Royal Netherlands Academy of Arts and Sciences (KNAW)

Ecological management of aquatic ecosystems: a complementary technique to reduce eutrophication-related perturbations.

Van Donk, E.; Gulati, R.D.

published in
Terrestrial and Aquatic Ecosystems: Perturbation and Recovery
1991

document version
Publisher's PDF, also known as Version of record

document license
CC BY

Link to publication in KNAW Research Portal

citation for published version (APA)
Van Donk, E., & Gulati, R. D. (1991). Ecological management of aquatic ecosystems: a complementary technique to reduce eutrophication-related perturbations. In O. Ravera (Ed.), *Terrestrial and Aquatic Ecosystems: Perturbation and Recovery* (pp. 566-575). Ellis Horwood.

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the KNAW public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain.
- You may freely distribute the URL identifying the publication in the KNAW public portal.

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:
pure@knaw.nl

Download date: 27. Apr. 2025

6.8

Ecological management of aquatic ecosystems: a complementary technique to reduce euthrophication-related perturbations

E. Van Donk
Agricultural University, Department of Nature Conservation, Laboratory of Aquatic Ecology, PO Box 8080, 6700 DD Wageningen, The Netherlands
R. D. Gulati
Limnological Institute, Rijksstraatweg 6, 3631 AC Nieuwersluis,
The Netherlands

INTRODUCTION

Anthropogenic perturbations have led to severe eutrophication of lakes and reservoirs throughout the world (Vollenweider 1976). High levels of phosphates and nitrates from household wastewater and from fertilized agricultural fields have led to nutrient-rich waters. These high nutrient levels favour phytoplankton growth especially of cyanobacteria in summer (Mur *et al.* 1978). The ensuing high turbidity leads to disappearance of most of the submerged macrophytes. The decline of water plants, both emergent and submerged, has several consequences. Piscivorous fish, such as pike (*Esox lucius*), require macrophyte stands which to spawn as well as to serve as a refuge for the larvae and young fish. Without such a refuge the young pike become highly vulnerable to piscivore predation, both intra- and interspecific (Grimm 1983), resulting in a drastic population decline.

In the absence of plants the sediment can become loose and unstructured, leading to frequent resuspension of bottom materials by benthivorous fish and wind, which again increases the turbidity. Cyprinids (bream, roach, tench, rudd and carp) prefer turbid, nutrient-rich conditions but salmonids (trout) and percids (perch and pike-perch) do not (Andersson 1987). The planktivorous young cyprinids visually select large and slow-moving zooplankters as prey, like large-sized daphnids. A decrease in grazing pressure on the phytoplankton that results leads to a further increase in phytoplankton abundance.

Traditionally attempts to alleviate eutrophication have been through control nutrient loading (Vollenweider 1976). This generally does not lead to improvement in water quality (Moss *et al.* 1986, Van Liere 1986, Andersson 1987). One theory that explains this is that of two stable states, one dominated by aquatic plants, the other by phytoplankton (Scheffer 1989). The buffering capacity of each state spans a wide range in nutrient loads and reduction of nutrients alone seems insufficient to switch from one state to the other (Scheffer, 1989). Amounts of phosphate and nitrate in the sediments are considerable and thus contribute to the continuing nutrient loading of the water under suitable redox conditions (Moss *et al.* 1986). Removal of these nutrient-rich sediments led to an improvement in water quality in some lakes, e.g. Cockshoot Broad (Moss *et al.* 1986) and Lake Trummen (Andersson *et al.* 1978), although in both cases the improvement lasted for only four years. The removal of sediment on a large scale is also impractical from the viewpoint of expense and disposal problems.

Studies on the dynamics of the zooplankton community have shown that the impact of planktivorous fish can cause a shift from large herbivores (e.g. *Daphnia*) to smaller ones (e.g. *Bosmina*) (Lynch 1979, Leah *et al.* 1980). Relieving this predation pressure should lead to a shift back to large herbivores and a subsequent increase in grazing pressure on the phytoplankton. The mechanism by which this can be realized is the manipulation of the fish stock. The possibility of using mussels, e.g. *Dreissena polymorpha,* in controlling cyanobacterial blooms, was suggested only recently (Reeders *et al.* 1989). The filtering capacity of a sufficiently large population can accomplish a reduction in algal biomass and hence an increase in water transparency.

These manipulations of the biotic communities, such that the system itself becomes involved in controlling the algal problem, were termed 'biomanipulation' by Shapiro *et al.* (1975). More recently the terms 'ecological management', 'ecotechnology' or 'top-down food-web control' have been used to describe manipulations of biotic factors in the ecosystem (Benndorf *et al.* 1988). Simplified food-web relationships and the levels at which nutrients and ecological management may have effect are shown in Fig. 1.

In this chapter we explore the possibilities of applying ecological management measures to improve water quality in the inland waters of the Netherlands, based on our recent experiences (Gulati 1989, Meÿer *et al.* 1989, Reeders *et al.* 1989; Van Donk *et al.* 1989).

METHODS

Ecological management of control phytoplankton growth can be carried out in several ways: (A) removal of planktivorous and benthivorous fish; (B) restocking with piscivorous fish and zooplankton; (C) placing of refuges for piscivorous fish and zooplankton; (D) enlargement of substrate for filtering mussels.

(A) All or most of the planktivorous fish and benthivorous fish can be removed by intensive fishing or using a fish poison like rotenone. This method is often applied in combination with method B because the planktivores are likely to return sooner or later either from increase of residual populations or reintroduction from other water bodies by water-birds (which may transport fish-eggs adhering to their body) or by the public (Meijer *et al.* 1989, Van Donk *et al.* 1989). The use of rotenone is

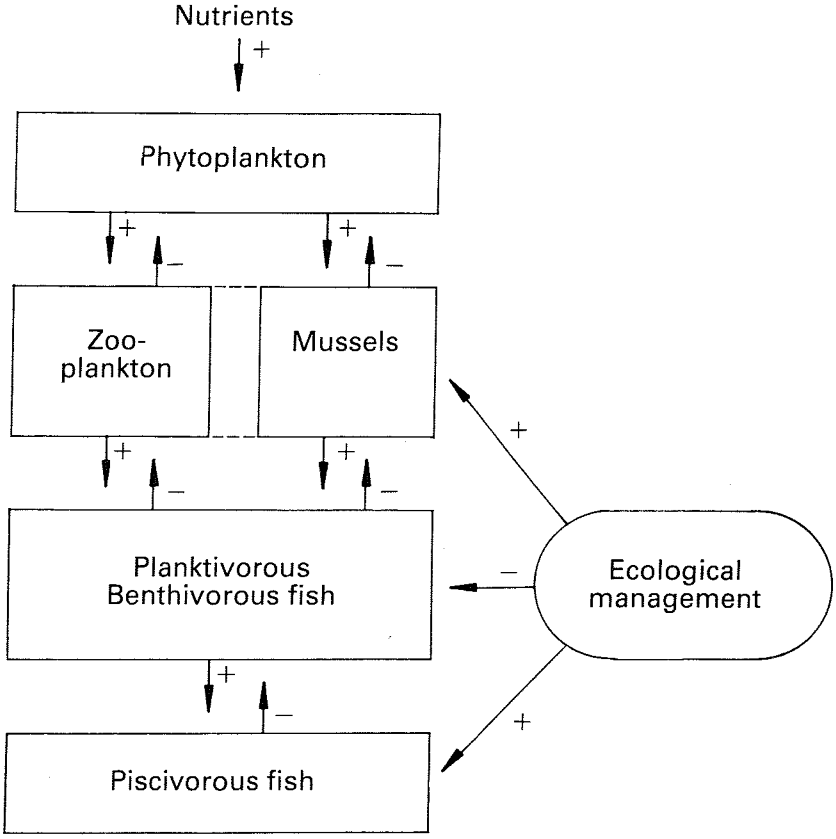

Fig. 1 — A simplified diagram of food-web relationships and the levels at which nutrient and ecological management have effect.

permitted in Scandinavian countries (Reinertsen & Olson 1984) and the USA (Shapiro & Wright 1984), but not allowed in the Netherlands.

(B) Restocking with piscivorous fish and sometimes also with inocula of zooplankton (Van Donk *et al.* 1989): application of measures A and B does not always ensure long-term success. Planktivores are likely to be decreased sufficiently if the piscivores become planktivores or cannibalistic. To prevent this, one may also apply measure C.

(C) Refuges allow maintenance of zooplankton and piscivores on a long-term basis without continuous need to manage the fish populations. Piscivores may use macrophyte refuges or artificial refuges, e.g. willow twigs fixed to the bottom for spawning and shelter against cannibalism. Zooplankton need refuges as shelter against visual predation by planktivores (Irvin *et al.* 1990). According to Shapiro (1990) the following possibilities for zooplankton refuges exist : (1) regions of low light intensity brought about by either depth, humic compounds or silt; (2) low-temperature regions that are inhabitable by zooplankton but not by plantivorous fish; (3) regions of low dissolved oxygen concentration inhabitable by herbivores but not by planktivorous fish; and (4) macrophytes or other physical refuges inhabitable by prey but not by their predators.

(D) Enlargement of the density of filter feeders, like mussels, by manipulating the substrate (Reeders *et al.* 1989): the population of *Dreissena* can be manipulated by addding shells and stones. Besides clearing the water of phytoplankton by grazing on it, the mussels act as phosphate pumps by removing particle-bound phosphate from the water column and depositing it to the bottom as pseudo-faeces. The deposited phosphate is adsorbed onto the sediment (Stanczykowska, 1984).

Some Dutch examples of methods used

The applicability and effectiveness of ecological management measures have recently been tested in the Netherlands in several shallow lakes dominated by cyanobacteria (Lake Zwemlust, Lake Bleiswijkse Zoom, Lake Noorddiep, Lake Breukeleveen) (see papers in Van Donk & Gulati 1989). In most of these whole-lake experiments a combination of ecological management measures was applied.

In Lake Zwemlust (1.5 ha; $\bar{Z}$ 1.5 m; external P load 2.2 g P m^{-2} yr^{-1}) all the fish (800 kg ha^{-1}, 75% *Abramis brama*) were removed by fishing and pumping out the water in March 1987. The lake was restocked with pike fingerlings and adult rudd (*Scardinius erythrophthalmus*) offspring, which served as food for pike. Stacks of willow twigs were fixed and roots of *Nuphar lutea* were planted to the bottom to provide refuges for pike and zooplankton (Van Donk *et al.* 1989).

From Lake Bleiswijkse Zoom (3.1 ha; $\bar{Z}$ 1.1 m; external P load 0.4 g P m^{-2} yr^{-1}) and Lake Noorddiep (4.5 ha; $\bar{Z}$ 1.1 m; external P load 0.2 g P m^{-2} yr^{-1}) about 85% of the planktivorous fish and benthivorous fish were removed by fishing in March 1987 (Meijer *et al.* 1989). Lake Bleiswijkse Zoom was restocked with pike-perch (*Stizostedion lucioperca*).

For Lake Breukeleveen (180 ha; $\bar{Z}$ 1.5 m; external P load 0.5 g P m^{-2} yr^{-1}), the inflow water entering the Loosdrecht Lakes has been dephosphorized by coagulation with $FeCl_3$ since mid-1984 (Van Liere 1986). Even though in this lake the external phosphorus load has been reduced to one-third, viz. from about 1.6 g P m^{-2} yr^{-1} in 1983 to about 0.5 g P m^{-2} yr^{-1} at present, the water transparency has not improved. In March 1989 about 85% of the planktivorous fish and benthivorous fish were removed by fishing with seine-nets. The lake was restocked with 70 000 pike fingerlings and zooplankton (about 32×10^6 daphnids, *Daphnia pulex* and *D. hyalina*) (Van Donk *et al.* 1990).

The applicability of mussels was tested in an experimental pond (25×25 m) separated from Lake Wolderwijd by a dam to allow exchange of water with lake. Thus conditions in the pond reflected those in the lake (Reeders & Bij de Vaate 1990). A cage containing mussels was placed in the pond.

RESULTS AND DISCUSSION

The experiments in the small lakes (1–5 ha), namely Lake Zwemlust, Lake Bleiswijkse Zoom and Lake Noorddiep, were successful. Within two months after the fish removal there was a shift in zooplankton from small-sized to large-sized species, which resulted in a dramatic decrease of the total phytoplankton biomass and increase in Secchi-disc transparency values (Gulati 1989, Meijer *et al.* 1989, Van Donk *et al.* 1989). As an example, in Fig. 2 are given the concentrations of the large-sized cladocerans (*Daphnia magna; D. pulex* and *D. hyalina*) and chlorophyll-a before and after ecological management in Lake Zwemlust. Before the manipulation of the small lakes submerged macrophytes were absent due to the low water transparency (Secchi depth 10–15 cm). However, one year after the operation, when the transparency was increased, 60–80% of the bottom area was covered by macrophytes (Ozimek *et al.* 1990).

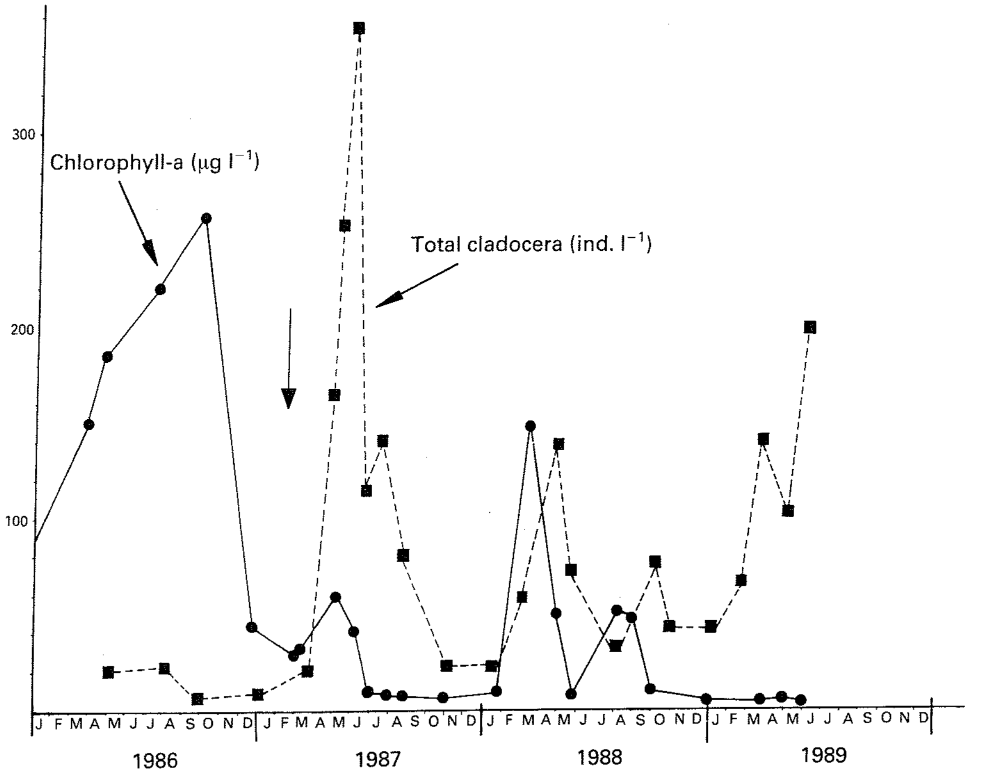

Fig. 2 — The concentrations of chlorophyll-a and cladocerans in Lake Zwemlust before and after ecological management.

A negative effect of the luxurious plant growth was that some species, like *Elodea nuttallii* in Lake Zwemlust, growing through the entire water column, interfered with the recreational use of this lake. Associated with the macrophytes and possibly with the absence of larger cyprinids — the diet of which also comprises snails — snail populations, especially *Lymnaea peregra* var. *ovata* and *L. stagnalis*, developed strongly. These species are known to act as intermediate host of the bird-parasitizing trematode *Trichobilharzia ocellata*, the cercaria of which cause an itching sensation

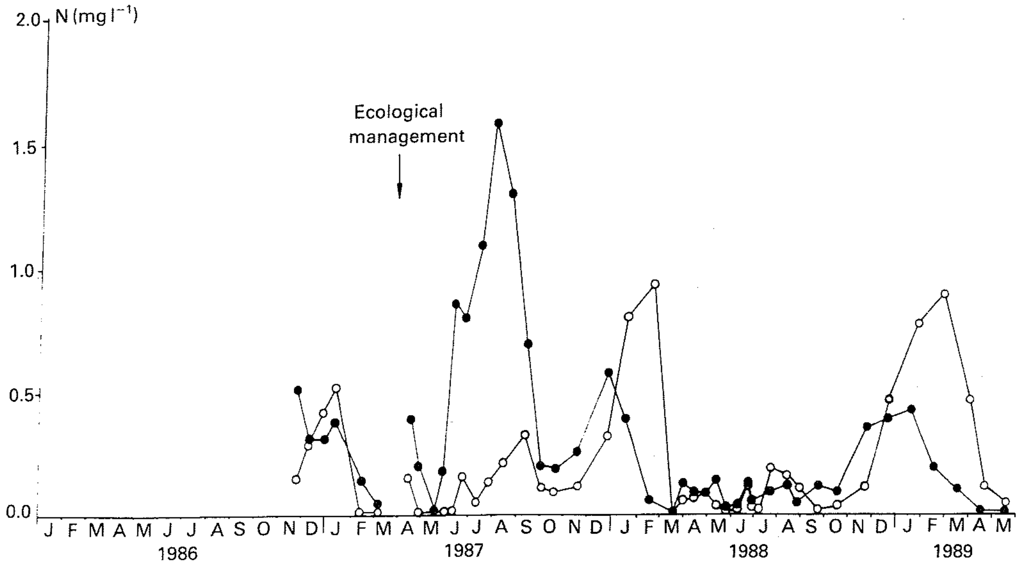

Fig. 3 — The concentrations of NH_4-N (●) and NO_3-N (○) in Lake Zwemlust before and after ecological management.

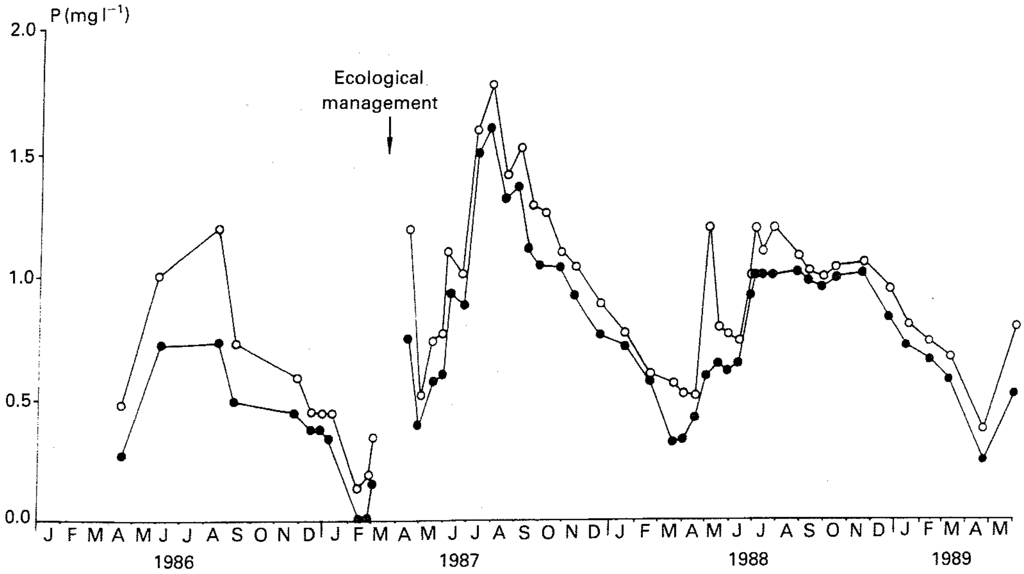

Fig. 4 — The concentrations of ortho-P (●) and total P (○) of Lake Zwemlust before and after ecological management.

at the point of contact with human skin, accompanied by rash (schistosome dermatitis or swimmers' itch). To reduce this nuisance for swimmers in Lake Zwemlust introduction of snail-eating fish like roach (*Rutilus rutilus*) and management of macrophytes were successfully applied in spring 1989.

A positive effect of the macrophyte growth was the high nitrate uptake, resulting in a low nitrate concentration and growth limitation for the phytoplankton in the lakes in the summers of 1988 and 1989. Nitrate and ammonium concentrations in Lake Zwemlust were reduced greatly after management measures (Fig. 3): even though directly after the operation in 1987 the nitrate concentrations were high, they were near detection level in 1988 and 1989. In contrast with nitrate concentration phosphate concentration in the lake did not change significantly (Fig. 4). The so-called 'CUWVO' line, based on observations made in several Dutch inland waters (CUWVO 1988), represents the maximum amount of chlorophyll-a possible at a particular total phospate concentration (Fig. 5). Points lying on the line represent cases in which phytoplankton is limited by phosphate and points to the right of the line cases in which phytoplankton is limited by a factor other than phosphate. All the small lakes are to the right of the line before and after the management measures; however, the larger Lake Breukeleveen, for which recently measures were taken, is the only one lying on the line. Bioassay experiments performed with the natural

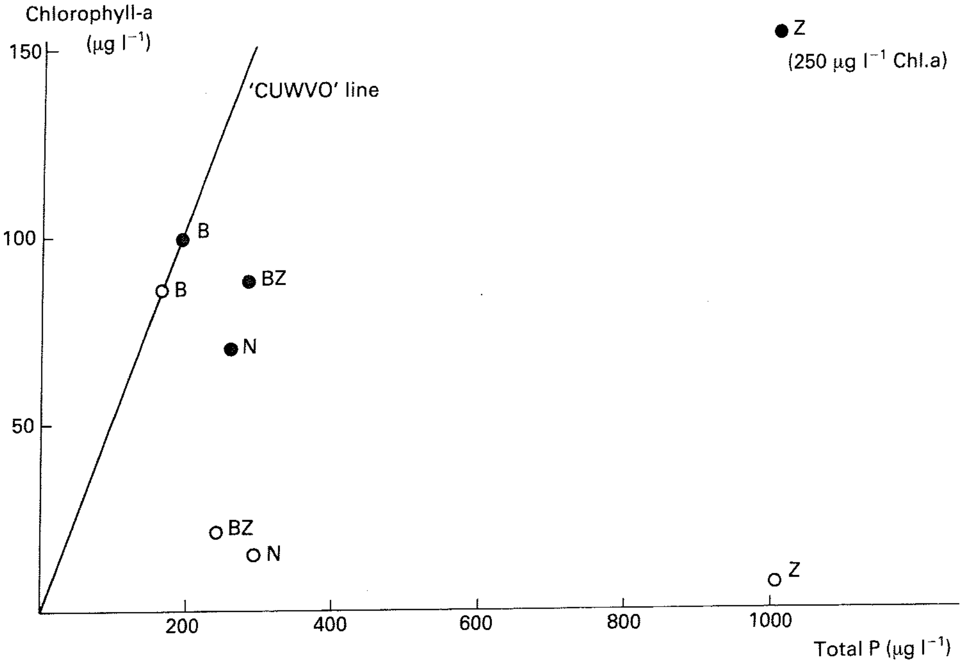

Fig. 5—The relation between chlorphyll-a and total P. The so-called 'CUWVO' line represents the maximum concentration of chlorphyll-a at different total P concentrations, based on a large number of observations in Dutch inland waters (CUWVO 1988). The values of the lakes are given before (●) and after ecological management (○). B=Lake Breukeleveen; BZ=Lake Bleiswijkse Zoom; N=Lake Noorddiep; Z=Lake Zwemlust.

phytoplankton community of Lake Zwemlust during 1986–1989 showed that before the manipulation measures in 1987 light was the main controlling factor, but after the measures the main factor was, in winter, temperature and/or light; in early spring, zooplankton grazing; and in summer, nitrogen (Van Donk *et al.* 1989).

It is still too early to speculate that ecological management in Lake Breukeleveen is not successful since only six months have elapsed after the measures were applied. According to the mark–recapture method 85% of the cyprinid fish were removed but the fry production of the residual fish population was high. The large-sized *Daphnia* stocked into this lake probably failed to grow and reproduce due to the high concentrations of cyanobacteria filaments at the time of the operation in early spring after an unusually mild winter; these high filament concentrations may clog the filtering apparatus of the daphnids (Gliwicz 1990). Additional measures being considered for 1990 include restocking with *Daphnia* and removal of fry.

From the experiments with *Dreissena polymorpha* in Lake Wolderwijd, Reeders *et al.* (1990) conclude that these mussels are very effective in filtering the phytoplankton out of the water; the filtering rate shows an inverse exponential relationship with the concentration of the suspended matter content of the water. Furthermore, a mussel density of about 675 per square metre is required such that grazing mortality of phytoplankton is comparable with its growth.

Summarizing, despite the unsolved problems so far of applying ecological management to reduce eutrophication effects, biological control measures have a great potential (Benndorf 1988). A closer understanding of the ecosystem functioning is needed than when nutrient measures are employed. Also such measures involve continuous watch and adjustment whether ecosystem indicates symptoms of instability. An important question related to the use of ecological management, as a restoration technique, is the long-term effectiveness of this measure. For example, in Lake Zwemlust, macrophyte removal seems to be necessary every year due to the continuing high nutrient loading rates. Ecological management is potentially cheap, but in the long run a combination of nutrient reduction and biomanipulation will probably prove most effective.

REFERENCES

Andersson, G. (1987) The influence of fish on eutrophic lake ecosystems. In: Vismara R. *et al.* (eds), *Lake pollution and recovery*. EWPCA, Milan, pp. 112–116.

Andersson, G., Berggren, H., Gronberg, G. & Gelin, C. (1978) Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes, *Hydrobiologia* **59** 9–15.

Benndorf, J. (1988) Objectives and unsolved problems in ecotechnology and biomanipulations: a preface. *Limnologica* **19** 5–11.

Benndorf, J., Schultz, H., Benndorf, A., Unger, R., Penz, E., Kneschke, H., Kossatz, K., Dumke, R., Hornig, U., Kruspe, R. & Reichel, S. (1988) Food-web manipulation by enhancement of piscivorous fish-stocks, long-term effects in the hypertrophic Bautzen Reservoir. *Limnologica* **19** 97–110.

CUWVO (1988) Samenvatting en conclusies van het vergelijkend onderzoek naar de eutrofiëring in nederlandse meren en plassen, resultaten van de derde eutrofiërings-enquete, 26 pp.

Gliwicz, Z. M. (1990) Why do cladocerans fail to control algal blooms? *Hydrobiologia* (in press).

Grimm, M. P. (1983) Regulation of biomass of small (<41 cm) northern pike (*Esox lucius* L.), with special reference to the contribution of individuals stocked as fingerlings (4–6 cm), *Fish. Manage.* **14** 115–133.

Gulati, R. D. (1989) Structure and feeding activity of zooplankton community in Lake Zwemlust, in the two years after biomanipulation. *Hydrobiol. Bull.* **23** 35–49.

Gulati, R. D. & Van Donk, E. (eds) (1989) Biomanipulation in the Netherlands. *Hydrobiol. Bull.* **23** 1–99.

Irvin, K., Moss, B. & Stansfield, J. (1990) The potential artificial refuges against fish predation in maintaining a community of large-bodied cladocera in a shallow eutrophic lake. *Hydrobiologia* (in press).

Leah, R. T., Moss, B. & Forrest, D. E. (1980) The role of predation in causing major changes in the limnology. *Int. Rev. Ges. Hydrobiol.* **65** 223–247.

Lynch, M. (1979) Predation, competition and zooplankton community structurean experimental study. *Limnol. Oceanogr.* **24** 253–272.

Meijer, M.-B., Raat, A. J. P. & Doef, R. W. (1989) Restoration by biomanipulation of Lake Bleiswijkse Zoom (The Netherlands): first results. *Hydrobiol. Bull.* **23** 49–59.

Moss, B., Balls, H., Irvine, K. & Stansfield, J. (1986) Restoration to two lowland lakes by isolation from nutrient-rich water sources with and without removal of sediment. *J. Appl. Ecol.* **23** 391–414.

Mur, L. R., Gons, H. J. & Van Liere, E. (1978) Competition of the green alga *Scenedesmus* and the blue-green alga *Oscillatoria. Mitt. Int. Ver. Limnol.* **21** 473–479.

Ozimek, T., Gulati, R. D. & Van Donk, E. (1990) Can macrophytes be useful in biomanipulation of lakes? The Lake Zwemlust examples. *Hydrobiologia* (in press).

Reeders, H. H., Bij de Vaate, A. & Slim, E. (1989) The filtration rate of *Dreissena polymorpha* (Bivalvia) in three Dutch lakes, with reference to biological water quality management. *Freshwater Biol.* (in press).

Reeders, H. H. & Bij de Vaate, A. (1990) Zebra mussels (*Dreissena polymorpha*): a new perspective for water quality management? *Hydrobiologia* (in press).

Reinertsen, H. & Olsen, Y. (1984) Effects of fish elimination on the phytoplankton community of a eutrophic lake. *Verh. Int. Verein. Limnol.* **22** 649–657.

Scheffer, M. (1989) Alternative stable states in eutrophic freshwater systems: a minimal model. *Hydrobiol. Bull.* **23** 73–85.

Shapiro, J. (1990) Biomanipulation: the next phase — making it last. *Hydrobiologia* (in press).

Shapiro, J. & Wright, D. I. (1984) Lake restoration by biomanipulation: Round Lake, Minnesota, *Freshwater Biol.* **14** 371–383.

Shapiro, J., Lamarra, V. & Lynch, M. (1975) Biomanipulation: an ecosystem approach to lake restoration. In: P. L. Brezonik & J. L. Fox (eds), *Water* *quality management through biological control,* Report No. ENV-07-75-1, University of Florida, Gainesville, pp. 85–96.

Stanczykowska, A. (1984) Role of bivalves in the phosphorus and nitrogen budget in lakes. *Verh. Int. Ver. Limnol.* **22** 982–985.

Van Donk, E. (1990) Changes in community structure and growth limitation of phytoplankton due to top-down food-web manipulation. *Verh. Int. Ver. Limnol.* **25** (in press).

Van Donk, E. & Gulati, R. D. (1989) Biomanipulation in the Netherlands: applications in fresh-water ecosystems and estuarine waters. *Hydrobiol. Bull.* **23** 99 pp.

Van Donk, E., Gulati, R. D. & Grimm, M. P. (1989) Food-web manipulation in Lake Zwemlust: positive and negative effects during the first two years. *Hydrobiol. Bull.* **23** 19–35.

Van Donk, E., Grimm, M. P., Gulati, R. D., Heuts, P. G. M., De Kloet, W. A. & Van Liere, E. (1990) A first attempt to apply whole-lake food-web manipulation on a large scale. *Hydrobiologia* (in press).

Van Liere, E., (1986) Loosdrecht lakes, origin, eutrophication, restoration and research programme. *Hydrobiol. Bull.* **20** 9–15.

Vollenweider, R. A. (1976) Advances in defining critical loading levels phorphosphorus in lake eutrophication, *Mem. Ist. Ital. Idrobiol.* **33** 53–83.

Zaret, T. M. (1980) *Predation and freshwater communities.* Yale University Press, New Haven, 187 pp.