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Effects of flow regulation on the establishment of alien fish species: A community structure approach to biological validation of environmental flows

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ABSTRACT

The lower Ebro River (Catalonia, Spain) has a fish community dominated by alien species in both richness (55%) and abundance (78%). This river stretch is regulated by many dams and its flow was severely reduced by increasing water uses. We found strong evidence that the success of establishment and dispersal of alien fish species in this Mediterranean large river is enhanced by flow reduction through decreased water flow velocity in the littoral zone. Results show that when water flow is below 0.40 m/s, the probability that a fish community is dominated by alien species is higher than 50%, according to a logistic regression model that achieved 91% of well classified cases when predicting alien species dominance over natives. This relationship was used to perform an ecologically-based validation (biological validation) of 12 environmental flows proposed by several authors using different hydrologically-based methods. An HEC-RAS model previously developed and validated by the Catalan Water Agency (ACA) was used to simulate water velocity in the littoral zone. Results show that most of the proposed environmental flows (i.e., 89, 100 and 122 m^3/s mean annual flow) favor a fish community structure dominated by alien species. The only biologically-validated environmental flows (227, 302 and 398 m^3/s for dry, medium and wet years, respectively) were those based on data from the Sacramento model and calculated with the RVA_{NGPRP} method.

1. Introduction

In Mediterranean regions, the aquatic ecosystems undergo strong natural fluctuations in its hydrological cycle, with a variability ranging from big floods to severe droughts (Caiola et al., 2001a,b; Ferreira et al., 2007a,b). To deal with this hydrological variability the main human response was the construction of reservoirs to regulate rivers. Reduced flood frequency and seasonal changes in the magnitude of discharge are the most common hydrological consequences of anthropogenic flow regulation (Maheshwari et al., 1995; Singer, 2007; Ibáñez et al., 2012a).

As a result of modified physical habitat, regulated rivers generally support altered composition, abundances and productivity of algae, macroinvertebrates, fish and other biota availability (Bunn and Arthington, 2002; Poff and Zimmerman, 2010). The lower Ebro River is a Mediterranean large river that has undergone an ecosystem shift due to oligotrophication and flow regime alteration (Ibáñez et al., 2012a,b) and is severely impacted by the presence of alien fish species (Maceda-Veiga et al., 2010). Alien fish are likely to successfully establish and invade under modified flow regimes, regardless of the recipient biota (e.g. Meffe, 1984; Strange et al., 1992; Lodge, 1993; Moyle and Light, 1996; Poff et al., 1997; Bunn and Arthington, 2002; Lytle and Poff, 2004; Propst and Gido, 2004; Olden et al., 2006; Kiernan et al., 2012; Gido et al., 2013). Among other impacts, alien fish negatively affects the native species at local scale (e.g. Fausch, 1988; Ross, 1991; Baltz and Moyle, 1993), and cause the decline of native populations or even local extinctions (Meffe, 1984; Moyle and Light, 1996; Caiola and Sostoa, 2002, 2005).

The recognition that the morphological, hydraulic and, by extension, biological parameters of surface waters intrinsically depend on river discharge, led to the development of the environmental flow concept. In places where there is contention between different water uses and flows are regulated, the environmental flow describes the amount of a river discharge required to sustain freshwater, estuarine and adjacent coastal ecosystems, as well as their services (Dyson et al., 2003). Therefore, the environmental flow requirements should be considered a water demand in the

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planning of allocation of scarce water resources, in a similar way as other demands that compete for the same water resource such as irrigation, public water supply, energy production, etc. (Meijer et al., 2012).

A widely used approach to evaluate the ecological impacts of changing flow regimes and, therefore, to biologically validate environmental flow proposals, is the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982). Its principle relies on the knowledge and basic description of the physical habitat requirements of stream biota and how the amount of suitable physical habitat changes with flow. The river littoral habitats (riparian zone and wetted area adjacent to the banks) play an important role in the ecological functioning of rivers, providing suitable habitat for fish (Cummins, 1993; Growns et al., 2003; Pander and Geist, 2010). In large rivers, this habitat becomes even more important due to its function of shelter (shade and coverage) (Pander and Geist, 2010) and feeding ground (Platts, 1983; Moring et al., 1985). Hydromorphological alterations that may occur in rivers' littoral zones have a direct impact on the fish community structure (Hawkins et al., 1983; Growns et al., 1998; Maridet et al., 1998; Lyons et al., 2000). Moreover, in large rivers, where fish community and habitat assessment have added technical difficulties, the littoral zones can be adequately sampled for hydromorphological characteristics (depth, water velocity, dominant substrate, aquatic vegetation coverage, quality and structure of riparian vegetation, etc.) and fish fauna (higher electrofishing efficiency than in the middle of the river channel).

The aim of the present study was to assess the effect of river littoral habitat descriptors that depend on flow dynamics (water velocity, depth and river bed structure) on the abundance of alien fish species versus native species in the lower Ebro River. Based on this, we aimed to develop a new approach to perform an ecologically-based validation (biological validation) of environmental flows. This new approach is applicable to other rivers with similar ecological problems and we expect that it can assist on the development and application of environmental flow programs.

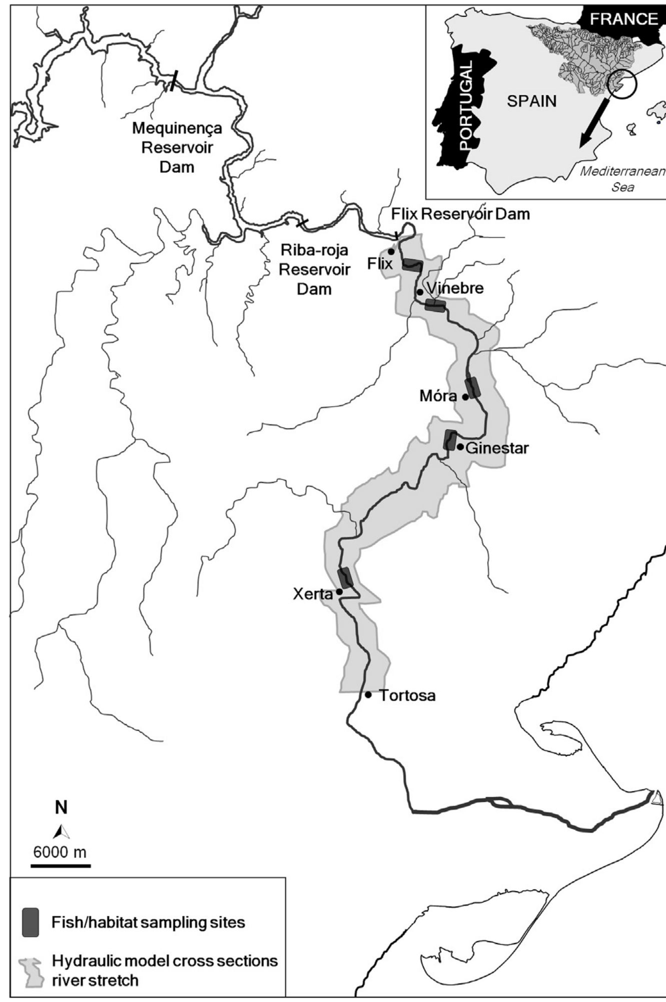

Fig. 1. Map showing the study area, the sampling sites for the fish/habitat sampling and the river stretch where the cross sections for the hydraulic model were performed.

2. Materials and methods

2.1. Study area

The study was conducted in the lower 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 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 agriculture with more than 10,000 km^2 of irrigation, corresponding 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 mean annual flow near the mouth (Tortosa) was 592 m^3/s at the beginning of the century. However, due to an increasing water usage, there is a continuous decreasing tendency since the 1970s (down to about 190 m^3/s in 2006) (Ebro Water Authority data). The lower Ebro hydrology, geomorphology and ecology are strongly impacted by the existence, features and operation of the reservoirs (Ibáñez et al., 2012a,b).

2.2. Habitat descriptors affecting the fish community

To sample the fish community from the lower Ebro River an electrofishing survey was performed in august 2006. Five sampling sites were randomly selected to perform the surveys in order to cover all the lower stretch morphological variability (Fig. 1). For this purpose we first analyzed aerial photographs in order to classify the lower Ebro River in four morphological types according to a simplified classification developed by Rosgen (1994). Four morphological river types were identified in the study area: steep stretches; moderately entrenched stretches; entrenched meanders; low gradient meanders. Then, a polyline GIS layer representing the lower Ebro River (Ebro Water Authority GIS layers available online) was classified according to these four morphological river types and transformed into a point type layer, with equidistant points (1 km). The points were randomly selected in order to ensure the coverage of the morphological variability, resulting in the aforementioned 5 sampling sites. As the river width in the study area varies between 150 m and 200 m, and CEN standards for fishing with electricity (CEN, 2003) advise that the sampling stretch length should be around ten times the river width, each sampling site consisted in a 2 km stretch. Each stretch was sampled in 10 equidistant points located in the littoral zone (left or right bank, selected randomly), resulting in a total of 50 sampling points. The catches of the 10 sampling points within each 2 km stretch, were analyzed for the cumulative number of species to Fig. out if ten points were an adequate sampling effort. In the five 2 km stretches, the effort curve stabilized between 8 and 9 points. Therefore, the 50 sampling points sufficiently represent the