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Biomanipulation of lake ecosystems: an introduction

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SUMMARY

1. This paper is an introduction to a special issue of *Freshwater Biology* containing selected papers from an international symposium on *Food Web Effects of Fish in Lake Ecosystems: Research Progress, Water Quality and Fisheries Management* held from 31 May to 3 June 2000 in Rheinsberg, Germany. The primary goal of the workshop was to enlarge the current view of fish-induced effects on lake ecosystems. An additional goal was to promote biomanipulation as a multiple-use tool for managing freshwater ecosystems.
2. The three main topics addressed at the workshop were: (i) mechanisms involved in biomanipulation, (ii) whole-lake case studies and (iii) management aspects in water quality and fisheries.
3. Mortality of *Daphnia*, nutrient recycling, habitat selection and fish predation are reported as important mechanisms governing food-web effects as a result of biomanipulation.
4. Whole-lake case studies indicate that repeated fish removal can help improve water quality of shallow lakes, but successful biomanipulation of deep, thermally stratifying lakes remains difficult.
5. In many cases, biomanipulation of lakes has proved to provide benefits in addition to improving water quality. As all lake users are potentially affected when biomanipulation is used as a lake management tool, their concerns need to be clearly recognised if biomanipulation is to be successful in practice.

Keywords: biomanipulation, case studies, fisheries management, mechanisms, water quality

Introduction

Biomanipulation has become a routine technique for improving water quality of lakes and reservoirs (Hansson *et al*., 1998; Drenner & Hambright, 1999). Although several scientific questions pertaining to biomanipulation require further study, the technique is sufficiently advanced from both the scientific and management point of view to make sound predictions of water quality improvement in many cases. Except for fishless lakes, the trophic interactions in pelagic communities as outlined by the 'trophic cascade model' (Carpenter, Kitchell & Hodgson, 1985) and the 'bottom-up : top-down theory' (McQueen, Post & Mills, 1986) exist in almost all lentic freshwater ecosystems. However, the specific structures and processes involved are highly variable. Both are influenced by top-down and bottom-up forces, making it sometimes difficult to predict the outcome of a biomanipulation experiment quantitatively. Nevertheless, our understanding of the technique has progressed remarkably since publication of the results of the 1989 symposium on biomanipulation in Amsterdam (Gulati *et al*., 1990).

From a management point of view, biomanipulation is likely to be most successful in the long term in shallow eutrophic lakes. Intense grazing on phytoplankton by *Daphnia* leads to greater water clarity, which in turn allows macrophytes to become the

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dominant primary producers, whereas phytoplankton is suppressed (Mehner *et al*., 2002). Although the macrophyte-dominated clear-water state of shallow lakes is generally considered stable, the plankton-dominated situation may return when nutrient loading is high and dense populations of benthivorous or planktivorous fish become re-established. Repeated biomanipulation measures, however, may recreate the clear-water state (Van de Bund & Van Donk 2002).

In stratified eutrophic lakes, the situation is apparently different. Following the spring clear-water phase caused by high *Daphnia* grazing rates, non-edible algae tend to dominate the phytoplankton community and cause low water transparency during summer. Therefore, one of the crucial factors for ensuring a sustained success of biomanipulation in stratified lakes is the ability to suppress the development of inedible algae throughout the summer. There are three possible approaches: (1) increasing light limitation of phytoplankton by (artificially) increasing mixing depth of the epilimnion, (2) increasing light attenuation by increasing the natural water colour of the lake (Oskam, 1978) and (3) increasing P-limitation by reducing external or internal nutrient loading. Below an external loading rate of about 0.6–0.8 g P m^{-2} a^{-1}, biomanipulation is predicted to reduce in-lake P concentrations and consequently increase P-limitation of phytoplankton (Benndorf, 1995).

Thus, the loading-concept and the biomanipulation approach cannot be dealt with independently of one another, as was originally proposed by Hrbacek *et al*. (1961) and Shapiro, Lamarra & Lynch (1975), in neither shallow nor deep stratified eutrophic lakes. In general, biomanipulation is now considered a useful technique to accelerate the recovery of culturally eutrophic lakes, although regular maintenance is required (McQueen, 1998; Benndorf *et al*., 2000). Biomanipulation can be a successful alternative to physical and chemical treatments to accelerate lake recovery often delayed because of persistently high rates of internal loading. Therefore, a combination of load reduction and in-lake restoration measures including biomanipulation is likely to improve water quality greatly in eutrophied lakes in the long term.

Overview of the papers in this special issue

During 31 May to 3 June 2000, a total of 56 participants from 15 countries met in Rheinsberg-Linow near Berlin, Germany, to discuss the recent advances in biomanipulation research from both a scientific and management point of view. The primary objective of this symposium was to enhance our current understanding of fish-induced effects on lake food webs to elucidate the potential of biomanipulation as an approach to both water quality and fisheries management. Furthermore, the effects of this combined water quality and fisheries management strategy on local economy were considered. In particular, we wished to promote biomanipulation as a multiple-purpose tool for managing culturally eutrophic lakes and reservoirs. Consequently, we invited presentations not only on the scientific background but also on the management aspects of biomanipulation. We explicitly encouraged comparisons between shallow and stratified lakes and among lakes in different climatic settings. Of the 43 presentations given at the workshop, 15 are summarised in this special issue of *Freshwater Biology*. They are followed by a synthesis reviewing the specific contributions to this issue and the general progress made since the first conference on biomanipulation in 1989.

The first two papers are concerned with general aspects of biomanipulation. Benndorf *et al*. (2002) argue that biomanipulation should be restricted to certain types of lakes that meet a set of conditions required for biomanipulation to be successful. Gliwicz (2002) points out that resource-related and predator-related impacts, although often considered compatible, control very different and to some extent independent characteristics of zooplankton populations.

The following six articles deal with mechanisms underlying the effects of biomanipulation on lake food webs. Lowering the mortality of *Daphnia* is one of the major goals in biomanipulation. However, mid-summer declines of *Daphnia* caused by a decline in food availability followed by synchronised ageing and death of the spring cohort may be inevitable in some years, even if the stock of planktivorous fish is well below a critical level (Hülsmann & Voigt, 2002). Using a bioenergetics model, Tarvainen, Sarvala & Helminen (2002) found that the percentage of P recycled by roach (*Rutilus rutilus* L.) was significant in the phosphorus balance of a biomanipulated lake, although this result may not hold true in general. Based on result from an enclosure experiment, Radke & Kahl (2002) conclude that silver carp

[*Hypophthalmichthys molitrix* (Val.)], a species capable of feeding on phytoplankton, should not be used for biomanipulation in mesotrophic lakes, because its effect on planktonic cladocerans was stronger than on phytoplankton. Applying an individual-based model, Hölker *et al*. (2002) provide quantitative evidence that altering the habitat selection mode of planktivorous roach by piscivore stocking may reduce zooplankton consumption substantially, and could therefore be used as a biomanipulation technique complementing the reduction of zooplanktivorous fish. Given favourable conditions, 0+ Eurasian perch (*Perca fluviatilis* L.) are able to prey on 0+ bream, thus become predators during the first summer of their life and consequently avoid the juvenile bottleneck (Beeck *et al*., 2002). Early piscivory of 0+ perch may help prevent the expected increase in 0+ cyprinids following reduction of adult cyprinids, which is considered important to ensure the long-term success of biomanipulation. Using radio-telemetry, Jacobsen *et al*. (2002) found perch to be equally active during the whole year, suggesting that this species can be an important predator of 0+ planktivorous fish even during winter. Supporting the development of a strong piscivorous perch population is therefore highly desirable in biomanipulation experiments.

The following set of three papers reports case studies on biomanipulation. Fifteen years of data from Lake Zwemlust in the Netherlands demonstrate that biomanipulation may have to be applied repeatedly to sustain the macrophyte-dominated clear-water state in the long term even in shallow lakes (Van de Bund & Van Donk, 2002). Stocking of differently sized pike (*Esox lucius* L.) in order to manipulate the food web of shallow lakes was found to be successful, but a refinement of current stocking practices is necessary (Skov *et al*., 2002). Improvement of stocking practices is especially important when 0+ pike is used, as is often the case, because 0+ pike have no detectable effect on 0+ roach, one of the major targets of biomanipulation in European lakes. The results presented by Dawidowicz *et al*. (2002) indicate that biomanipulation in deep, thermally stratifying lakes has little effect on water quality.

The next four papers explicitly address management aspects. Lathrop *et al*. (2002) show that harvest restrictions are an important prerequisite to create a well-developed piscivore population in lakes. The long-term study of Lake Mendota synthesised by Lathrop *et al*. (2002) also indicates that food-web effects can produce increased water clarity in stratified eutrophic lakes, even when P loadings are relatively high (0.85 g P m^{-2} $year^{-1}$). Based on long-term data, Wysujack & Mehner (2002) recommend fisheries management by a combination of piscivore introduction, catch restrictions and manual removal as the most promising biomanipulation strategy. The study by Lammens, Van Nes & Mooij (2002) indicates that the exploitation of bream populations in eutrophic shallow lakes may affect these lakes to varying degrees, depending on the intensity of fisheries, variation in recruitment and temperature fluctuations. The sometimes extremely high standing stocks of omnivorous fish in tropical reservoirs, tilapias in particular, accelerate nutrient turnover in the lake with major negative effect on water quality (Starling *et al*., 2002). The establishment of a small-scale commercial fishery targeted against these fishes would provide protein for the local population and improve the water quality of the reservoirs (Starling *et al*., 2002).

In summary, a moderate P-loading rate below 0.6–0.8 g P m^{-1} a^{-1} is an important factor to support long-term success of biomanipulation. Nutrient recycling by fish has to be taken into account, because it may supply considerable amounts of phosphorus at least in some lakes. The higher success rate of biomanipulation in shallow as opposed to stratified lakes might be attributed first of all to the recovery of submersed macrophytes as the major primary producers in these ecosystems. Niche shifts and size-structured interactions, particularly in fish populations, create complex food webs, which are hard to quantify and predict. Recommended proportions and densities of piscivorous fish are currently based on data from only a few biomanipulation experiments and need to be corroborated by additional and quantitative assessments of energy flow through lake food webs. In the long term, successful biomanipulation of shallow and stratified lakes can only be achieved by continued interventions. Biomanipulation as a tool in water quality and fisheries management requires the recognition of the concerns of all lake users. Biomanipulation research has clearly extended our understanding of complex lake food webs and should in turn promote a higher success rate of future biomanipulation experiments.

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