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Dietary habits of invasive Ponto-Caspian gobies in the Croatian part of the Danube River basin and their potential impact on benthic fish communities

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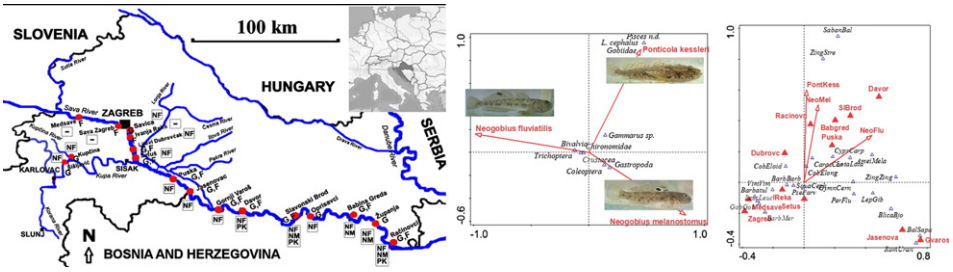
HIGHLIGHTS

- Dietary habits and impacts of invasive P-C gobies on other fish were studied
- Monkey and round goby preferred Trichoptera, Megaloptera and Coleoptera
- Bighead goby preferred Trichoptera, Gammarus and Pisces
- No negative impacts of the most abundant, monkey goby, on native fish populations
- Round goby negatively impacts native zingel, and bighead goby - chub populations

GRAPHICAL ABSTRACT



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ABSTRACT

Invasive Ponto-Caspian (P-C[1]) gobies have recently caused dramatic changes in fish assemblage structures throughout the Danube basin. While their presence in the Croatian part of the basin has been noted and distribution studied, their dietary habits and impacts on native fish communities have, until now, been unknown. In 2011, 17 locations in the Sava River Basin were sampled for fish and 15 for benthic invertebrates. Fish population monitoring data, available for nine seasons (2003–2006 and 2010–2014) and 12 locations, were used to analyse the impacts of P-C gobies on benthic fish abundance. Gut content analysis indicates that the monkey goby *Neogobius fluviatilis* diet is very diverse, but dominated by Trichoptera, Chironomidae, Bivalvia and Odonata. The diet overlaps considerably with the round goby *Neogobius melanostomus* diet, although Gastropoda are dominant in the latter's diet. Small fish and *Gammarus* sp. dominate the bighead goby *Ponticola kessleri* diet. Comparison of gut content with the prey available in the environment indicates that monkey and round gobies exhibit preference for Trichoptera, Megaloptera and Coleoptera, and bighead goby for Trichoptera, *Gammarus* sp. and Pisces. P-C gobies in the Sava River are spreading upstream, towards the reaches with lower fish diversity. Analyses indicate potentially positive impacts of P-C gobies' presence on some fish populations: round and bighead goby on Balkan golden loach *Sabanejewia balcanica* and monkey goby on common carp *Cyprinus carpio*, crucian carp *Carassius carassius*, burbot *Lota lota* and Balkan loach *Cobitis elongata*. However, there are also indications that bighead and round goby could adversely impact the native chub *Squalius cephalus* and zingel *Zingel zingel* populations, respectively. As P-C gobies are still in the expansionary period of invasion and the

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[1] P-C = Ponto-Caspian; NF = *Neogobius fluviatilis*; NM = *Neogobius melanostomus*; PK = *Ponticola kessleri*; CCA = canonical correspondence analysis; GLM = generalized linear model; n.d. = not determined.

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ecosystem still adapting to new circumstances, continued monitoring of fish population dynamics in the Sava basin is needed to determine the outcome and impacts of this invasion.

1. Introduction

The ongoing spread and proliferation of Ponto-Caspian (P-C) gobies, and particularly the dramatic changes they have caused in fish assemblage structures throughout Europe, have attracted a considerable amount of attention from conservationists and scientists alike (Jazdzewski and Konopacka, 2002; Copp et al., 2005a; Jurajda et al., 2005; Borza et al., 2009; Leuven et al., 2009; Manné et al., 2013). Expansion of four species of P-C gobies has been noted and studied in Croatia as well: monkey goby *Neogobius fluviatilis* (Pallas, 1814), bighead goby *Ponticola kessleri* (Günther, 1861), round goby *Neogobius melanostomus* (Pallas, 1814) and racer goby *Babka gymnotrachelus* (Kessler, 1857) (Polačik et al., 2008a; Piria et al., 2011a, 2011b; Šanda et al., 2013; Jakovlić et al., 2015). All four species are considered invasive (Copp et al., 2005a), as confirmed by the risk assessment analysis of non-native species (Copp et al., 2005b) in Croatia and Slovenia, which indicated a "high risk" for round goby and "medium to high risk" for the other three species (M. Piria, unpublished data).

Most of the continental Croatia (and a significant part of the Southeast Europe) belongs to the Sava River Basin, which represents 12% of the total Danube Basin area (Komatina and Grošelj, 2015). While there are presently relatively few significant hydromorphological alterations, mostly limited to Sava tributaries (Ogrinc et al., 2015), and the water quality has improved since the beginning of the 1990s, mostly as a result of the decline of heavy industry and mining (Treer et al., 2007), the presence of invasive species is becoming an increasingly important stressor in the basin (Copp et al., 2005a; Simonović et al., 2015). In the Sava basin, monkey goby is the most abundant and widely distributed among the P-C gobies, which has been brought in correlation (Jakovlić et al., 2015) to the abundance of its preferred habitat, sandy substrate (Simonović et al., 1998; Čápová et al., 2008; Kessel van et al., 2011). However, all four species can successfully subsist on mixed gravel/sand and rocky substrates (Kottelat and Freyhof, 2007). They feed on invertebrates and fish (Kakareko et al., 2005; Adámek et al., 2007; Borza et al., 2009; Grabowska et al., 2009; Brandner et al., 2013), depending on the habitat type, time of day and year, as well as the size of goby (Kornis et al., 2012). Their presence can have adverse impacts on benthic fauna diversity and ecosystem functioning (Kipp and Ricciardi, 2012). It has also been reported that their proliferation may have caused a progressive decline in some native benthic fish populations, such as *Cottus gobio* (Linnaeus, 1758), *Romanogobio albipinnatus* (Lukasch, 1933) and *Barbatula barbatula* (Linnaeus, 1758) (Borcherding et al., 2011; Copp et al., 2008; Jurajda et al., 2005; Corkum et al., 2004; Charlebois et al., 2001). Thus, it is possible that they might be adversely affecting the native populations of fish species occupying similar ecological niches in the largest (by discharge) Danube tributary, the Sava River, and its sub-tributaries. Accordingly, the main objectives of this study were to examine the: 1) dietary habits of P-C gobies and their preferences for prey available in the environment; and 2) effect of P-C gobies on other benthic-feeding fish using the multivariate approach.

2. Materials and methods

2.1. Study area and fish sampling

17 locations in the Sava basin were sampled in 2011 (Fig. 1, Appendix I) using electrofishing method as previously described (Jakovlić et al., 2015). Fish specimens were measured for standard length (SL) and total length (TL) to the nearest 0.1 cm. Scales for the age determination were taken from above the lateral line, below the anterior part of the dorsal fin. Sampled P-C goby specimens were frozen immediately after capture in order to preserve the gut contents. P-C goby specimens that were undamaged after thawing were dissected and the entire content of the anterior third of the gut was weighed and fixed in 96% ethanol. Recognisable organisms were subsequently identified to the family or, when possible, genus level. The age of specimens was estimated by counting annuli on scales using a microscope (×100) under transmitted light. All ages were determined twice by the same reader.

2.2. Benthic fauna sampling

In addition to fish fauna, sampling of the benthic fauna was carried out at the same locations, only at the Sava River (15 locations), from a diverse range of substrate types: stones (>6 cm), pebbles (2–64 mm), sand (0.06–2 mm) and mud (<0.06 mm). Sampling was carried out in triplicate, using a Surber sampler (30 × 30 cm, 250 mm mesh size). All sampled benthic fauna was preserved in 96% ethanol in the field. Identification of invertebrates from digestive tracts and benthic fauna samples was carried out in a laboratory according to Nilsson (1996, 1997) and the density of all benthos classes per square metre was calculated.

2.3. P-C goby gut content analysis, diet overlap and prey importance

Assessment of the fish diet was based on the frequency of occurrence *F%*, numerical frequency *N%* and mass frequency *W%* of the different diet components, using the following formulas:

$$F\% = \frac{f_i}{\sum f} \cdot 100$$

where f_i is a number of guts containing each prey item and $\sum f$ is the total number of guts with food;

$$N\% = \frac{n_i}{\sum n} \cdot 100$$

where n_i is the total number of a particular prey item and $\sum n$ is the total number of prey items consumed by the gobies;

$$W\% = \frac{w_i}{\sum w} \cdot 100$$

where w_i is the total mass of a single prey item and $\sum w$ is the total mass of prey items consumed by the gobies (Holden and Raitt, 1974).

The analysis of changes in feeding habits was performed using the following indexes (Hyslop, 1980):

$$\text{Fulness index}(FI\%) = \frac{\text{Total stomach contents weight}}{\text{Fish weight}} \cdot 100$$

$$\text{Vacuity coefficient}(VI\%) = \frac{\text{Number of empty stomachs}}{\text{Total number of guts analysed}} \cdot 100.$$

The mean percentage of each prey category was calculated for all three P-C gobies. Diet overlap was calculated using the index proposed by Schoener (1970):

$$\alpha = 1 - 0.5\left(\sum_{i=1}^{n} |PV_{xi} - PV_{yi}\right)$$