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Review

The effect of river restoration on fish, macroinvertebrates and aquatic macrophytes: A meta-analysis

Jochem Kail[a,*], Karel Brabec[b], Michaela Poppe[c], Kathrin Januschke[a]

[a] Department of Aquatic Ecology, University of Duisburg-Essen, Universitätsstrasse 5, 45141 Essen, Germany
[b] Faculty of Science, Research Centre for Toxic Compounds in the Environment, Masaryk University, Kamenice 753/5, Pavilion A29, 625 00 Brno, Czech Republic
[c] Institute of Hydrobiology and Aquatic Ecosystem Management, University of Natural Resources and Life Sciences Vienna (BOKU), Max-Emanuel-Straße 17, 1180 Vienna, Austria

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ABSTRACT

An increasing number of rivers have been restored over the past decades and several studies investigated the effect on biota. The published monitoring results have already been summarized in narrative reviews but there are few quantitative reviews and a comprehensive meta-analysis on different organism groups and factors influencing restoration effect is missing. We compiled monitoring results and information on catchment, river and project characteristics from peer-reviewed literature and unpublished databases to (i) quantify the effect of restoration measures on fish, macroinvertebrates and macrophytes, and (ii) identify predictors which influence restoration effect. Results indicated significant effects of restoration on all three organism groups, especially of widening projects on macrophyte richness/diversity, instream measures on fish and macroinvertebrates, and higher effects on abundance/biomass compared to richness/diversity. Restoration effect was most strongly affected by agricultural land use, river width and project age. Effects were smaller but restoration generally still increased richness/diversity and abundance/biomass in agricultural catchments. Since land use is a proxy for different pressures, the underlying causal relationships have to be investigated in more detail. Project age was the most important factor but had non-linear and even negative effects on restoration outcome, indicating that restoration effects may vanish over time. The meta-analysis indicated that river managers in general can expect an increase of richness/diversity and abundance/biomass of all three organism groups investigated, especially of macrophytes in widening projects and of fish and macroinvertebrates if instream measures are applied. However, variability was high, stressing the need for adaptive management approaches. Furthermore, the large but non-linear and different (even negative) effects of project age stressed the need for long-time monitoring to better understand the trajectories of change caused by restoration measures and to identify sustainable measures. The meta-analysis was restricted to metrics commonly reported in literature and future studies would greatly benefit from authorities and scientists reporting original monitoring data, which would allow to use functional metrics to investigate the effect of restoration measures and to infer causal relationships.

Contents

* Corresponding author. Tel.: +49 201 183 3046.
E-mail addresses: jochem.kail@uni-due.de (J. Kail), brabec@sci.muni.cz (K. Brabec), michaela.poppe@boku.ac.at (M. Poppe), kathrin.januschke@uni-due.de (K. Januschke).

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1. Introduction

River restoration has become a widely accepted societal objective in developed nations (Bernhardt et al., 2005; Shields et al., 2003), and an increasing number of rivers have been restored in the past decades to enhance the hydromorphological and biological state. However, only few projects have been monitored in detail, and hence, the knowledge on the effect of river restoration is limited (Bash and Ryan, 2002; Bernhardt et al., 2005). Nevertheless, monitoring results of several projects have been reported in peer-reviewed scientific literature.

The studies investigating the effect of river restoration on hydromorphology and biota reported contrasting results. Several studies on single organism groups showed that the ecological effect has been small even if local habitat conditions have substantially improved (Jähnig et al., 2010; Lepori et al., 2005; Palmer et al., 2010; Pretty et al., 2003; Stewart et al., 2009) while other studies found a significant positive effect on richness and abundance of macrophytes, macroinvertebrates, and fish (Lorenz et al., 2012; Miller et al., 2010; Schmutz et al., 2014; Whiteway et al., 2010). Moreover, the few comparative studies found different effects on different organism groups (Haase et al., 2013; Jähnig et al., 2009; Januschke et al., 2009). Most of these studies are primary research on single or multiple restoration projects (referred to as non-replicated and replicated studies in meta-analysis) and there are few reviews on the effect of river restoration on biota which make use of the growing number of monitoring results available in literature. Most of these narrative reviews qualitatively described restoration effects (Roni et al., 2002, 2008) or use semi-quantitative approaches like vote-counting (Palmer et al., 2014). However, quantitative meta-analyses of literature are rare, with one study on the effect of different restoration measures on invertebrates (Miller et al., 2010) and three similar studies on fish (Schmutz et al., 2014; Stewart et al., 2009; Whiteway et al., 2010). A quantitative meta-analysis on peer-reviewed literature comparing the effects of river restoration on different organism groups is missing.

The effect of reach-scale river restoration is potentially constrained by large-scale pressures and might depend on catchment, river and project characteristics. Projects are prone to failure if large scale pressures are not adequately considered (Bond and Lake, 2003; Miller et al., 2010; Palmer et al., 2010; Roni et al., 2008). Several empirical studies indicated that large-scale pressures like catchment land-use can be more important in shaping invertebrate and fish communities compared to pressures at smaller spatial scales (Roth et al., 1996; Stephenson and Morin, 2009; Sundermann et al., 2013). They limit invertebrate and fish assemblages (Bryce et al., 2010; Kail et al., 2012; Wang et al., 2007), and hence, potentially constrain the effect of reach-scale river restoration measures. However, in contrast to the numerous studies on the effect of catchment and river network conditions on the biological state, there is limited knowledge if and how these large-scale pressures affect restoration outcomes (but see Miller et al., 2010).

In this meta-analysis, the effect of restoration on biota was quantified based on results reported in peer-reviewed literature and monitoring data from unpublished databases. The first main objective was to assess the effect that can be expected from different restoration measures on different organism groups. We tested if restoration had an overall positive effect on the richness/diversity and abundance/biomass of fish, macroinvertebrates, and aquatic macrophytes (referred to as macrophytes in the following), and if the effect differed among organism groups, biological metrics (e.g. abundance, richness) and restoration measures. The second main objective was to identify conditions which influence restoration effects, i.e. identify catchment, river and project characteristics which either constrain or enhance the effect of restoration on biota and to assess their relative importance.

2. Materials and methods

2.1. Selection of restoration studies and original monitoring data

Studies were compiled from peer-reviewed literature and three unpublished databases. In peer-reviewed literature, studies were identified using the search engines Web of Science and SCOPUS by searching for the following keywords on 10.01.2012: (restor* OR rehabilit* OR revitali* OR renat* OR enhance* OR mitigate*) AND (aquatic habitat* OR reach* OR channel* OR stream* OR river* OR watershed* OR catchment* OR wetla* OR floodpla*). Out of the 3661 hits, 316 papers met the criteria on ecosystem, location, project objectives, progress, measures and effects (Table 1). The criteria on monitoring design and data as well as the basic environmental data reported in the publications or provided by authors on request (Table 1) further limited the number of suitable studies to $n = 69$. In

Table 1
Criteria for inclusion of peer-reviewed publications in the meta-analysis.

Criteria	Include	Exclude
Ecosystem	River channel, riparian area, floodplain	Lakes, coastal waters
Location	Global (European and non-European countries)	None
Project objectives	Restoration, rehabilitation, mitigation	Conventional engineering or flood protection
Progress	Implemented	Planned (e.g. River Basin Management Plans)
Measures	Hydromorphological measures	Water quality or river continuity only
Monitoring design	Before/After, Control/Impact or BACI	No monitoring data, only data after restoration
Monitoring data	Quantitative data on at least one biological metric of one organism group	No quantitative biological data
Environmental data	Basic river and project characteristics reported (e.g. location)	Replicated studies with limited information on single projects
Effects	Irrespective of effects (i.e. negative, non, and positive effects)	None