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River bioassessment and the preservation of threatened species: Towards acceptable biological quality criteria

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ABSTRACT

A central objective of environmental management is to maintain biodiversity, including populations of threatened species. Freshwater ecosystems are increasingly assessed by their biotic properties, but whether the resulting classifications of biotic condition are sufficient to protect species with conservation status has received very little consideration. We used data from 225 reference and impacted river sites from Finland to examine whether the occurrence and abundance of threatened macroinvertebrate species (TS) are associated with a commonly used estimate of biological condition (Observed-to-Expected number of predicted taxa of macroinvertebrates or O/E-ratio of taxonomic completeness, based on a predictive model). We suggest that a minimal acceptable condition below which restoration is needed, equivalent to, e.g. 'good' ecological status described by the European Union Water Framework Directive, should also ensure the occurrence of TS populations. We therefore followed conventional procedures for condition assessment, and examined two classifications by using the 10th or 25th percentiles of a reference O/E-distribution as alternative upper boundaries for the acceptable condition. The number and abundance of TS, and occurrence of individual TS showed positive relationships with the O/E. However, particularly if the 10th percentile threshold was used, there were only few occurrences and low abundance of TS in the suggested 'good' condition. The results imply that conventional criteria for satisfactory condition may not be sufficient for preservation of threatened river macroinvertebrates. However, our approach could bring an objective, meaningful, and societally acceptable means for setting site quality criteria in freshwater assessment.

1. Introduction

A central objective in environmental management is to maintain biodiversity, including populations of rare and threatened species, and decline in biodiversity may be greater in freshwaters than in any other ecosystem type (e.g. Dudgeon et al., 2006). Conditions of freshwater ecosystems are increasingly assessed by their biological properties (e.g. Davis and Simon, 1995; Wright et al., 2000; Paulsen et al., 2008); however, whether the outputs from standard bioassessments are also sufficient to protect threatened species has received very little consideration (Wright et al., 1993; Skriver, 1999; Linke and Norris, 2003; Thomas, 2005).

Environmental legislation typically mandates managers to define thresholds below which biotic condition is unacceptable and restoration is needed (Groffman et al., 2006; Andersen et al., 2009). For example, the main guideline for freshwater bioassessment in Europe (Water Framework Directive, WFD), permits 'slight' signs of anthropogenic decrease in 'level of diversity of macroinvertebrates' in 'good ecological status', the minimum acceptable condition (European Commission, 2000a). Such verbal criteria can be variously interpreted and, accordingly, the parameters used to define condition as well as class boundaries may be arbitrary (Simpson and Norris, 2000; Hawkins, 2006), raising concern about their compliance with the ultimate management objectives.

Biotic impairment in freshwaters is commonly assessed by deviation of observed (O) biotic properties from those expected (E) in the absence of anthropogenic disturbance (Bailey et al., 2004; Stoddard et al., 2006). A widely applied version of this reference condition approach is RIVPACS (River InVertebrate Prediction and Classification System; Moss et al., 1987; Wright et al., 2000; Hawkins et al., 2000), where the fauna expected at a site is predicted by multivariate modelling using data from minimally altered reference sites. Condition of the biota can then be evaluated

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with O/E of 'taxonomic completeness' (Hawkins, 2006; hereafter O/E) which is a site-specific proportion of observed taxa of those expected in the absence of anthropogenic stress. O should approximately equal E in undisturbed conditions, whereas O/E < 1 indicates apparent anthropogenic taxa loss (Clarke et al., 1996). Typically percentiles (e.g. 10th or 25th) of the natural reference O/E-distribution (Clarke et al., 1996; Kilgour et al., 1998) are used as thresholds to differentiate impaired sites and to anchor the required quality classification (European Commission, 2003; Poquet et al., 2009) along the biological condition gradient (Davies and Jackson, 2006).

O/E can be calculated either with all predicted taxa or only with a subset of taxa predicted to be common locally, e.g. those that are predicted to be captured with a probability of ≥0.5 at a site (Moss et al., 1987; Hawkins et al., 2000). Empirical evidence has shown that assessments based only on the common taxa subset perform well (likely because common taxa can be predicted more precisely than rarer taxa; Ostermiller and Hawkins, 2004; Clarke and Murphy, 2006), despite still being sensitive to human-caused disturbances (Van Sickle et al., 2007; Aroviita et al., 2008). Therefore, RIVPACS-type bioassessments in practice often use only common taxa (Smith et al., 1999; USEPA, 2006; Yuan et al., 2008). Focusing on common taxa could also be justified by the conjecture that these taxa are typically abundant when present and might therefore be ecologically more important than scarce rare taxa that may contribute little to the ecosystem functioning. However, whether assessments relying on common taxa could also safeguard the persistence of threatened species with conservation value is an important question.

Ideally, a level of assessed condition of biota that still supports the existence of threatened species could be found. Such a critical limit would provide a meaningful lower boundary value for an acceptable condition like the 'good' condition defined by the WFD. In this study, we investigated whether the occurrence and abundance of threatened macroinvertebrate species (TS) are associated with assessed condition of river macroinvertebrate assemblages in Finland. Specifically, we used an existing RIVPACS-type assessment of the macroinvertebrate assemblages (Aroviita et al., 2009) to evaluate (i) whether the occurrence and abundance of TS is associated with the O/E-ratios, (ii) whether the associations are dependent on the subset of taxa included in O/E, and (iii) whether conventional quality class boundaries for the O/E-ratio are appropriate for supporting TS or, (iv) whether such boundaries could be defined from the established associations.

2. Materials and methods

2.1. Data

We used a previously published dataset from boreal stream and river riffles from Western and Central Finland (61.7–64.3°N, 21.5–26.8°E; Aroviita et al., 2009). The study sites represent a wide size gradient (mean catchment area: 910 km^2, range: 2–9744 km^2) of lowland (mean altitude: 81 m a.s.l., range: 3–195 m a.s.l.) rivers draining mineral and organic catchments (mean peatland cover: 31%, range: 4–66%). All available sites with sufficient data were selected from a regional monitoring network and the dataset was augmented with targeted sampling to get a set more balanced with regard to catchment area and geology. The dataset included 96 sites with minimum alteration by human activities and therefore adjudged to be in reference or best-available condition (hereafter REF-sites). All remaining sites were assigned to impact sites (IMP, $n = 134$) where the biota was considered to be potentially impaired by various kinds of human activities (e.g. nutrient pollution, forestry, peat mining, acidification and hydromorphological alteration). Both REF and IMP subsets included the whole river size spectrum even though larger rivers were somewhat more dominating in the IMP set (Aroviita et al., 2009). Macroinvertebrate samples consist of either pooled three replicate 30-s point kick-samples (Nyman, 1995) or 2-min composite kick-sample (Mykrä et al., 2006) that were taken with a standard hand-net (rectangular frame, mesh size 0.3–0.5 mm) and aimed to cover dominant micro-habitats present in each fast-flowing riffle site. This sampling procedure typically captures more than 70% of the species present at a given site and occasion (Mykrä et al., 2006). Chironomids were not identified beyond family level and they were omitted from the analyses. The remaining non-chironomid individuals were identified to 138 taxa (81 species, 35 genera, 19 families and 3 higher groups). For each site, several characteristics of the catchment (e.g. latitude, longitude, site altitude and catchment area) were measured for the purpose of the RIVPACS-type modelling (see below). Aroviita et al. (2008, 2009) describe the data in more detail.

2.2. Threatened species

Threatened macroinvertebrate species (hereafter TS) were selected from the Red Lists of Finnish species (Rassi et al., 2001) by considering all threat categories for those groups (Ephemeroptera, Odonata, Plecoptera, Coleoptera and Trichoptera) with sufficient taxonomic resolution in the dataset. We additionally considered species classified as threatened by the EU Habitats directive (European Council, 1992).

2.3. RIVPACS-type model

We used an existing RIVPACS-type model developed for the whole study area (Aroviita et al., 2009) to obtain site-specific assessments (O/E-ratio) of the condition of macroinvertebrate assemblages. RIVPACS-type modelling combines clustering and discriminant function (DF) analyses and has been well described elsewhere (e.g. Moss et al., 1987; Hawkins et al., 2000; Wright et al., 2000). We thus describe here only the main steps of our model development. First, Flexible-β clustering (Agglomerative Nesting, Kaufman and Rousseeuw, 1990) was used to group the REF-sites to ten biologically similar clusters. Second, 'all-possible-subsets' procedure of Van Sickle et al. (2006) was used to select from candidate predictors insensitive to human influence those DF-model predictors that best explained the biological grouping. These predictors were catchment area, altitude, north coordinate, peatland cover and percentage of lakes (see Aroviita et al., 2009). Third, the DF-model was used to estimate a site-specific probability of capture for each taxon in the absence of human stress (Moss et al., 1987; Clarke et al., 1996), given our standard sampling. For each site, the observed number of taxa (O) was the number of captured taxa that reached a predetermined probability threshold (p_t), and the expected number of taxa (E) was the sum of all capture probabilities $\geq p_t$ (Moss et al., 1987; Hawkins et al., 2000). Final O/E-ratios for the REF-sites were obtained by internal leave-one-out cross-validation (see Aroviita et al., 2009).

To examine whether the associations of O/E and TS depended on the subset of taxa included in O/E, the index was calculated for each site using three levels of p_t: O/E_{0+} included all taxa that were predicted to be captured at any probability (p_t = 0+), whereas O/$E_{0.4}$ and O/$E_{0.8}$ included only those 'common' or 'very common' taxa that were predicted to be observed with at least 0.4 and 0.8 probabilities, respectively. All analyses were performed in the R-software (R Development Core Team, http://www.r-project.org).

2.4. Classification of biological condition

We developed two alternative classifications of biological quality. At each site we considered the macroinvertebrate