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The utility of predatory fish in biomanipulation of deep reservoirs

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ABSTRACT

Piscivorous fish may drive trophic cascades and maintain good water quality in lakes and reservoirs. Biomanipulation by stocking piscivores has been therefore suggested as a useful tool to regulate phytoplankton biomass in anthropogenically eutrophicated systems. We evaluated the top-down effects of piscivores on lower trophic levels in 13 deep, stratified Czech reservoirs that were built by damming rivers. In addition, the importance of piscivores was assessed in three deep, bank-side Dutch reservoirs that are artificially destratified. All the Czech reservoirs are regularly stocked with piscivores while the Dutch reservoirs have never been stocked. The piscivores had no significant top-down effect on the biomass of planktivorous and benthivorous fish and on phytoplankton biomass (measured as chlorophyll-*a* concentration) in the Czech reservoirs, although the proportion of piscivores in the fish community was high in half of them. The planktivore and benthivore biomass and the phytoplankton biomass correlated strongly with phosphorus concentration, which is in line with bottom-up control by nutrient supply. On the other hand, piscivores in the Dutch reservoirs dominated the fish community and apparently contributed to good water quality. Nevertheless, the primary cause of relatively low phytoplankton biomass in the Dutch reservoirs was the artificial destratification inducing light limitation on phytoplankton. We conclude that biomanipulation cannot substantially reduce phytoplankton biomass in the eutrophicated systems with high external nutrient input. The input should be reduced to control phytoplankton and if it is not possible, artificial destratification can be applied.

1. Introduction

Trophic cascade theory predicts that the impact of top predators translates down the food chain (so called "top-down" control) with alternating negative and positive effects on lower trophic levels (Carpenter et al., 1985). Manipulation of food webs based on this prediction, commonly referred to as biomanipulation, has become an increasingly applied management tool used to restore eutrophicated lakes and reservoirs (Gulati et al., 1990; Hansson et al., 1998; Mehner et al., 2002). The central goal of biomanipulation is to enhance large herbivorous zooplankton through the reduction of planktivorous fish. This leads to higher grazing pressure on phytoplankton and more transparent water, which in turn allows recovery of submerged vegetation and the associated fauna. During biomanipulation, undesirable planktivorous and bentivorous fish can be directly removed by seining or trawling (Horppila et al., 1998; Bergman et al., 1999) or indirectly reduced by enhancing piscivorous fish through stocking and catch restrictions (Benndorf et al., 1984; Lathrop et al., 2002).

Mehner et al. (2004) recommended a 30% proportion of piscivores in total fish biomass to efficiently balance production of small-bodied planktivorous fish, based on a bioenergetics model by Wysujack and Mehner (2002). Percentage of piscivores has also been suggested as a useful indicator of lake water quality and ecological status (Søndergaard et al., 2005) and of successful food-web modification (Benndorf, 1995; Mehner et al., 2004). Despite

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that, our understanding of the functional role of piscivores in lake ecosystems is incomplete. Potential trophic cascades driven by piscivores have received much less attention (Drenner and Hambright, 2002) than the well-known strong impacts of planktivorous fish on zooplankton and phytoplankton (Brett and Goldman, 1996; Jeppesen et al., 2003).

Moreover, introductions and stocking of piscivores is a prime example of a human activity that can lead to synergy or conflict with other interests. Piscivorous fish are frequently sought by recreational and professional fishermen. Biomanipulation can enhance the attractiveness of a particular water body for fishing but overexploitation of the predatory fish by anglers can compromise its efficiency (Scharf, 2007). In addition to fishing, productivity and nutrient loading are important and pervasive factors that affect the success of biomanipulation in lakes and reservoirs (Benndorf et al., 2002).

Studies from European lakes showed that the importance of piscivores in the natural fish community changes with increasing eutrophication (Persson et al., 1991; Jeppesen et al., 2000; Søndergaard et al., 2005). Highest proportions of piscivores in the total fish biomass occurred in moderately productive lakes and largely reflected the abundance of piscivorous perch, *Perca fluviatilis* L. (Persson et al., 1991). Local communities in highly productive lakes were predominated by cyprinids and the proportion of piscivores is low. Hence, it was postulated that the structure of natural fish community is shaped by predation in moderately productive lakes and chiefly by competitive interactions in highly productive systems (Persson, 1994). This has serious management repercussions, since the enhancement and maintenance of piscivore dominance in eutrophic systems often requires intense stocking and fishing restrictions (Benndorf, 1995; Salonen et al., 1996; Seďa et al., 2000).

In this study, we analyze the importance of piscivores in fish communities in 16 artificial Czech and Dutch lakes that differ in productivity and primary use, including the extent of recreational fishing. We examine relationships between the biomass of piscivores and selected environmental and trophic level variables to identify commonly recognized signatures of bottom-up and top-down regulations in the lake food webs. In particular, we test the expectation from the trophic cascade theory that the piscivore biomass negatively correlates with the biomass of prey fish and phytoplankton. We also compare reservoirs that are open and closed to recreational fishing as piscivores should be more abundant in unexploited systems.

2. Materials and methods

2.1. Study sites

Fish communities were examined in 13 Czech and three Dutch reservoirs (Table 1). The reservoirs range 72–2732 ha in surface area and were built between 1934 and 1979. The Czech reservoirs originate from damming rivers, i.e. were created by flooding natural, deep river valleys. They have a more or less elongated shape, increase in depth towards the dam and typically have one principal inflow at the upstream end. The reservoirs are thermally stratified during summer.

The Dutch impoundments include three nearby Biesbosch reservoirs, constructed by excavating former polders. They are more or less round-shaped and have an asphaltconcrete-lined dam around the whole perimeter. Compared to other lakes in the Netherlands, the Biesbosch reservoirs are exceptionally deep (mean depth 13–15 m; maximum depth 15–27 m). They are operated in a cascade. Water is pumped from the eutrophic river Meuse firstly to the De Gijster Reservoir, and subsequently to Honderd en Dertig and Petrusplaat reservoirs. Water column in each reservoir is artificially destratified by air injectors. The primary purpose of this artificial mixing is to impose light limitation on phytoplankton and thereby reduce algal biomass (van Breemen and Ketelaars, 1995).

The reservoirs can be classified either as drinking-water or multi-purpose reservoirs. The former are primarily used for storing and improving the quality of raw water, which is after further treatment supplied as drinking water, and recreational activities including fishing are prohibited (eight Czech and three Dutch reservoirs; Table 1). The multi-purpose reservoirs have several main uses (including for example power generation, industrial water supply, irrigation, river regulation and flood control, recreation), but all of them are also used for recreational fishing (restricted to angling in the Czech Republic) and we refer to them as recreational reservoirs (five Czech water bodies; Table 1).

Water level fluctuation is similar in all studied reservoirs and usually ranges between 0.2 and 2 m between 1 May and 30 June when most fish species spawn. All reservoirs are also old enough to pass through initial, unstable phases of the fish community succession (Kubečka, 1993). The Czech and Dutch reservoirs differ in stocking history: natural populations of piscivores in the Czech reservoirs have been supported by regular stocking, while the Dutch reservoirs have never been stocked. Large-scale removal of planktivorous and benthivorous fish as a biomanipulation tool

Table 1
Main characteristics of the studied Czech (CZ) and Dutch (NL) drinking-water (DW) and recreational (R) reservoirs. Water transparency (Transp.), epilimnetic total phosphorus (Total P) and chlorophyll-*a* (Chl-*a*) concentrations are mean values in the growing season (May–September).

Reservoir name (Country)	Use	Year of filling	Year of study	Mixed/stratified	Altitude (m)	Surface area (ha)	Mean depth (m)	Maximal depth (m)	Retention time (d)	Transp. (m)	Total P ($\mu g\ l^{-1}$)	Chl-*a* ($\mu g\ l^{-1}$)
Želivka (CZ)	DW	1975	2009	Strat.	379	1670	17	55	483	4.3	13.1	5.4
Vír (CZ)	DW	1958	2009	Strat.	469	223	25	65	176	2.2	35.1	29.3
Římov (CZ)	DW	1978	2008	Strat.	471	210	16	43	97	2.7	26.4	18.0
Žlutice (CZ)	DW	1968	2006	Strat.	509	161	9	23	153	2.5	25.8	14.8
Fláje (CZ)	DW	1961	2008	Strat.	737	149	15	47	405	2.4	9.6	5.5
Nýrsko (CZ)	DW	1969	2007	Strat.	524	148	14	34	181	6.5	8.8	4.0
Lučina (CZ)	DW	1975	2008	Strat.	534	80	7	22	49	1.6	32.3	18.6
Klíčava (CZ)	DW	1955	2007	Strat.	297	72	14	38	458	4.0	15.9	7.3
Orlík (CZ)	R	1963	2008	Strat.	354	2732	26	74	101	2.2	38.0	19.5
Vranov (CZ)	R	1934	2008	Strat.	352	765	17	58	145	2.6	57.0	31.1
Těrlicko (CZ)	R	1963	2008	Strat.	277	267	10	23	276	1.5	42.4	15.6
Žermanice (CZ)	R	1958	2008	Strat.	294	248	10	28	255	2.2	30.0	12.8
Seč (CZ)	R	1934	2008	Strat.	490	220	10	34	109	2.1	37.7	21.5
De Gijster (NL)	DW	1979	2008	Mix.	6	312	13	27	74	3.6	120.0	5.4
Honderd en Dertig (NL)	DW	1973	2008	Mix.	6	219	15	27	64	4.1	98.0	2.6
Petrusplaat (NL)	DW	1973	2008	Mix.	6	106	13	15	27	7.6	83.0	3.5