

A HABITAT FIT FOR FISH— AN AIM OF BIOMANIPULATION?

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Abstract

A recurring problem has been observed world-wide whereby eutrophication has caused an increase in algal biomass and has frequently resulted in the occurrence of blue-green algal blooms. Biomanipulation, the 'top-down' manipulation of food chains as a means of reducing algal biomass, has been the subject of considerable research effort in the northern hemisphere and has been used in a number of cases as a means of managing and restoring eutrophic lakes. Its track record has been variable, a number of successes being countered by examples where the manipulation has failed to have the desired result. Some possible reasons for these failures, the complexity of the systems, the resistance of blue-green algae to grazing and the instability of the manipulated fish populations, are discussed. Particular attention is paid to the latter with the likely responses of fish populations following their manipulation being explored. In terms of the future use of biomanipulation in Australia it is suggested that there are four key questions: 1) how can the fish manipulation best be achieved? 2) what are the important buffering mechanisms ensuring the sustainability of the manipulation? 3) how can these buffering mechanisms be promoted and 4) have we the necessary information on fish biology, behaviour and ecology to determine how best to manipulate the system?. The importance of the future involvement of fisheries scientists in biomanipulation research and use is stressed.

Background to biomanipulation

Since the mid 1970's, when the term "biomanipulation" was used to describe the restructuring of the biological community as an approach to combating eutrophication (Shapiro *et al.* 1975), there has been considerable research effort throughout the northern hemisphere to assess and determine the effectiveness of the technique. With the problems caused by eutrophication increasing over recent decades, interest in biomanipulation has increased as other, more engineering type, solutions have proven to have limited success. This culminated in an international conference entitled "Biomanipulation Tool for Water Management" (Gulati *et al.* 1990) at which the current experimental and practical experience of biomanipulation was discussed, and the shortcomings in knowledge identified. The original concept of biomanipulation espoused by Shapiro *et al.* (1975) was the 'manipulation of the biota of lakes and their habitats to facilitate certain interactions and results which we as lake users consider beneficial'. The word biomanipulation is now normally used in a more restricted sense to refer to food web, or 'top-down', manipulation of a system (Shapiro 1990). In the majority of cases the reason for manipulating a system is to reduce algal biomass, in particular when blue-green algae are a problem. The basic concept behind all food-web manipulations is summarised in Figure 1. Its success depends upon the extent of predation on the zooplankton being

reduced, ideally leading to an increase in the number of larger-sized individuals which are the most efficient grazers on phytoplankton and are thus best able to maintain a lower algal biomass. In the majority of cases the most significant predation pressure exerted on the zooplankton is due to fish. Manipulation of the fish population takes two main forms, removal of the zooplanktivorous fish resulting in a direct reduction in predation on the zooplankton, or enhancement of the piscivorous fish population as a means of reducing the zooplanktivorous fish. Examples exist where both approaches, or a combination of the two, have been used in an attempt to restore whole lakes. For example planktivorous fish were removed from Cockshoot Broad, U.K. in an attempt to reduce algal biomass, improve the underwater light climate and promote the growth of aquatic plants (B. Moss, personal communication). This approach has also been used at Lake Vaeng, Denmark (Søndergaard *et al.* 1990). More typically a combination of the two approaches has been used where the existing planktivorous populations are reduced as far as possible and the piscivorous fish populations are enhanced. Such an approach has been used as a restorative technique, for example for Lake Zwemlust (Van Donk *et al.* 1989; 1990a), Lake Bleiswijkse Zoom (Meijer *et al.* 1989) and Lake Breukeleveen (Van Donk *et al.* 1990b) in the Netherlands, Lake Frederiksborg Slotssø (Riemann *et al.* 1990) in Denmark, Lake Mosvatn (Sanni and Waervagen 1990) in Norway, and Lake Christina (Hanson and Butler 1990) in the U.S.A.

In Australia there has been very little work on biomanipulation. Geddes (1986) compared zooplankton communities in four farm dams, three of which were without fish and one stocked with redfin (*Perca fluviatilis*). He demonstrated differences in the species composition, abundance and size distribution of the zooplankton community which he attributed to the presence or absence of fish. Merrick and Ganf (1988) used enclosures to investigate the effects of

zooplankton grazing on phytoplankton in Mount Bold Reservoir, and demonstrated some reduction in phytoplankton biomass in grazed enclosures. Lund (1991) used small enclosures to assess the impact on the foodweb of mosquito fish control but concluded that it led to no significant improvement in water quality. To this time there has been no attempt to use biomanipulation of the food chain as a management tool for the restoration of waterbodies in Australia.

Biomanipulation—success or failure?

A number of enclosure experiments have demonstrated an increase in larger zooplankton in the absence of planktivorous fish (e.g. Andersson *et al.* 1978) and a reduction in phytoplankton biomass in the presence of more or larger zooplankton (e.g. Schoenberg and Carlson 1984). These provide strong evidence that biomanipulation works on a small experimental scale, but can it be scaled up to the 'whole lake' scale?. Evidence from those lakes which have been manipulated is contradictory. In some instances the effects have been dramatic with examples of a desired increase in the numbers and/or size of the zooplankton, a decrease in the phytoplankton biomass, increased water clarity, increased macrophyte growth and an improvement in the amenity, recreational, aesthetic and drinking water quality. For example removal of planktivorous and benthivorous fish, and the addition of piscivorous fish to Lake Zwemlust, a small lake (1.5 ha, 1.5m deep) in the Netherlands resulted in a reduction in the chlorophyll *a* concentration from in excess of 250 $\mu\text{g l}^{-1}$ to less than 5 $\mu\text{g l}^{-1}$ and eliminated the appearance of *Microcystis* blooms. There was an increase in the number of larger zooplankton and an increase in the previously sparse aquatic vegetation (Van Donk *et al.* 1990a). On a larger scale at Lake Christina (1619 ha, 1.25m deep) in the U.S.A., removal of the fish population, and restocking with a more balanced fish population, resulted in a shift to larger zooplankton

species, a reduction in chlorophyll *a* concentrations, an improvement in water transparency and an increase in submerged macrophytes (Hanson and Butler 1990).

In contrast many other attempts to biomanipulate lakes have failed to have the desired effect, or the initial improvements have been transient. For example in Lake Breukeleveen in the Netherlands (180 ha, 1.45m deep) removal of a substantial proportion (60-70%) of the planktivorous and benthivorous fish, the addition of 0+ piscivores, and seeding with large-sized daphnids failed to result in a reduction in the chlorophyll *a* concentration, improve the water transparency or increase the growth of aquatic plants (Van Donk *et al.* 1990b).

Why do biomanipulations fail?

The reasons for the difficulties encountered in making biomanipulations work are complex but perhaps fall into three categories. The basic food-web interactions are well understood, having been explored extensively in a large number of field enclosure and laboratory experiments, but the overall function of a lake or river system is complex and the end result of a manipulation is therefore difficult to predict. This may be particularly true in situations where there are significant populations of invertebrates which are predators on zooplankton and in turn are fed upon by fish. In such a case, removal of the fish population may result in an increase in these invertebrates, possibly increasing the overall predation pressure on the zooplankton, the reverse of the desired outcome. Secondly, the algae of greatest concern, the blue-greens, may be inedible and/or suppress the development of large-bodied zooplankton (Lampert 1981; Haney 1987). If so, reduction in the predation pressure exerted on the zooplankton by the fish is not going to feed through to a reduction in the phytoplankton biomass, and may even favour the development of blue-green algae. Finally,

and of most interest in the context of this paper, the manipulated fish populations are unstable. Figure 2 summarises the typical response of fish populations following their manipulation. Where an attempt is made to remove the zooplanktivorous fish it is virtually impossible to succeed in removing 100% of the population. The remaining fish, with an abundance of food and spawning sites and in the absence of piscivorous fish are likely to achieve good breeding success, resulting in a large number of 0+ fish which will have a detrimental effect upon the zooplankton populations, undermining the aim of the manipulation. In the absence of a significant breeding success such a manipulation may succeed, a stable and desirable reduced fish population becoming established. If a 100% fish kill is achieved and the desired changes in the zooplankton and phytoplankton populations occur, the long term stability of the change depends upon the timing and nature of the re-establishment of the fish population. Of the three options, a total failure of fish to recolonise is unlikely, and although perhaps desirable in terms of the control of algal problems, is not desirable from a fisheries point of view. Almost certainly fish will recolonise a waterbody within a relatively short period, the key point being whether it reverts to something similar to the original undesirable structure, a new undesirable structure or a desirable fish population. In a more complex manipulation where the piscivorous fish populations are enhanced in addition to the decrease in the zooplanktivorous fish, there is again a range of possible outcomes. The environmental conditions may be unsuitable for the piscivores, resulting in a failure of them to survive, effectively the manipulation then being simply a removal of zooplanktivorous fish, with the potential problems discussed previously. Alternatively the piscivores may survive and effectively control the zooplanktivores, preventing their increase to the point where they undermine the success of the manipulation, or they may survive but fail to control the zooplanktivores.

Thus we see that fish are a key component determining the success or otherwise of biomanipulation. In much previous work on biomanipulation, fish have been considered a 'problem' to be eliminated in order to achieve success. If biomanipulation is to be used in Australia, there are two approaches we can take, either continuing to view the fish as a component of the system which must be removed, or alternatively considering fish to be an integral part of the system, and aiming to achieve the reduced phytoplankton populations in tandem with the creation of habitats suitable for the maintenance of desirable fish populations.

This poses four key questions:

- 1) How can the initial manipulation of the fish populations best be achieved?
- 2) What are the important buffering mechanisms which in the long term will allow the coexistence of sustainable and desirable fish, zooplankton, plants and phytoplankton?
- 3) How can we promote the buffering mechanisms identified in 2)?
- 4) Do we know enough about the habitat requirements of fish to determine how to manipulate the environment in order to encourage the desired species and minimise undesirable species?

The first is largely a practical question of how to manipulate the fish population. Physical methods of fish capture are well developed and readily usable but not suitable or feasible in all circumstances. Chemical control methods, while being less expensive and more effective, may run into public relations and legislative difficulties. More difficult to answer might be the determination of which piscivorous species are suitable for control of zooplanktivorous fish, and knowing what their environmental requirements are so that their populations can successfully be enhanced.

The second question is one of the role of buffering mechanisms. In the long term, in order to establish a degree of stability in the system, buffering mechanisms are required to prevent the new desirable fish populations from reverting to their pre-manipulation undesirable state. This may simply involve a change in the species present. For example a piscivore, previously absent or only present in small numbers, may act as a buffer to the redevelopment of troublesome populations of zooplanktivores. Another important buffering mechanism might be the presence of some kind of refugia for zooplankton, allowing their coexistence with zooplanktivorous fish. Different types of refugia were discussed by Shapiro (1990). They include, for example, low light, cool temperatures, low dissolved oxygen, predator inefficiency, macrophytes and physical refuges. In shallow lakes the presence of macrophytes probably represents the best form of refugia. Macrophytes have been shown to act as a refuge for larger *Daphnia*, decreasing predation by planktivorous fish (Timms and Moss 1984). It was suggested that the presence of macrophytes in the Norfolk Broads, U.K. allowed the maintenance of clear water and low phytoplankton biomass in the face of very high nutrient concentrations (Moss *et al.* 1985).

This leads to the third question. If buffering mechanisms are identified which are important for the long term success of a biomanipulation how can they actually be created in the field? For example if macrophytes are shown to be a useful buffering mechanism how can their growth be encouraged.

Finally if we are going to attempt to manipulate fish populations do we know enough about the habitat requirements of Australian fish to determine how to manipulate the environment in order to encourage the desired, and minimise the undesirable, species? Probably of greatest importance is an understanding of the requirements of a small number of piscivorous species, which would be suitable species to

encourage, and of those zooplanktivorous species which can be identified as posing the greatest threat to zooplankton populations.

The future of biomanipulation in Australia

Over recent times we have observed an increase in the problems associated with eutrophication, particularly an increase in the occurrence of blue-green algal blooms. It has to be recognised that no single answer or approach exists which can solve all of these problems, but biomanipulation may represent one important weapon in overcoming them, either as a stand-alone technique, or in conjunction with other methods such as a reduction in nutrient concentrations. Fish are a central component of the biomanipulation process and it is important that fisheries scientists are actively involved in biomanipulation research to ensure that the existing knowledge and expertise on fish biology, behaviour and ecology is fully utilised and that the sustainability of fish populations, and the maintenance, creation or improvement of fish habitat can be integrated within the desired biomanipulation requirements, rather than fish again being considered purely as a problem to be overcome.

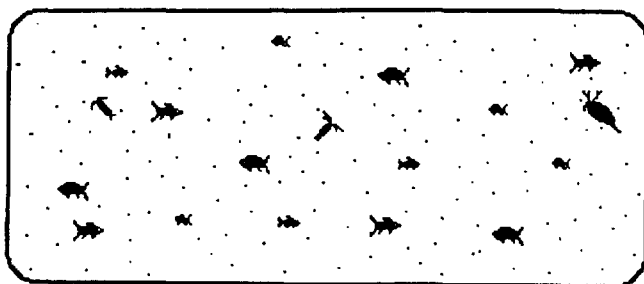
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PRE-BIOMANIPULATION

- 1 many zooplanktivorous fish
- 2 many phytoplankton
- 3 few zooplankton



Fish population
manipulated to
decrease
zooplanktivores

POST-MANIPULATION

- 1 few zooplanktivorous fish
- 2 reduced phytoplankton
- 3 more or larger zooplankton



Figure 1. Changes in zooplankton and phytoplankton populations in a waterbody following biomanipulation involving the elimination or reduction of zooplanktivorous fish.

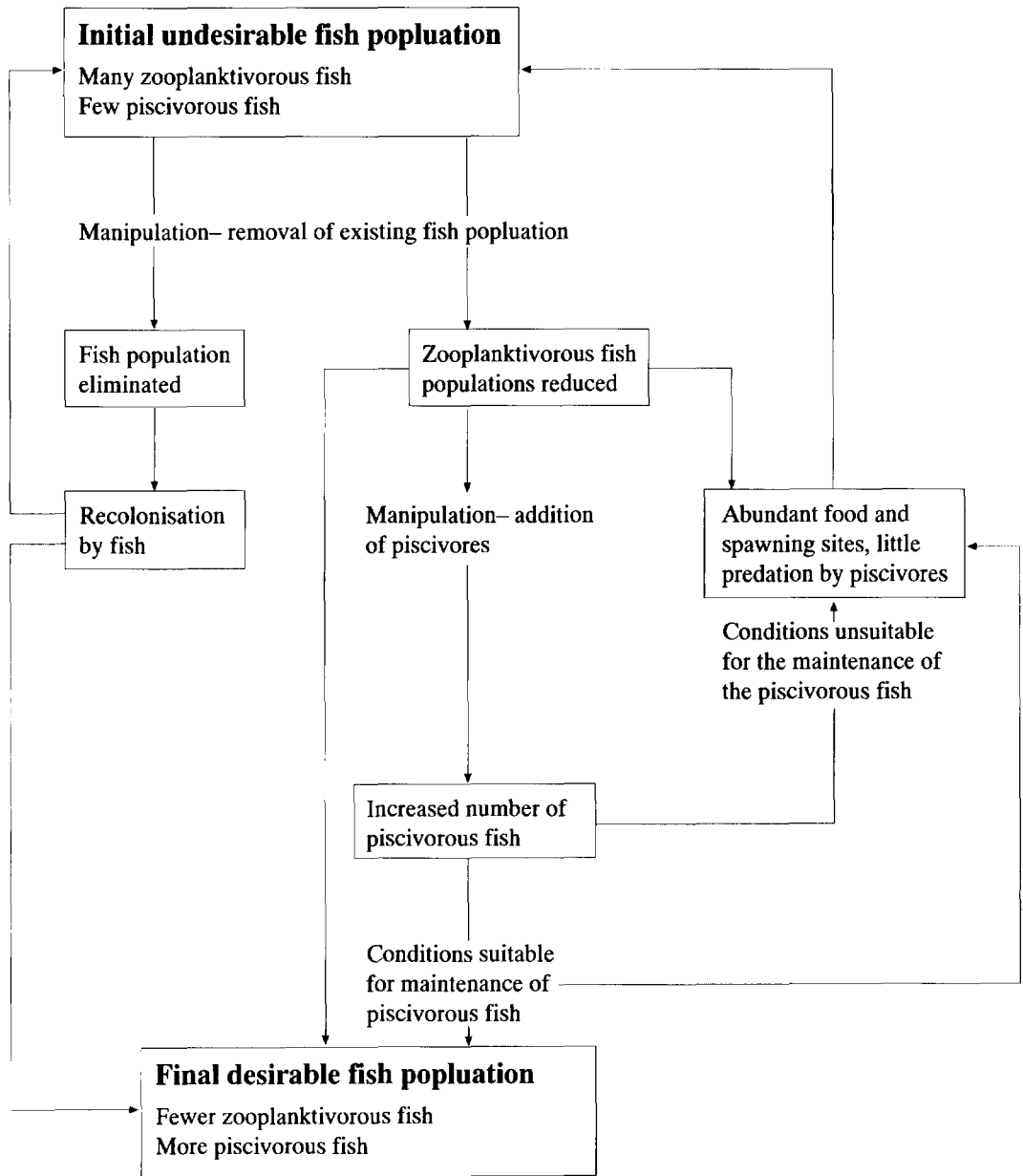


Figure 2. Likely outcomes following the manipulation of existing fish populations (for explanation see text).