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Effects of flow regime alteration on fluvial habitats and riparian quality in a semiarid Mediterranean basin

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ABSTRACT

The Segura River Basin is one of the most arid and regulated zones in the Mediterranean as well as Europe that includes four hydrologic river types, according to their natural flow regime: main stem rivers, stable streams, seasonal streams and temporary streams. The relationships between flow regime and fluvial and riparian habitats were studied at reference and hydrologically altered sites for each of the four types. Flow regime alteration was assessed using two procedures: (1) an indirect index, derived from variables associated with the main hydrologic pressures in the basin, and (2) reference and altered flow series analyses using the Indicators of Hydrologic Alteration (IHA) and the Indicators of Hydrologic Alteration in Rivers (IAHRIS). Habitats were characterized using the River Habitat Survey (RHS) and its derived Habitat Quality Assessment (HQA) score, whereas riparian condition was assessed using the Riparian Quality Index (RQI) and an inventory of riparian native/exotic species. Flow stability and magnitude were identified as the main hydrologic drivers of the stream habitats in the Segura Basin. Hydrologic alterations were similar to those described in other Mediterranean arid and semiarid areas where dams have reduced flow magnitude and variability and produced the inversion of seasonal patterns. Additionally, the Segura Basin presented two general trends: an increase in flow torrentiality in main stems and an increase in temporality in seasonal and temporary streams. With the indirect alteration index, main stems presented the highest degree of hydrologic alteration, which resulted in larger channel dimensions and less macrophytes and mesohabitats. However, according to the hydrologic analyses, the seasonal streams presented the greatest alteration, which was supported by the numerous changes in habitat features. These changes were associated with a larger proportion of uniform banktop vegetation as well as reduced riparian native plant richness and mesohabitat density. Both stream types presented consequent reductions in habitat and riparian quality as the degree of alteration increased. However, stable streams, those least impacted in the basin, and temporary streams, which are subject to great hydrologic stress in reference conditions, showed fewer changes in physical habitat due to hydrologic alteration. This study clarifies the relationships between hydrologic regime and physical habitat in Mediterranean basins. The hydrologic and habitat indicators that respond to human pressures and the thresholds that imply relevant changes in habitat and riparian quality presented here will play a fundamental role in the use of holistic frameworks when developing environmental flows on a regional scale.

1. Introduction

Flow regime is a major determinant of physical habitat in streams and rivers (Bunn and Arthington, 2002), and its alteration by human activities has caused serious degradation in aquatic and riparian ecosystems (Nilsson and Berggren, 2000; Richter et al., 2003). Hydrologic alteration influences habitat components such as wetted area (Froend and Van Der Moezel, 1994; Humphries et al., 1996); bars, benches and islands (Ligon et al., 1995); pools (Erskine et al., 1999); organic matter (Gawne et al., 2000); woody debris (Humphries et al., 1996); substrate composition (Sherrard and Erskine, 1991); and sediment transport, a co-determinant of physical habitat in river systems (Lloyd et al., 2003). The effects of hydrologic alteration on communities are driven by these changes (among others), given the fundamental role that physical habitat characteristics play in their structure and composition (Bunn and Arthington, 2002).

Most existing global literature focuses on the effects found downstream from dams, as they can explain up to 91% of total changes in flow and bed mobility parameters (Burke et al., 2009).

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However, the wide variety of effects does not allow a general quantitative relationship between flow alteration and ecological response to be developed (Poff and Zimmerman, 2010). In general, dams and their associated reservoirs impact freshwater diversity (McAllister et al., 2001) as a result of sharp decreases in riparian biodiversity downstream (Johnson et al., 1976; Ligon et al., 1995; Petts, 1980). The impact of flow modification on vegetation varies depending upon the taxonomic group considered (Bunn and Arthington, 2002), because aquatic, littoral, riparian and floodplain plants differ in flood tolerance and dependence (Blanch et al., 1999). However, despite the importance of physical habitats for communities in fluvial ecosystems (Power et al., 1988), where their characteristics can change more easily and quickly than in other ecosystems, studies on ecologically significant habitat features associated with river morphology and flow regime are scarce. Such studies are essential, as these changes are key to understanding the long-term ecological consequences of dams and other disturbances (Ligon et al., 1995).

In this context, developing flow alteration–ecological response relationships that reflect the direct and indirect influences of hydrologic alteration on both ecological processes and ecosystems by river type constitutes the basis of a holistic methodology for the assessment of environmental flows at regional scales, the "Ecological Limits of Hydrological Alteration" (ELOHA; Arthington et al., 2006; Poff et al., 2010). Due to the combination of increasingly high demands for water (e.g. Lorenzo-Lacruz et al., 2010) and its scarcity, studying these relationships is essential for ecologically based water management in Mediterranean areas. Human pressures in these areas have resulted in flow regulation through dams and reservoirs, water abstraction, diversion channels and inter-basin water transfers (e.g. the Tagus-Segura Transfer in SE Spain). Such infrastructures, especially those associated with agricultural demands, lead to significant modifications in flow regimes (see Belmar et al., 2010). In most rivers of the southern Iberian Peninsula, dam management to meet summer water demands has produced important changes in flow magnitude, variability and seasonality throughout the 1945–2005 period (Lorenzo-Lacruz et al., 2012). Such changes could increase globally in the coming decades, as future climate projections forecast a generalized decrease in precipitation and increased evapotranspiration in the Iberian Peninsula (Rodriguez-Puebla and Nieto, 2010) and Mediterranean areas (IPCC, 2007).

Therefore, it is essential to improve existing knowledge regarding the relationship between hydrologic alteration and ecological response, both for organisms and the physical habitat in which they live, in Mediterranean areas in general and in the most arid ones in particular. Some foundations have already been laid in Iberian Mediterranean basins. Batalla et al. (2004) defined and quantified hydrologic alteration in the Ebro River (NE Spain), where dams reduced variability in mean daily flows and caused an inversion in the monthly seasonal patterns (with reduced fall and winter peaks and summer releases for irrigation that increase baseflows). Magdaleno and Fernández (2011) studied the effect of high and low flow alterations on riparian forests and channel morphology by dams in a segment of the Ebro River. Boix et al. (2010) determined the effects of water abstraction on stream communities in some Catalonian rivers (NE Spain). Navarro-Llácer et al. (2010) revealed degradation in the ecological condition of reaches downstream from reservoirs in the Segura and Mundo rivers (SE Spain) using macroinvertebrate, fish and riparian quality indices. Garófano-Gómez et al. (2012) documented the stages of hydrologic alteration in the Júcar Basin (SE Spain) and analyzed changes in the riparian habitats. However, no author has delved into the diversity of hydrologic types present, which can be subject to different management strategies and, therefore, flow regime alterations. In this sense, no study undertaken in any Mediterranean area has characterized hydrologic alteration or defined relationships between flow alteration and physical habitat for different hydrologic types at basin scale.

The aims of this study were to: (1) characterize and quantify the main hydrologic alterations in the different river types of a semiarid Mediterranean basin (Segura River), using an indirect index and two sets of hydrologic indicators, and (2) determine the effects of flow regime alteration on fluvial habitats and riparian conditions for each type. The Segura River Basin is highly suitable for this purpose, as it presents a wide range of natural flow regimes (Belmar et al., 2011) and is also one of the most regulated basins in Europe (Ministerio de Medio Ambiente, 2004), with water demands exceeding 224% of that available and only 4% of runoff reaching the river mouth (Zimmer, 2010).

Hydrologic alteration was expected to present different patterns and effects for each river type. It was hypothesized that main stems would present the greatest hydrologic alteration due to increasing water demands and dams along their longitudinal axis, and in particular, an inversion in their seasonal pattern and a reduction in their inter- and intra-annual flow variability, as has been observed in other Mediterranean basins. However, tributaries were expected to present specific alterations associated with their individual management, dependent on natural flow regimes and land use configurations. In particular, streams with seasonal flow variations or even temporary regimes located in mid- and lowlands with large crop areas and flood control dams were expected to show a significant reduction both in flow magnitude and variability, as well as the greatest alteration in floods and droughts.

Such hydrologic alterations were anticipated to cause an overall reduction in fluvial habitat and riparian quality, although distinct effects were also expected in each river type. It was hypothesized that discharging large volumes of water from dams into main stems to address irrigation demands could produce increased channel dimensions, the homogenization of aquatic habitats, predominant turbulent flows and coarse substrates, lessen the diversity of aquatic and native riparian vegetation and increase alien species. At the opposite extreme, flow regulation by dams in more seasonal or even temporary streams should exacerbate droughts and cause a reduction of aquatic habitats and the invasion of riparian vegetation in channels.

2. Methods

2.1. Study area

The management area of the Segura River Basin, one of the most arid zones in the Iberian Mediterranean Region, presents four broad flow regime types (Belmar et al., 2011): main stem rivers, with an average annual discharge greater than 2 m^3/s; stable streams, which never cease flowing and have low seasonal flow variation; seasonal streams, which have a marked seasonal variation and eventually cease flowing (although perennial surface water persists); and temporary streams, without any flow more than 20% of the time. These river types were defined through a hydrologic classification developed using modeled natural flows and 73 indices that comprise monthly and annual measurements of flow magnitude central tendency and dispersion, as well as measurements of drought and flood duration. Moreover, they have biological significance, as they present distinct macroinvertebrate communities (Belmar et al., 2012).

Despite the relatively small size of the basin (18,870 km^2), the coexistence of these four flow regimes is explained by a strong climatic and altitudinal gradient from NW to SE. Climate ranges from wet (>1000 mm mean annual precipitation) and cold in the NW mountains (>1000 m a.s.l.) to semiarid and hot in the SE lowlands