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Fish community response to the longitudinal environmental gradient in Czech deep-valley reservoirs: Implications for ecological monitoring and management

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ABSTRACT

Ecological quality assessment of non-natural water bodies is, in contrast to natural systems, less developed and requires determining biological indicators that reliably reflect environmental conditions and anthropogenic pressures. This study was motivated to propose fish indicators appropriate for assessment of reservoir ecosystems in central Europe. We analysed changes in water quality, total biomass and the taxonomic, trophic and size composition of fish communities along the longitudinal axes of four elongated, deep-valley reservoirs. Due to high nutrient inputs from their catchments, the reservoirs exhibited pronounced within-system gradients in primary productivity and water transparency. Although fish communities were similar among the reservoirs and dominated by few native species, the community structure and biomass systematically changed along the longitudinal axes of the reservoirs. The biomass and proportion of planktivores/benthivores in the fish community were highest at eutrophic sites near the river inflow and declined substantially towards deep, more oligotrophic sites close to the dam. The biomass and proportion of piscivores significantly increased downstream within the reservoirs alongside improving water quality. At species level, perch *Perca fluviatilis* and bream *Abramis brama* responded most sensitively, although in opposite directions, to the longitudinal environmental gradient. The major longitudinal changes in fish community characteristics were found to be consistent between pelagic and benthic habitats. The results of this study suggest that fish communities are appropriate indicators of eutrophication and can be used for ecological quality assessment of non-natural lentic water bodies, such as reservoirs. Moreover, our results underline the necessity to consider within-system gradients in water quality and the fish community when planning sampling programmes for deep-valley reservoirs.

1. Introduction

Lake fish communities in temperate Europe are characterised by low regional and local taxonomic diversity, and the few dominant species are usually generalists with broad ecological niches (Tonn et al., 1990; Griffiths, 2006). Certain structural changes in lentic communities have, however, been repeatedly observed when sufficiently wide gradients of environmental conditions were examined (Jeppesen et al., 2000; Tammi et al., 2003; Mehner et al., 2005). For instance, lake morphology (i.e. surface area and depth) and altitude have been found to be crucial natural drivers determining local fish species richness and community composition (Mehner et al., 2005; Volta et al., 2011; Brucet et al., 2013). Among various anthropogenic stressors, increased productivity (i.e. eutrophication) has been identified as a major factor influencing fish communities. Eutrophication not only increases fish community biomass and causes shifts in species composition (Colby et al., 1972; Persson et al., 1991; Olin et al., 2002), but can also modify trophic and size structures of lake fish communities (Persson et al., 1992; Jeppesen et al., 2000; Emmrich et al., 2011).

The role of biological monitoring in the evaluation of European surface waters has increased considerably since the implementation of the Water Framework Directive (European Commission, 2000). The directive states that fish are one of the key biological

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components to be considered for assessing the ecological quality of aquatic ecosystems. Hence, structural and functional aspects of fish communities have recently been investigated by numerous studies in a multitude of lakes (e.g. Søndergaard et al., 2005; Garcia et al., 2006; Rask et al., 2010; Kelly et al., 2012; Argillier et al., 2013). These studies have demonstrated fish community responses to diverse natural and anthropogenic factors and have proposed fish-based methods to evaluate the ecological status of lakes in various parts of Europe. Much less attention has been paid to fish community assessment in artificial lakes (i.e. reservoirs: Godinho et al., 1998; Carol et al., 2006). The development of fish-based diagnostic tools for the ecological classification of reservoirs is thus less advanced (Navarro et al., 2009; Launois et al., 2011) compared to the elaborate approaches widely used for assessment of rivers and natural lakes (e.g. Pont et al., 2007; Schmutz et al., 2007; Birk et al., 2012). Nevertheless, given the number and importance of reservoirs in many states and regions, it is clear that biological criteria will be increasingly applied for assessing the ecological quality of these non-natural systems. Development of robust evaluation schemes well suited for reservoir management purposes will, however, inevitably require improved knowledge about the way in which biotic communities, including fish, in reservoirs react to environmental variations and anthropogenic perturbations.

Reservoirs are managed ecosystems that share a number of common features with natural lakes. The presence of the pelagic zone and processes such as thermal stratification, convective mixing, primary production or predator–prey interactions are basically the same in reservoirs as in natural lakes (Thornton et al., 1990). Nevertheless, reservoirs are evolutionarily much younger, they often experience greater water-level fluctuations and usually receive more nutrient and sediment inputs because they have relatively large drainage areas compared to natural lakes (Thornton et al., 1990). Selective forces may thus differ between reservoirs and natural lakes and may result in different fish communities in these two types of ecosystem (Whittier et al., 2002; Launois et al., 2011). Assessments of natural lakes have shown that depth and productivity are the principal drivers structuring local lake fish communities (Marshall and Ryan, 1987; Mehner et al., 2005; Miranda, 2011). Both depth and nutrient input control an array of water quality characteristics that consequently, directly or indirectly, influence fish assemblages. But are these drivers equally important for determining the community structure in artificial lentic systems such as reservoirs?

Reservoirs created by the damming of deep river valleys typically have an elongated morphology and, due to the influence of river inflows, they often show pronounced internal longitudinal gradients in their physicochemical conditions and primary productivity (Thornton et al., 1990; Caputo et al., 2008). These water bodies thus provide an excellent opportunity to examine how a spatially heterogeneous environment modulates fish communities in non-natural systems (Gido et al., 2002; Prchalová et al., 2009a). Better understanding of the major drivers that structure fish communities in reservoirs can greatly help to formulate effective management and restoration strategies for these non-natural systems.

In this study, we focused on variation in fish community characteristics within four stratified deep-valley reservoirs in the Czech Republic (Central Europe), which exhibit a pronounced environmental gradient of depth, productivity and water transparency along their longitudinal axes. By using quantitative data on taxonomic, trophic and size composition, we investigated whether the reservoir fish communities systematically responded to this gradient. We specifically aimed to (1) explore how fish communities in the reservoirs changed along the longitudinal environmental gradient, (2) identify fish characteristics that most strongly reflected the longitudinal environmental gradient, (3) examine whether pelagic and benthic communities showed the same response to the gradient, and (4) clarify whether fish–environment relationships in reservoirs followed similar patterns as were previously identified in natural lakes. Finally, we provide recommendations on how to improve monitoring and restoration practices for reservoir ecosystems in central Europe.

2. Material and methods

2.1. Study area

The study was carried out in four deep valley reservoirs located in the Czech Republic. Římov, Želivka and Vír reservoirs belong to European ecoregion number 9 (Central highlands), while the Vranov Reservoir falls into European ecoregion number 11 (Pannonian lowlands). Although lying in two ecoregions, the distance between the impoundments is not large (<155 km) and their altitudes are comparable (Table 1). Římov, Želivka and Vír reservoirs are primarily used for drinking water supply and any recreational activities, including angling, are prohibited on them. The Vranov Reservoir is utilised for water supply, flood prevention, hydropower

Table 1
Summary of the environmental characteristics of the studied reservoirs.

Parameter	Reservoir			
	Římov	Želivka	Vír	Vranov
Latitude (N)	48°51′00″	49°43′31″	49°33′53″	48°54′24″
Longitude (E)	14°29′28″	15°05′21″	16°18′36″	15°49′07″
Altitude above sea level (m)	471.4	377.0	467.1	350.1
Reservoir age (years)	33	34	52	77
Surface area (km^2)	2.1	14.3	2.1	6.1
Volume (mil. m^3)	32.1	266.6	47.9	111.5
Length (km)	9.6	31.0	6.2	22.3
Shoreline development ratio[a]	4.9	7.8	3.4	7.8
Maximum depth (m)	43.2	53.9	63.0	41.7
Mean depth (m)	15.8	18.6	24.7	20.0
Water level range (m)[b]	1.5	0.7	4.1	1.9
Retention time (days)[c]	85	445	154	132
Catchment area (km^2)	488.5	1178.5	410.4	2221.0
Inflow rate ($m^3 s^{-1}$)[d]	4.38	6.93	3.61	9.74
Inflowing river TP ($\mu g L^{-1}$)[e]	65	68	89	127

[a] Calculated as: shoreline length/($4\pi \times$ reservoir surface area)$^{0.5}$.
[b] Seasonal (April–June) mean for 2005–2009 (Želivka and Vír reservoirs) and 2007–2011 (Římov and Vranov reservoirs).
[c] Calculated as: reservoir volume/(inflow rate × 86,400).
[d] Long-term annual mean.
[e] Annual mean for 2006–2010.