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Research paper

The Ecological and Conservation Status of The Guadalquivir River Basin (s Spain) Through The Application Of A Fish-based Multimetric Index

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ABSTRACT

An index of biotic integrity (IBI) based on fish health, population age-structure, abundance and community richness of native and alien fish, originally developed for the Júcar basin (E Spain) (IBI-J), was adapted and validated here for another Mediterranean basin– the Guadalquivir (IBI-G). Until now, no one fish-based IBI − sensitive, useful in a large geographical context, simple and easily applied − has been employed in species-poor Mediterranean basins. Various attempts to develop such an index have generally failed to achieve all these objectives. In this paper, the applicability of the index was enhanced through several modifications to the metrics used in the original IBI-J, and a new version of the index was also developed which included an additional metric recommended by the author of the IBI-J. In the IBI-G each of the five metrics that make up the IBI (*percentage of individuals with anomalies*, *age structure of native fish population*, *relative native fish density*, *loss of native species* and *alien fish pressure*) were validated and adjusted to the specificities of a typical Mediterranean fish community. Both, IBI-J and IBI-G, are robust and coherent assessment tools, highly sensitive to the main pressure gradients observed in the study area, as demonstrated by its correlation with many pressure indicators (biotic and habitat indexes, habitat variables and physico-chemical parameters). It points to the real possibility of extending the same methodology to similar basins for the purposes of monitoring, management and ecological assessment, especially in contexts relating to the Water Framework Directive (WFD). In addition, this new index does not need undisturbed reference sites, a completely unreal requisite in Mediterranean basins, where there is a general scarcity of pristine sites to be used as reference conditions. The results of this study highlight the usefulness of IBI-J/IBI-G as a powerful biomonitoring tool, especially in application of the WFD.

1. Introduction

The use of biological elements for monitoring purposes dates as far back as the beginning of 20th century (e.g. Kolkowitz and Marsson, 1908), and its use is widespread nowadays (Rosenberg and Resh, 1993; Karr and Chu, 1999). Biological assessment is fundamental for the determination of the ecological status and conservation value of water bodies, as required, for example, by the Water Framework Directive (WFD) (European Community, 2000). The implementation of the WFD has led to the regulatory generalization of biological methods in European waters, including the use of algae, macrophytes, macroinvertebrates and fish.

In order to be useful, biological indicators, must meet various requirements (Heink and Kowarik, 2010; Bellinger and Sigee, 2010): ideally, they should have a broad ecological tolerance, provide quick responses to environmental changes, have a well-known taxonomy, be widely distributed, be easy and cheap to manage, respond to stress in a predictable way and anticipate changes so as to avoid them, be inclusive and have a low variability in response (Dale and Beyeler, 2001; Niemi and McDonald, 2004; Niemeijer and de Groot, 2008; Resh, 2008). In this sense, fish are excellent bioindicators, both at local and basin-scale, as well as under different disturbances (organic and nutrient pollution, hydromorphological alterations and changes in land use) and thereby provide complete information on the ecological status of any water mass (Hering et al., 2006; Birk et al., 2012; Hering et al., 2013). Freshwater fish, apart from fulfilling all the aforementioned conditions, also have a high conservation value, especially in Mediterranean areas where, in addition to a large number of endangered species, there can be found a high proportion of rare and endemic species (Clavero et al., 2004; Smith and Darwall, 2006). At the same time, the composition and structure of fish communities have the capacity to integrate information from lower trophic levels (CHE, 2007).

Multimetric indices based on the concept of biotic integrity (Index of Biological Integrity or IBI) are alternative methodologies for the determination of ecological status, very different from the traditional unidimensional biological indices. The IBI incorporates several

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alternative biological and/or community structural parameters (García et al., 2014; Pilière et al., 2014) with a contrasting capacity to provide information on different aspects of the system being monitored. The IBIs were originally developed for fish, specifically for running water communities from the eastern US, and convert information about several attributes of fish assemblages − metrics − into a single number for assessing the health of a water mass (Karr et al., 1986). Most multimetric biotic integrity indices are based on the original American IBI and have been applied everywhere, from the USA (e.g. Plafkin et al., 1989) to Europe (e.g. Pont et al., 2007), Africa (Kamdem Toham and Teugels, 1999) and Asia (Ganasan and Hughes, 1998). In many cases freshwater fish-based IBI indices have been used in its original format, including some reference conditions as the primary key. However, Mediterranean streams are highly unpredictable systems, subject to both natural and human induced disturbances (Prenda et al., 2006; Ferreira et al., 2007; Bonada and Resh, 2013). This instability has led to a species poor and ecologically tolerant fish fauna with low ecological specialization (Doadrio, 2001; Benejam et al., 2015). It makes it very difficult to select typical metrics based on fish taxonomy, trophic and habitat specialization or reproductive tactics. Furthermore, in the Mediterranean basin it is extremely difficult (probably almost impossible) to find undisturbed or reference stream reaches, where native fish assemblages have not been altered (de Jalón, 1987; Elvira, 1995; Prenda et al., 2006), or indeed any behaviourally well-known fish species (Maceda-Veiga and De Sostoa, 2011; Aparicio et al., 2011).

For these reasons the application of IBI indices in Mediterranean environments is a difficult task, and if it is to be practical and valid, any index proposal should solve the aforementioned problems (Aparicio et al., 2011). Although some indices of biotic integrity developed in the Iberian Peninsula incorporate reference conditions [e.g.Catalonia (Sostoa et al., 2003), or the Guadiana basin (Magalhaes et al., 2008; Hermoso et al., 2010)], in the Júcar basin, Aparicio et al. (2011) generated a version without the need for such undisturbed situations. In addition, the choice of metrics used to create the IBI-Júcar differed from previous IBI developments. Aparicio et al. (2011) elaborated a quick, robust and simple IBI, whose results were consistent and well validated, and consequently useful for the determination of the environmental quality of species-poor Mediterranean streams.

It is essential to know the current ecological status of Mediterranean streams and to be able to track their development over time, as much to measure the high degree of human disturbance that threatens these endangered habitats (Hooke, 2006) as to appreciate the extraordinary value of its similarly imperilled biodiversity (Smith and Darwall, 2006). This information needs to be gathered with adequate tools, combining conservation and environmental data in the form of an IBI index capable of determining precisely the ecological status of water masses and diagnosing their main conservation problems.

In this paper, we determine the ecological status and conservation value of a large and highly disturbed Iberian Mediterranean basin (the Guadalquivir river basin, S Spain) using an adapted version of the IBI-Júcar developed by Aparicio et al. (2011). In addition, other specific objectives were: (i) to adapt the IBI-Júcar index to the Guadalquivir basin and to check its usefulness in this new area; (ii) to develop a modified IBI-Júcar with the addition of a new metric, based on the condition index in fish, as recommended by Aparicio et al. (2011) and to compare the performance of both versions (with and without the condition metrics); (iii) to validate and assess the IBI scores and the ecological status assignments in the Guadalquivir basin; and (iv) to compare the performance of both IBIs and other one-dimensional biological quality indices, specifically to determine redundancies.

2. Methods

2.1. Study area

The Guadalquivir River Basin is in the south of the Iberian Peninsula (Fig. 1) and comprises an area of 57 439 km^2. The main channel is 680 km in length with an average flow of 164.3 $m^3 s^{-1}$. The river network, with 80 main tributaries, extends over 10 578 km of freshwater from which 238 km belong to transitional waters. The basin has a typical Mediterranean hydrological regime with high intra- and interannual discharge variation (Gasith1 and Resh2, 1999; Navarro et al., 2012; Confederación Hidrográfica del Guadalquivir 2015a). The Mediterranean climate is characterized by hot, dry summers with relatively mild temperatures in winter (annual average 16.8 °C) and irregular and rather low precipitations in wintertime or spring (annual average 550 $l\,m^{-2}$). The high temperatures combined with the lack of precipitation in summer result in a deep water deficit (Robles et al., 2002).

As a consequence of this endemic water scarcity, the natural flow patterns of the rivers have been strongly modified since ancient times, especially from the 18th century onwards. About 9.3% of the network is impounded by large dams and almost all flow is nowadays regulated. The water supply has reached a maximum, although demand continues to rise (Argüelles et al., 2012). Agriculture accounts for 87% of the water resources within the catchment area. More than 9000 hm^3 of river flow (26% of the total water volume within the entire basin) is retained in 29 large reservoirs (> 100 hm^3) and more than 140 smaller ones of less than 100 hm^3 (Navarro et al., 2007; Confederación hidrográfica del Guadalquivir, 2015b). The flow pattern of the basin has been strongly modified. According to the WFD 43% of all Guadalquivir inland water bodies have poor or low quality (Confederación Hidrográfica del Guadalquivir 2015a) (Table 1 Supplementary Material).

The catchment area is surrounded by mountain chains with altitudes ranging from 1000 m to more than 3000 m above sea level, contrasting with the low flat Guadalquivir valley. The basin is highly asymmetric, with geology, physiography, climate and human pressure all varying between the left −highly disturbed- and the right −less disturbed- main river margins. The valley is a flat land with highly developed intensive agriculture (Rodrguez-Diaz et al., 2007; Hermosín et al., 2013), and a very high human population density of about 70 hab km^{-2} (Confederación Hidrográfica del Guadalquivir 2015a). Consequently, human pressure (urban developments, industry, infrastructures, etc.) is very high. Agriculture has been undergoing major changes in Southern Spain since the end of the 1980s, from traditional non-irrigated extensive agriculture of typical Mediterranean crops (wheat, olives and wine) to a new, intensive, industrialised irrigated model, involving high levels of soil erosion, water abstraction and/or flow regulation, pesticide disposal, and many other side effects (Table 1 Supplementary Material). One direct consequence of these recent agricultural changes, typically associated with an increase in irrigated olive groves, has been the introduction of an extraordinary amount of suspended solids into the drainage network, causing extreme water turbidity (Carpintero 2015). This fact is seriously affecting the fish community inhabiting the lower Guadalquivir (González-Ortegón et al., 2010). Two other significant sources of human impact in the basin come from species introductions (Clavero et al., 2004) and wastewater disposal (Bhat and Blomquist, 2004).

Altogether, these disturbances have caused major changes in the Guadalquivir's freshwater fish fauna over the last two centuries. More than 50% of native species recorded in the basin are considered to be threatened and included in some of the IUCN categories (IUCN, 2015). At a national scale more than 85% of native species recorded in Guadalquivir are currently endangered (Doadrio, 2001). Regionally the information available is very scarce. The regional red book includes 14 endangered species (66.7% of total) and 1 extinct (Franco Ruiz and Rodríguez de los Santos, 2001).

2.2. Data sources and sampling protocols

Presence-absence data and relative fish density (catch-per-unit-effort, hereafter, CPUE) for all freshwater fish species were obtained from

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