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# Mountain river restoration measures and their success(ion): Effects on river morphology, local species pool, and functional composition of three organism groups

Kathrin Januschke[a,*], Sonja C. Jähnig[b,c], Armin W. Lorenz[a], Daniel Hering[a,d]

[a] Department of Aquatic Ecology, University of Duisburg-Essen, 45141 Essen, Germany
[b] Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, Frankfurt am Main D-60325, Germany
[c] Senckenberg Research Institute and Natural History Museum Frankfurt, Department of River Ecology and Conservation, Clamecystrasse 12, D-63571 Gelnhausen, Germany
[d] Centre of Water and Environmental Research, University of Duisburg-Essen, 45141 Essen, Germany

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ABSTRACT

We investigated temporal effects of restoration on river morphology, on species and functional composition of benthic invertebrates, floodplain vegetation and carabid beetles at three study sites in the mountain river Lahn (Germany). We sampled restored and nearby non-restored sections 3–5 years and 7–9 years after restoration. In the restored sections, instream microhabitat heterogeneity was higher due to the increased presence of finer substrates, while cobbles and coarse gravel were still dominant. Instream habitat composition did not change between the two sampling events. Areas of restored floodplain were characterized by a more diverse habitat mosaic and by unvegetated bars, vegetated islands and secondary channels. In restored sections, floodplain habitat heterogeneity was maintained 7–9 years after restoration, but vegetated areas increased, while unvegetated bars and aquatic areas decreased. The species composition of all studied groups was more variable over time in restored than non-restored sections. In contrast to benthic invertebrates, the immigration rate of floodplain vegetation and carabid beetle species was higher in restored sections. Assemblage composition of all three organism groups changed over time, with the highest change in carabid beetles and smallest in benthic invertebrates. Restoration changed the abundances of functional response groups, mainly for carabid beetles, by supporting species that indicate increased hydrodynamics and early successional stages. Changes of functional response groups in non-restored and restored sections across time indicated decreased hydrodynamics or hydrological connectivity for all organism groups. Although the response of organism groups differed, our results support the conjecture that restored sections accumulate species and enhance the local species pool.



## 1. Introduction

River morphology and biota depend on dynamic processes. Discharge patterns determine erosion, transport and deposition of bed material and, consequently, the channel form (Hughes, 1997; Ward et al., 2002). Beyond extreme floods, the bankfull discharge, which has a recurrence interval of approximately 1 year, is a key factor influencing riparian and aquatic habitats (Leopold, 1994; Surian et al., 2009), and associated biota and functions (Ward et al., 1999; Pedroli et al., 2002; Jansson et al., 2007). The resulting mosaic of floodplain habitats is unstable and shifts constantly (Ward et al., 1999; Robinson et al., 2002).

River restoration should ideally initiate near-natural dynamic processes, eventually leading to a habitat mosaic of different successional stages (Ward et al., 1999; Ward and Tockner, 2001). As part of the planning phase, the development of dynamic processes should be considered (Jansson et al., 2005). However, the effects of restoration depend on time and on the magnitude of floods as a main force for the development and maintenance of habitat diversity. Flooding magnitude and frequency influence the time required to observe the first effects of restoration and the long-term balance between rejuvenation and terrestrialization. Consequently, the targets of hydromorphological river restoration are best described by a dynamic guiding image (Palmer et al., 2005), as the objective is not a stable state but a dynamic system of natural rivers and their floodplains. From a conceptual viewpoint and with reference to the habitat heterogeneity hypothesis (Tews et al., 2004), hydromorphological restoration may increase species richness due to additional

* Corresponding author. Tel.: +49 201 183 3113; fax: +49 201 183 4442.
*E-mail address:* kathrin.januschke@uni-due.de (K. Januschke).

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niches. Functional response groups that are strongly depending on habitat conditions (Díaz and Cabido, 2001) may benefit most, e.g., species groups preferring moisture, patchy vegetation coverage or habitat disturbance induced by floods.

Monitoring the effects of river restoration has strongly focused on groups of aquatic organisms, especially benthic invertebrates. Benthic assemblages, however, are often poor measures of restored river morphology due to simultaneous impacts of water quality, flow regimes and dispersal barriers (Palmer et al., 2010; Lepori et al., 2005; Roni et al., 2006; Jähnig et al., 2009). From a conceptual viewpoint, the restoration of functional habitats (e.g., dead wood or gravel) may change the functional traits of benthic assemblages (Tullos et al., 2009). The effects of restoration on composition, richness and diversity of riparian assemblages are often more pronounced (Gilvaer and Willby, 2006; Lambeets et al., 2008a). Functional responses of riparian organisms may offer a better understanding of disturbance and restoration processes than benthic invertebrates (Merritt et al., 2010; Lambeets et al., 2009; Richards et al., 2002; Van Looy et al., 2005).

Overall, there is little understanding of how aquatic and riparian assemblage composition and functional response groups change after river restoration and if these effects persist over time. Data on restoration effects over longer time spans are still rare, although studies addressing morphology or single organism groups in restored river sections increased steadily in recent years (e.g., morphology: Buchanan et al., 2013, benthic invertebrates: Friberg et al., 1998; Muotka et al., 2002, floodplain vegetation: Baattrup-Pedersen et al., 2000, 2013). However, integrating studies comparing restoration effects on different aquatic and riparian organism groups over time are missing, although organism groups may differ strongly in the recolonization of restored floodplain section. For instance, riparian plants may colonize restored river sections from the soil seed bank (Leyer, 2006), and many riparian carabids are strong fliers and may colonize new habitats rapidly (Den Boer, 1990; Lambeets et al., 2008b). In contrast, benthic invertebrates include hololimnic species that live exclusively in the water and merolimnic insect species that spend parts of their life cycle outside the water. While hololimnic species mainly disperse by downstream drift over short distances (Turner and Williams, 2000; Elliott, 2003), merolimnic species may disperse actively over larger distances, but the time span available to active dispersal is short compared to carabid beetles.

In this study, we analyze effects of restoration on morphology, benthic invertebrates, floodplain vegetation and riparian carabid beetles in three restored sections of the Lahn River, a fourth order mountain river in Germany. We used a control-impact design and compared data obtained 3–5 and 7–9 years after restoration to analyze the effects of restoration and the temporal differences in instream microhabitats, floodplain mesohabitats, species pools and composition of functional response groups between two sampling events. We tested the following hypotheses:

- Hydromorphological restoration increases habitat heterogeneity of both instream microhabitats and floodplain mesohabitats. Habitat heterogeneity is maintained and promoted by dynamic processes initiated by restoration.
- Hydromorphological restoration creates habitats for additional taxa. Colonization patterns of restored sections over time differ between organism groups depending on dispersal and colonization abilities. Changes in species composition reflect habitat changes over time.
- Hydromorphological restoration supports functional response groups of organisms depending on hydrodynamics, hydrological connectivity, accumulation of organic matter and successional processes. Response time differs between organism groups, with the most rapid response from carabid beetles and the slowest response from benthic invertebrates. Once established the functional composition of the biota is maintained provided that the habitat heterogeneity persists.

**Table 1**
Study sites Cölbe, Ludwigshütte, and Wallau of the river Lahn between Bad Laasphe and Marburg: geographic position, catchment area, altitude and the year of restoration.

| Site name | Cölbe | Ludwigshütte | Wallau |
|---|---|---|---|
| Latitude (N) | 50°51′47″ | 50°55′29″ | 50°55′37″ |
| Longitude (E) | 8°47′25″ | 8°29′59″ | 8°29′20″ |
| Catchment size [m$^2$] | 650 | 288 | 278 |
| Altitude [m asl] | 190 | 300 | 190 |
| Restoration year | 2000 | 2002 | 2001 |

In summary, we analyzed the morphological and biological processes initiated by the restoration of channel morphology including the stability of newly generated habitats, succession and recolonization.

## 2. Methods

### 2.1. Study sites

We investigated three sites of the montane Lahn River between Bad Laasphe and Marburg (Fig. 1, Table 1). At each site, we sampled a pair of one restored section and one upstream non-restored section (500 m maximum distance). Each section was approximately 200 m long. Paired sections were similar in terms of catchment size, catchment land use, river size and slope. Sections were restored between 2000 and 2002. All three restoration measures aimed to increase habitat heterogeneity (personal information from Herbert Diehl, Bezirksregierung Gießen, the water manager in charge of restoration planning) as the river channels were straightened (Fig. 2), bordered by fixed embankments and characterized by homogeneous substrate, depth and flow condition. To initiate bank side erosion, bank fixations were removed. Moreover, multiple channels were created doubling the overall width of active channels (Fig. 3). To activate floodprone areas and enable sediment relocation in riparian zones (Fig. 4), the entrenchment depth was lowered (Cölbe) and upper soil layers were excavated (Wallau and Ludwigshütte).

The river gauge site ‘Biedenkopf’ (Fig. 1), located between the study sites Cölbe and Wallau, served as the hydrological reference for flood events and associated habitat turnover. It is a hydrological station of the Regional Environmental Authority of Hesse (Germany) continuously measuring water level and providing discharge data publicly.

### 2.2. Sampling design

The three study sites were sampled twice: 2005 (3–5 years after restoration) and 2009 (7–9 years after restoration), resulting in 12 samples (3 sites × 2 sections × 2 sampling events) per object of investigation. For each of the 12 samples, we investigated instream microhabitats, floodplain mesohabitats, benthic invertebrates, floodplain vegetation and riparian carabid beetles. For each organism group, we analyzed missing and additional taxa and functional response groups. These parameters were analyzed according to differences between the four sample groups ‘non-restored 2005’, ‘restored 2005’, ‘non-restored 2009’ and ‘restored 2009’ (hereafter referred to as sample group comparisons) whereas each sample group contains three samples, each per study site:

- non-restored sections 2005 vs. non-restored sections 2009, showing *temporal changes in non-restored sections*;