Ecological Indicators 48 (2015) 8–16

Contents lists available at ScienceDirect

Ecological Indicators

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

A review on the ecological quality status assessment in aquatic systems using community based indicators and ecotoxicological tools: what might be the added value of their combination?

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ARTICLE INFO

Article history:
Received 12 March 2014
Received in revised form 27 May 2014
Accepted 7 July 2014

Keywords:
Quality status
Ecological indices
Bioassays
Biomarkers
Water Framework Directive
WFD

ABSTRACT

The European Water Framework Directive (WFD) represents a transformation of the guidelines for water quality assessment and monitoring across all EU Member States. At present, it is widely accepted that the WFD requires holistic and multidisciplinary ecological approaches by integrating multiple lines of evidence. Within the scope of the WFD, the scientific community identified clear opportunities to take advantage of an ecotoxicological line of evidence. In this context, ecotoxicological tools, namely biomarkers and bioassays, were proposed to contribute to the integration of the chemical and biological indicators, and thus to provide an overall insight into the quality of a water body. More than one decade after the publication of the WFD, we reviewed the studies that have attempted to integrate ecotoxicological tools in the assessment of surface water bodies. For this purpose, we reviewed studies providing an ecological water status assessment through more conventional community based approaches, in which biomarkers and/or bioassays were also applied to complement the evaluation. Overall, from our review emerges that studies at community level appear suitable for assessing the ecological quality of water bodies, whereas the bioassays/biomarkers are especially useful as early warning systems and to investigate the causes of ecological impairment, allowing a better understanding of the cause–effect-relationships. In this sense, community level responses and biomarkers/bioassays seem to be clearly complementary, reinforcing the need of combining the approaches of different disciplines to achieve the best evaluation of ecosystem communities' health.

1. Introduction

The European Water Framework Directive (2000/60/EC, hereafter WFD; European Commission, 2000) constitutes one of the most important European Union (EU) pieces of environmental legislation in the water field. It represents a transformation of the guidelines for water quality assessment and monitoring across all EU Member States in terms of protection and management of inland surface, transitional, coastal and ground waters. The inherent aim of the WFD is to protect and prevent deterioration of European waters on the basis of their ecological community structures and, therefore, it implicitly relies on a good knowledge of the ecosystem functioning under specific environmental conditions, an ambitious assumption considering the complexity and heterogeneity of aquatic ecosystems. This 'Ecosystem Approach' (not included in the previous directives on water quality assessment) is a

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http://dx.doi.org/10.1016/j.ecolind.2014.07.024
1470-160X/

reflection of Europe's increasing efforts to improve, protect and conserve aquatic ecosystems and it is in line with the aims of other European Directives (such as the Habitats and Species Directive—92/43/EEC, Marine Strategy Framework Directive—2008/56/EC, Environmental Impact Assessment Directive—2011/92/EU).

Under the WFD, monitoring both the chemical and ecological status is seen as an extremely important tool to evaluate progress towards the established environmental objectives and to achieve, by 2015, the main aim of 'good water status' for all EU waters. To best obtain an assessment of the ecological quality status (EcoQS), the WFD goes further by making a distinction among three modes of monitoring surface waters: (1) surveillance monitoring to assess long-term water quality changes, while providing data to design and implement future monitoring programmes; (2) operational monitoring to establish the status of those water bodies at risk of failing environmental objectives; and (3) investigative monitoring to ascertain the causes of a water body failing to achieve the environmental objectives.

Currently, while each type of monitoring programme is required to cover the status of water bodies through a number of quality elements (biological and physico-chemical elements together with chemical pollutants), the techniques, guidelines, protocols and assessment tools to be used are not fully specified being still under different degrees of discussion and development (Allan et al., 2006). Thus, the successful implementation of the WFD created – and is currently raising – new challenges for the scientific community. There is a need to integrate chemical and ecological information to better address the quality of individual water bodies (Dworak et al., 2005; Graveline et al., 2010; Mostert, 2003). At present, it is widely accepted that new ecological perspectives for the WFD require holistic and multidisciplinary approaches by integrating multiple lines of evidence (Burton et al., 2002; Chapman et al., 2002; de Jonge et al., 2006).

Within the scope of the WFD, the scientific community identified clear opportunities to take advantage of an ecotoxicological line of evidence within the ecological approach (Brack et al., 2005; Sanchez and Porcher, 2009; Triebskorn et al., 2001, 2003). Although the WFD monitoring programme involved the use of both chemical and biological parameters, the use of biological effects methods, namely biomarkers and bioassays, were proposed to contribute to the smooth integration of the chemical and biological information, and thus to provide an overall insight into the quality of a water body (Allan et al., 2006; Hagger et al., 2006). Biomarkers and bioassays are recognized as potentially important lines of evidence to establish cause–effect relationships in ecological quality assessment within the WFD (European Commission, 2009, 2010). More specifically, they improve the capability to ascertain the causes of a failing ecological status in a water body and whether pollutants are the cause for not achieving a 'good status', closing thus the gap between ecology and chemistry (ICES (International Council for the Exploration of the Sea), 2007; Maas and van den Heuvel-Greve, 2004). Consequently, there are clear opportunities for the integration of biological effects into the three types of monitoring programmes for surface water, especially in investigative monitoring, in order to provide a more realistic assessment of impacts and exposure of aquatic organisms to contaminants and to unravel the underlying mechanisms of disruption (Allan et al., 2006; Collins et al., 2012; de Jonge et al., 2006; Dworak et al., 2005; ICES (International Council for the Exploration of the Sea), 2011; Keddy et al., 1995).

More than one decade after the publication of the WFD, we reviewed the studies that have attempted to integrate biological effects methods in the assessment of surface water bodies. For this purpose, we examined studies providing an ecological water status assessment through a traditional approach, based on the status of biological quality elements, and in which ecotoxicological tools, namely biomarkers and/or bioassays, were also applied to complement the assessment.

1.1. Community based approaches to assess the ecological quality status under the WFD: Ecological indices

Under the ecological approach of the WFD the assessment of the quality of the biological elements is based upon community level measures that represent key community aspects of one or more different biological compartments of the ecosystem (i.e. phytoplankton, other aquatic flora, benthic invertebrate and fish). Among the various approaches available for assessing the quality of the biological elements, the most commonly used in many European countries are those based on ecological indices (Birk et al., 2012; Pinto et al., 2009).

Overall, ecological indices are numerical adimensional values expressing the general status of ecosystems through the description of different aspects of the structure and the sensitivity of communities (diversity, abundance, tolerance and/or its combination). These metrics are commonly based on taxonomic identification of organisms, from family to species level. In this sense, we follow the definition by Hyatt (2001), see also Pinto et al. (2009) of ecological indices, which are used as: "quantitative tools in simplifying, through discrete and rigorous methodologies, the attributes and weights of multiple indicators with the intention of providing broader indication of a resource, or the resource attribute(s), being assessed".

Following the publication of the WFD many efforts have been done to develop ecological indices and improve previously described ones to holistically assess the ecological status of water bodies. Nowadays a large number of indices have been developed and fine-tuned for this purpose (Borja and Dauer, 2008; Borja et al., 2009; Dauvin et al., 2010, 2012; Diaz et al., 2004; ICES (International Council for the Exploration of the Sea), 2004; Lyche-Solheim et al., 2013; Pérez-Domínguez et al., 2012; Pinto et al., 2009; Vačkář et al., 2012).

These indices can be classified as univariate (based on individual-species data or community structure measures, such as species diversity, richness, abundance) or multimetric (based on the combination of several metrics of community response to stress, and can be complemented with multivariate analysis methods (based on ordination or correlation analyses) to describe the assemblage patterns.

1.1.1. Reference conditions

A key point of the community approach consists in establishing specific reference conditions. Furthermore, the use of appropriate methods for setting reference conditions appears to be key in order to be able to detect pressures to assess the EcoQS with precision (Borja et al., 2012; van Hoey et al., 2013). These reference conditions must be specifically established not only for the general categories of surface water defined by the WFD (rivers, lakes, transitional waters, coastal waters and heavily modified or artificial water bodies) but also for the different types of water bodies within each category, in order to obtain a best approach for different geographical and habitat conditions.

To establish reference conditions, EU Member States are required to make decisions about what constitutes a minor human disturbance, which brings some technical and conceptual difficulties. On one hand, there is an enormous natural temporal variation (e.g., seasonal changes) in the physicochemical and biological characteristics within each water body (Beiras and Durán, 2013). On the other hand, there are ecological questions about the real meaning of a high status that can only be addressed under the perspective of societal values and other practical considerations (Pollard and