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BIOMANIPULATION, NEW PERSPECTIVES FOR RESTORATION OF SHALLOW, EUTROPHIC LAKES IN THE NETHERLANDS

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KEYWORDS: Biomanipulation; lake restoration; fish-stock management; eutrophication; algae.

ABSTRACT

Eutrophication of Dutch lakes has led to massive algal growth, disappearance of most of the macrophytes and disturbance of the food chain. The pike population has fallen sharply and bream developed very strongly, in the absence of this predator. Eutrophication problems are primarily being tackled by reducing nutrient loading. Restoration of water quality, however, seems to be impeded by the present structure of the food chain, *i.e.* the large bream stock. Biomanipulation, especially fish stock control with the aim of reducing the bream stock and increasing that of predatory fish, can accelerate the process of restoration. For the further development of biomanipulation it is very important that water authorities and managers of fish stocks agree on a common strategy.

INTRODUCTION

The control of excessive algal growth in inland waters in The Netherlands is based primarily on reducing the load of nutrients, especially phosphorus. Biomanipulation measures may speed up the recovery of water quality considerably. Biomanipulation or biological control means directly manipulating the biotic communities in such a way that the system itself becomes involved in controlling the algae problem. The most practical possibilities lie in controlling fish populations.

Research in other countries on biomanipulation has yielded promising results (SHAPIRO and WRIGHT, 1984; BENNDORF *et al.*, 1988; NORDIC SYMPOSIUM, 1988). However, these results cannot be applied to the extremely shallow lakes (1-2 m) in The Netherlands without further study. Therefore, the Institute for Inland Water Management and Waste Water Treatment started research on biomanipulation in 1985, in collaboration with the Organization for Improvement of Inland Fisheries, the Limnological Institute, and the Provincial Water Board of Utrecht. Results are published by MEIJER *et al.* (1989a, 1989b), VAN DONK *et al.* (1989a, 1989b) and SCHEFFER (1989).

This article considers the relevance of biological control for the restoration of shallow, eutrophic lakes in The Netherlands and will deal with important administrative aspects of fish stock control.

WHY BIOMANIPULATION?

Why may biomanipulation be useful for the control of excessive algal growth? One might suppose that if the external load of nutrients is sufficiently reduced, the biological system will simply restore itself. However, the recovery process can take a very long time and the results may only become apparent when very low nutrient loadings are achieved. Delayed restoration in The Netherlands is evident from the studies in the Loosdrecht lakes (GONS *et al.*, 1986) and Lake Veluwe (HOSPER and MEIJER, 1986). Similar phenomena have also been reported for lakes in other countries (SAS, 1989).

Biotic systems show a resistance to changes both with increasing and with decreasing nutrient loading, following a curve as illustrated in Fig. 1. The general course of the eutrophication process may be described as follows. First the nutrient loading increases but the water remains clear because initially the extra nutrients are 'processed' by the abundant littoral vegetation and by the lake sedi-

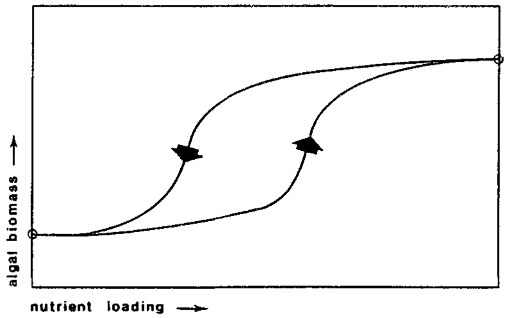

Fig. 1. Changes in algal biomass with increasing and decreasing nutrient loading; note that for the same nutrient loading, a lake under restoration may have more algal biomass than before restoration.

ments. Secondly, increased primary production of phytoplankton is balanced by its increased consumption by zooplankton. At a certain point, a critical threshold is crossed. Littoral vegetation becomes overgrown with epiphytic and filamentous algae and the plants die from lack of light (PHILLIPS *et al.*, 1978). The disappearance of the vegetation has drastic consequences for the ecosystem (CARPENTER and LODGE, 1986; GRIMM, 1985; DE NIE, 1987). The structure of the food chain changes in such a way that the biomass of algae increases sharply (see later).

The process of restoration is similar; the severely disturbed food chain of the eutrophic system is resistant to changes following a reduction in nutrient loading. A critical threshold must be passed before improvement in water quality begins. The restoration process can be accelerated through the use of biological control measures, which may influence the structure of the biotic communities. The following sections will consider the functioning of food chains in shallow, eutrophic lakes in The Netherlands and the ecology of the most important fish species with respect to biomanipulation, *viz.* pike (*Esox lucius*) and bream (*Abramis brama*).

FOODCHAINS IN SHALLOW, EUTROPHIC LAKES

The biomass of algae in the water is determined by the rates of algal production, sedimentation and decay but also by the rate of consumption. In eutrophic lakes, grazing by zooplankton may exceed or equal the production of algae, especially in early summer, as a result of which water clarity can increase sharply (GULATI, 1983). The larger zooplankton species such as *Daphnia magna*, *D.pulex* and *D.hyalina* are especially effective as grazers (GULATI, 1989). In some water bodies, zebra mussels (*Dreissena polymorpha*) can also substantially contribute to the consumption of algae (RICHTER, 1985; RICHTER *et al.*, 1987). Zooplankton are eaten by young fish and by mature fish of many common species, e.g. bream and roach (*Rutilus rutilus*). At the top of the food chain are predatory fish, fish-eating birds and fishermen. Important predatory fish in The Netherlands include pike, pike perch (*Stizostedion lucioperca*), perch (*Perca fluviatilis*) and eel (*Anguilla anguilla*).

In shallow Dutch lakes, before they became hypertrophic, pike used to play an important regulatory role in structuring the food chain (GRIMM, 1985; 1989). However, in most of these lakes eutrophication has led to the disappearance of aquatic vegetation, an essential factor in the habitat of pike (see later). Pike-perch has only partly been able to take over the regulatory role of the pike. Although pike-perch is well adapted to turbid, algae-dominated waters, it is originally a warm-water species; thus its growth in The Netherlands is almost always suboptimal. Summer temperatures strictly determine the success of annual recruitment (WILLEMSEN, 1985), and especially in cold summers the growth of young pike-perch lags behind. At the same time, bream, the primary prey species, grows relatively fast. In such years young bream soon grow too large to be swallowed by pike-perch (VAN DENSEN and GRIMM, 1988).

The bream appears to be exceptionally successful in the turbid waters with sediments rich in benthic organisms and hardly any vegetation that hinders feeding. The reduced risk of predation and the fact that bream can efficiently use zooplankton as well as benthos as a food source (LAMMENS, 1986), are additional factors for the success of bream. Practically all the shallow lakes in The Netherlands are infested with bream (LAMMENS, 1986; VAN DENSEN, 1985; VAN DENSEN *et al.*, 1986). The enormous bream population reduces zooplankton densities and promotes nutrient cycling through bioturbation, leading to an increase in algal biomass. In larger and deeper lakes (4-6 m) in The Netherlands, such as Lake IJssel and Lake Marken, bream are not overly abundant (CAZEMIER, 1986; 1987) because predatory fish (pike-perch, perch and eel) are still able to regulate the prey population.

ECOLOGY OF PIKE AND BREAM

Research at the Organization for the Improvement of Inland Fisheries has given an insight into the ecology of the pike in the Dutch waters (GRIMM, 1981; 1983; 1985; 1989). The survival of this fish appears to be strongly dependent on the availability of refuges, usually provided by aquatic vegetation. Pike need hiding places to reduce the risk of intraspecific predation and to provide cover for their own hunting. Pike are able to swallow prey of a size up to two thirds of their own length and make no distinction among fish species; thus, cannibalism is quite common. Moreover, pike larvae attach themselves to plants for their first few days. In water with abundant aquatic vegetation, the survival of young pike is relatively high and their large numbers can effectively regulate the abundance of young bream.

The interactions among the biota and their environment in shallow, eutrophic Dutch lakes is illustrated in Fig. 2. The reduction in light penetration

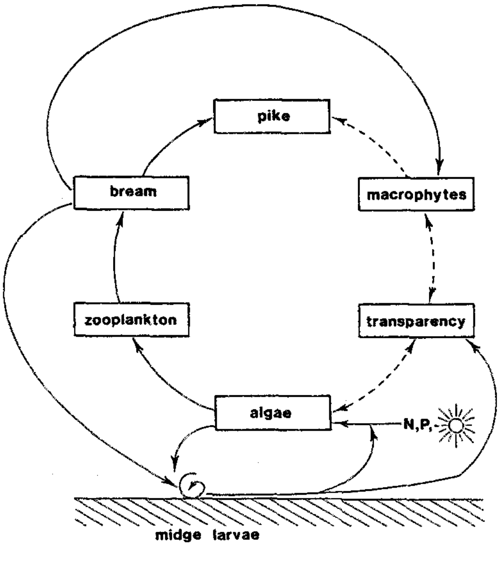

Fig. 2. Interaction among the biota and their environment in shallow, eutrophic Dutch lakes. Increased nutrient loading is leading to more algae, less light reaching the plants, fewer plants, lesser pike, more bream, decrease in large zooplankton, even more algae, *etc.* Bream is feeding on zooplankton as well as on benthic organisms and stirs up the sediments resulting in release of nutrients, increased turbidity of the water, and mechanical disturbance of rooted macrophytes.

accompanying the eutrophication of these lakes has caused elimination of the macrophytes and, indirectly, a decline in the pike populations. With environmental conditions favouring planktonic algae and bream, the larger zooplankton, macrophytes and pike have been virtually eliminated from many systems. The feeding strategies of the bream, as well as their sheer abundance (several hundreds of kg.ha^{-1}; CAZEMIER, 1982; LAMMENS, 1986), tend to impose a homeostasis on the system, resisting the restoration of water quality. The enormous numbers of young bream in the spring decimate zooplankton standing crop, reducing the grazing pressure on phytoplankton. The larger bream grub up the sediments intensively in search of food (mainly midge larvae), processing tens of litres of mud, often to a depth of several centimetres (LAMMENS, 1986). This feeding behaviour promotes nutrient recycling and hampers plant growth through a reduction in light penetration as well as through direct mechanical disturbance of the roots of the plants (TEN WINKEL, 1987). Since bream can live for 15-20 years, the current proliferation of the species may influence water quality for a long time, even if recruitment were effectively suppressed.

PRACTICAL POSSIBILITIES

Clear water, rich littoral vegetation and a strong pike population may be considered as the ecological objective for shallow, originally eutrophic lakes in The Netherlands. The question is how to get from the present hypertrophic, turbid and bream-infested waters to this desired situation. To make restoration possible, the tendency of these systems to resist change must be overcome. Tackling the nutrient loading is of primary importance, but restoration of water quality is hindered by the 'bream effect', and supplementary measures are necessary. The possibilities may in principle be derived from Fig. 2. Artificial reduction of the bream population may be expected to lead to a chain of events in the sequence higher densities of large zooplankton, a lower biomass of algae, clearer water, more macrophytes, more pike, less bream, *etc.* Besides, a radical reduction of the bream stock can contribute to decreased resuspension of the sediments and thus reduced turbidity and nutrient recycling and less mechanical disturbance for the rooting of plants.

For effective reduction of the bream stock, however, not only the older individuals but also the extremely abundant young fish must be caught. The only practical method for the latter is the introduction of young predatory fish. Such forms of fish stock control, involving fishing-out and release of young predatory fish, have successfully been applied to some small (1-5 ha) lakes in The Netherlands (MEIJER *et al.*, 1989b; VAN DONK *et al.*, 1989a and 1989b). The first results show a spectacular increase in transparency and a rapid colonization of macrophytes.

Crucial for the success of such operations is the choice of the right predatory fish. Releasing young pike in 'barren' waters without the appropriate habitat will lead to strong intraspecific predation and a resultant collapse of the population. However, if a rapid colonization of macrophytes is expected just after the bream reduction, the introduction of young pike may be very effective. Pike-perch and catfish (*Silurus glanis*) offer better prospects if the colonization of macrophytes is not so successful and takes more time. Both species are well suited to turbid, algae-rich waters. As noted earlier the problem with the pike-perch population in The Netherlands is that satisfactory growth requires high summer temperatures. A possible solution is the release of young pike-perch which are reared in a fish farm at elevated temperatures, giving them a head start in growth compared with their prey. The catfish is on the list of protected species, so officially it may not be caught or released. Permission has, however, been granted for its use in experimental ponds.

PERSPECTIVES

Interest in biological control is directed primarily at shallow, algae-rich, bream-infested waters. The prospects for effective control of fish populations are the best in isolated waters which are easy to manipulate. An important practical question is whether a single intervention in the fish population will be enough, or whether such measures will have to be taken repeatedly. The answer probably depends on the nutrient loading (BENNDORF, 1987; SCHEFFER, 1989). With a low loading, one intervention may be sufficient to bring the system back to a stable, clear water state. If for practical reasons it is not feasible to reduce the nutrient loading far enough, continuous control of the fish population, may still be needed to maintain the desired water clarity. However, it remains questionable whether a system managed in this way will be properly balanced in plant and animal life. The continued high nutrient loading may well lead to a luxuriant growth of aquatic macrophytes as well as filamentous algae. The necessity of continuous fish stock control may also come from the fact that many Dutch lakes are interconnected by canals, ditches and sluices. Large bream populations may be re-introduced through the connecting canals.

The applicability and effectiveness of the biological control must be clarified by further research in various bodies of water in The Netherlands. After the successful operations in very small lakes (1-5 ha), experiments are in preparation for the larger, but relatively isolated lakes, namely Lake Breukeleveen (180 ha) and Lake Wolderwijd (2,900 ha).

The main questions that have to be answered beforehand, concern the technical implementation of the fisheries (costs, effectiveness) and a prognosis of the response of the system. This prognosis is focussed on the direct effects of bream reduction on transparency and on the colonization rate of macrophytes (pike habitat). In large lakes the direct effects on transparency may be less significant than in small lakes because these lakes are generally more sensitive to the wind-induced resuspension of sediments.

THE ORGANIZATION OF FISH-STOCK MANAGEMENT

Administrative aspects also need to be considered when investigating the possibilities of biomanipulation measures. It is implicit in any plan that measures intended to improve the functioning of the ecosystem are also beneficial for natural scenery, recreation and fishing. The multiplicity of the potential benefit of such a programme is important to bear in mind, because, in The Netherlands, there is a division of responsibilities for the management of fish and water. The Fisheries Act states that fish population control may only be practised by those having fishing rights. Fishing rights in The Netherlands are generally split between scaly fishes and the eel. The rights to fishing and management of the scaly fish are granted to angling organizations. On the other hand, professional fishermen have the rights to catch eel. Thus, both anglers and professional fishermen are legally entitled to take management measures, often in the same body of water. To prevent conflicts of interest, management committees have been set up in which anglers and professional fishermen can agree on approaches for managing fish populations. New management committees should be organized in which water quality authorities participate, especially in planning the application of biomanipulation measures.

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