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Linking fish-based biological indicators with hydrological dynamics in a Mediterranean river: Relevance for environmental flow regimes

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ABSTRACT

The relationship between flow dynamics and biological communities becomes especially relevant in Mediterranean rivers. Given their natural variability and growing anthropogenic pressures, their low sections are subjected to multiple impacts. The definition of ecohydrological relationships in Mediterranean rivers may constitute a useful management tool. Historically, fishes were the first group used to assess community-level ecological quality, and different indices and metrics have been proposed. However, up to date many of these indicators have showed to be insensitive to flow regime changes or hydrological alteration. There is therefore a need to deepen into the ecohydrological relationships between such indicators and flow regimes in Mediterranean (and other) rivers. This study presents an analysis of the relationship between interannual flow regimes in the lower section of the Ebro River, defined using a set of daily and hourly hydrological indices, and ecological quality based on fish community, assessed through indices designed to fulfill the Water Framework Directive (WFD) in Europe: the Indices of Biotic Integrity in Catalan rivers (IBICAT2010 and IBICAT2b) and the new European Fish Index (EFI+). In order to identify spatiotemporal patterns, hydrological indices were computed using time periods of different amplitude and ecological quality was obtained in different transects along the river section, even within the same water units or 'water masses' (subdivisions of surface waters to fulfill the WFD in Spain). Our results showed that IBICAT2010 was the most correlated with hydrological indices, followed by IBICAT2b and EFI+. The latter showed an almost null correlation with hydrological indices, which may be due to issues associated with the sampling technique, the definition of transects and because it does not uses stream typologies. Correlations among some hydrological and biological indices were observed, with temporal and spatial patterns. On one hand, daily hydrological indices showed relationship with ecological quality when they were computed using between 9 and 36 months of flow records (previous to the sampling date) whereas subdaily indices responded better to periods between 3 and 9 months of records. On the other hand, some sampling transects showed clearer relationships than others, even within the same water mass, which suggests an influence of hydromorphological variability on the obtained ecological quality scores.

1. Introduction

The 'natural flow regime paradigm' (Poff et al., 1997) defined flow dynamics as one of the main drivers of ecological properties of rivers and streams. Therefore, hydrological alteration is a potential risk for aquatic ecosystems, as it has effects on aquatic communities (Poff and Zimmerman, 2010) that may alter their characteristics even at evolutionary time scales (e.g. Mims and Olden, 2012). Specially in Mediterranean streams and rivers, subjected to a high natural hydrological variability (Gasith and& Resh, 1999; Caiola et al., 2001a,b) and to many pressures frequently associated with agricultural activities, such as flow regulation by dams and water extraction for irrigation (Ferreira et al., 2007b).

The Water Framework Directive (WFD; 2000/60/EC) established the objective to achieve a 'good ecological status' in the water bodies of the European Union (including those artificial and heavily modified). With the aim of achieving this objective, the Directive requires the subdivision of surface waters into 'discrete and significant elements' or 'water bodies' (in Spain, 'water masses'). However, the Directive does not provide explicit guidance on how to identify the elements that should be regarded as 'discrete and significant' and, as a consequence, the different water bodies may present relatively heterogeneous

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characteristics such as the length of the stream section.

Whereas classical approaches have focused on target species to define ecohydrological relationships (e.g. Instream Flow Incremental Methodology, IFIM; Bovee and Milhous, 1978), the WFD focuses on the assessment of community-based ecological integrity. Some studies have focused on macroinvertebrates (Buffagni et al., 2005; Bennett et al., 2011; Birk and Hering, 2006, 2009), macrophytes (Birk et al., 2006; Birk and Willby, 2010) or diatoms (Birk and Hering, 2009), but the first method to assess the biotic integrity of rivers was developed specifically for fishes (e.g., Karr, 1981; Fausch et al., 1984). Fishes not only possess a higher direct socio-economic impact than other aquatic organisms but also are key indicators of ecological condition in rivers. In comparison with other taxa, they tend to be more responsive to hydromorphological disturbances (Birk et al., 2012; Marzin et al. (2012a,b), connectivity loss (Schiemer, 2000; Sindilariu et al., 2006) and other stressors that act at wide spatial and temporal scales (Harris, 1995; Simon, 1999).

The first attempt to develop fish-based methods for ecological assessment in streams and rivers across the whole European Mediterranean basin, and fulfill the Water Framework Directive (WFD), was made within the EU-funded FAME (Development, Evaluation and Implementation of a Standardized Fish-based Assessment Method for the Ecological Status of European Rivers; http://fame.boku.ac.at) and EFI+ (Improvement and Spatial extension of the European Fish Index; http://efi-plus.boku.ac.at/index.htm) projects. The main output of these two projects was the new European Fish Index (EFI+), the first standardized fish-based assessment applicable across nearly the whole range of European rivers (Pont et al., 2006, 2007). It is a predictive multimetric index that derives reference conditions of individual sites from abiotic environmental characteristics and quantifies the deviation between the predicted and the observed fish assemblages (Pont et al., 2006). The metrics that integrate the index are based on functional guilds that describe the main ecological and biological characteristics of fish assemblages (Logez et al., 2013). Although such index was reasonably accurate at the European scale, its applicability varied among different biogeographical regions and countries (Pont et al., 2007; Urbanic and Podgornik, 2008; Logez et al., 2010). In Spanish Mediterranean rivers, the Mediterranean Index of Biotic Integrity or IBIMED is used as a fish-based assessment method suitable for the evaluation of ecological quality. First developed for Catalan rivers under the designation of IBICAT (Index of Biotic Integrity for Catalan rivers; Sostoa et al., 2004), an improved version of this index was developed in 2010 (IBICAT2010; Sostoa et al., 2010) before being adapted to the rest of Mediterranean Spanish rivers under the designation of IBIMED. IBICAT2010 and IBIMED are similar in the Ebro River, except for the different species, ecological guilds and thresholds of the Ecological Quality Ratio (EQR) classes. They follow a type-specific method based on eight environmental variables that were selected as the best descriptors of a river classification based on historical fish distribution. More details on the EFI+ and IBIMED may be found in Segurado et al. (2014). Finally, a type-specific variant of IBICAT (IBICAT2b) uses between 4 and 8 metrics depending on river type and has been validated with environmental pressures both throughout Catalonia and the whole Ebro River Basin (Sostoa et al., 2010). IBICAT, its variant (IBICAT2b) and EFI+ have been described as correlated in the Ebro Basin (García-Berthou and Bae, 2014).

Despite aquatic communities are in general strongly affected by hydrology, most of the methods developed for the assessment of biological quality elements are largely insensitive to flow regime changes or hydrological alteration (e.g. Poff and Zimmerman, 2010; Demars et al., 2012; Friberg, 2014). For example, only 40% of the methods developed for fishes are sensitive to flow modifications (Rinaldi et al., 2013). There is a need for development of biological methods to provide metrics sensitive to hydrological pressures and alteration of flow components (European Commission, 2015), which means that further investigation of the relationships between current biological indices (and metrics) and hydrological regimes results essential. Defining ecohydrological relationships in Mediterranean (and other) rivers constitutes a powerful tool for water management, in consonance with frameworks such as the Ecological Limits of Hydrological alteration (ELOHA; Poff et al., 2010).

Spatial and temporal scaling phenomena should be considered when establishing a monitoring program. The dimensions of variation change along spatial/temporal gradients of salinity, habitat complexity and productivity and among different levels of biological organization. Without an adequate evaluation of such variation, representative samples cannot be taken (Livingston, 1987). In this context, for example, studies on juvenile salmonids and other fishes suggest that more than 5 years before and later are needed to detect significant changes in fish abundance after physical habitat shifts (e.g. caused by hydrological variations) unless the magnitude of change in fish abundance is large (> threefold) or the treatments and controls are extensively replicated (Bisson et al., 1997; Roni et al., 2003). Attention must be paid also to temporal resolution, as the use of hourly records together with daily flows may allow distinguishing effects caused by particular flow regime characteristics such as hydro-peaking (e.g. Macnaughton et al., 2017).

The aim of this study was to test the ability of different hydrological indices to explain changes in ecological quality assessed through fishes in the lower section of a Mediterranean river (Ebro from Flix to Tortosa). IBICAT2010, IBICAT2b and EFI+ were employed in order to compare their relationship with hydrology. The relationships between IBICAT2010 and its metrics were also assessed. Different time scales (from months to years) and data resolutions (daily and hourly) were employed for the computation of the hydrological indices. We hypothesized a similar relationship among the three ecological indices and the hydrological indices used (based on García-Berthou and Bae, 2014). In addition, we expected daily hydrological indices computed with the shortest time scales (counted since the moment in which the sample was taken) not to show a relationship with ecological quality given that, as stated above, previous authors highlighted the necessity of relatively long series to detect changes in fishes after habitat shifts (Bisson et al., 1997; Roni et al., 2003). Subdaily (hourly) indices were expected to respond within shorter periods than daily indices.

2. Material and methods

2.1. Study area

The study was conducted in the low Ebro River, located in the NE of the Iberian Peninsula (Catalonia, Spain; Fig. 1). The study area extends from the reservoir furthest downstream (Flix) to the upper limit of the estuary (Tortosa), where the river is about 80 km long and 150 m wide. The Ebro River is 928 km long and has a drainage area of 85 550 km^2. It is the Spanish River with the highest mean annual flow and one of the most important tributaries to the Mediterranean Sea. The main land use in the basin is agricultural with more than 10 000 km^2 of irrigation, which corresponds to approximately 90% of the water usage in the basin. The whole basin is strongly regulated by nearly 200 dams, most of them built between 1940 and 1970 (Ibáñez et al., 2012a; Nebra et al., 2011). The lower Ebro hydrology, morphology and ecology are strongly impacted by the existence, features and operation of such dams (Ibáñez et al., 2012a,b). Apart from the Flix reservoir, upstream of the studied section, two weirs are located in the lower Ebro: Ascó and Xerta. The former is aimed to provide water for refrigeration for a nuclear plant whereas the latter is intended for irrigation. The Flix reservoir derives most of the water income through a channel that avoids the meander located directly below the dam. Only reduced water volumes are liberated intermittently to the meander, when flow overcomes the maximum allocated to produce electricity.

This river section is composed by four water masses (Fig. 1) according to the current Ebro's Water Plan: ES091463 (from the Xerta weir to Tortosa), ES091461 (from Ascó to Xerta Weir), ES091460 (from Flix to Ascó) and ES091459 (Flix meander). The water mass ES091461 is by far longer than the others (Fig. 1).

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