Ecological Indicators 55 (2015) 74–85

Contents lists available at ScienceDirect

Ecological Indicators

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

Do fish larvae have advantages over adults and other components for assessing estuarine ecological quality?

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ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form
26 December 2014
Accepted 9 March 2015

Keywords:
Ecological quality status
Fish larvae
Estuaries
Multimetric fish index
Anthropogenic pressures

ABSTRACT

Using a novel approach to the assessment of ecological quality status of estuarine ecosystems, this study hypothesizes that compared to adult fishes and other components, the younger fish stages will be more sensitive and act as an early warning and will reflect more effectively the ecological status of estuaries. Larval stages of fishes were used to assess the ecological quality status (EQS) of four NW Portuguese estuaries, with different types and magnitudes of human pressures. The larval fish assemblages, together with water column characteristics and pollution indicators (faecal contamination and nutrient load) were sampled in the Lima, Cávado, Ave and Douro estuaries, during spring and autumn 2009. The four estuaries were classified in terms of human pressures by a global pressure index that identified the Cávado estuary as the least impacted estuary, followed by the Ave and Lima, both classified as moderately impacted system, while the Douro was classified as a highly impacted system. The Ave emerged as the most polluted system, carrying the highest nutrient load and sewage contamination. Larval fish assemblages included estuarine species, marine migrants, marine stragglers and the larger estuaries had higher species richness. Compared to adult fishes, three multimetric fish-based indices classified the Cávado, Ave and Douro estuaries with a lower ecological status when fish larvae were used. Similarly, the EQS assessed by macroinvertebrates were equal or higher when compared with fish larvae results. The EQS assessed by fish larvae was negatively correlated with sewage contamination and nitrogen nutrients, but did not reflect other anthropogenic pressures expressed by the global pressure index, which was only detected by adult fish. Fish larvae assessments were able to detect short-time events of hydrological manipulations observed in the Cávado estuary, as well as a seasonal decrease of water quality especially evident in the Ave estuary. The indices used denoted some limitations to the use of fish larvae data, thus emphasising the need for new indices to test the observed tendency for lower EQS given by fish larvae. The advantages and disadvantages of using fish larvae as more sensitive and accurate bioindicators of ecosystem integrity is also discussed as a means of providing strategically important information for improved estuarine management.

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1. Introduction

The historical degradation of estuaries has led to the need to protect and restore the ecological integrity of these ecosystems (McLusky and Elliott, 2004). Worldwide, governance aims to protect, maintain and/or restore the habitat integrity of estuaries (Borja et al., 2010), enhancing conservation and ultimately the sustainable delivery of estuarine ecosystem services. For example, the European Union Water Framework Directive (WFD, European Commission, 2000) aims to achieve a Good Ecological Status (GEcS) for all surface waters, including transitional waters such as estuaries; this requires an assessment based on an ecosystem-based approach, including hydromorphological, physical–chemical and biological quality elements. The WFD defines ecological status according to the scale High, Good, Moderate, Poor and Bad, used as the primary determinant of management needs for surface waters (Birk et al., 2012). The WFD requires that multiple biological quality elements BQEs, as algae, plants, phytoplankton, macroinvertebrates and fish are combined into an overall

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http://dx.doi.org/10.1016/j.ecolind.2015.03.005
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assessment of water bodies, moving from individual biological components to consider the ecosystem as a whole (Hering et al., 2010; Caroni et al., 2013).

Fishes are valuable and publicly highly relevant indicators of environmental changes (Whitfield and Elliott, 2002), and are included as statutory biological quality elements (BQE) in EU environmental policies such as the WFD and also the Marine Strategy Framework Directive (MSFD, European Commission, 2008). Fish-based indices have long been used to monitor changes in aquatic ecosystems and as a means to communicate complex environmental information (Harrison and Whitfield, 2004). With the implementation of international environmental policies several multimetric fish-based indices have been recently proposed to assess the quality status of aquatic environments (see Pérez-Domínguez et al., 2012). Fish-based indices form the link between the actual condition of the habitats and its interpretation that, consequently, leads to management actions of either conservation or (often costly) restoration (Birk et al., 2012). As such, these indices should ideally provide reliable and accurate outputs, in order to define strategic and precise management plans to ensure the maintenance of the ecosystem services and societal benefits (Atkins et al., 2011).

Several characteristics of fish communities, such as their wide distribution in aquatic environments, major role in food webs and direct economic value, which when associated with the cost-effective means for fish assessment including taxonomic training and stakeholder appreciation of quality condition changes, enhance their use as environmental indicators (e.g. Breine et al., 2010; Elliott and Hemingway, 2002; Harrison and Whitfield, 2004; Whitfield and Elliott, 2002; Pérez-Domínguez et al., 2012). Nevertheless, the use of fishes as indicators of environmental quality can also have limitations because of their high mobility, temporal variability (seasonality) and specific sampling requirements (Whitfield and Elliott, 2002; Harrison and Whitfield, 2004). Such disadvantages are considered to be outweighed by the numerous advantages (Harrison and Whitfield, 2004; Gamito et al., 2012), but there is the continuing need to the increase of the accuracy and sensitivity of fish as an ecological bioassessment tool l (Alvarez et al., 2013; Pérez-Domínguez et al., 2012; Borja et al., 2013).

Risk assessment and risk management are central to environmental management which in turn relies on bioassessment to detect anthropogenic impacts and their causes (Cairns, 2003; Elliott, 2014), whose reliability has several economical and socio-political implications (Birk et al., 2012; Gamito et al., 2012). The use of indicators of ecosystem integrity relies on their accuracy and sensitivity to anthropogenic pressures impacting on a particular water body. Early larval stages of fishes show a high vulnerability to environmental shifts (Ramos et al., 2006, 2009) and importance as pollution indicators (Longwell et al., 1992; Gordina et al., 2001; Westernhagen et al., 2001). As such, embryo-larval stages of fishes have been extensively used in toxicity tests, due to their higher sensitivity than adults to toxicants (McKim, 1977). Recently, we demonstrated that estuaries with different levels of anthropogenic pressures exhibit distinct larval and juvenile fish assemblages (Ramos et al., 2012) and also emphasized the potential role of larval stages of fishes as indicators of hydrological pressures that are difficult to measure (Courrat et al., 2009). Moreover, the use of fish larvae integrates valuable information about spawning areas and nurseries and connectivity between marine/river habitats in the assessment of ecological integrity; it will also benefit from the reduced sampling costs. However, to the best of our knowledge, none of the current indices to assess the ecological quality of estuarine ecosystems have explored the potential of larval stages of fishes as more sensitive indicators. Hence here we hypothesize that fish larvae will be more sensitive and therefore will reflect more effectively the effects of anthropogenic pressures than adults. This has implications in terms of management decisions prompting new directions in defining monitoring programmes. Thus, the present study aims to (i) test whether fish larvae give the same, different or more information than classical bioindicators as adult fishes and macroinvertebrates, and (ii) compare the sensitivity of the indices to anthropogenic pressures.

2. Materials and methods

2.1. Study area

Four estuaries of NW Portugal were sampled: the Lima (41°40′N and 8°50′W), Cávado (41°32′N and 8°47′W), Ave (41°20′N and 8°44′W), and Douro (41°08′N and 8°40′W), which gave the necessary conditions to test the above hypotheses, i.e. geographical proximity, similar geomorphological features and different level and degree of human pressures. The four estuaries are in the same biogeographical area (NW Iberian Peninsula) thus limiting the potential biogeographical bias and latitudinal confounding factor (Ley, 2005; Coates et al., 2007). Geomorphologically, all the estuaries are mesotidal channel-type systems; the Ave and Cávado are small systems with a total area of 1.3 km^2 and 4.3 km^2, while the Douro and Lima are larger estuaries (7.3 km^2 and 11.3 km^2, respectively). Hydrologically, all systems are seasonally vertically stratified, despite the differences in the average annual river flow: Ave 32 $m^3 s^{-1}$ Lima 59 $m^3 s^{-1}$, Cávado 67 $m^3 s^{-1}$ and Douro 488 $m^3 s^{-1}$) (INAG, 2013).

The Ave and Douro are highly urbanized estuaries and highly modified by human activities. As such, these systems have been morphologically reshaped, the tidal limit has been artificially limited by a weir in the Ave and a large dam in the Douro estuary. Due to land-claim, saltmarsh areas are limited in the Ave estuary and restricted to a small area near the river mouth in Douro estuary. The river mouth has also been restricted by the presence of artificial jetties projecting from the coastline. Despite the major modifications at the outer Lima estuary, resulting in a deep navigation channel with walled banks hosting a large shipyard, commercial port and fishing harbour, the estuary still encompasses important intertidal saltmarsh areas and natural banks. Similarly, the Cávado estuary, where the seaward section of the north bank is artificial and comprises a fishing harbour and two marinas, still retains several saltmarsh areas, mainly in the lower estuary, where there is an important intertidal embayment on the south bank close to the river mouth.

2.2. Sampling surveys

During spring and autumn 2009, three stations in the Ave, four in the Cávado and six in the Lima and Douro estuaries were sampled (Fig. 1). The number of sampling stations was proportional to the size of each estuary and was chosen in order to cover all the salinity gradient of each estuary, in accordance to the limits of the transitional water (Fig. 1) defined for the Portuguese implementation of the WFD (Cabral et al., 2012). Larval fish assemblages were collected during flood tides with subsurface (1–2 m depth) planktonic nets towed at a constant velocity of approx. 1 ms^{-1} for 5 min, with a conical 1 m diameter, 3 m long and 500 μm mesh size plankton net. A flowmeter (Hydro-Bios) was attached to the net to calculate the volume of water filtered. The location of the sampling stations was obtained using a Magellan 315 GPS unit. Ichthyoplankton samples were immediately fixed in 4% buffered formalin (pH = 8) and after sorting, fish larvae were preserved in 95% ethanol. Fish larvae were sorted and identified to highest taxonomic separation, species level, whenever possible. Abundance

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