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When a river is affected by a reservoir: Trophic interactions and flexibility in feeding strategies of alpine bullhead (*Cottus poecilopus*) and European bullhead (*Cottus gobio*)

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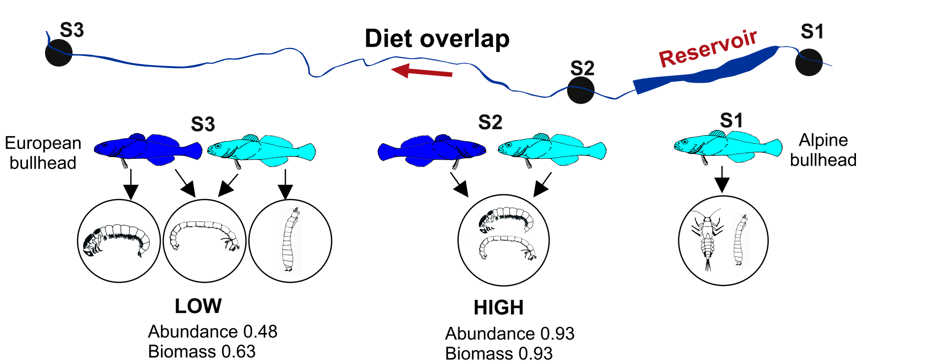
HIGHLIGHTS

- How reservoirs affect trophic interactions and altitudinal distribution of fishes.
- Anthropogenic disturbances in montane aquatic environment were evaluated.
- Diet of two fish species protected by law (alpine and European bullhead) was analysed.
- The reservoir affected their altitudinal distribution; trophic competition increased.
- Both species adapted to changes, though their ability of coexistence became limited.

GRAPHICAL ABSTRACT



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ABSTRACT

The alpine bullhead and European bullhead are benthic fish species protected by law in several European countries. One of the problems of European rivers is the ever-increasing number of reservoirs, which has adverse impacts on aquatic ecosystems. Feeding ecology of both species evaluated separately has been a subject of several studies, however, none of the studies paid attention to feeding interactions between them. Thus, the aims of the study were to evaluate trophic interactions of the two bullhead species and to assess their ability to cope with environmental disturbances caused by a reservoir. The study area consisted of three sites on the river Čierny Váh (Slovakia) that differed from each other by the intensity of pressures posed by the reservoir. The two species were found to coexist at two sites below the reservoir, because the reservoir affected their distribution along the river. For alpine bullhead, chironomid, hydropsychid and baetid larvae were the most important prey items, whereas the diet spectrum of European bullhead contained hydropsychid, chironomid larvae and detritus. Differences in diet composition were found among sampling sites. Temporal variations in the diet composition demonstrated that alpine bullhead is a more flexible feeder than European bullhead. Being predominantly food generalists, both species were able to shift their feeding strategies towards specialization when exposed to environmental disturbances at the most affected site. The reservoir increased the diet overlap between the two species, and thus changed their trophic interactions. Both alpine bullhead and European bullhead managed to cope with environmental disturbances caused by the reservoir, however, in lower population densities. Moreover, the reduced diversity of resources increased the potential for trophic competition between them.

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1. Introduction

The alpine bullhead *Cottus poecilopus* and the European bullhead *Cottus gobio* are bottom-dwelling freshwater fish species, typical inhabitants of the trout zone that corresponds to mountain and sub-mountain streams (Huet, 1959). Alpine bullhead is usually found in the uppermost parts of streams, whereas European bullhead prefers lower sections, although areas of occurrence of the two species can partially overlap (Andreasson, 1969; Tomlinson and Perrow, 2003).

The European bullhead is a fish species of great conservation interest, listed in Annex II of EU Habitats Directive as "of community interest whose consideration requires the designation of special areas of conservation". Both alpine bullhead and European bullhead are protected by law in several European countries. These species may be successfully and permanently protected only in river sanctuaries where there is no water pollution and any yield oriented trout management (Lelek, 1987). The European bullhead is threatened in many parts of its range by habitat alterations (Knaepkens et al., 2004).

One of the most prominent environmental problems of European rivers is the increasing number of dams, reservoirs and other types of barriers. The damming of rivers has a strong adverse impact on the ecosystem structure and functioning resulting from a number of changes in physical and chemical parameters in particular flows, water temperature regimes, oxygen and nutrient cycle (Nilsson et al., 2005; Pringle, 2003). This all influences the species composition of aquatic communities and becomes a limiting factor of sensitive species occurrence (Moss, 2010; Ward and Stanford, 1979).

Feeding ecology of fishes is a combination of many important ecological components that include behaviour, condition, habitat use, energy intake, as well as intraspecific and interspecific interactions (Zacharia and Abdurahiman, 2004). Thus, investigations on feeding ecology of fishes provide a basis for understanding the trophic interactions in the aquatic environment. Indeed, several papers have focused on food resource partitioning between alpine bullhead and Atlantic salmon (Amundsen and Gabler, 2008; Gabler and Amundsen, 1999, 2010; Sánchez-Hernández et al., 2016), and alpine bullhead versus brown trout (Hesthagen et al., 2004; Holmen et al., 2003; Louhi et al., 2014). Feeding ecology of both bullhead species evaluated separately has been a subject of several studies, and thus the diet composition of each species is relatively well known (Sánchez-Hernández et al., 2016; Vlach et al., 2013) but none of the studies paid attention to interactions between them.

Thus, this study had two main aims: 1) to evaluate trophic interactions of alpine bullhead and European bullhead; and 2) to assess their ability to cope with environmental disturbances caused by a reservoir. To fulfil the main aims, specific objectives were to 1) undertake a comprehensive taxonomic analysis of the diet spectrum of both alpine bullhead and European bullhead and to characterize temporal changes in its composition; 2) determine the feeding strategy of both species; 3) analyse their stomach fullness and Fulton's condition factor; and 4) assess their competition for food.

2. Materials and methods

2.1. Study area, collection and processing of samples

The study area is a metarhithral stream according to the classification by Krno (1987), and it consisted of three sites on the river Čierny Váh (Low Tatra Mountains, West Carpathians, Northern Slovakia), which is affected by a pumped-storage hydropower plant (PSHP). This PSHP releases stabilized discharge that depends on the inflow discharge and does not generate daily water level fluctuations or peaking. All three sampling sites have similar discharge conditions, which are governed by snow melt-induced peak flows during spring (data provided by the Slovak Hydro-Meteorological Institute, 2013). The first sampling site (S1) was situated above the reservoir, whereas the other two sampling sites (S2 and S3) were located below the reservoir (Fig. 1; Table 1).

Intensity of disturbances, at the three sites was evaluated following the approach of pressure assessment developed for the process of intercalibration for implementing the European Union Water Framework Directive, where a pressure is defined as physical expression, of human activities that change the status of the environment (Van de Bund, 2009). Habitats of the three sites examined in this study were thus characterized using the following ten criteria of pressures: barrier above the site, barrier below the site, impoundment, water level fluctuation, reservoir above the site, temperature alteration, channelization, riparian vegetation, local habitat alteration, water quality alteration. Each pressure was assessed based on a four-scale modality of the potential influence on fish communities (no, low, medium, high) expressed numerically as 1, 2, 3, 4, respectively. The final pressure index, that is considered to reflect the intensity of disturbances, was then calculated as a sum of all ten criteria values, which provides the possible range from 10 (minimum disturbance) to 40 (maximum disturbance).

At S1, which was least affected by the reservoir, stony-gravel substrate (cobbles and pebbles) predominated with a small proportion of sand sediment at the banks (Table 1). The right bank of the stretch was steep, eroded and densely overgrown by natural riparian vegetation. At S2, the presence and operation of PSHP resulted in discontinuity of the river (barrier), and apparent habitat alterations (Table 1). The bottom was modified partially by blocks of concrete and/or large boulders (200–400 mm), though, thanks to smaller gravel and sandy areas at the banks, the diversity of substrate was higher than at S1 (Table 1). In the shallower places, the bottom was covered with moss and/or filamentous algae. The stretch at S2 was straightened, and the riparian vegetation was almost completely removed. The PSHP affected the temperature conditions (Table 1) that resulted in increased primary production (APEM, 2015). Concerning the man-made alterations, S2 was the most impacted site (Table 1). At S3, the river had almost natural character, with no hydromorphological alterations (Table 1). The substrate was made up of pebbles and cobbles, and the bottom was not so much overgrown with moss as at S2. Variable depth generated a higher diversity of microhabitats with slowly flowing areas and riffles.

The samples of fish were collected by standard electrofishing following the CEN directive "Water Analysis – Fishing with Electricity" (EN 14011; CEN, 2003), from equally long stretches (100 m) in each site, on 17 June (spring), 11 September (summer) and 11 November 2014 (autumn, Table 2). Total length (TL) of each fish was measured to the nearest 1 mm, and subsequently released carefully back to the stream, except the subsamples (alpine bullhead and European bullhead) that were used for further laboratory analyses. These specimens were killed with an overdose of 2 phenoxyethanol and then preserved in 4% formaldehyde solution. The samples (273 specimens of alpine bullhead, and 89 specimens of European bullhead; Table 2) were measured to the nearest 0.01 mm using vernier calliper, and weighed to the nearest 0.01 g before dissection.

The gut contents of each specimen were removed, weighed (to 0.1 mg) and analysed under stereomicroscope to identify prey categories (individual fish were analysed separately). Prey items were identified to the lowest recognisable taxa and counted, and the relative weight of each food category to the biomass of total contents was estimated as described by Hyslop (1980), and then recalculated into weights based on the weight of total gut content.

Diet composition was expressed in terms of relative abundances ($\%N_i$), percentage of biomass ($\%B_i$) and frequency of occurrence ($\%F$). These were calculated for each food item from the entire food bulk as $\%N_i = 100 \sum N_i(\sum N_t)^{-1}$ and $\%B_i = 100 \sum B_i(\sum B_t)^{-1}$, where N_i (B_i) = total digestive tract content (by numbers or weight) composed by food item i and N_t (B_t) = total digestive tract content (by numbers or weight) of all digestive tracts in the entire sample. The frequency of occurrence ($\%F$) was defined as proportion of fish containing given prey category.