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Recovery of fish fauna in the upper Warta River, Poland: Long-term (1963–2012) monitoring study

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ABSTRACT

The Warta River (795 km long) is the largest, right side tributary of the Odra (Oder) River. The study presents results from one of the best-documented long-term monitoring projects in Poland based on four terms of electrofishing: 1963–66, 1986–88, 1996–98 and 2011–12, conducted in the upper Warta. The Warta River underwent human-induced modifications typical for most European lowland rivers (damming, regulation, water pollution), of which the most destructive for fish was point-source water pollution. In the late 1980s, pollution reached its highest level and stopped increasing as the former political system collapsed and many industrial plants went bankrupt. Surprisingly, recovered fish assemblages were not recorded during the sampling in 1996–98, but in 2011–12. This is why we believe that in large degraded rivers, it takes about 10–20 years before a considerable improvement in fish fauna can be observed. Ichthyofauna recovered to a good status, but was qualitatively different compared to the good status observed in the 1960s. On the one hand, in 2011–12, high species richness and high assemblage diversity were observed, and many species, including seven rheophils, were more common than earlier. On the other hand, the populations of catadromous eel and anadromous vimba have not recovered, and these species were absent in the 2011–12 samples. Because water quality has improved, the most important factor seems to be the impact of the Jeziorsko dam reservoir which is located downstream of the study area and has no fish pass.

The above patterns were recognised in this paper with a Kohonen artificial neural network, which is a tool methodically correct for analysing complex non-linear relations. Additionally, indicator species analysis allowed for the identification of significant associations of taxa with specific environmental states and was helpful in determination of ecological statuses of the river stretches. We therefore recommend the combined use of Kohonen artificial neural networks and indicator species analysis in long-term monitoring analyses.

1. Introduction

In the 19th and 20th centuries, riverine biota has undergone significant changes resulting from a drastic transformation of streams due to human activity. The rapid urban and industrial development resulted in significant amounts of toxic, untreated or only pre-treated, wastewater discharged into rivers (Antal et al., 2013; Jurajda et al., 2010). The use of detergents in households and the use of natural and artificial fertilisers in crop fields, often in close proximity to watercourses, with little concern for preservation of ecotones, enabled the flow of significant amounts of nutrients to surface waters (Décamps et al., 2004). Moreover, many adverse changes in river ecosystems were introduced as part of flood protection. Rivers were embanked and thus separated from oxbow lakes and floodplains, which significantly reduced the diversification of habitats available for aquatic organisms (Lusk et al., 2003). Riverbeds became regulated, which additionally reduced the diversity of abiotic conditions in river cross profiles (Aarts et al., 2004; Wolter and Vilcinskas, 1997). The rivers were impounded and dams made movements of many aquatic organisms along rivers impossible or hindered them (Petts, 1984).

Animal assemblages reacted with increasing biotic homogenisation, including species extinction, which stimulated the concern about restoration of aquatic environments. This is why knowledge of the primary biological status and the extent of biota changes became especially valuable. In practise, the most comfortable situation for researchers is the possibility of long-term qualitative comparison (what lived in a given watercourse several decades ago and what lives there now) and long-term quantitative comparison (how abundant were particular species in a given watercourse several decades ago and how abundant they are now). Such long-term comparisons for fish assemblages in rivers are rarely possible because of the scarcity of historical data. Additionally, low resolution of historical studies and application of different sampling designs and methods in follow-ups often limit comparisons to the

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binary scale (qualitative) level, i.e. the presence or absence of particular species. Results of such comparisons are usually presented in distribution maps or "+/−" tables. Of course, such basic analyses do not reflect the majority of changes in biota as most of them are much subtler than the disappearance or appearance of particular species, i.e. they are declines or increases in long-lasting (meta)populations, which can be shown only with quantitative analyses (Kruk, 2006).

However, there are also methodological limitations of such analyses. Firstly, fish abundances in samples usually do not precisely reflect the original abundances of populations, mostly because of imperfections of fishing gear and active avoidance by fish (Mann and Penczak, 1984). Secondly, most field biotic data exhibit skewed distributions, and abundances of especially rare species with many zeroes in a data set cannot be effectively normalised by any transformation (Quinn and Keough, 2002). Thirdly, the environmental variables are related in a complex (non-linear) way. Because of that, many conventional tools, due to linearity assumptions, cannot be applied in such cases (Brosse et al., 2001). In this paper, we used an artificial neural network (ANN). ANNs are simple structural and functional models of a human brain. They learn features from the data themselves and they do need require *a priori* knowledge of the model underlying the studied phenomena or meeting rigorous assumptions (Brosse et al., 2001; Lek et al., 2005). Therefore, they can be used for modelling complex population and/or assemblage responses to environmental changes with the use of "difficult" field data (Lek and Guégan, 1999; Lek et al., 2005).

Fish assemblages in the upper Warta River (Odra/Oder system) have been monitored since the 1960s. Moreover, the fish were sampled with the same method, i.e. electrofishing (with a known effort), making qualitative and quantitative comparisons, and thus much more far-reaching conclusions, possible. The river underwent human-induced modifications typical for most European lowland rivers, of which the most destructive for fish populations was point-source water pollution which increased successively until the late 1980s (Kruk, 2006). The environmental modifications resulted in profound changes in fish assemblages, including declines or even extinction of certain rheophilic and/or migratory species and an increased dominance of eurytopic fish (Kruk, 2004, 2006). In the late 1980s, pollution reached its highest level and stopped increasing as the political system collapsed in 1989 and many industrial plants went bankrupt (Bochenek, 2010). Surprisingly, during sampling almost one decade later, in the 1990s, the poorest ichthyofauna than ever was recorded (Kruk, 2004, 2006). Moreover, at that time, despite the improvement in water quality, we recorded similarly poor conditions of fish assemblages in the Pilica River (Vistula system) (Kruk and Penczak, 2013; Penczak et al., 2014). Lately, a further reduction of the amount of pollutants discharged to rivers took place in Poland, resulting from the construction and modernisation of numerous wastewater treatment plants.

Therefore, in 2011–12, we decided to re-investigate the condition of fish assemblages in the upper Warta River. Consequently, the aim of this study was to assess whether fish fauna in the upper Warta River finally reacted to the significant improvement in water quality.

2. Material and methods

2.1. Study area

The Warta River is the largest, right side tributary of the Odra (Oder) River and the third longest Polish river (795.2 km) (the second longest with regard to the stretch located within Poland). Its catchment area comprises an area of 54,519.6 km^2 (Czarnecka, 2005). The study area was situated between kilometres 102 and 282 of its course (Fig. 1). In general, river width was 25–60 m and mean depth was 0.8–2.5 m (Ciepłucha et al., 2014). Mean discharge was 24.90 m^3 s^{-1} in Działoszyn (170th km) and 45.70 m^3 s^{-1} in Sieradz (271st km) (Fig. 1), while mean maximum discharges were, respectively, 97.80 and 165.70 m^3 s^{-1} (all calculated for 1951–2010) (IMGW, 2013). The river bed was covered with sand with admixture of gravel and cobbles. Overhanging terrestrial plants (including willow branches), submerged tree roots, submerged branches, fallen trees and emerged plants were the main types of shelter for fish. Detailed morphometric characteristics of the study area within the last five decades are presented in Penczak (1969), Przybylski et al. (1993), Kruk et al. (2000) and Ciepłucha et al. (2014).

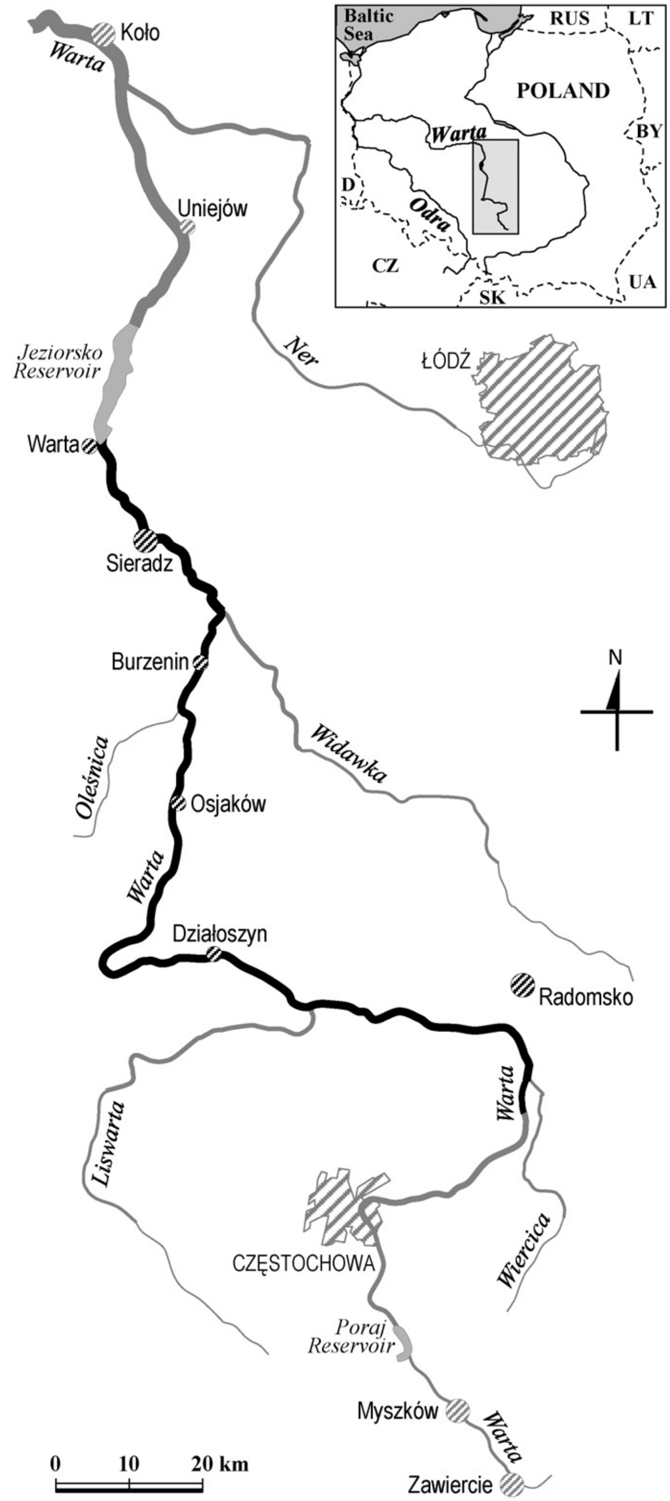

Fig. 1. Study area (marked in black). Urban areas are marked as hatched surfaces.

The study area has been considerably impacted by humans since the 1960s despite the fact that it has been the best-preserved section of the Warta, as there has been little urbanisation in its vicinity (Kruk, 2007;