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Assessment of the Physical Habitat Suitability (PHS) for three autochthonous fish species in the Duero River (Spain) with the modelling tool IberHABITAT

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Abstract

The module IberHABITAT, developed for the 2D hydraulic model Iber, is based on the combination of both hydraulic and hydrobiological variables to create a habitat or eco-hydraulic model. This module allows to obtain classified areas of Physical Habitat Suitability (PHS) in the form of a Combined suitability index (C index: 0.0-1.0) for targeted fish species in relation to a specific discharge. This particular approach has been applied in a 17.2 km-long pilot section of the Duero River between Toro and Zamora (Spain) within the DRAINAGE project for the integral management of flood risk. For the present study, the IberHABITAT modelling tool was run to obtain the SPH areas for three autochthonous fish species under four discharges: mean and minimum annual flow, and two ecological flows (ordinary conditions and drought conditions). The selection of the targeted fish species (*Luciobarbus bocagei*, *Pseudochondrostoma duriensis* and *Squalius carolitertii*), was based on previous surveys by the Duero River Basin Authority. A bathymetric survey was specifically obtained for this study, since the study area is characterized by complex geomorphology (bars, islands, pools, etc.). Results on the C index were then classified into four categories and areas corresponding to the maximum category (4-Excellent conditions) were calculated. It is noteworthy that, under very low flow conditions, the most suitable areas for the adult and juvenile stages of *B. bocagei* are almost non-existent. At present, the recurrence of periods of minimum flows, as well as their duration, may be limiting the diversity of fish communities in the study section.

Keywords: combined suitability index, Duero River; 2D eco-hydraulic modelling, IberHABITAT, physical habitat suitability

1. INTRODUCTION

Ecohydraulic models based on physical habitat suitability (PHS) are used to simulate and determine which habitats in an ecosystem are best suited for the life stages of one or more species (Yao et al., 2018). They are based on “habitat suitability curves”, which represent the functional relationship between a physical habitat variable (hydraulic, geomorphological, physical-chemical) and the degree of suitability of the aquatic fauna to the variability in these parameters (Conallin *et al.*, 2010; Sanz-Ramos *et al.*, 2016). More specifically, physical habitat models based on 2D models such as IberHABITAT, are those that most accurately represent the complex mosaics of distributions of hydraulic variables, such as water depths and flow velocities (Sanz-Ramos *et al.*, 2019). Currently, the habitat or eco-hydraulic model is becoming an increasingly relevant tool in river ecology to assess impacts on rivers (Boavida *et al.*, 2020) and to predict the effects of river restoration actions, especially in the context of achieving the good ecological status of water bodies established by the Water Framework Directive 2000/60/EC (Habersack *et al.*, 2014).

For the present study, the IberHABITAT module of the Iber 2D hydraulic model (Bladé *et al.*, 2014) has been used to obtain the PHS areas of three species of native fish under four different discharges in a pilot section of the Duero River upstream Zamora (Spain). This work is framed within the DRAINAGE project for the integral management of flood risk (http://drainage.cedex.es/), a multidisciplinary project whose main goal is to improve the resilience of urban and peri-urban areas to flooding. The eco-hydraulic perspective presented here is necessary for the characterisation of the study area as baseline for the proposal of nature-based solutions, seeking to balance the objectives of nature conservation with the prevention of flood damage.

The objective of this work is to determine the suitability of physical habitat as a basis for the design of green infrastructure and the establishment of the ecological flow regime in the third planning cycle. The specific objectives of the study are:

i. obtaining the spatial distribution of the SPH of different life stages of targeted fish species in relation to selected flows, and calculating the areas of highest suitability in the study site for the species and stages considered; and
ii. discussing the applicability of the results to river management, especially in the case of the minimum flows, and to restoration measures.

2. METHODS

2.1 Study site

The catchment area of Duero River basin is the largest of the Iberian Peninsula, and over 80 % corresponds to Spanish territory. The Duero River is also the highest-flow river of the Iberian Peninsula, it flows predominantly west through the north-west part of central Spain and into northern Portugal, to its mouth at the Porto estuary, in the Atlantic Ocean. The climate is Mediterranean, with remarkable continental influence. Its flow regime is predominantly pluvial, with low water levels in summer, and high-water levels during winter and spring that, occasionally, may result in catastrophic floods.

The study site is a 17.2 km long section of the Duero River, located upstream from the N-630 highway bridge in Zamora City, in Northwest Spain (Figure 1). This Duero River section is characterized by a meandering planform (sinuosity index of 1.5) within a wide floodplain, the predominant flow direction is East-West. The average altitude is 628 m a.s.l., the mean annual discharge is 98.8 m³/s (MITERD, 2021). The study area partly includes the European Natura 2000 Special Area of Conservation (SAC) "Riberas del río Duero y afluentes" (Site code: ES4170083). The study section is composed of two water bodies: the water body 396 -"Rio Duero desde confluencia con arroyo Reguera hasta confluencia con arroyo de Algodre", which is classified as natural, and the water body 397-"Rio Duero desde confluencia con el arroyo de Algodre hasta confluencia con arroyo de Valderrey en Zamora", which has been declared highly modified since 2013 due to morphological alteration in longitudinal continuity (MITECO, 2016). The gauging station 02121 "Río Duero in Zamora" is located 1.1 km from the end of the study section, and hydrological data recorded in this station since 2002 (MITERD, 2021) have been used in this study for the selection of simulated discharges and for the calibration and validation of results.

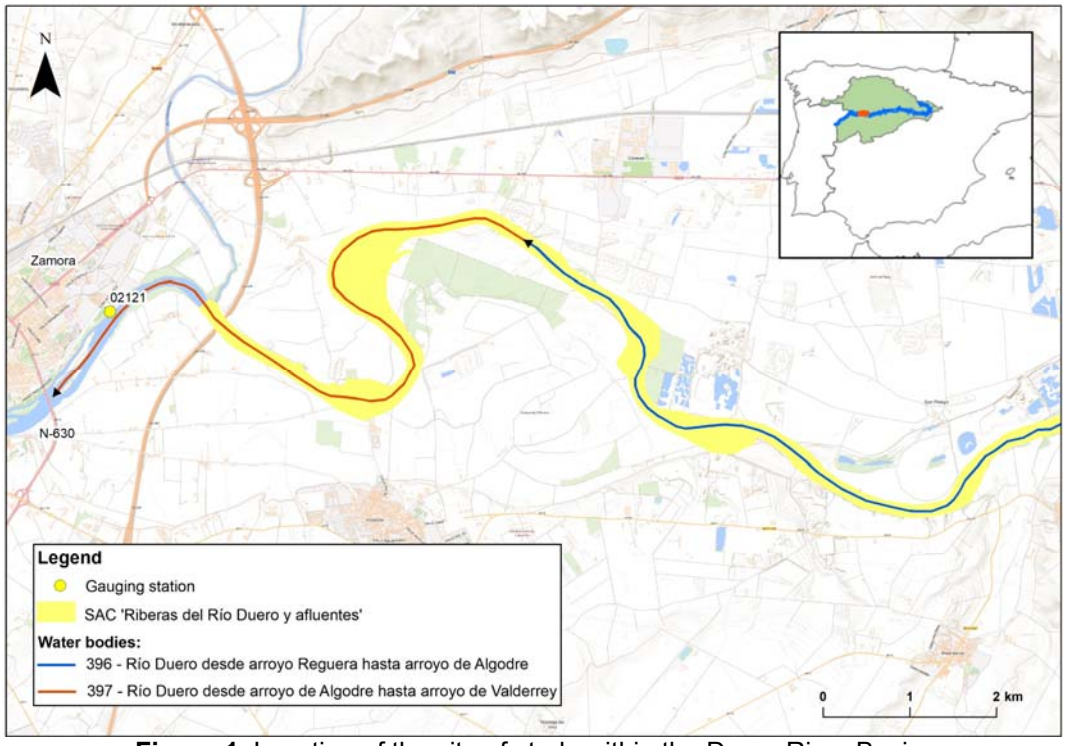

Figure 1. Location of the site of study within the Duero River Basin.

2.2 Materials

For the present study, a bathymetric survey was specifically obtained (DRAINAGE, 2020), since the study area is characterized by complex geomorphology (bars, islands, pools, backwater areas, etc.). This bathymetric survey was integrated with the Digital Terrain Model (DTM) of the National Geographic Institute (CNIG, 2021) in a single DTM of 5 m resolution, which was georeferenced in the UTM ETRS89 Zone 30 coordinate system. The studied area consisted of the active channel area (195.6 ha) of the 17.2 km long of the Duero River, as well as an area 100 m wide on both banks, resulting in a total area of 645.2 ha. This additional area is necessary for calibrating and validating the results of the eco-hydraulic model.

For the selection of discharges to be simulated (Table 1), hydrological data recorded in the 02121 gauging station in Zamora were retrieved from the Spanish Yearbook of Gauging Stations (MITERD, 2021). The selected discharges included the annual mean flow (Qmean_annual), the annual minimum flow (Qmin_annual), and similar to the study by Sanz-Ramos *et al.* (2016), two minimum flows included in the Duero River Management Plan 2015-2021 (MITECO, 2016): the minimum environmental flow under ordinary conditions (Qenv_ord), and under prolonged drought conditions (Qenv_dro).

Table 1. Selection of discharges.

Selected discharges	Description	Value (m^3/s)
Qmean_annual	Annual mean flow	98,16
Qmin_annual	Annual mean flow	37,17
Qenv_ord	Minimum e-flow under ordinary conditions	16,00
Qenv_dro	Minimum e-flow under prolonged drought conditions	8,00

Two surveys carried out in 2011 by the Duero River Basin Authority indicated the fish species present in the study area, with a noteworthy predominance of exotic species over autochthonous. The Iberian barbel (*Luciobarbus bocagei*) was detected in water bodies 397 and 395 (located upstream of the study area), and also in the latter: the Iberian straight-mouth nase (*Pseudochondrostoma duriense*), and the Iberian chub (*Squalius carolitertii*). The availability of habitat sustainability curves for those autochthonous fish species in the Duero River Management Plan (CHD, 2015) determined the following selection of life stages: Iberian barbel (fry, juvenile and adult), Iberian chub (fry and adult) and Iberian straight-mouth nase (fry).

2.3 Data analysis

The implementation of the eco-hydraulic model IberHABITAT encompassed the pre-processing and the post-processing phases. In the pre-processing phase, the inputs were the topography, the customized suitability curves and the hydraulic boundary conditions. The IberHABITAT module already included the pre-established suitability curves for all life stages of the Iberian barbel; however, the suitability curves of water depths and flow velocities for the Iberian chub and the Iberian straight-mouth nase had to be manually entered. A structured mesh composed of 211,677 elements was generated that allowed for the best optimisation of calculating times. The model was calibrated adjusting the channel roughness, i.e., Manning's coefficient, and validated with the recorded data from the Zamora gauging station. Differences between recorded and simulated water levels were below seven centimetres, which indicated that the simulated results greatly agreed with the observed data.

As a result of the post-processing, 24 raster maps were obtained with areas that indicate the Physical Habitat Suitability (PHS) for the species and life stages in relation to the simulated discharges. The PHS is expressed as a Combined suitability index (C index) for each cell, with values ranging between zero and one: those values close to one indicate a high degree of suitability or adequacy and, on the contrary, a low degree of suitability is associated to values close to zero. Results on the C index were then reclassified according to four categories (Table 2).

Table 2. Categories of the C index. Source: Sanz-Ramos *et al.* (2016).

C index values	Category	Description
0.0 – 0.3	1	Poor conditions
0.3 – 0.5	2	Fair conditions
0.5 – 0.8	3	Good conditions
0.8 – 1.0	4	Excellent conditions

Areas corresponding to the category 4 - Excellent conditions were calculated with ArcGIS tools, and then divided by the total available area in order to obtain the percentage of area with the highest suitability. The ultimate objective of this analysis was examining which discharges determined the highest suitability for the species and life stages considered.

3. RESULTS

Figure 2 shows, for each simulated discharge, the percentage (%) of available area that corresponds to C index values in the category 4 - Excellent conditions. For a better analysis of the influence of the reduction of discharges, these are displayed, from left to right, from the highest to the lowest discharge value.

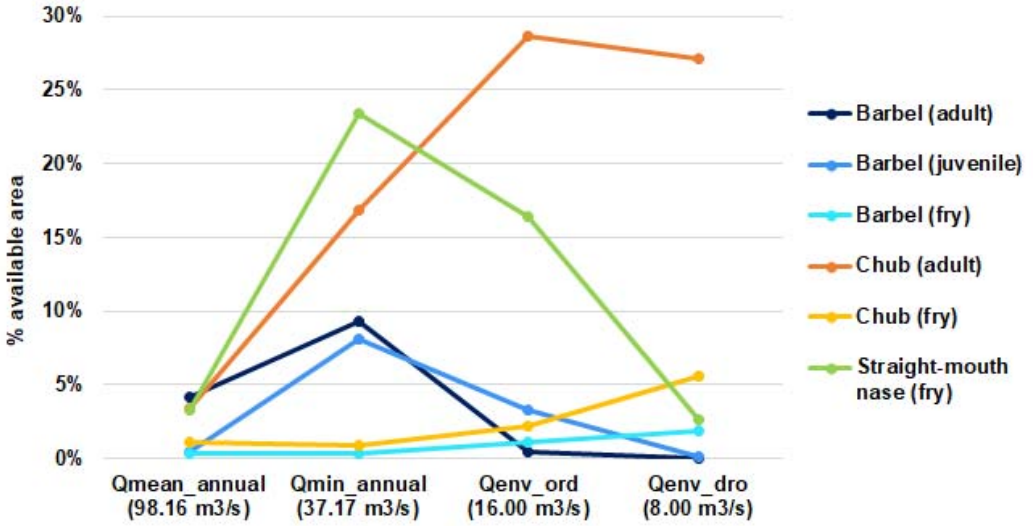

Figure 2. Area percentage (%) of excellent suitability conditions (C index: 0.8 – 1) for all fish stages considered in relation with the simulated discharges.

These results showed that the largest areas with excellent conditions for the adult and juvenile Iberian barbel, and for the Iberian straight-mouth nase (fry) occurred with the minimum annual flow (Qmin_annual). It is also significant that for the fry life stage of both the Iberian barbel and the Iberian chub, the area percentages had an increasing tendency inversely to the decrease in the values of the simulated discharges, with the largest percentages corresponding to the minimum environmental flow under prolonged drought conditions (Qenv_dro). However, for the adult barbel, the opposite trend was detected, with decreasing percentages as the values of the simulated discharges decreased, reaching a null value with the minimum environmental flow under prolonged drought conditions (Qenv_dro). On the other hand, the adult Iberian chub presented the largest percentages with the minimum environmental flow under ordinary conditions (Qenv_ord), and under prolonged drought conditions (Qenv_dro), with percentages higher than 25% of the total available area.

4. CONCLUSIONS

In the present study, the IberHABITAT eco-hydraulic model has been applied to a Duero River section, resulting in the spatial distributions of the C index areas of a series of native fish species and the relationships between the physical habitat and selected flows have been obtained. The following conclusions from the study can be drawn:

- Results indicate that certain flows are necessary according to the life stage of each fish, so it would have to be verified that these flows occur in the corresponding reproductive periods of each species. For example, the minimum environmental flow under prolonged drought conditions determine null areas of highest suitability for the adult Iberian barbel, which implies that these flows would very negatively affect the species if they occur in the reproductive period (between February and June).
- It can also be concluded that, due to the effects of climate change, the recurrence of periods of minimum flows is expected to increase, particularly in the dry season, and for more prolonged durations, which in turn will greatly limit the diversity and distribution of the native fish communities on the study area in the future.
- Regarding the applicability of this study, it should be noted that this initial analysis of the suitability of the physical habitat for fish species is of particular interest when evaluating possible river management and restoration measures. In particular, since it is a reproducible eco-hydraulic model, new boundary conditions can be introduced for simulations related to changes in management measures, such as increases in environmental flows, or for simulations related to more intense droughts and reduced circulating flows associated with climate change projections. Finally, the comparison allows simulations to be carried out that include modifications of the DTM related to nature-based solutions (for example, the reconnection of abandoned meanders), so that changes in the suitability of the fish habitat associated with these measures could be verified.

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