

Multivariate analysis of long term water quality changes of shallow Lake Balaton

G. Kiss, Gy. Dévai, B. Tóthmérész and A. Szabó

Introduction

Lake Balaton, the largest lake of Central Europe, is a typical shallow lake; thus, the reaction of the lake is more sensitive than in the case of deep lakes. The volume of the water body is smaller compared to the catchment area, the surface of the contact zone of the water body and the bed is larger, and the exchange rate of the water is faster than in the case of deep lakes. The border of the trophogenic and tropholitic zone is usually in the sediment. Wind creates a frequent turnover of the water and the upper layer of the sediment. The lake has four characteristic basins with strikingly different size and nutrient load, which results in exaggerated spatial and temporal differences because the state of the lake may change considerably from year-to-year and also from basin-to-basin.

The water quality state of Lake Balaton has been monitored regularly since the 1970s. This paper is a comparative analysis based on a long-term data set of algae, trophic and saprobic parameters, from 1980 to 2001, in the whole lake with special emphasis on the four basins of Lake Balaton.

Key words: phytoplankton, water qualification, diversity, trophity, saprobity, Lake Balaton

Methods

Lake Balaton is the largest lake of Central Europe (approx. 600 km²); its length is 77 km and its width ranges from 4 to 14 km. There are four characteristic basins of the lake (from east to west): Siófok-basin (S), Akali-basin (or Szemes-basin; A), Szigliget-basin (Sz) and Keszthely-basin (K).

We studied five characteristic years (1980, 1982, 1987, 1994 and 2001) based on the following judgments. Two years (1982 and 1994) had an extreme algal bloom during the summers; in 1987 a moderate algal bloom; and 1980 and 2001 no algal bloom. Samples were taken from March to December each year, depending on the ice period. The number of samples were: 1980 (12 samples); 1982 (21); 1987 (21); 1994 (24); and 2001 (20).

Algal count and biomass were determined from the samples (VÖRÖS 1984). We examined the trophic and saprobic parameters (DÉVAI 1992) of chemical oxygen demand with potassium permanganate (cp), chemical oxygen demand with potassium dichromate (cd), biological oxygen demand (bod), organic nitrogen (on), total nitrogen (tn) and total phosphorous (tp). We also examined the influence of three biological parameters, chlorophyll-a (ca), algal count (ac), algal biomass (ab). Laboratory measurements were based on the Hungarian national standard.

Multidimensional scaling (MDS) was used to display the similarities of pooled samples of the studied basins. Normalized Canberra coefficient was used to calculate the dissimilarity of the samples (LEGENDRE & LEGENDRE 1998). Canonical correspondence analysis (CCA) was used to explore the relationship of the abundance relationships of algae and the chemical variables, and the amount of chlorophyll-a, algal biomass and the algal count. Diversity of assemblages was measured by the Shannon diversity. R package was used during the calculations (R Development Core Team 2004).

Results

A total of 172 alga taxa were identified in the studied samples. The yearly averages of the studied parameters for the basins were calculated (Table 1).

MDS revealed that algal assemblages in 2001 and 1987 were similar; all basins are in a compact group on the scatterplot (Fig. 1). Similarly, the basins of 1982 and 1994 were similarly grouped. The basins were in a separate group in 1980. The Siófok basin was an outlier both in 1980 and 1982.

The result of CCA based on the algal assemblages and the 6 measured trophic and saprobic parameters reveals that separation of the samples in 1982 was caused by the high concentration of organic nitrogen and total nitrogen; also

Table 1. Characteristics of the algae assemblages of Lake Balaton in the four basins during the studied years.

Water bodies	Years	Chlorophyll- <i>a</i> ($\mu\text{g/l}$)	Algal count (10^3 ind./ml)	Algal biomass (mg/l)	Number of algae taxa
Siófok-basin	1980	8.7	2.12	1.23	70
	1982	11.5	11.37	2.65	66
	1987	9.1	3.28	0.75	54
	1994	18.1	22.80	7.09	49
	2001	8.2	2.93	1.28	52
Akali-basin	1980	19.1	9.16	4.00	67
	1982	25.1	33.55	6.39	54
	1987	11.5	3.70	0.97	44
	1994	27.6	29.07	9.47	49
	2001	13.0	4.25	1.87	48
Szigliget-basin	1980	40.7	20.70	4.98	66
	1982	40.6	62.15	11.81	49
	1987	26.3	9.17	2.49	50
	1994	35.9	27.31	10.45	48
	2001	16.9	5.90	2.82	53
Keszthely-basin	1980	49.4	28.18	6.48	75
	1982	64.8	80.75	14.97	57
	1987	44.8	14.93	4.62	64
	1994	38.1	27.14	10.70	45
	2001	17.9	6.29	2.80	51

the low concentration of organic nitrogen and total nitrogen characterized the separation the years 1987 and 2001 (Fig. 2). The high concentration of total phosphorous was characteristic to the year 1994.

During the algae bloom years (1982 and 1994) the Shannon diversity (Fig. 3) of the algae assemblages was much lower than in the years with usual algae dynamics (1980, 1987, 2001). The same pattern was observed by the evenness of the algae assemblages.

Discussion

The algae pattern was relatively homogeneous in each basin of the lake in 1982, a year with algal bloom. The algae assemblages of the basins were also similar in 2001, when there was no extreme algae bloom (Fig. 1). A clear separation was usually seen between the basins of the eastern side of the Lake Balaton (S and A) and western side (Sz and K). The eastern basins were characterized by relatively good water quality (1980, 1987) and basins of the western side with lower water quality. The Siófok-basin

was separated from the other basins in 1982 (Fig. 1) and was characterized by an unusually high chlorophyll-*a* concentration and algal biomass. This suggests that predecessors of the algae bloom of 1982 were present in the Siófok-basin even in 1980.

Substantial nutrient loads enter the Lake Balaton; however, there are considerable differences in the nutrient loads and volumes of the basins, especially where the River Zala flows into Keszthely-basin. It transports nutrients from half of the total water catchment area, encompassing 5179 km². Until the beginning of 1980, just one third of the phosphorous load reached the Keszthely-basin, which is just the 5% of the total volume of the lake. This resulted in a hypertrophy, and the concentration of the chlorophyll-*a* frequently exceeded the level of 100 $\mu\text{g/l}$ (HERODEK 1984, VÖRÖS & NAGYGÖDE 1993, BIRÓ & VÖRÖS 1982). The changes in water quality were analysed by modeling from the beginning of the study (SOMLYÓDY 1986), and the phytoplankton of the lake has been studied in detail (VÖRÖS & PADISÁK 1991, PADISÁK et al. 1984). Recently the

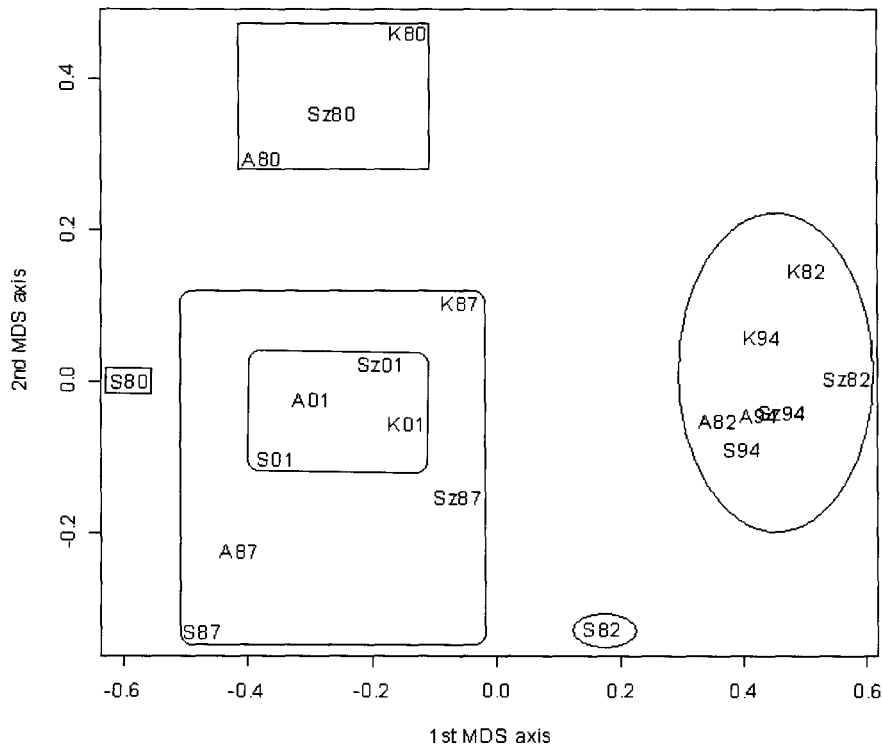


Fig. 1. Multidimensional scaling (MDS) of the algae assemblages of Lake Balaton during the studied years. Notations: S – Siófok-basin, A – Akali-basin (or Szemes-basin), Sz – Szigliget-basin, and K – Keszthely-basin.

cyanobacteria, and especially the dynamics of *Cylindrospermopsis raciborskii*, was studied (PADISÁK 1997).

The Shannon diversity of the algae assemblages was much lower during the algae bloom due to the overwhelming dominance of one or two cyanobacterium species (Fig. 3). In 1982 and 1994, the years of algae bloom, the diversity was just the half or less than in 1980, when the water quality state was good.

Acknowledgements

We are grateful to the Central Trans-Danubian Inspectorate for Environmental Protection providing the facilities and laboratory equipments. We are indebted for free availability of the data in the data set of the authority.

References

- BÍRÓ, P. & VÖRÖS, L., 1982: Relationships between phytoplankton and fish yields in Lake Balaton. – *Hydrobiologia* **97**: 3–7.
- DÉVAI, Gy., 1992: Vizminőség és ökológiai vízminőség. [Water quality and ecological water qualification.] – *Acta Biol. debrecina, Suppl. Oecol. Hung.* **4**: 240 pp.
- HERODEK, S., 1984: The eutrophication of Lake Balaton: Measurements, modeling and management. – *Verh. Internat. Verein. Limnol.* **22**: 1087–1091.
- LEGENDRE, P. & LEGENDRE, L., 1998: *Numerical Ecology*. – Elsevier Science, Amsterdam, The Netherlands.
- PADISÁK, J., 1997: *Cylindrospermopsis raciborskii* (Woloszynska) Seenaya et Subba Raju, an expanding, highly adaptive cyanobacterium: worldwide distribution and review of its ecology. – *Arch. Hydrobiol./Suppl.* **107** (Monogr. Studies): 563–593.
- PADISÁK, J., G.-TÓTH, L. & VÖRÖS, L., 1984: *Anabaenopsis raciborskii* Wolosz. bloom in Lake Balaton in the summer and autumn of 1982. – *BFB-Bericht* **51**: 77–81.

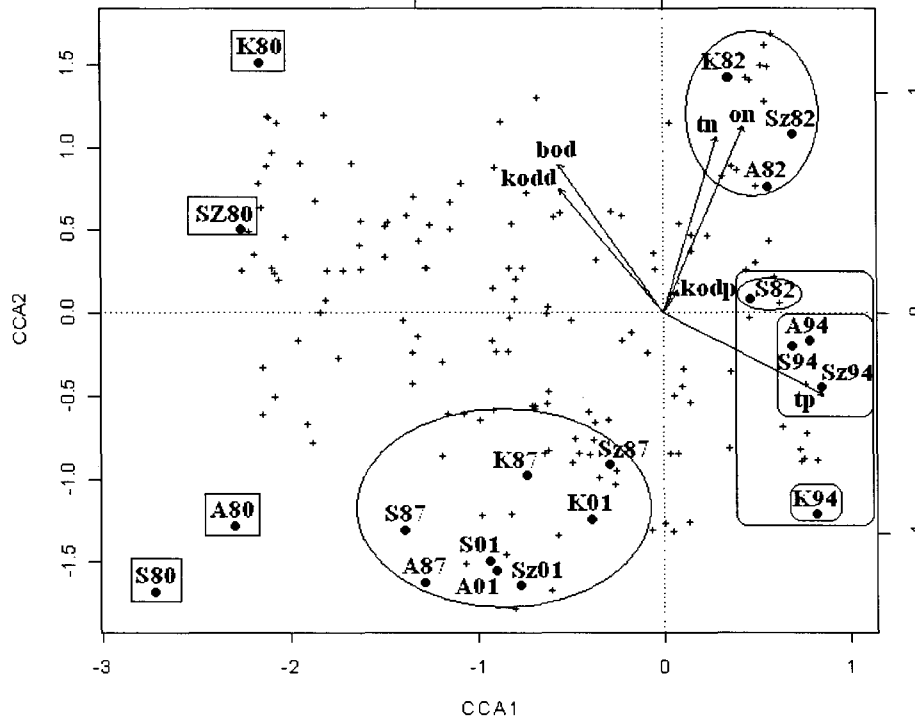


Fig. 2. Canonical correspondence analysis of the algae assemblages of the basins of Lake Balaton and the trophic and saprobic parameters. Notations: cp – chemical oxygen demand with potassium permanganate, cd – chemical oxygen demand with potassium dichromate, bod – biological oxygen demand, on – organic nitrogen, tn – total nitrogen, tp – total phosphorous, ca – chlorophyll-*a*, ac – algal count, ab – algal biomass. + signs denotes the algae species.

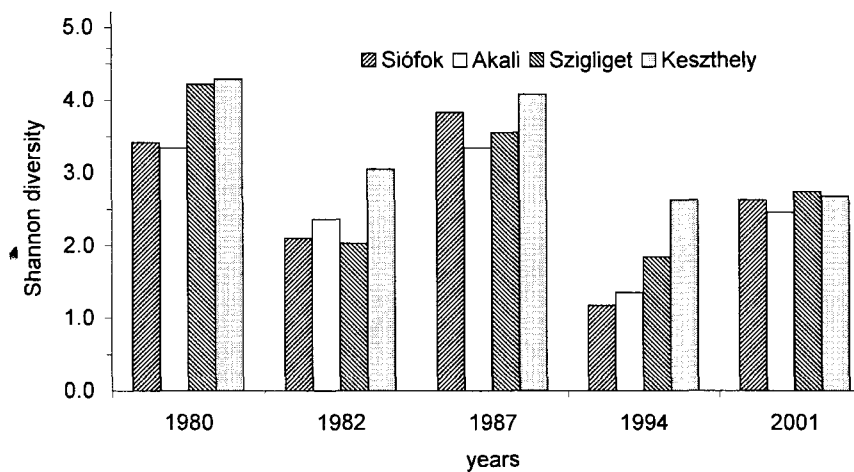


Fig. 3. Shannon diversity of the algae assemblages of the four basins of Lake Balaton during the studied years.

- R. Development Core Team, 2004: R: A language and environment for statistical computing. – R Foundation for Statistical Computing, Vienna, Austria. (<http://www.R-project.org>)
- SOMLYÓDY, L., 1986: Eutrophication management models. – In: SOMLYÓDY, L. & VAN STRATEN, G. (Eds.): Modeling and managing shallow lake eutrophication. With application to Lake Balaton: 69–109. Springer Verlag, Berlin.
- VÖRÖS, L. & PADISÁK, J., 1991: Phytoplankton biomass and chlorophyll-a in some shallow lakes in Central Europe. – *Hydrobiologia* **215**: 111–119.
- VÖRÖS, L. & NAGYGÖDE, P., 1993: Long-term changes of phytoplankton in Lake Balaton (Hungary). – *Verh. Internat. Verein. Limnol.* **25**: 682–686.
- Authors' address:
G. KISS, Central Trans-Danubian Inspectorate for Environmental Protection, P.O. Box 137, H-8000 Székesfehérvár, Hungary.
E-mail; kisgabor@freemail.hu
Gy. DÉVAI, Department of Hydrobiology, University of Debrecen, P.O. Box 57, H-4010 Debrecen, Hungary.
B. TÓTHMÉRÉSZ, Ecological Institute, University of Debrecen, P.O. Box 71, H-4010 Debrecen, Hungary.
A. SZABÓ, Middle-Tisza Regional Environmental Inspectorate, Ságvári krt. 4, H-5000 Szolnok, Hungary.