Adaptive management and restoration of a complex floodplain system using artificial flooding (Sarine floodplain, Western Switzerland)

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Abstract

Artificial floods are becoming more common as operational measures to restore impacted hydrological and ecomorphological dynamics in floodplains downstream of dams. Major challenges arise in dimensioning of artificial floods regarding their magnitude, duration and frequency of flood releases for general applicability and implementation. Here we use in situ ecomorphological measurements, supported by remote sensing and hydraulic modelling to monitor, evaluate, predict, and plan the ecomorphological effects of artificial floods in a residual flow section of a complex floodplain. This approach supports the dimensioning and implementation of artificial flood programs for restoration according to an adaptive management plan.

Key words: Adaptive management, artificial flooding, ecomorphology, hydropower production, monitoring, restoration

1. Introduction

Floodplains are highly diverse and dynamic systems (Tockner & Stanford, 2002; Stanford et al., 2005). Although they cover only 0.3 % of Switzerland's land area, around 10 % of the country's fauna live exclusively, 32 % regularly and 42 % occasionally in floodplains (Rust-Duebié et al., 2006). At the same time, rivers and floodplains are intensively used worldwide, especially for energy production through hydropower. It is widely documented that hydropower exploitation can severely affect the natural flow and bed-load regime. This is due to the disruption of longitudinal connectivity by dams and weirs, the abstraction of water, or the generation of unnatural flow and level fluctuations. This results in several ecomorphological deficits, such as a lack of habitat and bedload dynamics, clogging of the riverbed, and changes in the composition of biotic communities among others (Tonolla et al., 2022; Doering et al., 2018; Robinson et al., 2012). Artificial floods, in combination with sediment replenishments, are possible measures to eliminate or reduce such deficits. These measures are suitable for rivers and floodplains downstream of reservoirs characterized by a strongly altered discharge and/or bedload regime, i.e. by absent or severely reduced flooding events and the retention of bedload.

1.1. The Sarine floodplain in Switzerland and artificial flooding

The Sarine floodplain is located below the Rossens dam of Lake Greyezer (Canton FR, Western Switzerland). Downstram of Lake Greyezer, one of the four largest reservoirs in Switzerland, a 13 km long residual flow section with a constant low discharge of about 3.5 m^3/s extends. Decades of residual flow management, bedload retention and the resulting lack of discharge and bedload dynamics led to an - undesirable - stabilization of the floodplain system below the dam. The high dynamics and diversity typical for natural floodplains decreased overall. As a result, floodplain-typical habitats such as open gravel areas, which depend on these dynamics, declined sharply, and the macrozoobenthos community adapted to the stable conditions with exceptionally high densities and lentic taxa (adapted to slow flowing water) dominating. In addition, colmation of the riverbed and strong algae growth occurred (Tonolla et al., 2022; Doering et al., 2018).

To counteract ecomorphological deficits in the Sarine floodplain between 2016 and 2022 six artificial flood events were released and monitored from the Rossens dam with maximum discharges of 161 m^3/s (June 2016), 195 m^3/s (Sept. 2016; Figure 1), 113 m^3/s (Oct. 2020), 302 m^3/s (Jul. 2021), and 75 m^3/s (Mai 2022).

Figure 1: Artificial flood on the Sarine below the Rossens dam on 14 and 15 September 2016. Image: ZHAW Research Group for Ecohydrology.

2. Ecomorphological impacts of artificial floods

The floods resulted only in a short-term change in the macrozoobenthos community in the residual flow reach and not in a significant, long-term reduction in macrozoobenthos density. Considering macrozoobenthos orders, the relative proportion of the more rheophilic taxa (adapted to fast moving water) of Ephemeroptera, Plecoptera and Trichoptera (EPT) was highest immediately following a flood event but decreased fast over time without flood disturbance. The most significant increase in relative EPT abundance occurred following the highest artificial flood in 2021 (302 m^3/s) whereas significant reduction of periphyton abundance occurred even at low maximum flood discharge (2022; 75 m^3/s) but also with rapid regeneration between floods (Figure 2). This suggest that flood magnitudes and frequencies have an important influence on the macrozoobenthos community and periphyton abundance.

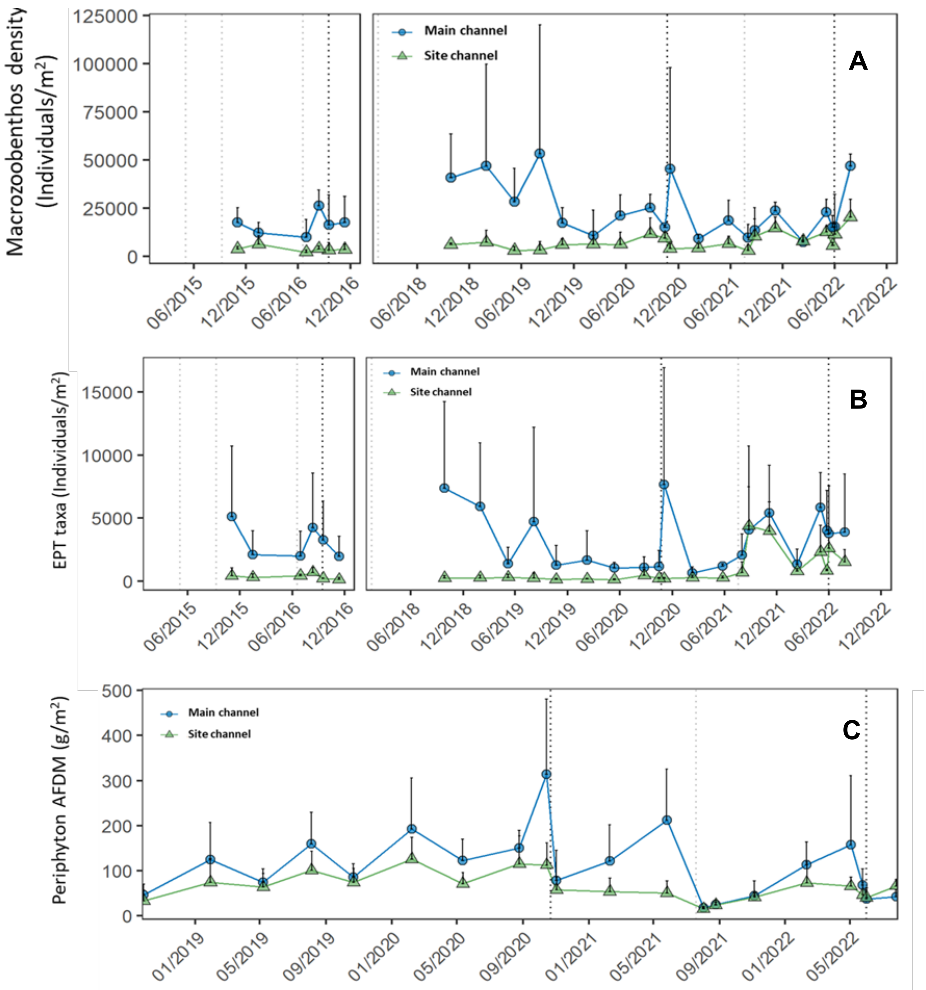

Figure 2: *A and B: Temporal changes in mean macrozoobenthos and EPT taxa density (individuals per m²) in the main (blue) and side (green) channels (2015-2022). The black solid lines show the standard deviation. No macrozoobenthos data were collected in 2017. C: Temporal change in periphyton abundance as ash free dry mass (AFDM) in g per m² in the main (blue) and side (green) channels (2018 to 2022). Flood events are marked with dotted lines.*

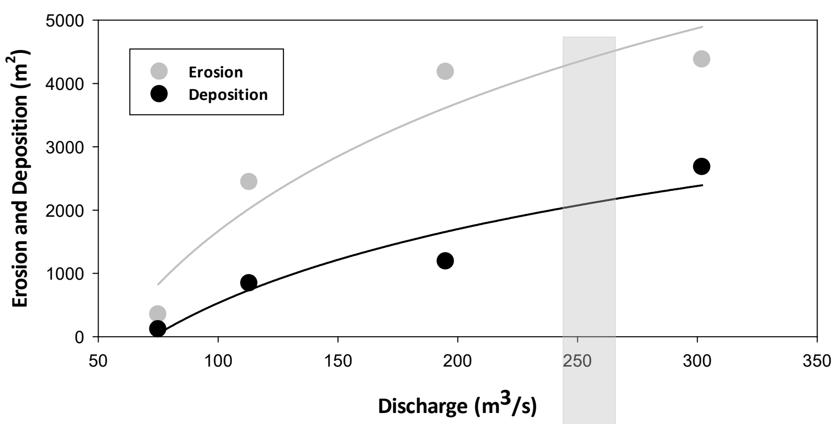

Figure 3: *Erosion (gray points) and deposition (black points) in m² by flood event including logarithmic models (line). The gray area indicates the knick point where the increase of erosion and deposition, respectively, gets smaller compared to the increase of discharge.*

Morphological habitat changes remotely sensed (UAV) and quantified as erosion and deposition differed depending on the flood event. For example, the two strongest floods studied in

2016 (195 m^3/s) and 2021 (302 m^3/s) resulted in the most significant erosion primarily of lower vegetation and redistribution of sediments leading into in new, open gravel areas. However, erosion and deposition increased continuously with floods up to approximately 200 m^3/s, before remaining relatively stable, i.e. increase in erosion and deposition is lower than increase in discharge (Figure 3). Further, it could be shown that artificial flooding transports sediments downstream leading to a sediment deficit into the residual flow section of the Sarine.

3. Adaptive management of the Sarine floodplain

After studying several artificial floods in the Sarine floodplain, the magnitude and frequency of floods seems to be of great importance in the sustainable mitigation and elimination of ecomorphological deficits in the residual flow stretch. Single flood events of low frequency can change the ecomorphological conditions of this floodplain only short term, but without frequent disturbance the system shifts back within a short time to residual flow conditions and no sustainable changes occur. These results correspond to a long-term monitoring of the Alpine river Spöl in eastern Switzerland (Robinson et al., 2012). Further, floods with a high maximum discharge lead to extensive bedload rearrangement and disturbance of the riverbed and play an important role in the redynamization of the residual flow section. Based on our results and in close collaboration with the hydropower producer we designed an artificial flood program including sediment replenishments with alternating frequent low and high magnitude floods (one each per year at different seasons) to initialize (high magnitude flood) and maintain (low magnitude flood) floodplain dynamics and sustainable ecomorphological improvements. The design of the flood program is supported by ecohydraulic modelling for the prediction of different flood scenarios including ecomorphological changes. The model is constantly validated, calibrated, and improved by including our in situ (ground truth) and remotely sensed monitoring data. Based on this long-term monitoring including predictions the flood program will be continuously adapted according to actual long-term results in the framework of an adaptive management involving different stakeholders from science and practice and under consideration of economical (e.g., energy production) and ecomorphological needs and challenges.

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