Limnological characteristic of an artificial swimming pond system treated with "effective microorganisms" (EM)

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The study describes the limnological background of water bodies of an artificial swimming pond system (Eco-Camp Eggerding in Upper-Austria) treated with 'effective microorganisms' (EM). According to HIGA and PARR (2007) the cell suspension of EM is a mixture of microorganisms composed mainly of lactic acid bacteria and yeasts, while photosynthetic bacteria, actinomycetes and other types of microorganisms are less abundant. EM was added weekly to the retention pond cascades of the water network system connected to the swimming ponds. Measurements of physiochemical and biological parameters were conducted for two swimming ponds (maximum depth of 5-6 m) and one cascade of retention ponds. Samples were taken in a three-week interval from May to September 2005 during bathing season. Compared to natural lakes the artificial ponds can be described as environments of a mesotrophic to eutrophic state. The transparency of water was good. According to the high water transparency measured by underwater light profiles and Secchi depth we calculated a euphotic layer of 10 m on average. This euphotic zone describes the water surface layer where sufficient light is available for algal photosynthesis. Since the euphotic depth of 10 m exceeds the maximum morphometric depth of 6 m, the photosynthetic oxygen evolution by algae is generated from the surface to the bottom sediment layer in the swimming ponds. We assume that the enhanced availability of ortho-phosphate for plant growth were due to amplified microbial activity by EM in addition to naturally occurring heterotrophic organisms in the swimming pond system. The heterotrophic microorganisms are important for cycling organic- and particulate-bound phosphorus into inorganic phosphorus (e.g. ortho-phosphate). We found evidence for enhanced nutrient cycling during EM-treatment by the following three observations. 1: The sediment layer (sludge at bottom) accumulated during years with EM-treatment was more shallow than compared with earlier years without added EM (personal observation reported by the owner of the swimming pond system). 2: The enhanced phosphorus availability coincided with a high ratio of chlorophyll-a concentration per total phosphorus of the water column. Chlorophyll-a is a rough estimator for the algal biomass while total phosphorus is a common parameter measuring a variety of phosphorus components in the water volume. Hence, a high ratio of chlorophyll-a to total phosphorus indicates that a relative high portion of the total phosphorus pool was available for algal growth and hence utilised by planktonic algae. This phenomenon of efficient phosphorus utilisation by algae is commonly described in mesotrophic lakes where phosphorus is limiting the algal growth in the water column. 3: The algal community structure (phytoplankton) indicates again the high efficiency of phosphorus utilisation by algal growth during summer. The summer plankton in the swimming ponds was dominated by needle shaped and small cell forms. These cells are characterised by a relative high surface to volume ratio and are representative for fast growing species during periods of initial phases of high phosphorus availability.

The success in maintaining the water quality of the swimming pond system by treatment with EM, however, seemed to be achieved only in combination with another accompanying treatment. This second treatment was aimed to remove phosphorus initially mobilized by EM and hence

available as phosphorus nutrient source for growth of algae in the swimming pool system. This step was accomplished by growing and harvesting filamentous green algae in the cascades of retention ponds. We could show that phosphorus in these retention ponds was mainly allocated to the filamentous green algae of the genera *Cladophora*, *Zygnema* and *Spirogyra* while microalgae of the plankton community developed only low biomass. Furthermore, the effect of binding phosphorus by filamentous algal mats was enhanced by the P-uptake capacity of phytobenthic algae. These harmless mats of green algae in the retention ponds are settled by other microbial diatoms that increased the portion of phosphorus taken up. We emphasise that regular harvesting of biomass of these macroalgae and attached phytobenthic community is the decisive guarantor maintaining the high water quality in the EM treated artificial swimming pond system. In other artificial systems biomass of primary producers were usually removed by harvesting macrophytes (aquatic plants). It is worth notifying that the time schedule for harvesting macroalgae has an advantage compared to macrophytes. Biomass removal of macroalgae can be performed continuously during bathing season in summer. In contrast harvesting of aquatic plants only makes sense in fall.

Figure 1. Swimming pond T2 with a shallow basin for children (the two left pictures) and the view to the local bistro. The right panel shows clear water in detail at the beginning of bathing season by the end of June.

Short description of results

The artificial swimming pond system in Edenaichet near Eggerding in Upper Austria is operated by Felix Hingsamer as “Eco-camp”. The system consists of three swimming ponds and a number of cascades of retention ponds. On sunny, on-season days up to 1,300 visitors are counted (http://www.oekocamp.at/folgeseiten/index2.html). The limnological measurements were conducted in a three-week interval from May 19th to September 22nd, 2006, during bathing season. Samples were taken from two ponds (T2 and 3) and one cascade of the retention ponds (RB2) shown in figure 1 and 2. The "effective microorganisms" (EM) were incubated in form of a living cell suspension into the retention ponds once a week since April 2006 and during the investigation period. The EM are part of the regenerative microorganisms preventing anaerobic sediment conditions. These microorganisms contribute to decompose sludge by nutrient cycling and hence make nutrients available again for algae growth. The aim of the study was to describe an artificial swimming pond system treated with EM by its limnological characteristic. Furthermore, these described effects of EM treatment will be compared with plankton communities and nutrient cycling in natural waters.

Figure 2. Aerial view with investigated ponds T2 to T3 and cascade of retention ponds RB 2 (photo: July 2005).

Figure 3. Cascade of retention ponds. The right picture shows the gravel-sand bedding.

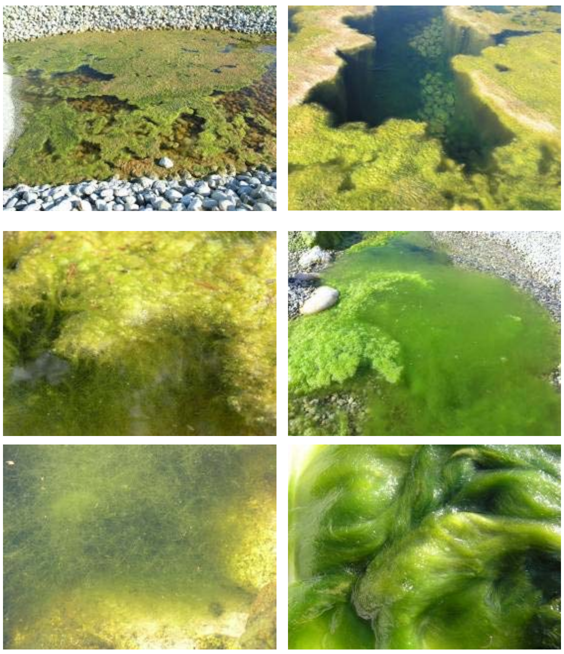

Figure 4. Growing of filamentous macroalgae in the retention ponds. The fresh biomass per volume water was up to 100-fold higher for filamentous green macroalgae in the retention ponds than for plankton microalgae in the swimming ponds. The mats of macroalgae were regularly harvested to remove phosphorus from the water network system. About 87 mg of phosphorus per retention pond were removed by harvesting the total biomass of macroalgae covering 65-80 % of the surface of a retention pond. The treatment of EM enhanced the growth of macroalgae in the retention basins. Microscopical pictures of the filamentous macroalgae are shown in figure 5.

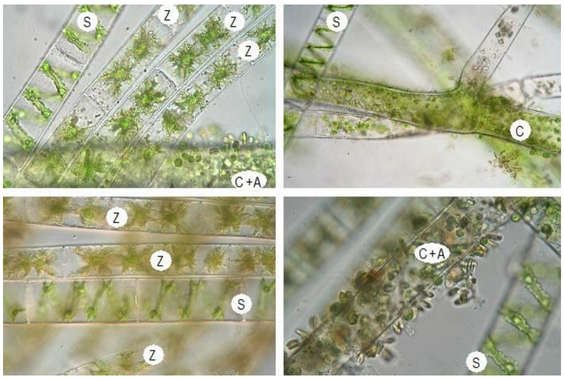

Figure 5. The mats of filamentous macroalgae of the retention ponds were species of the three genera *Zygnema* (Z), *Spirogyra* (S) and *Cladophora* (C). These green algae are harmless since they cannot form any algal toxins. The growing and harvesting of these algal mats were aimed to remove phosphorus from the artificial swimming pond system (see details in figure 4). Some filaments are covered by benthic microalgae (C+ A), which also bind phosphorus building up biomass. It is adventageous to grow and harvest macroalgae rather than macrophytes (aquatic plants), since macroalgal biomass can be removed during bathing season. Harvesting of aquatic plants only makes sense in fall. *Microscopic photos by Charlotte Wöber*.

Weak thermal summer stratification was observed for the two swimming ponds with a maximum depth of 5-6 m. The maximum temperature difference along the water column was just 0.5° degrees Celsius. Consequently only a weak enrichment of nutrients at deeper depth layers was observed during summery stratification. According to stratification, the concentrations of total phosphorus (TP) were 1.3-fold higher in the deep-water layer than in the surface layer (epilimnion). Correspondingly we measured 1.35-fold higher concentrations of soluble reactive silica (SRSi) at deeper strata than near the surface. The concentrations of nitrate in deeper layers, however, corresponded to those of the surface water. The mean euphotic zone is defined as the water layer of efficient photosynthesis and was on average 10 m deep (maximum of 14 m). The euphotic depth was calculated from measured underwater light profiles. This value of 10 m theoretically exceeds the actual water depth of 5-6 m. Even if the water basins were twice as deep, the transparency of water is so high that photosynthesis would still be possible at the bottom of the pools. The annual mean of Secci depth was 2.8-2.9 m in both swimming ponds and 3.1 m in summer. From the fact of good water transparency the swimming ponds are therefore classified as mesotrophic.

Figure 6 shows the relationship between plankton algal biomass (measured by the pigment chlorophyll which is ubiquitous in all freshwater algae) and the total phosphorus pool. The data are shown for the artificial swimming ponds and lakes. It is clearly shown that a higher portion of phosphorus was allocated to the planktonic microalgae in the swimming ponds compared to most lakes. This situation indicates the mobilisation and hence enhanced availability of phosphorus nutrient sources for algal growth in the EM treated swimming pond system. A comparable relationship was found in alpine mesotrophic lakes. The increased mobilisation and shorter turnover rates of nutrients in natural lakes, however, were specific responses for “classical” and “microbial loop” food webs of nutrient poor ecosystems (e.g. mesotrophic alpine lakes “Tiefe Seen-Österr. Alpenvorland, deep lakes Austrian Alps; - Bayer. Alpenvorland, deep alpine lakes in Bavaria in figure 6). According to figure 6, the trophic state of swimming ponds assessed by chl-a:TP ratio is mesotroph to weak eutrophic. Therefore, the water quality assessed from algal biomass and phosphorus pool is less good than described above under the aspect of water transparency.

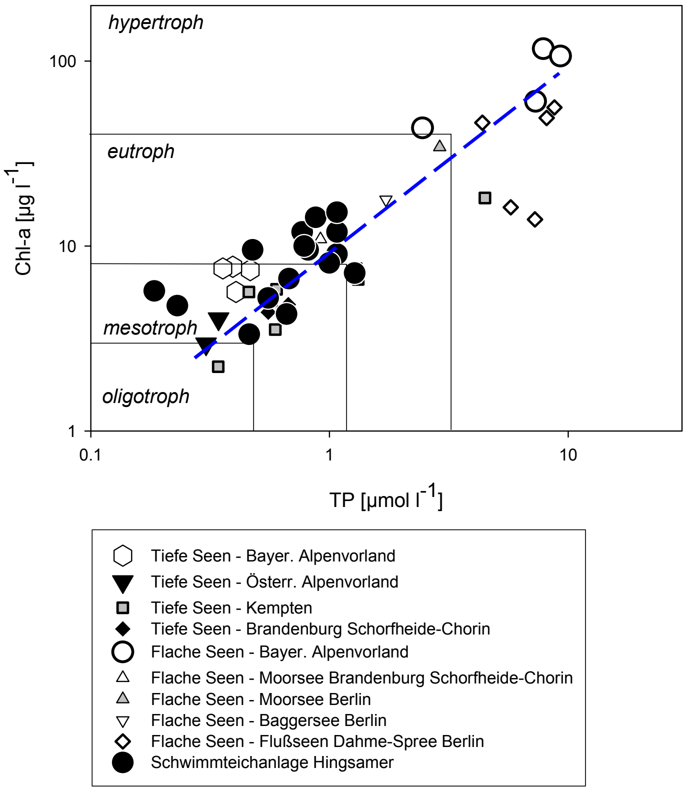

Figure 6. Relationship between concentrations of chlorophyll-a (Chl a) and of total phosphorus (TP) in the surface-layer of the swimming ponds of the eco-camp (black full circles) in comparison with lakes.
It is worth notifying, that the points of chl-a:TP ratio of the eco-camp are mainly distributed on the left side of the blue dashed line. This indicates that water treated with EM over months are utilising phosphorus compounds efficiently, building up a relative algal biomass (estimated by pigment chlorophyll-a).
(data from other lakes from Teubner 1996, Teubner et al. 2006)

In accordance with enhanced availability of phosphorus during bathing season, the summer phytoplankton structure resembled the typical algal community common in spring in shallow lakes. The summer phytoplankton in the artificial swimming ponds was dominated by needle-shaped diatoms that commonly developed in spring during periods of high phosphorus and silica concentrations in a mixed water column. These diatom cells are characterized by a relative high cell surface to cell volume ratio. Another dominant algal group were small cells of green algae due to a low abundance of zooplankton (mainly species of *Daphnia* and *Megacyclops*) grazing algae.

The number of heterotrophic bacterial cells in relation to the concentration of total phosphorus and chlorophyll-a are displayed for the swimming ponds and retention ponds of the eco-camp and in comparison also for shallow lakes of moderate eutrophic (mesotrophic) and eutrophic states (figure 7). We found a relative high proportion between the number of heterotrophic bacterial cells and TP concentration for the swimming ponds as it is commonly found in meso-trophic lakes (high ratio of numbers of heterotrophic bacterial cells to TP concentration). In addition we also found an enhanced portion of bacterial cells to planktonic algal cells estimated by chlorophyll-a (high ratio of numbers of heterotrophic bacterial cells to chl-a concentration) for both, the swimming ponds and the mesotrophic lakes. This relative enhancement of hetero-trophic organisms indicates a higher microbial activity, accomplishing shorter turnover times for nutrient cycling. We found a particular, even higher ratio of the abundance of heterotrophic bacterial cells to microalgal chlorophyll-a concentration in the retention ponds. This finding is in accordance with the observation that biomass of primary producers was mainly built up by fila-mentous macroalgal mats (figure 4) and not by microscopic planktonic algae in the retention ponds. Moreover the saprobic index for benthic algal species, a measure for the level of organic pollution, indicated a good water quality for the swimming pond system (class II). Furthermore it

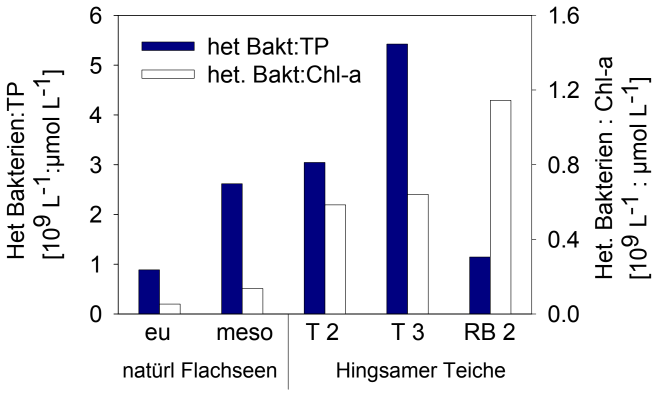

Figure 7. Proportions between the number of heterotrophic bacterial cells and concentration of TP (het. Bakt:TP) or chlorophyll-a (het. Bakt:Chl-a). The figure shows data for swimming ponds (T2 and 3) and retention pond (RB2) of the eco-camp ('Hingsamer Teiche') in comparison with shallow eu- and mesotrophic lakes ('natürl Flachseen'). All data points refer to an average over the two months June-July (data from lakes from Teubner 2006).

can be reported that less sediment material was accumulated at the bottom layer of the swimming ponds, since the artificial system was treated with EM.

Since we have not measured the reference condition for an artificial swimming pond system, we are not allowed to give numbers calculating the contribution maintaining the water quality by microbial activities of EM treatment. Among open questions we have further no information which portion of living cells of EM-species along the variety of above suggested organisms were most effective for nutrient cycling in the swimming ponds, how effective were contributions by dead cell material (e.g. endo- and ecto-enzymes in the EM suspension) and if the success of treatment by EM were mainly due to their overwhelming microbial activity or by inhibiting and destroying the naturally occurring microbial community in the pond. Results presented in figure 6 and 7 and the deposit of only small amounts of sediment material at the bottom layer indicate, however, that the overall microbial community in addition to growing mats of macroalgae seem to construct a nutrient-cycling and food-web structure comparable to mesotrophic natural lakes.

Further literature on mechanisms of utilisation of phosphorus compounds by algae in lakes and artificial swimming pond systems and other aspects discussed above are recommended by the following references:

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