Seasonal and long-term trends in phytoplankton as a function of P and N loads in shallow Lake Balaton.

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Rapid eutrophication of large (600 km^2), shallow (3.2 m) Lake Balaton has been reversed by a set of large-scale management measures (sewage diversion, P removal from sewage, pre-reservoir construction on the largest tributary, the Zala River; etc.) taken during the late 1980ies. Further load reduction resulted from the collapse of agriculture after 1989 and from lasting droughts (e.g. 2000-2004). The trajectory of eutrophication and recovery has been tightly followed in Basin 1 of Lake Balaton (38 km^2). The Zala River (catchment area 2500 km^2) carries about 30% of the total nutrient loads of the whole lake to this basin.

We present seasonal and long-term changes in the biomass and composition of phytoplankton (weekly to biweekly data) as a function of external nutrient loads (daily data) in Basin 1. Where adequate, we consider both the results of experimental work concerning in-lake N and P cycling and high frequency field data of phytoplankton and relevant physical conditions. Our conclusions that may apply to other shallow, temperate lakes are as follows:

1. P, N and light limitation of algal growth shows dynamic, unpredictable variability. In contrast to this, limitation of the maximum biomass (carrying capacity) is more predictable. In spring, N or P limitation prevails depending on the external N and P loads. In summer, the carrying capacity is P determined.

2. Internal loads of both P and N are key components in satisfying algal nutrient demand during summer.

3. Yearly mean biomass of phytoplankton decreased by a factor of about 3 in the post-management period. Duration of the high-biomass summer period also decreased significantly. Nevertheless, the share of N_2-fixating cyanobacteria did not change much (up to 90-95% in the summer and 30-40% on a yearly basis). This may be due to the molar ratios of external NO_3-N to PO_4-P well below the Redfield ratio during summer (5 and 1 before and after inundation of a reed-dominated anaerobic wetland area at the mouth of the Zala River, respectively).

4. Although low N:P loading ratios are thought to provide competitive advantage to cyanobacteria as also observed in Lake Balaton, the relationship is not as straightforward as it may seem. Thus, N_2-fixation is rarely a major source of N for cyanobacteria in Basin 1 since fixation has high energy demand and ammonium uptake affinity of the dominant cyanobacteria exceeds that of other phytoplankters. High temperature, low light availability and pulsed nutrient supply also select for N_2-fixing cyanobacteria. These selective forces prevail during the summer while the need for atmospheric N is restricted to the periods of exceptionally high growth.