Geomorphic and ecological monitoring of an experimental sediment reintroduction into the Rhine River downstream of the Kembs dam

Bilan éco-morphologique de la recharge sédimentaire expérimentale sur le Vieux Rhin

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RÉSUMÉ

Une recharge sédimentaire expérimentale a été réalisée en 2010 dans le chenal du Vieux Rhin court-circuité entre Kembs et Breisach, dans le but d'évaluer les possibilités de restaurer la dynamique sédimentaire et améliorer les processus écologiques associés à cette dynamique. 23.000 m^3 de sédiments ont été injectés, sous la forme d'un dépôt de 620 m de long et 12 m de large, déconnecté de la berge. Un suivi morphologique a été mis en place, combinant des relevés bathymétriques, de l'imagerie aérienne, du traçage sédimentaire et des mesures granulométriques. 5 états ont été caractérisés depuis 2009 (pré-injection, post-injection et post-crues), mettant en évidence les modes de transfert de la charge, pour analyser les risques environnementaux potentiels et tester des indicateurs de réponses des habitats. Le suivi de deux compartiments biologiques (flore et macro invertébrés) a également été réalisé : des transects de végétation ont été disposés entre Kembs et Vogelgrün et sont suivis depuis 2010 pour évaluer leur évolution suite à la recharge. Les macro invertébrés ont été échantillonnés en 2013 sur les transects à l'amont de la zone de recharge, en position intermédiaire et à l'aval immédiat. Cette présentation dresse le bilan des réponses morpho-écologiques après 5 ans de suivi, permettant d'alimenter le retour d'expérience en vue de futures actions pour diversifier les habitats aquatiques et riverains.

ABSTRACT

An experimental gravel reintroduction was conducted into the Rhine River to assess the feasibility of restoring the sedimentary dynamics and improving the morpho-ecological processes over the medium and long terms. 23.000 m^3 of sediments were supplied in 2010 in a 50 km long, by-passed river reach between the Kembs and Breisach dams. A deposit of 620 m long, 12 m wide and disconnected from the bank was created. Geomorphic monitoring was implemented, coupling bathymetric and topographic surveys, multi-date aerial imagery, bedload tracing and grain size sampling. Five states have been surveyed since 2009 (initial, post-injection and post-floods). This permitted to understand sediment transfer processes, assess the potential risks for society and test physical evaluation indicators. Ecological monitoring was also conducted: cross-section vegetation transects were placed between Kembs and Vogelgrün and changes have been monitored since 2010. An analysis of invertebrate compartment was performed in 2013, on transects immediately upstream the injection site, in intermediate positions and close downstream the injection site. This paper restitutes the morpho-ecological responses after 5-year monitoring. It provides feedback for guiding future restoration strategies to diversify aquatic and riparian habitats of the Old Rhine.

KEYWORDS

Sediment reintroduction, ecological responses, restoration, geomorphic monitoring, Old Rhine

1 INTRODUCTION

The Upper Rhine River has been heavily modified by engineering works for flood protection, navigation and hydro-electricity production. Rectification (19th century), groynes (1930's), Kembs dam and lateral canal construction (1928-1959) induced channel dewatering, bed incision, bed armouring and alteration of ecological habitats in the 50 km long, by-passed "Old Rhine". The river reach is now concerned by restoration issues: in 2010, 23.000 m^3 of sediment were supplied into the channel, as a part of a European program (INTERREG "Redynamization of the Old Rhine" 2009-2012) and actions supported by Electricité de France (EDF) within the Kembs dam relicensing process (2003-2014). The objectives of these programs were to assess feasibility of restoring the bedload transport and improving the morpho-ecological processes of the Old Rhine over the medium and long terms.

The artificial deposit, located along the right bank, was created after excavating gravels from a flood retention area on the German floodplain (D_{50} of the injected sediment ~ 12 to 46 mm; D_{50} of the armoured channel bed ~ 60 mm). The injection site was 620 m long, 12 m wide, 3 m high and disconnected from the bank (Figure 1).

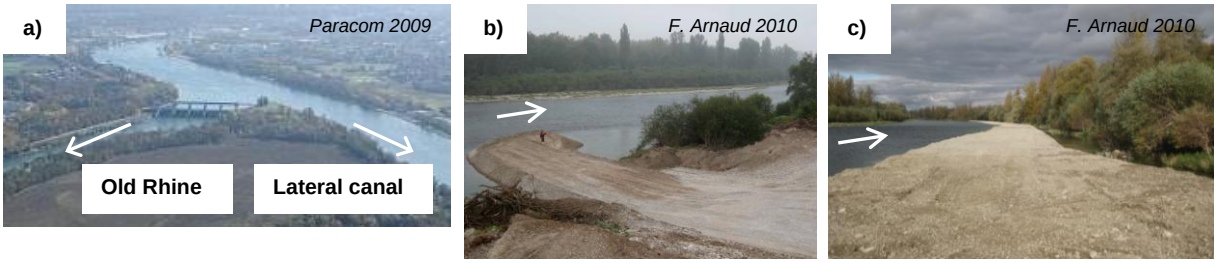

Figure 1. View of the sediment injection works (b, c) in the Old Rhine below the Kembs dam (a).

Geomorphic monitoring was implemented to understand the modes and characteristics of sediment transfer, provide *in situ* calibration data for hydro-sedimentary modelling, assess the potential environmental risks and test indicators of habitat improvement within the context of large rivers. The ecological monitoring was performed to analyze the impact of sediment reintroduction on aquatic invertebrate communities, aquatic and terrestrial vegetation. The main hypothesis was that habitats are modified due to augmented deposits and / or erosion processes and thus the diversity and distribution of plant and invertebrate communities are modified too.

This contribution summarizes the morpho-ecological responses after 5-year monitoring. It provides feedback to help stakeholders guide the process-based restoration of the river reach.

2 METHODS

A "before-after" framework was implemented, permitting to survey five geomorphic states since 2009 (initial, post-injection, post-Q_2 and Q_{15} floods). Geomorphic monitoring was based on 4 complementary techniques (Béal *et al.,* 2012): (i) bathymetric and topographic transects every 50 m, (ii) multi-date, high resolution aerial imagery, (iii) bedload tracing (1500 RFID passive integrated transponders inserted into pebbles), and (iv) grain size sampling of in-channel and emerged gravel bars.

Ecological monitoring consisted in 12 vegetation cross-sections surveyed every 100 m in the injection zone to 10 km between Kembs (KP 182) and Vogelgrün (KP 222). Surveys covered the upstream part of the injection site, the injection site itself, and the downstream part, from 2010 to 2012. From 2013, monitoring was restricted to 4 transects: one immediately upstream the injection site (T4), two in intermediate positions (T5-T6) and one close downstream (T7). Floristic lists of aquatic and terrestrial communities were established. Macro invertebrate sampling was performed in 2013 on the 4 transects, using a Hess sampler suited to sand, gravel, cobble and small boulder riverbed substrates. 5 samples were collected per transect in the largest range of meso habitats with regards to grain-size substrate and flow velocity conditions. Water depth, substrate description and water quality (dissolved oxygen, temperature and conductivity) were measured at the location of each invertebrate sample.

3 RESULTS AND DISCUSSION

Positions of RFID pebbles recovered after floods (return rates between 42% and 10%) were consistent with deposit areas identified from aerial images and topo-bathymetric transects (Figure 2.a). Tracer cloud centroids indicated a mean gravel displacement distance of appr. 150 m per Q_2 flood (Figure 2.b). Grain-size monitoring of one in-channel site indicated sediment fining (D_{50} decrease from 98 to

68 mm), suggesting possible enhancement of aquatic habitat conditions. This highlighted the need to develop new methods for sampling grain-size in larger channel areas to better assess the effects of restoration (automated grain-size sampling from photographs taken with a waterproof box).

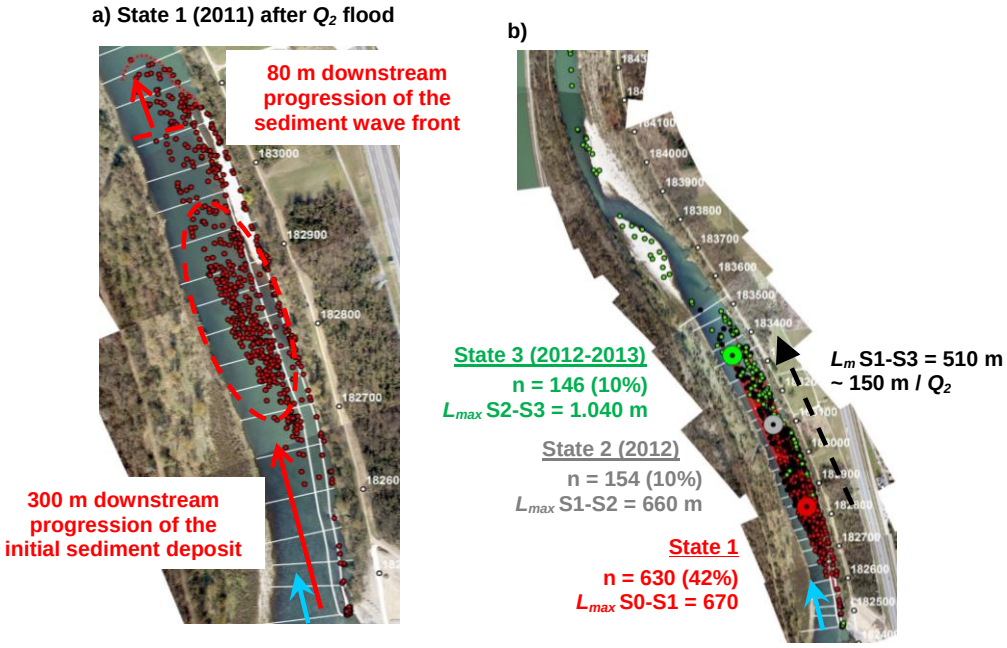

Figure 2. a) Geomorphic changes of the injection site between 2010 and 2011 (state 1). b) Position of RFID tracers recovered after floods between 2010 and 2013 (states 1, 2, 3).

There was low change in occurrence of aquatic plants in the riverbed excepted colonization by *Elodea nuttallii,* an invasive species in fine grained sediments. Terrestrial vegetation colonized rapidly the new gravel bar, and disappeared with the remobilization of gravel bar with floods. Indeed we noticed that floods impacted more vegetation changes than sediment input itself. Variations in macro invertebrate densities were also observed along the river reach, in particular a small decline of the invasive amphipod *Dikerogammarus villosus*.

4 CONCLUSION

The experimental sediment reintroduction was useful to improve knowledge on bedload transport processes and solve methodological difficulties for large river monitoring. Potential risks, e.g. threat to downstream infrastructures, were avoided regarding low sediment transfer. Little change in vegetation has been observed throughout the restoration program. Ecological monitoring must be continued to quantify these changes over a longer time period and better understand the dynamics of exotic species. The study of the benthic fauna post-injection and upstream/downstream the deposit zone allowed to rule on the decline in density of a highly structuring invasive species.

Interdisciplinary approaches in geomorphology, ecology as well as hydraulic modelling and sociology permit to make recommendations for large-scale and sustainable restoration plans: appr. 750.000 m^3 of gravel should be supplied to the Old Rhine to improve bedforms diversification on a 50 cm sediment thickness, a 100 m wide channel and over a sufficient river reach (15-20 km). Coupling gravel reintroduction with channel widening should be useful to increase the riverscape complexity. The most appropriate sediment source should be quantified on the whole study reach, as well as the modalities of sediment reintroduction, and the monitoring program to assess the operation efficiency, in a collaborative planning with all stakeholders.

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