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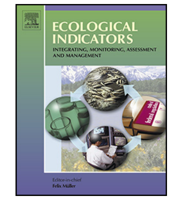

Comparing responses of freshwater fish and invertebrate community integrity along multiple environmental gradients

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ABSTRACT

Multimetric indices of biotic integrity provide a quantitative measure of biological quality and have been developed for several taxonomic groups. Community integrity for fish is typically represented by the multimetric Index of Biotic Integrity (IBI), while for macroinverterates the Invertebrate Community Index (ICI) can be applied. Given the considerable sampling efforts required for biomonitoring, it is important to know the extent to which indices based on particular taxonomic groups respond differently to (anthropogenic) stressors in the environment. The three goals of our study were (1) to assess the concordance of freshwater fish and macroinvertebrate communities, (2) to derive stressor–response relationships for IBI and ICI pertaining to multiple environmental factors and (3) to compare the responses of IBI and ICI to these environmental factors in the state of Ohio (USA). We used a database containing abiotic as well as biotic information for 545 local catchments located across Ohio (USA). Our 22 environmental factors covered physiography, water chemistry, physical habitat quality and toxic pressure. Concordance between the fish and invertebrate communities was assessed using a Mantel test. Response patterns of IBI and ICI to each of the environmental factors were analyzed by constructing stressor–response curves with Boosted Regression Trees (BRT). Fish community integrity was primarily related to physical characteristics of the stream (channel- and riffle quality) and latitude, whereas invertebrate community integrity mainly responded to the phosphorus concentration. Response curves showed that the two indices responded similarly to most of the water chemistry variables, while responses differed for physiographical and physical habitat quality variables.

1. Introduction

In biomonitoring, the environmental quality of a given site is judged from its species assemblages, based on knowledge of environment–biota relationships. In this context, multimetric indices of biotic integrity are widely used to evaluate the biological and thus environmental quality of a site. Integrity indices use multiple characteristics of biotic communities (e.g., the richness and or abundance of specific taxonomic or functional groups) and measure their deviation from values observed in reference sites (Joy and De'ath, 2004; Weigel et al., 2006; Whittier et al., 2007). Reference sites are usually defined as the least disturbed sites in a given ecoregion, and serve as the basis for evaluating the degree of anthropogenic disturbance of sites belonging to the same ecoregion. Various biotic integrity indices exist, based on different taxonomic groups, such as fish, invertebrates, birds, terrestrial arthropods and wetland plant communities, and adapted to specific geographic areas (Bryce et al., 2002; DeKeyser et al., 2003; Karr and Kimberling, 2003; Klemm et al., 2003; Joy and De'ath, 2004). Given the considerable investments in time and money required to conduct detailed field ecological assessments, an important question is whether the biotic integrity of particular taxonomic groups can be used to predict that of other groups, particularly in response to (anthropogenic) stressors in the environment (Heino, 2010).

Predicting the composition and integrity of one group according to another's requires strong community concordance, defined as the degree of similarity in assemblage structure patterns among taxonomic groups (Paavola et al., 2006). Recently, several studies have investigated community concordance among different taxonomic groups used in ecological assessments, but they obtained contradicting results. For example, freshwater fish and invertebrate

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communities appeared concordant in some studies and not in others (Paavola et al., 2006; Infante et al., 2009; Dolph et al., 2011; Rooney and Bayley, 2012). Community concordance values were influenced by the study's spatial scale (Paavola et al., 2006) and by the biological traits of the organisms of concern (Grenouillet et al., 2008). Studies addressing the underlying causes of community concordance found that similarities in assemblage structure patterns may originate from similar responses to environmental gradients (e.g. Neff and Jackson, 2013), but also from biotic interactions (e.g. Grenouillet et al., 2008; Larsen et al., 2012). Most studies conclude that the concordance between fish and invertebrates is not sufficient to use those two taxa as surrogates for each other, even in case of strong concordance, because the two groups are not driven by the same environmental factors (Grenouillet et al., 2008; Infante et al., 2009; Dolph et al., 2011; Padial et al., 2012). However, studies addressing differences in environmental drivers between fish and invertebrates typically quantify these in terms of the overall correlation between the response and a particular environmental driver (e.g. Bedoya et al., 2011; Infante et al., 2009; Neff and Jackson, 2013). Thus, these studies do not provide detailed information on changes in the responses along the environmental gradients. Such information is especially relevant as it would allow to identify where on the environmental gradient management measures would be the most effective.

The three goals of our study were (1) to assess the concordance of freshwater fish and macroinvertebrate communities, (2) to derive stressor–response relationships for fish and invertebrate community integrity pertaining to multiple environmental factors and (3) to compare the environmental responses of fish and invertebrate community integrity in the state of Ohio (USA). Using a database containing biotic and abiotic information for 545 local catchments across the state of Ohio (USA), we first quantified the concordance between fish and invertebrate communities using Bray–Curtis dissimilarity matrices and a Mantel test. Then, we assessed changes in the integrity of the two communities along the gradients of 22 environmental factors belonging to four categories (physiography, physical stream habitat, water chemistry and mixture toxic pressure). Community integrity was represented by the multimetric Index of Biotic Integrity (IBI) and the Invertebrate Community Index (ICI) for the fish and the invertebrates, respectively. Responses of IBI and ICI to environmental factors were analyzed with Boosted Regression Trees (BRT). We determined the magnitude of the effect of each environmental predictor on the two indices, and extracted response curves for each environmental factor to visualize potential differences in environmental responses between IBI and ICI.

2. Methods

The dataset used in our study is part of a database developed by a consortium of companies and institutes including The Procter & Gamble Co., the Dutch Institute for Public Health and the Environment (RIVM) and Waterborne Environmental, Inc. Biotic data were available from 545 biomonitoring sites of the Ohio EPA located across the state of Ohio (Fig. 1). Each biomonitoring site was sampled once during the period 2000–2008. Local catchments were delineated based on the National Hydrography Dataset Plus (NHD Plus, USEPA and USGS, 2005), such that there was one Ohio EPA biomonitoring site within each catchment. Abiotic variables were measured within each local catchment during the same year as biotic data. Below, we provide a brief description of the biotic and abiotic variables included in our study. More details on the data collection and processing are given in Appendix A.

2.1. Biotic indices

Fish were sampled by either boat-mounted or wading electrofishing methods (Sportyak generator or long-line generator). The invertebrates were collected with Hester-Dendy artificial substrates and D-net kicks (Ohio EPA, 1989). Fishes were all identified at species level, while invertebrates were identified at species level whenever possible, else at genus or family level. Presence–absence data were available for 736 invertebrate taxa and 129 fish taxa. In addition, the database contained two multimetric indices representing the integrity of the fish and invertebrate communities. The Index of Biotic Integrity (IBI) measures the biological integrity of the fish community by quantifying the deviation from communities observed in minimally disturbed reference sites. It is composed of 12 submetrics describing structural (e.g., species richness or proportion of individuals from given taxonomic groups) and functional (e.g., pollution-tolerant taxa, trophic groups) aspects of the fish community. The raw values of the submetrics, as obtained from field data, are assigned scores according to the degree of deviation from the values expected at a reference site, located in a stream of similar size in a similar ecoregion. The reference sites for each of the five ecoregions of Ohio were defined by expert judgment as sites with minimum human influence (Ohio EPA, 1987). Each metric can take a value of 1, 3 or 5; the higher the deviation from reference conditions, the lower the score. The overall IBI score is obtained by summing all submetric scores and ranges from 12 (integrity highly deviating from reference conditions) to 60 (integrity similar to reference conditions). The Invertebrate Community Index (ICI) is quantified according to a similar procedure. It includes 10 submetrics which can take values of 0, 2, 4 or 6. Hence, the overall index ranges from 0 to 60 (Ohio EPA, 1987). For reasons of comparability, we rescaled both indices to a 0–100 range.

2.2. Environmental predictors

The 22 environmental predictors we included belong to four categories: physiography, physical habitat quality, water chemistry and toxic pressure (Table 1). Watershed area was used as a surrogate for discharge volume, altitude accounted for climatic parameters and slope for flow velocity. We included latitude and longitude to account for spatial autocorrelation, large-scale biogeographical patterns and unmeasured but potentially relevant environmental variables. Examples include precipitation or anthropogenic factors like impervious cover of the soil, which influences the hydrological regime. The stream physical habitat quality was expressed by the seven submetrics of the Qualitative Habitat Evaluation Index (QHEI; Ohio EPA, 2006) (Table 1). The QHEI is a multimetric index evaluating the physical macrohabitat quality in running waters. Its submetrics are related to particular characteristics of the stream habitat, such as substrate quality or channel morphology. Based on expert judgment, scores are assigned to each submetric, which are then summed to arrive at an overall score ranging from 0 (poorest quality) to 100 (maximum quality). Nine water chemistry predictors were included: pH, oxygen demand (biological and chemical), nutrient concentrations (total nitrogen and total phosphorus), total dissolved and total suspended solids, conductivity and hardness (Table 1). Toxic pressure was expressed as the multi-substance Potentially Affected Fraction of species (msPAF) due to the combined impacts of several groups of toxicants: industrial products, household products, synthetic estrogens and pharmaceuticals. The msPAF was calculated based on environmental concentrations of the substances combined with bioavailability assessments, ecotoxicity data and mixture toxicity models (Posthuma et al., 2002; De Zwart et al., 2006; Posthuma