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The role of fish stock management in the control of eutrophication in shallow lakes in The Netherlands

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Abstract

Eutrophication of Dutch shallow lakes (1-3 m deep) has led to a dramatic change in the structure and functioning of the food web. Over the last twenty-five years littoral vegetation has almost disappeared from Dutch shallow lakes as a consequence of eutrophication. Simultaneously the habitat of the important predator fish pike has disappeared. As a result, bream has reached very high biomasses in most shallow lakes. In controlling eutrophication the national policy is aiming at reduction of nutrient loading of lakes. It seems, however, that a wider variety of measures is needed to speed lake recovery. Fish stock management can be of importance in such an integrated approach. Bream may negatively influence the recovery process as a result of its feeding strategy. In the presence of an abundant planktivorous and benthivorous bream stock, zooplankton grazing of algae is low, and the water may become very turbid. This situation may slow down lake recovery even if the external nutrient loading has been severely reduced. Regulation of the bream population may therefore contribute to solving eutrophication problems by lowering the internal resistance of the ecosystem against changes. Biomanipulation experiments have started recently in small lakes in the Netherlands. The experiments are primarily directed at reducing the bream population by fisheries, and introducing predatory fish. Fish stock management in combination with nutrient reduction may thus help in solving the eutrophication problem by initiating a positive feed back process in the food web that may convert ecosystem structure into a socially desirable, *i.e.*, a stable and highly diverse ecosystem.

1. Introduction

Living in the Netherlands one always has water nearby. Ponds, canals, ditches, lakes, streams and rivers are plentiful and cover a surface area which amounts to about 3500 km^2. These aquatic ecosystems are being used for fishery, recreational boating, swimming, boat traffic, industrial use, drinking water supply and agricultural purposes. Each of these functions makes its own specific demands. These demands can not always be complementary. Industrial discharges and drinking water supply obviously won't go together. Water quality management in the Netherlands focuses on the protection of specific functions of surface waters as mentioned above, but also directly on the protection and development of ecosystems. This latter objective has much in common with the general objectives of fish stock management. Water quality management and fish stock management thus share a common interest. In spite of this there is in the Netherlands a situation in which responsibilities for fish stock management and water quality management are separated by law. In this paper attention is paid to fish stock management as a tool in eutrophication control. Results of recent biomanipulation experiments (regulating fisheries) in eutrophic lakes are given. The results show that this type of lake restoration may speed up recovery processes. This integrated approach of lake restoration may turn out profitable both to managers of fish stocks and water quality, and thus emphasises the need for a dialogue between all parties involved.

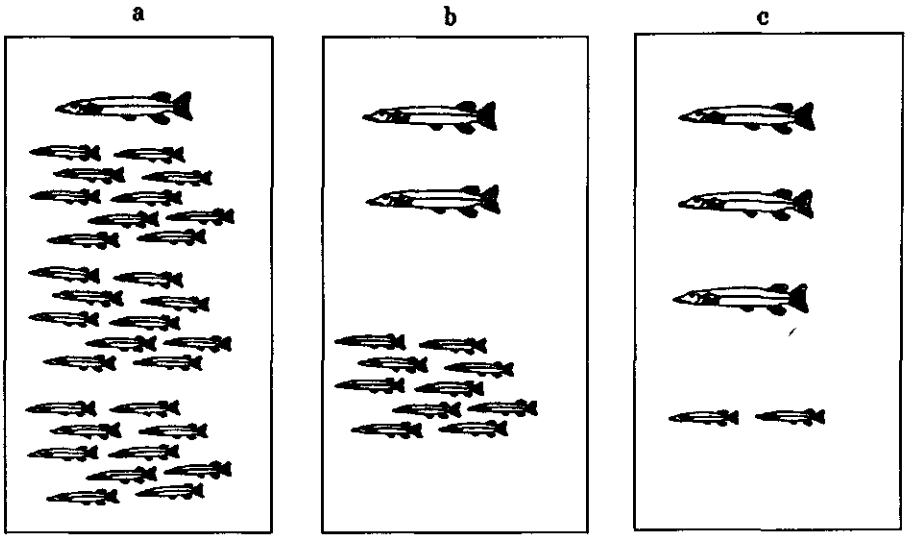


Figure 1. The structure of pike populations in situations where there are decreasing amounts of vegetation. Small pike (<45 cm) protect themselves from cannibalism by hiding among plants. In passing from situation a to situation c, plant growth decreases because of eutrophication, and the structure of the pike population becomes unbalanced (Source: Organisation for the Improvement of Inland Fisheries).

2. Consequences of eutrophication

Eutrophication is a serious problem in Dutch shallow (1-3 m depth) lakes. It has led to a dramatic change in the structure and functioning of the aquatic food chain. In general the eutrophication process can be described as follows. Eutrophication starts with an increase in nutrient load. The water remains clear as the extra nutrients are processed by the abundant littoral vegetation and the lake sediment (ecosystem resistance).

Continuous nutrient loading, however, leads to a prolific growth of filamentous algae upon the higher plants. This results in the disappearance of macrophytes due to a lack of light for growth. This disappearance has drastic consequences for the ecosystem (Van Vierssen, Hootsmans & Vermaat 1985, Carpenter, Stephen & Lodge 1986, Grimm

1985). The most characteristic change is a sharp increase in the abundance of planktonic algae. Persistent nutrient loading eventually leads to permanent bloom of cyanobacteria, which results in a highly stable ecosystem of poor quality.

Over the last twenty-five years, littoral vegetation has almost disappeared from Dutch shallow lakes as a consequence of eutrophication. With the disappearance of submerged vegetation the habitat of the northern pike *(Esox lucius)* was destroyed. The survival of this species has been found to be strongly dependent on the availability of hiding places, which in general are plants or plant remains (Grimm 1981, 1983). Pike hatchlings are attached to plants in the first days of their lives. Pike seek shelter between submerged plants to protect themselves from cannibalism, or to hide themselves when hunting. The relation between hiding places and the structure of a pike population is illustrated in *Figure 1*. In water rich in macrophytes the survival of young pike is relatively high and their large numbers can effectively regulate young bream *(Abramis brama)*. It will be clear that the disappearance of littoral vegetation is an important cause of the decline in numbers of pike, and an increase in those of bream in shallow waters. Bream have found exceptionally good conditions in the algae rich open waters, since these provide an abundant food supply (zooplankton and midge larvae) and greatly reduce the risk of predation. Almost all Dutch shallow lakes are now bream infested (Lammens 1986, van Densen 1985, van Densen, Dijkers & Veerman 1986) with dense populations having biomasses of several hundred kg/ha (Cazemier 1982). This enormous bream stock enhances the algal biomass by reducing the zooplankton density (lowered grazing pressure) and by renewing the supply of nutrients from the lake sediments (bioturbation). Thus, the process of eutrophication has led to a situation in which most Dutch shallow lakes have a life community dominated by algae and bream.

3. Current strategy of eutrophication control

Eutrophication control in the Netherlands aims at reducing the phosphorus load from the environment. Measures are being taken to reduce the phosphorus contents of detergents, to remove phosphate from the effluents of sewage treatment stations, and to lower industrial discharges and the release of phosphorus from agricultural areas. Lowering phosphorus loading should solve the problem of algal blooms by lowering lake productivity. Despite major efforts over the past few years, hardly any recovery can be seen at all. We think that biological feedback mechanisms underlie this lack of recovery. In the process of eutrophication, a critical threshold in nutrient concentrations has to be exceeded before any biological response by the system may be seen *(Figure 2)*. In the same way it might be expected that in lake restoration programmes, nutrient concentrations have to be reduced to a certain threshold value before a response can be expected. In fact, two levels have to be passed before changes can take place. As a first step it is necessary to remove the nutrient store in the lake to make phosphorus or nitrogen a limiting factor for algal growth. A positive biological response of the system may then follow directly, but usually a second step is needed because of the internal resistance of the ecosystem to changes. Large quantities of detritus have been formed on the bottoms of the shallow lakes from the abundant algae. Benthivorous fish, feeding on this, may then increase nutrient concentrations and turbidity, thus lowering the effectiveness of measures aimed at reducing nutrient loadings from external sources. Release of phosphorus from lake sediments is another factor which can frustrate lake recovery. High algal biomass can maintain a big flux of phosphorus from the lake sediment. In summer this internal flux may be as high as the external phosphorus loading of the lake (Boström, Jansson & Forsberg 1987). These feedback mechanisms oblige the water quality manager to put an extra effort into reducing the phosphorus load of the lake before the primary objective of the restoration programme, lowering the algal biomass, can be achieved. When this goal is reached problems still remain to be solved. Ecosystem quality stays rather poor as plant growth is impaired by large quantities of benthivorous bream which turn up plant roots (ten Winkel & Meulemans 1984). Large quantities of new born bream may decimate the zooplankton, thereby reducing the consumption of algae. As bream can live up to an age of 20 years the present heavy infestation of bream in the Dutch shallow lakes may continue to influence water quality for a long time. These biological mechanisms lead to the conclusion that solving the eutrophication problem simply by reducing the (external) phosphorus load will be successful in the long term, but a very time consuming method.

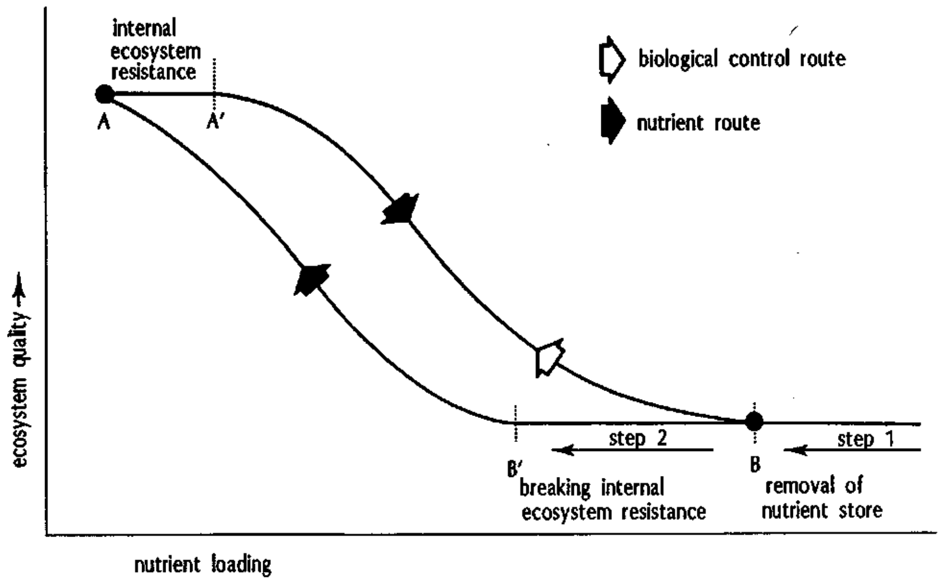


Figure 2. Diagram representing ecosystem quality in response to nutrient loading. Nutrient loading beyond optimal situation A leads to ecosystem decay (A' to B) after a period of internal ecosystem resistance. Beyond point B, ecosystem delay is limited by other factors (e.g. light). Lake restoration by nutrient reduction is a two-step process (dark upward arrow). Biological control methods may speed up lake recovery (light arrow) by altering threshold concentration B' into B (adapted from Hosper, Meijer & Jagtman 1987).

4. Objectives from the viewpoint of fish stock management

In the preceding paragraphs it was recognized that eutrophication leads to ecosystem decay. From the viewpoint of water quality management this is a problem because protection and development of the ecosystem is a general objective. Clearly, from the viewpoint of fish stock management, eutrophication is a problem too. Fish make demands on their environment. Their basic needs are good water quality, a sufficient supply of suitable food, an opportunity to find cover (vegetation), good spawning conditions and migration opportunities. Eutrophication interferes with many of these demands. Individual growth of cyprinids, for instance, is poor in most eutrophic lakes, as a consequence

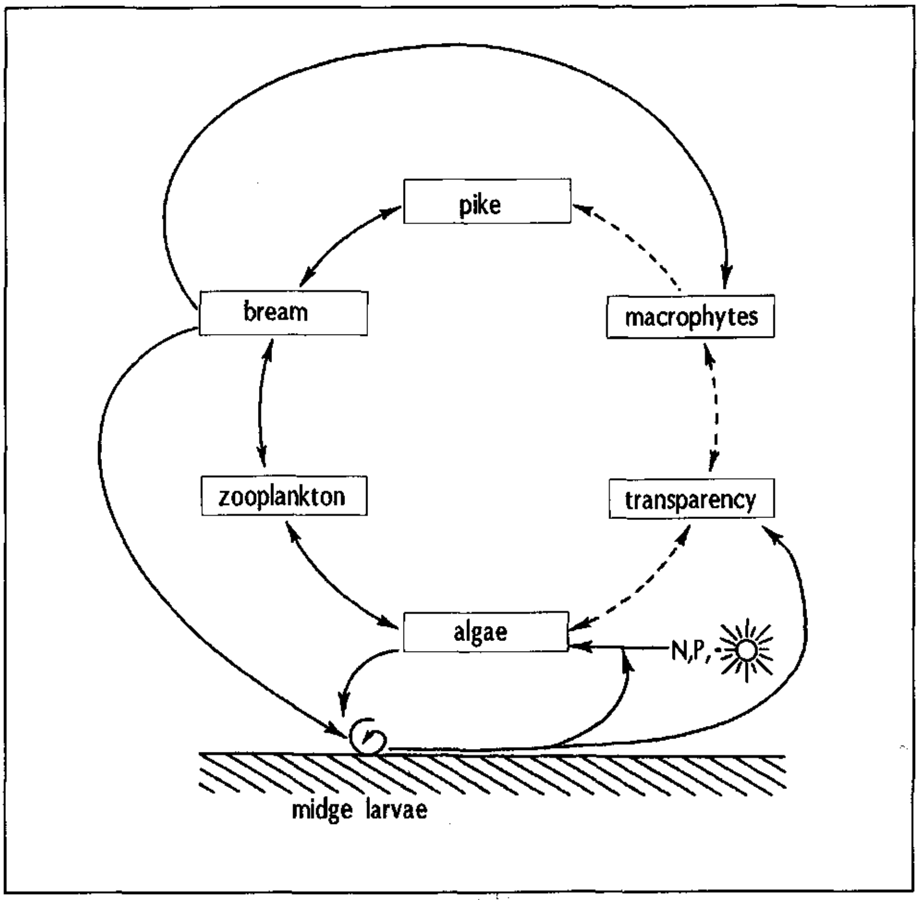


Figure 3. Principal food chain relations in a eutrophic lake. Algae and bream dominate, resulting in turbid water (negative spiral). Zooplankton, pike and macrophytes are few in number (from Hosper *et al.* 1987).

of the density of the stock present. Fishery organizations have determined this and seek remedial measures. The eutrophication of Dutch inland waters has to be reduced (Feith 1982, NVVS 1985). An overcrowded stock of cyprinids is recognized as an effect of eutrophication and although regulating fisheries are considered useful in reducing this stock, it is believed that these measures only take away the symptoms of eutrophication (NVVS 1985). Reduction of nutrient loading has to be the main objective. Without nutrient reduction the eutrophication problem will not be solved. It is important that fisheries regulation does more than 'just take away the symptoms of eutrophication'. By regulating the cyprinid stock in a eutrophic lake, conditions are set which favour a switch to a more diverse ecosystem. Considering the biological feedback mechanisms in an eutrophic lake, it might even be expected that the critical threshold concentration at which lake recovery sets in might be altered in a positive way. Objectives like species diversity, good growth of the fish stock, and the presence of pike and rudd *(Scardinius erythrophthalmus)* (NVVS 1985) thus come within reach. This is a strong argument for using biological measures in parallel with nutrient load reducing measures in eutrophication control.

5. Biological control in practice

How can we get from the situation of turbid, algal-rich, bream-infested water, to one of clear water, a rich littoral vegetation and a strong pike population? This question was raised when we started to think about the possibilities of biological control methods in water quality management. On the basis of preliminary research (Meijer *et al.* 1987), literature reviews (Richter 1985) and interviews with fish scientists, a theory was developed which proved helpful in choosing the key elements in the food chain at which to direct measures (Hosper, Meijer & Jagtman 1987). The principle food chain relations are depicted in *Figure 3* . Reducing the nutrient load is the primary objective to decrease the biomass of algae. When nutrient concentrations start to limit the growth of algae the importance of biological measures grows. Artificial reduction of the bream population may lead to an increase in the number of (large) zooplankton, which causes, through their grazing, a lower algal biomass. In turn this may lead to clearer water, chances for higher plants to grow, the return of pike, an increase in predation of bream and more zooplankton etc. A positive spiral may thus be set in motion. Less re-suspension of sediments as well as the reduced disturbance of rooted macrophytes also brings about positive feedback processes leading to the desired lake conditions.

Pikeperch *(Stizostedion lucioperca)* is known to be able to maintain itself in turbid algal-rich waters. This makes it a suitable predatory species for reducing the large numbers of cyprinids in eutrophic lakes. There is probably little point in releasing young pike in 'bare' waters, due to the strong intraspecific trait of cannibalism. Considering this, pikeperch seemed to be the most attractive species to experiment with. Following successful pond experiments in 1986 (Meijer *et al.* 1987), it was decided to start experiments under natural conditions in 1987. The results of two of these experiments are discussed in the following section.

Table 1. Data on fish removed from the Galgje compartment in the Bleiswijkse Zoom in April 1987 (from Meijer, Raat & Doef 1988).

Species	length (cm)	number	weight (kg)
Stizostedion lucioperca (pikeperch)	< 12	200	0.4
	12-22	11	0.7
	22-37	205	55.3
	37-46	101	73.4
	>46	45	96.9
Subtotal:			226.7
Abramis brama (bream)	8-16	33 521	636.5
Blicca bjoerkna (silver bream)	16-24	398	41.3
	24-29	158	45.1
	29-34	219	110.8
	>34	455	353.8
Subtotal:			1 187.5
Cyprinus carpio (carp)		108	550.0
Esox lucius (pike)		5	16.3
Perca fluviatilis (perch)		7	0.8
Rutilus rutilus (roach)		63	1.4
Carassius carassius (crucian carp)		3	1.5
Anguilla anguilla (eel)		62	
Total weight removed:			*circa* 2 000

6. Case studies

6.1 Case 1: Bleiswijkse Zoom (Meijer, Raat & Doef 1988)

The Bleiswijkse Zoom system of three small inter-connected lakes, covering a total of 14.4 ha, was formed in 1970 for recreational purposes. In its first years of existence the system was characterised by high phosphorus concentrations (0.4 mg/l) resulting in peak chlorophyll levels of 300 g/l and a transparency depth of about 0.2 m. In 1986 the question was raised as to whether fish stock management could help in improving water quality. In co-operation with the Organization for the Improvement of Inland Fisheries, which uses the lakes for research purposes, a management scheme was devised which aimed at controlling the rather dense stock of cyprinids. The lake system was divided into two

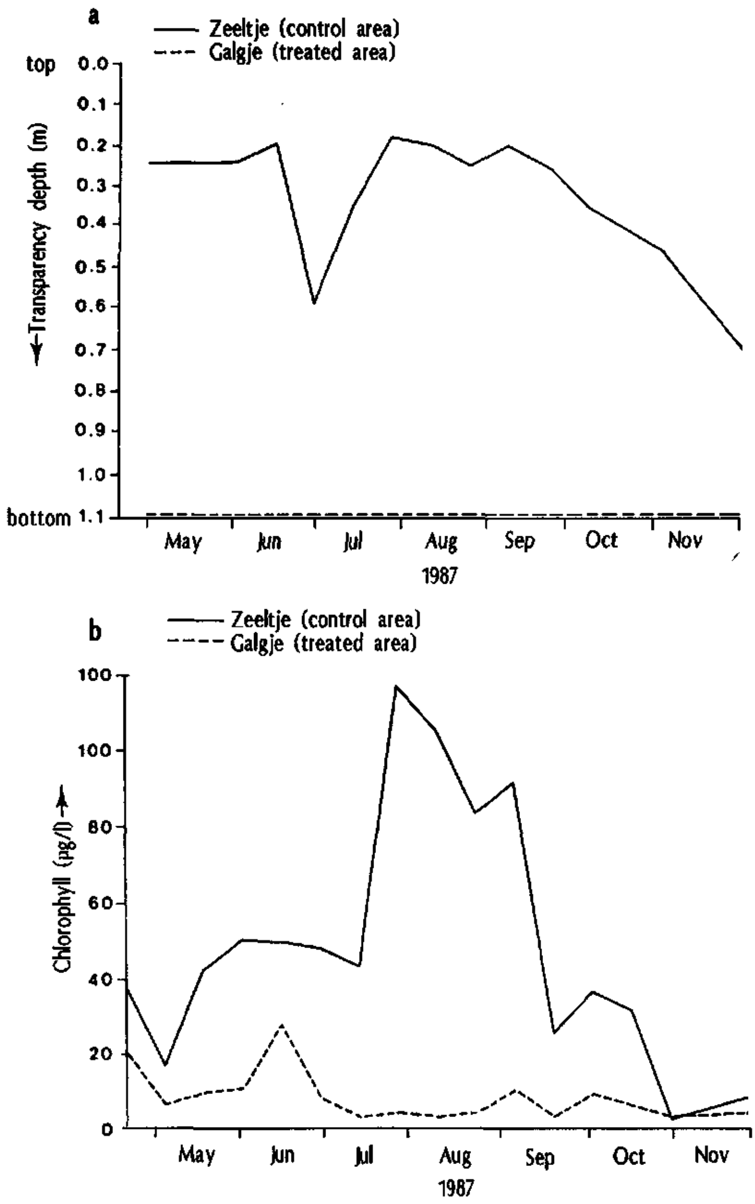


Figure 4. Changes in the Bleiswijkse Zoom following management of the fish stock in April 1987. a. transparency depth. b. chlorophyll concentration (from Meijer *et al.* 1988).

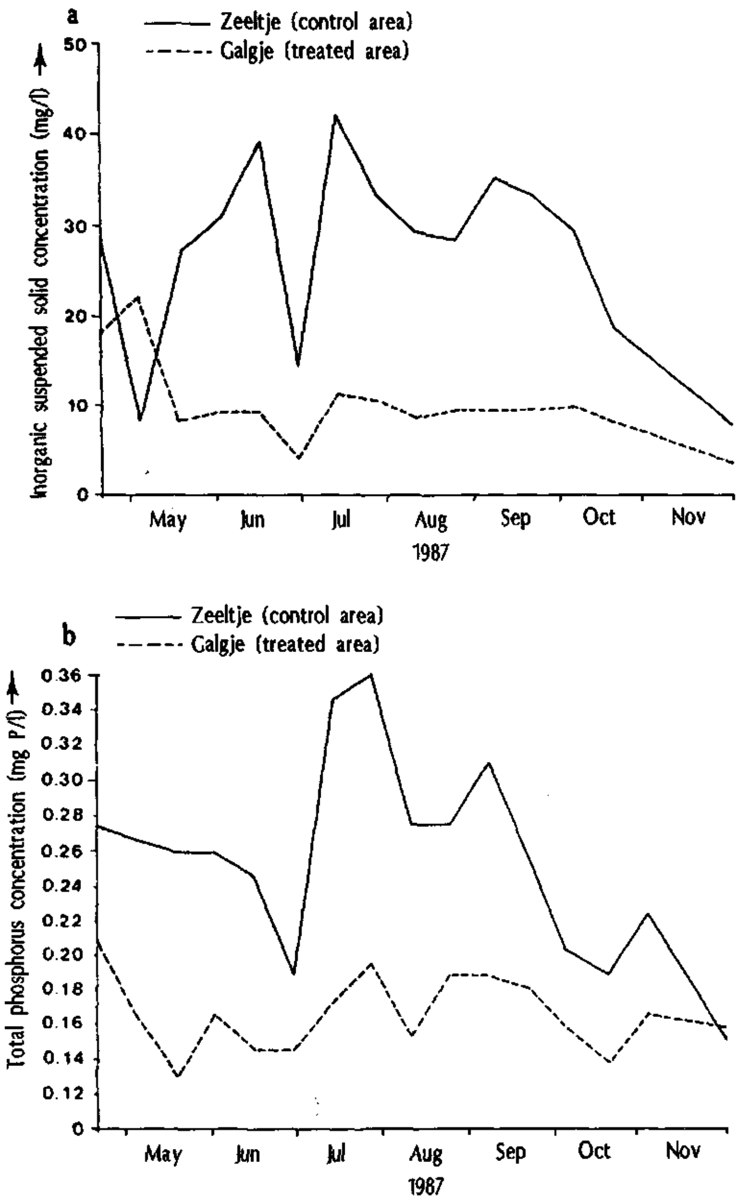


Figure 5. Changes in the Bleiswijkse Zoom following management of the fish stock in April 1987. a. inorganic suspended solid concentration. b. total phosphorus concentration (from Meijer *et al.* 1988).

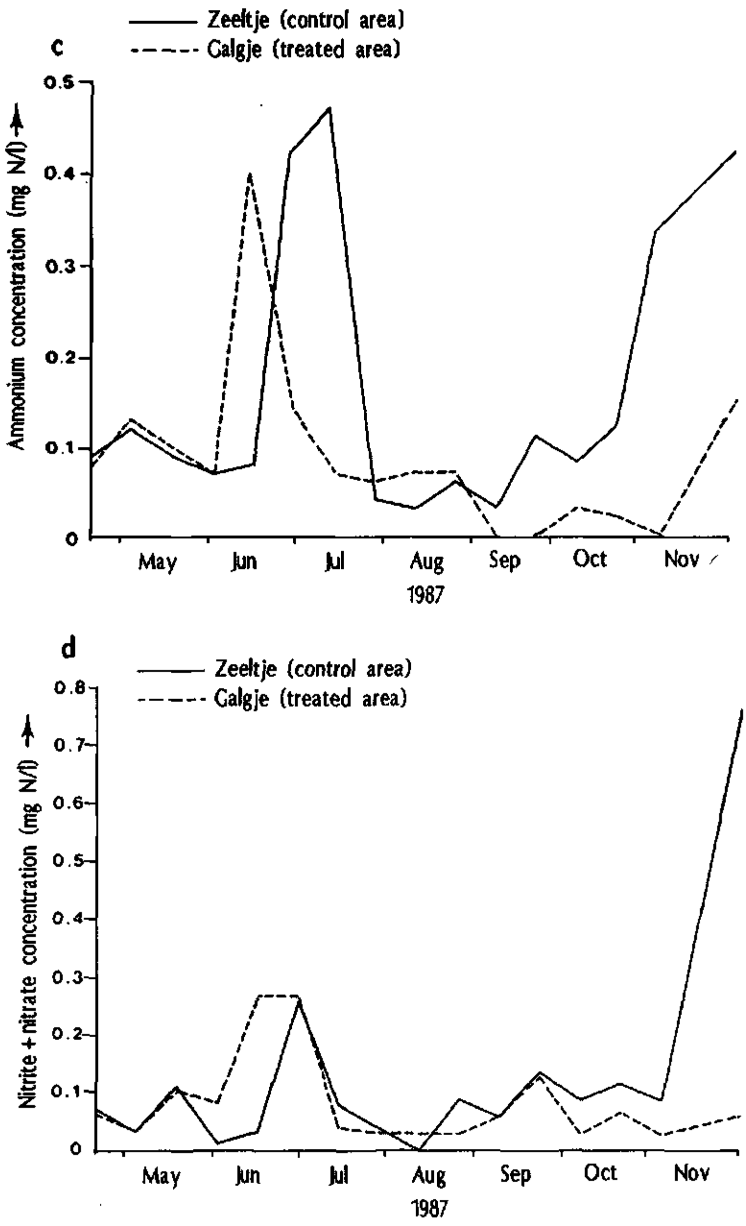


Figure 5. Changes in the Bleiswijkse Zoom following management of the fish stock in April 1987. c. ammonium concentration. d. nitrite and nitrate concentration (from Meijer *et al.* 1988).

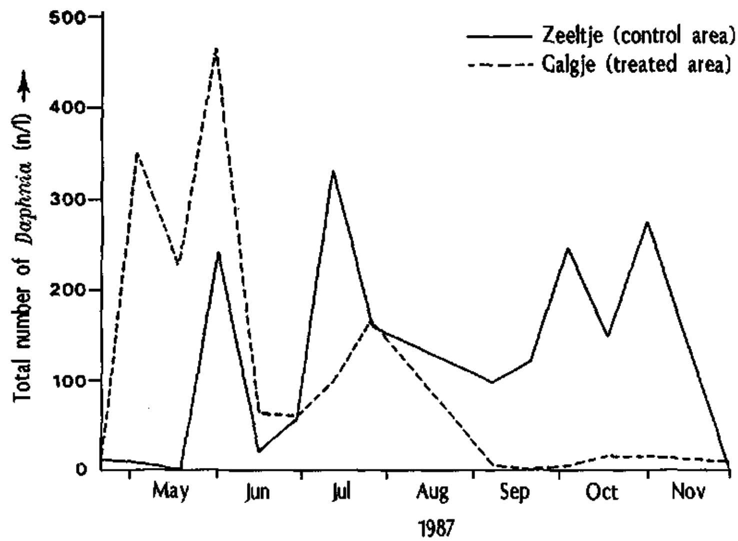


Figure 6. Total number of *Daphnia* in the Bleiswijkse Zoom following fish stock management in April 1987 (from Meijer *et al.* 1988).

compartments called Galgje (3.1 ha; treated area) and Zeeltje (11.3 ha; control area). Water quality in these two compartments was similar before treatment. After being separated by a dam, exchange of fish between the compartments could not occur. The treatment of the Galgje compartment consisted of removing about 2000 kg of fish *(Table 1)*, mainly (1200 kg) bream and silver bream *(Blicca bjoerkna)*, carp *(Cyprinus carpio)* (500 kg) and pikeperch (200 kg). By the end of April 1987 1200 young pikeperch of 2.5 cm length were introduced to regulate newly born bream from the residual bream stock. In the Zeeltje compartment no treatment was undertaken. Within a few weeks of treatment water quality had improved tremendously in the Galgje compartment *(Figures 4a, b, 5a, b, c, d)*. Nutrient and suspended solid concentrations were reduced, chlorophyll levels were extremely low and transparency had increased to 1.1 m (the bottom). Macrophytes, predominantly *Chara vulgaris* var. *longibracteata*, grew rapidly. Large zooplankters like *Daphnia hyalina* first increased rapidly, but their numbers dropped from June onwards *(Figure 6)*. However, algal biomass remained low, despite the reduced grazing by zooplankton. There are indications that the prolific growth of Characeae has something to do with this. Allelopathy may have suppressed the growth of the algae, but it is possible that a lack of nutrients (nitrogen) may have been a limiting factor. By contrast, in the Zeeltje compartment no improvement was seen. However, the growth and survival of the newly introduced pikeperch was poor, presumably due to the dense vegetation (100% cover) which would have hindered them when hunting. In fact, surprisingly, the measures taken resulted in the development of a pike habitat rather than a pikeperch habitat (more open water). Since pike had been almost totally removed from the system, and their numbers are still low, a number of young pike will be re-introduced in 1988.

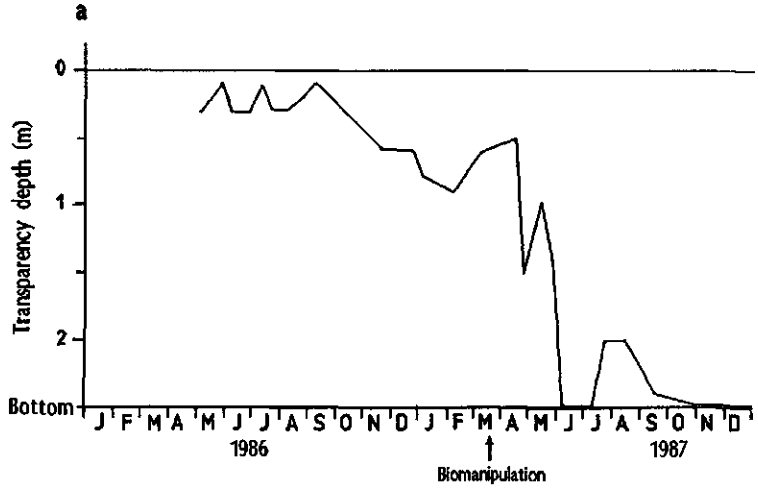
Measures taken resulted in the fast recovery of the Galgje compartment, with ecosystem alterations being in line with expectations and we anticipate that the presence of macrophytes will now stabilize the ecosystem (Scheffer 1989). Ecosystem monitoring will be continued for the coming three years.

Table 2. Data on fish removed from Lake Zwemlust (March 1987) by seine-netting and electro-fishing (From van Donk, Slim & Grimm, 1988).

Species	length (cm)	number	weight (kg)
Abramis brama (bream)	>20	116	99.4
	10-20	10 005	435.0
	<10	6 208	50.6
Rutilus rutilus (roach)	>10	4 025	64.0
	<10	2 912	24.7
Esox lucius (pike)		44	56.6
Leucaspius delineatus		18 547	30.8
Scardinius erythrophthalmus (rudd)	>20	4	1.0
	10-22	223	5.5
	<10	115	0.6
Blicca bjoerkna (silver bream)		575	9.2
Anguilla anguilla (eel)		24	15.7
Tinca tinca (tench)		7	6.4
Cyprinus carpio (carp)		1	6.4
Perca fluviatilis (perch)	>20	9	3.2
	<20	357	1.7
Stizostedion lucioperca (pikeperch)		1	0.2
Total number and weight removed:		43 173	811.0

6.2 Case 2: Lake Zwemlust (van Donk, Slim & Grimm 1988, van Donk, Gulati & Grimm 1987)

Lake Zwemlust is a shallow (mean depth 1.5 m) hypertrophic lake of 1.5 ha in the centre of The Netherlands. Low transparency depths (0.1-0.3 m) and algal blooms *(Microcystis aeruginosa)* have characterised this lake for years at a stretch. Lake Zwemlust is in use as a natural swimming pool and water quality was not very attractive for recreational activities. The common strategy of reducing the phosphorus loading of the lake to induce



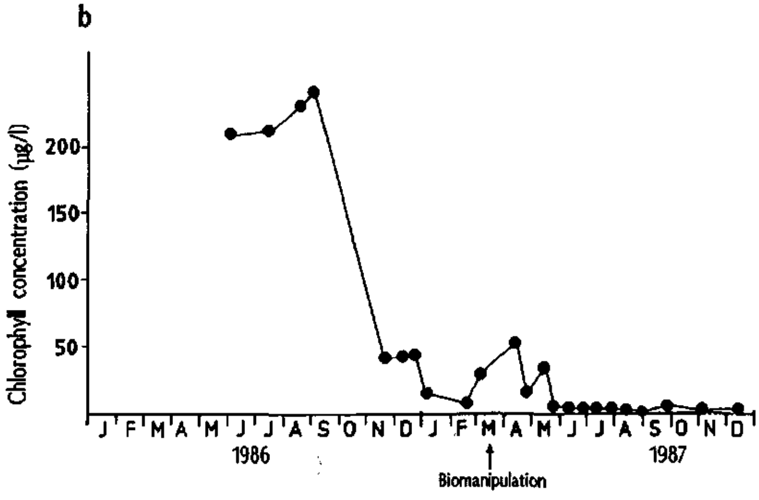


Figure 7. Changes in Lake Zwemlust before and after biomanipulation in March 1987. a. tranparency depth. b. chlorophyll concentration (from van Donk *et al.* 1988).

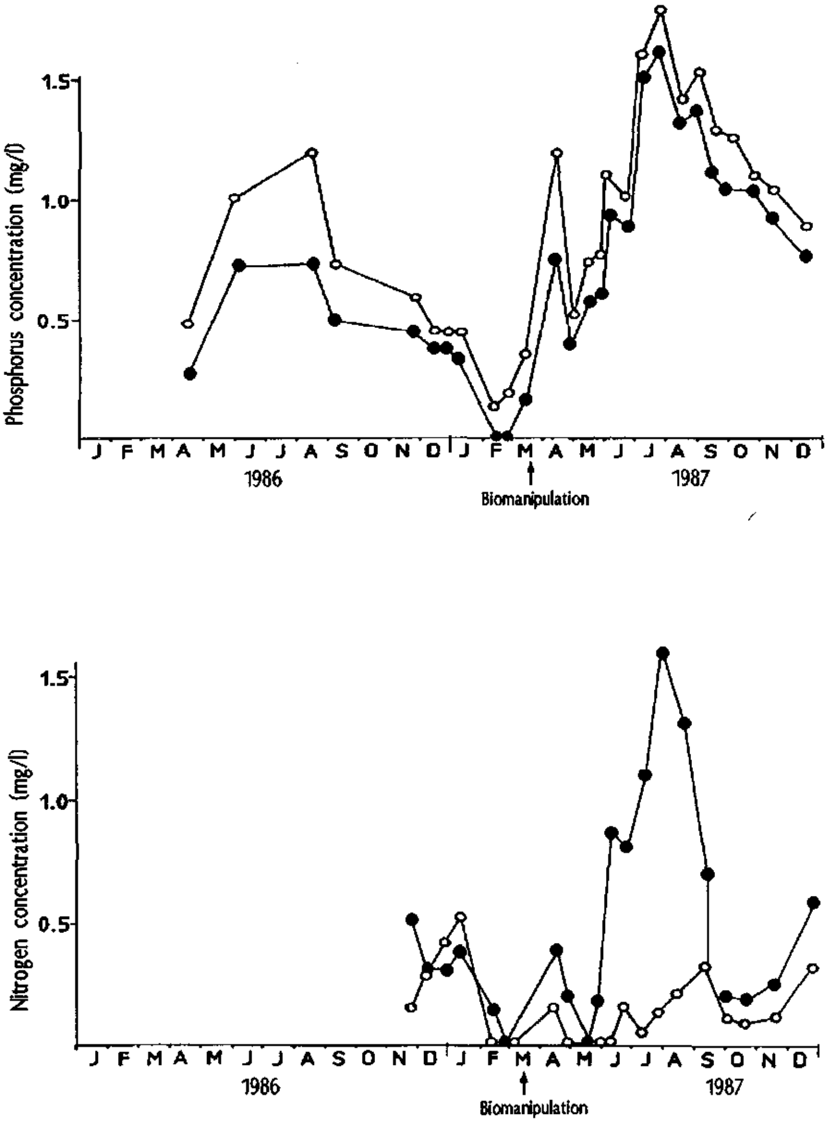


Figure 8. Changes in Lake Zwemlust before and after biomanipulation in March 1987. a. Phosphorus concentration . ● orthophosphate, **O** total phosphate. b. nitrogen concentration, ● ammonium, **O** nitrate.

lake recovery proved not to be possible, as this lake only receives seepage water from the nearby nutrient rich River Vecht. The tool of fish stock management was therefore tested. Measures taken consisted of draining the lake by pumping, and eliminating the predominantly planktivorous and benthivorous fish population *(Table 2)* by seine-netting and electro-fishing. The lake was subsequently restocked with 1500 northern pike fingerlings and a low density of rudd as food supply for the pike. Stacks of willow twigs, roots of *Nuphar luteum* and seedlings of *Chara* sp. were brought in as a refuge and spawning place for the pike and as shelter for the zooplankton.

These measures resulted in increased transparencies of 1-2 m *(Figure 7a)*, low chlorophyll levels, below 5μg/l *(Figure 7b)*, and a dense zooplankton population, predominantly *Daphnia* sp. In contrast to the Bleiswijkse Zoom system, nutrient concentrations remained extremely high *(Figures 8a* and *b)*. This is probably due to the dominant effect of seepage, whereas in the Bleiswijkse Zoom system, nutrient concentrations dropped as a result of reduced bioturbation by bream and carp. Growth of rudd was extremely good due to the abundant food supply. Survival of the stocked pike was low, as expected, due to cannibalism and a lack of fish larvae to feed upon. Midge larvae and zooplankton were dominant elements in the diet of the pike. Finally, growth of macrophytes was good, but was hampered by the development of large green algae like *Hydrodyction* sp. and *Enteromorpha* sp. These results are generally in line with expectations. The anticipated decrease in the biomass of cyanophyceae, due to enhanced zooplankton grazing, was confirmed experimentally and led to increased transparency. Growth of macro-algae may however, pose a threat to continued macrophyte development and may eventually affect ecosystem stability. In this way the Zwemlust and Bleiswijkse Zoom systems have exhibited differential development.

7. Concluding remarks

Preliminary results of managing fish stocks to reduce eutrophication in Dutch shallow lakes are hopeful. Expectations of ecosystem development after regulating fisheries are confirmed in general. Even when extremely high nutrient concentrations are present, ecosystem quality seems to be capable of improvement following fish stock management. Subsequent development of macrophytes is a key factor in stabilizing newly recovered ecosystems. Macrophytes may reduce nutrient concentrations, but it seems that, conversely, high nutrient concentrations decrease the chances of continuous macrophyte development. So the basic need to reduce nutrient loadings remains and is crucial. It is however, important to recognize that fish stock management may effect nutrient concentrations as well, either in a positive or a negative way, depending upon the density and composition of the stock present. This is a strong argument for all parties involved discussing the possibilities of integrated lake management, notwithstanding the current situation of responsibilities being separated. Effective fish stock management may speed up lake recovery by reducing eutrophication problems and bringing about the possibility of a new ecosystem equilibrium. The stability of this new ecosystem equilibrium will depend upon the trophic state of the lake. Research will be continued to find out which level of nutrient concentration may be considered 'safe' for retaining a socially desirable, stable and diverse ecosystem.

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