



Original Articles

Consistent, congruent or redundant? Lotic community and organisational response to disturbance

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ABSTRACT

Although different organisms and metrics are used in aquatic ecosystem assessment, deciding which organism group(s) or community level to apply tends to be based on the local level of taxonomic expertise, rather than the discriminatory power or precision of a given response to specific stressors. We compare the response of two different organism groups (fish and invertebrates) and ecological traits (fish guilds and invertebrate traits) to putative stress gradients, using northern Portuguese rivers as a case study. The rivers covered a quality gradient ranging from reference conditions to high levels of disturbance across classes of ecological status within designated Water Framework Directive monitoring networks. We tested three hypotheses: 1) Ecological traits respond better to regional level human impacts (e.g. land use), while taxa better respond to local factors (e.g. habitat changes or water quality); 2) Invertebrate traits or fish guilds respond to a wider range of anthropogenic disturbances compared to taxa and are not as strongly affected by temporal variation; 3) these two communities respond differently along the studied gradients.

We used canonical correspondence analyses, including partial correspondence analysis and principal response curves to analyze change in composition and metrics and the relative contribution of environmental variables for each biological data set. We carried out analyses between sites and along a temporal gradient, complemented by linkage trees and logistic regressions. Conclusions are more complex than the formulated hypotheses. Although both invertebrate and fish communities revealed a similar ability to assess impairment, invertebrates responded more strongly to local disturbances, whereas the fish composition or traits/guilds were more sensitive to larger scale variation. Results for temporal variation analyses suggested that invertebrate traits more accurately detected change in environmental factors but variation in the taxonomic composition of fish species also followed a temporal gradient. Differences on community response reinforce the importance of a combined approach, using types of community data, to detect environmental impacts.

1. Introduction

The European Water Framework Directive (WFD; European Commission, 2000) legislates for the use of Biological Quality Elements (BQE: fish, invertebrates, diatoms, plants and phytoplankton) via integrated assessment methods to determine the status of EU waterbodies. Among them, benthic macroinvertebrates and fish have a long history as bioindicators (Rosenberg and Resh, 1993; Bonada et al., 2006; Schmera et al., 2017) in freshwater bioassessment (Norris and Thorns, 1999). Mondy et al. (2012) consider that ecological assessment methods must meet an optimal trade-off between 3 factors: (i) high discrimination efficiency, (ii) low specificity and (iii) high levels of stability in least impaired conditions.

Several studies show that invertebrate taxa better detect local impacts (e.g. habitat or water quality parameters) reflecting longitudinal and also temporal fluvial gradients (Statzner and Méricoux, 2005; Kuzmanovica et al., 2017). However, invertebrate species traits based response is stronger across broader geographical area; traits translate the habitat requirements of a given taxa based on the “template” that shapes community composition at a given site (Bonada et al., 2007; Demars et al., 2012; Cortes et al., 2013). Trait-based indices are a promising alternative to traditional taxonomic methods in the assessment of causal relationships between specific stressors and macroinvertebrate community response (Doledec and Statzner, 2008; Murphy et al., 2013; Schuwirth et al., 2015; Kuzmanovica et al., 2017). Similarly, fish guild based metrics seem to respond to regional impacts, such

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as agricultural land use (Krause et al., 2013) or poor fluvial connectivity (Musil et al., 2012; Hughes et al., 2009). This is because guilds express changes in fluvial energy source inputs, water quality, flow regime, habitat quality, and biotic interactions linked to biotic integrity (Karr et al., 1986). Predictable and quantifiable response of fish communities to human impacts (Schinegger et al., 2013) can therefore be obtained by assigning fish species to habitat-related ecological guilds. This approach forms the basis of the index of biotic integrity (IBI; Karr, 1991), and subsequent IBI and multimetric indices applied under the WFD, such as the European Fish Index (Schmutz et al., 2007), the Fish-based Index of Biotic Integrity for Portuguese Wadeable Streams (F-IBIP) (INAG, Afn., 2012), the Mediterranean Index of Biotic Integrity (IBIMED) (Segurado et al., 2014) or the Index of Community Integrity (ICI) (Hermoso et al., 2010). The latter two indices were specifically developed for Mediterranean region fluvial systems, which are characterized by low numbers of fish species per site but high levels of regional endemism and spatial and temporal changes (see Hermoso et al., 2010; Segurado et al., 2014). Guild-based multimetric methods have been used to study extensive geographical areas (Esselman et al., 2013; Terra et al., 2013; Chen et al., 2017) where a careful metric selection process is necessary to allow comparability across regions.

However, community structure and function is shaped by the interplay of environmental factors situated at different spatial scales that act as filters. However, multiscale interactions make it difficult to discern underlying patterns (Poff, 1997; Cortes et al., 2009).

This study assesses the taxa and traits/guilds of benthic macro-invertebrates and fish communities across a gradient of disturbance in fluvial systems of northern Portugal. The first hypothesis is that BQE species composition is more sensitive to both local sources of variation (habitat level) and temporal gradients, thereby better reflecting seasonal change. The second hypothesis is that traits better distinguish variation at a higher spatial scale and display greater temporal stability. We also assess differences in the response of taxonomic based metrics and traits to see if there is a common pattern between fish and invertebrate indicators. We aim to find out if traits and guilds exhibit lower levels of variation across temporal and spatial scales, making them more suitable for studies at higher spatial scales, and if taxonomic composition based responses are more sensitive to local conditions and as well to temporal variation in environmental conditions. Inherent to this approach is the complementary character between these two communities.

2. Methods

2.1. Study area, sampling design and environmental characterization

The study was carried out at sites in two WFD defined River Basins Districts (RBD) in Northeast Portugal: RBD2 includes the Rivers Cávado, Ave and Leça and RBD3 comprises the Douro catchment (Fig. 1). The population of RBD2 and RBD3 mainly resides in the coastal areas. The Ave and Cávado catchments have the highest national human population density (378 hab/km² and 265 hab/km², respectively). Anthropogenic pressures are diverse and intense in the Ave catchment, comprising industrial effluent discharges (textiles and metallurgic industries), organic effluents from cattle farming, urban development and intensive agriculture. In contrast, similar order (*sensu* Strahler) tributaries of the Douro often contain WFD reference conditions due to the lower population pressure levels. Predominant land use in RBD3 is forest, shrub and extensive agriculture with low fertilizer loads.

A total of nine sites were selected from the national WFD monitoring network (7 in RBD2 and 2 in RBD3, see Table 1). The sites covered a large range of ecological conditions and disturbance gradients. Two different spatial levels were used to define the ecological condition of each site, namely (i) catchment level (land use and landscape fragmentation), (ii) local level (river channel and water quality)

(see Cortes et al. 2013 for a more detailed description).

Because of the restricted number of sites used in the study, only 3 ecological quality classes were considered: “Good” (comprising sites classified as having “high” and “good” ecological status) “Moderate” and “Poor” (grouping sites classified as having “Bad” and “Poor” ecological status; see Table 1). These classes derived from all WFD quality elements (biological plus physicochemical and hydromorphological support elements).

Water quality parameters, fractal descriptors (related mainly to landscape fragmentation) and non-fractal metrics (types of soil use), as well as habitat descriptors (based on River Habitat Survey (Raven et al., 1997), were determined for each item. Fractal metrics describe the size, shape and dispersal of patches of land, which essentially comprise individual polygons or contiguous set of cells within the catchment. Non-fractal metrics were calculated to describe the relative proportions of different classes of land cover. We calculated fractal metric considering the different land cover types or non-fractal metrics. Table 2 lists all environmental variables by regional and local spatial scales.

2.2. Sampling and processing of biological and ecological indicators

We collected seasonal samples of benthic invertebrates and fish in summer and winter of 2011–12, the summer of 2012 and spring of 2013 (N = four sampling periods). Invertebrate assemblages were collected with a hand-net following a WFD compliant protocol (INAG I.P., 2008a), then sorted and identified to family level. The macro-invertebrate data were organized into two data groups: a) Relative abundance of taxa, resulting in a matrix comprising 63 invertebrate families (see Table A1, Appendix); b) Biological traits (maximal potential size, life cycle duration, potential number of cycles per year, aquatic stages, reproduction, dispersal, resistance forms, food and feeding habits), physiological traits (respiration, temperature preference, pH preference, trophic status, saprobity and salinity preference); ecological traits (biogeographic regions, altitude, longitudinal and transversal distribution, substrate preference, locomotion and substrate relation and current velocity) reflecting the life history of taxa and adaptive responses to environmental factors.

Each trait was divided into a number of modalities (secondary traits) following Usseglio-Polatera et al. (2000) and Tachet et al. (2010), resulting in a total of 106 modalities distributed across the broader set of invertebrate traits (n = 21). Traits were quantified using the methodology applied by Cortes et al. (2013): a score from 0 to 3 was allocated to each taxon according to its affinity to each trait category. A score of 0 was attributed to trait categories for which no information was available. Affinity scores for each family were computed by averaging the affinity scores of genera belonging to the same family. Finally, the taxa-trait fuzzy matrix was multiplied by the number of individuals in the respective families transformed in a site-trait array of the number of taxa in each site. Relevant available literature such as Varandas and Cortes (2010) was used to obtain missing information on organism traits or modalities. Spearman rank correlations were used to derive a non-redundant matrix of 55 modalities from an initial matrix with 106 modalities (see Table A2, Appendix).

Fish were captured using a WFD compliant electrofishing protocol (INAG I.P., 2008b) identified, weighed and measured. Fish data was divided into 2 data groups:

- Relative abundance of taxa (n = 13 species; Table A3, Appendix);
- Classes of guilds following FAME (2004), Matono (2012) and Oliveira et al. (2009, 2012). A total of twenty-six fish guilds were organised into six ecological functional groups: 1) overall tolerance guilds, based on the ability of species to survive and reproduce across a range of natural environmental conditions; 2) trophic guilds, based on adult diet food items; 3) feeding habitat guilds, based on the preferred living and feeding habits; 4) reproduction guilds, based on spawning substrate; 5) migratory behaviour guilds;

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