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A fish-based index for assessing the ecological status of Polish transitional and coastal waters

Szymon Smoliński [a,*], Joanna Całkiewicz [b]

[a] Department of Fisheries Resources, National Marine Fisheries Research Institute, Kołłątaja 1, 81-332 Gdynia, Poland
[b] Department of Logistics and Monitoring, National Marine Fisheries Research Institute, Poland

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ABSTRACT

Fish assemblages are considered indicators of aquatic ecosystem quality. Based on how fish communities respond to anthropogenic pressures, we developed a multimetric fish index for evaluating the health of both coastal and transitional waters. Fish data were collected along the Polish coast in the years 2011, 2013 and 2014 using different types of gear. Redundancy analysis showed that the most important environmental factor affecting fish community was salinity. Responses to anthropogenic disturbances of 20 candidate metrics were tested by generalized linear models, taking into account salinity, sampling protocol and the proxy of human pressures described by the Baltic Sea Impact Index (BSII). Five selected metrics were combined in a Multimetric Index, which showed negative significant correlation with BSII. The index presented herein appeared to be a good tool for assessing the ecological state of highly impacted Polish transitional and coastal areas and complies with the Water Framework Directive requirements.

1. Introduction

The European Water Framework Directive (WFD; 2000/60/EC) has changed the focus of environmental monitoring in bodies of water from pollution control to ecological integrity assessment, with different groups of organisms as indicators (Borja et al., 2008). The status of a biological assemblage indirectly presents the condition of the environment because the organisms react to shifts in ecological factors (Karr, 1981). Fish are considered to be one of the Biological Quality Elements (BQE; according to the WFD terminology). They occur in most water types, they can be relatively easily identified to the taxonomic level of species, and the results of assessment are interpretable for a wide audience (Pérez-Domínguez et al., 2012). Fish assemblages are exposed to a broad range of anthropogenic impacts, which may cause changes in these communities (Barausse et al., 2011; Henriques et al., 2013; Möllmann et al., 2009; Myers and Worm, 2003), so they appear to be relevant as indicators of aquatic ecosystems health (Karr, 1981; Pérez-Domínguez et al., 2012; Roset et al., 2007; Whitfield and Elliot, 2002). Due to the WFD requirements, all member states of the European Union are obligated to assess the quality of transitional waters using fish as one of the BQE (Borja, 2005).

The multimetric fish index proposed by Karr (1981) is a combination of several metrics, which provide a description of fish assemblage characteristics. An array of measures, rather than a single indicator, incorporate information about water resource quality and provide a more robust and sensitive tool (Harrison and Whitfield, 2004). For example, Pérez-Domínguez et al. (2012) distinguished a few groups of metrics, including (i) species richness and diversity related measures, (ii) metrics featured on the trophic role of fish or (iii) their specific way of habitat usage, and (iv) metrics taking into account fish abundance and condition. One Multimetric Index can incorporate a variety of mentioned types, making assessment more complete and functional (Deegan et al., 1997; Roset et al., 2007). The essential task is to find a proper combination of applicable metrics. In general, the main steps of Multimetric Index development include a calculation of candidate metrics, evaluation of their suitability, test of the metrics responses to a stressor gradient, selection of core metrics, and scoring of the final combination (Hering et al., 2006).

The aim of this study was to develop a fish-based Multimetric Index and assessment system for an evaluation of the ecological status of Polish transitional waters that would meet the requirements of the Water Framework Directive and could be applied to coastal areas. The approach described in this paper presents the site-specific method as a way of integrating information on environmental gradients and sampling protocol in the metric modeling and assessment system. A state-of-the-art statistical approach that incorporates multivariate analysis and generalized linear models was used to test the response of fish metrics to anthropogenic pressures (Courrat et al., 2009; Delpech et al., 2010).

* Corresponding author.
E-mail address: ssmolinski@mir.gdynia.pl (S. Smoliński).

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2. Materials and methods

2.1. Fish sampling

Fish data were collected in the years 2011, 2013 and 2014 along the Polish coast (Fig. 1). All sampling stations were located in transitional and coastal areas, which were divided into 18 water bodies (9 transitional and 9 coastal). With respect to the WFD, an assessment of the ecological status with fish as indicators is required for transitional and is not for coastal areas. Despite this, in the present study, we used both data from transitional and coastal waters. First, doing so allowed for the acquisition of additional information on coastal ecosystem quality and creates opportunities for the development of a consistent assessment system. Second, by including coastal data, we were able to enlarge the dataset for analysis and obtain a sufficient gradient of the stressor.

Surveys were conducted by qualified biologists and followed the protocol of national ichthyofauna monitoring in summer (July–August) and/or in autumn (October–November). Three net types were used: the Polish coastal survey net, the Polish coastal multimesh net and the Nordic coastal multimesh gillnets (see HELCOM (2015a) for a detailed description). In each location, a set of two, four or six nets were positioned for 12 night hours. At each station and season, samples were collected twice, resulting in 355 samples being taken in total. Due to harsh environmental conditions in the river mouths of the Vistula, Dziwna and Swina rivers, an additional 20 surveys were carried out using a bottom trawl with a standardized 10 mm mesh in the codend and trawling duration from 15 to 30 min at approximately 3.0 knots of haul speed.

All fish caught were identified, counted and measured for their total length immediately after the survey. We aggregated data per station and season for every gear type. Catch data were expressed as the catch per night, per net, and per one hour of trawling. After the exclusion of outliers or observations containing missing values, 94 observations were used for further statistical analysis.

2.2. Baltic Sea Impact Index as a proxy of disturbance

We used the Baltic Sea Impact Index (BSII) (HELCOM, 2010; Korpinen et al., 2012) as a proxy of human disturbances in the studied areas. The values of these synthetic indicators, calculated using data layers of different anthropogenic pressures and ecosystem components, reflect the cumulated potential impacts of multiple human stressors (Andersen et al., 2015). The BSII is estimated using the methodology of the global index (Halpern et al., 2008), but incorporates more detailed data sets for 5 km × 5 km grids along the Baltic Sea (Korpinen et al., 2012). Because a large part of the BSII model comprises information on the inputs of nutrients and organic matter, hazardous substances and fishing pressure (30%, 30% and 25% of cumulative impact, respectively), the model was found to be a good description for the overall pressure affecting fish communities (Blaber et al., 2000; Snickars et al., 2015; Wikner and Andersson, 2012).

To obtain an index value for each sampling sites, we used a Geographic Information System (GIS) and shape file (*.shp) of BSII (HELCOM, 2015b) (Fig. 2). We calculated the area-weighted mean of the BSII scores for each of the 18 polygons (water bodies) to evaluate human disturbances within whole areas.

2.3. Survey and environmental data

Anthropogenic disturbances may cause an ecological response in the fish community, but the physical and chemical conditions within the estuary or coastal areas also play an important role (Olsson et al., 2012; Whitfield and Elliot, 2002). Therefore, during the fish monitoring surveys, essential environmental variables were recorded. According to the sampling protocol depth, surface water temperature, bottom water temperature, salinity and water transparency (visibility of a Secchi disk) were measured. Because the fish data were aggregated, we calculated the mean values for the environmental variables.

To evaluate the importance of the environmental factors affecting fish community composition, we used multivariate methods. After running a detrended correspondence analysis (DCA; Hill and Gauch, 1980), we chose a partial redundancy analysis (pRDA; ter Braak and Smilauer, 2002; Wollenberg, 1977), as appropriate for data showing a linear distribution (Liu, 1997). This statistical technique calculates ordination of species and environmental data and considers "covariables". It provides a direct gradient analysis right after removing the effect of conditioning variables.

All statistical treatments of data, including the preliminary exploration, DCA, pRDA, and the further described metrics calculation, modeling, scoring and final Multimetric Index evaluation, were performed in *R* scientific computing language (R Development Core Team, 2011). We used the *decorana* function for DCA and the algorithm of Legendre and Legendre's (2012) implemented in the *rda* function of the *vegan* package (Oksanen et al., 2008) to perform pRDA. We prepared three matrices for the analysis: a matrix of fish species abundances after performing a Hellinger transformation, which makes community composition data reliable for linear modeling (Legendre and Gallagher,

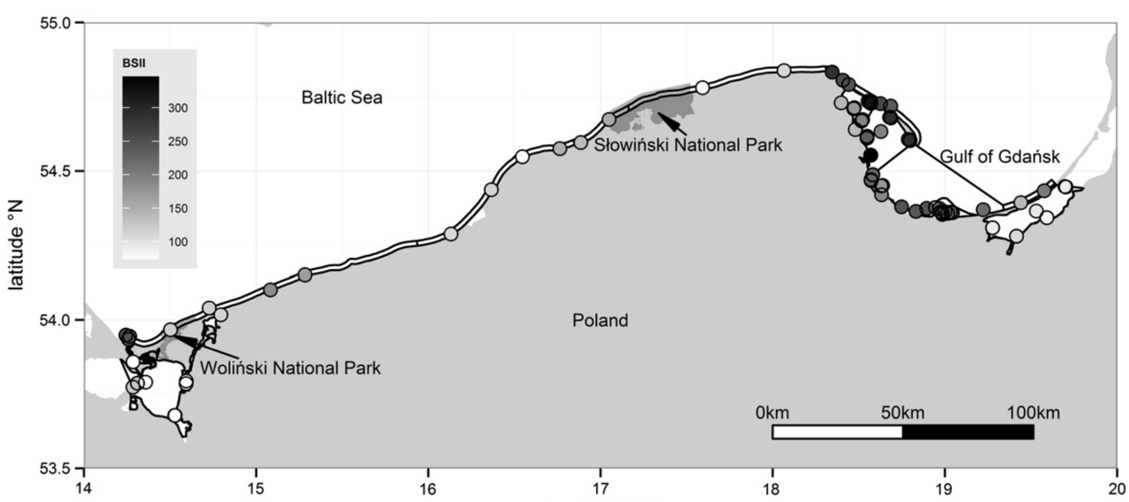

Fig. 1. Fish sampling site locations. The color of the points indicate a value of the Baltic Sea Impact Index for a particular site (see Section 2.2), and solid lines show the borders of the water bodies.