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Long-term analysis of fish assemblage structure in the middle section of the Sava River – The impact of pollution, flood protection and dam construction

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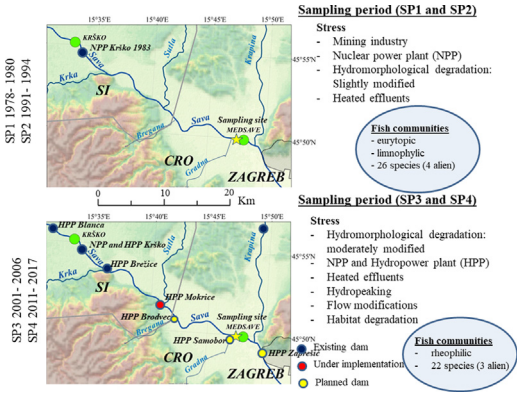
HIGHLIGHTS

- Variations in fish assemblages of the Sava River from 1978 to 2017 were analyzed.
- Limnophilic and eurytopic types of fish group were predominant from 1978 to 1980.
- Four alien fish species recorded 1978–1991, of which three remained until today.
- Changes in species composition and decline in diversity has been noted after 2001.
- Threatened *Telestes souffia* appears to be missing from the Medsave site.

GRAPHICAL ABSTRACT



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ABSTRACT

At the beginning of the 20th century, the middle section of the Sava River in Croatia was unaffected by major human activities and rich in ichthyofauna. The Sava River was important for commercial and recreational fishing for the local population, which still remains today. However, the 1920s mining industry was established in Slovenia, which emitted carbon dust into the Sava River. At the same time, the construction of embankments to mitigate flooding started in the middle section. Furthermore, in the 1980s, the Krško nuclear power plant (NPP), and in the 2010s, the Krško hydropower plant (HPP) were built in Slovenia. These activities could have an impact on the composition of fish communities downstream from the major sources of disturbances. Therefore, the main aim of this paper were to analyze the changes in fish assemblages of the Sava River from 1978 to 2017, prior to and after the construction of Krško NPP and HPP at the Medsave site on the Sava River, 20 km downstream from the major construction operations. Collected data were divided into four sampling periods (SP): SP1, from 1978 to 1980; SP2, from 1991 to 1994; SP3, from 2001 to 2006, and SP4 from 2011 to 2017.

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Hydromorphological alteration
Stressor

Besides alien fish species, water quality and hydromorphological modifications were identified as significant stressors. In SP1 and SP2 limnophilic and eurytopic fish groups were predominant, and 26 different fish species were identified, but in SP3 and SP4 rheophilic fish groups become dominant, and the diversity has declined to 21 species. Threatened species blageon, *Telestes souffia* seems to be missing from the main course of the Sava River in last 20 years. It can be concluded that disturbances in the fish assemblage pattern have coincided with the presence of multiple stressors of human origin.

1. Introduction

Human activities expose inland water ecosystems to a wide range of stressors that threaten freshwater biodiversity and ecosystem processes (Dudgeon et al., 2006; Simonović et al., 2017). Five major threat categories to freshwater biodiversity have been identified: flow modification; destruction or degradation of habitats; overexploitation; water pollution; invasion by exotic species (Dudgeon et al., 2006). The construction of nuclear (NPP) and hydropower plants (HPP) and their hydrological effects can significantly affect aquatic habitats, organisms and riverine ecosystem processes (Teixeira et al., 2012; Tonolla et al., 2017), and increase the risk of most of the threats identified by Dudgeon et al. (2006). The formation of a reservoir transforms a river into a lake, affecting turbulent river sections and causing fluctuating water levels, thus affecting flow and temperature regimes, sediment transport and species communities (Vörösmarty et al., 2010; Freyhof et al., 2015). The shift from lotic to lentic environments after dam construction often favors generalist over specialist species, and rheophilic fish species are either eliminated or severely reduced in numbers (Liermann et al., 2012); it alters assemblages of taxonomic groups and puts endemic species at increased risk of extinction, leading to biotic homogenization (Freyhof et al., 2015; Weiss et al., 2018). Furthermore, construction of HPPs, dams, and weirs cause interruption in longitudinal connectivity, upstream and downstream fish migration (Calles and Greenberg, 2009), which lead to loss of species, isolation, and decline in many fish populations (Branco et al., 2014). Additionally, depending on the amount and temperature of the discharged water, heated effluents can induce dramatic and unpredictable climatic and hydrological effects and influence the biological features of the local environment (Rong-Quen et al., 2001). This can affect fish assemblage structures by decreasing species richness and benthic cover, as an indirect impact to the fish community (Teixeira et al., 2009).

The Balkan region is a European refuge of clean and wild rivers and lakes (Vejnovic, 2017) characterized by extreme hydrographic fragmentation, with hundreds of autonomous river basins, numerous natural lakes, and artificial large and small reservoirs (Piria et al., 2018). However, the Balkan Peninsula has been under increased pressure from construction of >2500 HPPs (Schwarz and Vienna, 2015, 2017). The Adriatic Sea basin in Croatia is characterized by short and isolated karst river catchments while the Black Sea Basin represents the Danube River with vast areas of inland water network dominated by two large rivers, Sava and Drava (Piria et al., 2018). Future HPPs are planned along sensitive karst rivers as well as the large lowland rivers of the Black Sea Basin such as Drava, Sava, and Kupa (Schwarz and Vienna, 2015).

At the beginning of the 20th century, Sava River in Croatia was good water quality, rich in ichthyofauna and important inland water for commercial and recreational fishing (Habeković et al., 1990), but after 1920, carbon dust was emitted from the heavy and mining industries that started up (Simončič, 1945). In the period between 1945 and 1975, massive fish kills were observed due to heavy pollution (Herefort-Michieli, 1969; Munjko and Meštrović, 1975). Fortunately, heavy and mining industries were abandoned in Slovenia at the beginning of 1990s during the transition period to a market economy (Treer et al., 2007).

In the last 100 years, many interventions in the riverbed of the Sava for flood protection were carried out (Slukan Altić, 2010), causing habitat loss for fish spawning. The construction of HPP began in the upper part of the Sava River in Slovenia in early 1950, causing substantial changes in ichthyofaunal and other biocenose structures (Herefort-Michieli, 1969). Today, the subalpine upper Sava River in Slovenia crosses several breakthrough stretches and small basins, and is partially impounded by hydropower dams (Schwarz, 2016). In 1980s, the Krško NPP that was built on the Sava River at its middle part near the border between Croatia and Slovenia, broke upstream fish migration (Povž, 1989). Recent HPP projects along the stretch of the Sava River between the town of Krško and the city of Zagreb resulted in the construction of Krško and Brežice HPPs, which started work in 2014 and 2017, respectively (Schwarz and Vienna, 2017). In addition, due to the increasing demand for energy production, future HPP (and/or NPP) projects are planned in the Sava River Basin, despite the fact that its significant part is under the protection of Natura 2000 (Schwarz, 2016).

The construction of HPPs and its associated hydrological effects can alter the fish species composition (Benejam et al., 2014). However, detailed fish assemblage analyses of the Sava River before 1978 have never been systematically undertaken. Most of the data collected in the early and mid 20th century were obtained from lists of commercial and sport fisherman's catches (Habeković and Popović, 1991). Self-sustaining population of sterlet sturgeon *Acipenser ruthenus* (Linnaeus, 1758) was extirpated from the Sava River due to the construction of the Iron Gates I and II HPPs in 1985 (Hensel and Holčík, 1997). Also, huchen *Hucho hucho* (Linnaeus, 1758), the largest European salmonid that used to be abundant in the Sava River (Simončič, 1945), was already affected by the construction of dams and its population remained self-sustaining only in the short stretch of upper Sava River (Freyhof et al., 2015). After sterlet and huchen extinction in the middle section of the Sava between Krško and Zagreb, cyprinid fish species were predominantly present in the littoral zone in the 1980s (Habeković et al., 1990, 1997), dominated by chub *Squalius cephalus* (Linnaeus, 1758) (Habeković et al., 1993, 1997).

In Croatia, three HPPs are currently under construction, while the building of 124 more is planned. Out of this number, nine planned and one under construction are located in the Sava River basin (Schwarz and Vienna, 2015, 2017). Increasing energy demand as a result of human population growth, implies the construction of new HPPs and NPPs, but consequently also increases the number and magnitude of the associated impacts (Teixeira et al., 2012; Freyhof et al., 2015; Tonolla et al., 2017; Weiss et al., 2018).

In this study data on the impact of human activities on freshwater ichthyofauna and necessity for protection of good-quality rivers as well as the conservation of endangered species will be presented. Detailed fish assemblage analyses downstream of Krško NPP before and after its construction have never been performed. Furthermore, the impact of construction of several HPPs between the town of Krško and the city of Zagreb, the pressure of hydromorphological changes in the last 10 years, and the changes in the water quality of the Sava River including how it affected the fish assemblages, remains unknown. Thus, we hypothesized that there have been changes in the structure of fish assemblages caused by multiple human impacts downstream of the main interventions in the Sava river bed. The aims of this research were to (1) analyze the variations in fish assemblages in the Sava River before and after NPP Krško started to operate; (2) investigate