Limnologica xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Limnologica

journal homepage: www.elsevier.com/locate/limno

Pressure-specific and multiple pressure response of fish assemblages in European running waters

Rafaela Schinegger*,[1], Clemens Trautwein, Stefan Schmutz

Institute of Hydrobiology and Aquatic Ecosystem Management, Department of Water, Atmosphere and Environment, BOKU, University of Natural Resources and Life Sciences, Vienna, Austria

ARTICLE INFO

Article history:
Received 18 October 2012
Accepted 20 May 2013
Available online xxx

Keywords:
Fish metrics
Water Framework Directive
Multiple pressures
River types

ABSTRACT

We classified homogenous river types across Europe and searched for fish metrics qualified to show responses to specific pressures (hydromorphological pressures or water quality pressures) vs. multiple pressures in these river types. We analysed fish taxa lists from 3105 sites in 16 ecoregions and 14 countries. Sites were pre-classified for 15 selected pressures to separate unimpacted from impacted sites. Hierarchical cluster analysis was used to split unimpacted sites into four homogenous river types based on species composition and geographical location. Classification trees were employed to predict associated river types for impacted sites with four environmental variables. We defined a set of 129 candidate fish metrics to select the best reacting metrics for each river type. The candidate metrics represented tolerances/intolerances of species associated with six metric types: habitat, migration, water quality sensitivity, reproduction, trophic level and biodiversity. The results showed that 17 uncorrelated metrics reacted to pressures in the four river types. Metrics responded specifically to water quality pressures and hydromorphological pressures in three river types and to multiple pressures in all river types. Four metrics associated with water quality sensitivity showed a significant reaction in up to three river types, whereas 13 metrics were specific to individual river types. Our results contribute to the better understanding of fish assemblage response to human pressures at a pan-European scale. The results are especially important for European river management and restoration, as it is necessary to uncover underlying processes and effects of human pressures on aquatic communities.

Introduction

The development of fish-based methods for the assessment of human pressures on the aquatic ecosystem has a long history. There has been considerable scientific effort to define appropriate fish metrics and fish indices for the assessment of the ecological status of different types of running waters in the United States (Fausch et al., 1990; Lyons, 1992; McCormick et al., 2001; Mebane et al., 2003; Hughes et al., 2004; Whittier et al., 2007; Pont et al., 2009). Most of the work has been within the framework of the "Clean Water Act", based on the "Index of Biotic Integrity" (IBI) and the related findings of Karr (1981).

In Europe, the EU Water Framework Directive (WFD, European Commission, 2000) has been a major driver in the development of standardised fish based assessment methods and metrics to determine the ecological status of European rivers and the classification of human degradation (Oberdorff et al., 2001, 2002; Pont et al., 2005, 2007; Roset et al., 2007; Segurado et al., 2011; Logez and Pont, 2011).

Subsequent, EU-funded projects such as FAME (FAME Consortium, 2004) and "European Fish Index Plus (EFI+)" (EFI+ Consortium, 2009), have developed multi-metric indices based on fish assemblages and analysed relationships between fishes and human pressures. Additional studies by Noble et al. (2007b), Melcher et al. (2007), Schmutz et al. (2007b), Virbickas and Kesminas (2007), Grenouillet et al. (2007) and Ferreira et al. (2007) aimed to find appropriate metrics that showed different reactions under unimpacted/impacted conditions for various regions in Europe.

Numerous studies have analysed fish metrics to detect pressures by differentiating between reference and degraded sites (Bailey et al., 1998; Hughes et al., 1998; Karr and Chu, 2000; Hering et al., 2006; Pont et al., 2006, 2009; Stoddard et al., 2008; Southerland et al., 2007; Logez and Pont, 2011). Low quality data and information gaps regarding pressures have produced errors and bias in fish metric responses to different types of

* Corresponding author at: Max Emanuel-Straße 17, 1180 Vienna, Austria. Tel.: +43 1 47654 5223; fax: +43 1 47654 5217.
E-mail address: rafaela.schinegger@boku.ac.at (R. Schinegger).
[1] http://www.wau.boku.ac.at/ihg.html.

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http://dx.doi.org/10.1016/j.limno.2013.05.008

pressures. Consequently, although providing reliable results at the large scale, pan-European fish metrics were unable to differentiate between unimpacted and impacted conditions in specific areas, river types or pressure situations (Melcher et al., 2007; Schmutz et al., 2007a,b; Pont et al., 2007). The EFI+ project (EFI+ Consortium, 2009, http://efi-plus.boku.ac.at/), tried to overcome these problems by identifying and collecting important pressures across Europe on a more accurate and standardised basis. Based on these data, Schinegger et al. (2012) showed that (1) degradation of European rivers is widespread, (2) single water quality pressures (W) are not dominant, but (3) many European rivers are affected by hydromorphological pressures (HMC) or a combination of pressure types (W + HMC). Furthermore, Schinegger et al. (2012) found that hydromorphological pressures (HMC) are the key pressures in alpine regions and headwaters and water quality pressures (W) and multiple pressures (W + HMC) prevail in lowlands.

According to Hering et al. (2006) and Logez and Pont (2011), the signal reflected by metrics should only display the variability of pressures between sites and not the environmental differences between them. Furthermore, Hughes and Oberdorff (1999), Roset et al. (2007) and Pont et al. (2009) stated that the creation of new IBIs and IBI scoring criteria to suit natural regional and local differences might be unsuitable when applied to areas outside those for which they were developed. Subsequently many studies have focused on a predefined ecoregion approach. The Illies ecoregion system (Illies, 1978) is the only widely used pan-European classification and was adopted by the WFD. However, Schmutz et al. (2007a) argue that the Illies system has never been evaluated for its ability to discriminate among fish assemblages at a continental scale. Schmutz et al. (2007a) also stated that two spatial dimensions structure fish assemblages at the large scale: the zoogeography across Europe and the longitudinal pattern within each river. Schmutz et al. (2007b) and Melcher et al. (2007) then developed the Fish Assemblage Types (FATs) as an underlying concept for a "Spatially Based Method (SBM)" of classification, which divides rivers into units with homogenous fish assemblages (i.e. a river type specific approach). The SBM approach was initially applied to individual ecoregions (Ferreira et al., 2007; Grenouillet et al., 2007; Noble et al., 2007b; Virbickas and Kesminas, 2007), and then simultaneously to all ecoregions (Melcher et al., 2007; Schmutz et al., 2007a). However, as the SBM approach only applies to rivers belonging to FATs defined in previous studies, it is necessary to extend the geographic range of the SBM.

Based on these previous findings, our study represents a pan-European approach to test the response of fish assemblages to pressures in different river types. Our intent was (1) to define homogenous river types across Europe and (2) to find appropriate fish metrics for these types, showing a response to specific and multiple human pressures.

Methods and data

Allocation and pre-classification of sites

All data were extracted from an extensive database (EFI+ Consortium, 2007) containing fish surveys conducted by several academic institutions and environmental agencies across Europe. Sites were sampled by electrofishing (wading) during low flow periods using European standards (CEN, 2003). We included only sites with fished areas greater than 100 m^2 and having more than 50 caught individuals to minimise the risk of false absences.

Due to multiple sampling sites located in one river, we applied another selection step to compensate for possible spatial autocorrelation. Dispersed distribution of sampling sites was defined in three classes based on upstream catchment size and three thresholds for distance along the stream network between sampling sites. Threshold for (1) small catchments (<1000 km^2) was >5 km distance, (2) for medium catchments (1000–10,000 km^2) >10 km, and (3) for large catchments (>=10,000 km^2) >50 km. The dataset comes for sites from 2079 rivers of which 1553 (74.6%) rivers are associated with only one sampling site, 307 (14.8%) rivers are associated with two sampling sites, and 218 (10.5%) rivers are associated with three or more sampling sites within the entire river. Median catchment size is 82 km^2 and 90% of the sites have a catchment size below 1000 km^2.

After this first step, 3105 sites in 16 ecoregions and 14 countries were available for our analyses. Pre-classification of sites was done for 15 selected pressure variables (Table 1) in order to separate unimpacted sites (no or very slight pressure) from strongly impacted sites. Pressure variables were selected by Schinegger et al. (2012) according to known effects on aquatic habitats and organisms.

In total, 716 sites were classified as unimpacted (classes 1 and 2) and 2389 sites as impacted (classes 3, 4 and 5). Furthermore, impacted sites were associated with specific pressures and pressure combinations according to Schinegger et al. (2012), (see "Group" in Table 1 for details). In this context, 390 sites were impacted only by water quality pressures (W), 771 sites only by hydromorphological pressures (HMC) and 1228 sites by multiple pressures (HMWC), i.e. a combination of water quality and hydromorphological pressures (Schinegger et al., 2012). Fig. 1 shows the spatial location and pressure status of sites.

Fish metrics description

As suggested the EFI+ Consortium (2009), six structural and functional types of metrics were considered for candidate metrics: biodiversity, habitat, migration, reproduction, trophic level and water quality sensitivity. In the dataset, 116 fish species were assigned to tolerances related to these attributes according to the EFI+ classification, based on previous literature and completed by expert judgement (Holzer, 2008; EFI+ Consortium, 2009; Annex Table 1).

In total, 129 candidate metrics were pre-selected for further analyses (Table 2). The selected metrics included six variants: number of species, density (number of individuals per ha) and biomass (kg per ha) per metric as well as relative information on number of species, density and biomass (as percentage of total species). According to Noble et al. (2007a) and Virbickas and Kesminas (2007), these variants reflect most of the important ecological aspects of metrics. Associated references and reactions can be found in Table 2. As information on fish length was not available for a large part of our dataset, we decided not to consider metrics based on size classes/life stages.

River type modelling

To classify fish data in similar groups across Europe, homogenous river types (river types) based on fish assemblage data were modelled using only unimpacted sites. We conducted a hierarchical cluster analysis (agnes, R Core Development Team, 2011) after Ward's method, with Euclidean distance as similarity measure including four fish metrics: percentage of lithophilic species (Repro_LITH_perc_nsp), percentage of omnivorous species (Atroph_OMNI_perc_nsp), percentage of potamodromous species (Mig_POTAD_perc_nsp) and percentage of rheophilic species (Hab_RH_perc_nsp) as well as geographic position to include regionalisation. The threshold for identifying distinct river types was set by eye in the cluster dendrogram to find a feasible number of strong and well-separated river types.

Please cite this article in press as: Schinegger, R., et al., Pressure-specific and multiple pressure response of fish assemblages in European running waters. Limnologica (2013), http://dx.doi.org/10.1016/j.limno.2013.05.008