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Ecological consequences of a manual reduction of roach and bream in a eutrophic, temperate lake

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Abstract

A biomanipulation experiment was carried out in the eutrophic lake, Frederiksborg Slotssø (Denmark). During 1987 and 1988, densities of roach (*Rutilus rutilus*) and bream (*Abramis brama*) were reduced, using seine and pounding nets, and large-sized perch (*Perca fluviatilis*) were added instead. Nutrients, oxygen, phytoplankton, zooplankton, fish and zoobenthos were measured two years after the manipulation and compared with results obtained two years before the manipulation.

A total amount of 6524 kg wet weight of roach and bream was removed. Roach and bream constituted 45% of the total fish biomass after the reduction, compared with 78% before the manipulation. Recruitment of roach decreased, and mortality rates of young-of-the-year perch were lower after the fish reduction. After the manipulation, decreases in phytoplankton biomass coincided with increases in zooplankton biomass during spring and autumn periods, although, the mid-summer level of the biomass of cyanobacteria did not change. Inorganic nutrients generally increased, but no significant changes were found, either in the oxygen budget or in the community structure or quantitative distribution of zoobenthos after the fish manipulation. Although the effects of the fish manipulations were not as pronounced as those found in lakes with lower nutrient regimes, the results indicate positive changes in the water quality. Nevertheless, it is probably necessary to continue a fish reduction programme to maintain or further improve the water quality.

Introduction

A theoretical model of the structure and functioning of eutrophic lakes predicts that planktivorous fish control the growth of macrozooplankton (Riemann *et al.*, 1986; Persson *et al.*, 1988). The model, and direct observations on the impact of fish communities in eutrophic lakes (Johansson & Persson, 1986) suggest a possible scenario for changing the structure of the food chain by manipulations of the fish communities.

In eutrophic temperate lakes, pelagic food chains are characterized by high levels of phytoplankton, relatively low densities of macrozooplankton, and large numbers of cyprinid fish populations (Riemann & Søndergaard, 1986; Persson *et al.*, 1988). These often undesirably high levels of phytoplankton occur primarily because of an increase in the biomass and changes in the community structure of phytoplankton owing to an increase of nutrients (Kristiansen, 1986; Søndergaard *et al.*, 1988).

Moreover, subsequent secondary changes occur in the fish communities: bream and roach outcompete perch, and large populations of small-sized bream and roach develop. They are controlled by food sources rather than by predators (Persson *et al.*, 1988), and they exert an intense predation pressure on macrozooplankton populations, leading to a further increase in the phytoplankton biomass.

Traditionally, external and internal nutrient loadings are reduced to reduce growth of phytoplankton (Vollenweider, 1968). Alternatively, or in combination with nutrient control, manipulation of fish populations has been carried out (see review by Shapiro *et al.*, 1982). These manipulations have generally included exterminations of fish by partial poisoning (Lynch, 1979; Lynch & Shapiro, 1981) or whole lake poisoning (Stenson *et al.*, 1978; Shapiro & Wright, 1984; Reinertsen & Olsen, 1984; Reinertsen *et al.*, 1990). Since both planktivorous and piscivorous fish populations are removed by poisoning, invertebrate predators may take over the role of controlling zooplankton. Moreover, ethical restrictions against poisoning whole lakes with, e.g., rotenone, commonly play an important role in many countries. As an alternative to total removal of fish communities, addition of piscivorous fish has also been employed (Benndorf *et al.*, 1984; Edmondson & Litt, 1984; Shapiro & Wright, 1984). Benndorf *et al.* (1988) concluded from studies in the Bautzen Reservoir that enhancements of piscivorous pikeperch (*Stizostedion lucioperca*), combined with catch restrictions for piscivores, gave a stable moderate stock of planktivorous fish, and prevented an excessive development of carnivorous invertebrates.

Whatever the basis for manipulations of lake food chains, long-term studies are scanty in the literature. From a theoretical point of view, natural populations of herbivorous zooplankton have a potential capacity to control phytoplankton by grazing in eutrophic lakes (Lampert, 1988), although mid-summer blooms of cyanobacteria can suppress the filtering rates and fecundity of *Daphnia* (Dawidowicz *et al.*, 1988).

The main objective of this study was to examine major ecological consequences of a manual removal of a substantial part of the planktivorous fish populations in a hypereutrophic, temperate lake. The fish populations were caught in nets, and roach and bream were selectively removed. In addition, large-sized perch were added. The consequences of these changes on nutrients, oxygen, phytoplankton and zooplankton, bottom invertebrates and the community structure of the population of fish were measured during two years and compared with results obtained before the manipulation.

Methods and materials

Sampling

Water samples were collected from the central part of eutrophic Frederiksborg Slotssø (Andersen & Jacobsen, 1979) from 1 m, 3 m, 5 m and 7 m depths with a 3-litre plastic water sampler. The lake has a surface area of 21 ha, a mean depth of about 3 m, and a maximum depth of 8 m. A temperature stratification normally occurs during May–September. Hydrographical data and a diagram of the lake are presented in Table 1 and Fig. 1.

Inorganic nutrients

Phosphate and nitrate were measured according to Murphy & Riley (1962) and Strickland & Parsons (1972), respectively. In the determination of ammonia reagents were added immediately after sampling (Riemann & Schierup, 1978) and samples were analyzed according to Sólorzano (1969).

Table 1. Hydrographical data from Frederiksborg Slotssø.

Drainage area, km^2	6.60
Lake area, km^2	0.21
Maximum depth, m	8.0
Mean depth, m	3.1
Volume m^3	6.4×10^5

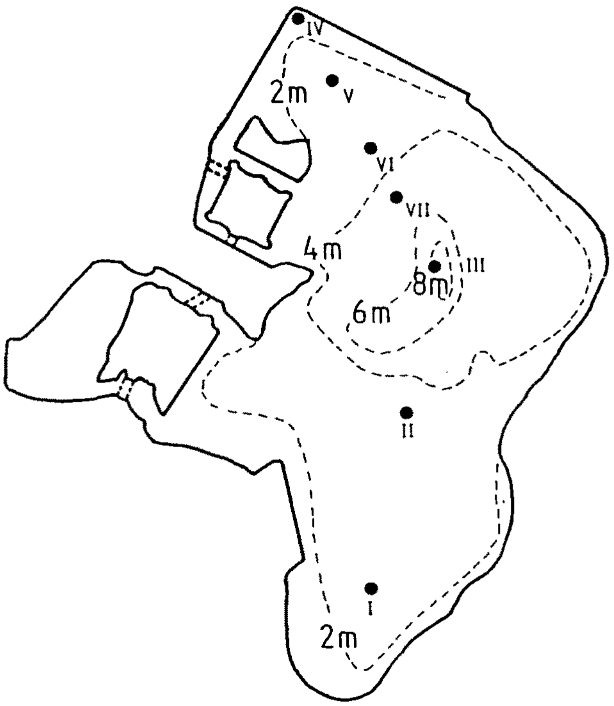

Fig. 1. Diagram of Frederiksborg Slotssø. Depth isopleths and sampling stations for zoobenthos are indicated by Roman numbers.

Plankton

The phytoplankton chlorophyll-*a* content was extracted in 96% ethanol for 20 h without homogenization of filters (Jespersen & Christoffersen, 1987), and pigment extracts were measured spectrophotometrically (Beckman 240) or fluorometrically (Aminco 2000) without corrections for degradation products. Fluorometric emission values were calibrated to absorbance readings using chlorophyll extracts from natural phytoplankton populations. Samples for qualitative determinations were fixed in Lugol.

Zooplankton (size > 140 μm) was identified to species. Plankton collected on the nets was fixed with 70% ethanol and later counted in an inverted microscope. At each sampling, the dry weight of the dominating zooplankton species was determined by weighing 100 individuals on an electrobalance after drying at 60 °C for 24 h. Biomass was calculated assuming 40% of the dry wet weight to be carbon.

Zoobenthos

Seven sampling stations (I–VII) located on two transects (Fig. 1) covered depths from 0.5 to 8 m. Bottom sediment at station IV (0.5 m depth) was gravel mixed with mud, roots, and decaying macrophyte material. At station II (2-m depth) the sediment consisted of roots from an earlier, submerged macrophytic vegetation mixed with a fine chalks gytje. At the remaining five stations the sediment was a soft black mud substrate.

Sampling was carried out monthly in summer and at larger intervals during winter from August 1985 to May 1988. On each of the 18 sampling dates and at each station, 5 core samples (20 cm^2) were taken. Samples were sieved through a 200 μm filter and preserved in 4% formalin. Animals were sorted by hand under 2.5 × magnification. Biomass was estimated by weighing intact animals on an automatic microelectrobalance (Satorius S4) with an accuracy of ± 1 μg. Ash-free dry weight (AFDW) was derived by subtracting ash content after ignition (1 hr, 550 °C) from dry weight (24 h, 60 °C). As the animals were stored in formalin for 1–2 years, corrections for weight loss were made (Lindegaard & Mortensen, 1988). Measured AFDW was multiplied by 1.67 for animals with haemoglobin (40% weight loss) and 1.43 for animals without haemoglobin (30% loss). The carbon content was assumed to constitute 55% of the AFDW (Waters, 1977).

Fish

The fishery study programme included: 1) a selective reduction of the roach, bream and crucian carp populations, 2) stocking with perch, and 3) estimation of the total fish populations.

1. The work concerning fish manipulation was started in April 1986 and continued throughout the year by seining and permanent pounding nets. Fishing was also carried out during the spring and summer of 1987, as well as during the spring of 1988. Different seine nets were used, with mesh sizes ranging from 1.5 to 0.7 cm knot to knot.

From each catch, roach, bream, and crucian carp were manually selected and either counted or weighed. All other fish were registered, and a certain number marked before being released. Generally, only fish > 10 cm were marked.

2. The lake was stocked in May 1987 and in May 1988 with about 1500 perch with an average weight of about 200 g.per individual.

3. Adult fish populations were estimated in 1984, 1986, and 1987 by either single-marking or multiple-marking methods. During 1984, 26 170 fish were marked and of these, 704 were recaptured (Müller & Jensen, unpubl. data). In 1986 and 1987, 2613 and 2186 fish, respectively, were marked and reintroduced into the lake; of these 389 and 216 were recaptured, respectively. Further details are presented in Jeppesen *et al.* (1989). The estimates from both the single-marking and the multiple-marking data were calculated using the formulae given by Chapman (Chapman, 1954). The 95% confidence limits of the calculated estimates of mean biomass values of roach and bream varied between 13 and 18% in 1984, 51 and 62% in 1986, and 29 and 62% in 1987. Further details are presented in Jeppesen *et al.* (1989). Density of the young fish was measured using a modified buoyant net as described by Baganal (1974). At about fortnight intervals from June to October, 40 of these self-releasing 'dip-nets' (with a diameter of 1.5 m) were placed regularly in the lake. The fish caught were counted, measured, and weighed. The total density of the young of the year was then assumed to be directly proportional to the catch per area of the nets.

Results

Fish

The estimated total fish biomass was 9500 kg wet weight in 1986 before the manipulation, corresponding to 45 g wet weight m^{-2} (Fig. 2). Roach and bream constituted 78% of the total biomass. The bream density in 1984 was more than two times that in 1986. In 1984, 34% of the adult

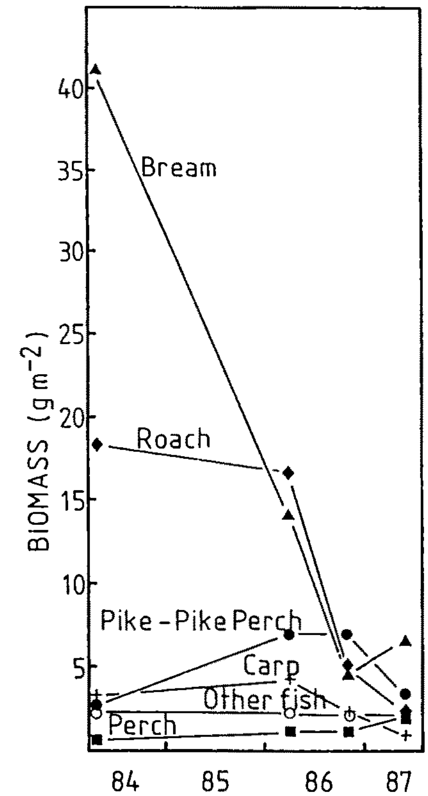

Fig. 2. Biomass (g wet weight m^{-2}) of different fish species during 1984–1987. Pike and pikeperch are added together. Other fish were rudd, tench, ruffe and eel. Details about the number of fish marked and recaptured as well as the calculated confidence limits are presented elsewhere (Jeppesen *et al.*, 1989).

bream > 25 cm was severely infected with *Ligula interstinalis*, but only a few bream were infected in 1986. During 1986–88, 6700 kg roach and bream that were removed from the lake constituted 45% of the total fish biomass in autumn 1987. Pike and pikeperch decreased and perch increased after the manipulations (Fig. 2), although most of the increase in perch was due to the stocking of perch.

The number of roach larvae decreased markedly after the fish reduction (Fig. 3), while the mortality rate was almost the same as in 1986. The slope of the regression line for 1987 was not significantly larger than zero, but that for 1986 was (Student's t test, $p < 0.05$). On the contrary, there were twenty times more perch fry at the end of 1987 than in 1986. Recruitment of perch was similar in 1986 and 1987, but mortality was higher

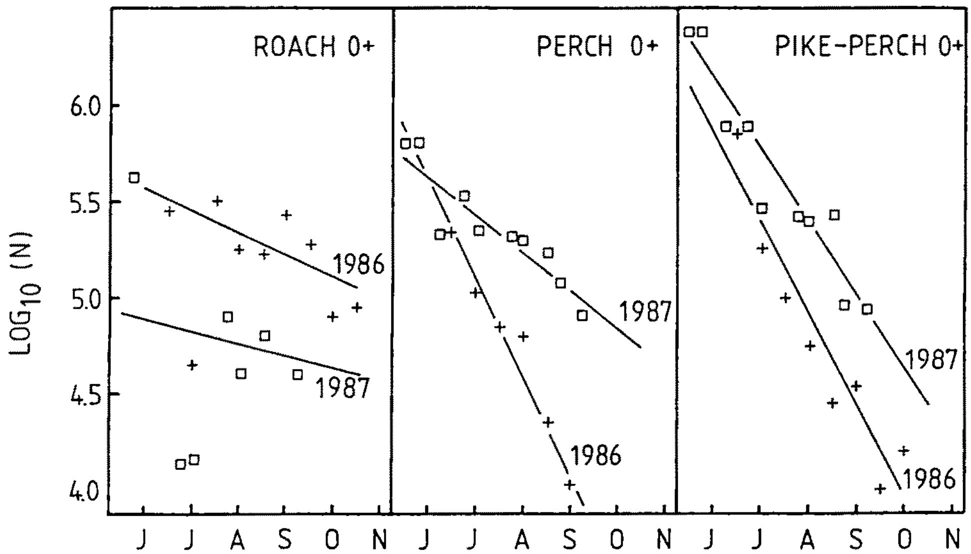

Fig. 3. Seasonal changes in the density of young-of-the-year (0^+) of roach, perch, and pikeperch during 1986 and 1987. The three points for roach during June/July 1987 are not included in the regression.

in 1986. Mortality of pikeperch was similar in 1986 and in 1987, but recruitment was somewhat better in 1987.

Oxygen, nutrients, and transparency

The average mean values of the water column during May–September are presented in Table 2. The oxygen concentration did not change after the manipulation, but nutrients and transparency generally increased. The nitrate concentrations in 1988 were significantly (*t*-test, $p < 0.001$) higher than in 1986 and 1987, and ammonia and phosphate concentrations were significantly higher ($p < 0.005, p < 0.0001$, respectively) in 1988 than during 1986.

Phytoplankton

Diatoms (*Stephanodiscus*, *Cyclotella*, *Melosira* sp.) dominated during April and May followed by a bloom of cyanobacteria during June to October. *Microcystis* dominated in 1984, but not in 1986; in 1987, it was replaced by *Aphanizomenon* in August. The highest chlorophyll values were found during the summer (June–September) in all four years (Fig. 4). There were no effects of fish removal on the chlorophyll concentration during July and August. The duration of cyanobacteria bloom decreased during 1987 and 1988 compared with its duration before the fish removal (1984 and 1986).

Table 2. Average summer values (May–September) for the entire water column in Frederiksborg Slotssø during four years for oxygen, ammonia, nitrate, phosphate and transparency. Values in brackets represent 95% confidence limits.

	1984	1986	1987	1988
Oxygen, mg l^{-1}	–	5.4 (0.6)	5.4 (0.8)	5.6 (1.3)
Ammonia, $\mu g\ l^{-1}$	–	417 (483)	1682 (1577)	1783 (614)
Nitrate, $\mu g\ l^{-1}$	–	33 (62)	37 (9)	217 (96)
Phosphate, $\mu g\ l^{-1}$	–	113 (62)	248 (78)	447 (131)
Transparency, m	0.58 (0.2)	0.58 (0.2)	0.81 (0.1)	0.82 (0.3)

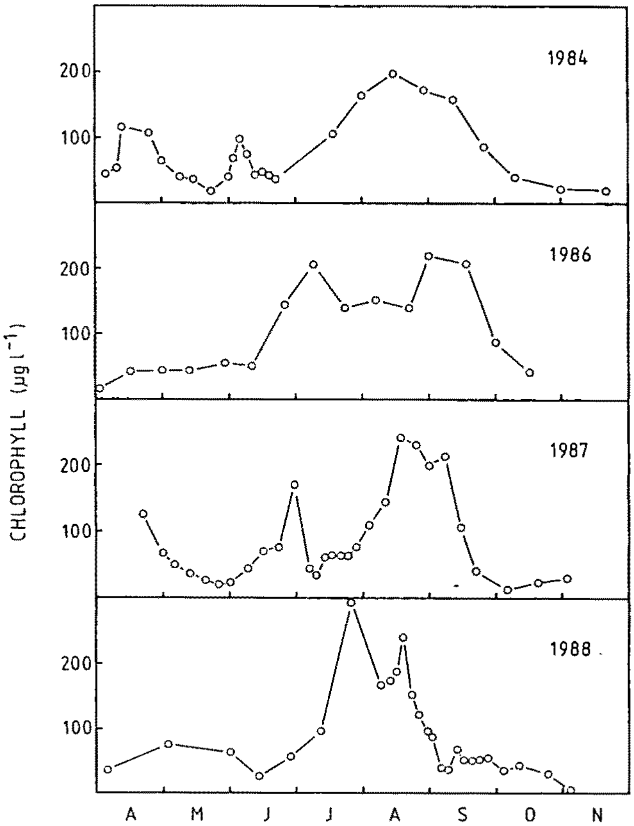

Fig. 4. Seasonal changes in the phytoplankton chlorophyll content during 1984 and 1986 (before the manipulation) and during 1987 and 1988 (after the manipulation).

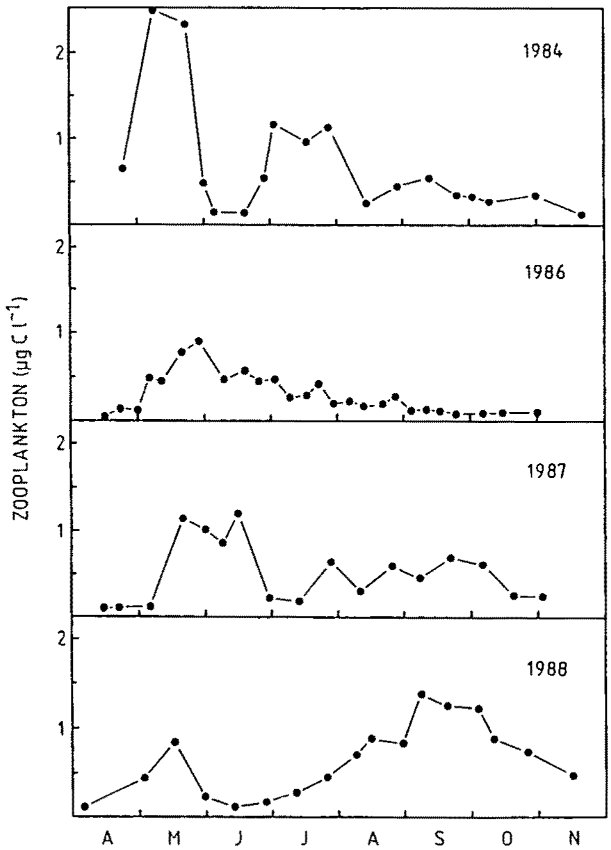

Fig. 5. Seasonal changes in the biomass of macrozooplankton (> 140 μm) before the manipulation (1984 and 1986) and after the manipulation (1987 and 1988).

Zooplankton

The biomass of macrozooplankton (> 140 μm) was calculated as the mean value for the entire water column throughout the four years (Fig. 5). During spring, *Bosmina coregoni* (Baird), *Cyclops strenuus* (Fisch), and *Mesocyclops leuckartii* (Claus) dominated, followed by *Chydorus sphaericus* (O.F.M.) and *Daphnia cucullata* (Sars) in June or July. *Eudiaptomus graciloides* (Lillj.) occurred frequently throughout the year, with highest biomass values during spring and autumn.

The monthly average values for transparency, chlorophyll, and biomass of zooplankton for the period June–September for the two years before the fish manipulation were compared with data obtained after (Fig. 6). During September, a pronounced increase in transparency and zooplankton biomass coincided with a decrease in chlorophyll. Similar but smaller changes were also observed during June, whereas changes were more irregular during July and August.

Zoobenthos

Dominating species were oligochaetes and chironomids, both containing haemoglobin. *Chaoborus flavicans* (Meig.) dominated at some stations from early winter to spring. The oligochaetes found were mainly substrate feeders, while dominating chironomids (*Chironomus plumosus* and *Glyptotendipes* sp.) and the prosobranchs *Bithynia tentaculata* and *Valvata piscinalis* are all filter-feeders. Abundance and carbon biomass are presented from the station most rich in species (Table 3). The average densities for all stations ranged from

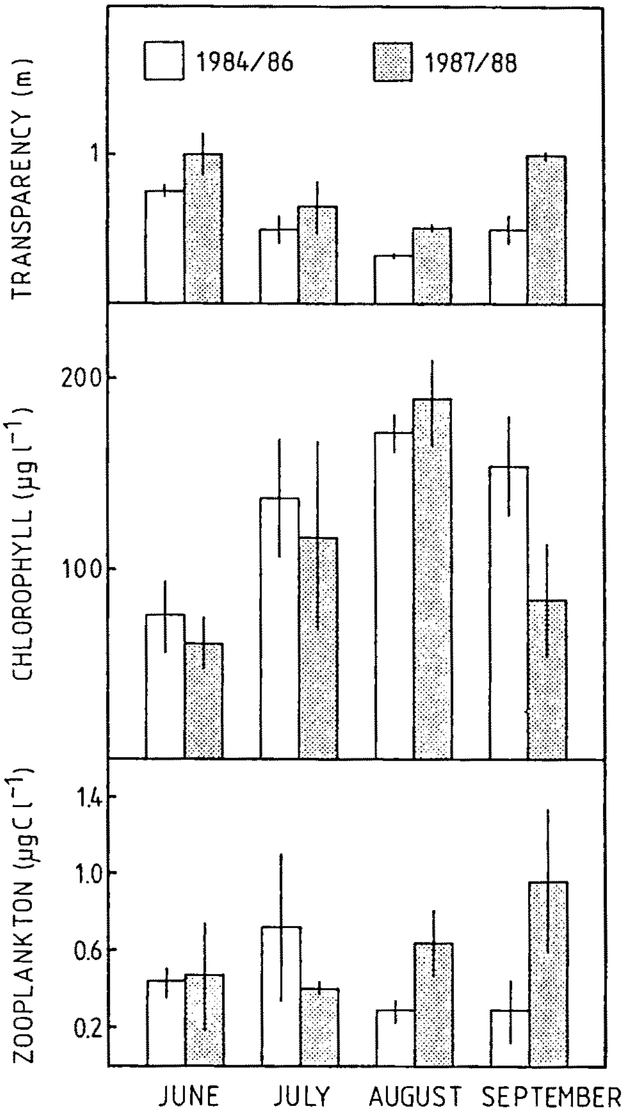

Fig. 6. Monthly average values for 1984 and 1986 (before the manipulation) and after the manipulation (1987 and 1988) of transparency, phytoplankton chlorophyll content and biomass of macrozooplankton (> 140 μm). Bars represent total variation.

342 to 2028 ind. m^{-2} and the carbon biomass from 185 to 1278 mg C m^{-2} from August 1985 to June 1988. None of the mean density or biomass values was significant different at the 5% level (data not shown). A few individuals of *Anodonta* sp. had biomass 6–75 times higher than the total biomass of the rest of the zoobenthos community.

Discussion

The rationale of the fish manipulation was two-fold. First, the manual reduction in young roach and bream was performed to reduce the predation pressure on macrozooplankton. Second, additions of large perch were carried out to increase the population of piscivorous perch, which is reduced in eutrophic, temperate lakes owing to interspecific competition by roach (Keast, 1977; Persson, 1983a, 1986). As expected, the selective removal of roach and bream and the addition of large perch caused a number of major changes in the fish populations. The contribution of roach and bream to total fish biomass decreased from 78% before the manipulation to 45% in autumn 1987 after the manipulation. Recruitment of roach was reduced in 1987 (Fig. 3), but growth of young roach was enhanced during 1988 (unpubl. data).

The population density of roach is often ten times that of perch in eutrophic lakes mainly because roach is omnivorous and survives on a diet dominated by cladoceran zooplankton (Andersson, 1980; Henrikson *et al.*, 1980; Leah *et al.*, 1980) and cyanobacteria and detritus (Persson, 1983b; Johansson & Persson, 1986). Moreover, roach feeds very effectively on cladoceran zooplankton. Several procedures have been suggested to reduce the stock of planktivorous fish (see Benndorf *et al.*, 1988 and references herein). Biomanipulation of fish populations in Denmark by means of whole-lake poisoning is often avoided on ethical arguments. Therefore, a manual reduction of planktivorous fish, combined with additions of large-sized perch is used as an effective alternative. A number of chemical and biological changes occurred after the manipulations of the fish populations. Inorganic nutrients generally increased and the duration of cyanobacteria bloom decreased. In Frederiksborg Slotssø, external phosphorus loading has been reduced, since most of the sewage from the surrounding city and from Frederiksborg Castle was diverted during 1965–1969. Nevertheless, at present the internal phosphorus loading is extremely high (Andersen & Jacobsen, 1979).

Table 3. Abundances and biomasses of zoobenthos at Station IV in Lake Frederiksborg Slotssø during 1985–86 (average of 8 sampling dates) and 1987–88 (average of 10 sampling dates).

Taxa	No m^{-2}		Mg C m^{-2}	
	1985/86	1987/88	1985/86	1987/88
Nematoda	38	78	24	54
Oligochaeta				
Limnodrilus sp.	163	178	52	22
Potamothrix hammoniensis (Mich)	438	244	92	58
Psammoryctides barbatus (Grube)	513	189	249	116
Psammoryctides albicola (Mich)	163	67	106	47
Others	63	55	41	9
Mollusca				
Anodonta sp.	38	22	20834*	12346*
Pisidium sp.	13	11	3	4
Others	202	78	963	271
Crustacea				
Ansellus aquaticus (L)	25	122	12	127
Odonata				
Coenagrionidae	13	0	46	0
Ephemeroptera				
Caenis sp.	75	11	14	4
Coleoptera				
Donacia sp.	0	11	0	3
Diptera				
Chironomus plumosus	163	122	157	265
Glyptotendipes sp.	888	1289	430	564
Others	126	154	16	132
Others	88	89	186	168
Total	3097	2775	2439	1935

* Biomass of Anodonta is not included in total.

Phosphate and inorganic nitrogen, which probably regulated phytoplankton primary production in periods before the manipulations, are now present in excess quantities throughout the season after the manipulations. A decrease in total phosphorus after biomanipulation has been reported from mesotrophic lakes (Henriksen *et al.*, 1980; Wright & Shapiro, 1984). However, in the eutrophic Bautzen Reservoir, Benndorf *et al.* (1988), who reported an average increase of 150% of total phosphorus after biomanipulation, cautioned about the potential risk of continued blooms of cyanobacteria. They concluded that, although the principal mechanisms of biomanipulation operate in lakes with various levels of P-loadings, the uncertainty of the response increases with increasing nutrient loads. The results from Frederiksborg Slotssø generally support this conclusion. Although pronounced effects were found in the fish populations, the oxygen budget and distribution of zoobenthos did not change, and the mid-summer blooms of cyanobacteria continued. Low chlorophyll levels during autumn, however, coincided with increases in the biomass of crustaceans, like in the Bautzen Reservoir (Benndorf *et al.*, 1988) after stocking with pikeperch supplemented by catch restrictions for pike and pikeperch. Although the changes observed in Frederiksborg Slotssø are not as dramatic as those reported from biomanipulation experiments in lakes with lower P-loadings (Shapiro, 1980; Shapiro & Wright, 1984; Reinertsen & Olsen, 1984; Jeppesen *et al.*, 1989), they do indicate an improvement of the water quality, which allows the users of the lake (fishermen's association) to continue a more diverse fishing at least an extra month (September) during the season.

It is still not known whether natural populations of cladocerans have a potential capacity to control blooms of cyanobacteria which often occur in nutrient-rich lakes. Laboratory experiments indicate that various cyanobacteria may reduce net assimilation rates, growth, and reproduction of cladocerans (Lampert, 1981; Porter & McDonough, 1984; Infante & Abella, 1985; Dawidowicz *et al.*, 1988). In a whole-lake experiment in Lake Haugatjern, removal of the whole fish population in 1980 and restocking with arctic char during 1982–1984 gave long-term reductions in phytoplankton biomass and changes in the phytoplankton community towards fast-growing species (Reinertsen & Olsen, 1984; Reinertsen *et al.*, 1990). In several other biomanipulation experiments, a varying degree of fish predation on zooplankton complicates interpretations of the role of zooplankton as grazers on phytoplankton communities (Benndorf *et al.*, 1988 and references herein).

An important question is whether the observed positive changes of the water quality in Frederiksborg Slotssø represent changes that can be maintained or even improved with or without continued manipulations of the fish populations. Although we have not observed any obvious physical differences between the two periods we examined, we cannot exclude the temperature effects or if conditions between years could have contributed to the observed changes. The periodically coupled oscillations in biomasses of phytoplankton and zooplankton suggest, however, true food chain reactions. Moreover, results from the Bautzen Reservoir (Benndorf *et al.*, 1988) and eutrophic Lake Haussee (Kasprzak *et al.*, 1988) suggest that a stable, moderate stock of planktivorous fish is needed before positive effects can be expected. Whether this is enough to prevent a recurrence of the conditions that prevailed before the manipulation is not known. Our study on the biomanipulation of the fish populations in Frederiksborg Slotssø suggest that a positive effect could be maintained and even enhanced during the second year after the manipulation.

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