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Geomorphic status of regulated rivers in the Iberian Peninsula

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HIGHLIGHTS

- Hydrogeomorphic alterations of 74 river sites in four large basins are analysed.
- An index to assess the channel's Geomorphic Status (GS) has been developed.
- Flow regulation causes a reduction of the flow competence and loss of river's dynamism.
- Formerly active bars disappear as they are encroached by vegetation.
- Channel stabilization limits river's activity and degrades the fluvial ecosystem.

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ABSTRACT

River regulation by dams modifies flow regimes, interrupts the transfer of sediment through channel networks, and alters downstream bed dynamics, altogether affecting channel form and processes. So far, most studies on the geomorphic impacts of dams are restricted to single rivers, or even single river stretches. In this paper we analyse the geomorphic status of 74 river sites distributed across four large basins in the Iberian Peninsula (i.e. 47 sites located downstream of dams). For this purpose, we combine field data with hydrological data available from water agencies, and analyse historical (1970) and current aerial photographs. In particular, we have developed a Geomorphic Status (GS) index that allows us to assess the physical structure of a given channel reach and its change through time. The GS encompasses a determination of changes in sedimentary units, sediment availability, bar stability and channel flow capacity. Sites are statistically grouped in four clusters based on contrasted physical and climate characteristics. Results emphasise that regulation changes river's flow regime with a generalized reduction of the magnitude and frequency of floods (thus flow competence). This, in addition to the decrease downstream sediment supply, results in the loss of active bars as they are encroached by vegetation, to the point that only reaches with little or no regulation maintain exposed sedimentary deposits. The GS of regulated river reaches is negatively correlated with magnitude of the impoundment (regulation). Heavily impacted reaches present channel stabilization and, in contrast to the hydrological response, the distance and number of tributaries do not reverse the geomorphic impact of the dams. Stabilization limits river dynamics and may contribute to the environmental degradation of the fluvial ecosystem. Overall, results describe the degree of geomorphological alteration experienced by representative Iberian rivers mostly because of regulation, challenging the successful long-term implementation of river basin management programmes.

1. Introduction

The form of an alluvial channel results from the interaction between water flow, sediment flux and basin landscape features, and it may change over time as a result of the continuous interplay between natural and human factors (e.g. Church, 2002; Rinaldi et al., 2013). Although channel forms such as gravel bars may appear stable, the grains of which it is composed are replaced regularly (i.e. annual flood) by new sediment from upstream. These fluvial processes are maintained in *quasi*-equilibrium through a spatial and temporal dynamic balance between water and sediment transport that

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promotes the creation and maintenance of habitats, and ensures ecosystems' integrity (Petts, 2000).

Rivers in Mediterranean regions are particularly affected by human impacts which modify hydrology, sediment fluxes, and channel forms at different scales. Dams stand out among these impacts, as they alter flow regimes, interrupt the sediment transfer, and subsequently change downstream erosion and deposition patterns (e.g. Brandt, 2000; Vericat and Batalla, 2006). Overall, the impacts of dams in dryland rivers tend to be more pronounced than those in more humid regions, since channel form and river ecology are adapted to highly variable flows (Gasith and Resh, 1999; Batalla et al., 2004). Following impoundment, the river undergoes a complex adjustment in channel shape that involves changes in width, depth, bed level, slope, bed material (i.e. grain size), bedforms and planform configuration (Brandt, 2000). As geomorphology is fundamental for river's ecosystem functioning, adjustments in physical habitat typically bring important effects for both the biota and ecosystem processes (Elosegi et al., 2010). Responses vary according to channel substrate and shape, flow regime, valley gradient, and the geophysical history (Merritt and Cooper, 2000). In particular, dams reduce high flows (hence flow competence and the associated physical disturbance), and often increase base flows (Batalla et al., 2004); altogether making these fragile environments more suitable for exotic species not adapted to marked hydrological cycles (Kondolf, 1997).

Owing to the highly variable and complex responses of river systems, most studies have been undertaken to simply examine the dam impact on a specific fluvial site (e.g. Surian, 1999; Gilvear, 2004; Vericat et al., 2006; Wyzga et al., 2012), whereas few studies cover broader spatial and temporal scales (e.g. Graf, 2006; Fitzhugh and Vogel, 2011; Batalla and Vericat, 2011). In parallel, indices have been developed to evaluate the physical river quality, mostly for restoration purposes (e.g. Raven et al., 1997; LAWA, 2000; Ollero et al., 2008; Rinaldi et al., 2013), all of them involving field work, and nearly all ignoring the temporal evolution of river channels. Nowadays, the high availability of data (e.g. hydrological data and aerial images) and the technologies for their analysis (i.e. GIS) provide new opportunities to make a more detailed analysis of the geomorphological changes over time, and also allow examining the current channel state in relation to pre-dam conditions (i.e. taken as reference conditions for the comparative analysis in this paper).

The main objective of this paper is to examine the effects of the dams on the channel geomorphology of 74 selected river reaches in the Iberian Peninsula. To accomplish this objective we present a methodology that integrates flow series and climate data, catchment scale information (i.e. GIS layers) and digital elevation models, ancient and contemporary aerial imagery, and field data. The study sites are first statistically classified (clustered) based on their climatic and hydrological characteristics (i.e. multivariate analysis). Subsequently, changes on the hydrological and flood regimes in each cluster are analysed with special emphasis to those reaches downstream from dams. The geomorphic status of study reaches is assessed by means of a novel Geomorphic Status (hereafter GS) index that is presented to evaluate channel's geomorphic activity; results are finally coupled and interpreted at the light of the hydrological changes, together with a discussion on the factors that most influence river channel activity.

2. Study sites

We analyse a selection of river sites in four contrasting basins in the Iberian Peninsula (Fig. 1): Ebro (85,530 km^2), Llobregat (4923 km^2), Júcar (21,632 km^2) and Guadalquivir (57,527 km^2). Catchments are mostly located in the Mediterranean region, altogether encompassing an extensive latitudinal, thermal, rainfall and hydrological gradient.

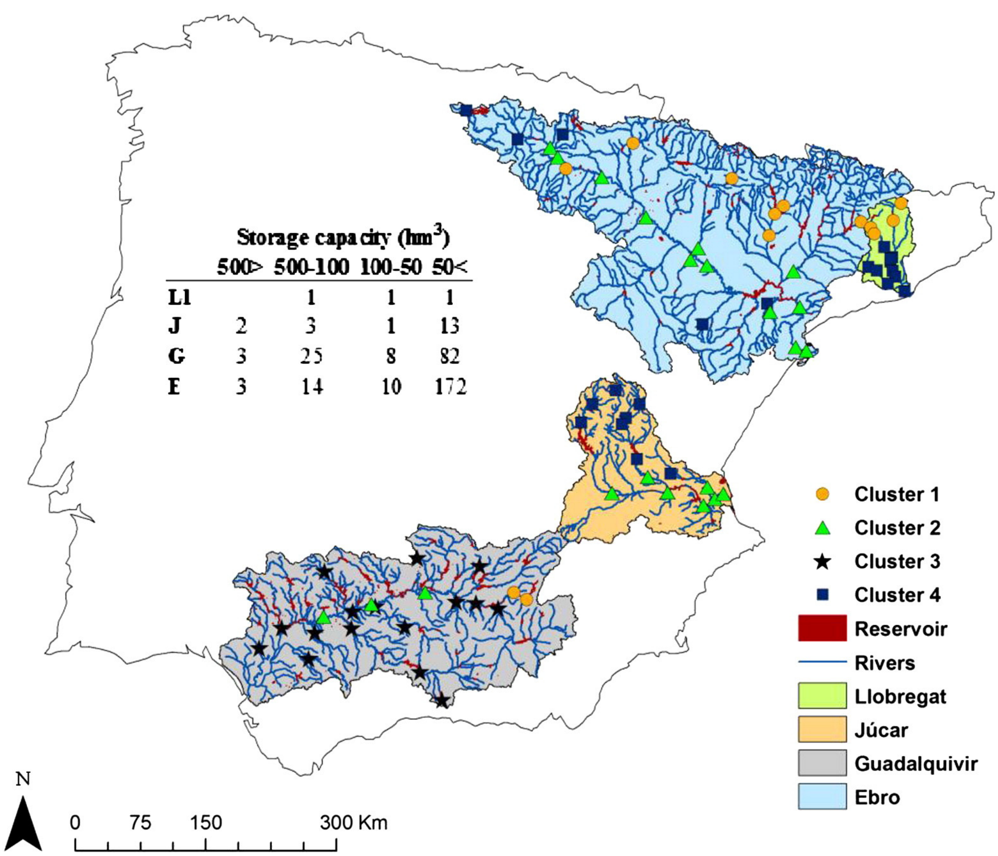

Fig. 1. The Iberian Peninsula with location of the study sites and reservoirs in each basin. The inset represents the number of reservoirs and their storage capacity for each of the basins. Sites are represented by symbols that indicate the physiographic and climatic cluster to which they belong (see Methods section for further information on clustering analysis).