



Short communication

Detecting restoration impacts in inter-connected habitats: Spring invertebrate communities in a restored wetland

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ABSTRACT

Habitat restoration that improves the ecological status of a target ecosystem may have undesired effects in adjoining ecosystems. We assessed how restoration of a mire influenced benthic macroinvertebrates in associated freshwater springs. We included springs affected by restoration and compared these to remote control springs. We collected pre-restoration samples in May 2001 and post-restoration samples in May 2003, 2005 and 2010. Following restoration, water table rose in the whole mire. Restoration also caused profound changes to groundwater quality but, for the most part, water quality returned close to pre-restoration conditions within two years. Reflecting these chemical and hydrological changes, restoration altered spring invertebrate communities, especially the relative abundances of species, but had only weak effect on species richness. The proportional abundance of spring-dependent macroinvertebrates decreased in the restoration area, whereas their proportion remained stable in the remote control sites. Macroinvertebrate community structure at the remote control sites remained almost unchanged throughout the study, whereas communities in the restoration-area springs showed profound changes after restoration, followed by a slow recovery toward the initial conditions. Our results suggest that restoration planning and monitoring should be extended to adjoining ecosystems, and not only species richness but more complete compositional analysis of communities and species abundances should be used to indicate restoration impacts.

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1. Introduction

Ecosystem restoration is regarded as a keystone strategy for biodiversity conservation (Wilson, 1992), yet the criteria for ecologically successful restoration are vaguely defined. For example, restoration often lacks a clear, achievable goal ('guiding image') (Palmer et al., 2005) and experimental designs that enable rigorous evaluation of restoration are logistically hard to achieve (Osenberg et al., 2006).

Wetland restoration typically aims at enhancing the hydrological functionality of the landscape (Haapalehto et al., 2011), often resulting in rapid hydrological and chemical changes (Jauhiainen et al., 2002). In Finland, where the majority of peatlands were drained by the late 1980s to support forest growth, wetland restoration usually consists of filling of the ditches to recreate the pre-drainage mire landscape. Responses to restoration

in adjacent, inter-connected habitats have remained practically unstudied, however. As freshwater springs often occur as parts of wetland complexes, they may be indirectly affected by wetland restoration. Yet, it is unknown whether, and to what extent, wetland restoration is beneficial, neutral, or even harmful, to spring biodiversity. Springs support several specialist taxa many of which are weak dispersers (e.g. Pohjamo et al., 2008) and have fragmented geographical distributions (Ilmonen et al., 2009). Therefore, recolonization of restored springs may be slow, and spring biota may become dominated by generalist freshwater taxa. Little is known, however, about the rates of assemblage recovery and the dynamics that spring assemblages undergo after wetland restoration.

We assessed how wetland restoration affects biological communities in a non-target ecosystem, using spring macroinvertebrates as our focal indicator group. We expected that a few tolerant generalists would increase after restoration, while more sensitive taxa, particularly spring specialists, are reduced. We also anticipated that communities in control springs (within the same watershed but not directly affected by restoration activities) might also respond to restoration, but less strongly than those in the directly-impacted

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springs. In contrast, we expected remote control springs in a separate watershed to remain stable throughout the monitoring period, reflecting the stability of springs in the absence of human disturbance.

2. Materials and methods

2.1. Study area and field sampling

Our study comprised a Before–After–Control–Impact (BACI) design (see Underwood, 1994) with multiple impacted and control sites, as well as remote control sites independent of any restoration activities. We monitored spring invertebrate communities following restoration of a mire that was ditched in 1970 to enhance forest growth. Restoration was conducted by Metsähallitus Natural Heritage Services in the winter of 2001–2002 and it mainly consisted of excavator-aided filling of the ditches. The main goal was to enhance the recovery of the northernmost occurrence of a floristically valuable habitat type, groundwater-dependent calcareous fens. The restored mire, covering ca. 18 ha, is located in eastern Finland (online appendix, Fig. A.1) (62°15′30″N, 27°39′44″E), and it is influenced by groundwater discharge from numerous springs.

The directly-impacted springs ($n=6$) were located in ditches that were filled during the restoration works. Adjacent control sites ($n=4$) remained physically intact, protected by a buffer of 5–10 m from any restoration activities. The four remote control sites are located 300 km southwest from the restoration area (60°28′34″N, 23°39′40″E), but within the same ecoregion (Fig. A.1). All springs studied, both in the restoration area and in the remote control area, were permanent cold-water springs. In the restoration area, the springs were sparsely vegetated rheocrenes or limnocrenes, whereas in the remote control area, one of the springs was a limnocrone and the other three were rheohelocrene complexes.

Restoration caused profound short-term changes to the hydrological conditions and chemical quality of the groundwater: increased amount of suspended material, depletion of oxygen, and dissolving of metals. For the most part, water quality returned close to pre-restoration condition by 2004 (online appendix Table A.1). Following restoration, water table rose in the whole mire (online appendix, Fig. A.2).

We monitored the invertebrate assemblages across nine years to detect trends, if any, in several response variables: taxonomic richness, proportion of spring specialists, and community composition. We collected the pre-restoration samples in May 2001, and post-restoration samples in May 2003, 2005 and 2010, using a D-frame hand net (20 cm wide, 0.5-mm mesh size) by sweeping submerged substrates (1-m sweeps) or by pressing mossy and muddy substrates and collecting loose material into the net (see Ilmonen and Paasivirta, 2005). One to five replicate samples were taken in each spring, depending on the size of the spring. We also measured bryophyte cover and maximum depth for each replicate sample, and recorded water temperature on each visit to a spring.

We identified all benthic macroinvertebrates (dipterans included) to the lowest taxonomical level feasible, usually species, and classified taxa to freshwater generalists vs. spring specialists (crenophilous taxa, see Paasivirta, 2007; Ilmonen et al., 2009; for a full species inventory, see online appendix Table B.1). Because the separation between strict crenobionts (species living exclusively in springs) and crenophiles (species preferring springs and other cold, stable habitats) is difficult and varies across the geographical range of a species (e.g. *Crunoecia irrorata* (Curtis 1834), see Ilmonen, 2008), we defined all crenobiont and crenophilous species as spring specialists.

2.2. Statistical analyses

We first analyzed the effect of restoration on community-level attributes by using generalized linear mixed modeling (GLMM) in the ‘MCMCglmm’ package (Hadfield, 2010) in the R statistical environment (R Development Core Team, 2010). MCMCglmm is a Bayesian modeling method, and it utilizes prior probabilities of the covariances and fixed effects for estimating the posterior distributions of the effects of interest (Hadfield, 2010). Our response variables were (1) the proportional abundance of crenophilous taxa of all benthic invertebrates, and (2) total taxon richness (rarefied to 100 individuals). Explanatory variables included the effects of Time (years 2001, 2003, 2005, and 2010), Treatment (remote control, restoration area control, and restoration area impact) and their interaction. We ran all GLMMs for 130,000 iterations with a burn-in phase of 30 000 and a thinning interval of 50. We used deviance information criterion (DIC) to find the best fitting model (lowest DIC), and posterior p-values, in addition to posterior effect estimates and their 95% confidence intervals, to assess the impact of Time, Treatment and their interaction (see Hadfield, 2010). We used p-values to facilitate the assessment of effects, but placed more emphasis on estimates of effect sizes and their CIs in our interpretation.

Next, we tested for the effects of restoration on community composition using the ‘adonis’ function in ‘vegan’ (Oksanen et al., 2010). This procedure allows a stratified analysis (replicate samples nested within springs), as well as testing of the Time × Treatment interaction effects. Finally, to visualize shifts in community composition through time, we used non-metric multidimensional scaling (NMDS) based on functions ‘metaMDS’ and ‘envfit’ in the vegan package. We used the abundance-based Bray–Curtis dissimilarity metric in all community analyses.

3. Results

Following mire restoration, the proportional abundance of crenophiles collapsed in both the impacted and control springs in the restoration area, whereas in the remote control sites their proportion remained stable (Fig. 1a–c). Within the restored mire, crenophiles tended to decrease more in the impacted than in control sites. By 2010, crenophile abundance in the control sites had recovered to the pre-restoration level and almost so in the impacted sites. These interpretations were supported by the MCMCglmm, where the interaction term (Time × Treatment) was strongest in the restoration-area impacted sites in the 2003 and 2005 surveys ($p < 0.01$) and weaker in 2010 ($p = 0.10$) (Table 1).

The abundances of a few abundant taxa changed markedly after restoration, particularly the generalist chironomid species, *Psectrotanyptus varius* (Fabricius, 1787) (Chironomidae: Tanyptodinae) from complete absence in 2001 to a mean of 107 individuals per spring in 2003 (Fig. 1d–f). In subsequent years, this species again declined to an average of 8.5 (2005) and 2.7 (2010) individuals per spring. In addition, the abundance of a generalist stonefly species *Nemoura cinerea* (Retzius 1783) (Plecoptera: Nemouridae) increased, while the crenophiles *Nemurella pictetii* Klapalek 1900 (Plecoptera: Nemouridae) and *Leuctra nigra* (Olivier 1811) (Plecoptera: Leuctridae) declined following the restoration. No corresponding changes occurred in the remote control springs where *P. varius* was not recorded during the study period (see Table B.1).

Rarefied species richness was overall lower in the restoration area (restoration control mean 11.7 [range 7.3–17.8], restoration impact mean 10.9 [range 2.0–20.5], remote control mean 18.5 [range 14.3–22.8] with no detectable temporal trend (see also Table B.1). In the remote control area, species richness increased slightly through time, causing an overall difference between the

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