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A fish-based index for the assessment of the ecological quality of temperate lakes

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ABSTRACT

A fish – based index for the assessment of the ecological quality of natural temperate lakes was developed, in accordance to the requirements of the Water Framework Directive (WFD) 2000/60/EC. As a case study, 11 natural lakes located at northern and western Greece were selected. Fish surveys were conducted during mid summer to mid autumn in 2010, 2011 and 2012 using Nordic gillnets and electrofishing. Environmental parameters and anthropogenic pressures were assessed for each lake. Fish species richness, abundance, trophic, reproductive and habitat functional guilds were used for extracting a set of 107 metrics, meeting the requirements of the WFD. All metrics were initially tested as candidates for the index development. A stepwise linear regression of each metric against environmental parameters (lake area, altitude, maximum depth, alkalinity) and anthropogenic pressures (drainage area covered by non-natural land uses – NNLC, water total phosphorus concentrations – TP, Lake Habitat Modification Score – LHMS) was initially conducted for ensuring pressure-response relationships. Reference conditions for each lake were estimated by the hindcasting procedure and the ecological quality for each lake was expressed as the ecological quality ratio (EQR) by a value ranging from 0 (poor quality) to 1 (excellent quality). Two fish fauna metrics, the relative numerical abundance of introduced species ($Introduced_a$) and the relative biomass of omnivorous species ($OMNI_b$) were finally extracted as the most significant, responding to LHMS and TP, respectively. The final index was expressed as the mean values of the EQRs of these two metrics. The multimetric fish index presented herein could serve as a tool for assessing the ecological quality of natural lakes at broad geographical scale and generally, in the Mediterranean temperate lakes with similar hydromorphological characteristics.

1. Introduction

Aquatic ecosystems, globally, are threatened due to anthropogenic pressures (Dudgeon et al., 2006). Water pollution and the loss of microhabitats due to hydromorphological alterations, are among the most significant pressures that have detrimental impacts on the aquatic organisms (Moyle and Leidy, 1992; Camargo and Alonso, 2006). This has sounded the alarm over their urgent protection. In this framework, the monitoring of their biological communities was promoted (Karr, 1991; Karr and Chu, 2006; WFD, 2000/60/EC), mainly after the admission that (Karr, 1981; Whitfield and Elliott, 2002): (a) biological communities respond to long-term environmental conditions and reflect more accurately the “health” of the ecosystem determined by physical, chemical and biological parameters and (b) biological communities reflect the effects of the synergy of many pressures.

The first “biological monitoring” efforts aiming to the assessment of the “health” of superficial water bodies, are dated in the early 20th century (Kolkwitz and Marsson, 1909). Over the years, the increasing knowledge of the ways the biological communities respond to human pressures enabled the development of biological indices, which can provide a holistic assessment of the ecological quality of ecosystems (Fausch et al., 1990; Karr, 1991; Hering et al., 2006; Hellawell, 2012). Such indices are expressed by a numerical value, they reflect the impacts of human pressures upon the aquatic biological communities and estimate the ecological quality of the ecosystem (Karr, 1981; Hering et al., 2006). Hence, they are a very helpful tool for communication among scientists, stakeholders and public.

Many taxonomic groups have been used for the assessment of the ecological quality of the water bodies such as benthic macroinvertebrates (Lenat, 1988; Kashian and Burton, 2000), macrophytes

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(Croft and Chow-Fraser, 2007), phytoplankton (Padisak et al., 2006; Crossetti and Bicudo, 2008) zooplankton (Gannon and Stemberger, 1978) and fish (Karr, 1981; Kennard et al., 2006; Argillier et al., 2013). Biological monitoring of surface waters in Europe was boosted by the implementation of the Water Framework Directive (WFD, 2000/60/EC), which requires a systematic monitoring of aquatic ecosystems and the development of national assessment systems for the estimation of the ecological quality of all surface water bodies (inland, transitional and coastal waters) based on biological quality elements.

In compliance with the requirements of the WFD 2000/60/EC, these biological indices, should rely on clear pressure – response relations and express the ecological quality as the deviation from reference conditions (i.e the conditions that exist under the absence or nearly absence of human disturbances), that is called Ecological Quality Ratio (EQR). This ratio should conclude to a five class, colour scale from 0 to 1. Zero corresponds to very disturbed and 1 to nearly undisturbed water bodies.

After the ratification of the WFD by the European member states, more than 230 evaluation systems (based on biological elements) have been developed and intercallibrated for different water bodies (rivers, lakes, transitional and coastal waters) (Poikane et al., 2015). The first fish based indices for the ecological quality assessment of lakes, were developed in Northern and Central European countries, where time series of fish fauna monitoring data were available [i.e. Belpaire et al., 2000 (Belgium); Appelberg et al., 2000 (Sweden); Gassner et al., 2003 (Austria)]. Moreover, in these countries the systematic fish fauna monitoring immediately started after the implementation of the WFD, allowing for the development of additional indices (Holmgren et al., 2007 (Sweden); Rask et al., 2010 (Finland); Launois et al., 2011a (France); Sutela et al., 2011 (Finland); Kelly et al., 2012 (Ireland); Olin et al., 2013 (Finland)). More recently, a fish index (EUindex) with a very wide geographically applicable potential was developed (Argillier et al., 2013) based on data gathered in the framework of WISER project (http://www.wiser.eu/).

For the Mediterranean lakes, multi-element indices based on fish and other biological elements (e.g. macrophytes, phytoplankton) have been proposed (Moss et al., 2003; Søndergaard et al., 2005; Nõges and Nõges, 2006). However, indices using only fish metrics are very limited (Volta, 2009). This could be attributed to difficulties in gathering fish monitoring data and mainly in establishing reference conditions, due to the absence of undisturbed lentic water bodies (Hering et al., 2010). For the determination of reference conditions, the criteria established by each Geographical Intercallibration Group or even by each Member State should be followed. Greece participated in the Mediterranean Intercallibration Group (Pardo et al., 2011) where the following thresholds were set for the selection of reference lentic water bodies (regarding phytoplankton and macrophytes): a) the 91% of the drainage area should be covered by natural land and b) the agricultural areas should cover less than 7% of the drainage area (Pardo et al., 2011). Under the absence of undisturbed water bodies, other methods have been used for the establishment of reference conditions, among which are model-based methods (Launois et al., 2011a; Argillier et al., 2013).

The aim of the present study was to develop a multimetric fish based index for the assessment of the ecological quality of natural temperate lakes. Both environmental parameters and parameters that serve as proxies of human pressures were considered in order to ensure clear pressure-response relationships. We used, as case study, data collected from surveys in 11 Greek lakes. Finally, we proposed the expansion of the developed index to lentic systems in a broader scale, in the Mediterranean countries.

2. Materials and methods

2.1. Studied lakes

Eleven natural lakes in North-Western Greece were studied. The studied lakes are at altitudes between 16 and 851.3 m.a.s.l., with different limnological characteristics (Table 1): shallow (mean depth <3 m), relatively deep (mean depth: 3–15 m) and deep lakes (mean depth >15 m) with surface areas ranging from 1.70 km^2 (small) to 72.02 km^2 (large). Their eutrophication status also varied from mesotrophic to hyper-eutrophic (Table 1).

2.2. Sampling

Fish sampling took place once per lake during mid summer to mid autumn in the years 2010, 2011 and 2012, following the European standards (EN14757) for lake water bodies (CEN, 2005). Random stratified sampling was conducted using benthic and pelagic Nordic type gillnets. Pelagic gillnets were set in the deepest part of 6 out of the 11 studied lakes with maximum depth > 7.5 m, in stratified depth zones (i.e.: 0–5.9 m, 6–11.9 m, etc.). Benthic and pelagic gillnets were set in the afternoon and lifted the next morning, ensuring a stable soak time of approximate 12 h as proposed by CEN (2005), to allow comparison with other studies. Electrofishing was also conducted (in accordance with European standards: EN14011) in the littoral zone of the lakes, in order to reveal the presence of bottom dwelling fish species.

Along with fish sampling certain water physico-chemical parameters (pH, temperature, dissolved oxygen concentration, conductivity, transparency) were recorded in situ and water samples were taken for the estimation of total suspended solids and the concentrations of nitrate ($N—NO_3$), nitrite ($N—NO_2$) and ammonium ($N—NH_4$) nitrogen, phosphorus of orthophosphates ($P\text{-}PO_4$), total phosphorus (TP), total nitrogen (TN) and Chl-a. Moreover, the sampling protocols of the Lake Habitat Survey (Rowan et al., 2006) were completed and the index of Lake's Habitat Modification Score (LHMS) (Rowan et al., 2006) was calculated as a proxy of the general degradation of the lake. The LHMS takes values between 0 and 42 (Rowan et al., 2006). However, as nuisance plant species (as they are defined by Rowan (2008)) were not considered in the present study, the highest value the LHMS could take was 38.

2.3. Environmental descriptors and pressures

Initially, a total of 34 parameters regarding environmental descriptors and anthropogenic pressures (e.g. the nutrient loads produced at the drainage area due to agriculture and animal stocks) were assessed. However, intercorrelated (Spearman rank correlation; $r_s > 0.6$) parameters were excluded and those which had the higher ecological interpretation were included in further analysis.

Finally, the environmental descriptors selected were (Table 1) the lake area (L_a), the altitude (Alt), the maximum depth (Z_{max}) and the alkalinity of water (Alk), as a proxy of the possible influence of drainage geology in water quality.

The percentage coverage of each lake's drainage area by non-natural land use (NNLC) (estimated by ArcGIS 10) and the concentrations of total phosphorus in the water, were considered as proxies of eutrophication (Launois et al., 2011a; Argillier et al., 2013). Moreover, the LHMS was used as a proxy (Launois et al., 2011a) of the morphological alterations and human pressures on the lakes.

2.4. Fish fauna metrics

Fish specimens were identified to species level, measured for total length (TL, cm) and weighed (W, g). The fish species were