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Towards stressor-specific macroinvertebrate indices: Which traits and taxonomic groups are associated with vulnerable and tolerant taxa?

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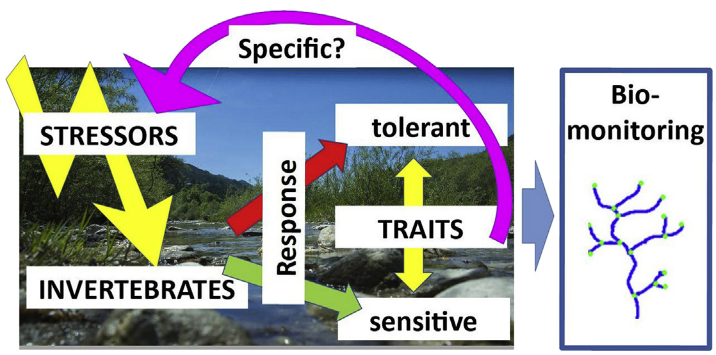
HIGHLIGHTS

- Macroinvertebrate abundances changed along water quality gradients.
- Taxa responses showed little specificity towards different gradients.
- Traits associated with decreasing and increasing taxa were determined.
- Assessment of traits improved mechanistic understanding of taxa responses.

GRAPHICAL ABSTRACT



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ABSTRACT

Monitoring of macroinvertebrate communities is frequently used to define the ecological health status of rivers. Ideally, biomonitoring should also give an indication on the major stressors acting on the macroinvertebrate communities supporting the selection of appropriate management measures. However, most indices are affected by more than one stressor. Biological traits (e.g. size, generation time, reproduction) could potentially lead to more stressor-specific indices. However, such an approach has rarely been tested.

In this study we classify 324 macroinvertebrate taxa as vulnerable (decreasing abundances) or tolerant (increasing abundances) along 21 environmental gradients (i.e. nutrients, major ions, oxygen and micropollutants) from 422 monitoring sites in Germany using Threshold Indicator Taxa Analysis (TITAN). Subsequently, we investigate which biological traits and taxonomic groups are associated with taxa classified as vulnerable or tolerant with regard to specific gradients.

The response of most taxa towards different gradients was similar and especially high for correlated gradients. Traits associated with vulnerable taxa across most gradients included: larval aquatic life stages, isolated cemented eggs, reproductive cycle per year <1, scrapers, aerial and aquatic active dispersal and plastron respiration. Traits associated with tolerant taxa included: adult aquatic life stages, polyvoltinism, ovoviviparity or egg clutches in vegetation, food preference for dead animals or living microinvertebrates, substrate preference for macrophytes, microphytes, silt or mud and a body size >2–4 cm.

Our results question whether stressor-specific indices based on macroinvertebrate assemblages can be achieved using single traits, because we observed that similar taxa responded to different gradients and also similar traits

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were associated with vulnerable and tolerant taxa across a variety of water quality gradients. Future studies should examine whether combinations of traits focusing on specific taxonomic groups achieve higher stressor specificity.

1. Introduction

Biomonitoring of freshwater invertebrates is widely used to gauge and track changes in the environment and to define the ecological state or health of a biological system (Cairns and Pratt, 1993; Friberg et al., 2011). The major advantage is that the biological state is measured directly, instead of inferring perturbations based on chemical measures or other potential pressures (Extence and Ferguson, 1989). Thus, ecological health assessment based on biomonitoring forms the basis for environmental management decisions in Europe (European Parliament and Council, 2000). The ecological health status of rivers is mainly derived from indices that compare the occurrence, abundance, community composition or richness of – for example all or specific macroinvertebrate taxa – to some sort of expected or reference condition (Armitage et al., 1983; Birk et al., 2012; Böhmer et al., 2004b; Extence and Ferguson, 1989). Although these taxonomy-based indices provide good evidence of general degradation, they are often limited in their ability to indicate which stressor is causing the degradation (Böhmer et al., 2004a; Schäfer et al., 2011). Multiple stressors acting on a single freshwater community is the prevalent situation in Europe (Schäfer et al., 2016). Therefore, applied freshwater scientists and managers are interested in obtaining more stressor-specific indices in order to enable identification of the causative stressor whether that is toxicants, nutrient enrichment or poor habitat quality (Baird et al., 2008; Boxall et al., 2012; Culp et al., 2011; Rubach et al., 2011). This knowledge would allow the selection of the most (cost-)effective water management measure including chemical regulatory decisions.

Trait-based biomonitoring approaches have been suggested to achieve this aim (Menezes et al., 2010; Statzner and Bêche, 2010). Traits are "well-defined, measurable properties of organisms usually measured at the individual level and used comparatively across species" (McGill et al., 2006). They can represent adaptations to local habitat conditions (Southwood, 1977) such as body form, respiration strategy and locomotion type (Townsend and Hildrew, 1994; Tullos et al., 2009; Verberk et al., 2008). Therefore, traits may improve a mechanistic understanding of cause-effect relationships by integrating ecological theory (i.e. the habitat templet concept) into biomonitoring (Bonada et al., 2007; Statzner and Bêche, 2010) and thus indicating the stressor(s) responsible for the biological impairment (Dolédec and Statzner, 2008; Mondy et al., 2016; Mondy and Usseglio-Polatera, 2013; Rubach et al., 2011). For example, the SPEcies At Risk (SPEAR) index was developed following this approach and incorporates physiological (relative pesticide sensitivity) and biological traits that are assumed to increase the vulnerability of taxa to pesticides (generation time ≥ 0.5 per year, low migration ability, and presence of aquatic stages during the time of maximum exposure to pesticides, Liess and von der Ohe, 2005). This index successfully discriminated between reference and pesticide-contaminated sites in different European biogeographic regions and was shown to react specific to pesticides exposure in small agricultural streams (Schäfer et al., 2007). However, other studies reported that the index also responded to habitat quality and other stressors (Mondy et al., 2012; Rasmussen et al., 2012). Shared sensitivity of taxa to a variety of stressors and the fact that many stressors co-occur in the environment (Schäfer et al., 2016) can explain why such indices respond to more than one environmental gradient. Thus, the development of truly stressor-specific indices based on the assessment of invertebrate communities is a major challenge regardless whether the trait-profile or the taxonomic composition is assessed.

This study was designed to assess the feasibility and support the development of stressor-specific indices based on macroinvertebrates. We identify and compare taxon-specific responses to different water quality gradients and explore which traits are associated with vulnerable and tolerant taxa with respect to these different gradients. Two main questions are addressed: 1) Can we identify taxa that respond differently (with increasing or decreasing abundances) to different water quality gradients (e.g. increasing phosphorus or nitrite concentrations) in the field? 2) Which biological traits and which taxonomic groups are associated with the vulnerable and tolerant taxa and are they stressor-specific? We address the first question by applying Threshold Indicator Taxa Analysis (TITAN, Baker and King, 2010) to identify taxa that respond with an abrupt decrease (defined as vulnerable taxa) or increase in abundances (tolerant taxa) along 20 water quality gradients including gradients of major ions (e.g. sodium), physico-chemical parameters (e.g. oxygen), nutrients (e.g. nitrate) and common wastewater associated organic micropollutants (e.g. DEET). Since TITAN is a univariate approach, where the effect of co-variables cannot be assessed, we applied TITAN also to a catchment size gradient (smaller to larger streams) as an "external" co-variable. The second question is addressed by applying indicator species analysis (Dufrêne and Legendre, 1997) to trait affinity scores associated with the group of taxa identified as vulnerable or tolerant through TITAN. Based on hypotheses from previous studies (Liess and von der Ohe, 2005; Mondy et al., 2016; Mondy and Usseglio-Polatera, 2013; Statzner and Bêche, 2010), we expect to see several traits as indicative of taxa occurring at clean or impaired sites, respectively. Following the recommendation by Lange et al. (2014), we do, however, not limit the test for relationships to these a priori hypothesised associations. The primary aim was to identify taxa and traits in an explorative approach that may help to develop more stressor-specific trait-based biomonitoring tools. In addition, these taxa and traits may help to target the selection of new model organisms for chemical risk assessment experiments (Rubach et al., 2011, 2012).

2. Methods

2.1. Monitoring data

We used monitoring data provided by the Saxon State Agency for Environment, Agriculture and Geology (LfULG) containing information on macroinvertebrate abundances and a complete set of 20 water quality variables from 422 sites across Saxony, Germany. Following the rationale described in Berger et al. (2016, 2017), only the most recent macroinvertebrate samples (taken 2008–2014) for a given site collected between February and July (recommended sampling season) was included in the analysis. Kick sampling was used to sample macroinvertebrates according to their relative coverage across 20 sub-habitats in a 100 m-long stream section using a hand net (25 cm × 25 cm, Haase et al., 2004). The organisms are then pooled (total sample area of 1.25 m^2), counted in the laboratory and identified down to a taxonomic level as specified in the 'Operational Taxalist for Running Water in Germany' (Haase et al., 2006). In total, 324 taxa with occurrence frequency > 3 were identified across the 422 sites (see Supplementary information Table S1 for taxa identities). Sites covered a range of stream types with catchment areas between 1.5 and 55,590 km^2 (see Table 1). The considered environmental variables included major ions (MI), nutrients (NU), micropollutants (MP) and other physicochemical conditions (PC; see Table 1 for the number of measurements and detection frequencies) as well as the catchment size as a proxy of river size. All