

NEW TOOLS TO ASSESS THE SUITABILITY OF PHYSICAL HABITAT (SPH) AND THE WEIGHTED USABLE AREA (WUA) FOR FISHES

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ABSTRACT

The assessment of the Suitability of Physical Habitat (SPH) and the Weighted Usable Area (WUA) for fishes has been traditionally performed by means of simple habitat models based on experimental campaigns. In parallel with the improvements of the computer capabilities, some eco-hydraulic numerical models have been developed for the detailed analysis of river hydrodynamics. Recently, specific modules for habitat simulation have been introduced in several 2D hydraulic models. This work presents a new modelling tool to assess fish suitability based on the hydraulic model Iber. The model has been developed to work in a coupled way with the other modules, using the same easy workflow of Iber. The model includes enhances as tools for the geometry / mesh built-up process (LIDAR points cloud), the possibility to choose several fish species from a database or defiend by the user, the possibility to calculate different steady flows in the same simulation and a specific postprocess tools to represent the WUA as a function of discharge.

1. INTRODUCTION

The Water Framework Directive, WFD [1], introduced a challenge for EU countries regarding the ecological and environmental management. This new framework pushed the member states to legislate to improve the ecological state of water bodies, both continental and coastal [2].

The characterization and quantification of physical habitat is a wide used tool for the environmental management of aquatic ecosystems. A commonly used methodology for the assessment of physical habitat for fishes is the Instream Flow Incremental Methodology, IFIM [3], which combines hydraulic and biological models to create a habitat model. On one hand, biological models are usually defined by means of relationships between physical, chemical, hydraulic aspects and the suitability of the fish towards these. On the other hand, hydraulic models provide the hydraulic micro- and macro-habitat conditions, being the water depth and velocity the main variables resulting from the simulations.

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The high cost of field campaigns, in general, and the difficulties for data collection in rivers, in particular, has pushed the development of new tools for eco-hydraulic modelling. The integration of biological models into tools for numerical simulation of river hydraulics has been a common trend in recent years. Currently, models like RHYHABSIM [4], in 1D, and River2D [5], in 2D, both integrated into a numerical habitat model [6], are widely used for the characterization and quantification of the Suitability of Physical Habitat (SPH) and the Weighted Usable Area (WUA) for fishes. However, the process of building-up the model and the numerical techniques used by these tools makes them quite complex to use and with limitations under complex flows and irregular geometries [6–9].

In the present work, the 2D-numerical hydraulic model Iber [10] is presented as a numerical habitat model. The biological model has been integrated into Iber allowing to calculate the SPH and WUA for fishes. This new module is integrated in a unique user-friendly interface [11]. In addition, some enhances have been implemented that facilitate the built-up process and the results analysis. Some are the construction of model geometries and mesh from a cloud of LIDAR points, the possibility to choose several suitability curves for various fish species, or feed user's defined database of curves, the possibility to calculate different steady flows in the same simulation, and a specific tool to obtain the relation between discharge and WUA.

2. NUMERICAL MODEL

Iber is a two-dimensional hydraulic model based on Finite Volume Method, FVM [12,13]. It solves 2D Saint Venant equations (2D-SWE) using 1st order Roe or 2nd order Minmod schemes [14]. The equations 2D-SWE (Equations 1, 2 and 3) are solved with an unstructured finite volume solver explicit in time.

$$\frac{\delta h}{\delta t} + \frac{\delta q_x}{\delta x} + \frac{\delta q_y}{\delta y} = 0 \quad (1)$$

$$\frac{\delta q_x}{\delta t} + \frac{\delta}{\delta x} \left(\frac{q_x^2}{h} + g \frac{h^2}{2} \right) + \frac{\delta}{\delta y} \left(\frac{q_x q_y}{h} \right) = -gh \frac{\delta z_b}{\delta x} - \frac{\tau_{b,x}}{\rho} - \frac{\delta}{\delta x} (h \overline{u'_x u'_x}) - \frac{\delta}{\delta y} (h \overline{u'_x u'_y}) \quad (2)$$

$$\frac{\delta q_x}{\delta t} + \frac{\delta}{\delta y} \left(\frac{q_y^2}{h} + g \frac{h^2}{2} \right) + \frac{\delta}{\delta x} \left(\frac{q_x q_y}{h} \right) = -gh \frac{\delta z_b}{\delta y} - \frac{\tau_{b,y}}{\rho} - \frac{\delta}{\delta y} (h \overline{u'_y u'_y}) - \frac{\delta}{\delta x} (h \overline{u'_x u'_y}) \quad (3)$$

were h is the water depth, q_x and q_y are the X- and Y-direction fluxes, g is the gravity acceleration, ρ is the water density, z_b is the bottom elevation, τ_b is the friction caused by the bottom and u_i' are the turbulent stress forces. A detailed explanation about the model can be found in [10].

2. IBER AS A HABITAT MODEL

The Iber model is integrated into the pre- and post-process interface GiD [11], which provides an easy workflow. To create a project, at least three main steps are needed: pre-process (e.g. mesh importation/creation from DTM file and implementation of hydraulic conditions); calculation options and process (modules activation and configuration); and post-process (results visualization, analysis and exportation). The main contribution of the fish module is remains in the possibility to choose one or more types of fish from a database before

calculating (interface improvements). This new module is prepared to be integrated with other Iber modules (Figure 1).

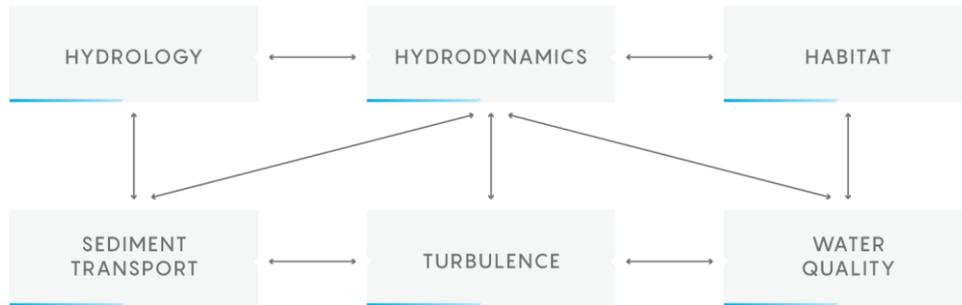


Figure 1: Modules implemented in Iber.

2.2 Pre-process tools

Apart from the geometry and mesh creation enhanced tools, the main new capabilities in the pre-process in relation with habitat simulation are.

A new boundary condition called “Stepped discharge” (Figure 2a). This tool consists in a list of discharges that are used to perform a simulation. The discharge remains constant until the steady flow is achieved, controlling the point where steady flow occurs by means of a tolerance (difference between inlet and outlet discharges). The “Stepped discharge” tool allows analysing, in the same model, several steady flows reducing the computational time (the next discharge starts with the hydrodynamic conditions calculated with the previous one) and the built-up and analysing time.

A biological model based on suitability curves of several fishes and their stadiums. This module was implemented in the code. Apart from choosing from variety of existing species, the user has the possibility to introduce its own suitability curves (Figure 2b). The current version includes suitability curves for velocity, depth and. The substrate is associated to a land use or soil type, as is done with the bottom roughness. Thus can be spatially distributed and loaded into the model from a land use or soil type georeferenced database (Figure 2d).

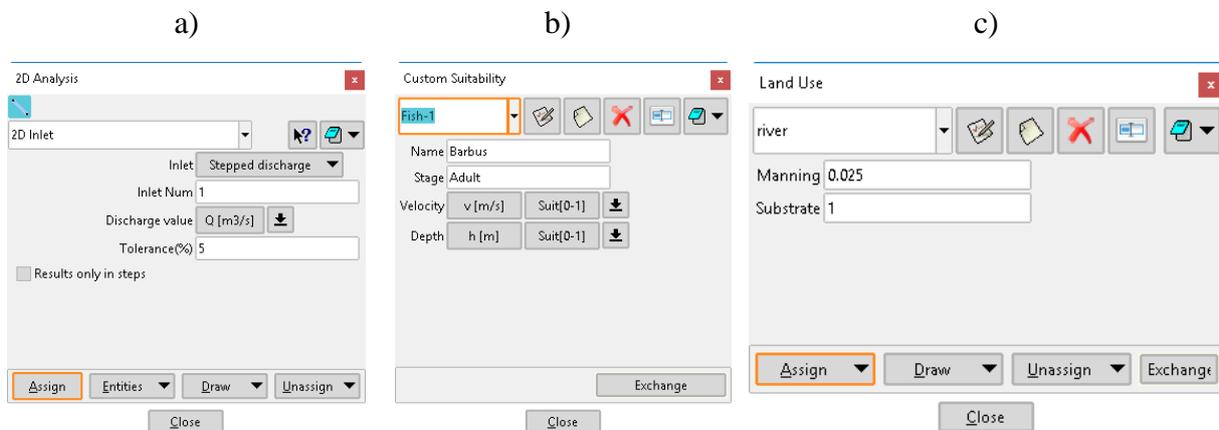


Figure 2: New tools implemented into the new habitat module of Iber. Pre-process tools.

2.2 Calculation options

In order to activate the new habitat module of Iber, it is only necessary to select one or more of the fish species of the database (Figure 3). The current version includes two species families: salmonidae (*Salmo trutta*) and cyprinidae (*Barbus bocagei*, *Chondrostoma polylepis* and *Squalius cephalus*).

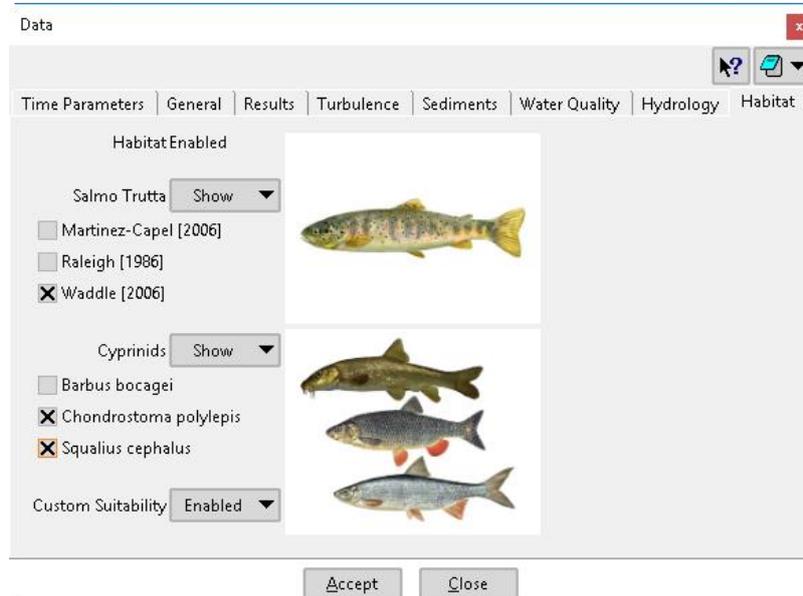


Figure 3: New tools implemented into the new habitat module of Iber. Calculation options.

2.2 Post-process tools

Apart from the general tools to analyse the results, the current version has the possibility to analyse partial and global results of SPH in the program. The SPH is represented for each specie and stadium in each element and each time step (Figure 4a), so the definition of the most suitable areas depend on the spatial discretization of the mesh (Figure 4b).

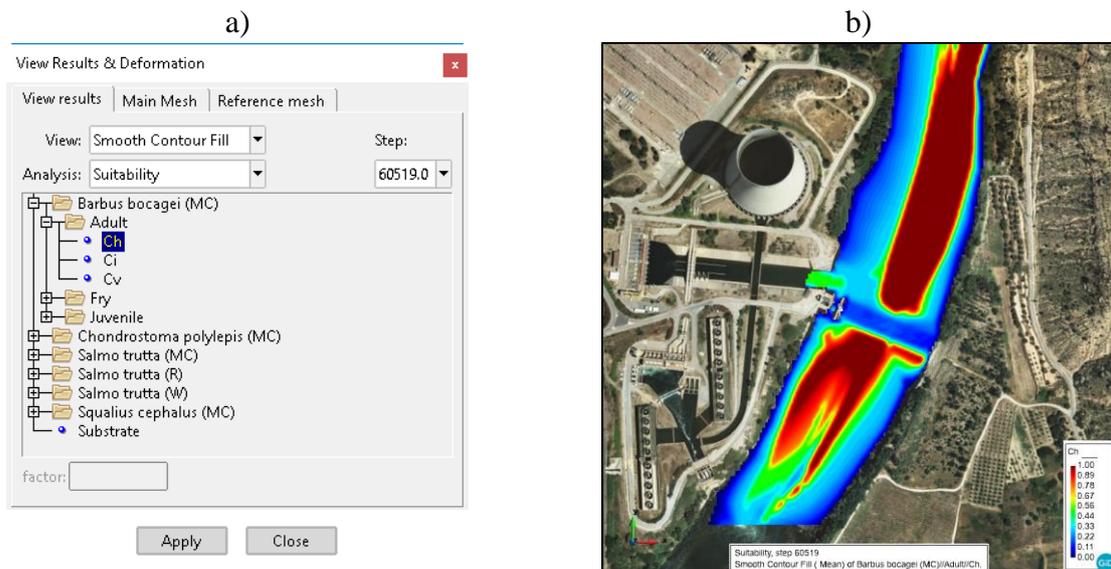


Figure 4: Visualization of the depth suitability index.

In addition, automatically calculates directly the WUA for each discharge (unsteady flow or steady flow through “Stepped discharge” option), providing not only a value but also the evolution along the simulation (Figure 5). Partial results are also calculated (e.g. wet area) and written in an ASCII plain file (e.g. ranges of WUA) for each specie and stadium. Indeed, Iber provides direct relationship between WUA and discharges.

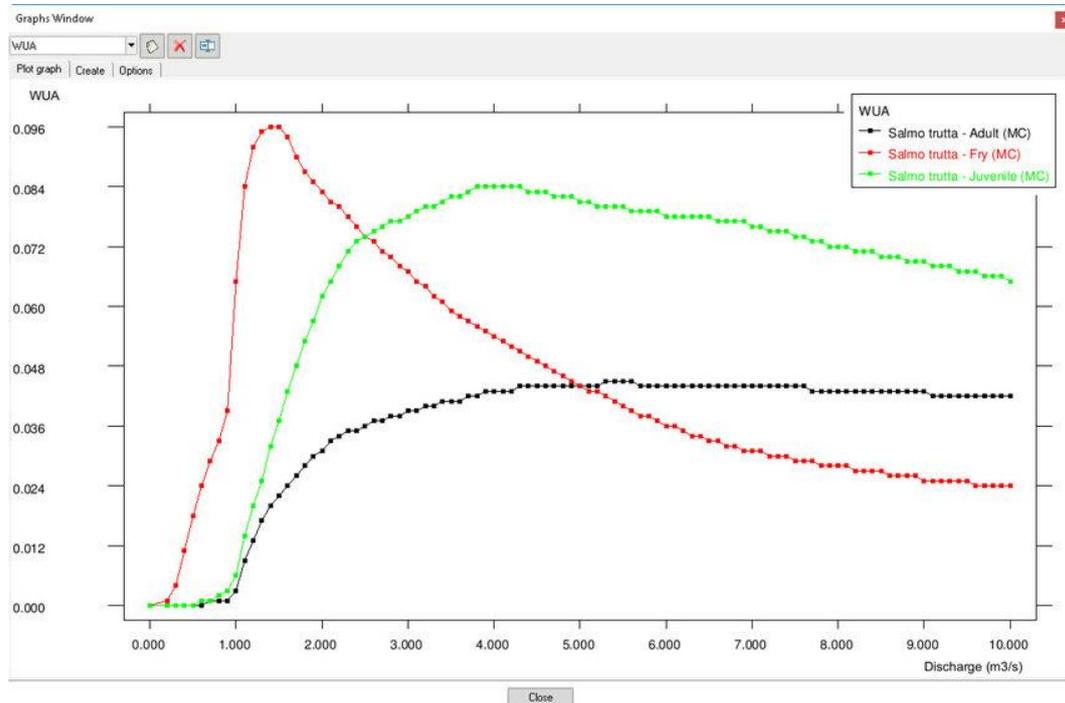


Figure 5: New tools implemented into the new habitat module of Iber. Post-process tools.

3. APPLICATIONS

The new model was applied in two rivers: Eume (Galicia, Spain) and Cinca (Aragón, Spain). Two different reaches compose the first one, a discontinuous part (step-pool morphology) in the upper basin, and a low slope continuous part in the lower reach characterize the first one. The second one is a gravel braided river.

The study on Eume River proved the capability of Iber to ensure good results in a river with complex morphology. In Figure 6, results of different suitability indexes are presented for SPH representation. The capability of a detailed 2D model when representing the complex hydraulics allows obtaining also very detailed space distribution of the indexes. It can be observed that the indexes vary along the river axis, but also in the width.

In Cinca River, apart from the SPW, the evolution with time of the WUA was studied. Cinca River was studied. The case corresponds to a 10 days simulation in a 10-km length, where the discharge varied between minimum values of 10 m³/s and maximum values of 250 m³/s. *Chondrostoma polylepis* was the objective fish. Figure 7 shows the WUA evolution during the period. A first analysis of the results shows that low discharges provide more WUA for the fry stadium. For juvenile and adults, when the flow rises, even though the value of SPH increases, their WUA remains relatively constant along the simulation (0.03 and 0.06 respectively).

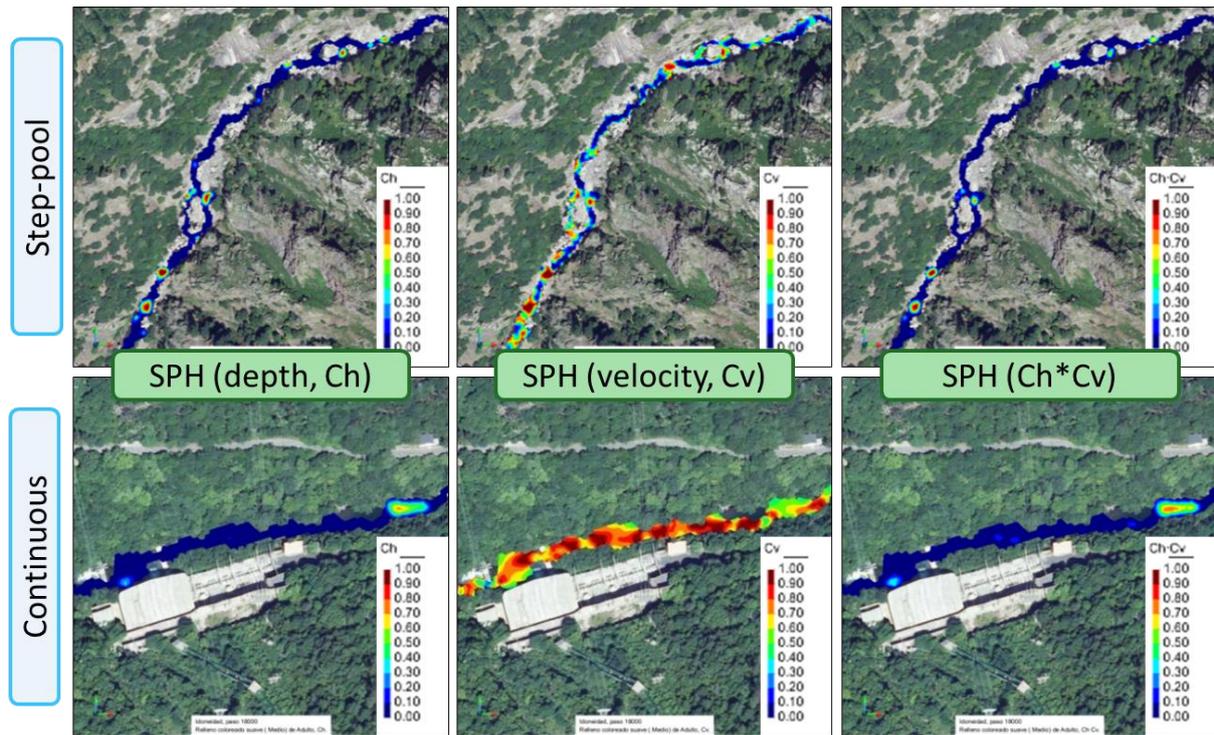


Figure 6: Representation of the SPH in Eume River. *Salmo trutta* suitability distribution for water depth (left), water velocity (middle) and product (right) in the step-pool part (above) and continuous part (below).

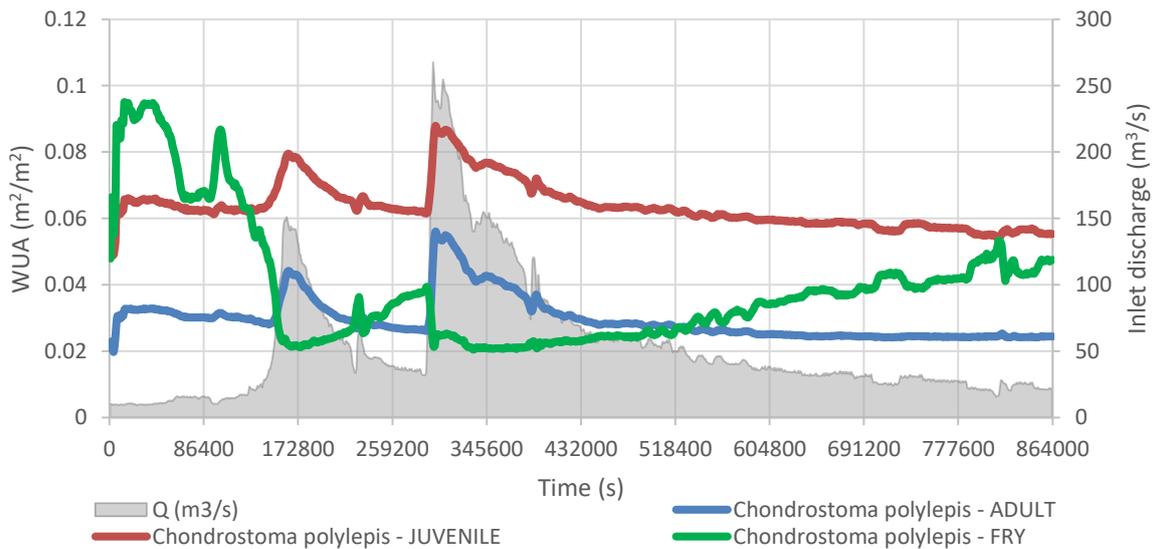


Figure 7: Evolution of the WUA in Cinca River (*Chondrostoma polylepis*).

4. CONCLUSIONS

The integration of a biological model into Iber, provides a new eco-hydraulic numerical model based on a 2D hydrodynamic model that uses the Finite Volume Method, and thus benefits from the robustness and stability of this family of numerical schemes. The new habitat model includes several improvements, and benefits from the easy workflow and the user-friendly interface which Iber is based on.

The model includes several pre-defined species and stadiums, with data loaded in a pre-existing database. In addition, the user can feed the model specific suitability curves based on depth, velocity and substrate variables. That provides the possibility to analyse the SPH and the WUA for any specie and stadium provided the required suitability curves are previously obtained,

The model was applied to two rivers, in which different morphology (step-pool and continuous reach) and temporal scenarios were tested. The model provided suitable results for both cases with a low model construction effort thanks to the capability to simulate several steady flows with the new tool “Stepped discharge”. Also the results show the advantages of using a detailed 2D model, able to properly represent the complex hydrodynamics patterns resulting from also complex morphologies. In addition, unsteady flows were analysed in order to know the SPH and the WUA variations as a function of the discharge, but also of the hydrograph shape.

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