The central role of fish in lake restoration and management

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Abstract

The central role of fish in lake restoration and management has a practical purpose: fish are much easier to manipulate than nutrients, phytoplankton and zooplankton, and therefore they are a relatively easy (additional) instrument in restoration and management. The management of the fish stock may be a measure of water quality, of fish stock composition or a measure of both and may vary from very drastic removal of planktivorous and benthivorous fish to a more gradual change in the population by continual predator management and less drastic reduction of inedible prey. For lake restoration, drastic removal is the most efficient in order to obtain clear water and vegetation and a subsequent fish community adapted to this. Continual management will result in a more gradual change and may be more acceptable to the interest of both fishermen and water quality managers.

Introduction

There is an essential difference between the role of fish in lake management and the role of fish in ecosystems. In restoration and management it has the meaning of practicality: fish are much easier to handle than nutrients or phytoplankton and therefore they are a relatively easy instrument in restoration and management. The role of fish in ecosystems is not more than being part of the ecosystem, clearly influencing it, but there is no reason that the role should be central. Therefore it should be clear that the role of fish in management relates to practicality and the effects of changing the fish stock on the ecosystem.

The goal of restoration and management should be well defined, clarifying the (future) use of the lake. Water quality objectives may conflict with the wishes of fishery management or the wishes of nature conservation demanding specific food for visiting birds. So the management of fish stocks may serve many purposes depending on the wish of the water manager. This paper focusses on three aspects of fish management:

1. Fishery management as a measure of water quality.
2. Fishery management as a measure of fish stock composition.
3. Fishery management as a measure of both.

Firstly the effect of fish on the structure of the ecosystem is considered in general; discriminating between planktivorous, benthivorous and piscivorous fish. Then the development of a fish community in an eutrophic open water system and its effect of the successive stages on algal development is described. A case study where fishery and water quality management were combined concludes this paper.

The effect of fish on the structure of the ecosystem

There have been many experimental studies showing the effect (removal or addition) of fish on the structure of the ecosystem (Kerfoot & Sih, 1987; Carpenter, 1988; Gulati et al., 1990; Jeppesen et al., 1997). Characteristic is the cascading effect through all trophic levels and the more-or-less drastic change of the ecosystem, particularly at the appearence or disappearence of vegetation. Many of these studies proved to be useful for management purposes and were the basis

for a restoration handbook in the Netherlands (Hosper & Meijer, 1992) and later in the U.K. (Moss et al., 1996). In this section, the effect of removal and addition of fishes will be described and some case studies used to illustrate the seperate effects of planktivory, benthivory and piscivory.

Total removal

The most drastic effects are found by (almost) complete removal of the fish stock. The most famous example is lake Zwemlust. In this lake the total fish stock was removed by pumping out the water and removing 100% of the fish. The effects of the experiment on all trophic levels are very well described (Van Donk et al., 1990b). The main result was a drastic switch from turbid to clear water caused by a high grazing pressure of *Daphnia* spp. and the subsequent development of vegetation and slight decrease in nutrients (Meijer et al., 1994b; Van Donk & Gulati, 1995). Afterwards the lake was stocked with pike (*Esox lucius*) and rudd (*Scardinius erythrophtalmus*). Because pike could not control the rudd population, the fish population increased and the system started to oscillate between clear and turbid. Many more birds visited the lake and influenced the succession of the vegetation (Van Donk & Gulati, 1995).

In many other lakes, large scale removals have been applied, not total, but usually 50–80% of the total fish stock. The effect in the first year is usually a marked positive effect on transparency and development of the *Daphnia* spp. populations. If no vegetation develops, the system easily reverts to the former situation, but if vegetation develops, the system becomes more stable and nutrients slightly decrease in concentration. One of the buffering mechanisms of the vegetation is providing refuges for daphnids. During the day, daphnids hide among the vegetation as protection against predation from visual feeders and come out during the night to feed in the open water (Timms & Moss, 1984; Schriver et al., 1995; Jeppesen et al., 1996). However, oscillaton between clear and turbid is difficult to prevent (Van Donk et al., 1990b; Jeppesen et al., 1990, 1995; Persson et al., 1993; Scheffer et al., 1993; Meijer et al., 1994a, b).

Stocking with planktivorous, benthivorous or piscivorous fish

Usually the fish stock is composed of many species and size-classes with specific selectivities regarding their food organisms. Specific effects of planktivory, benthivory or piscivory can not usually be discriminated and so can only be determined in experimental conditions.

Planktivorous fish

The general effect of planktivorous fish on zooplankton is not that all zooplankton species are reduced, but mainly the larger specimens and species. Within the *Daphnia* spp. group *D. magna* and *D. pulex* are the first to disappear (Van Donk et al., 1990). At very high predation pressure *D. galeata* also disappears and usually *D. cucullata* dominates together with other small cladorans such as *Bosmina longirostris* and *Chydorus sphaericus.* The smaller species have a lower grazing efficiency than the large daphnids and have therefore a lower grazing impact on phytoplankton (Brooks & Dodson, 1965). The effect of planktivores on zooplankton, particularly daphnids, has been demonstrated in many fields and experimental studies, of which the studies of Hrbaceck et al. (1961) and Brooks & Dodson (1965) are most famous. There is no doubt that evidence for the effect of planktivorous fish, particularly the size and species composition of zooplankton is overwhelming (Andersson, et al., 1978; Stenson et al., 1978; Nilsson & Pejler, 1973; Anderson, 1984; Lammens et al., 1985; Jeppesen et al., 1990; Meijer et al. 1990a; Berg et al., 1994).

A good example of an experimental study on the effect of planktivorous fish is shown by the study of Meijer et al. (1990a). Ten (0.1 ha) ponds were divided into halves and each half stocked with planktivorous fish (young-of-the-year roach and bream) with the other half remaining fishless. During the spring peak of the daphnid population, the biomass of the fish was still small and no difference was found in size and species composition of zooplankton. Only in summer when predation became high because of increasing biomass of the planktivorous fish, *Daphnia* spp. populations were suppressed, but the other zooplankton species increased. In these latter halves the algal population increased and transparency decreased in comparison to the fishless halves.

Benthivorous fish

Benthivorous fish feed on bottom-dwelling organisms. The consequence of this feeding is that nutrients are transported from the benthic to the pelagic phase and sometimes (in case of bream (*Abramis brama*) and carp (*Cyprinus carpio*)) there may also be

a considerable resuspension of sediments because of their feeding behaviour (Lammens & Hoogenboezem, 1991). Other effects may be that they prevent macrophyte seedlings developing (Ten Winkel & Meulemans, 1984). Benthivorous fish are usually larger than planktivorous fish and species such as bream and carp are not vulnerable to predation by piscivorous fish (Lammens, 1989). Several studies of bream and carp (Lamarra, 1975; Anderson, 1978; Meijer et al., 1990a, b; Breukelaar et al., 1994) have shown a combined effect of high concentrations of suspended solids and high concentrations of nutrients. The number of field studies demonstrating these effects is much less than those on planktivorous fish.

The effect of benthivorous fish may be difficult to determine in the field, because of the interacting effects of wind and the presence of planktivorous fish. An elegant experimental study was carried out by Breukelaar et al. (1994). In a series of fish ponds, varying amounts of benthivorous bream and carp were stocked. Highly significant correlations between fish biomass and concentration of resuspended sediment were found, but also with chlorophyll '*a*' and nutrient concentrations (Breukelaar et al., 1994). The feeding behaviour of bream and carp clearly influenced turbidity by the direct action of feeding and thus resuspension of sediments, but also due to the release of nutrients from bottom sediments and from digested benthos displacing nutrients from the benthic to the pelagic phase.

Piscivorous fish

Piscivorous fish feed on fishes which are usually 10–40% of their body length. In Europe pike, pikeperch (*Stizostedion lucioperca)* and perch (*Perca fluviatilis)* are the most abundant predators (Willemsen, 1977; Popova & Sytina, 1977). Pikeperch is most successful in open and turbid water because it hunts by search, whereas for pike the opposite is true – it lives in overgrown, clear water and hunts by ambush. Perch is intermediate as it prefers open and clear water and it usually hunts by search in groups (Dziekonska, 1954; Savino & Stein, 1989; Chapman et al., 1989; Eklov & Persson, 1996).

Stocking with piscivorous fish may have pronounced effects, providing both the prey population and the habitat are suitable for the predator. The introduction of pikeperch in a Norwegian lake forced the roach to move from the open water and effects on chlorophyll and transparency were demonstrated

(Brabrand & Faafeng, 1993). Another example of predator stocking was shown in lake Bautzen where short-term effects of annual stocking with 0+ pike and pikeperch were apparent as increase in clarity because of a reduction of the planktivorous fish and increase in density of *Daphnia galeata*. Longer-term effects, however, were apparent as an increase in *Microcystis* blooms and increase in toxicity (Benndorf et al., 1984; 1988). Similar short-term effects of 0+ pike stocking were found in some Danish lakes (Jeppesen et al., 1996) . However, there has been no study to date which demonstrates an effect of pike, perch or pikeperch which is similar to the complete removal of fish in eutrophic lakes. Piscivore stocking has only been successful when done permanently; it has not proved possible to prevent subsequent successful recruitment of cyprinids (Benndorf, 1990).

Fish stock development after complete removal

One of the arguments against biomanipulation is that the ecosystem effects are not stable and that the system will return to its original situation, that is, full of fish and full of algae. If, in the first years after removal, no vegetation develops, the original community will indeed return quickly (Van Donk et al., 1990b; Meijer et al., 1994a). Depending on the success of the original removal this period may vary from one to ten years (Van Donk & Gulati, 1995). If vegetation does develop, then the conditions for fish, zooplankton and benthos will also differ and then a different fish community will develop (Meijer et al., 1996).

A good example is the well-studied development of the fish community in the eutrophic lake Volkerak (5000 ha, average depth 5 m) which changed from a marine into freshwater community. It is illustrative because it shows the effect of (unintended) stocking a lake with fish (larvae) and the effect that has had on the total ecosystem. The development of the fish community is characteristic of situations when nutrient levels are high (>0.1 mg P l^{-1}), but there is no fish management at all. The managers were afraid that the lake would quickly turn into an algal-dominated system (Ligtvoet, 1993).

In its first year of transition from marine to freshwater, the lake was flushed from the adjacent eutrophic rivers (Hollands Diep/ Haringvliet). The chloride concentration decreased to 400–500 mg l^{-1} and the lake was suitable for all freshwater fish. The first species in-
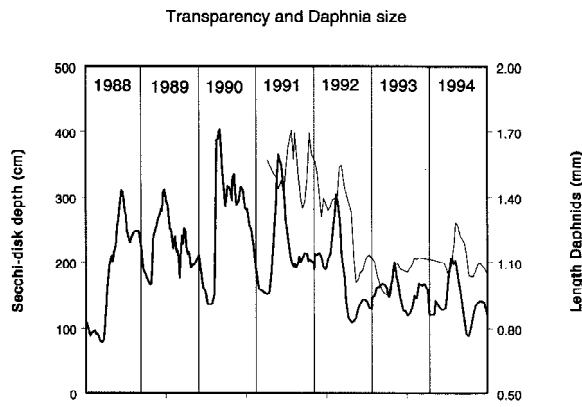
Transparency and Daphnia size

Figure 1. Transparency of Lake Volkerak and mean length of daphnids (thin line).

Daphnids and Chlorophyll
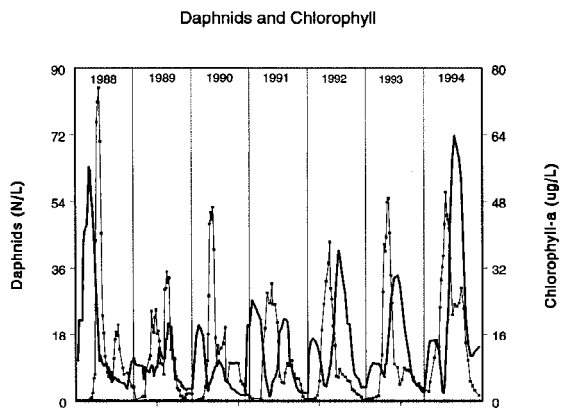
Figure 2. Chlorophyll 'a' in Lake Volkerak and density of daphnids (thin line).

Total biomass

Figure 3. Development of fish biomass in Lake Volkerak.

vading the system were perch and pikeperch, entering the lake as larvae (adult fish did not enter). Because the larvae of these species are pelagic in their early stages, they are easily distributed through the open water, whereas cyprinids (roach and bream) are born in littoral regions and are not passivily transported to the open water. Therefore percids dominated over cyprinids in the first years. The fear of the lake manager that the lake would change quickly to an algal-dominated system did not come true for the first four years. The lake had a transparency of 2–4 m (Figure 1). Fish biomass was low and dominated by perch, growing extremely rapidly on a diet of *Neomysis integer* and *D. pulex* (Houthuizen et al., 1993). The zooplankton was dominated by *D. pulex* and the algal biomass was <20 μg l^{-1}, although nutrient levels were not limiting (Figure 2). This community is typical for mesotrophic (<50 μg P l^{-1}) conditions (Persson et al., 1991).
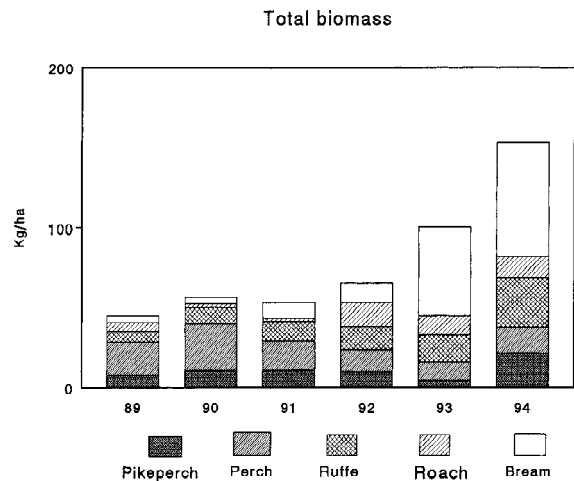
The recruitment of cyprinids was limited as long as the recruitment was dependent on small numbers of incoming larvae, but as soon as the roach population became adult (after three years) a potentially high recruitment was possible. By the fifth year the recruitment of roach was very strong and could no longer be prevented by perch and pikeperch. In that year *D. pulex* disappeared and the transparency decreased from 3 to 1 m (Figure 1). During this summer *Microcystis aeruginosa* become dominant. *D. pulex* was replaced by *D. galeata* and did not return. This implied that the average size of the daphnids decreased from 1.5 to 1 mm, although the density did not change (Figures 1 and 2). The roach population remained high and the bream and pikeperch population increased as well (Figure 3). Although the recruitment of bream and pikeperch was usually much lower than that of roach and perch, their survival was much higher and after seven years the bream and pikeperch population had become dominant within the fish community. This stage of community development is characteristic for eutrophic lakes and is quite stable in the absence of management (Lammens, 1989; Persson et al., 1991)

The development of the fish community attracted large numbers of piscivorous birds, mainly grebes and cormorants (Figure 4). In the last few years their numbers have increased to several thousands and the total fish removal was considerable, almost similar to the consumption by piscivorous fish (Figure 5). Because the annual recruitment, growth and mortality of all species was known (Ligtvoet et al., 1994), the dynamics of the total fish community could be similated and the largest part of the mortality could be explained as a
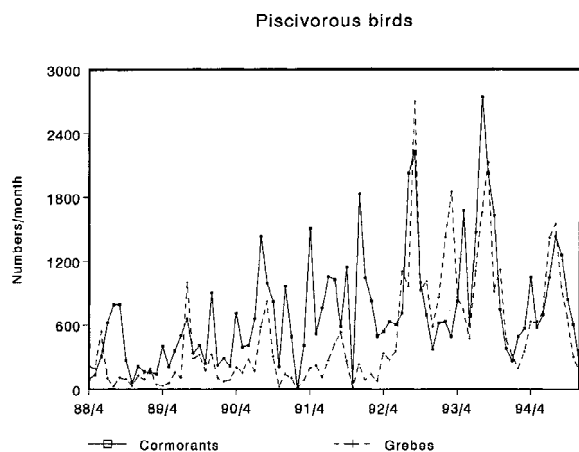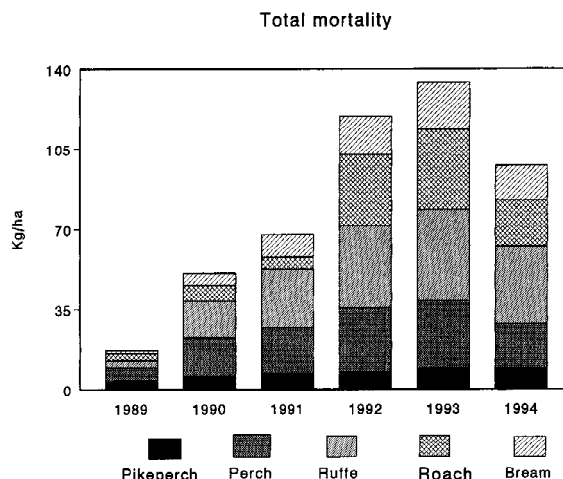
Piscivorous birds

Figure 4. Piscivorous birds in Lake Volkerak.

Total mortality

Figure 5. Total removal of cyprinid fish, Lake Volkerak.

Total mortality

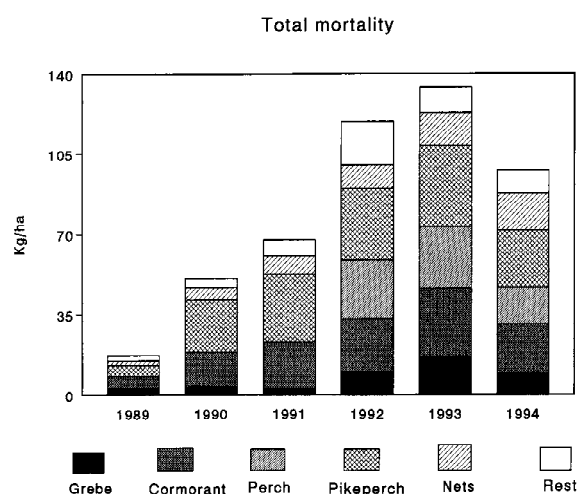*Figure 6.* Total mortality by species, Lake Volkerak.

result of predation by fish and birds. For the simulation I used an Indivudual Based Model (PISCATOR, Lammens et al., 1995) and compared the total mortality in the lake with mortality caused by the sum of the main predators, that is predation by piscivorous fish, birds, fishery and other causes. It was surprising to see that the yearly annual mortality equalled the total biomass (Figures 3 and 6) and that, with the knowledge of the annual recruitment and selectivity of piscivorous fish and birds, the development of the fish community could fairly accurately be predicted.

It is clear that in eutrophic conditions the development of the fish population cannot be stopped by piscivorous fish, particularly when long-lived species such as bream (and carp) are present. After a few years' growth they become only slightly vulnerable

to predation and because of their long lifespan they can build up a considerable biomass. Only a few successful recruitments of roach and bream are sufficient to escape the predation pressure. With our current knowledge, it cannot be predicted how successful the recruitment of a particular species will be and therefore it cannot be anticipated by predator stocking. Therefore it will be impossible to prevent a fish community development, typical for specific conditions. However, it is possible to change the fish community in a more desirable composition by management, as explained in the next section.

Management of predator and invulnerable prey

Instead of doing nothing or severely reducing the fish stock, management can be performed with the help of a commercial fishery if lakes are too large for complete fish removal. In the Frisian lakes (10 000 ha), an experimental fishery was set up for 5 years (1990–1995) to change the predator (pikeperch) population in such a way that the population would be dominated by relatively small individuals (Lammens & Klein Breteler, 1995). The hypothesis was that removing the relatively large specimens would increase the survival chances of the smaller ones similar to that found in pike (Grimm, 1981a, b) and as was more or less apparent from earlier fishery periods (Lammens et al., 1990). A pikeperch population consisting of relatively small individuals would exert a higher predation pressure on the small planktivorous fish and would therefore be beneficial for water quality.
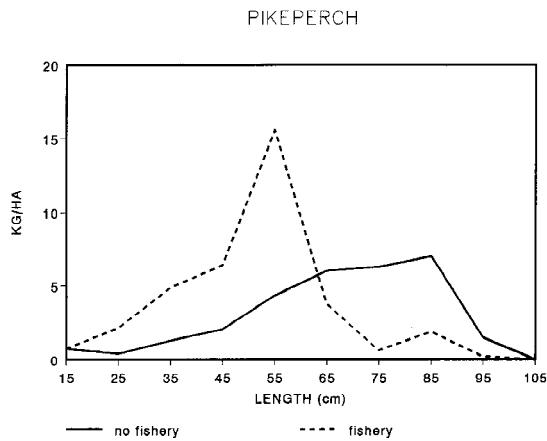
PIKEPERCH

Figure 7. Pikeperch biomass per length class under conditions of fishing and no fishing.

Planktivorous fish

Figure 8. Planktivorous fish biomass per length class under conditions of fishing and no fishing.

BREAM

Figure 9. Bream biomass per length class under conditions of fishing and no fishing.

An intensive gill-net fishery was started in 1989 to remove pikeperch >60 cm. The profit from the yield of pikeperch (which have a high market value) was used to pay a seine net fishery to remove bream >20 cm (which have a low market value) . Removing bream would benefit water quality (Breukelaar et al., 1994) and create better feeding conditions for eel (Lammens et al., 1985) and thus benefit the commercial fishermen. In order to evaluate the experimental fishery, a registration system was set up to to document all the catches and a monitoring program to estimate the biomass and size, and species composition of the fish was continued for 5 years. This monitoring program had already started 5 years previously and so a good reference situation was present.

The pikeperch population changed from a population dominated by large specimens into one dominated by small specimens. The biomass before 1990 had been dominated by the size-class 60–90 cm and after 1990 by the size-class 40–60 cm (Figure 7). The total biomass increased slightly even though 5–8 kg ha^{-1} was harvested each year. Therefore the original goal of changing the population structure was successful. It may be questionable whether a period of 5 years is sufficient to cover the large variation in recruitment and thus to predict this effect for a longer period: the change, however, was sufficient to establish an indirect effect on the biomass of small planktivorous fish. A greater than two-fold increase of 40–60 cm pikeperch was probably mainly responsible for a two-fold decrease of planktivorous fish <15 cm (Figure 8). So both the direct and indirect effects were clear regarding this pikeperch fishery.

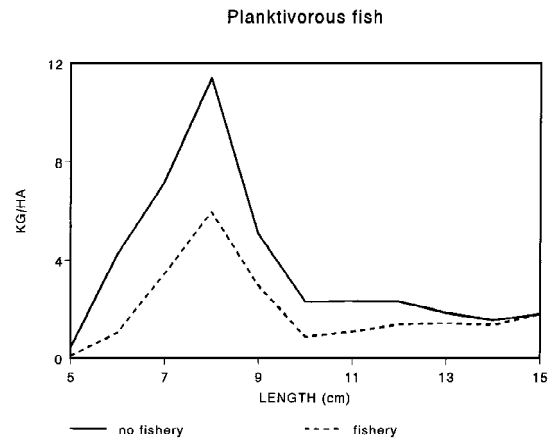The direct effect of the bream fishery on the total population was only visible in early summer, shortly after the winter fishery stopped. This reduction (30–50 kg ha^{-1}, 30–35% of the total benthivorous part of the poplation) was compensated during the summer by indivual growth, not by an increase in numbers. The population gradually increased in biomass over the course of the summer after the recovery of spawning at the end of June (Lammens et al., 1985). Feeding activity and release of nutrients must have been 30–35% lower in spring and early summer than in preceeding years and have affected the nutrient concentration (Breukelaar et al., 1994). So an indirect effect of the fishery was an decrease in release of nutrients. Because of the improved growth and increase in maximal size of fish, the reduction in numbers was compensated for, and the total biomass at the end of the year hardly changed (Figure 9). Another indirect effect was a decrease in bream <15 cm because of increased predation comparable to the general decrease of planktivorous fish.
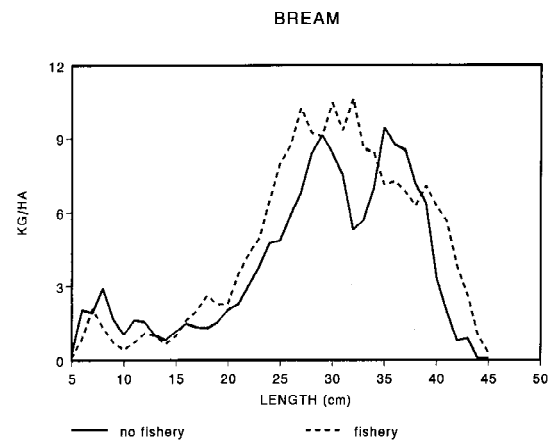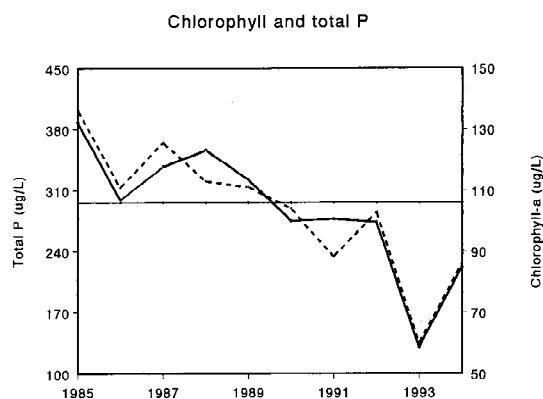
Figure 10. Annual change in chlorophyll 'a' and total phosphorus in the Frisian lakes.

By the total reduction of 250 kg bream ha^{-1} over 5 years a total amount of 0.1 g P m^{-2} was removed and, although this corresponded to the extra reduction of phosphorus in these 5 years (Figure 10), it is not necessarily the direct cause of this reduction. It seems most likely that the decrease in phosphorus and chlorophyll concentration was caused by the decreased activity of the (smaller) bream population in spring and early summer in combination with an increased grazing pressure of daphnids.

So, although it is difficult to discriminate all the separate effects and determine how much of the water quality improvement is caused by management of predator and inedible prey separately or is caused by the interaction of measures, there are strong indications that fish management contributed substantially and that it is worthy of consideration in large lakes.

Conclusions

The central role of fish in lake restoration and management may largely have a practical purpose: fish are more easy to manipulate than nutrients, phytoplankton and zooplankton, and are therefore an easy (additional) instrument for management. Management measures may vary from very drastic removal of planktivorous and benthivorous fish to a more gradual change in the population by continual predator management and less drastic reduction of inedible prey. For lake restoration, drastic removal is the most efficient in order to obtain clear water and vegetation and a subsequent fish community adapted to this. At high nutrient concentrations the old situation may easily return. Continual management is less drastic and will result in a more gradual change: this may be more acceptable to the interests of both fisherman and water quality managers.

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