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Application and validation of a new approach for modelling benthic invertebrate dispersal: First colonisation of a former open sewer system

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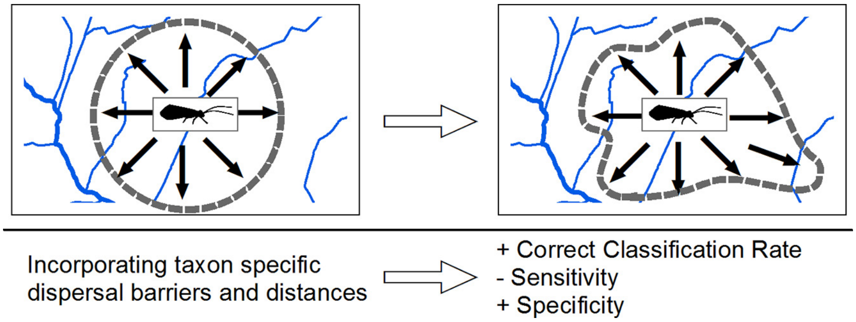
HIGHLIGHTS

- Recolonisation of restored rivers depends on the regional species pool.
- Aquatic insect dispersal is known to be affected by migration barriers.
- Therefore, dispersal models were based upon the least-cost algorithm.
- Dispersal models including migration barriers result in more accurate predictions.
- Yet, dispersal models revealed only a modest goodness of fit.

GRAPHICAL ABSTRACT



Incorporating taxon specific dispersal barriers and distances

+ Correct Classification Rate
- Sensitivity
+ Specificity

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ABSTRACT

Within a heavily modified catchment, formerly polluted streams are now free of untreated wastewater. Additionally, the morphology of streams has been improved by physical habitat restoration. Both water quality and structural improvements offered a unique opportunity to investigate the recolonisation of restored sections by benthic macroinvertebrates. As dispersal is a key mechanism for recolonisation, we developed a method to predict the dispersal of 18 aquatic insect taxa to 35,338 river sections (section length: 2 m) within the catchment. Source populations of insect taxa were sampled at 33 sites. In addition, 14 morphologically restored sites were sampled and constituted the validation dataset. We applied a "least-cost" modelling approach within a raster-based GIS model, combining taxon-specific aquatic and terrestrial dispersal capabilities with the "friction" that physical migration barriers impose on dispersal of aquatic and terrestrial stages. This taxon-specific modelling approach was compared to a conservative modelling approach, assuming a Euclidean distance of 5 km as the maximum dispersal distance for any source population regardless of dispersal barriers. Least-cost modelling showed a significantly better performance in terms of the correct classification rate (CCR) and true predicted absences (specificity), with on average 37% points higher CCR and 42% points higher specificity. Sensitivity was 18% points lower. At 71% of the validation sites, recolonisation was predicted with at least a modest goodness of fit (CCR > 70%). Conversely, the conservative modelling approach achieved a modest goodness of fit for only 14% of the validation sites. For 44% of the taxa, least-cost modelling showed a high CCR (= 100%), whereas the conservative approach showed a high CCR for none of the taxa. Our approach can help water managers select appropriate sites for restoration to increase recolonisation and biological recovery.

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1. Introduction

Freshwater systems are among the most strongly impacted ecosystems by humans (Sala et al., 2000) due to multiple human water uses (e.g., water withdrawal, transport, damming and recreation). These impacts lead to habitat fragmentation and reductions in biodiversity, with the extinction rate of freshwater species estimated to be as much as five times higher than for terrestrial species (Ricciardi and Rasmussen, 1999; Riis and Sand-Jensen, 2001). Numerous restoration projects have been implemented in the last few decades (e.g., Bernhardt et al., 2005, 2007; Feld et al., 2011) to improve the status of aquatic ecosystems and maintain biodiversity. Yet, morphological restorations (e.g., re-meandering, physical habitat enhancement, riparian vegetation improvement) often do not lead to significant changes in the benthic invertebrate community, although positive effects on the availability and diversity of benthic habitats can be observed (Feld et al., 2011; Haase et al., 2013; Jähnig et al., 2009; Palmer et al., 2010). Among the most commonly assumed reasons for poor biological recovery of morphological restorations is the lack of nearby source populations capable of (re-) colonising a restored section (Feld et al., 2011; Sundermann et al., 2011a).

Dispersal is the central ecological mechanism that determines recolonisation (Hanski, 1998), besides other important factors, for example, mating behaviour, oviposition and "propagule pressure" (Masters et al., 2007). Smith et al. (2015) showed that species composition models based on local habitat parameters can be improved by adding dispersal parameters. Yet, the knowledge on benthic invertebrate recolonisation and its environmental predictors is scarce. Dispersal capabilities largely differ among species (Elliott, 2003). Merolimnic insect species (with winged adult stages) can cross catchments within a short time span, whereas dispersal of hololimnic species is limited to the wetted part of a water body. Even within merolimnic insects, there is a broad range of terrestrial dispersal capabilities depending on the order considered (Bis and Usseglio-Polatera, 2004; Bilton et al., 2001; Poff et al., 2006; Schmidt-Kloiber and Hering, 2012; Vieira et al., 2006). Long distance dispersal events (>50 km) have been reported for the dragonfly *Anax junius* (Wikelski et al., 2006) (order Odonata) and for passive (wind-assisted) dispersal of weak flyers (e.g., species of the insect orders Ephemeroptera, Diptera and Plecoptera) (Bilton et al., 2001), while short dispersal distances (<5 km) have been found for *Hydropsyche hageni* (Kovats et al., 1996) (order Trichoptera).

As studies on landscape permeability have shown, dispersal further depends on the presence and type of landscape barriers (Keller et al., 2012; Pflüger and Balkenhol, 2014). Clearly, weirs can fully block the upstream dispersal of larval stages. Therefore, dispersal barriers can hinder or even completely inhibit biological recovery after morphological restoration. However, the role of terrestrial structures is not easy to identify; they can either facilitate (e.g., Ehlert, 2009) or hinder dispersal of adult stages (e.g., Blakely et al., 2006; Briers et al., 2002; Winterbourn et al., 2007).

In an earlier study, we found that considering physical dispersal barriers can improve prediction of dispersal over more conservative methods that, for instance, only use distance to estimate the recolonisation of a site (Sondermann et al., 2015). After analysing the distances to source populations, Sundermann et al. (2011b) found that the ecological quality of benthic communities was positively correlated with the presence of high-quality taxa within 5 km of a given site, which is in line with distances that have been found for fish in lower mountainous rivers of Germany (Stoll et al., 2013). Although they provide a useful rule of thumb, purely distance-based approaches neglect the role of riverine and landscape barriers in dispersal.

Here, we apply a new modelling approach, considering both species dispersal distances and landscape barriers. We combine the potential dispersal modes of merolimnic taxa and identified river sections, reachable either by larval aquatic up- and downstream dispersal or adult aerial dispersal. We chose a catchment with many restored river sections that has been depleted of habitat sensitive species for decades. This catchment offers ideal conditions for validation purposes because predictions can be validated against species presences and absences. The direction of recolonisation is evident. Species recently recorded in

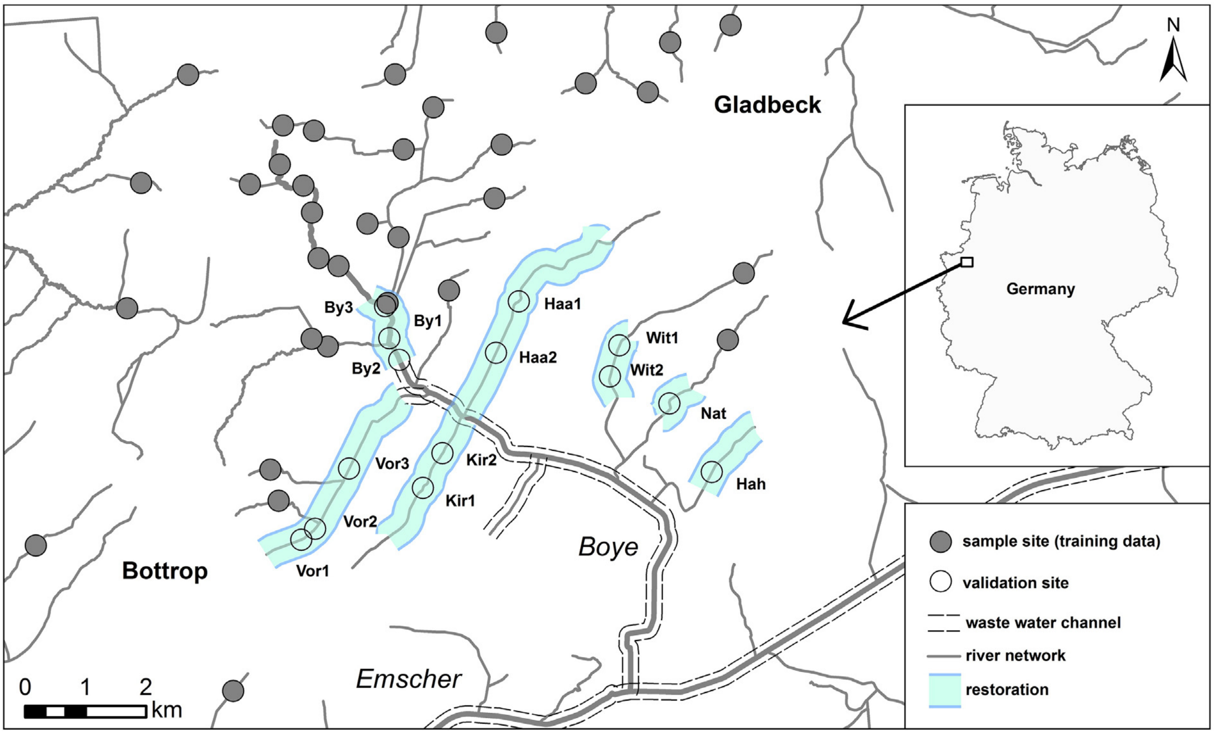

Fig. 1. Study area and the location of 47 sample sites (Winking et al., 2013, 2014, unpublished). Species records at 33 sample sites were used to train dispersal models, while records from 14 sites (e.g., Haa1, Haa2) within restored river sections were used for model validation.