What are the differential consequences on components of a planktonic food web induced by in-lake restoration of a shallow urban seepage lake?

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Introduction

The aim of restoration of the oxbow-lake Alte Donau in Vienna heavily used for recreation was the reduction of internal phosphorus dynamics because of unwanted cyanobacterial blooms, in this case of *Cylindrospermopsis raceborski* SEENAYYA et SUBBA RAJU (MAYER et al. 1997, DOKULIL & MAYER 1996). The restoration according to the RIPLOX-technique (RIPL & FEIBICKE 1992, RIPL 1994) started in 1995 and was done in two steps: $FeCl_3$- solution to precipitate phosphorus (3.4.-5.5.1995 and 1.4.-14.5.1996) and $Ca(NO_3)_2$-solution for oxidation of the sediment (22.5.1995 and 23.5.96, for details refer to DOKULIL et al. 1998). The aim of the present study is to describe the extent and the quality of the modification brought about by the restoration on different pelagic communities. Therefore the changes of functional and taxonomical groups within and between plankton assemblages before the restoration (1994) were compared with the situation after treatment (1995/96).

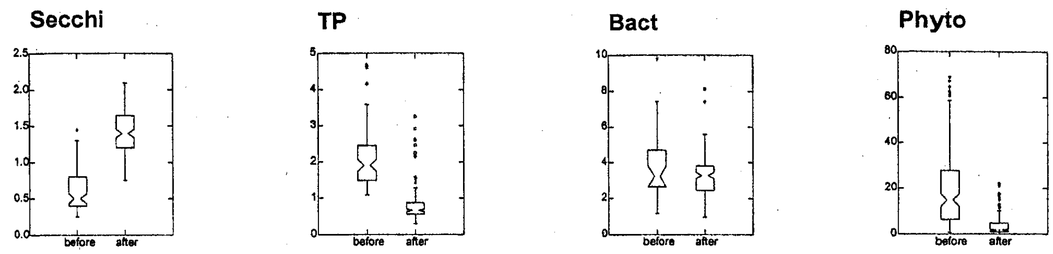
Materials and methods

The lake restored is the Alte Donau, an oxbow lake of the river Danube within the city of Vienna. Samples were taken at biweekly intervals at two, three or five stations from 1994-96. For details of investigation techniques refer to MAYER et al. (1997) and DOKULIL et al. (1998).

Discriminant analyses are based on seasonal averages: (spring: March-May, summer: June-August, autumn: September-November, winter: December-February). Logarithmic data were standardised for multivariate statistical analyses (HENRION & HENRION 1995) using the computer program STATGRAPHICS plus 3.0 (STSC, inc. USA). Triangular diagrams (Fig. 4) based on annual averages were created in GRAPHER for Windows 4.0, Golden Software, Inc. Each point indicates a ratio of the three components at the corner and represents the sum of the components equal to 100% (e.g. carnivorous crustaceans+herbivorous crustaceans+rotifers=100). The corners of the triangle represent one component only (100%) and the absence of the remaining two components. To overcome strong clustering of points because large differences in the amounts of the three components, data were normalised according to: $c_{norm} = \frac{c}{\sum_{i=1}^{n} c_i}$. After normalisation points become more scattered and are easier to distinguish, but the ratios can not be read directly. It is, however, possible to recalculate these original ratios. Because of normalisation it is possible to compare variations of variables with different dimensions (e.g. carbon content of bacteria with biovolume of phytoplankton, Fig. 4 A) in the same way like components with identical dimensions (assuming that calculation from one to another dimension would be done by a constant). For further complex calculations in normalised triangular diagrams refer to TEUBNER (1996, 1998).

Results

Restoration resulted in significant reduction of total phosphorus in the pelagic zone, accompanied by a significant increase of secchi depth (non-overlapping of the notches in Fig. 1). While the phytoplankton biomass was significantly reduced the heterotrophic bacteria remained at about the same level. Accordingly autotrophic primary production was strongly reduced, whereas only a small decline in bacterial production was observed. This resulted in a lower PP:BP ratio after the start of the restoration in spring 1995 (Fig. 2). As a consequence the relative contribution of heterotrophic bacteria to the total grazable biomass increased because of the drastic reduction of phytoplankton. The detailed relation between the biomass of Phycophyta, Cyanobacteria and heterotrophic bacteria is shown in Fig. 3 A. A clear dominance of Cyanobacteria were measured for 1994 (points near the corner Cyano), whereas constant low cyanobacteria prevailed in 1995-96 (points arranged



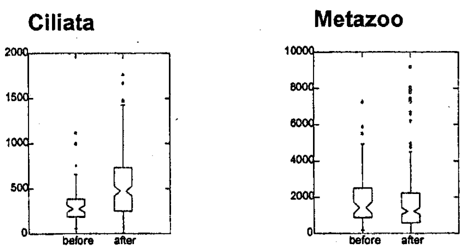


Fig. 1: Notched Box-Whisker plot for Secchi depth [m], total phosphorus [TP in µmol l^{-1}], phytoplankton [mm^3 l^{-1}], heterotrophic bacteria [10^3 l^{-1}], ciliates and metazooplankton [µg l^{-1}] before and after start of restoration. The length of the notches indicate 95% confidence intervals, the narrowed notches the median. Data : n= 256 (TP, secchi depth), n=262 (phytoplankton, ciliates, metazooplankton), n= 188 (het. bacteria).

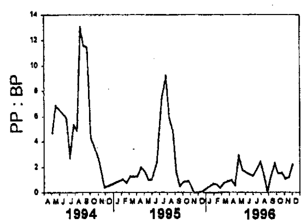
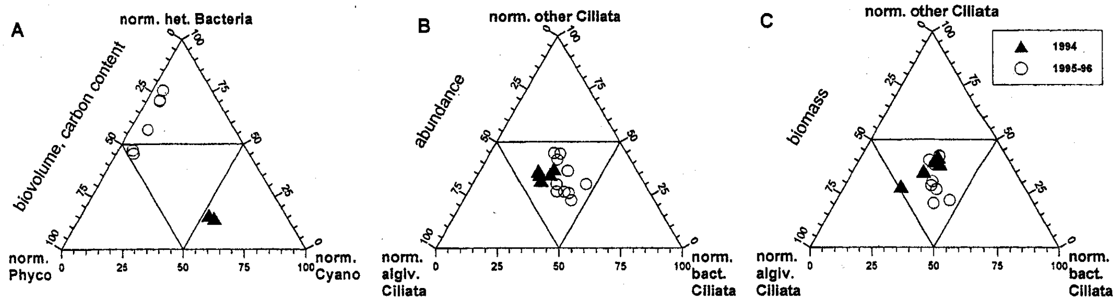


Fig. 2: Ratio of autotrophic primary production (PP) to bacterial production (BP) for the year before (1994) and after the start of restoration (1995-96).
PP and BP in g C m^{-2} d^{-1}.



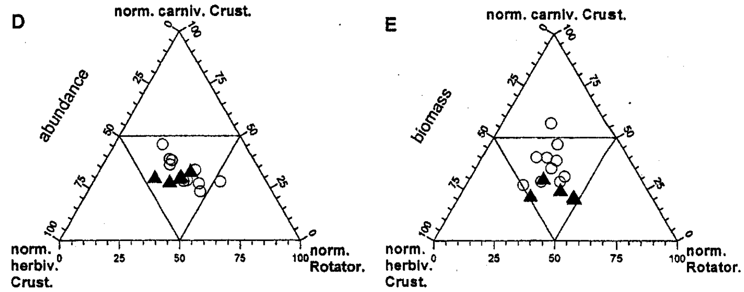
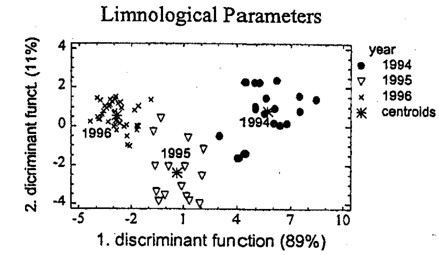


Fig. 3: Triangular diagrams for proportions of components within biomass of Phyto-Bacterioplankton (A), abundance and biomass of ciliates (B-C) and metazooplankton (D-E) before (1994) and after start of restauration (1995-96).

All data normalised (see method), components: A: heterotrophic bacteria (in carbon content), Phycophyta and Cyanobacteria (in biovolume), B-C: Ciliata: exclusively algivores & bacterivores, the remaining "other", D-E: metazooplankton: carnivorous, herbivorous crustaceans, Rotatoria. Sum of components ($\sum_{i=1}^{n} \text{component}_i$) for recalculation of ratios: A: het.Bact.=488 carbon content µg l^{-1}, Phyco=33 mm^3 l^{-1}, Cyano=25 mm3 l^{-1}, B-C: algiv. Cil.=251247 indiv. 10^3 l^{-1} or 2345 µg l^{-1}, bact. Cil.=168725 indiv. 10^3 l^{-1}or 759 µg l^{-1}, oth. Cil.=157830 indiv. 10^3 l^{-1} or 3287 µg l^{-1}, D-E: (carn. Crust.=513 indiv. 10^3 l^{-1}or 10340 µg l^{-1}, herb. Crust.=2777 indiv. 10^3 l^{-1}or 3654 µg l^{-1}, Rotat.=12527 indiv. 10^3 l^{-1}or 1607 µg l^{-1}).

criteria	o. s. r. (%)
limnological parameters	97
algal classes	96 (96)
morphotypes of heterotr. bacteria	83 (88)
taxonomical groups of ciliates	67 (75)
tax. groups of metazooplankton	62 (65)



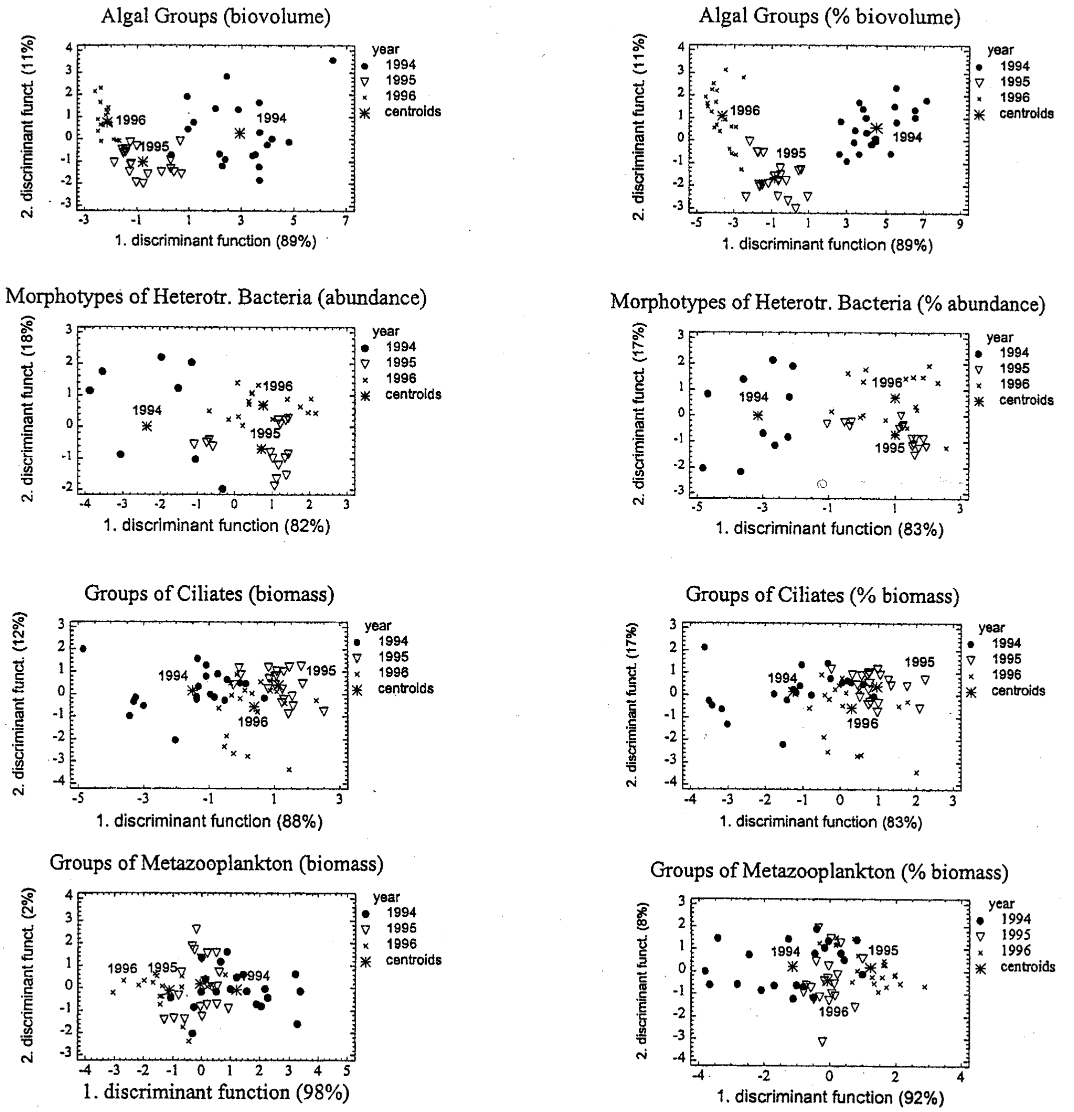


Fig. 4: Discriminant analyses to visualise differences between years 1994-96 according to various criteria: limnological parameters (Secchi depth, inorganic seston, chlorophyll-a, particulate-N and -P, dissolved organic-N and -P, PO_4-P, soluble reactive Si), heterotrophic bacteria (coccoids, filaments, rods, vibrios), phytoplankton (Cyanobacteria, Bacillario-, Dino-, Crypto-, Chryso-, Chloro-, Euglenophyceae), Ciliates (Haptorida, Hymenostomata, Oligotrichida, Peritrichia, Prostomatida) and metazooplankton (Calanoida, Cyclopoida, Cladocera, Rotatoria). A high overall success rate (o. s. r. in table) and separation of the point sets of the three years (graphs) indicate a distinct situation from year to year.

Table: for planktonic organisms the % of the overall success rate is given twice: for absolute and for relative amounts (the last in brackets). Corresponding graphs are the plots of the second versus first discriminant function (percentage of variance accounted for by each discriminant function in brackets on the axis).

along the axis of het.bacteria:Phyco) at increased contributions of heterotrophic bacteria (point near by the corner het. bacteria). The Cyanobacteria contributed at least 50 % of total biovolume at any seasonal averages before 1994 (annual average 60-80%), but only 10-15 % of annual averages after restoration. The biomass of ciliates was significantly increased with restoration whereas the biomass of metazooplankton (crustaceans and rotifers) marginally decreased (Fig. 1). The comparison of functional groups, however, shows a general tendency of declining abundance and biomass of algivores or herbivores in relation to the remaining groups (Fig. 3 B-E).
Ciliate species exclusively feeding on bacteria tend to increase in both numbers and biomass whereas in the Metazooplankton the biomass of carnivorous individuals increase (indicated by the position of points close the respective corner). Although the abundances of both carnivores and rotifers increased (Fig. 3D) the biomass of carnivores was much more affected because of their body size (Fig.3E).
Changes of limnological parameters and taxonomical groups within pelagic communities are shown via discriminant analysis in Fig. 4. The overall success rate for predictions of membership of the grouping variable's categories (= three years 1994-96) developed in this analysis is shown in the Table inserted in Fig.4. If the samples taken in 1994, for example, are predicted for the category 1994 a correct classification is given. In the case of limnological parameters a high number of the samples was correctly classified (97 %). This implies, that years characterised by limnological parameters are distinctly different (parameters see caption of Fig. 4). This is in accordance with separation of point sets for the three years in the plot of the two discriminant functions (Fig. 4) and the significance of changes of a lot of limnological parameters during restoration (e.g. Secchi depth and TP in Fig. 1, chlorophyll-a). The highest overall success rate between the planktonic communities is calculated for phytoplankton (96 %, see also separation of point sets of years in the plot). This result is due to the rapid decline of the cyanobacterial bloom and the re-establishment of various algal classes, mainly of the diatoms, green algae and cryptophyceans. Pelagic communities are sorted according to decreasing overall success rate in the Table in Fig. 4. Correct classification decreased from phytoplankton, through morphotypes of heterotrophic bacteria and taxonomic groups of ciliates down to metazooplankton.

Discussion and Conclusions

The restoration, focussed on reduction of internal phosphorus load, primarily effected the phytoplankton. Biomass reduction was accompanied by qualitative changes from cyanobacterial dominance to a mixture of many algal classes. To a lesser degree the composition of morphotypes of heterotrophic bacteria was influenced. Changes of taxonomical composition of ciliates and metazooplankton were minimal. Whereas taxonomical changes in the community structure imply alterations of physiological adaptations and strategies in phytoplankton, ciliates and metazooplankton, variation of morphotypes of heterotrophic bacteria remain unclear. Nevertheless, although the absolute biomass of heterotrophic bacteria were more or less unchanged, their relative contribution increased in relation to the strongly declined algal biomass. Therefore after restoration the bacteria became more important as alternative prey organisms. As a consequence the ciliate biomass increased and within the ciliate community the bacterivorous species were favoured. The higher biomass of carnivorous individuals of crustaceans during restoration could be seen as response to the increased ciliate biomass.

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