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Ecological state of a mountain river before and after a large flood: Implications for river status assessment

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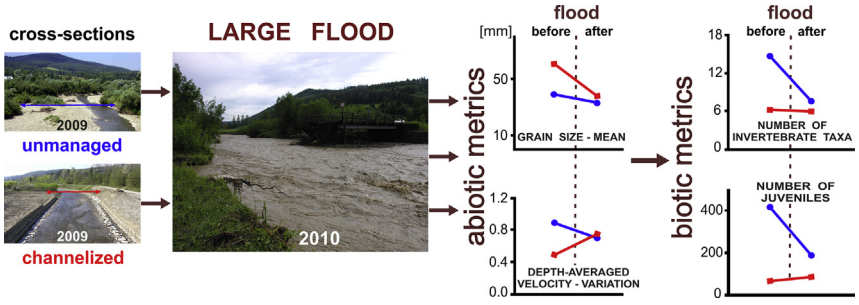
HIGHLIGHTS

- Impact of a large flood on the ecological quality of a mountain river was evaluated.
- Physical habitats, fish and benthic invertebrates in channelized and unmanaged cross-sections were assessed before and after the flood.
- The flood differently affected particular elements of the river ecosystem in channelized and unmanaged cross-sections.
- Differences in some abiotic and biotic metrics between the two types of river reaches were obliterated.
- River quality assessment should be based on repeated surveys to balance the effect of extreme hydrological events.

GRAPHICAL ABSTRACT



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ABSTRACT

Assessment of the ecological status of rivers is key to monitoring the achievement of the environmental goal of the EU Water Framework Directive and the success of restoration projects. In summer of 2009 and 2010, repeated assessments of physical habitat conditions and of fish and benthic invertebrate communities were performed at low-flow conditions in 10 unmanaged and 10 channelized cross-sections of the Biała River, Polish Carpathians. Between the two surveys, an 80-year flood occurred, significantly affecting habitat characteristics and river communities. In unmanaged cross-sections, active channel width increased, whereas the degree of cross-sectional variation of flow velocity decreased. In channelized cross-sections, the increase in active channel width and the cross-sectional variation of flow velocity was accompanied by a decrease in bed-material grain size. Before the flood, the unmanaged cross-sections hosted 2.3 times more benthic invertebrate taxa than the channelized ones, whereas after the flood, the number of taxa they supported was so reduced that the taxonomic richness of benthic invertebrate assemblages in both cross-section types became similar. In comparison to pre-flood conditions, the abundance of fish juveniles (YOY) in unmanaged cross-sections was reduced nearly by half; before the flood they hosted 5 times more juvenile individuals than channelized cross-sections and only twice as many after the flood. Finally, a differing assessment of flood impact on the ecological river quality was obtained with the invertebrate-based BMWP-PL index and the European Fish Index, with the former indicating a

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significant reduction of the quality in unmanaged cross-sections and the latter pointing to no such change. The results indicate that assessments performed before or after a major flood may yield significantly different results for the quality of abiotic and biotic elements of the river ecosystem. Final assessment should thus be based on repeated surveys to balance the effect of extreme hydrological events.

1. Introduction

Floods exert significant, positive impact on the functioning of undisturbed river ecosystems (Wydoski and Wick, 2011). Particularly, the Flood Pulse Concept (Junk et al., 1989) emphasized the importance of recurrent flooding for lateral exchange of water, organisms and nutrients between a river and its floodplain, and in-channel fluctuations of discharge, called flow pulses, were indicated to create a shifting habitat mosaic of aquatic and terrestrial habitats in rivers (Tockner et al., 2000). Floods flush out fines from bed material, making the substrate suitable for spawning of lithophilic fish (Crisp, 2000), and supply river channels with large wood beneficial for river ecosystems (Gregory et al., 2003). With maintained complexity of flow pattern and heterogeneity of habitat conditions in rivers, aquatic biota can find refuges during flood flows (e.g. Burgherr et al., 2002). Floods are also considered as disturbances by stream ecologists (Lake, 2000) as they reconfigure channel morphology and the associated habitat template, reset the development of vegetation along river margins and within the rivers (Hupp and Bornette, 2003), and redistribute biota to downstream sections. Flood disturbances may beneficially influence river communities as they control development of exotic species, less adapted to the local hydrological regime than native species (Bernardo et al., 2003).

Large/extreme floods are usually considered a threat to aquatic ecosystems (Wydoski and Wick, 2011). Such understanding of these events seems to reflect their particularly detrimental role in river systems disturbed by human pressures (i.e. almost all in Europe and other developed regions), in which hydromorphological modifications result in disruption or weakening of one or more vectors of three-dimensional connectivity of the ecosystems (Wohl, 2004), making post-flood recovery of their communities difficult and/or slow. For instance, disconnection of rivers from their floodplains results in a loss of floodplain integrity (Ward and Stanford, 1995) and floodplains cease to serve as refuges for riverine fish during floods. However, analysis of impacts of a major flood on a river ecosystem requires observations shortly before and after the event, which are rare because of unpredictable occurrence of such events. For instance, a study on the Alpine river Isar in south Germany observed no significant, negative impact of a 100-year flood on the benthic invertebrate community (Hering et al., 2004), but the reliability of this conclusion is reduced by the fact that the pre-flood survey occurred a few years before the event.

Recognition of human-induced deterioration of the ecological state of many rivers brought about the need to monitor biotic and abiotic components of river ecosystems. Moreover, several countries have implemented restoration measures aimed at the rehabilitation of natural river hydromorphology (Rinaldi et al., 2013) considered crucial to improvement of the ecological state of rivers. A measurable improvement of the ecological conditions in rivers is essential not only to achieve the environmental target of the Water Framework Directive of the European Union (European Commission, 2000), but also to achieve the intended effects of restoration projects. Expected improvements in ecological quality resulting from remedial measures can be assessed only through rigorous assessment of pre-restoration conditions that encompasses both physical habitat conditions and river communities (Pander and Geist, 2013). However, results of an ecological quality assessment may depend on timing of major hydrological events, such as floods or droughts, before the assessment is performed.

In the twentieth century, hydromorphological quality of the gravel-bed Biała River in the Polish Carpathians was considerably degraded (Hajdukiewicz et al., 2017), and in the years 2008–2009, an erodible corridor was delimited within which the river could reinstate its morphology. In 2009, at the beginning of the restoration project, physical habitat conditions and benthic invertebrate and fish communities were surveyed in unmanaged and channelized cross-sections of the Biała. Results of the surveys were used to assess the ecological river state in reaches with different types of channel management. In late spring 2010, an 80-year flood occurred and the surveys were repeated after the event.

This study (i) identifies flood-induced changes in abiotic and biotic metrics in channelized and unmanaged cross-sections, (ii) compares pre- and post-flood assessments of ecological quality with fish- and benthic invertebrate-based indices in the two types of river cross-sections, and (iii) determines how the flood changed mutual relations of particular elements of the ecological status of the river between its channelized and unmanaged reaches.

2. Study setting

2.1. General river and catchment characteristics

The Biała River is a 102-km-long, gravel-bed river draining a catchment of 983 km^2 in the flysch part of the Western Carpathians. In its upper course, the river—originating at 730 m a.s.l.—flows through the Beskid Niski Mountains typified by low-mountain relief. Here, it is fed with coarse- to medium-grained, sandstone material and forms a wide, multi-thread channel in unmanaged reaches (Wyżga et al., 2016b). In its middle course, the Biała flows within the Ciężkowice Foothills underlain by alternating sandstone and shale complexes that are a source of both cobble to pebble material and large amounts of fine sediment. Substantial amounts of cohesive, fine sediment in the floodplain cause that the Biała forms a sinuous channel, while maintaining its gravel-bed characteristics.

Annual rainfall in the catchment varies between 650–700 mm in its lowermost parts and 950 mm at the highest altitudes (Niedźwiedź and Obrębska-Starklowa, 1991), while the runoff coefficient ranges from <30% to 50%, respectively (Dynowska, 1991). The river hydrology is characterized by frequent snowmelt floods of small to medium magnitude and rare, large floods caused by prolonged summer rains. The upper part of the catchment lacks larger aquifers and the river exhibits high flow variability. Average annual discharge at the Grybów gauging station (Fig. 1) is 2.8 $m^3\ s^{-1}$ and the average annual flood is 93 $m^3\ s^{-1}$, while the coefficient of runoff irregularity (ratio of the maximum and the minimum recorded discharge) calculated for a 50-year observation period is 7500.

2.2. Human impacts on the Biała River and establishing an erodible corridor

Over the twentieth century the Biała River was changed gradually by human activity. The entire middle course and the lower part of the mountain course of the river experienced a substantial decrease in channel width (to between 25% and 15% of the pre-regulation width), while the river bed incised by up to 2.5 m. The principal causes of these changes were: channel regulation that replaced the multi-thread