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LONG-TERM CHANGES OF THE BENTHIC DIATOM ASSEMBLAGES IN THE SHALLOW LAKE BALATON, HUNGARY

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Abstract: The present study deals with changes in the benthic diatom assemblages from Lake Balaton based on the successive diatom floras in the lake sediment during the last five decades. The present author included in the synoptic list her recent findings – 62 diatom taxa identified in 2005. During the last five decades, altogether 122 benthic diatoms, belonging to 43 genera, have been identified from the micro-phytobenthos of the lake. This paper aims to provide not only a complete checklist of the benthic diatoms inhabiting the Balaton, but also to document, based on the available published data, the changes in its diatom assemblages over the last five decades. The comparison was based on the data of Gizella Tamás (late 1960s), and the database of Márta Hajós (1980s), together with the present author's recent floristic findings in 2005. Analyses of the diversity and relative abundance of diatom frustules were undertaken in four basins and five transects of the lake. There have been detected significant differences in the relative abundance of species and the Shannon diversity index values with regard to the different sampling locations. The comparison of these data related to the diatom communities indicate remarkable quantitative differences and it seems that taxonomic identification practice employed had some influence on the assessment of distribution patterns. This study should serve as a baseline for further ecological, nature conservation and water quality studies.

Keywords: Lake Balaton, sediment, benthic diatoms, Shannon diversity, frustule abundance.

Introduction

The short- and long-term changes of water quality in the shallow Lake Balaton have long been a focus of interest. This peculiar shallow lake is unique among Central European lakes for its diverse algal flora [4, 11, 18]. Among the hundreds of algal taxa living in the lake, at least two diatoms are known to be endemic species [12, 21].

The first comprehensive documentation of the shallow, oligotrophic Lake Balaton with regard to its diatom flora was published more than a century ago [18]. This first handbook illustrated 378 diatom taxa in 17 tables and provided also their detailed descriptions. Modern scientific investigations of the benthic diatoms can be ascribed to the middle of the 20th century when Szemes, Tamás & Uherkovich [22-29] made pioneering achievements. The investigations of Tamás [23-26] provided comprehensive information about qualitative and quantitative changes in the phytobenthos. In the studies of Uherkovich [27-29], floristic and taxonomic explorations were emphasized. The latest results have established the functional attributes of benthic diatoms in Lake Balaton and the spatial distribution of the micro-phytobenthos living in the surface layers of the mud in open water [2, 30]. It is clear from the available literature that Lake Balaton has a very complex, but unfortunately poorly documented, algal flora [5, 6]. The present author has recently initiated detailed studies regarding the microphytobenthos of Lake Balaton. The aim of this paper is to review changes in species composition over the past fifty years.

Material and Methods

The study site was the shallow Lake Balaton, having the following physico-chemical parameters: latitude – 46°54'N; longitude – 17°55'E; elevation – 105 m a.s.l. (at 100 cm water level); maximum depth – 11 m; mean depth – 3.32 m (at 100 cm water level); surface area – 597 km^2; catchment area – 5775 km^2; mean pH = 8.4–8.6; electric conductance = 600 – 700 $\mu S\ cm^{-1}$; available phosphorus – 6 $\mu g.l^{-1}$ and available nitrogen – 6 $\mu g.l^{-1}$.

The lake could be divided into four characteristic basins of different size and nutrient supply as a result of the extreme spatial and temporal differences from basin to basin [10]. The largest tributary stream, the Zala River (draining an area of 2622 km^2) enters the smallest, south-western Keszthely-basin (Basin 1). The only outflow of the lake connects the eastern Siófok-basin (Basin 4) with the Danube. Evidence for human activity attests to continuous land use around the lake [16].

Without disturbing the surface, sediment cores were collected in 2005 with a tube sampler from the four basins and five transects (Fig. 1). The first is (from west to east) the Keszthely-basin with transect 1, the second is the Szigliget-basin, with transect 2, the third is the Szemes-basin with transect 3, and the fourth is the Siófok-basin with two sampling transects – 4 and 5.

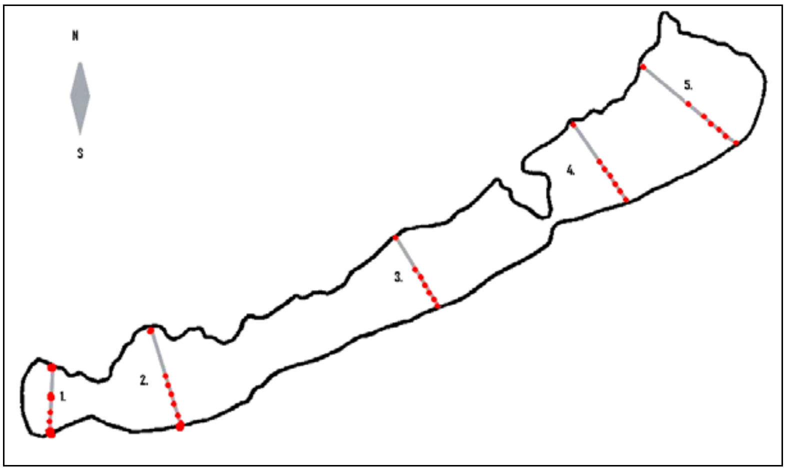

Fig. 1: Sketch map of Lake Balaton with its four basins and the five sampling transects

Diatom frustules were cleaned and prepared following standard techniques: carbonate dissolution by hydrochloric acid, organic matter oxidation by H_2O_2 and repeated rinsing in demineralized water [1, 17]. The cleaned and dried frustules were embedded in Styrax mounting medium. On each slide 10 microscope fields were randomly chosen and a minimum 400 valves were identified and counted with a Nikon Optiphot-2 interference microscope using a 100 X oil immersion lens. Taxonomic identification of diatoms was carried out according to the keys and nomenclature of “Diatoms of Europe” [12, 13, 15] and “Süsswasserflora von Mitteleuropa” [14]. For comparative long-term analysis, three different datasets were used to detect floristic changes in Lake Balaton: the records of Tamás [23-26], Hajós cf. Buczkó, Vörös and Cserny [4] and my present findings (Table 1). The second dataset was compiled from the results of the detailed paleolimnological study organized and conducted by Tibor Cserny [7]. The investigation of the diatoms carried out mainly by Márta Hajós (1916–2000) was part of the above-mentioned multi-proxy analysis according to Buczkó [3]. Márta Hajós completed 17 borehole analyses. However, only one of the drillings (borehole Tó-24) was published in her lifetime [8, 9]. Five boreholes (Tó-9, -11,-13, 15–16) were analysed by Kőváry-Gulyás, as Hajós’s Ph.D. student. Kőváry-Gulyás’s results are available only in manuscript. Boreholes Tó-1 and Tó-25 were studied by Buczkó, Vörös and Cserny [4]. Here I used only the lists of taxa corresponding to the uppermost samples for each borehole.

Synonyms of taxa are given in this paper where the cited investigators used earlier diatom names. The light micrographs of some dominant and characteristic species were carried out in the Hungarian Natural History Museum, employing Leica DM LB2 Microsystems (100 X HCX PLAN APO lens) and Fujifilm FinePix S2 Pro Digital Camera.

The relative abundance of diatoms was expressed as the percentage of total diatom frustules counted in a sample. For the analysis and presentation of data the author used univariate methods such as Shannon diversity index, evenness and species richness, subsequently verified with statistical analyses (ANOVA).

Results and Discussion

During the investigations carried out over the last 60 years on the benthic diatom assemblages of Lake Balaton, 122 diatom taxa (belonging to 43 genera) were identified (Table 1). In 2005, during the counting procedure, 62 diatom taxa were recognized by the present author from the lake sediments. The dominant components in the lacustrine sediment communities of Lake Balaton are fragilarioid diatoms. Most are common benthic taxa, the usual members of diatom assemblages living on sandy bottoms. They are mainly alkaliphilous or indifferent diatoms.

Among the diatoms recorded, only nine taxa were common to all studies (Table 1). Dominant species in the late 1960s according to Tamás [23-26] were *Aulacoseira granulata, Diploneis puella, Navicula cryptocephala* and *Epithemia sorex*. Dominant species in the late 1980s, according to Hajós (cited by Buczkó, Vörös and Cserny [4]), were *Staurosirella pinnata* (= *Fragilaria pinnata*) and *Amphora pediculus* (= *Amphora ovalis* var. *pediculus*).

The dominant species identified in 2005 were:

Amphora ovalis Kützing, Bacillariophyceae, *Thalassiophysales*. Frequent and constant in 2005. It is one of the most abundant diatoms in the sediment in all the investigated periods. Common, alkaliphilous species.

Amphora pediculus (Kützing) Grunow, (Syn.*: Amphora ovalis* Kützing var. *pediculus* Kützing), Bacillariophyceae, *Thalassiophysales* (Plate I: fig. 6). One of the most abundant species in Lake Balaton. Its abundance significantly was higher in 2005; it attained a peak at site 3, with 16% share. Its abundance was constant but at low percentages. Occurs commonly in rivers and streams, sometimes epiphytic on plants and other diatoms.

Aulacoseira granulata (Ehrenberg) Symoensen, Coscinodiscophyceae, *Aulacoseiraceae* (Plate I: figs. 1-4). Common, variable species occurring in pelagic and littoral zone of mesotrophic and eutrophic stagnant waters. It was one of the most abundant and constant species in the samples, achieving 15% share.

Encyonema minutum (Hilse) Mann, Bacillariophyceae, *Cymbellales.* One of the most abundant diatom taxa in 2005, with a 10% percentage contribution at site 5. It was absent in earlier periods. The species occurs in waters with continuously high oxygen supply, mainly in mesotrophic lakes.

Fragilaria leptostauron (Ehrenberg) Hustedt, Bacillariophyceae, *Fragilariales*. Almost the dominant diatom taxon in the sediment of Lake Balaton in 2005. It was also frequently found in the late 1980s, but entirely lacking in the 60s. Frustules have a highly distended middle portion. Widely distributed in temperate, slightly alkaline waters.

Staurosira construens Ehrenberg (Syn.: *Fragilaria construens* (Ehrenberg) Grunow), Bacillariophyceae, *Fragilariales* (Plate I: fig. 5). It is one of the most frequent species in the sediment, occurring continuously at each site and all the time. This diatom species is widespread, alkaliphilous, characteristic of eutrophic waters.

Cavinula scutelloides (W. Smith) Lange-Berthalot (Syn.: *Navicula scutelloides* W.Smith ex Gregory). Bacillariophyceae, *Naviculales*. It was present in all periods throughout the sediment, attained a peak in 2005 at site 1. Cosmopolitan element, it is common in eutrophic waters. This species is one of the most characteristic species for Lake Balaton.

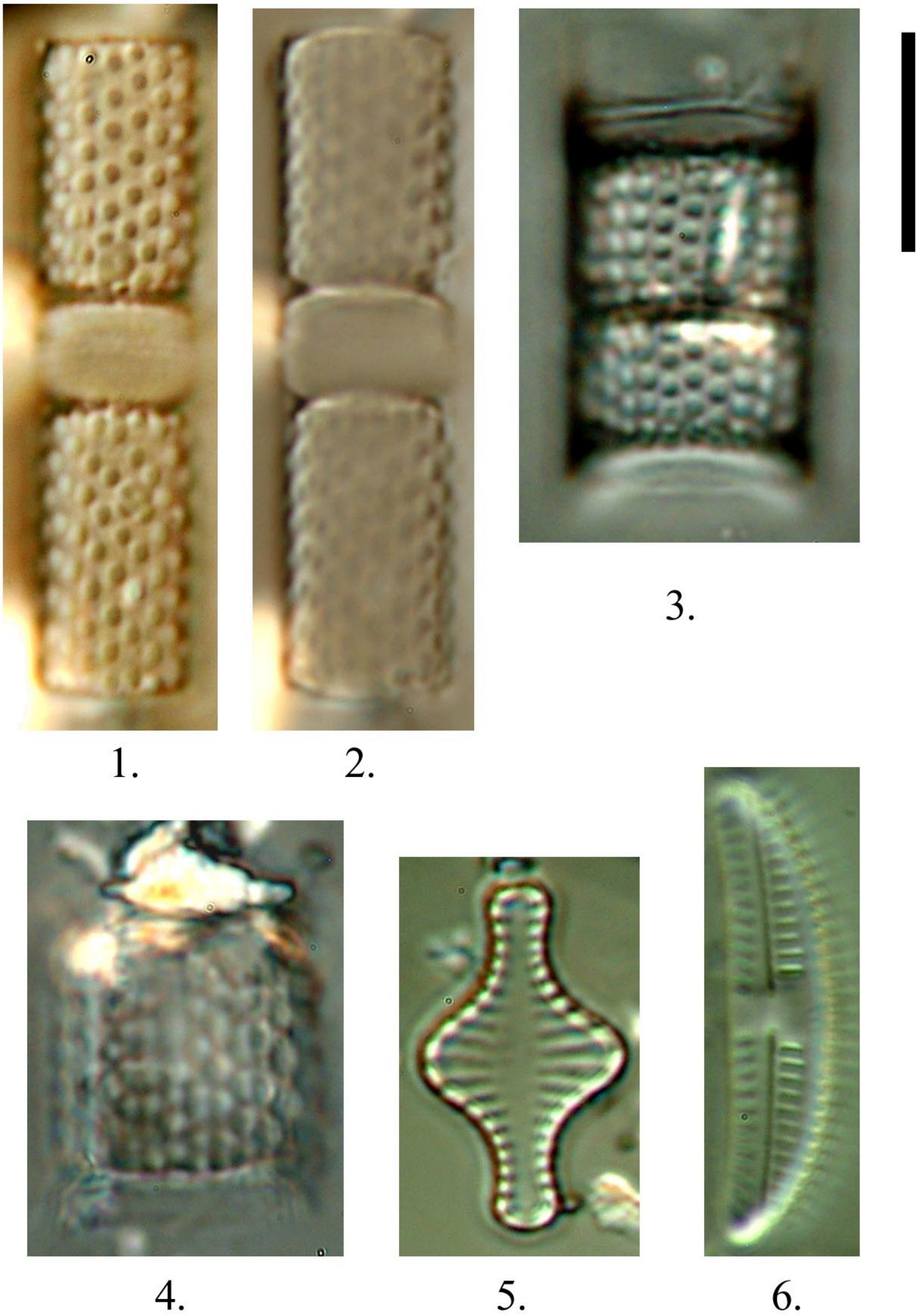

Plate I: Figs. 1-4. *Aulacoseira granulata* (Ehrenberg) Simonsen; 5. *Staurosira construens* Ehrenberg; 6. *Amphora pediculus* (Kützing) Grunow . Scale bar 10 micrometer.

Table 1: Synoptic list of diatoms recorded from the Lake Balaton sediment surface in the last fifty years

Diatom taxa \ Years of records	1965	1966	1967	1980	2005
Acanthoceras zachariasii (Brun) Simonsen; Syn.: Attheya zachariasii Brun	-	+	-	-	-
Achnanthidium minutissimum (Kützing) Czarnecki	-	-	-	-	+
Amphora ovalis Kützing	+	+	+	+	+
Amphora pediculus (Kützing) Grunow; Syn.: Amphora ovalis Kützing var. pediculus Kützing	+	+	+	+	+
Asterionella formosa Hassal	+	-	+	-	-
Aulacoseira granulata (Ehrenberg) Simonsen	+	+	+	+	+
Aulacoseira granulata var. *angustissima* (O. Müller) Simonsen	+	+	+	-	-
Caloneis bacillum (Grunow) Cleve	-	-	-	-	+
Caloneis schumanniana (Bory) Cleve	-	-	-	-	+
Caloneis schumanniana var. *biconstricta* (Grun.) Reichelt	+	+	+	+	-
Campylodiscus balatonis Pantocsek	-	-	+	-	+
Campylodiscus hibernicus Ehrenberg; Syn.: Campylodiscus noricus Ehrenberg var. hibernicus (Ehrenberg) Grunow	-	-	-	-	+
Cavinula scutelloides (W. Smith) Lange-Bertalot	+	+	+	+	+
Cocconeis neodiminuta Krammer	-	-	-	+	-
Cocconeis placentula Ehrenberg	-	-	-	-	+
Cocconeis thumensis A. Mayer	-	-	-	-	+
Cyclostephanus dubius (Fricke) Round; Syn.: Cyclotella bodanica Grunow; Syn.: C. radiosa (Grun.)Lemm., C. balatonis Pantocsek	+	+	+	+	+
Cyclotella comta (Ehrenberg) Kützing	-	-	-	+	-
Cyclotella meneghiniana Kützing	-	-	-	+	-
Cyclotella ocellata Pantocsek	+	+	+	+	+
Cymatopleura elliptica (Brébisson ex Kützing) W.Smith	-	+	+	+	+
Cymatopleura solea (Brébisson et Godey) W. Smith	+	+	+	-	+
Cymbella affinis Kützing	-	-	-	-	+
Cymbella aspera (Ehrenberg) Cleve	-	-	-	+	-
Cymbella cymbiformis Hustedt	-	+	-	-	-
Cymbella helvetica Kützing	-	-	-	+	-
Cymbella lanceolata (Ehrenberg) Kirchner	-	-	-	-	+
Cymbella neocistula Krammer; Syn.: Cymbella cistula (Ehrenberg) Kirchner	-	-	-	+	-
Cymbella prostrata (Berkeley) Cleve	-	-	-	-	+
Cymbella proxima Reimer	-	-	-	-	+
Cymbella tumida (Brébisson) van Heurck	-	-	-	-	+
Cymbopleura inaequalis (Ehrenberg) Krammer; Syn.: Cymbella ehrenbergii Kützing	+	+	+	-	-
Cymbopleura schmidtii (Grunow) Stenger-Kovács	-	-	-	-	+
Diatoma moniliforme Bory	-	-	-	-	+
Diatoma tenuis C. Agardh	-	-	-	-	+
Diploneis oblongella (Naegeli) Cleve-Euler	-	-	-	-	+
Diploneis pseudoovalis Hustedt	-	-	-	+	-
Diploneis puella (Schumann) Cleve	+	+	+	-	-
Encyonema muelleri (Hustedt) D.G. Mann; Syn.: Cymbella muelleri Hustedt	-	-	-	-	+
Encyonema minutum (Hilse) D.G.Mann	-	-	-	-	+
Encyonema silesiacum (Bleisch) D.G. Mann; Syn. Cymbella silesiaca Bleisch	-	-	-	-	+
Epithemia argus (Ehrenberg) Kützing	-	-	-	+	-
Epithemia frickei Krammer	-	-	-	+	-
Epithemia goeppertiana Hilse	-	-	-	+	-
Epithemia hyndmannii W. Sm.	-	-	-	+	-
Epithemia sorex Kützing	+	+	+	-	+
Fragilaria arcus (Ehrenberg) Cleve	+	+	-	-	-
Fragilaria capucina Desmazières	+	+	+	+	+

Fragilaria heidenii Østrup	-	-	-	+	-
Fragilaria leptostauron (Ehrenberg) Hustedt	-	-	-	+	+
Fragilaria martyi (Héribaud) Lange-Bertalot	+	+	+	-	-
Fragilariforma cf. virescens (Ralfs) Williams et Round; Syn.: *Fragilaria virescens* Ralfs	-	-	-	-	+
Gomphonema angustatum (Kützing) Rabenhorst	+	+	-	-	+
Gomphonema angustum Agardh; Syn.: Gomphonema dichotomum Kützing	-	-	-	-	+
Gomphonema capitatum Ehrenberg	-	-	-	+	-
Gomphonema olivaceum (Hornem.) Brébisson	-	-	-	-	+
Gyrosigma attenuatum (Kützing) Rabenhorst	+	+	+	+	-
Gyrosigma distortum var. *parkeri* (Harrison) Cleve	-	-	-	+	-
Gyrosigma kützingii (Grunow) Cleve	+	+	+	-	-
Gyrosigma cf. spencerii (Quekett) Griffith et Henfrey	-	-	-	-	+
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski; Syn.: Navicula capitata var. hungarica (Grunow) R.Ross; *Navicula hungarica* Grunow	+	+	+	+	-
Hippodonta costulata (Grun.) Lange-Bertalot, Metzeltin et Witkowski; Syn.: Navicula costulata Gunow in Cleve et Grunow	+	+	+	-	-
Karayevia clevei (Grunow in Cleve et Grunow) Round et Bukhtiyarova	+	+	+	-	+
Mastogloia elliptica (C. Agardh) Cleve	-	-	-	+	-
Mastogloia smithii Thwaites	-	-	-	+	-
Melosira varians C. Agardh	-	+	-	-	-
Navicula capitatoradiata Germain	-	-	-	-	+
Navicula cryptocephala Kützing	+	+	+	-	-
Navicula cryptotenella Lange-Bertalot	+	-	-	-	+
Navicula gracilis Ehrenberg	-	+	-	-	-
Navicula laterostrata Hustedt	-	-	-	-	+
Navicula menisculus Schumann	-	-	-	+	-
Navicula oblonga Kützing	-	-	-	+	-
Navicula peregrina (Ehrrnberg) Kützing	-	-	-	+	-
Navicula phyllepta Kützing	-	-	-	-	+
Navicula pseudotuscula Hustedt	-	-	-	+	-
Navicula radiosa Kützing	-	-	-	-	+
Navicula reinhardtii (Grunow) Grunow in Cleve et Möller	+	-	-	-	-
Navicula tripunctata (O.F. Müller) Bory	-	-	-	-	+
Neidium binodis (Ehrenberg) Cleve	+	+	+	-	+
Nitzschia acicularis (Kützing) W.Smith	+	+	+	-	-
Nitzschia amphibia Grunow	+	+	+	+	+
Nitzschia commutatoides Lange-Bertalot	-	-	-	-	+
Nitzschia dissipata (Kützing) Grunow	-	-	-	-	+
Nitzschia fasciculata Grunow	-	-	-	-	+
Nitzschia frustulum (Kützing) Grunow	-	-	-	+	-
Nitzschia fruticosa Hustedt	-	-	-	-	+
Nitzschia intermedia Hantzsch ex Cleve et Grunow	-	-	-	-	+
Nitzschia palea (Kützing) W. Smith	-	+	+	-	-
Nitzschia recta Hantzsch ex Rabenhorst	-	-	-	-	+
Nitzschia sigmoidea (Nitzsch) W. Smith	+	+	+	-	-
Nitzschia solita Hustedt	-	-	-	-	+
Nitzschia vitrea Norman	-	-	-	+	-
Pinnularia cf. microstauron (Ehrenberg) Cleve	-	-	-	+	-
Pinnularia subcapitata W. Gregory	-	-	-	-	+
Pinnularia sp.	-	+	-	-	-
Placoneis dicephala (W.Smith) Mereschkowsky; Syn.: Navicula dicephala (Ehrenberg) W.Smith	+	+	+	-	-
Placoneis elginensis (Gregory) E.J. Cox; Syn.: Navicula elginensis (Gregory) Ralfs	-	-	-	+	-
Placoneis gastrum (Ehrenberg) Mereschowsky; Syn.: Navicula gastrum Ehrenberg	-	-	-	-	+
Placoneis placentula (Ehrenberg) Heinzerling;	+	+	+	+	+

Syn.: Navicula placentula (Ehrenberg) Kützing					
Pseudostaurosira brevistriata (Grunow in Van Heurck) D.M.Williams et Round; Syn.: Fragilaria brevistriata Grunow	-	-	-	+	+
Rhoicosphenia abbreviata (C. Agardh) Lange-Bertalot	-	-	-	-	+
Rhopalodia gibba (Ehrenberg) O. Müller	+	+	+	+	-
Sellaphora pupula (Kützing) Mereschowsky; Syn.: Navicula pupula Kützing	-	+	-	-	-
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	-	+	-	-	-
Stauroneis smithii Grunow var**.** *incisa* Pantocsek	-	-	-	+	-
Staurosira construens Ehrenberg	+	+	+	+	+
Staurosirella lapponica (Grunow) Williams et Round; Syn.: Fragilaria lapponica Grunow	-	-	-	+	-
Staurosirella pinnata (Ehrenberg) D.M.Williams et Round; Syn.: Fragilaria pinnata Ehrenberg	-	-	-	+	-
Stenopterobia pelagica Hustedst	+	+	+	-	-
Surirella biseriata Brébisson in Brébisson & Godey	+	+	+	+	-
Surirella brébissonii Krammer et Lange-Bertalot	-	-	-	-	+
Surirella elegans Ehrenberg	-	-	+	-	+
Surirella ovalis Brébisson	-	-	-	-	+
Surirella patella Kützing	-	-	-	-	+
Surirella robusta var. *splendida* Ehrrenberg	-	+	-	-	-
Surirella tenera **W.**Gregory	-	+	+	-	+
Surirella turgida W.Smith	-	+	-	-	-
Synedra parasitica (W. Smith) Hustedt; Syn.: Fragilaria parasitica (W. Smith) Grunow in Van Heurck	-	-	-	+	-
Tryblionella angustata W. Smith; Syn.: Nitzschia angustata (W. Smith) Grunow	+	+	+	+	-
Tryblionella debilis Arnott in O'Meara; Syn.: Nitzschia tryblionella var. debilis (Arnott) A. Mayer	+	+	+	-	-
Ulnaria ulna (Nitzsch) Compère; Syn.: Fragilaria ulna (Nitzsch) Lange-Bertalot	-	-	-	+	-
Total sp. number:	**37**	**46**	**38**	**48**	**62**

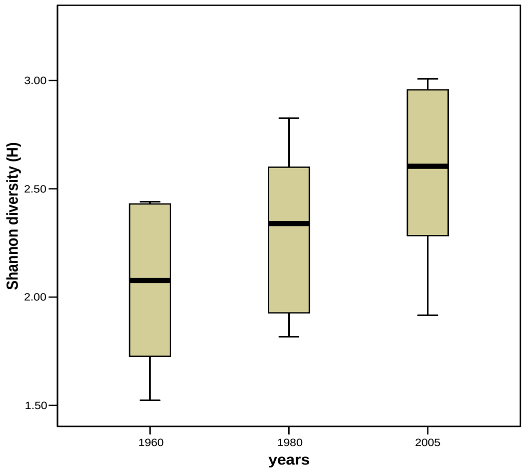

Fig. 2: Changes in the Shannon diversity (H) of the benthic diatoms in the three investigation periods in Lake Balaton. (One-way analysis of variance (ANOVA); p= 0.2)

Furthermore, I compared the diatom assemblages corresponding to three periods – the 1960s and 1980s and the year 2005, employing the Shannon diversity index (Fig. 2) and the relative abundance of frustules (Fig. 3). It became evident that both the Shannon index and frustule abundance have exhibited a tendency to increase during the last fifty years.

The increasing tendency of the Shannon index and abundance of frustules since 1960 in the microphytobenthos assemblages, in accordance with the middle disturbance hypothesis [19, 20], is possibly due to changes in lake trophicity. However, changes in light microscopical techniques and taxonomic identification practice might have some disturbing influence on the results.

Although the observations are rather preliminary and not conclusive in all studies, they suggest differences between the different basins of the lake, with regard to the Shannon index values and abundance of frustules. Even Tamás's comments [23-26] from the late 1960s make references to slight differences in diversity between the basins, from west to east: the minimum diversity (H=1.0), detected at site no. 3, the diversity attaining its maximum (H= 2.71) in the eastern basins. Following the data of Hajós (cited by Buczkó, Vörös and Cserny [4]) the same increasing trend was found from the western (H=1.82) to the eastern basins (H= 2.83), paralleled by the number of species ranging between 11 and 43. The species diversity in 2005 ranged between 1.5 and 3.0, without significant differences, except a moderate increasing tendency from site 1 to site 5.

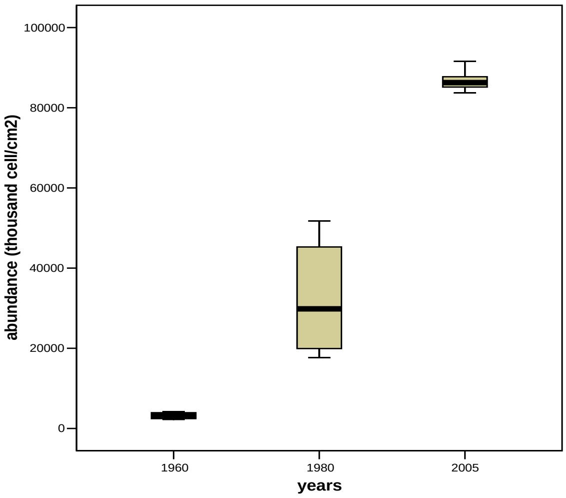

Fig. 3: Changes in diatom abundances during the last five decades. Note the significant increase in frustule abundance (One-way analysis of variance; p= 0.001).

Conclusions

The present author identified 62 diatom taxa in 2005. According to the investigations performed over the last five decades in three different periods (the late 1960s and 1980s, and recently in 2005), the diatom flora of the lake micro-phytobenthos includes 122 diatom taxa, only nine being common for all sampling periods.

The analyses of the structure of diatom assemblages based on diversity index and cell abundance demonstrate marked changes on the level of the benthic diatom flora of the lake, during the last fifty years. These changes reflect modifications in the trophic state of the lake.
The present result should constitute a baseline for further ecological, nature conservation and water quality studies.

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SCHIMBĂRI DE LUNGĂ DURATĂ ÎN COMUNITĂŢILE DE DIATOMEE BENTONICE DIN LACUL BALATON, UNGARIA

(Rezumat)

Lucrarea se referă la schimbările intervenite în compoziţia floristică a comunităţilor de diatomee bentonice care s-au succedat pe sedimentul Lacului Balaton în ultimele cinci decenii. Autoarea prezentei lucrări a inclus în tabelul sinoptic (tab. 1) recentele sale rezultate: 62 taxoni de diatomee identificate în 2005. În cursul celor cinci decenii, în total 122 taxoni au fost semnalaţi (aparţinând la 43 de genuri) în microfitobentosul lacului. Lucrarea intenţionează nu numai furnizarea inventarului diatomeelor bentonice din Balaton, dar să documenteze pe baza datelor publicate schimbările care au avut loc în cele cinci decenii. Comparaţiile au avut la bază datele furnizate de Gizella Tamás, pentru sfârşitul deceniului şase al secolului 20, baza de date a lui Márta Hajós, pentru anii optzeci ai aceluiaşi secol, respectiv datele recente (din 2005) ale autoarei de faţă.

Cercetările au fost extinse şi asupra diferenţelor care există între diferitele bazine ale lacului. Analizele diversităţii şi a abundenţei relative a frustulelor de diatomee au fost efectuate de autoare în 2005 de-a lungul a cinci transecte, în cele 4 bazine ale Lacului Balaton. S-au evidenţiat diferenţe semnificative în ceea ce priveşte abundenţa relativă a celulelor de diatomee şi valorile indicelui de diversitate Shannon în funcţie de locurile de colectare. Prezenta lucrare ar putea servi ca punct de plecare pentru studii microfitobentonice ecologice, de ocrotirea mediului şi de monitorizarea calităţii apei.

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