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Long-term changes of phytoplankton in the northeastern Siófok Basin of Lake Balaton, Hungary, between 1933 and 1994

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Lake Balaton, like many other large lakes, underwent a rapid eutrophication during the 1960s-1970s. Its phytoplankton community was originally dominated by diatoms (*Cyclotella, Aulacoseira*) and dinoflagellates (*Ceratium*). Parallel with the eutrophication heterocytic blue green algae, especially *Cylindrospermopsis raciborskii*, became increasingly important. The restoration project that started in the eighties and as a result of which the P-load of the lake significantly decreased, has so far not resulted in a decrease in phytoplankton biomass.

KEYWORDS: eutrophication, restoration, phytoplankton, *Cylindrospermopsis*

INTRODUCTION

Lake Balaton is the largest shallow lake in Central Europe. The elongated lake (length: 77.9 km; average width: 7.2 km) has a surface area of 593 km^2, and has a mean depth of 3.14 m (maximum: 11 m). The theoretical retention time is 3-8 years. The catchment area of the lake is 5182 km^2; the Zala River itself drains an area of 2622 km^2. As a result of the increased phosphorous load, the originally mesotrophic lake underwent rapid eutrophication that began in the 1960s-1970s (Herodek, 1984). Because the majority of the nutrient load is received by the western basin, a sharp trophic gradient developed in the lake: the western part is hypertrophic, while the eastern is still meso-eutrophic. Between 1975 and 1981 the total phosphorus load was estimated as 2.47 g m^{-2} $year^{-1}$ in western part of the lake, and 0.31 g m^{-2} $year^{-1}$ in the eastern part (Somlyódi & Jolánkai, 1986).

In the early 1980s a large scale management program has started to slow down and reverse eutrophication of the lake. This included, among others, (1) the elimination of the most dangerous point-like sources; (2) establishing a more efficient sewage treatment together with a sewage transfer system around the eastern part and (3) the construction of two protecting reservoirs on the western tributaries. So far the program has resulted in about 40 % reduction of the biologically available phosphorus load of the lake [3].

This paper describes the phytoplankton changes between 1933 and 1994 in the meso-eutrophic Siófok Basin of the lake; namely
i) long term trends of change;
ii) floristic changes that were observed in the last 60 years and

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iii) the recently (1982-1994) observed sharp interannual variation in phytoplankton biomass with special attention to *Cylindrospermopsis raciborskii* WOLOSZ., a key species in the lake.

SOURCE OF THE DATA

Phytoplankton of the northeastern part of the lake has been quantitatively studied since 1931. Data between 1931 and 1975 are available in publications that are listed in Padisák & G.-Tóth (1991). Since 1982 biweekly samples are taken by the Water Authority (Székesfehérvár). The author's own data are based on weekly samplings and they are continuous since 1989. Phytoplankton (except for very early studies) were counted by the standard inverted microscope method; biomass data are based on geometric estimations. This work was supported by the Hungarian Science Foundation (OTKA-6285).

RESULTS AND DISCUSSION

i) Long-term quantitative changes

In the meso-eutrophic Tihany region of the lake annual average biomass started at several hundreds of $\mu g\ l^{-1}$ in the early decades of the century; similar data were recorded in the middle sixties (Fig. 1). Then a trend like increase began up to several thousands $\mu g\ l^{-1}$. Beside the overall increasing tendency there are characteristic pulses (1982, 1992, 1993, 1994) in phytoplankton biomass. Three of them (1982, 1992, 1994) can be attributed to *Cylindrospermopsis raciborskii.* In May 1993 an unusual bloom of *Dinobryon sociale* EHR. occurred as a chance event (Reynolds et al. 1993).

ii) Floristic and compositional changes

Until the middle seventies *Cyclotella radiosa* (W. SMITH) LEMM. and occasionally *Fragilaria tenera* (W. SMITH) LANGE-BERTALOT dominated in the spring bloom and by late summers *Aulacoseira granulata* (EHR.) SIM., *A. granulata var. angustissima* (O. MÜLLER) SIM. and *Ceratium hirundinella* (O. F. MÜLLER) BERGH became dominant. Blue-green algae did not dominate the late summer phytoplankton and they were mostly coccal species, like *Snowella lacustris* KOM. & HIND. New species of heterocytic blue-green algae appeared in the flora in the early seventies especially in the western part of the lake then they slowly penetrated to the NE Basin. Their contribution to total biomass showed an increasing tendency from the middle seventies on, however, *Ceratium* remained dominant (Fig. 2a, b). *Cylindrospermopsis raciborskii,* a heterocytic blue-green alga of subtropical origin, was first found in 1978 and became soon a key species in whole lake area.

iii) Development of Cylindrospermopsis blooms

Cylindrospermopsis raciborskii bloomed moderately in the SW basin in 1979. In 1982, a heavy *Cylindrospermopsis* bloom swept through the whole lake. Since that time the species appeared in the plankton each year and almost invariably bloomed in the SW basin late summers (Padisák, 1994). Comparable blooms were observed in the NE basin in 1992 and in 1994.

The year, 1982, when *Cylindrospermopsis* bloomed first in the lake was a meteorologically exceptional year. Unusually heavy rainfalls occurred in July and in the first part of August, then the weather was very calm and warm until October. The meteorological background is analyzed in detail in G.-Tóth & Padisák (1986). In the cited reference, a similarly important role was attributed to the preceding rainfalls which were supposed to increase the external nutrient load of the lake. The 1982, 1992 and 1994 *Cylindrospermopsis* blooms were very similar with the notable difference that the bloom developed quicker in 1992. In 1994, the development occurred both sooner and quicker.

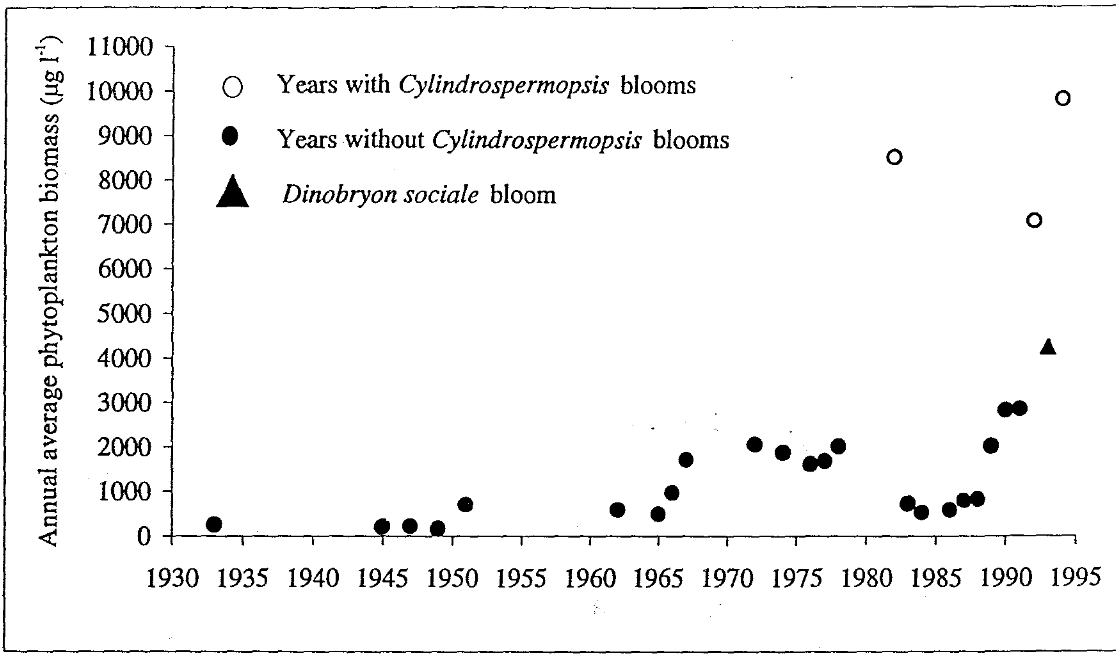

Fig. 1: Annual average phytoplankton biomass in the northeastern Siófok Basin of Lake Balaton between 1933 and 1994

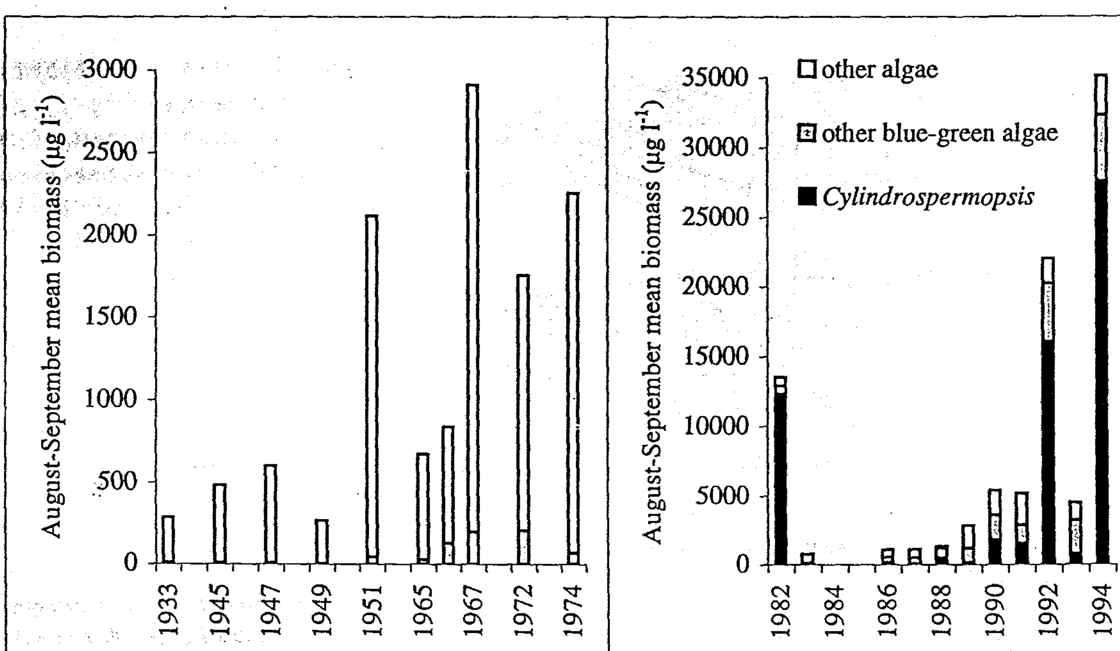

Fig. 2: August-September average phytoplankton biomass in the northeastern Siófok Basin of Lake Balaton between 1933 and 1974 (a) and between 1982 and 1994. Symbols on panel (b) apply to both graphs.

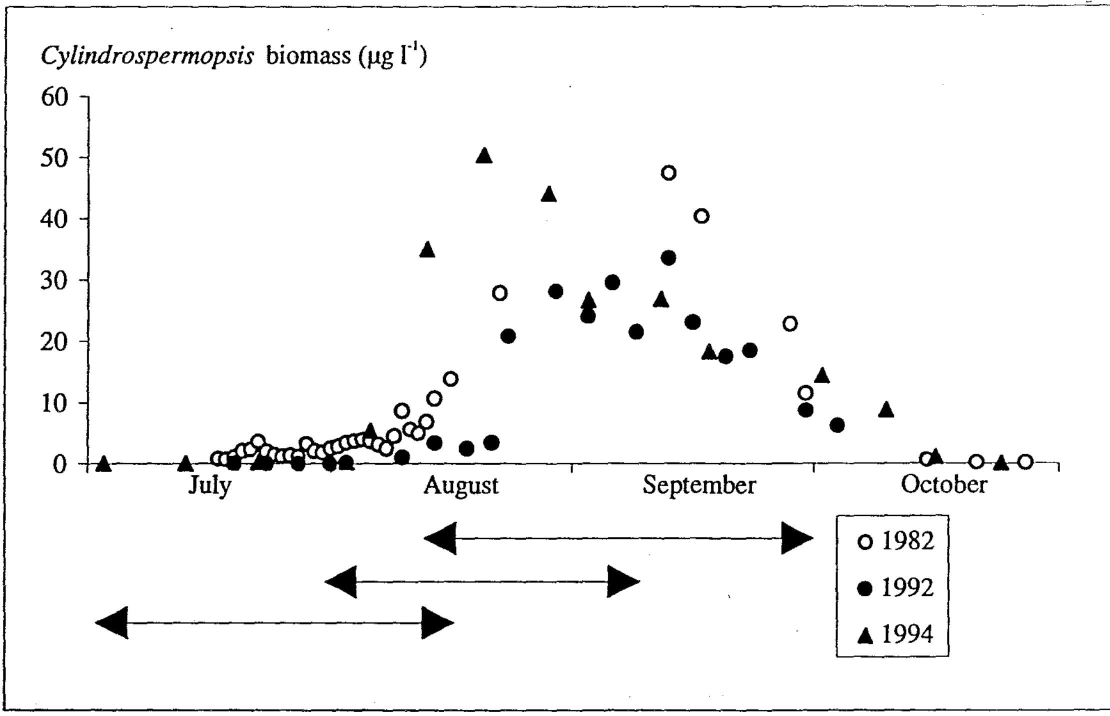

Fig. 3: Biomass (µg l^{-1}) of *Cylindrospermopsis raciborskii* in July-October of 1982, 1992 and 1994. Arro indicate the beginning, the end and the extension of long, calm weather

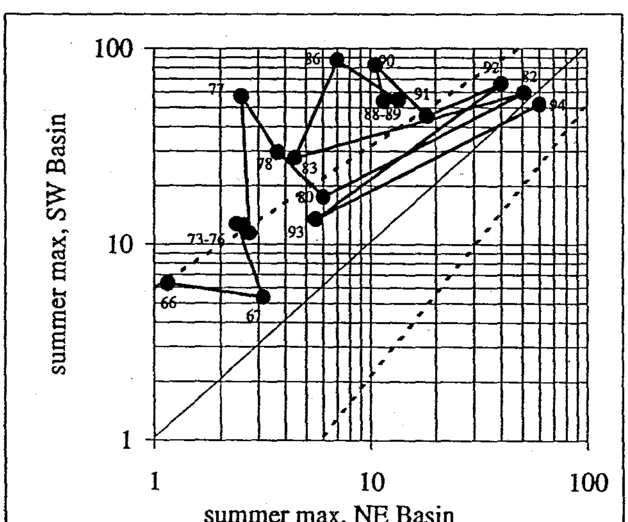

Fig. 4: Summer maxima of phytoplankton biomass (mg l^{-1}, log-log scale) in the NE and SW basins of Lake Balaton. Dotted lines provide the range within which the difference is less than five-fold

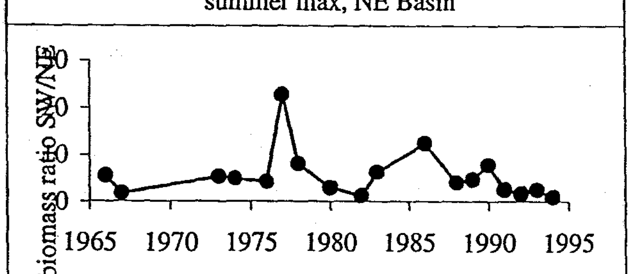

Fig. 5: Summer maximal phytoplankton biomass in the SW basin divided by that in the NE basin of Lake Balato between 1966 and 1994

The net increase rate of the population was 0.17 d^{-1} in 1982, 0.24 d^{-1} in 1992 and 0.32 d^{-1} in 1994 (Fig. 3). The weather prior to and during the 1992 and 1994 bloom was even calmer and warmer than in 1982 supporting the principal role of warm weather in the development of the *Cylindrospermopsis* blooms. Laboratory experiments (Gorzó, 1987) showed that *Cylindrospermopsis* akinetes have a high and narrow (~ 22-24 ^{o}C) temperature optimum of germination so that under natural conditions in Lake Balaton high temperature is the key stimulus of *Cylindrospermopsis* blooms.

In 1992 and in 1994 no heavy rainfalls occurred prior to the water blooms. Increasing evidence substantiates that the nutrient demand of the growth can rather be found in the internal nutrient, especially phosphorous, recycling between the open water and the sediment of the lake than in an increased external load. Boström *et al.*, concluded that migration into the water column of bottom dwelling blue-green algae (e.g. overwintering *Microcystis*) moves significant loads of intracellular N and P out of the sediment. P-uptake experiments in *Gloeotrichia echinulata* (J. E. SMITH) P. RICHTER showed (Istvánovics et al. 1993) that P assimilation and growth are completely separated both in time and space: growth was preceded by benthic P assimilation; the epilimnetic growth was based ultimately on internally stored phosphorus. Other observations also indicate a similar life strategy of *Cylindrospermopsis*.

At the beginning of the eutrophication relationship between the external P load phytoplankton biomass fitted well to the Vollenweider model. The restoration management significantly reduced the P-load. Recent analyses (Istvánovics et al. in prep.) on the relationships between P loading and algal biomass in the hypertrophic SW basin of the lake found the two variables uncoupled indicating that phytoplankton biomass is no longer P-limited; both N and light limitations are of increasing importance. Originally, no higher than 5-fold difference was observed between the summer maximal algal biomass in the NE and SW basins (Fig. 4, Fig. 5). In the 1970s-1980s considerable difference was found between the two parts of the lake, with few exceptions. Since 1991 on the difference remained below five-fold continuously. These decrease in difference in summer peaks seem to predict an increasing homogenization throughout the lake.

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