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Submersed aquatic macrophytes and associated fauna as an effect of dam operation on a large lowland river

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ABSTRACT

An atypical development of submersed aquatic macrophytes (SAM, mainly *Stuckenia* and *Potamogeton*) in the large lowland alluvial Warta River (Poland) occurred annually as an effect of discharge changes caused by dam operation. The ecological responses of SAM with their associated flora and fauna to a deep water release through the Jeziorsko dam were investigated over a 20-year period in terms of their effects on the flora and fauna: firstly those associated with SAM and secondly organisms constituting mass downstream flush out from the reservoir, whose survival is enabled by the aquatic macrophytes' habitat.

In the tailwater of the Warta River, SAM and their associated organisms disappeared at the end of each summer as an effect of water level management in the reservoir. In addition, reconstruction of this diverse and rich biota began every year at the end of May, resulting in a similar abundance of the main biological groups, such as benthos, epiphytes and zooplankton. This phenomenon applies to all of the above-mentioned ecological groups, except for fish assemblages with domination of roach, perch and ruffe, which change in terms of abundance from season to season. Thus, SAM caused an increase in the structural complexity of the alluvial tailwater, and were not only the substrate for attachment for epiphytic chironomids (mainly Orthocladiinae, *Cricotopus*) but also a refuge for young fish and habitat for large sized pelophilous forms of Chironomini (*Chironomus* and *Glyptotendipes*). This last ecological group developed due to trapping organic matter by water plants.

1. Introduction

Submersed aquatic macrophytes (SAM) are frequently studied at fundamental or applied levels, such as water quality assessment and management for both rivers (Kohler et al., 2010; Szoszkiewicz et al., 2010a, 2010b, 2014; Lorenz et al., 2012) and lakes (Kornijów et al., 2001). In many lentic ecosystems, SAM are crucial for maintaining a clear water state in shallow mesotrophic and eutrophic lakes where they play a key role in the shallow lake food web, contrary to ecosystems with turbid water and a dominance of phytoplankton (Jeppesen et al., 1998; van Donk and van de Bund, 2002; Tarkowska-Kukuryk 2014). In turn, SAM are rather undesirable elements in large rivers because they modify the in-river environment mainly by altering river flows and by decreasing the depth due to trapping sediments. As this phenomenon is usually believed to exert negative environmental impacts, attempts to counteract it, using various methods such as artificial floodings, were applied in rivers (Ibáñez et al., 2012). However, SAM are a very important component of riverine biota, causing an increase in habitat structural complexity, especially in alluvial ecosystems (Benítez-Mora and Camargo, 2014). Furthermore, the submersed plants' morphological characteristics (size, number and orientation of leaves and steams) influence both invertebrate (Tokeshi and Pinder, 1985; Grzybkowska et al., 2003; Tóth et al., 2012) and fish abundance and distribution (Chick and McIvor, 1997; Grenouillet and Pont, 2001; Li et al., 2010). Macrophytes also provide shelter

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for organisms (spatial refuge against predators) and are utilized as spawning and attachment sites (Papas, 2007). Most importantly, SAM are an excellent surface for epiphyton and are also beneficial for large populations of pelophilous macrobenthic fauna owing to organic matter deposition at the bottom (Grzybkowska et al., 2003). But contrary to epiphyton some groups of invertebrates, represented by grazers, like snails, macrocrustaceans and cladoceran zooplankters, are able to protect aquatic macrophytes by removing epiphytes and phytoplanktonic algae. On one hand, the plants themselves help the process of defence because they are a source of biochemical compounds that negatively affects the growth of algae (allelopathy); this phenomenon includes all biochemical interactions between higher plants as well as between the SAM and microorganisms, which includes both stimulatory and inhibitory actions (de Nie, 1987; van Donk and van de Bund, 2002; Papas, 2007). On the other hand, SAM also attract fish; consequently, these vertebrates become an important part of a complex network of relations between nutrients, epiphytes, herbivorous invertebrates and benthos (de Nie, 1987; Dukowska and Grzybkowska, 2014). Thus, SAM may support a high density of small fish individuals, because submersed plant beds also offer protection from predators by hindering the predators' foraging activities (Rozas and Odum, 1988). Moreover, the activity of these vertebrates may decline monotonically with increasing habitat complexity (Manatunge et al., 2000).

The main aim of our original research study is to show the influence of dam operation on the bottom recolonization by submersed macrophytes and associated organisms: epiphytic and benthic fauna, zooplankton and fish assemblages, in the tailwater of the lowland Warta River, during planned water reservoir management. This aspect is very interesting and important for ecologists who investigate trophic interactions in large lowland rivers; appearance of SAM in this kind of ecosystems enriched typical alluvial ecosystem.

2. Study area

The Warta River rises 380 m above sea level, is 808 km long and empties into the Oder River at 13 m above sea level. Its catchment area is ca. 53 710 km^2 and its slope ranges from 2.0–1.0‰ in the upper course, and from 0.3–0.1‰ in the middle and lower courses (EMPHP, 2007).

The study site was established in this lowland alluvial river approximately 1.5 km downstream of the Jeziorsko Reservoir and dam, constructed in 1986. The maximal surface area reaches 42.3 km^2 (Fig. 1), the dam being 2.73 km in length; thus, this is the second largest dam reservoir in Poland in terms of area (Andrzejewski, 1987). The hydroelectric plant was built and started functioning in 1994. This late construction of the hydroelectric power station caused its location outside the dam. The powerhouse was built on the right bank of the Warta in the immediate vicinity of the dam and the main weir. Its water conveyance structure includes two pipelines under the dam, with a diameter of 2.8 m each, which deliver water to two Kaplan turbines and generators (4.89 MW) (Fig. 2). The water may also be released through the spillway gates of the weir (three upper and four bottom spillway gates) down to the river only during floods, such as those in 1997 and 2010, and sometimes before the spring and autumn emptying of the reservoir while waiting for expected high water levels (The Regional Water Management Authority in Poznań, 2013).

During sampling in the 1990s and later the discharge of the Warta River below the dam was characterised by high fluctuations, including natural floods (July 1997, May 2010), and stabilized in the summer of 2004 at a much lower level (Fig. 1A). One consequence of this phenomenon was the highest abundance of submersed macrophytes in 2004 in comparison to other cycles (Fig. 1B). SAM started to spread along a short reach of the tailwater each year from the summer of 1992, which is rather untypical for large lowland rivers. In the investigated reach, large patches of *Stuckenia pectinata* (L.) (rather closer to the midchannel with a faster water velocity) and small patches of *Potamogeton lucens* L. (closer to the shallow bank with a slower water velocity) covered the transitional riverbed zone, which is located between the depositional area close to the banks and the midriver channel.

The riparian vegetation was mainly willows (*Salix* spp.) and occasionally included *Alnus glutinosa* (L.) Gaertn. Detailed site descriptions can be found in Grzybkowska et al. (1990), Grzybkowska et al. (2003), Penczak and Głowacki (2012), Dukowska and Grzybkowska (2014), Lik et al. (2014, 2015).

3. Material and methods

Benthic samples were collected in five study periods from 1988 to 2011. Macrophytes and their epiphytic fauna were taken three times (1999, 2004, 2011). At the SAM habitat zooplankton and fish were also collected (2004, 2011). Thus these investigations begun two years after the reservoir started functioning routinely (1986), both before (1988, 1992) and after the construction of a hydroelectric plant (1994) (the remaining years). The percentage of river bottom covered by macrophytes, samples of particulate organic matter and inorganic substrate, macrophytes, zoobenthos and epiphytic fauna, zooplankton, and fish, were collected, at the same time, within an area sized 40 m by 2.5 m, and extending along the bank and along the transitional zone.

The percentage of river bottom covered by macrophytes was measured monthly, from June through August, in each sampling period (Fig. 1B).

To estimate the biomass of plants growing in the study site, a special frame (0.5 × 0.7 m) was placed on the riverine bottom, and *Stuckenia* vegetation within the frame was collected. This procedure was repeated three times on each sampling occasion. In the laboratory, the pondweeds were dried for 24 h at 65 °C to estimate their dry weight per 1 m^2 (d w m^{-2}).

In order to estimate only the abundance of the epiphytic fauna that had settled on the dominant *S. pectinata,* five plant samples were taken separately on each sampling occasion (1999, 2004 and 2011). Fragments of stems with leaves were cut off under the water surface, stored in plastic containers, and preserved in formalin in the field. In the laboratory, the plant material was removed from the containers and thoroughly rinsed in water. The invertebrates were washed off the plants, preserved in 4% formalin, identified to the species level when possible, counted, and their wet weights were assessed. Plants were dried for 24 h at 65 °C and then weighed to estimate their dry weight. The obtained data were recalculated to estimate the density of macroinvertebrates per 1 m^2 of *Stuckenia* covered riverine bottom on the given sampling occasions.

Each sample of benthic invertebrates consisted of 10 subsamples of 10 cm^2 each (100 cm^2 of stream-bed area) taken with a tubular sampler. The invertebrates were sorted from the detritus and macrophytes by hand and preserved in 4% formalin prepared with riverine water. All macroinvertebrates from these quantitative samples were counted, and their wet weight (w w) assessed; these data were used to estimate the density in a given sampling habitat. Macroinvertebrates were classified to the lowest taxonomic level of the dominant macrobenthic group, while chironomids were identified to the species level when possible. As an exact identification on the basis of their larvae was often impossible, their immature stages were reared in the laboratory from additional qualitative samples taken each time in order to obtain larval and pupal skins, and imagines.