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Limiting factors and thresholds for macroinvertebrate assemblages in European rivers: Empirical evidence from three datasets on water quality, catchment urbanization, and river restoration

Jochem Kail[a,*], Jens Arle[b], Sonja C. Jähnig[c,d]

[a] Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, D-12587 Berlin, Germany
[b] Federal Environment Agency, Section of the Marine Environment, Wörlitzer Platz 1, D-06844 Dessau-Roßlau, Germany
[c] Senckenberg Research Institute and Natural History Museum Frankfurt, Department of Limnology and Conservation, Clamecystraße 12, D-63571 Gelnhausen, Germany
[d] Biodiversity and Climate Research Centre (BiK-F), Senckenberganlage 25, 60325 Frankfurt am Main, Germany

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ABSTRACT

It has been widely stated that pressures acting at large spatial scales influence local habitat conditions and might limit the effects of local restoration measures. However, only a few empirical studies have used statistical methods that have explicitly been developed to investigate such wedge-shaped relationships. The objectives of the present study were (i) to identify pressures acting as limiting factors and to investigate the mitigating effects of local restoration measures in three datasets from European rivers, (ii) to derive thresholds for the ecological status of invertebrates, and (iii) to compare results derived from two statistical approaches, one using aggregated response variables like biological metrics (quantile regression trees), another using taxon-specific responses to derive separate community thresholds for the negative response of sensitive and the positive response of tolerant taxa (Threshold Indicator Taxa Analysis, TITAN). The results indicated that wedge-shaped relationships, typically resulting from limiting factors, are common in datasets from Central European rivers. There was empirical evidence for limiting effects of water pollution and catchment land use and an indication of a mitigating effect of hydromorphological restoration measures. The results emphasize the need to consider such large-scale pressures in river management and restoration because they potentially constrain the effects of local restoration measures. The thresholds derived for the aggregated response variables (metrics) and the community thresholds for sensitive taxa were in good agreement with values reported in the literature but differed markedly depending on the statistical method used. A possible reason is the different focuses of the methods on (i) the threshold for an aggregated response variable (metric), which includes the negative and positive response, and hence, reflects ecosystem functioning, and (ii) the community threshold of sensitive taxa based on taxon-specific negative responses, which is possibly best suited for species conservation issues. However, this interpretation requires further analysis since the results of the two methods showed no consistent differences.

1. Introduction

It has been stated that river biota primarily depends on water quality (Moerke and Lamberti, 2006; Roy et al., 2003) or urbanization in general (Stepenuck et al., 2002; Roy et al., 2003), and that these large-scale pressures may even be limiting. If an anthropogenic pressure acts as a limiting factor, biological metrics will not exceed some upper value due to the pressure, whereas values less than the upper limit occur due to other pressures (Cade and Noon, 2003). This results in constraint envelopes or wedge-shaped relationships (Fig. 1), which are believed to be common in river ecosystems (Wang et al., 2003, 2007) and ecology in general (Cade et al., 1999). However, only a few empirical studies have been carried out on the limiting effects of water pollution (Langford et al., 2009) or other large-scale pressures on invertebrates using statistical methods that have explicitly been developed to investigate wedge-shaped relationships. Empirical data indicate that wedge-shaped relationships occur and invertebrate assemblages can be limited by high metal concentrations (Stockdale et al., 2010), high nutrient concentrations (Wang et al., 2007), fine sediments (Bryce et al., 2010), and streamflow characteristics (Konrad et al., 2008). Thresholds can be identified if the biological metrics do not change continuously but instead change rapidly with a small increase along

* Corresponding author. Tel.: +49 228 44 636 33; fax: +49 228 44 636 32.
E-mail addresses: jochem.kail@igb-berlin.de (J. Kail), Jens.Arle@uba.de (J. Arle), Sonja.Jaehnig@senckenberg.de (S.C. Jähnig).

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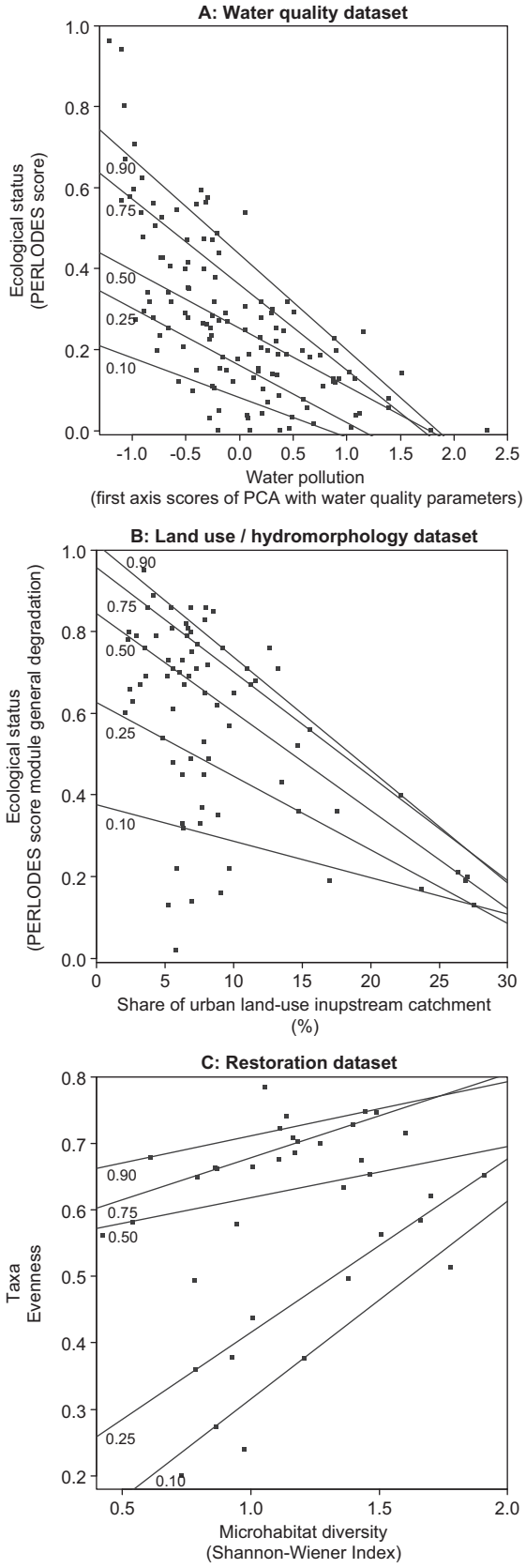

Fig. 1. Wedge-shaped scatterplots of invertebrate metrics and anthropogenic pressures. The 0.10–0.90 quantile regression lines are given. A: $n = 126$ samples from lower mountain streams in middle Germany; B: $n = 76$ samples from lower mountain rivers in western Germany; C: $n = 39$ samples from non-restored and restored rivers across Europe.

the pressure gradient. Threshold values strongly depend on the statistical method used, and only a few studies have compared the results of different methods using the same datasets (Brenden et al., 2008; Dodds et al., 2010).

Information on limiting factors and their respective threshold values is of great interest for river managers and essential to effectively manage and restore degraded rivers. Water managers expect ecological improvement following restoration, especially if the creation of habitats has been successful. However, there is increasing evidence that even restoration measures that lead to an increase in local habitat diversity have no statistically significant effect on river biota, particularly on benthic invertebrates (Lepori et al., 2005; Jähnig et al., 2009, 2010; Palmer et al., 2010). This might be due to large-scale pressures such as catchment land use, which have not yet been considered in most restoration projects (Matthews et al., 2009), although they potentially constrain the effects of reach-scale hydromorphological restoration measures (Bond and Lake, 2003; Roni et al., 2008; Palmer et al., 2010). The European Water Framework Directive (2000/60/EEC of December 22, 2000; WFD) requires that all waters achieve good ecological status and only slightly deviate from natural reference conditions, which has become the main objective of most restoration projects in Europe. The ecological status is quantified in many European member states using multi-metric assessment methods, and good ecological status corresponds to a specific score value. However, there is little information on the limiting effects of large-scale pressures on the biological metrics developed for the WFD and respective threshold values.

The objectives of the present study were to (i) search for anthropogenic pressures acting as limiting factors for the ecological status of invertebrates in three datasets from European rivers, (ii) identify threshold values above which there is a rapid decrease of ecological status, representing a point beyond which reach-scale restoration will be most likely insufficient to reach good ecological status, and (iii) compare threshold values using two different statistical methods.

2. Methods

2.1. General approach

Three independent datasets were investigated: water quality, land use/hydromorphology, and restoration datasets. Each dataset included benthic invertebrate taxon lists, metrics or assessment results derived from these lists, and selected abiotic variables, which reflect different anthropogenic pressures. Each dataset was first screened visually for wedge-shaped bivariate relationships. Second, the observed wedge-shaped relationships were analyzed using quantile regression. Third, two different approaches were used to identify thresholds, and their results were compared: a regression tree approach using aggregated response variables (biological metrics) and Threshold Indicator Taxa Analysis (TITAN), which identifies community thresholds based on taxon-specific responses.

2.2. Study areas and datasets

All invertebrate sites in the water quality and land use/hydromorphology dataset were sampled, and their ecological status was assessed by regional authorities with the PERLODES method, which essentially corresponds to the AQEM method (Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates, Hering et al., 2004). It is a stream-type and stressor-specific method to assess the ecological status of rivers according to the