Science of the Total Environment 569–570 (2016) 361–372

Contents lists available at ScienceDirect

Science of the Total Environment

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

# Macroinvertebrate community assembly in pools created during peatland restoration

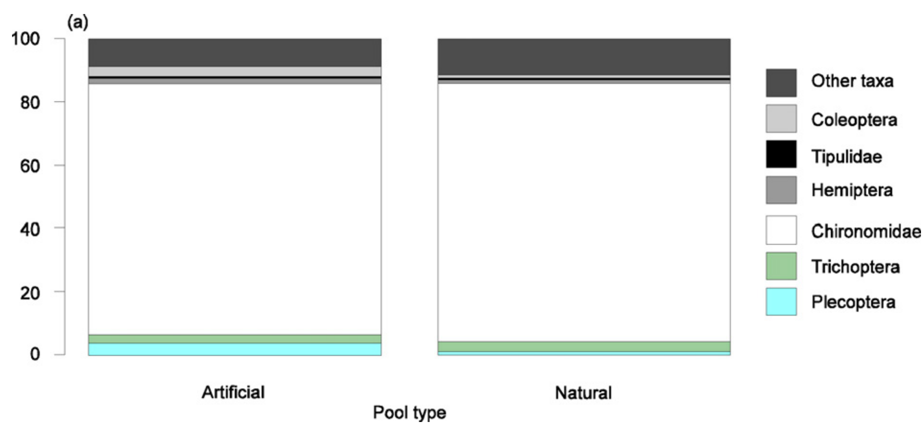
Lee E. Brown *, Sorain J. Ramchunder, Jeannie M. Beadle, &, Joseph Holden

water@leeds, School of Geography, University of Leeds, Leeds, LS2 9JT, UK

## HIGHLIGHTS

- We assessed the benefits of peatland pool restoration for aquatic biodiversity.
- Biomonitoring metrics and community composition suggested different outcomes to restoration.
- Null model approaches provided a clearer suggestion that restoration was successful.
- Analysis of assembly processes should be used when planning and evaluating ecological restorations.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 29 March 2016
Received in revised form 10 June 2016
Accepted 20 June 2016
Available online 24 June 2016

Editor: D. Barcelo

*Keywords:*
Ditch-blocking
Drainage
Niche
Pond
Restoration
Stochastic

## ABSTRACT

Many degraded ecosystems are subject to restoration attempts, providing new opportunities to unravel the processes of ecological community assembly. Restoration of previously drained northern peatlands, primarily to promote peat and carbon accumulation, has created hundreds of thousands of new open water pools. We assessed the potential benefits of this wetland restoration for aquatic biodiversity, and how communities reassemble, by comparing pool ecosystems in regions of the UK Pennines on intact (never drained) versus restored (blocked drainage-ditches) peatland. We also evaluated the conceptual idea that comparing reference ecosystems in terms of their compositional similarity to null assemblages (and thus the relative importance of stochastic versus deterministic assembly) can guide evaluations of restoration success better than analyses of community composition or diversity. Community composition data highlighted some differences in the macroinvertebrate composition of restored pools compared to undisturbed peatland pools, which could be used to suggest that alternative end-points to restoration were influenced by stochastic processes. However, widely used diversity metrics indicated no differences between undisturbed and restored pools. Novel evaluations of restoration using null models confirmed the similarity of deterministic assembly processes from the national species pool across all pools. Stochastic elements were important drivers of between-pool differences at the regional-scale but the scale of these effects was also similar across most of the pools studied. The amalgamation of assembly theory into ecosystem restoration monitoring allows us to conclude with more certainty that restoration has been successful from an ecological perspective in these systems. Evaluation of these UK findings compared to those from peatlands across

* Corresponding author.
*E-mail address:* l.brown@leeds.ac.uk (L.E. Brown).

http://dx.doi.org/10.1016/j.scitotenv.2016.06.169

Europe and North America further suggests that restoring peatland pools delivers significant benefits for aquatic fauna by providing extensive new habitat that is largely equivalent to natural pools. More generally, we suggest that assembly theory could provide new benchmarks for planning and evaluating ecological restoration success.


## 1. Introduction

Degraded, damaged or destroyed ecosystems are the subject of ever increasing attempts to effect restoration of ecological processes, conserve biodiversity and sustain the livelihoods of people who depend upon them (Allison, 2012). Billions of dollars are spent annually on ecosystem restoration (Goldstein et al., 2008; Birch et al., 2010), with estimates for the U.S. alone running to $9.5B per annum (BenDor et al., 2015). Restoration efforts can include the removal of barriers to recovery, reconfiguration of habitats, or assistance with species recolonization. Biodiversity increases are often cited as a key goal of restoration (Kirkman et al., 2013). However, only 35–44% of restoration programmes across a wide range of ecosystem types have been reported as having favourable outcomes for biodiversity (Benayas et al., 2009; Jones and Schmitz, 2009) leading to the often repeated conclusion that many ecological restoration attempts have been unsuccessful (Lockwood and Pimm, 1999).

A typical focus of ecosystem restoration monitoring is the assessment of empirically measurable attributes of a community such as diversity and abundance (Seabloom and Valk, 2003; Klimkowska et al., 2007; Palmer et al., 2010), biomonitoring index scores (Bonada et al., 2006), indicator species abundance (Pykälä, 2003; González et al., 2013) or aspects of ecosystem functioning (Lepori et al., 2005; Foster et al., 2007) relative to control or reference sites. A potential reason for the reported low success rates, and often unexpected results of ecological restoration, is that structural and functional attributes of ecosystems can reach alternative states as post-restoration succession proceeds (Suding et al., 2004; Hobbs, 2007). Significant drivers of changes in ecosystem structure and functioning include dispersal and colonisation success, biotic interactions and feedbacks which can introduce significant stochasticity to community composition (Ledger et al., 2006; Chase, 2007; Heino et al., 2015) and thus to restoration outcomes. However, incorporating knowledge of reference-community assembly processes in the planning or evaluation of restoration programmes has still not begun (Lockwood and Pimm, 1999; Chase, 2007).

Where environmental conditions do not impose excessively strong controls on biodiversity, there is often a distribution of potential restoration end points which arises rather than a single definable end point (Chase, 2007; Milner et al., 2011). In conceptual terms, evaluating restoration success based on a system's ability to assemble towards this range of states should be desired by practitioners where it is also the case in their reference system(s). However, a general focus by restoration practitioners on restoring abiotic habitat to deliver quite specific biodiversity outcomes means that deterministic (niche) processes of community assembly (Belyea and Lancaster, 1999) are essentially a major consideration within restoration design. In these cases, restoration is only likely to be deemed completely successful where it is aimed at ecosystems that already have strong deterministic assembly processes which serve to 'filter' (Poff, 1997; Fattorini and Halle, 2004) the species pool towards a narrowly defined end point, similar to the reference state.

In environments such as wetlands, which have been degraded historically via land drainage activities, heterogeneity may be decreased following rewetting which aims to homogenise water-table variations and vegetation across a site (Verberk et al., 2010). In such ecosystems, restoration activities provide ideal opportunities to evaluate biological community assembly processes because environmental homogeneity should promote high similarity between the biota of restored environments and local reference sites, especially if environmental conditions are harsh enough to serve as deterministic influences on community assembly (Thompson and Townsend, 2006; Brown and Milner, 2012). In contrast, if stochastic dispersal events or internal dynamics are important drivers of assembly (Belyea and Lancaster, 1999; Heino, 2012), communities in restored wetland sites might not fully resemble those in reference sites even if environmental conditions show no difference.

Peatlands cover ~4 M km$^2$ of northern temperate and boreal regions (Yu, 2012) and large expanses of N. Europe, N. America and Russia have been impacted by land drainage (Holden et al., 2004; Mazerolle et al., 2006; Hannigan et al., 2011; Beadle et al., 2015). Recognition of the global environmental implications of peatland degradation has led to attempts to rewet drained peatlands, with the aim of restoring the growth of peat-forming vegetation, promoting peat accumulation and thus enhancing terrestrial carbon sinks (Poulin et al., 2004; Ramchunder et al., 2009). UK blanket peatlands (Fig. 1) have historically been subjected to intensive drainage to lower the water table in attempts to make the land more suitable for agriculture, gun-sports, commercial forestry or for peat extraction for use as fuel or in horticulture (Holden et al., 2007). Large-scale restoration practices have created hundreds of thousands of open water pools, ponds and lakes (Beadle et al., 2015) but to date they have received relatively little attention with respect to their biodiversity and/or community (re-) assembly compared with studies of their hydrology, chemistry and gas emissions (Haapalehto et al., 2011). Despite the potential importance of new bog pools for aquatic biodiversity, these habitat features are also potential hotspots for the release of both $CH_4$ and $CO_2$ (Cliché-Trudeau et al., 2012). This is important because some consideration is being given to infilling ditches, rather than creating pools, to reduce greenhouse gas releases (Parry et al., 2014). It is therefore vital that the biodiversity of these habitats is studied to provide a balanced research base that can inform future management and conservation decisions.

This study investigated the physicochemical characteristics and macroinvertebrate communities of natural versus artificial pools ecosystems, with the aim of first providing a comparative evaluation of their macroinvertebrate community composition. Specifically, we sought to answer the question: do restored pool environments support assemblages similar to naturally formed pools? Second, the integration of ecological theory with practice has been a long-standing goal of restoration (Temperton et al., 2004; Hobbs, 2007), and here we evaluate the benefits of such an approach to assess restoration success alongside widely used measures of community composition and diversity metrics. Third, we evaluated whether or not these pool systems contain biota similar to pools on restored peatlands elsewhere in the northern hemisphere, to shed light on the potential to generalise our findings of deterministic versus stochastic constraints on peatland pool macroinvertebrate communities.

## 2. Methods

### 2.1. Study sites

The study examined 40 independent bog pools (20 natural, 20 artificial) on three occasions in the Pennines of northern England, UK. Potential sites with pools were identified using aerial images available online. All shortlisted sites were visited to ground-truth the management techniques and pool size. The final selection of study sites was determined by selecting restored sites with similar lengths of time for colonisation since peatland restoration had occurred (5–10 years), and where restored peatlands could be compared to nearby intact peatlands with no history of artificial drainage management. Of the 40 pools selected for study, 20 were located in the North Pennines region and 20 in the South Pennines (10 pools on undisturbed peatland vs 10 pools