Ecological Engineering 62 (2014) 129–139

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

The ecological value of stream restoration measures: An evaluation on ecosystem and target species scales

Melanie Mueller, Joachim Pander, Juergen Geist*

Aquatic Systems Biology Unit, Department of Ecology and Ecosystem Management, Technische Universität München, Mühlenweg 22, D-85350 Freising, Germany

ARTICLE INFO

Article history:
Received 15 May 2013
Received in revised form 7 October 2013
Accepted 21 October 2013
Available online 23 November 2013

Keywords:
Restoration ecology
Fish habitat
Macroinvertebrate
Biodiversity
Substratum
Bioindication

ABSTRACT

Stream restoration is widely applied for conservation of freshwater ecosystems, but systematic comparisons on the effects of different techniques are rare. In this study, we systematically evaluated two types of gravel introduction, substratum raking and the placement of boulders in six streams. We compared indicator-based and multi-scale approaches that simultaneously assess effects on target species, different taxonomic groups and on ecosystem scale. Gravel introduction had by far the strongest effects on macroinvertebrates (increase of species density and numbers of individuals), periphyton (increase of cell numbers) and macrophytes (decrease of coverage, species numbers and biomass), followed by substratum raking. The placement of boulders had no significant long-term effects on aquatic communities. Over all investigated restoration treatments, fish community composition only changed significantly in 50% of the study rivers depending on the occurrence of species sensitive to the structures introduced by the restoration treatments. These were lithophilic, rheophilic and invertivorous fishes, comprising several species listed in the Red List of endangered species, which used the added 16–32 mm gravel as juvenile habitat. Areas with introduced gravel were also most frequently used by spawning *Salmo trutta*, *Thymallus thymallus* and *Phoxinus phoxinus*. In contrast, active bioindication using *Salmo trutta* eggs indicated that none of the restoration treatments was sufficient to enhance habitat conditions in deeper substratum layers throughout the egg incubation period. Our results suggest that instream restoration measures can contribute to freshwater biodiversity conservation, but reproductive success of species depending on long-term improvement of interstitial water quality cannot be achieved without considering catchment effects and natural substratum dynamics.

1. Introduction

Stream ecosystems comprise about 10% of global biodiversity, even though they cover less than 1% of the earth's surface (Strayer and Dudgeon, 2010). At the same time, freshwaters provide the most essential ecosystem services for human existence (Vitousek et al., 1997; Geist, 2011). Consequently, there is high anthropogenic pressure on these ecosystems, causing a strong depletion of riverine species that runs even faster than the loss of terrestrial biodiversity in tropical rain forests (Bernhardt et al., 2005). To mitigate the proceeding degradation of aquatic ecosystems, river restoration has recently become a widely applied management strategy (Sondergard and Jeppesen, 2007). Since stream-bed habitats are well known to play a key role in the ecological functioning of rivers (e.g. Bretschko, 1995; Boulton et al., 1998; Sternecker et al., 2013a; Mueller et al., 2013b), improving substratum quality has become a core target in stream restoration. For instance, in the restoration of salmonid stocks, huge financial effort is invested to improve the availability and quality of spawning gravel (Kondolf et al., 1996). While the requirements on substratum quality are well documented for many riverine species (e.g. fishes: Sternecker et al., 2013a; freshwater molluscs: Geist and Auerswald, 2007; macroinvertebrates: Bretschko, 1981) with a large body of scientific literature on the adverse effects of stream bed degradation (e.g. fine sediment input: Jones et al., 2012; alteration of natural substratum transport: Habersack and Kreisler, 2013; gravel mining: Brown et al., 1998), it still remains widely unknown how to effectively restore non-favourable stream-bed conditions to favourable conditions. This is mostly due to the trial- and error-based approach practiced in restoration management (Jansson et al., 2005; Pander and Geist, 2013) and the limited availability of systematic studies on this topic following scientific standards. Most studies evaluating stream restoration are either based on geomorphologic effects (e.g. Zeh and Dönni, 1994; Rubin et al., 2004; Meyer et al., 2008)

* Corresponding author. Tel.: +49 8161 713767; fax: +49 8161 713477.
E-mail address: geist@wzw.tum.de (J. Geist).

0925-8574/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2013.10.030

or focus on indicator species to determine potential improvements (e.g. Pretty et al., 2003; Miller et al., 2009; Cooksley et al., 2012; Lorenz et al., 2012; Pulg et al., 2013). The applied indicators are usually riverine flagship species of high socioeconomic value (Muotka et al., 2002; Geist, 2010). According to the indicator species concept (Primack, 2010; Reynolds and Souty-Grosset, 2011), all other species co-occuring with the indicator species are also supposed to benefit from measures that improve habitat quality for the target species. This includes important food web components such as primary producers (e.g. algae and macrophytes) and invertebrates (e.g. aquatic insects, molluscs and crayfishes), which may also comprise critically threatened organisms (e.g. Plecoptera: Fochetti and De Figueroa, 2006). However, several authors highlighted that different species or taxonomic groups do not react congruently to environmental changes (e.g. anthropogenic impacts: Mueller et al., 2011; Heino, 2010; restoration measures: Pander and Geist, 2013). Consequently, an improvement or failure for target species does not necessarily predict similar responses on ecosystem level. Since target species are not the only taxa to contribute to the conservation value of stream restoration, the evaluation of restoration success needs a holistic approach which integrates the consideration of several endpoints on different scales (target species, indicator groups, ecosystem scale), as recently proposed by Geist (2011) and Pander and Geist (2013). To date, such approaches have rarely been systematically tested due to their high time- and cost intensity, despite the recognition of the need for such studies expressed by restoration ecologists (e.g. Muotka et al., 2002; Arlettaz et al., 2011).

Herein, we evaluate the success of four different stream substratum restoration treatments at multiple scales, from single target species (lithophilic and rheophilic fish species) and single taxonomic groups to communities (algae, macroinvertebrates, macrophytes, fishes), and the entire ecosystem (changes in overall aquatic community composition and diversity). Specifically, we hypothesize that the four substratum restoration treatments differ in their effects on reproductive success and population structure of lithophilic and rheophilic fishes as well as in their ecosystem scale effects. The focus of this study was on biological endpoints since these are the typical targets of any restoration action. Based on the outcome of the study, we compare the conservation value of the investigated restoration measures. In this context, we evaluate the suitability of the indicator species concept for determining restoration success and investigate how the choice of endpoint affects the results. Particularly, we hypothesize that there is low congruency between restoration success for target species and ecosystem scale effects.

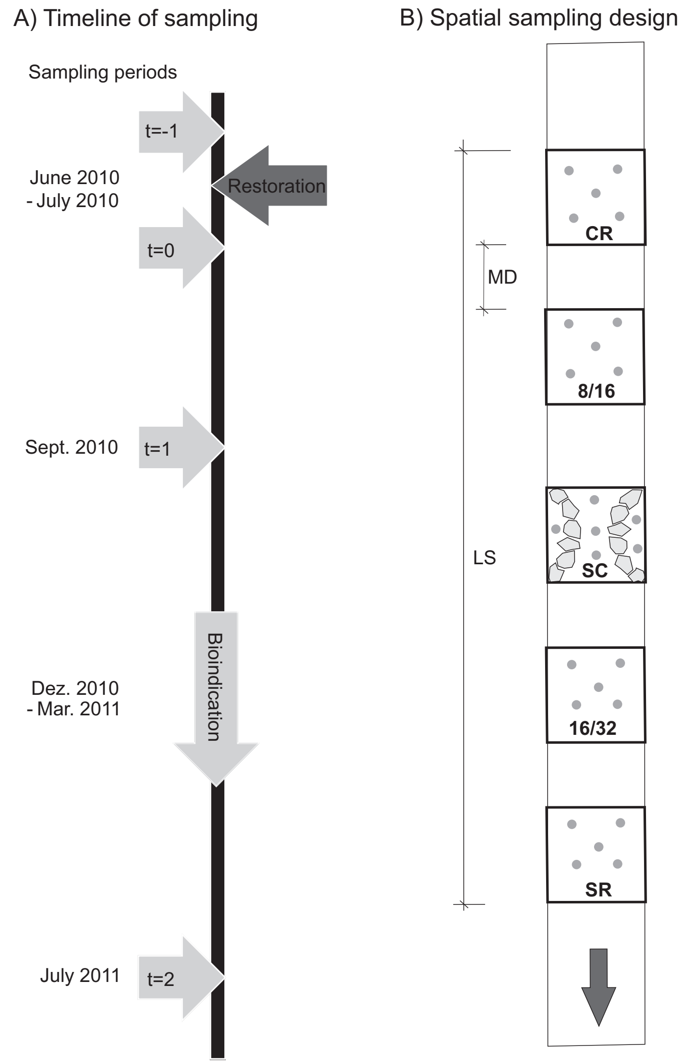

Fig. 1. Schematic of the sampling concerning (A) timeline and (B) spatial sampling design. (A) Dark grey arrow = implementation of the restoration measures; bright grey arrows = sampling periods. (B) MD = minimum distance between sampling sites (70 m); LS = length of sampling stretch (330–3520 m); CR = upstream control site; 8/16 = gravel introduction of the particle size 8–16 mm, position randomly assigned in each study river; 16/32 = gravel introduction of the particle size 16–32 mm, position randomly assigned in each study river; SC = sickle-formed constrictor, position randomly assigned in each study river; SR = substratum raking, downstream site in each river; filled grey circles indicate sampling points.

2. Material and methods

2.1. Study rivers and restoration treatments

The study was conducted between June 2010 and June 2011 in six rivers from three major central-European drainage systems (Danube, Main/Rhine, Elbe) within Germany. The rivers represented small streams in cool, humid, sub-oceanic climate, with mean annual discharges ranging between 0.42 and 0.88 m^3/s. They differed in their river morphology, fluvial dynamics and bedrock geology, comprising three calcareous (Günz (G): 48°16′10.23″ N, 10°19′29.77″ E, Mühlangergraben (M): 48°23′33.59″ N, 11°43′31.82″ E, Wiesent (W): 49°54′30.63″ N, 11°19′11.62″ E) and three siliceous rivers (Große Ohe (O): 48°43′48.32″ N, 13°15′14.73″ E, Perlenbach (P): 50°13′33.74″ N, 12°05′02.50″ E, Südliche Regnitz (R): 50°17′13.04″ N, 12°00′03.18″ E). A detailed description of their physicochemical properties is presented in Braun et al. (2012). The study section in each river was located within headwater reaches, without confluence of tributaries directly before or within the study section. The fish community in these sections was formerly dominated by rheophilic specialists (brown trout *Salmo trutta* L., European grayling *Thymallus thymallus* L., nase *Chondrostoma nasus*, barbel *Barbus barbus*). In each study section, four different restoration treatments were completed and investigated for their biological effects. The treatments were gravel introduction of the grain sizes 16–32 mm (16/32) and 8–16 mm (8/16), substratum raking (SR) and the placement of boulders as sickle-formed current constrictor (referred to as "sickle-formed constrictor" SC in the following text). The treatment sites were arranged downstream of an untreated control site (CR) in each river. The SR site was located at the bottom end of the site to avoid high fine sediment deposition on other treatment sites caused by raking (Sternecker et al., 2013b); the 8/16, 16/32 and SC sites were arranged randomly in between CR and SR sites (Fig. 1). The length of the studied river sections incorporating all