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Fish community and fisheries management of Brno Reservoir following revitalisation measures

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Abstract. Brno Reservoir (259 ha) is one of the most intensively utilised waterbodies in the Czech Republic, being used simultaneously for recreation, sport, fisheries, boating and electric power production. Despite this, no consistent fish survey has yet been performed at the reservoir. Between 2009 and 2012, a number of measures, including fish biomanipulation, were applied to improve water quality. Large cyprinids (mainly common bream *Abramis brama*) were removed and predatory fish (e.g. pike *Esox lucius*, zander *Sander lucioperca*) stocked. In September 2012 and 2013, we carried out an extensive study of the fish community in order to describe the present fish assemblage and evaluate the success of biomanipulation. Fish were sampled at 11 locations using electrofishing (inlet zone) and beach seining (lake zone). Twenty-three species and one hybrid were recorded (inlet zone – 20, lake zone – 14), with roach *Rutilus rutilus* and bleak *Alburnus alburnus* (plus perch *Perca fluviatilis*) dominant in inlet samples, but carp *Cyprinus carpio* dominant by biomass; and white bream *Blicca bjoerkna* and roach dominant in the lake zone, both by abundance and biomass. Predatory species represented 14-17 % of biomass in both the inlet and lake zones in both years. The final results of biomanipulation were questionable. While a low proportion of adult bream suggests successful removal, populations of small cyprinids, such as roach and white bream, increased in compensation. There was little evidence for an increase in predatory fish following stocking, probably due to angling pressure. Our results indicate that biomanipulation to improve ecological water quality in reservoirs is unlikely to be successful when they are managed specifically for carp and predator angling.

Key words: biomanipulation, recreational reservoir, eutrophication

Introduction

Of the ca. 120 man-made reservoirs in the Czech Republic, few have described fish communities and their management in any detail (for exceptions see Římov – Vašek et al. 2006, Prchalová et al. 2009, Říha et al. 2009; Klíčava – Pivnička 1992; and Lipno – Vostradovský & Tichý 1999). Despite implementation of the EU Water Framework Directive (2000/60/EC) in 2008 leading to a wider survey of Czech reservoirs and their ecological status (Blabolil et al. 2014), there is still limited information available on their fish communities. As an example, Brno Reservoir (259 ha) is one of the most intensively utilised waterbodies in the Czech Republic, being used simultaneously for recreation, sport, fisheries, boating and electric power production; yet there has been no study on the reservoir's fish community, despite its status as an important, large artificial lake on the outskirts of the second largest city in the Czech Republic. Only fragmentary information is available on species composition in the reservoir, based on earlier studies on specific aspects of the fish assemblage (Wohlgemuth 1979, Adámek & Jurajda 2011).

World-wide, many lakes and reservoirs in densely populated or intensively cultivated areas have become eutrophic and turbid (Søndergaad et al. 2008). This also applies to the Czech Republic, where decades of excessive loading with nitrogen and phosphorus have created ideal conditions for phytoplankton production, resulting in increased turbidity, decreased oxygen availability and decreased biological diversity. On average, 64 tonnes of phosphorus were transported into the Brno reservoir annually; making the water highly eutrophic (Adámek & Jurajda 2011). The cyanobacterial blooms arising from such eutrophication had become a serious problem in the reservoir from the 1990s on (Bláha et al. 2010). In 2009, the Morava River Basin Authority instigated a project to revitalise water quality in the reservoir and a comprehensive range of physical (aeration, destratification, partial reservoir emptying, bottom drying and liming), chemical (inflow phosphate precipitation) and biological (fish reduction, predatory fish stocking) measures were implemented in 2009 and 2010 (Moronga et al. 2012). To the best of our knowledge, this is the first time biomanipulation has been attempted on a reservoir as heavily utilised as that at Brno, and in a reservoir so strongly focused on management for angling of carp *Cyprinus carpio* and predatory species.

Biomanipulation as a tool for shifting eutrophic lakes from a turbid phytoplankton-dominated state to a clear-water macrophyte dominated state has been in use for decades (see Hansson 1998, Lammens et al. 2002). Roach and common bream are usually the main targets of biomanipulation in northern European shallow temperate lakes (Lathrop et al. 2002, Mehner et al. 2002, Van de Bund & Van Donk 2002, Søndergaad et al. 2008) as they not only feed on zooplankton but also disturb the sediment in their search for bottom-dwelling invertebrates (Boll et al. 2012, Adámek & Maršálek 2013). In addition, the density and biomass of predators, such as pike *Esox lucius*, zander *Sander lucioperca*, European catfish *Silurus glanis* or asp *Aspius aspius*, is often artificially increased in order to reduce numbers of small planktivorous fish (Lathrop et al. 2002, Skov & Nilsson 2007, Vašek et al. 2013). Many previous biomanipulation studies (e.g. Hansson 1998, Mehner et al. 2002, Lammens et al. 2002, Søndergaard et al. 2008) have confirmed that large-scale removal of benthivorous species can have positive consequences for water quality in shallow eutrophic lakes. In all cases, however, the strength of effect depended on the efficiency of fish removal and its duration (see Van de Bund & Van Donk 2002 and Boll et al. 2012).

As part of the Morava River Authority's efforts to monitor the revitalisation process, we were asked to initiate a study to 1) provide baseline data on the current fish community composition, 2) to evaluate possible impacts of biomanipulation measures on the fish assemblage, and 3) to evaluate possible impacts of the current fish assemblage on reservoir water quality.

Material and Methods

Study area

Constructed over 1936-1939 and filled in the early 1940s, Brno Reservoir remains an important artificial water storage body within the South Moravian water management system. Situated on the River Svratka (56 r. km), the reservoir is 10 km long, has a surface area of ca. 259 ha and a maximum depth of 19 m (Nehyba et al. 2011). It has a maximum retained water volume of 18.4 million m^3, though constant storage volume is normally calculated at 7.6 million m^3 (Vlček 1984). Mean hydraulic retention time is estimated at 21 days, ranging from 6 to 48 days during periods of high and low discharge (Duras et al. 2010). While the reservoir was originally constructed to stabilise river discharge and reduce flooding, it also serves as a source of electricity production, as a drinking water resource and for recreational and angling activities.

The reservoir has two distinct zones, a narrow canyon-like inlet zone (ca. 107 ha, 4 million m^3) with steep rocky banks and a depth ranging between 2.1 m at the inflow to 4.7 m where it transitions to an extensive lower lake zone (ca. 152 ha, 22 million m^3), which has a depth of 17.4 m near the dam (Fig. 1). The lake zone shoreline, which is widely used for recreation during the summer, comprises gravel beaches leading to grass meadows and forest.

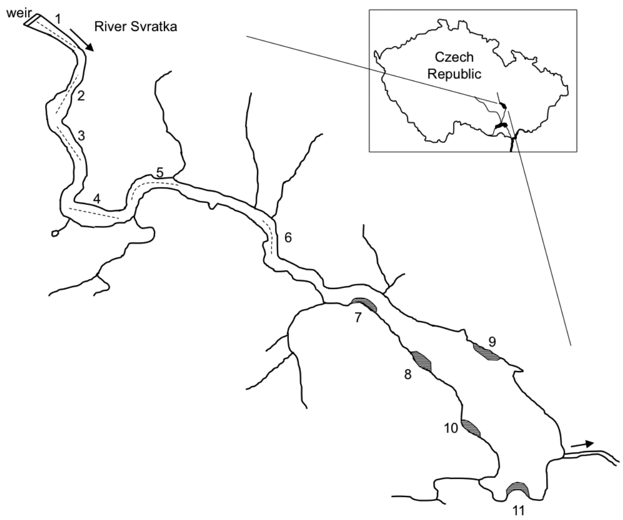

Fig. 1. Map of the Brno Reservoir study area showing sampling localities in the inlet zone sampled by electrofishing (----) and those in the lake zone sampled by beach seining (≡≡≡).

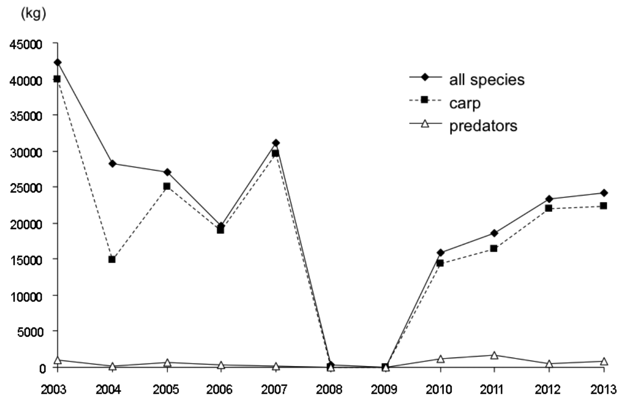

Fig. 2. Total biomass of all fish (combined), carp and predators (combined) stocked in Brno Reservoir between 2003 and 2013 (data from the Moravian Anglers Union).

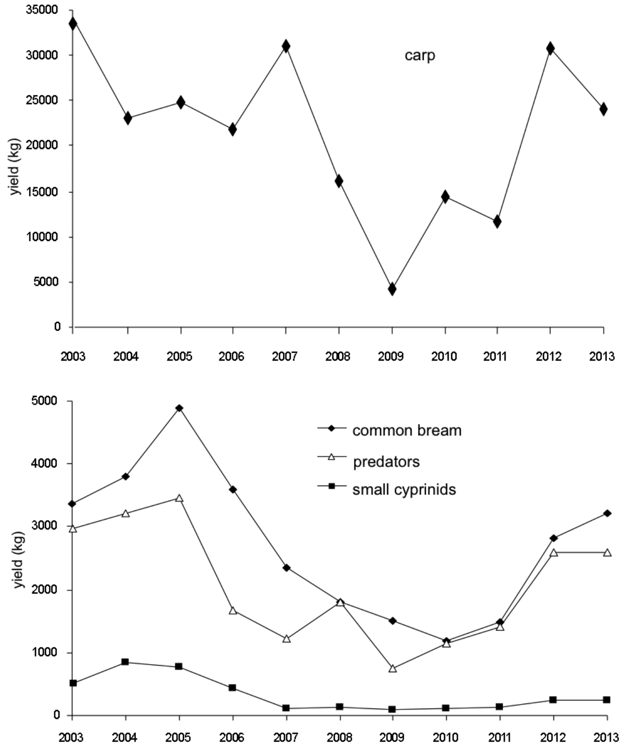

Fig. 3. The annual angling yield from Brno Reservoir between 2003 and 2013 (data from the Moravian Anglers Union).

Fisheries management

Brno Reservoir is managed as a fishing ground (Svratka 4, No. 461 141) by the Moravian Anglers Union (Local Anglers Club – Brno 2), who stock fish in the reservoir several times each year. As no fish survey had been undertaken prior to revitalisation, data for numbers and biomass of fish stocked, along with data on fish caught each year (the anglers must report all fish caught and removed to the angling authorities, who use the data to calculate angling performance and future stocking levels) were provided by the Moravian Anglers Union in order to determine angling effort targeted to individual fish species and the response of the fish community to angling pressure (see Figs. 2, 3). Using this data, fish assemblage composition and its development or impact on water quality can also be estimated (for further details see Adámek & Jurajda 2011).

Amelioration measures applied

As part of the revitalisation programme, three basic amelioration measures were applied: partial draining of the reservoir (PDoR), water aeration and destratification during the refilling process and fish biomanipulation through removal of overpopulated planktivorous cyprinids and increased stocking of predatory species.

PDoR was initiated in autumn 2008 and remained in place until spring 2010. The water level was decreased by around nine metres, resulting in a reduction of total water surface area by approx. 70 % (i.e. from 259 to 78 ha). During this period, airborne liming was applied at 800 kg of pulverised limestone per hectare of open dry bottom. During spring/summer 2009, most of the dry reservoir bottom was covered with a dense bed of terrestrial plants arising from the bottom seed bank. Before re-filling the reservoir, the majority of plant biomass was removed.

During refilling in 2011, the water in the lake zone was aerated and destratified using twenty aeration towers that pumped an air/water mixture into the hypoxic water layer on the lake bottom and/or re-pumped oxygenated water from the euphotic zone into the deeper hypolimnion (Palčík et al. 2011). Finally, phosphorus was precipitated out of the water through addition of ferrous sulphate via three jet pumps installed at the inflow. These pumps are still operating and have achieved 90 % efficiency levels (Moronga et al. 2012).

Fish removal was undertaken by the Morava River Authority and the Moravian Anglers Union at the onset of the spawning season from 2008 to 2012 (not 2010). In total, 11 tonnes of planktivorous cyprinids (mainly common bream *Abramis brama*) were removed from the inflow area by boat electrofishing (two hand-held anodes, EFKO FEG 13000, Honda 13 kW, ca. 300 V, 60 A, 50-80 Hz), resulting in an estimated reduction in fish density of around 50 kg/ha. Following re-filling of the reservoir in 2010, 76425 0+ to 2+ predatory fish (pike, zander, asp and catfish) were introduced into the reservoir in an effort to control numbers of small fish. In 2011, a further 55038 0+ to 2+ predatory fish were stocked.

Post-revitalisation fish sampling

Fish 1+ and older were caught at six localities along the inlet zone in September of 2012 and 2013 (Fig. 1) by boat electrofishing (see above). Sampling took place during the day along both banks while travelling upstream. The length of each stretch sampled (average 400 m) was noted and the number of individuals caught recalculated as density and presented as catch per unit effort (CPUE), i.e. individuals per 100 m stretch (see Kubečka et al. 2010).

From September to October 2012 and 2013, beach seine nets (100 m long, max. 7 m deep, 2 cm mesh) were used to sample fish at five localities during the night (Fig. 1, same sites both years). Beach seining could only be undertaken in the lake zone as the

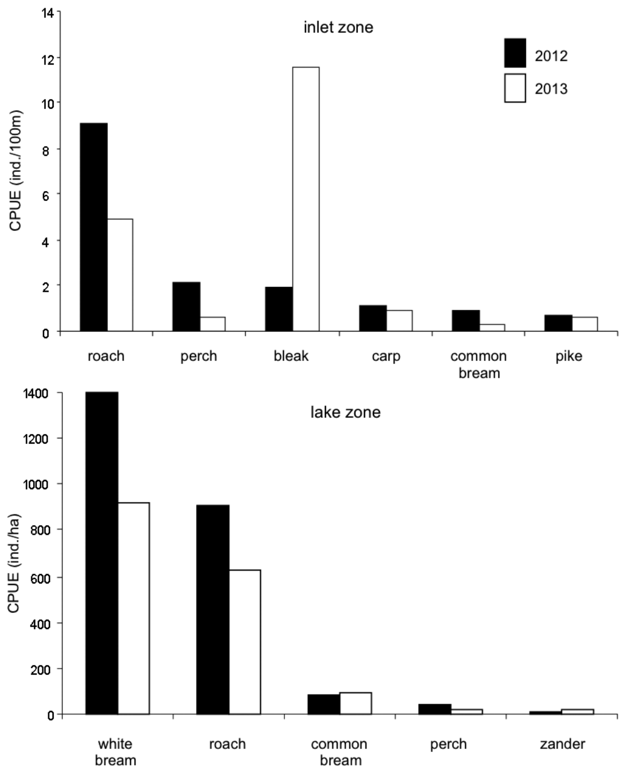

Fig. 4. Dominant fish species (CPUE) in the inlet and lake zones of Brno Reservoir in 2012 and 2013.

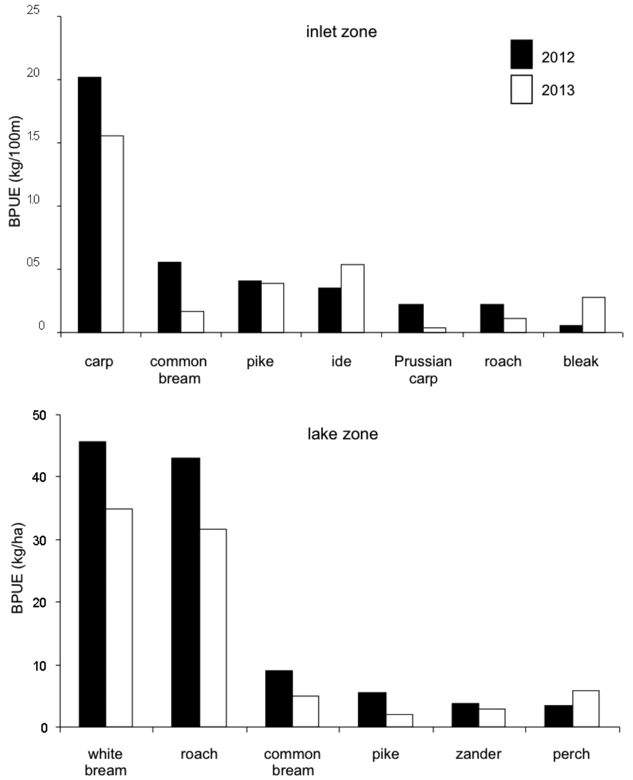

Fig. 5. Biomass of dominant fish species (BPUE) in the inlet and lake zones of Brno Reservoir in 2012 and 2013.

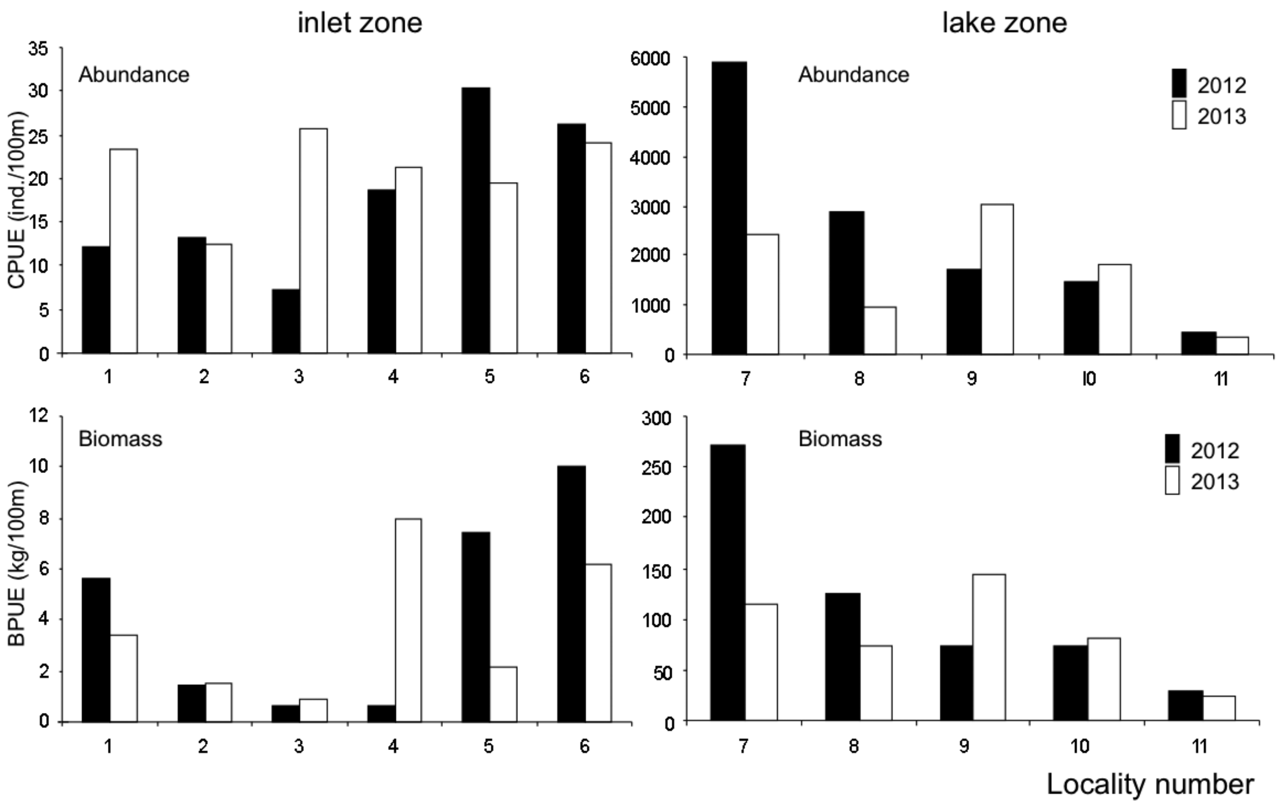

Fig. 6. Fish density (CPUE) and biomass (BPUE) at sites along the longitudinal profile of the Brno Reservoir (inlet and lake zones) surveyed in 2012 and 2013.

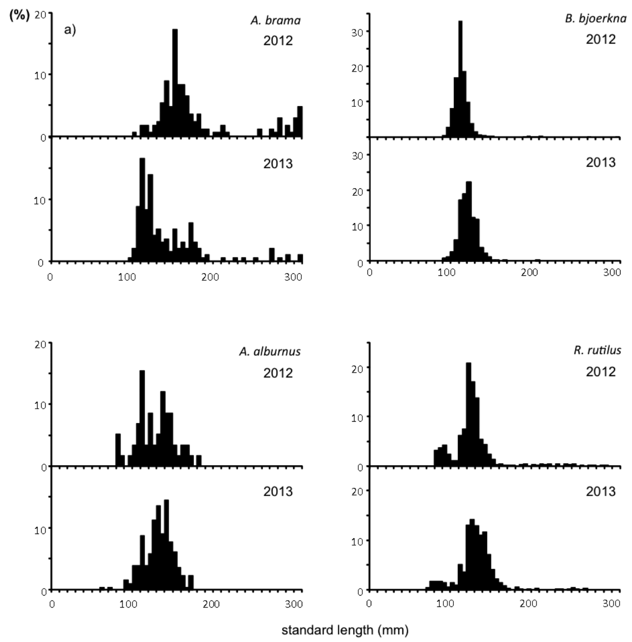

Fig. 7. Length-frequency distribution of dominant planktivorous and benthivorous species in Brno Reservoir in 2012 and 2013 (inlet and lake zones combined).

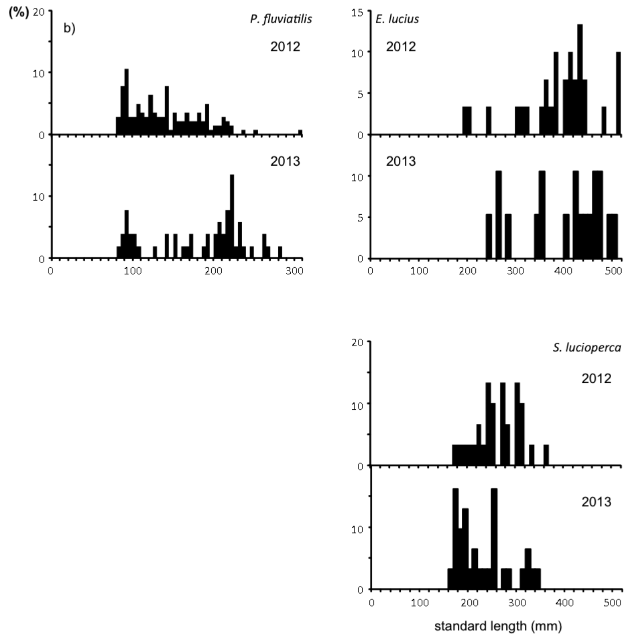

Fig. 8. Length-frequency distribution of dominant predatory fish species in Brno Reservoir in 2012 and 2013 (inlet and lake zones combined).

beaches elsewhere were obstructed with trees, fallen branches and other obstacles. As with electrofishing, the number of 1+ and older fish caught was recalculated as CPUE, i.e. individuals per hectare, (see Kubečka et al. 2010).

All fish were determined to species, individually measured (standard length, SL) and weighed according to species and size cohort, then released back to the water. The F/C ratio (Holčík & Hensel 1971), was calculated as the relationship between biomass of non-predatory fish (i.e. planktivorous, benthivorous and herbivorous species; F) and that of predatory fish (C), calculated separately for electrofishing (day) and beach seining (night) samples. The F/C ratio is a simple expression of fish community balance in natural waterbodies. Values between 3.0 and 6.0 indicate an optimal ratio, while values > 10 demonstrate undesirable fish community conditions, with a strong prevalence of non-predatory fish (Holčík & Hensel 1971).

Results

Post-revitalisation fish assemblage

A total of 9222 fish (≥ 1+ year), comprising 23 species (plus one hybrid) from five families, were caught during surveying in 2012 and 2013, with 21 species caught in the inlet zone and 15 in the lake zone (Table 1). In both years, roach, perch and bleak dominated at the inlet zone by abundance, with carp dominant by biomass. White bream and roach were dominant in the lake zone in terms of both abundance and biomass (Table 2, Figs. 4, 5). Predatory species comprised 14-17 % of biomass in both the inlet and lake zones in both years, with abundance reaching 2-3 % in the lake zone but 8-17 % in the inlet zone (Table 2, Figs. 4, 5). During sampling in 2012, the F/C ratio was 6.1 in the inlet zone and 6.3 in the lake zone. While the F/C ratio remained at 6.2 in the lake zone over 2013, values at the inlet dropped to 4.8. These values were all close to or within the optimal ratio of 3-6 (Holčík & Hensel 1971).

No gradient in fish density or biomass was observed in electrofishing samples from the inlet zone (Fig. 6). Beach seine catches from the lake zone, however, showed a decrease in density and biomass towards the dam in both years (Fig. 6).

Histograms of relative length-frequency distribution all show multiple year-classes for common bream, roach and bleak (cumulative data from the inlet and lake zones). The distribution of white bream, however, was restricted to a narrow size range between 100 and 150 mm SL (Fig. 7). Pike and zander were mainly represented by younger fishes of < 500 and 400 mm SL, respectively (Fig. 8).

Fisheries management and effect of biomanipulation measures

The total biomass of fish stocked in the reservoir each year remained similar before and after PDoR in 2008 and 2009, when no stocking took place (Fig.

Table 1. List of fish species recorded in the inlet and lake zones of Brno Reservoir during surveys in 2012 and 2013, with classification into ecological and reproductive guilds according to Schiemer & Waidbacher (1992) and Balon (1975).

Common name	Scientific name	Ecological guild	Reproductive guild	Inlet	Lake
Salmonidae					
brown trout	*Salmo trutta* m. *fario*	rheophilic A	lithophilic	+	
Esocidae					
pike	*Esox lucius*	eurytopic	phytophilic	+	+
Cyprinidae					
roach	*Rutilus rutilus*	eurytopic	phyto-lithophilic	+	+
chub	*Squalius cephalus*	rheophilic A	lithophilic	+	+
ide	*Leuciscus idus*	rheophilic B	phyto-lithophilic	+	+
rudd	*Scardinius erythrophthalmus*	limnophilic	phytophilic	+	+
grass carp	*Ctenopharyngodon idella*	eurytopic	pelagophilic	+	
asp	*Aspius aspius*	rheophilic B	lithophilic	+	+
tench	*Tinca tinca*	limnophilic	phytophilic	+	
nase	*Chondrostoma nasus*	rheophilic A	lithophilic	+	
gudgeon	*Gobio gobio*	rheophilic B	psamophilic	+	
bleak	*Alburnus alburnus*	eurytopic	phyto-lithophilic	+	+
spirlin	*Alburnoides bipunctatus*	rheophilic A	lithophilic	+	
white bream	*Abramis bjoerkna*	eurytopic	phytophilic	+	+
common bream	*Abramis brama*	eurytopic	phyto-lithophilic	+	+
zope	*Abramis ballerus*	rheophilic B	lithophilic		+
hybrid	(*Abramis* × *Rutilus*)			+	+
vimba	*Vimba vimba*	rheophilic A	lithophilic		+
Prussian carp	*Carassius auratus*	eurytopic	phytophilic	+	
carp	*Cyprinus carpio*	eurytopic	phytophilic	+	
Siluridae					
wells	*Silurus glanis*	eurytopic	phytophilic	+	
Percidae					
perch	*Perca fluviatilis*	eurytopic	phyto-lithophilic	+	+
zander	*Sander lucioperca*	eurytopic	phytophilic		+
ruffe	*Gymnocephalus cernuus*	eurytopic	phyto-lithophilic	+	+

2). Common carp were by far the most intensively released fish species, both before and after PDoR (Fig. 2). Predatory species were usually the second largest group released, with other fish species released only occasionally. The annual angling yield of carp and predatory fish tended to reflect stocking effort (e.g. compare Figs. 2 and 3). During PDoR (2008-2009), the angling yield dropped to ca. 50 % of that in previous years, with only a slow increase over 2010 and 2011. In 2012 and 2013, however, the angling yield again reached values similar to those prior to PDoR. Common bream angling yield decreased from 2005 onwards, with the decline continuing over the 2008-2011 "bream removal" period, reflecting either continuation of the original downward trend or the success of the removal campaign. In 2012 and 2013, however, angling yields increased again to values approaching those prior to PDoR. The yield of small cyprinids and percids, including roach, rudd *Scardinius erythrophthalmus*, Prussian carp *Carassius gibelio* and bleak (summarised as "small cyprinids" by angling clubs; usually taken for live/dead bait), had declined greatly even before PDoR, and remained relatively low until 2012 (Fig. 3). Catches of other coarse fish (including tench *Tinca tinca*, chub *Leuciscus cephalus* and nase *Chondrostoma nasus*) rarely, if ever, exceeded 50 individuals per year.

Discussion

Post-revitalisation fish assemblage

This study recorded 23 fish species, with cyprinids dominating the assemblage. Even after

Table 2. Relative density (CPUE) and relative biomass (BPUE) of fish species recorded in the Brno Reservoir inlet (CPUE = inds/100 m of shoreline, BPUE = kg/100 m shoreline) and lake (CPUE = inds/ha, BPUE = kg/ha) zones in 2012 and 2013.

	Inlet zone				Lake zone			
Species	CPUE		BPUE		CPUE		BPUE	
	2012	2013	2012	2013	2012	2013	2012	2013
S. trutta m. fario	-	0.04	-	0.01	-	-	-	-
E. lucius	0.71	0.65	0.40	0.39	6.12	2.04	5.50	1.94
R. rutilus	9.05	4.92	0.21	0.11	910.06	629.81	42.93	31.74
S. cephalus	0.12	0.13	0.05	0.04	2.04	1.53	0.13	0.48
L. idus	0.47	0.78	0.35	0.54	1.02	5.10	0.08	0.79
S. erythrophthalmus	0.43	0.31	0.04	0.01	1.53	-	0.08	-
C. idella	-	0.09	-	0.07	-	-	-	-
A. aspius	0.20	0.35	0.02	0.16	9.68	3.57	2.98	1.35
T. tinca	0.12	0.09	0.08	0.02	-	1.02	-	0.33
Ch. nasus	0.04	-	0.03	-	-	-	-	-
G. gobio	-	0.13	-	< 0.01	-	-	-	-
A. alburnus	1.92	11.50	0.06	0.28	4.59	29.04	0.25	1.26
A. bipunctatus	0.04	-	< 0.01	-	-	-	-	-
A. bjoerkna	0.12	0.04	0.05	0.01	1397.71	914.65	45.71	34.95
A. brama	0.90	0.35	0.55	0.17	80.51	94.27	9.02	5.06
A. ballerus	-	-	-	-	0.51	-	0.08	-
hybrid	0.04	-	< 0.01	-	1.02	7.13	0.03	0.69
V. vimba	-	-	-	-	7.13	1.02	0.54	0.13
C. auratus	0.27	0.13	0.22	0.04	-	-	-	-
C. carpio	1.14	0.96	2.02	1.55	-	0.51	-	0.69
S. glanis	0.04	-	0.01	-	-	-	-	-
P. fluviatilis	2.19	0.61	0.16	0.04	43.82	18.34	3.46	5.86
S. lucioperca	-	-	-	-	15.29	15.80	3.75	2.89
G. cernuus	0.39	-	< 0.01	-	11.21	-	0.20	-
∑	18.17	21.09	4.25	3.43	2492.23	1723.82	114.67	87.48

biomanipulation, the reservoir fish assemblage corresponded with the "stable cyprinid stage" typical of Central European reservoirs, as defined by Kubečka (1993), with roach, common bream and white bream contributing > 50 % of fish stock biomass. In the lake zone, roach and white bream were the most abundant species, occasionally contributing > 85 % of biomass. At the inlet zone, roach were most abundant in 2012 and bleak in 2013. In both years, however, carp dominated by biomass. Carp were mainly recorded at sites with fallen trees and steep valley banks, sites that offer minimal access to anglers. In the lake zone, a correspondingly low occurrence of carp corresponded with increased angling effort associated with ease of access.

The fish assemblage in the reservoir corresponds with that observed in most European lowland lakes and reservoirs, being dominated by roach, bream and perch (Lewin et al. 2004, Järvalt et al. 2005, Brosse et al. 2007, Říha et al. 2009). Some authors also include rudd in the list of abundant littoral fish in lowland European lentic systems (e.g. Irz et al. 2002, Jeppesen et al. 2006). In Brno Reservoir, however, rudd were almost absent, presumably due to a lack of aquatic macrophytes, which are required for successful breeding by rudd. Other species (e.g. ruffe *Gymnocephalus cernuus*) tend to be rather uncommon in reservoirs, their distribution and numbers depending on local geography or the physical characteristics of the system (Jeppesen et al. 2006).

Overall, the proportion of predatory fish in the reservoir did not reflect the level of eutrophication (Jeppesen et al. 2000, Søndergaard et al. 2005) but corresponded with the level of fisheries management (see below). In highly productive (eutrophic) reservoirs, the proportion of piscivorous fish is generally low (Jeppesen et al. 2000, Søndergaard et al. 2005); hence, enhancement and maintenance of these species at levels suitable for angling requires intense stocking and fishing restrictions (Vašek et al. 2013). Larger/

older predatory fish are rare in the reservoir (Fig. 5), a situation typical of most other reservoirs in the Czech Republic (Vašek et al. 2013). Such fish are usually removed by anglers in recreational reservoirs (to eat or as trophy fish), or poached in reservoirs managed for drinking water, despite angling being prohibited. Despite this, the F/C biomass ratio between non-predatory and predatory fish in the reservoir indicates that the two categories occur at a close-to-optimal ratio (see Holčík & Hensel 1971).

The spatial distribution of fish within a waterbody is not random and in large lakes and reservoirs, fish distribution patterns can have important ecological consequences (Vašek et al. 2006, Prchalová et al. 2009). Longitudinal gradients in fish abundance and biomass have been observed in many reservoirs (e.g. Vašek et al. 2003, Mathews et al. 2004, Draštík et al. 2008, Prchalová et al. 2009) and often represent decreasing trophic levels from the tributary to the dam (Vašek et al. 2004, Prchalová et al. 2009). In this study, longitudinal patterns in abundance and biomass were only partially observed, mainly in the lake area (Fig. 6). At the inlet zone, all sites were electrofished along the bankside; meaning that differences in bank structure were decisive in dictating species presence, despite the length of bank sampled (average 400 m). For example, sites with a higher percentage of fallen trees (e.g. sites 5 and 6, Fig. 6) had higher species abundance and biomass as the woody debris provided a greater degree of refuge compared to less structured sites.

Evaluation of biomanipulation measures

While water quality in Brno Reservoir improved after the amelioration measures applied (Moronga et al. 2012), it appears that the biomanipulation measures only played a minor role in the process. Both bream and small cyprinids are not a preferred species for anglers; hence, the Anglers Union does not object to their removal from the reservoir during the spawning period. Biomanipulation of bream (and small cyprinids), therefore, appeared to be an ideal measure for addressing the reservoir's water quality issues, especially as the reservoir is multi-functional, i.e. the interests of both the Anglers Union and the water management authorities having to be taken into account. Such measures, however, appear to have had only limited success. Angling yield data (Fig. 3) suggest that the bream population recovered immediately after removal stopped (note that angling yield statistics can suffer from relatively high bias). Surveys of 0+ fish, for example, demonstrate a large decrease in bream reproduction (Jurajda, unpublished data) and our seine sampling also showed a marked drop in adult bream caught. Whether bream removal was successful or not, it appears to have had limited impact on overall water quality as small cyprinid species (roach, silver bream) are still abundant and now dominate the fish assemblage in some parts of the reservoir. Dominance of small cyprinid species may be even worse for water quality as they are of no interest to anglers except as bait. Removal of such small cyprinids through a massive sampling campaign would be much less efficient than removal of adult bream as, rather than spawning in the littoral zone of the whole reservoir, adult bream form spawning shoals in the tributary zone, hence they are easily targeted for large-scale removal. Adult bream were also targeted as they burrow in sediment to obtain their food, thereby mobilising nutrients such as nitrogen and phosphorous that contribute to eutrophication (bioturbation). From a water quality perspective, however, it makes little sense to remove adult bream only when the reservoir is heavily managed for other species, such as carp, that also burrow in sediment and mobilise nutrients; albeit at a lower level than bream (Breukelaar et al. 1994).

Increasing the density and biomass of piscivorous fish as a means of indirectly reducing smaller planktivorous fish has been applied in many previous biomanipulation projects (e.g. Lathrop et al. 2002, Skov et al. 2002, Mehner 2010, Vašek et al. 2013). It has been suggested, however, that the evidence for strong top-down effects from the use of piscivores is questionable (Seda et al. 2000). Mehner et al. (2004) recommended that piscivores needed to represent a 30 % proportion of total fish biomass in order to efficiently control recruitment of small planktivorous fish. In the Brno Reservoir, predatory species comprised only 17 % of biomass in the inlet zone and 14 % of biomass in the lake zone, i.e. about half that required. We suggest several reasons why stocking of predators appears not to have been successful as a biomanipulation measure in the reservoir.

First, results of previous biomanipulation projects (e.g. Benndorf 1990, Benndorf et al. 2002) have shown that stratified eutrophic lakes show no reduction in planktivorous species (and subsequent reduction in algal blooms) following piscivore enhancement if phosphorous loading remains high. Benndorf et al. (2002) suggested that biomanipulation through increased stocking of predators is not applicable in reservoirs with a total annual phosphorous loading exceeding 0.8 g.m^{-2} or a concentration of 50 mg.m^{-3}

(Jeppesen & Sammalkorpi 2002). In Brno Reservoir, the annual phosphorous loading prior to PDoR exceeded ca. 20 g.m^{-2}, though this has now been reduced to ca. 10 g.m^{-2} (Morava River Authority, unpublished data). Levels are still too high, therefore, to allow piscivores to control production of planktivorous species. Furthermore, sediment disturbance by (stocked) carp means that phosphorous and nitrogen are constantly being recycled into the water column.

Second, piscivorous species, such as pike and zander, are highly sought after by anglers. As these species receive no added protection after stocking, many are removed from the reservoir each year. Increased stocking, therefore, simply led to an increased angling yield and not to population enforcement. In addition, natural reproduction by pike and zander is negligible, in part due to a lack of suitable spawning grounds (low macrophyte growth, steep banks), and could not compensate for the angling pressure (Adámek & Jurajda 2011). Indeed, the depth of the reservoir, the lack of littoral macrophyte growth and factors such as recreational bathing, boat traffic and high water surface fluctuation are all likely to impede efforts to obtain a clear-water macrophyte-dominated system. Protection of predatory fish, either completely (fishing ban, catch-and-release) or via increased size-limits would be highly desirable in this case; however, such levels of protection would be almost impossible to enforce in the Czech Republic due to hostility from local anglers, the high likelihood of illegal fishing (Vašek et al. 2013) and the low probability of success for such a measure (Moravian Anglers Union manager, pers. comm.).

Stocking other, less "attractive" predatory species may be better way of effectively decreasing the proportion of small non-predatory fish. Asp, in particular, show great potential for biomanipulation as they are of low interest to anglers due to their poor flesh quality and poor catchability; what is more, they reproduce naturally and are easily cultured for stocking. On the other hand, their poor catchability and low flesh quality are the very reasons why angling clubs have no interest in stocking the species in their waters. In recreational reservoirs, therefore, the biological function of predatory fish species is limited as they never reach a sufficiently high density. It would be unrealistic to increase the biomass added further, and to maintain piscivore densities at such high levels over the long-term when they remain a favoured fish for anglers.

Conclusion

The present fish community structure in Brno Reservoir corresponds with the "stable cyprinid stage" typical of Central European reservoirs, primarily through fisheries management. As the reservoir is multi-purpose, fisheries management must represent a compromise between recreational fisheries and water quality issues. As a result, biomanipulation of fish stocks to control water quality has proved unsuccessful, primarily due to the angler's desire to catch and remove large carp and pike or zander. Top-down biomanipulation has proved to have a low economic and public relations cost/effect ratio and, if water quality is to improve in the presence of recreational fisheries, a solution is still required that will maintain the ratio between non-predatory and predatory fish biomass at an appropriate level. Future management activity in the reservoir, therefore, will be oriented toward significantly decreasing phosphorous load in the reservoir, rather than expecting any significant improvement in water quality due to fish biomanipulation.

Overall, biomanipulation is unlikely ever to be successful in Brno Reservoir due to the impracticability of obtaining a clear-water macrophyte-dominated system (water depth, littoral zone with low macrophyte growth, recreation bathing, boat traffic, high water surface fluctuation) and due to its management as a carp/predator fishery.

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