

Bio-manipulation of a small, urban lake – removal of fish exclude bluegreen blooms

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Introduction

A series of investigators have shown that fish predation affects species composition and abundance of zooplankton (HRBÁČEK 1962, BROOKS & DODSON 1965, STENSON 1972). Large filter-feeding cladocerans may in turn have a decisive influence on phytoplankton biomass and species composition (PENNINGTON 1941). Hence, changes in the fish population may induce modifications in the phytoplankton community. Different types of change in fish populations have been reported to influence the plankton (BROOKS & DODSON 1965, SHAPIRO et al. 1975, DEBERNARDI & GUISSANI 1977, ANDERSSON et al. 1978, FOTT et al. 1980, LEAH et al. 1980, BENNDORF et al. 1984, REINERTSEN & OLSEN, 1984, EDMONDSON & ABELLA 1988). The fish population influence phytoplankton through its effects on the food chains (top-down control), but bentivorous fish may also recycle plant nutrients from the sediments otherwise unavailable to phytoplankton growth (ANDERSON et al. 1978, BRABRAND et al. 1990).

This investigation was aimed at studying the food web interactions after fish removal by rotenone in a shallow, hypertrophic lake.

Study area

Lake Helgetjern is a small (12 ha) and shallow (max. depth = 3.5 m) lake in SE Norway. The lake has a small catchment area (90 ha), mainly coniferous forest, giving it distinct humic nature. Since the 1950's the lake has been the recipient for untreated domestic sewage, the peak loading occurred in the 1960's and 1970's. There are no indications of changes in the phosphorus load after 1980. However, a sewer crossing the lake also has sporadic leaks of unknown quantities of domestic sewage.

During the last decades massive blooms of cyanobacteria developed in the lake. Although the lake is shallow, it is thermally stratified for several months of the ice-free season, since it is protected from wind action by the surrounding forest. Due to the considerable organic loading of the sediments from sewage and from algal blooms, and insufficient wind exposition, the lower 0.5–1.0 m of water above the sediment became anaerobic or had low oxygen conditions during summer.

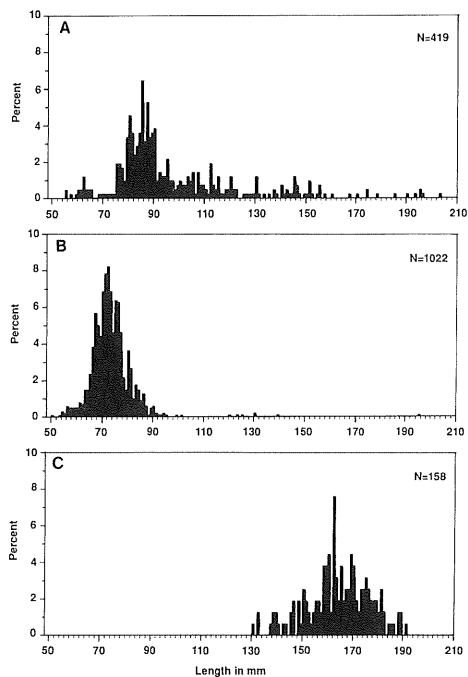


Fig. 1. Total fish length distribution during the experimental period: A) Seine net catches predominantly of roach in June 1984, just before the rotenone treatment. B) After rotenone treatment in November 1986, showing dominance of 0⁺ perch (62–90 mm) and roach (52–73 mm). C) Gill net catches of immigrated roach in 1987 showing dominance of adults.

A dense population of fish was dominated by roach (*Rutilus rutilus*) before rotenone treatment (Fig. 1 A), with perch (*Perca fluviatilis*) and pike (*Esox lucius*) in lower numbers. Winter mortality of roach has been observed, but this did not influence the summer fish biomass because of annual immigration of roach. A small concrete barrier with metal nets (mesh 2 mm) was built to prevent the reimmigration of fish from the downstream lake after the rotenone treatment.

0368-0770/90/0024-0597 \$ 1.50

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The rotenone treatment was performed in two steps in 1984 (July 7 and September 10), as c. 10% of the roach population (mainly larger individuals) survived the first treatment. After the second treatment, judged by gill net catches (mesh size 10, 19.5 and 22.5 mm), less than 0.1% of the original fish biomass remained. Bottom areas covered with nets (mesh size 10 mm) showed fish removal corresponding to c. $100 \text{ kg} \cdot \text{ha}^{-1}$.

Nevertheless, in spring 1986 just before spawning a limited number of adult roach and perch were able to migrate into Helgetjern, due to damage in the barrier. Spawning gave rise to large numbers of 0^+ of both species during summer 1986 (Fig. 1B).

In November 1986 the lake was again treated with rotenone, but in May 1987 fish migration once more occurred. The fish population during summer 1987 consisted exclusively of adult roach, confined mainly to the littoral zone (Fig. 1C). In 1988, spawning of both roach and perch occurred, and both 0^+ and adult fish were present during summer and autumn, while 1^+ and 2^+ were absent.

To encourage a rapid response in the fish-free situation a large number of large herbivorous zooplankton: *Daphnia pulex*, *D. magna* and *D. longispina*, were introduced in autumn 1984 (adults) and in spring 1985 ephippia.

Results

The repeated rotenone treatment followed by fish removal gave major effects in the lake, including nutrient fractions, phytoplankton and zooplankton, while reimmigration of fish produced conditions similar to the situation before the manipulation.

The visual impact of the treatment on the lake was striking. Seasonal mean values of transparency were much higher during years with low fish density (Fig. 2C). The transparency decreased from spring values reaching almost 1 meter to less than 0.2 m during phytoplankton blooms in summers with high fish biomass. In the years with low fish predation the spring values were more than 1 m while maximal values in July 1985 exceeded 2.8 m. No transparency value this year was lower than 1.5 m. Also in 1986, when a small population of yearlings of roach and perch were present, a considerably lower transparency occurred than in 1985 and 1987.

The seasonal weighted mean concentrations of phosphorus from 0–2 m depth (only 0–2 m samples are presented throughout) are presented for the years 1983–88 in Fig. 2A. The high values during the late 1970's decreased gradually during the experimental period. This is considered mainly a delayed response to reduced external loading before 1983.

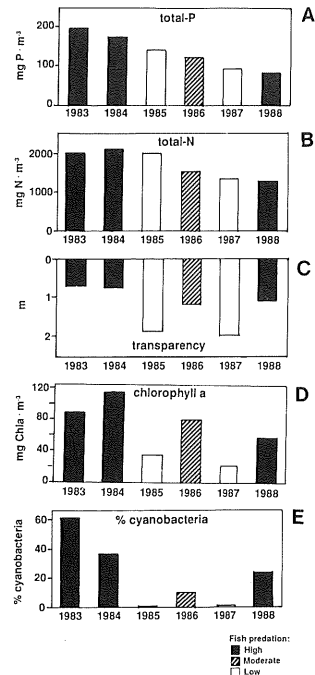


Fig. 2. Seasonal weighted mean values (May-October) of A) total-phosphorus and B) total-nitrogen, C) Secchi disc transparency, D) chlorophyll-*a* and E) percentage Cyanobacteria of total phytoplankton biomass.

Spring concentrations reached near $100 \text{ mg total-P} \cdot \text{m}^{-3}$ during the pretreatment years, increasing to ca. $300 \text{ mg P} \cdot \text{m}^{-3}$ during summer. The rotenone treatment did not seem to have any strong direct impact on the spring overturn phosphorus P-values, but after treatment with rotenone the phosphorus increase-rate during summer was lower, the highest value during August was close to $200 \text{ mg P} \cdot \text{m}^{-3}$ (Fig. 3). The relative proportions of the different fractions of phosphorus changed dramatically. Most of the phosphorus was found in organic seston before the treatment, while after the treatment an increasing fraction was found as SRP, readily available for algal growth. In August and September 1985 and 1987 more than 75% of the total-P was SRP.

Seasonal values of nitrogen showed only minor reductions after 1985 (Fig. 2B), even though nitrogen fractions behaved similar to phosphorus. The fractions available for algal assimilation, nitrate and ammonium, were only found under the ice in winter and spring before the treatment.

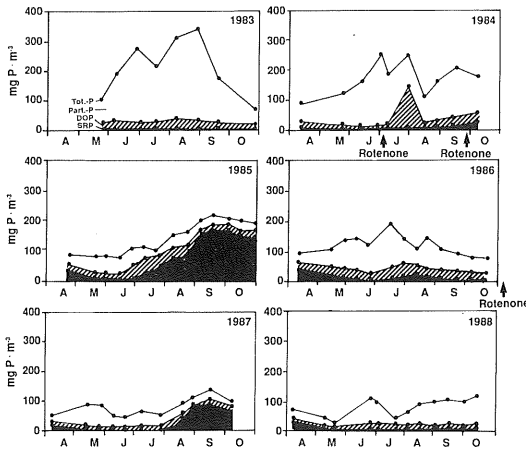


Fig. 3. Phosphorus fractions in the 0–2 meter layer.

In 1983 the peak value of algal biomass was near $30 \text{ mg wet wt} \cdot \text{l}^{-1}$, corresponding to $185 \text{ mg Chl-}a \cdot \text{m}^{-3}$. Seasonal mean chlorophyll values (Fig. 2D) show marked reductions during low fish predation, but even the moderate predation from yearlings in 1986 resulted in high phytoplankton densities.

In the late 1970's heavy blooms of *Oscillatoria agardhii* were observed. In 1983 and 1984 the phytoplankton was dominated by *Anabaena solitaria* f. *planctonica*, *Oscillatoria agardhii* and *Microcystis aeruginosa* in decreasing order of concentrations. However, immediately after the rotenone treatment the phytoplankton composition was totally changed. The bluegreens, normally dominant during summer and autumn, suddenly disappeared after the first rotenone treatment when the diatom *Synedra acus* var. *radians* and the euglenoid *Trachelomonas hispida* became dominant.

A spring peak developed in 1985 consisting of the species *Trachelomonas hispida*, *Eudorina elegans* and *Nitzschia gracilis*, ending up in total concentrations above 2 m depth equalling $15.5 \text{ mg} \cdot \text{l}^{-1}$ wet wt., corresponding to $230 \text{ mg Chl-}a \cdot \text{m}^{-3}$. During the last week of June and the first week of July the epilimnetic phytoplankton population apparently collapsed to concentration close to 1%, remaining low the rest of the growth season ($< 0.6 \text{ mm}^3 \cdot \text{m}^{-3}$ or $< 13 \text{ mg Chl-}a \cdot \text{m}^{-3}$). The dominant species were *Cryptomonas marsonii* and small forms of Chrysophyceae. However, samples from 2.5 and 3.0 m depth still revealed considerable metalimnetic

concentrations of *Trachelomonas hispida* probably taking advantage of the high nutrient concentrations, improved light conditions and its low digestibility for herbivores.

During 1987, with low fish density and only adult roach present (Fig. 1C), the percentage of bluegreen algae never exceeded 10%. The phytoplankton consisted of a diverse mixture dominated by Chlorophyceae, Bacillariophyceae and Cryptophyceae in contrast to the two "high fish" years 1986 and 1988 distinguished by high total algal biomass and high percentage of bluegreens (*Anabaena tenericaulis* and *A. solitaria* f. *planctonica*) and cryptomonads (species of *Cryptomonas*).

Before the rotenone treatment the zooplankton was dominated by rotifers and small *Bosmina longirostris* (Fig. 4).

The collapse of the phytoplankton coincided with the growth of large *Daphnia*: *D. longispina* and *D. pulex* (Fig. 4). The former species reaching $120 \text{ ind.} \cdot \text{l}^{-1}$ during the first week of July 1985 and 1987 gradually decreasing until November. A similar peak of *D. pulex* was observed in August 1987.

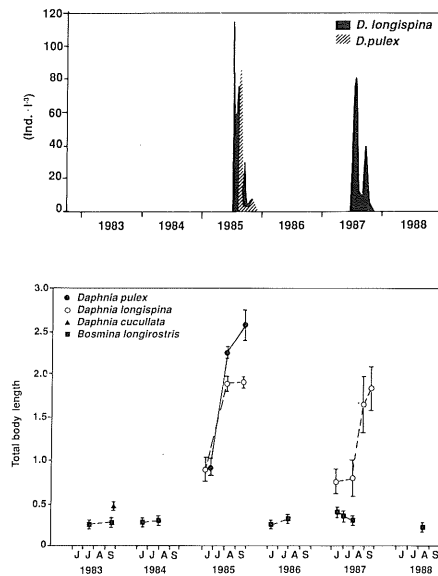


Fig. 4. A) Large species of *Daphnia* were introduced to Helgetjern after rotenone treatment in autumn 1984 and spring 1985. *D. pulex* and *D. longispina* occurred in the two years 1985 and 1987 with low fish predation. Even in 1986 with only moderate concentrations of perch and roach (0^+) these grazers could not survive. B) Mean body length of dominant Cladocera 1983–1988.

Discussion

The rapid decline in phytoplankton biomass and change in species composition during the two "low-fish" years clearly demonstrate the potential for top-down control of the lower trophic levels in this lake. Even though rotenone may have severe and selective effects on different species and stages of zooplankton (ANDERSON 1970) and phytoplankton, this could not explain the seasonal development in the two years following the rotenone treatments, namely that the zooplankton and phytoplankton changed dramatically when *Daphnia* became abundant. Since dissolved fractions of phosphorus and nitrogen were in excess during both years in question (Fig. 3), we conclude that the phytoplankton was controlled by grazing in 1985 and 1987.

Increased occurrence of large herbivores in meso- and eutrophic lakes is an important step towards a phytoplankton community without dominance of bluegreens. However, the mechanism of these changes are not fully understood. This may be a result of increased cycling of nutrients (RIGLER 1964) and hence, increased competitive ability for small rapid-growing algal species (LEHMAN 1980, STERNER 1986). These processes may be stimulated even during dominance of bluegreens, due to high turnover of other edible components of the system, e.g. bacteria, detritus and certain algae.

It is also obvious that these components play an important role in the planktonic foodweb during high herbivore density, since the algal production was far from sufficient alone to support the rapid growth of *Daphnia* (Fig. 4). In this way bacteria may play an additional role by its high relative P-content (VADSTEIN et al. 1988) giving high P-regeneration.

Our assays on P-release from sediment indicated that this was not of major importance for the P-cycling in this lake, neither due to high pH nor anaerobic conditions. We therefore conclude that the increased total P-concentration in the lake during the "high-fish" summers was caused by re-suspension of sediments and excretion by fish. The excretion rate of phosphorus by roach is greatly influenced by the food items consumed. This was also supported by observations of gut contents of the roach, showing ingestion of zooplankton and sediment/detritus. A phosphorus model for the deep, mesotrophic Lake Gjersjøen (BRABRAND et al. 1990) indicates that phosphorus excretion from roach can to some extent explain the increased phosphorus concentration during "high-fish"

summers, assuming an original roach biomass in Helgetjern of c. $100 \text{ kg} \cdot \text{ha}^{-1}$.

Another factor possibly adding to those giving lower P-concentration after reducing the fish population, is the increased nutrient loss due to increased P-sedimentation by dead zooplankton (WRIGHT & SHAPIRO 1984, HENRIKSON et al. 1980). This is confirmed by observations in a mesoscale experimental plant of chained biodams where the dominant reason for P-reduction was sedimentation of dead *Daphnia* (A. ERLANDSEN & T. KÄLLQVIST pers. comm.).

Many authors have stressed that invertebrate predators may suppress large, effective herbivores (STENSON 1978, EDMONDSON & ABELLA 1988, BRABRAND et al. 1986, 1987). Even during the "low-fish" years in Helgetjern invertebrate predators were not able to increase sufficiently to suppress the herbivores all through the season. On the other hand, in 1987 even a low biomass of yearling perch and roach were able to suppress all larger zooplankton (Fig. 4A). This is in agreement with the general observations of LAZZARO (1987) and also from carp ponds (FOTT et al. 1980). BENNDORF et al. (1988) also concluded that during high predation from perch on young stages of all fish species in Lake Bautzen, predation on zooplankton was also reduced.

Conclusions

Removal of fish enabled mass occurrence of effective filter-feeding zooplankton, which, in turn, led to a dramatic reduction of algal biomass and percentage of Cyanobacteria despite the high levels of dissolved P and N in the lake (Fig. 5).

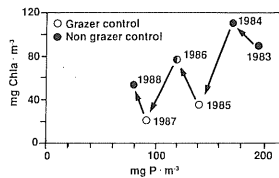


Fig. 5. The fish population may have strong effects on the phytoplankton in a lake. In Helgetjern reduced P-concentration led to a near linear decrease in phytoplankton during the "high-fish" years (●), but in the "low-fish" years (○) the reductions were considerably greater. Even a small population of 0⁺ fish (●) reduced the effective herbivore zooplankton sufficiently to allow the phytoplankton utilize available nutrients to maximal growth.

The rotenone treatment itself led to a marked change in the phytoplankton from dominance of cyanobacteria to a more diverse community.

Even low abundance of yearling perch and roach in a subsequent year notably reduced the effective herbivores, whereas a considerable density of larger fish did not have the same effect the preceding year.

Due to repeated immigration of roach we can not extend our conclusions to longterm effects of fish removal.

Acknowledgements

J. E. LØVIK, M. MJELDE and T. J. OREDALEN at NIVA have skillfully carried out most of the sampling. BØRGE JOHANSEN living close to the lake carried out skillful and conscientious maintenance of the fish-barrier. P. BRETUM, NIVA counted the phytoplankton while Z. DZIKOWSKA and A. LYCHE, both University of Oslo, counted and measured the zooplankton. Thanks are also due to A. ERLANDSEN for carrying out measurements on P-exchange from sediments and to J. E. BRITAIN for improving the English. Data from Helgetjern from 1979–81 were kindly placed at our disposal by O. M. SKULBERG, NIVA. This study forms part of the research programme on eutrophication of inland waters supported by the Norwegian Council for Scientific and Industrial Research (NTNF), the Norwegian Institute for Water Research and the University of Oslo.

References

- ANDERSON, S., 1970: Effects of rotenone on zooplankton communities and a study of their recovery patterns in two mountain lakes in Alberta. – *J. Fish. Res. Bd. Can.* **27**: 1335–1356.
- ANDERSON, C., BERGGREN, H., CRONBERG, G. & GELIN, C., 1978: Effects of planktivorous and benthivorous fish on organisms and water chemistry in eutrophic lakes. – *Hydrobiologia* **59**: 9–15.
- BENNDORF, J., KNESCHKE, H., KOSSATZ, K. & PENZ, E., 1984: Manipulation of the pelagic food web by stocking with predacious fish. – *Int. Rev. ges. Hydrobiol.* **69**: 407–428.
- BRABRAND, Å., FAAFENG, B. A. & NILSSEN, J. P. M., 1986: Juvenile roach and invertebrate predators: delaying the recovery phase of eutrophic lakes by suppression of effective filter-feeders. – *J. Fish Biol.* **29**: 99–106.
- – – 1987: Pelagic predators and interfering algae: stabilizing factors in temperate eutrophic lakes. – *Arch. Hydrobiol.* **110** (4): 533–552.
- – – 1990: Phosphorus supply to phytoplankton production – relative importance of fish excretion versus external loading. – *Can. J. Fish. Aquat. Sci.* **47** (2): 364–372.
- BROOKS, J. L. & DODSON, S. I., 1965: Predation, body size, and composition of plankton. – *Science* **150**: 28–35.
- DEBERNARDI, R. & GUISSANI, G., 1977: The effects of mass fish mortality on zooplankton structure and dynamics in a small Italian lake (Lago de Annone). – *Verh. Internat. Verein. Limnol.* **20**: 1045–1048.
- EDMONDSON, W. T. & ABELLA, S. E. B., 1988: Unplanned biomanipulation in Lake Washington. – *Limnologia* (Berlin) **19** (1): 73–79.
- FOTT, J., PECHAR, L. & PRAŽÁKOVÁ, M., 1980: Fish as a factor controlling water quality in ponds. – *Int. Rev. ges. Hydrobiol.* **2**: 255–261.
- HENRIKSON, L., NYMAN, H. G., OSCARSON, H. G. & STENSON, J. A. E., 1980: Trophic changes without changes in the external nutrient loading. – *Hydrobiologia* **68**: 257–263.
- HRBÁČEK, J., 1962: Species composition and the amount of zooplankton in relation to the fish stock. – *Rozpr. Česk. Akad. Věd, Řada, Mat. Přír. Věd.* **72** (10), 116 pp.
- LAMMENS, E. H. R. R., 1988: Trophic interactions in the hypertrophic Lake Tjeukemer: Top-down and bottom-up effects in relation to hydrology, predation and bioturbation during the period 1974–1985. – *Limnologia* (Berlin) **19** (1): 81–85.
- LEAH, R. T., MOSS, B. & FORREST, D. E., 1980: The role of predation in causing major changes in the limnology of a hyper eutrophic lake. – *Int. Rev. ges. Hydrobiol.* **65**: 223–247.
- LEHMAN, J. T., 1980: Release and cycling of nutrients between planktonic algae and herbivores. – *Limnol. Oceanogr.* **25**: 620–632.
- PENNINGTON, W., 1941: The control of the number of freshwater phytoplankton by small invertebrate animals. – *J. Ecol.* **29**: 204–211.
- REINERTSEN, H. & OLSEN, Y., 1984: Effects of fish elimination on the phytoplankton community of a eutrophic lake. – *Verh. Internat. Verein. Limnol.* **22**: 649–657.
- RIGLER, F. H., 1964: The contribution of zooplankton to the turnover of phosphorus in the epilimnion of lakes. – *Can. Fish Culturist* **32**: 3–9.
- SHAPIRO, J., LAMARRA, V. & LYNCH, M., 1975: Biomanipulation: An ecosystem approach to lake restoration. – In: BREZONIK, P. L. & FOX, J. L. (Eds.): Proc. symp. on water quality management through biological control. – Rep. No. ENV-07-75-1, Univ. of Florida, Gainesville: 85–96.
- STENSON, J. A. E., 1972: Fish predation effects on tree species composition of the zooplankton community in eight small forest lakes. – *Rep. Inst. Freshwat. Res. Drottningholm* **52**: 132–148.
- 1978: Predator – prey relations between fish and invertebrate prey in some forest lakes. – *Inst. Freshwat. Res. Drottningholm. Rep.* **58**: 166–183.

STERNER, R. W., 1986: Herbivores' direct and indirect effects on algal populations. – *Science* **231**: 605–607.

VADSTEIN, O., JENSEN, A., OLSEN, Y. & REINERTSEN, H., 1988: Growth and phosphorus status of limnetic phytoplankton and bacteria. – *Limnol. Oceanogr.* **33** (4): 489–503.

WRIGHT, D. I. & SHAPIRO, J., 1984: Nutrient reduction by biomanipulation: an unexpected phenomenon

and its possible cause. – *Verh. Int. Verein. Limnol.* **22**: 518–524.

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