Hydrobiologia **275/276**: 65–70, 1994.
E. Mortensen et al. (eds), Nutrient Dynamics and Biological Structure in Shallow Freshwater and Brackish Lakes.

Food web manipulation in a small, eutrophic Lake Wirbel, Poland: effect of stocking with juvenile pike on planktivorous fish

Andrzej Prejs [1], Andrzej Martyniak [2], Sławomir Boroń [2], Piotr Hliwa [2] & Paweł Koperski [1]
[1] *Department of Hydrobiology, University of Warsaw, Nowy Świat 67, 00-046 Warsaw, Poland;*
[2] *Department of Fisheries, Academy of Agriculture and Technology, 10-957 Olsztyn-Kortowo*

Key words: biomanipulation, eutrophication, whole-lake experiment, fish stock management, predation, *Esox lucius*

Abstract

In a four year experiment (1988–1991) carried out in a shallow, eutrophic lake, an increase in young-of-the-year pike (*Esox lucius*) density was used to control planktivorous fish assemblages consisting mainly of small-sized cyprinids: roach (*Rutilus rutilus*), *Leucaspius delineatus*, and white bream (*Blicca bjoerkna*). Stocking with pike fry of *ca* 30 mm in three successive springs resulted in large-scale mortality among prey of vulnerable sizes. Rotenone treatment at the end of the fourth year showed that roach and white bream populations contained few 0+ to 2+ fish, but very high numbers of 3+ to 6+ fish. By this time, short-lived, slow-growing *L. delineatus*, with no size refuge from predators, had been driven almost to extinction.

Introduction

During the last three decades a great number of shallow lakes of European lowland have been severely affected by eutrophication. This includes dramatic changes in fish fauna which, from balanced assemblages of strong piscivore and moderate stocks of fast growing prey species, have changed into communities composed of weak piscivores with abundant, small and slow growing planktivores and benthivores (e.g. Hartmann, 1977; Holcik, 1977; Prejs, 1978; Grimm, 1989). Such changes in fish fauna favour strong and prolonged increases in algal biomass. The chance to improve water quality of such lakes may lie in manipulation of the biotic communities, namely by controlling the density of planktivorous and benthivorous fish. This would result in increased density of large cladocerans that are capable of reducing algae standing crop and decreased water turbidity and nutrient recycling. Apart from controversial use of toxins, there are two methods of reducing unwanted fish populations: selective fishing, and an increase in piscivore abundance. As suggested by Grimm (1989), Benndorf (1990) and McQueen (1990), to obtain desirable results these two methods should be combined. However, the greater the dominance by small-sized fish, the more important becomes the use of adequate predator stock.

In many small, shallow lakes of Central Europe, the bulk of the zooplankton is consumed by two or three generations of the extremely abundant roach (*Rutilus rutilus*) and *Leucaspius delineatus* (Prejs, 1988). The role of the latter, because of its very small size (maximum 90 mm of fork length, mature at 30 mm), is often neglected. Here, the only practical method seems to be substantial enhancement of the piscivore stock, although, the success of this in reducing unwanted prey populations is often problematic (e.g. Franklin & Smith, 1963; Grimm 1981, 1983; Prejs, 1988; Raat, 1988).

Our long-term biomanipulation experiment is aimed at improvement of water quality in a shallow eutrophic lake. The experiment fits the Benndorf's (1990) fourth type of whole-lake studies, in which fish stock are intentionally changed to study the response of the entire food web. In this paper special attention is paid to the practical aspects of fish stock manipulation *i.e.* to the effect of the introduction of juvenile pike (*Esox lucius*) on the density and age structure of the resident planktivores.

Study site, material and methods

The lake

Lake Wirbel is a small (11 ha), shallow (mean depth 1.8 m, max. depth 4.4 m, volume 197000 m^3), eutrophic, polimictic lake in northern Poland (54° 01′ N, 21° 13′ E). It is a semi-isolated lake with a catchment area consisting of mixed forest and arable land. Water transparency in July–August of the premanipulation year (1987) ranged from 0.4 to 0.8 m, and summer total phosphorus concentration was *ca* 150 $\mu g\,l^{-1}$ P-PO_4 19 $\mu g\ l^{-1}$. The macrovegetation which covered *ca* 19% of the lake surface, was composed mainly of emergent plants (*Carex sp.*, *Phragmites australis*, and *Typha latifolia* – *ca* 7% of the lake surface), floating-leaved species (*Nymphaea alba*, *Nuphar luteum* – *ca* 10.4% of the lake surface) and *Stratiotes aloides*. There where few submerged macrophytes; only poor stands of two species (*Ceratophyllum demersum* and *Myriophyllum spicatum*) being present.

The fishes

Preliminary catches (electrical shocker, gill-nets and dip-nets) carried out during summer of the pre-manipulation year (1987) showed the fish assemblage to be numerically dominated by roach and *L. delineatus*, with white bream (*Blicca bjoerkna*) and perch (*Perca fluviatilis*) being subdominants. Pike, bream (*Abramis brama*) and rudd (*Scardinius erythrophtalmus*) were less numerous; tench (*Tinca tinca*) and crucian carp (*Carassius carassius*) were present in small numbers. Catches carried out four times a day with sets of gill-nets of various size, small seine-nets and dip-nets, showed differences in diel distribution of small-sized cyprinids. During the day most young-of-the-year of different species, and also cohorts of 1+ and 2+ roach and *L. delineatus*, occupied shallow, relatively small areas overgrown with *S. aloides* and *Carex* sp. and surrounded with floating-leaved plants. During the night many fish migrated from these areas and were found dispersed in the open water.

The experiment

The main task of the study was to maximize the stock of juvenile pike which, as gape limited predators, are forced to feed on small prey. The experiment started in October 1987 when 2800 pond-raised 0+ pike marked by pelvic fin amputation were introduced into the lake. In each of the years that followed pike were introduced four times: three times in May as fry of *ca* 30 mm and once in October as juveniles of *ca* 170 mm (Table 1). The time of spring stockings always coincided approximately with the appearance of newly-hatched roach larvae. Also, to increase the probability of a distinct reduction of planktivores, a number of 'intralake' stockings were made. It was found that dense stands of *S. aloides*, which during summer were occupied by very numerous

Table 1. Pike introductions into Lake Wirbel. May: fry *ca* 30 mm, October: juveniles *ca* 170 mm.

Year	Number of fish (ind. ha^{-1})	
	May	October
1987		250
1988		
1989	640	90
1990	3200	
1991	3200	

planktivores, were virtually free of piscivorous fish. Hence, from June 1990, we released there all pike of body length below 250 mm and some large perch that were caught in the vicinity.

As a supplementary measure, size-selective catches (electrical shocker and gill nets) were carried out. These were targeted at reducing the density of pike over 450 mm body lenght, which could eat all the newly-introduced individuals (Grimm, 1981, 1983) and at controlling larger roach and bream, which have great reproductive capacities. The density of fish occupying the largest (*ca* 1500 m^2) area overgrown with *S. aloides* was estimated each midsummer. This was done by visual counting of fish from a boat in several selected patches. To test the effect of piscivore stock enhancement on the density and age structure of planktivorous fish, the lake was treated with rotenone (0.6 mg l^{-1} at water temperature 12°, water transparency 90 cm) in October 1991. To facilitate the penetration of rotenone, most of floating-leaved plants and *S. aloides* were removed from the lake prior to the treatment. The belt of emergent plants was also thinned in several areas.

Poisoned fish remaining at the water surface were collected and deposited on the shore. Special care was taken of small fish (< 50 mm), which were collected separately as far as was possible. Fish remaining at the bottom in shallow water (< 0.5 m) were counted directly from a boat in randomly selected areas of *ca* 50 m^2 each. To estimate the number of fish that sank in deeper water, squares (70 m^2 each) made of fine mesh were placed at the bottom in different zones of the lake prior to the treatment. Ropes and weights attached to these squares allowed them to be pulled safely to the surface. Fish collected from the surface and from submerged squares were sorted and weighed. To estimate the number, size and mass distribution of dominant species (roach, white bream, *L. delineatus* and perch) samples of 600 individuals of each species were taken. Smallest individuals (< 50 mm) of these species and all fish of less numerous species, were counted separately. In addition, scale samples were taken for age determination.

Results

Fish assemblage in overgrown areas

The majority of fish occupying the extensive stands of *S. aloides* formed multispecies schools. In midsummer (July/August) of 1988 and 1989 the schools consisted of several hundred (sometimes several thousand) fish. In 1990 and 1991 the schools were strikingly smaller, most not exceeding 100–200 fish. Decreased densities of juveniles were also observed in other overgrown areas. Rough estimation of fish present within the area overgrown with *S. aloides* (*ca* 1500 m^2) yielded a value of *ca* 48×10^3 fish for midsummer of 1988, *ca* 30×10^3 for 1989 and *ca* 7×10^3 for 1990 and 1991. Dip-net samples taken within the multispecies schools in August 1989 showed them to be dominated by 0+ *L. delineatus*, which accounted for 55–75% of the total numbers of young-of-the-year fish. In samples taken in 1990 and 1991, *L. delineatus* accounted for 35–40%, which was slightly less than the proportion of roach.

During 1988 and 1989 no pike or piscivorous perch were captured within this area. From June 1990, pike and some large perch captured in the vicinity at the time of successive fishing, were released in stands of *S. aloides*. During the 1990 and 1991 seasons these predators were then frequently caught there.

Fish assemblage at the time of poisoning

Assessments made after the lake was treated with rotenone showed the fish assemblage to be distinctly dominated by roach (Table 2). The number of *L. delineatus*, the most numerous species in 1987–1989, was very low. The position of pike would have been stronger if the 180 individuals that were removed prior to the treatment had been considered. Of the five dominant species at the time of poisoning, the pattern of age distribution was similar in three species: viz. strikingly low proportions of the youngest two (perch) or three (roach and white bream) age-classes

Table 2. Numbers and biomass of fish assessed after rotenone treatment in Lake Wirbel

Fish species	Number	Biomass (kg)
Roach	152000	1605
White bream	38000	343
Perch	12800	187
L. delineatus	9000	11
Pike	1100 (1280)[a]	320 (440)[a]
Bream	350	44
Rudd	250	7
Tench	60	24
Crucian carp	40	3
Total	213600	2535
per 1 ha	19418	230

[a] Including pike removed prior to the treatment.

(Table 3). In the small-bodied *L. delineatus* the current young-of-the-year prevailed. In the pike population the youngest three classes accounted for over 95% of the total number. Undoubtedly, such an age structure resulted from the constant effort to control the density of large pike.

Discussion

At the time of poisoning the breeding stocks of the roach (first breeding at three years of age) and white bream (first breeding at two years) populations consisted of several age-classes including very abundant 3+ to 6+ classes (Table 3). This practically excludes the possibility that low population fecundity in the years 1989–1991 was the main cause of three successive poor age-classes. Also, the fishing mortalities in 0+ and 1+ fish were neglibile. Thus, the extremely low abundance of 0+ prey fish at the end of the 1991 growing season is linked to heavy mortality induced by the 0+ pike introduced in May. Consequently, low abundance of 1+ and 2+ in October 1991 reflect low abundance of 0+ prey fish in October 1989–1990, *i.e.* in the years of the first and second stocking with pike fry. Further, strong 3+ to 6+ age-classes of roach and white bream in October 1991 manifest high abundance of 0+ fish at the end of the growing season 1985–1988. This period includes premanipulation years (1985–1987), and the first of the manipulation years (1988), when resident pike density was increased by introduction of juveniles at the end of the 1987 growing season. At the end of 1991 dominant prey species *i.e.* roach and white bream, still possessed great reproductive capacity (Table 3). This was not the case with the once very numerous *L. delineatus*. This short-lived species, with no size refuge from predators, was driven almost to extinction (Table 3). However, in spite of generally low density of all age-classes, it still had a high proportion of 0+ fish compared with other prey species. The reason is probably that young *L. delineatus*, which appear in the lake later than

Table 3. Age structure (ind. ha^{-1}) of dominant fish species assessed at the time of rotenone treatment in Lake Wirbel.

Age-class	Fish species				
	Roach	White bream	Perch	*L. delineatus*	Pike
0+	463	110	49	349	32
1+	254	55	28	298	15
2+	279	55	638	51	43
3+	7030	1413	426		2.7
4+	2390	832	3.4		1.6
5+	1990	971	8.2		1.1
6+	1188	7	4.6		0.5
7+	207	7	4.6		
8+	138	2	3.4		
≥9+		3			

e.g. roach larvae, are too small during most of their first season to be profitable prey for 0 + pike and large perch. For example, the size range of fish consumed by 0 + pike in June–July in Lake Wirbel was *ca* 18–42 mm (Hliwa, unpublished), during which time the size of 0 + *L. delineatus* did not exceed 16 mm. Thus, increased predation might eliminate mostly larger, mature (1 +, 2 +) individuals, and by this indirectly control the recruitment of young-of-the-year fish.

There are more arguments for linking the low density of 0 + prey fish to the presence of 0 + pike stocked in May. It is difficult to estimate the ratio of the stocked to resident 0 + pike. However, based on a rough estimation of the resident fry densities, we believe that by stocking 3200 ind ha^{-1} in May, the total numbers of 0 + pike on the day of stocking increased by ten to twenty times. Also, it is pertinent to add that number of stocked fry was many times higher than that recommended by Polish stocking programs, *i.e.* 450 ind ha^{-1} when stocked as early larvae, and less than 100 ind when stocked as fry of size 25–30 mm. Pike fry, which at the time of introduction were 20–30 mm in size, were forced to feed on very small prey, such as roach larvae, which constitute their first fish food consumed in large quantities (Pliszka, 1953).

The 0 + pike in Lake Wirbel attained *ca* 180 mm at the end of the growing season. Pike of such size are expected to consume *ca* 600 cyprinid fry during their first season (Grimm, 1989). According to Grimm (1989), 80–90% of the total numerical consumption of 0 + pike is realized in June and July. Assuming that 3000 ind ha^{-1} (including resident 0 +) survived until the end of July, the approximate total consumption would be 1.5 million fry ha^{-1}, which according to Grimm (1989), is sufficient to reduce the exploited population. The indirect evidence of such reduction occurring in Lake Wirbel during June–July, was the very low density of juveniles assessed in August 1990 and 1991 *i.e.* in the years of heavy stocking with early 0 + pike. Consequently, in midsummer the density of prey potentially available to 0 + pike was no longer sufficient to support an overabundant predator. This can indicate the beginning of a sharp decline of stocked pike (Bugenberg de Jong, 1968; Grimm, 1989), whose survival rate assessed in autumn is usually low (e.g. 6%: Van Donk *et al.*, 1989) or very low (*ca* 1%: this experiment).

It seems that we are justified in linking heavy stocking with pike fry to very low abundance of their potential prey. To quantify the impact of the increased predation by 0 + pike, the numerical strength of 0 + roach was back-calculated for October of the premanipulation and manipulation years. This was based on data assessed at the time of poisoning in October 1991 (Table 3). The mean mortality rate of 37% (Rudenko, 1971; Mann, 1973) was used in the back-calculation. The strength of 0 + roach yielded values between 15 and 28×10^3 ha^{-1} for October 1985–1988, and less than 1 thous ha^{-1} for October 1989–1990, the years of stocking with early 0 + pike (Fig. 1).

Pike juveniles stocked at the end of the growing season (midOctober), in the period of diminishing feeding activity, could not cause such large changes in prey densities. Moreover, during win-

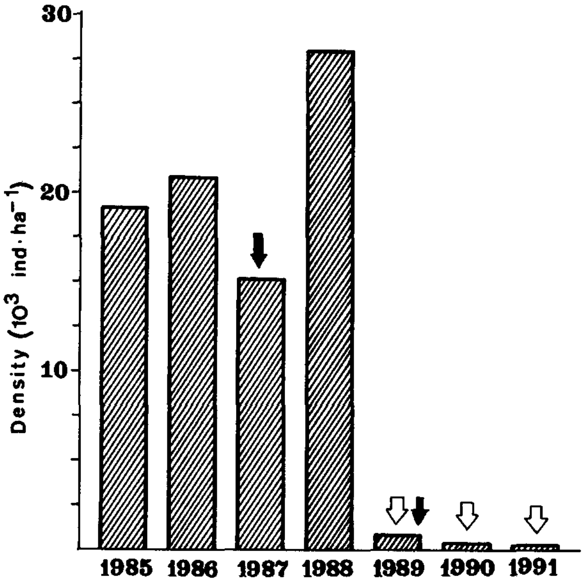

Fig. 1. Density (ind ha^{-1}) of young-of-the-year roach estimated for October of the premanipulation years (1985–1987) and manipulation years. Black arrows: pike juveniles stocked in October, white arrows: pike fry stocked in May.

ter, the abundance of the stocked cohort is substantially lowered and mortality of 50% is not unrealistic (e.g. Rudenko, 1967; Mann, 1973; Raat, 1988). Therefore, the stocked cohort would be reduced from 250 ind ha^{-1} in October 1987 and 90 ind ha^{-1} in October 1989, to 120 and 45 ind ha^{-1} in the following spring. In spring at *ca* 200 mm length, the 0+/1+ pike is capable of consuming prey more diverse in size, including fish of age-classes 1+ to 3+. At the time of appearance of newly-hatched roach, the 1+ pike are well established in preying on larger fish. The proportion of the marked 0+ pike stocked in October 1987 and 1989 (250 and 90 ind ha^{-1}), to the resident pike of respective age-classes in catches carried out throughout the successive years ranged from 30 to 70%. At the time of rotenone treatment (October 1991) marked 2+ pike accounted for 37% of the total 2+ class numbers, and marked 4+ were 45% of the total 4+ class numbers.

The management implications are that in small, shallow lakes, dominated by two, sometimes three small-sized cyprinid species, yearly stocking with adequate numbers of pike fry (*ca* 30 mm of size) can result in significant suppression of successive 0+ prey fish. This can be achieved even when survival of the stocked pike assessed at the end of the growing season is very low. To obtain the best results, the time of predator stocking should approximately coincide with the appearance of newly-hatched larvae of the dominant prey species. Also, it is recommended that predator access to the densely vegetated habitats that shelter their potential prey be facilitated.

Acknowledgements

We are grateful to G. Halvorsen, S. Lazarek and J. Nordland for providing rotenone. R. Blitek, P. Byszewski, A. Danielewicz, A. Jachner, T. Janecki, R. Sidorowicz, T. Szymański, M. Ślusarczyk are gratefully acknowledged for field assistance and Stuart Donachie for linguistic correction of the manuscript. This work was financially supported by KBN grant (6 0540) to A. Prejs.

References

Benndorf, J., 1990. Conditions for effective biomanipulation; conclusions derived from whole-lake experiments in Europe. Hydrobiologia 200–201/Dev. Hydrobiol. 61: 187–203.

Franklin, D. R & L. L. Smith, 1963. Early life history of the northern pike (*Esox lucius L.*) with special reference to the factors influencing the numerical strength of year classes. Trans. am. Fish. Soc. 92: 91–110.

Grimm, M. P., 1981. Intraspecific predation as a principal factor controlling the biomass of northern pike (*Esox lucius L.*). Fish. Mgmt 12: 77–79.

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. Mgmt 14: 115–134.

Grimm, M. P., 1989. Northern pike (*Esox lucius* L.) and aquatic vegetation, tools in the management of fisheries and water quality in shallow waters. Hydrobiol. Bull. 23: 59–65.

Hartmann, J., 1977. Fischereilische veranderungen in kulturbendigt eutrophierenden Seen. Schweiz. Z. Hydrol. 39: 248–254.

Holcik, J., 1977. Changes in fish community of Klicava reservoir with particular reference to Eurasian perch (*Perca fluviatilis*), 1957–1972. J. Fish. Res. Bd Can. 34: 1734–1747.

Mann, R. H. K., 1973. Observations on the age, growth and reproduction and food of the roach *Rutilus rutilus* (L.) in two rivers in southern England. J. Fish Biol. 5: 707–736.

McQueen, D. J., 1990. Manipulating lake community structure: where do we go from here? Freshwat. Biol. 23: 613–620.

Pliszka, F., 1953. The effect of spawning conditions in lakes on the survival rate of juveniles. Pol. Arch. Hydrobiol. 14: 166–188 (in Polish).

Prejs, A., 1978. Eutrophication and the ichtyofauna. Wiad. ekol. 23: 201–208 (in Polish).

Prejs, A., 1988. Biomanipulation. V. Piscivorous fishes as a factor limiting the density of planktivores. Wiad. ekol. 34: 295–302 (in Polish).

Raat, A. J. P., 1988. Synopsis of biological data on northern pike (*Esox lucius* L.). FAO Fish. Synopsis (145), 178 pp.

Rudenko, G. P., 1967. From the experience of determining number, ichtyomass and output of fish in a roach lake. Izv. Gos. nauch. issled. Inst. ozer-retz. rybn. choz. 64: 19–38 (in Russian).

Rudenko, G. P., 1971. Biomass and abundance of fish in roach-perch type lake. Vopr. Ichtiol. 11: 630–642 (in Russian).

Van Donk, E., R. D. Gulati & M. P. Grimm, 1989. Food-web manipulation in Lake Zwemlust, positive and negative effects during the first two years. Hydrobiol. Bull. 23: 19–34.