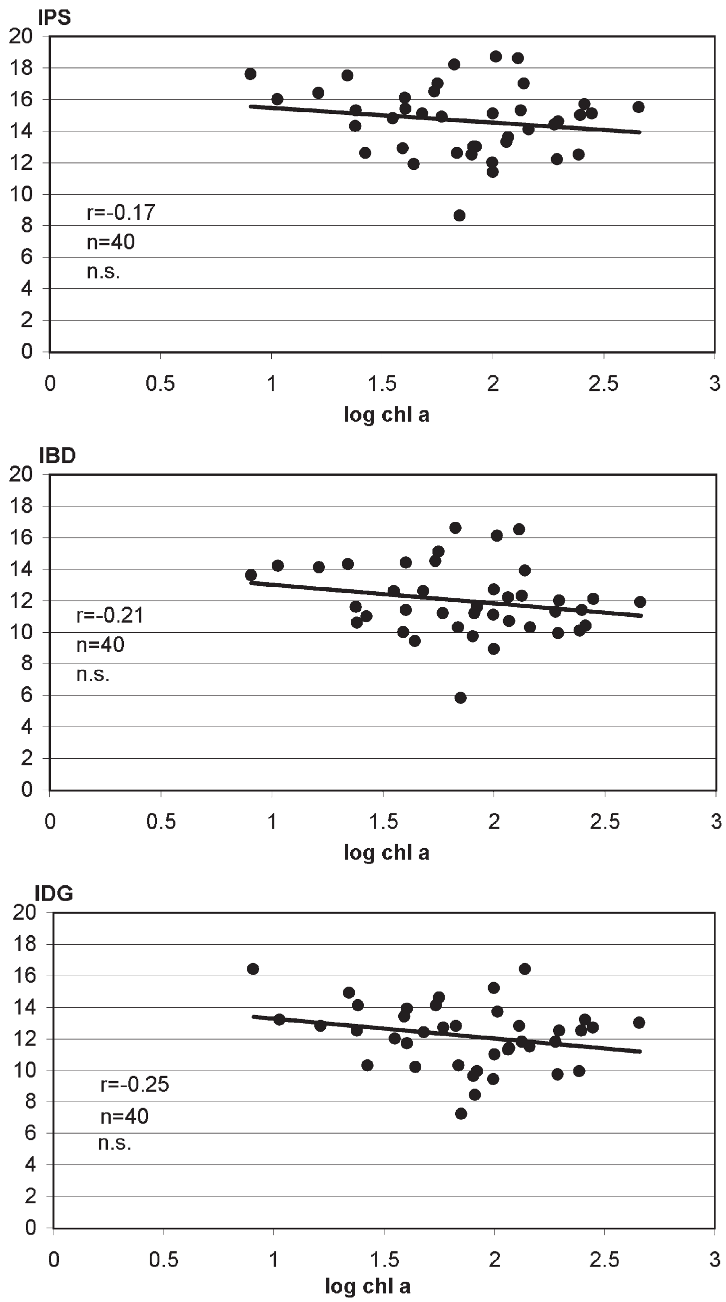

Fig. 4. Correlation of the indices IPS, IBD and IDG with the logarithm of chlorophyll-a content of the periphyton. r = correlation coefficient, p = level of significance, n = number of samples, n.s. = non-significant

courses placed in woods before the foliage fully develops). For sampling frequency of lake periphyton no standards are available yet. (Here, it should be remarked that in our experience one sampling a year is not always sufficient for flowing waters either.) In Lake Velence, samples were collected in July and October in 2001 and in May, August and October in 2003. As Figure 5 clearly shows, the index values of the same sampling points changed one, sometimes even two categories between the sampling times. Thus, to be able to clarify the question of sampling frequency, further investigations are necessary.

Summarising, we can state that the water quality of Lake Velence is good only when the water level is sufficiently high, whereas in years of drought wa-

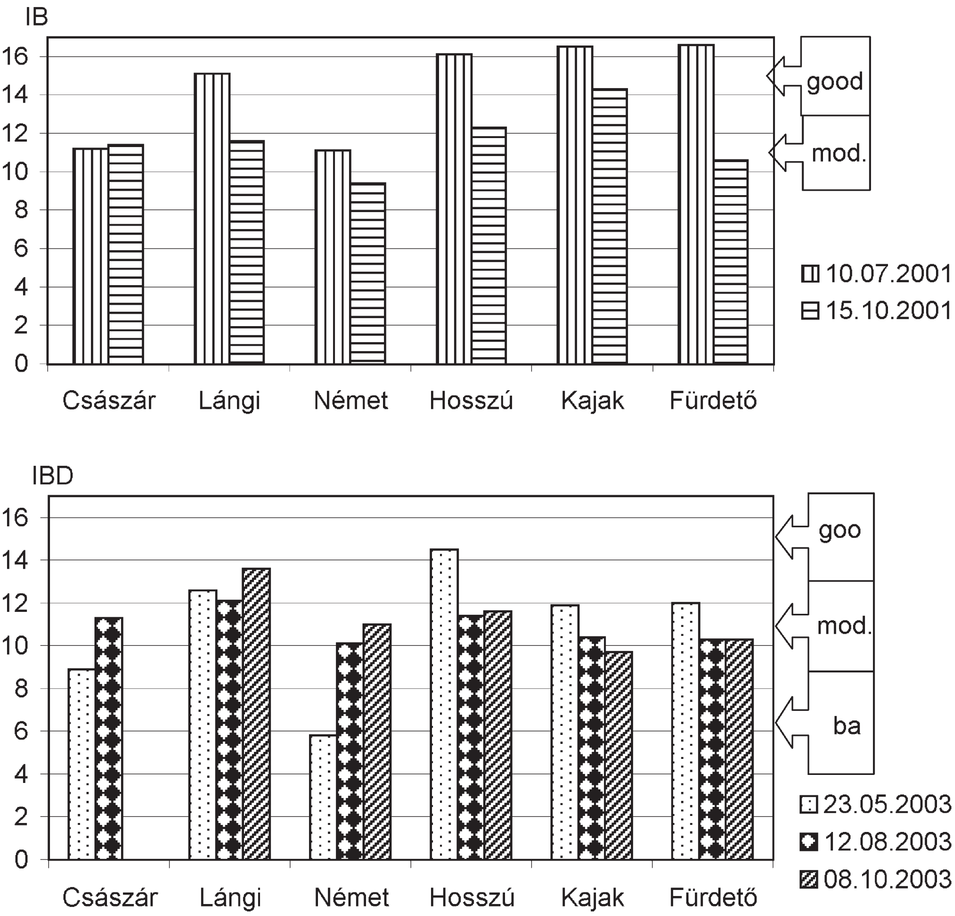

Fig. 5. Change of the index IBD in 2001 and 2003 at the different sampling points and times. Mod. = moderate

ter level sinks below the adequate level and this leads to deterioration of water quality, as we could observe in 2003. Water quality changes can be detected very well by monitoring diatoms of reed periphyton. We propose that collecting from reed stems 5–20 cm below the water surface, analysing benthic diatoms and evaluating the data by Omnidia software is an appropriate method for following up water quality changes. Furthermore we suggest that the index IBD is the best suited for tracing water quality and classifying the ecological status of Lake Velence. However, if diatom species can only be determined at the genus level for some reason, the index IDG might also prove to be appropriate. In this case, however, it must be considered that this index evaluates water quality on a less accurate scale. We propose to put these results to test on other lakes, too. However, if the species stock of the lake differs largely from that of index IBD, the index IPS might render a more accurate qualification possible.

Comparison of benthic diatom composition of several different types of natural substrata is a task to solve in future. Reed periphyton is appropriate for monitoring purposes, but comparison of periphyton from different aquatic plants and stones is necessary in order to be able to monitor water bodies where reed is not available. Here, it should be noted that Poulíčková *et al.* (2004) did analyse this question. In the littoral region of Austrian lakes in the vicinity of the Alps they compared the suitability of benthic diatoms from reed, stone and lake sediment for water quality indication. Reed periphyton was found the most appropriate for this. Based on the available data, it is not yet possible to declare the same about Hungarian lakes. However, it can be stated with certainty that vertical substrata mean a more expedient choice because these are less affected by sedimentation from the phytoplankton.

Another open question is that of sampling frequency, which definitely needs further investigations. For the time being, seasonal sampling (in the vegetation period; that means three times a year) seems to be an acceptable solution, but it is conceivable that this frequency can be decreased as the result of further investigations.

It is also serviceable to measure several parameters of the periphyton simultaneously, e.g. chlorophyll-a content of unit surface area or non-diatomous algae. Unfortunately, well usable Hungarian standards are not available at present. We are convinced that the ratio of different algal groups, moreover the quantity of periphyton is be related to water quality. At the moment, however, the only available standard method is the use of benthic diatoms, which (after have been found appropriate in the case of several Spanish lakes) has already proved to be suitable for Lake Velence.

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Acknowledgement – This work was supported by the Hungarian Scientific Research Fund (OTKA T032444).

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