CLARA Project

Final Report, University of Trento

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1 Overview

The present document represents the final project report related to the subcontract within the H2020 project CLARA (H2020-SC5-2016-2017/H2020-SC5-2016-TwoStage) that has been signed between the Department of Civil, Environmental and Mechanical Engineering of the University of Trento and the Univeristy of Parma, Centro Interdipartimentale di ricerca per l'Energia Ambiente (CIDEA).

As foreseen by the subcontract agreement, the present report includes the results of the application of the MesoHABSIM methodology to the Parma river, with the aim to obtain a quantitative relation between the available habitat for a target fish species and the streamflow (habitat - streamflow rating curve). Such results may be used to predict and to assess the impact on seasonal dynamics and of climate change in the future. Below the original text of the agreement (in Italian) is reported:

Report in formato digitale contenente i risultati dell'applicazione della metodologia MesoHABSIM al torrente Parma allo scopo di ricavare la relazione fra l'habitat disponibile per le specie target e la portata in alveo, risultati che verranno utilizzati in termini previsionali sia per valutare l'impatto sulle dinamiche stagionali sia per valutare l'impatto dei cambiamenti climatici in un clima futuro..

Aims and structure

The present report presents an innovative approach to habitat modelling at the mesoscale based on a combination of 2D hydraulic modelling and cluster analysis techniques. It is particularly suitable for large river systems with complex morphology where traditional field surveys of habitat at the mesoscale becomes difficult when not prohibitive at non-wadable field conditions. Results of the analysis have to be seen as preliminary outputs of a methodology that is presently under development, and has a high potential for future application. In this sense, it must be beared in mind that the employed method has some differences from the official version of the MesoHABSIM method that is routinely used in Italy for ordinary river management purposes, for which an approach based on hydraulic modelling is still under development. Furthermore, the biological models used in the present work are simplified versions of the actual biological models embedded in the SimStream software used by MesoHABSIM.

The report is structured as follows

- Section 2 describes the methods used, with focus on the 2D, fixed-bed hydraulic model and the cluster analysis tools employed to estract the HMUs (Hydro-Morphological Units) from the outputs of the hydraulic model. The model is applied to a reach of the Parma river that has been chosen in agreement with the CLARA project partners.

- Section 3 describes the results obtained from the application of the hydraulic model and, aftwerwards, from the application of the cluster analysis algorithm. Such results have to be viewed as illustrative of the potential of the presented approach, which is under ongoing development.

2 Materials and Methods

2.1 Study site

2.2 A brief introduction into habitat modeling

To understand the effects that man-made structures and water management choices can have on the hydro-morphology of rivers, and consequently on the ecological communities they sustain, in-stream habitat simulation models are commonly used. These tools can be implemented to analyse how habitat characteristic change in space and time, with the final aim to find the optimal conditions to preserve aquatic communities.

Traditionally, a micro-scale approach is used to model habitats (Bovee [1982], Ahmadi-Nedushan et al. [2006]). To overcome limitations of the traditional approach, newer methodologies use the meso-scale (or mesohabitats) to describe hydro-morphological characteristics of the river system. Mesohabitats are shown to often correspond to hydro-morphological units (HMUs), such as riffles and pools (Newson and Newson [2000]), and are therefore suitable to represent the complex hydro-morphological characteristics of mountain streams (Vezza et al. [2012]). By using a higher scale in comparison to traditional approaches, it is possible to survey longer stretches of the river, and to integrate a higher number of environmental habitat descriptors (Parasiewicz [2001]).

The MesoHABSIM methodology is currently being used to model habitat variations in Italy, for small high gradient streams in the Alps and the Apennine region (Vezza et al. [2014b,a]).

2.3 Description of the method

The MesoHABSIM methodology works by integrating three components:

1. A hydro-morphological description of the variation of the meso-habitat mosaic dependent on the streamflow rate

2. A statistical biological model that describes the preferences of a target species and life-stage towards the hydro-morphological characteristics of a river

3. An integration between the hydro-morphological (1) and biological (2) elements that allows to compute a habitat-streamflow rating curve, that describes the quantitative relationship between the available suitable habitat, expressed in Weighted Usable Area (WUA), and the river streamflow.

Table 2.1: Description of main Hydro-Morphological Units (modified from)

HMU	Description of hydromorphological characteristics
Cascade	Sequence of stepped rapids formed by boulders and large cobbles, creating small waterfalls and small pools behind boulders
Rapid	Stretches of fast flowing water in high gradient reaches, formed by boulders and large cobbles. Flow is turbulent and characterized by higher air concentration (white-water) or broken standing waves (during low flows). Convex streambed shape
Riffle	Shallow and fast flow, uniform sediment, which rarely protude out of the flow. Undulating but unbroken flow surface
Step	Near-vertical drops in the channel bed spanning the entire width. Flow is dominated by spill resistance.
Glide	Regular longitudinal bed profile, with a smooth or rippled water surface, flowing parallel to the stream bed.
Pool	Channel-spanning depression in the channel bed. Characterized by deep and relatively slow velocity flows.
Artificial element	Any non-natural element that significantly modifies fluvial processes and the morphology and assemblage of units. Examples include: check dams, weirs and ramps.

The hydro-morphological description

Once a representative reach has been chosen, the mesohabitat mosaic is mapped, and environmental descriptors for each habitat are collected. The MesoHABSIM methodology uses as template for the river mesohabitats the Hydro-Morphological-Units (HMU), based on the classification of Belletti et al. [2017]. The HMU represent areas that are homogenous in terms of flow, substrate and form, and can usually by inferred by visual observation. The main HMU types, and their characteristics, are represented in tab. 2.1.

HMUs are mapped in the field using a portable GIS system. For small streams, a laser rangefinder connected to a GIS recording device is recommended. For larger streams, a total station, a survey grade handheld GPS device or an unmanned aerial vehicle (UAV) could be used. An example of a surveyed mesohabitat mosaic can be found in fig. Once the mosaic of mesohabitats has been mapped, environmental descriptors for each unit needs to be collected. Overall, 51 descriptors are collected: the type of HMU; the average slope of each unit; the presence of refugia; the frequency classes for substrate type, flow depth and velocity; and the Froude number. More details are given in tab. 2.2. The distributions of flow depth and velocity are collected in-stream using a flow-meter, while the substrate classes are estimated visually. Usually, no less than 10 points are measured for each unit, while the spatial distribution of these points is done following a random-stratified approach, in such a way that the overall representative distribution of the HMU can be sampled.

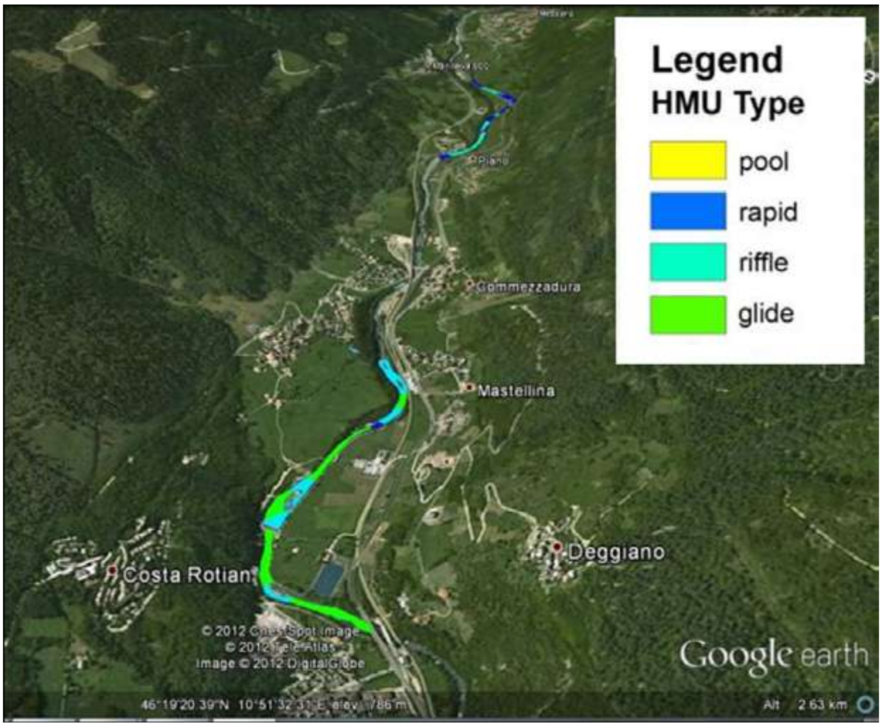


Figure 2.1: Example of a surveyed mesohabitat mosaic, on the Noce River (NE Italy), in two sub-reaches with differing morphological conditions. The background image is taken from Google Earth©. Image has been reprinted from Vezza et al. [2017], fig. 2.13, page 18.

Table 2.2: Environmental variables used to describe habitat attributes

Variable name	Unit	N. classes	Categories and description
HMU type	yes/no	13	Pothole, cascade, rapid, riffle, step, glide, pool, dune system, floodplain lake, wetland, artificial element
HMU gradient	%	1	Longitudinal mean slope of the water surface
HMU longitudinal connectivity	yes/no	1	binary attribute describing longitudinal connectivity
Cover	yes/no	7	boulders, canopy shading, woody debris, overhanging vegetation, submerged vegetation, shallow margin, undercut bank
Substrate	% of random sample	12	pelal, psammal, akal, microlithal, mesolithal, macrolithal, megalithal, phytal, xylal, sapropel, detritus, debris
Water depth	% of random sample	9	classes in 15 cm increments (up to $\geq 120\,cm$)
Flow velocity	% of random sample	9	classes in 15 cm/s increments (up to $\geq 120\,cm$)
Froude number		1	average over HMU area

The biological model

In order to relate the physical and environmental description of the river habitats with the presence and abundance of biological species, multivariate statistical models have been created using the ensemble machine learning algorithm Random Forest (Breiman [2001]).

Random Forest (RF) is a decision tree based classifier. The RF algorithm restructures data with a cross-validation procedures, randomly choosing the independent variables in each tree node. By creating an ensemble of n trees (a "forest"), and averaging over their predictions, the dependent variable can be estimated. Depending on whether the variable is categorical or continuous, RF can be used as a classifier or for regressions. RF has a number of advantages over other machine learning techniques: predictions are performed using all available variables; there is no need to operate transformation on data; it is resistant to outliers; and the risk of over-fitting is minimal. It is therefore considered competitive with or superior to many other common algorithms used for classification and prediction (Siroky [2009]), and is often used in ecological modeling (Cutler et al. [2007]).

The biological models in the MesoHABSIM model are constructed to identify the environmental parameteres that most strongly influence presence and abundance of a selected species and life stage. Two binary models are constructed to define habitat suitability of HMUs in terms of presence/absence, and presence/abundance. The output of the RF biological models is a probability of presence (or abundance), that when higher than 0.5 classifies the mesohabitat as suitable for presence (or abundance) of the selected species and life stage. The final output for the reach is then computed by integrating the outputs from the presence/absence and presence/abundance models. . The final output will then be given in terms of Weighted Usable Area (in m^2), and as percentage of the maximal wetted area of the river reach in consideration. An example can be seen in fig. 2.2.

The biological models are constructed by surveying habitat conditions and counting individuals in natural streams, in which natural and self-sustaining populations are present.

A step by step guide and additional information on how the MesoHABSIM methodology is implemented, can be found in the manual Vezza et al. [2017], in italian language.

2.4 Hydraulic model

The most modern techniques for the study of the ecosystemic suitability of the mesoscale habitat (mesohabitat) are based on the identification, within a river reach, of homogeneous hydro-morphological units characterized by their own value of habitat suitability based on the statistics of the hydraulical and sedimentological parameters. The workflow is repeated for different values of the flow discharge, and the cumulative results are elaborated to obtain the so-called habitat curves as functions of the water discharge. The analysi is nowadays conducted almost exclusively through physical measurements in the field, when the hydrological regime is low enough. Although field surveys shall be the starting point of any kind of mesoscale habitat analysis, the modeling approach ap-

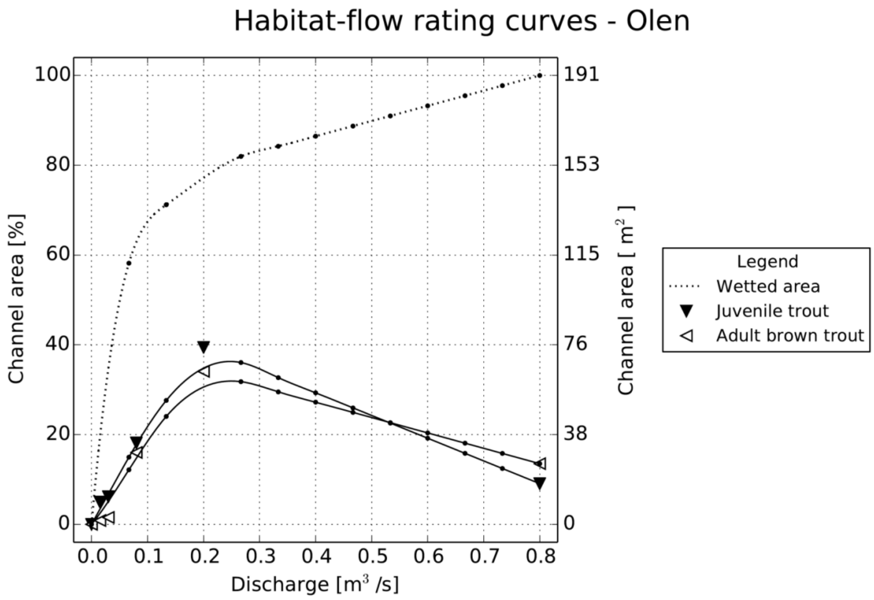


Figure 2.2: Habitat-streamflow rating curve for the Olen stream (Alagna Valsesia, Vercelly, Italy), obtained using the SimStream software for the application of the MesoHABSIM methodology. The depicted curves are for the species adult and juvenile brown trout (Salmo trutta), based on surveys conducted at streamflow values of 15, 30, 80, 200 and 800 $l \cdot s^{-1}$. Image has been reprinted from Vezza et al. [2017], fig. 4.2 page 32.

pears necessary, especially where the variability of hydrological conditions imply danger in entering the river for measurements. Also the presence of physical, logistic or meteorological factors, besides the hydrological ones, requires the use of hydraulic modeling. To this end, the University of Trento has developed a two-dimensional hydraulic model, that can be adapted to complex geometries; the model is fast and has a solid algorithm for wet-dry interfaces management. The model should be validated and calibrated through a series of field surveys in low flow conditions, and then used in predictive mode to simulate the distribution of hydraulic parameters on the model domain at the higher flows. In the present context, however, the lack of feedback data to conduct a real validation imposed to run the model in a purely predictive fashion. Hence, we recommend a high level of caution in the use of results: the calibration of a hydraulic model, even if performed on a very limited number of parameters (typically the only resistance function), has the role of compensating for a whole series of unknowns and approximations that the model without calibration is not properly able to quantify. The hydraulic model is further employed within a clustering and classification analysis, in order to identify homogeneous hydro-morphological units at the mesoscale.

The numerical model

The study of the mesoscale habitat, in modern mesohabitat approaches [Vezza et al., 2014c] in the context of the MesoHABSIM methodology [Parasiewicz et al., 2013], requires a precise description of the flow field and bathymetry of the water. The spatial distribution of hydraulic parameters must be associated with information on the substrate or with a reasonable estimate of the particle size distribution. While a field analysis is fundamental in order to estimate particle size distribution, the spatial structure of flow velocity and shear stress can be estimated using a properly validated and calibrated numerical model.

The model equations are those of conservation of the liquid mass and of the momentum of incompressible fluids averaged over the vertical. The evelation of bed and of the free surface are indicated respectively with $b(x, y)$ and $h(x, y; t)$, where x and y represent two spatial coordinates (in the present case they represent the coordinates, in meters, according to the Universal Transverse Mercator projection, as converted by the reference system WGS84 zone 32N in which the data were supplied), while t is time (in seconds). The water flow field is defined by the local depth of the flow $D(x, y; t)$ and by the velocity field declined in the two directions $U(x, y; t)$ and $V(x, y; t)$. The governing equations are therefore expressed in the following form:

$$\frac{\partial D}{\partial t} + \frac{\partial DU}{\partial x} + \frac{\partial DV}{\partial y} = 0 \tag{2.1a}$$

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} = -g\frac{\partial b}{\partial x} - \gamma\frac{U}{D} \tag{2.1b}$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} = -g\frac{\partial b}{\partial y} - \gamma\frac{V}{D} \tag{2.1c}$$

where g represents the acceleration due to gravity, equal to $9.81\mathrm{m/s^2}$, and $\gamma = \frac{g\sqrt{U^2+V^2}}{k_s^2 D^{4/3}}$

is the friction term, k_s is the Strickler's friction coefficient.

Given the morphological complexity of natural river systems, the model is based on an unstructured grids. On this kind of mesh, which is processed in a semi-automatically fashion by an integrated mesher based on the *gmsh* package [Geuzaine and Remacle, 2009], we implemented a two-dimensional model with a semi-implicit finite volume discretization. The semi-implicit scheme allows a partial decouplement between flow velocity and local depth, whereby the mass conservation equation is implicitly solved [Casulli, 1990, Casulli and Cheng, 1992] and the time-step restriction according to the " Courant-Friedrichs- Levy " law is therefore relaxed since it solely depends on the average speed of the current and not on the celerity of small amplitude waves [Casulli and Cattani, 1994]; the steady flow solution at different flow discharges, with consistent presence of dry-wet interfaces, is tackled by implementing a solid wet-and-dry algorithm [Casulli, 2009]. To minimize the computational time the model runs the progressive filling of the initially dry domain according to a simplified formulation that neglects the contribution of non-linear convection: this allows to solve the system in a fully implicit form which is indeed very fast. Once the approximate regime solution is reached, it is corrected by introducing the effect of non-linear convection until a new convergence is reached. Finally, the model provides the possibility of sub-grid modeling [Casulli and Stelling, 2011], in which the water volume and the local depth of the flow field are discretized on a more refined grid with respect to that of the flow velocity. Therefore, the steady flow solution results from an asymptotic solution, in which the input flow rate is kept constant and the output flow regulated on the basis of the inflow conditions. The convergence of the solution is assumed when no further significant change in the structure of the flow field within the domain occurs. Regarding the boundary conditions, normal flow is imposed in the upstream and downstream sections: the reference slope is assumed as equal to the average of the entire reach, while the distribution of the inlet flow discharge through the boundary elemnts' interfaces is determined by the Engelund method [Engelund, 1964].

Data

The analyzed area is reported in figure 2.3, together with points of field measurements.

Figure 2.3: Study area with previous points of measure.

The input data of the model primarily consist of a digital terrain model, which is delimited by the following UTM coordinates

Easting 601461.099m − 604666.885m;

Northing 4944868.336m − 4947140.055m;

resolution 0.95m × 0.95m.

The coefficient k_s was estimated based on the following particle size data referring to measurements performed within an active channel: $d_{50} = 48.72$mm and $d_{84} = 93.26$mm. Using Strickler's formulas

$$k_s = \frac{21}{d_{50}^{1/6}} \quad \text{e} \quad k_s = \frac{26.6}{d_{90}^{1/6}}, \tag{2.2}$$

and substituting the d_{84} in place of the d_{90}, we estimated a value of $k_s \simeq 38\text{m}^{1/3}/\text{s}$.

We carried out two simulations with the discharge corresponding to the incipient movement of the bed material ($Q_2 = 6.2\text{m}^3/\text{s}$) and to the half of it $Q_1 = 3.1\text{m}^3/\text{s}$.

2.4.1 Unstructured grid

As previously explained, the morphological complexity of natural river systems requires the use of an unstructured mesh. The mesh employed in the present analysis consists of 75791 triangular elements, each with three neighbors (except the boundary elements whose neighbors are normally two), a total number of 114126 edges (interfaces between triangles) and 38335 nodes (triangle vertices). The discretized area is shown in figure 2.4 together with the digital elevation model. A zoom on mesh elements is reported in figure 2.5.

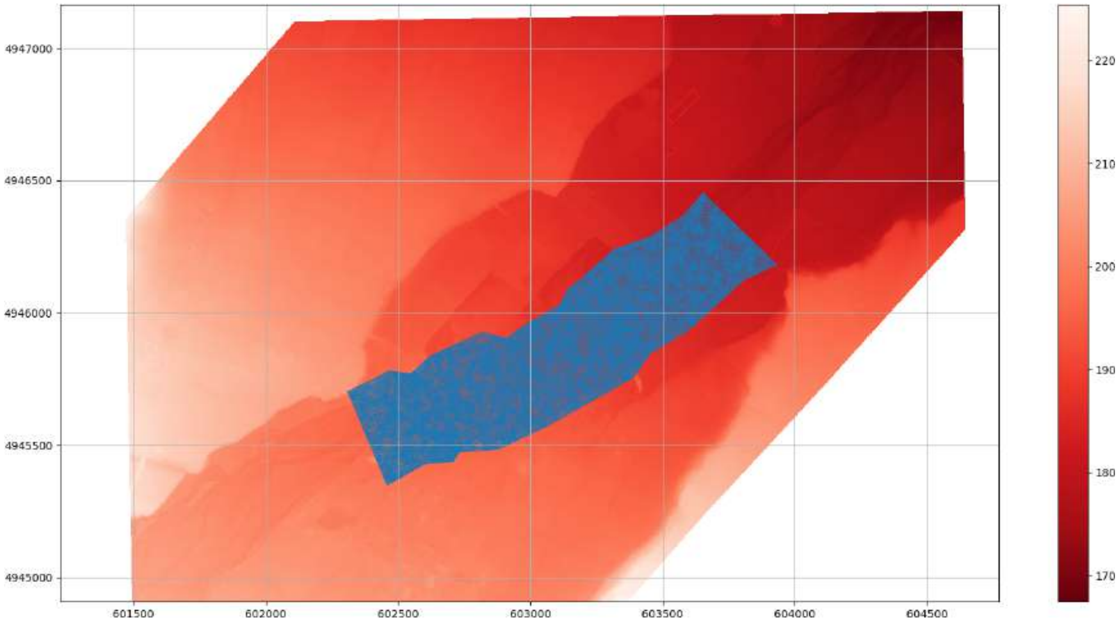


Figure 2.4: Digital elevation model and discretization of the numerical domain on an unstructured grid.

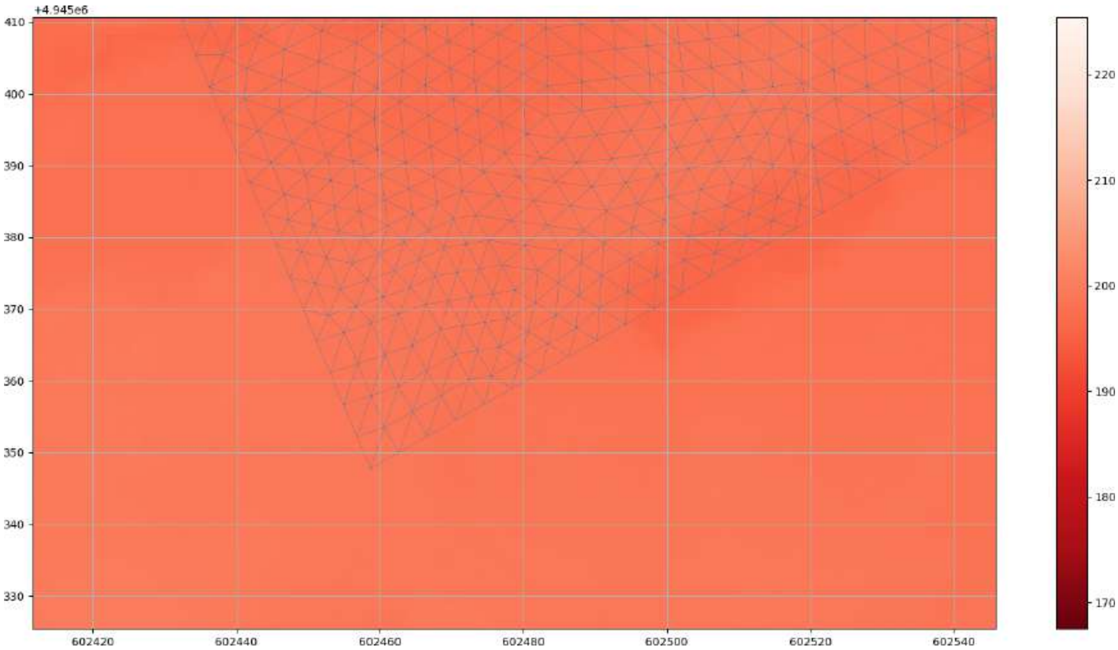


Figure 2.5: Unstructured grid detail close to domain border.

2.5 Mesohabitat extraction from hydraulic modelling

Hydraulic models offer the user the opportunity to simulate flows in a given river or reach, that would be to difficult or impractical to survey otherwise. One of the major drawbacks of such models is the need of bathymetrical, and calibration and validation data. A Digital Terrain Model (DTM) has to be constructed, based on which a computational mesh is then extracted, through whose nodes and polygons the mathematical equations of the hydraulic model will simulate the water flow. In the case of 1-dimensional models, the reconstruction of the DTM is usually performed by interpolating cross-sectional profiles of the river bed and surroundings, that are measured at a regular spacing. For 2- and 3-dimensional models, a more detailed representation of the river bed is needed, which survey can often be costly both in terms of time and money. But with advent of newer technologies, such as Airborne Bathymetrical Lidar (ABL), or RGB-pictures based reconstruction through Structure from Motion (SfM), the ability to acquire DTM at sub-meter resolution has become feasible.

In addition, the use of 2D hydraulic models, which requires a higher cost in terms of computational power, due to higher number of cells and nodes, compared to a 1D-model, has also become feasible, since even consumer-grade computer can nowadays be used to simulate flows in feasible timespans.

In parallel to these developments, more complex habitat models have been built. It has been recognized that the meso-scale more appropriately describes a scale relevant for many ecological species, such as fish. Moreover, a wider range of environmental descriptors can be used to describe physical habitats, integrating additional information, such as presence of covers and vegetation, instead of only the local flow description. Describing a river reach at the mesos-scale also allows faster surveys, and the ability to map longer reaches, as compared to more traditional micro-scale surveys.

One of the key challenges in the application of meso-scale habitat models in the case non-wadable rivers, i.e. large rivers, or at higher flows, in which instream surveys become unfeasible, is their integration with hydraulic models. These could be used to estimate the mosaic of mesohabitats, allowing to sample in non-wadable conditions, or by reducing the challenge of surveying different hydrological conditions, due to weather, seasons, or water management.

Various approaches have been attempted to classify mesohabitats in terms of hydraulic characteristics. These parametric classification approaches require to define thresholds for hydraulic descriptors (e.g. flow depth, velocity or Froude n.), that are then used for the classification of hydraulic mesh nodes into mesohabitat types. Examples if such an approach can be found in Jowett [1993], Wyrick et al. [2014]. In Jowett [1993], after classifying river stretches into mesohabitats in rivers across New Zealand, hydraulic parameters were measured within each unit, and a simple classification for pools, runs and riffles, based on the Froude number was suggested. In Wyrick et al. [2014], channel landforms are delineated using meter-scale hydraulic models for two rivers in SE USA. The classification system is based on thresholds for flow depth and velocity, defined based on visual assessments and expert knowledge. Although conceptually simple, the parametric classification approach requires defintion of the thresholds that is river and discharge specific, and no unified theory has been formulated so far. A calibration process is therefore needed, requiring time, effort and profound knowledge of the analysed river system.

Another approach that has been attempted, consists in the use of unsupervised clustering techniques. The river flow is grouped into clusters by means of unsupervised machine learning algorithms, and these clusters are then used to classify hydraulic mesh points. Using unsupervised techniques overcomes the need and uncertainties related to assigning and defining the classification system for the different hydro-morphological unit types. Examples of this approach can be found in Legleiter and Goodchild [2005], Wallis et al. [2012]. In both works, fuzzy-c clustering is used to classify the river flow into classes, using the variables depth and velocity.

The methodology applied for this work is also based on the use unsupervised clustering techniques. A brief general introduction into clustering will be given, followed by the description of the applied methodology. Finally, the simplified biological models used for this work will be outlined.

A (brief) introduction into clustering

Cluster analysis is a branch of data mining whose main objective is grouping objects into so-called clusters, in a way that make objects in the same cluster more similar to each other than with objects of other clusters. Clustering algorithms are widely used in many fields, such as machine learning, image analysis, pattern recognition, medicine, social sciences, and increasingly also in ecological sciences.

Clustering algorithms are considered to be unsupervised grouping algorithms, that work only based on a notion of similarity between the data. No labels (i.e. a-priori information as to which group each individual object should belong to) are assigned.

One of the most common and widely used clustering algorithms is k-means clustering (Lloyd [1982]). The final outcome of the algorithm is the assigment of each object to a pre-defined number of k clusters. The k-means algorithm works by:

1. Selecting k cluster centers
2. Assigning each object to its closest cluster center
3. Reassigning each center as being the mean of its istances
4. Steps 2 and 3 are repetead until either no change occurs anymore, or a pre-defined number of iteration steps has been reached

The algorithm works by minimizing the variance, i.e. the within cluster sum of squares (WCSS), and maximing squared deviations between objects of different clusters, i.e. the between-cluster sum of squares (BCSS).

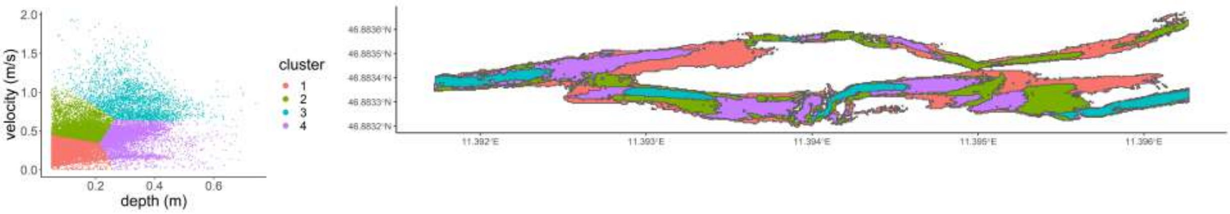
From clustering to habitat patches

To extract mesohabitats from flow, two steps are necessary:

1. the clusterization of simulated flow data
2. the regionalization of flow clusters into contiguous hydraulic patches

In step 1, the k-means algorithm is implemented to clusterize flow data. The algorithm is implemented on the hydraulic mesh nodes, using as variables depth and depth-averaged-velocity. Once the clusters are obtained, the hydraulic mesh is rasterized. Contiguous raster pixel, belonging to the same cluster type, are merged together. Finally, the arising patches of contiguous points of the same cluster type are turned into polygons. Finally, this new set of polygons constitutes the mosaic of mesohabitats, that will be assessed for habitat suitability by applying a biological model.

The k-means algorithm is an unsupervised clustering algorithm, that divides the data points into groups based so as to minimize within cluster variance, and as to maximize between clusters variance. The only parameter that needs to be set be the user is the number of clusters k. The choice of k will influence the size and distribution of modelled mesohabitats, influencing the final estimation of habitat suitability. Therefore, a choice, based on some criteria, needs to be taken regarding the number of clusters, so as to optimize the segmentation into mesohabitats. The optimal choice of k and model parameters is currently analysed within a PhD thesis at the University of Trento, to be finished in Spring 2020. For this report, the criteria used for the definition of k will be based on the average size of mesohabitats resulting from the segmentation process, ensuring that the resulting segmentation yields habitats that are close in size to the mesohabitats usually mapped during field surveys. More details will be given in the upcoming thesis by David Farò.



(a) (b)

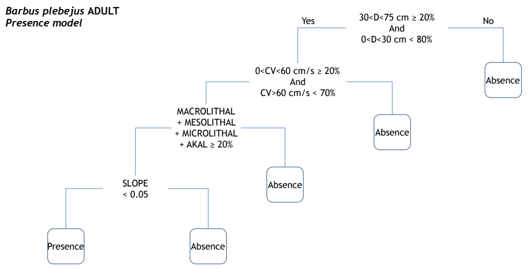
Figure 2.6: Example of extraction of mesohabitat units from clusterization, for a reach of the river Mareit (NE Italy), at $Q = 1.7m^3/s$. The two steps of the procedure are shown: first, depth-velocity points from the output of the 2D hydraulic model are clusterized (a), and then contiguous patches belonging to the same cluster type are merged together into polygons (b)

The simplified biological model

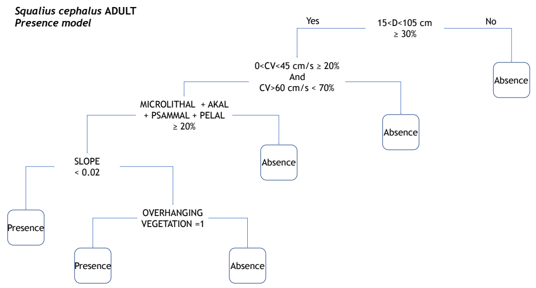
To be able to implement the MesoHABSIM methodology within the context of hydraulic model-based mesohabitat mapping, in context where no spatial information about the presence of refugia, and the spatial distribution of substrate classes is available, a simplified version of the biological model needs to be constructed. The simplified model considers only preferences of the species and life stage towards hydraulic descriptors (i.e. flow depth and velocity), that constitute the only output of the hydraulic model. These simplified model can be either extracted from the RF models, or by parametrizing species (and life stage) preferences towards environmental descriptors by surveying the existing scientific literature. In the former case, relevant variables are selected from the RF model, and ranges of the parameters estimated. In the latter case, ranges are directly estimated from existing studies, in which habitat and flow preferences are described.

In a study by Adamczyk et al. [2019], different habitat suitability criterias are tested for Bullhead (Cottus gobio). An inductive logistic regression model is developed from electrofishing data obtained from multiple mountainous streams in NW Italy. Deductive Categorical Habitat Suitability Criterias (CHSC) are generated from expert knowledge and information gathered from reviewing the literature. Although model comparison and validation shows that the inductive approach using logistic regression is more precise and reflects site- and species- specific characteristics, the deductive approach yields similar results.

Presence/absence models for the adult Italian barbel (Barbus plebejus) and common chub (Squalius cephalus), used in this study, were constructed using a similar approach as the one depicted in Adamczyk et al. [2019]. The categorical habitat suitability criterias can be seen in fig. 2.7. These simplified models were developed to be used in the context of hydraulic modeling-based mesohabitat extraction, and only represent a simplification of the RF models implemented in the software SimStream, and which is recommended in the case of a MesoHABSIM application. More details about the models and the software



(a)



(b)

Figure 2.7: Categorical habitat suitability criteria for (a) adult Italian barbel (Barbus plebejus) and (b) common chub (Squalius cephalus)

can be found in Vezza et al. [2017].

Once the presence/absence is computed for each HMU, using the CHSC, an overall estimate of habitat suitability for the river reach can be done, by adding the areas of suitable mesohabitats, in terms of WUA (in m^2), and also expressed as % of maximal wetted area. Combining the results of each examined streamflow value Q, a habitat-streamflow rating curve can be obtained.

3 Results

3.1 Hydraulic modeling

In this section we report the numerical results for both simulations:

$\mathbf{Q}_1$ 3.1m^3/s

$\mathbf{Q}_2$ 6.2m^3/s

Result for Run Q_1

In the present section the results for the run Q_1 are reported. The distribution of water depth and flow velocity magnitude are mostly confined within the approximate ranges $0-0.3$m/s and $0-0.5$m/s, respectively, with median values of 0.07m and 0.5m/s. The dominant flow direction is $E-N-E$ (around 15° with rspect to the x axis). Figure 3.1 shows the spatial distribution of flow depth and velocity over the detrended digital elevation model. Figure 3.2 shows the statistical distributions of depth and velocity magnitude, while figure 3.3 also displays the velocity orientation.

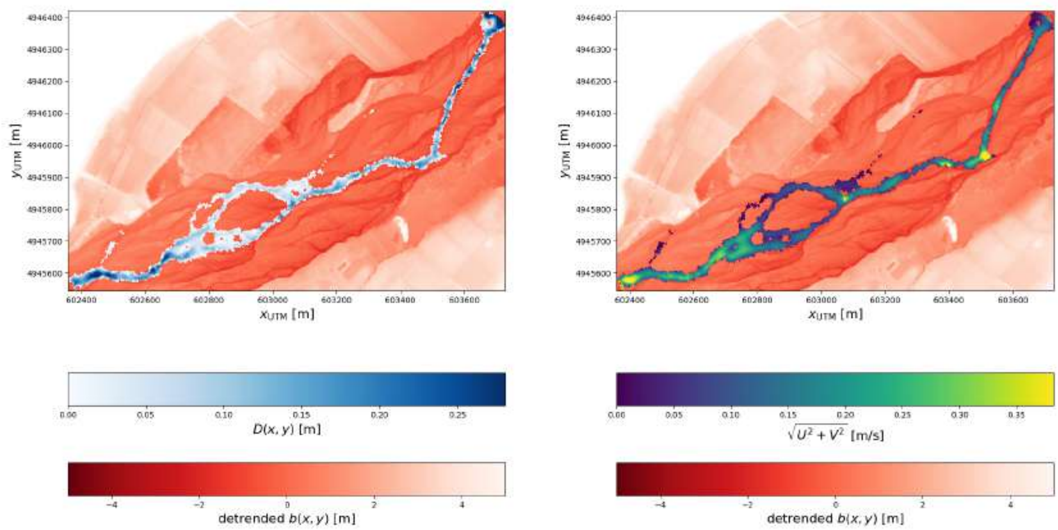


Figure 3.1: Steady state results for water depth and flow velocity for the run Q_1.

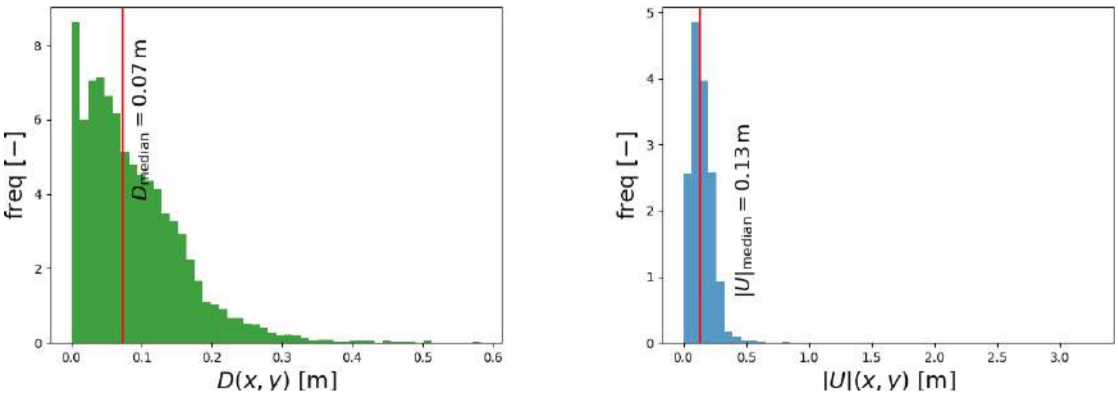


Figure 3.2: Histograms of water depths and flow velocity magnitude for the run Q_1.

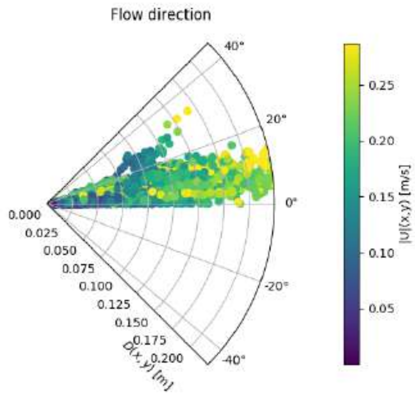


Figure 3.3: Flow depth (radial axis), velocity magnitude (color) and direction (angular axis) Q_1.

Result for Run Q_2

The steady flow simulation obtained from the model for the run Q_2 displays, as expected, larger values of depth and velocity. The channel structure is very similar to the one obtained for the previous run, which is consistent with the spatial structure of the bed elevation given by the digital terrain model. The distribution of water depth and flow velocity magnitude are mostly confined within the approximate ranges $0-0.3$m/s and $0-1.0$m/s, respectively, with median values of 0.08m and 0.19m/s. The dominant flow direction is $E-N-E$ (around 15° with rspect to the x axis). Figure 3.4 shows the spatial distribution of flow depth and velocity over the detrended digital elevation model. Figure 3.5 shows the statistical distributions of depth and velocity magnitude, while figure 3.6 also displays the velocity orientation.

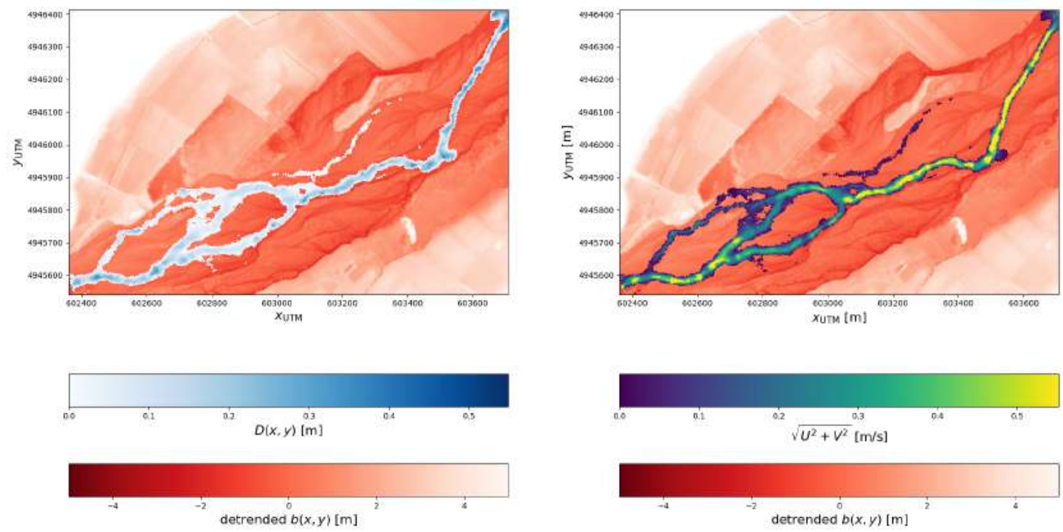


Figure 3.4: Steady state results for water depth and flow velocity for the run Q_2.

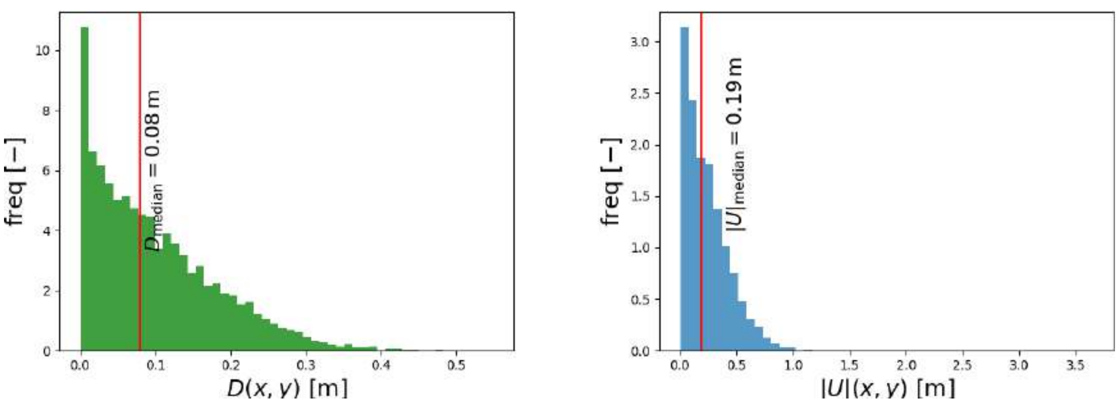
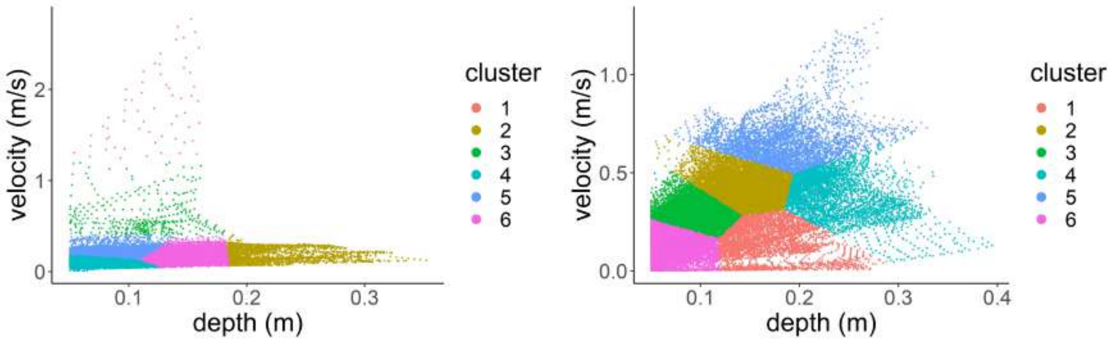


Figure 3.5: Histograms of water depths and flow velocity magnitude for the run Q_2.



(a) (b)

Figure 3.7: Step 1: Clusterization of flow data, for discharges $Q = 3.1m^3/s$ (a), and $Q = 6.2m^3/s$ (b), for k = 6

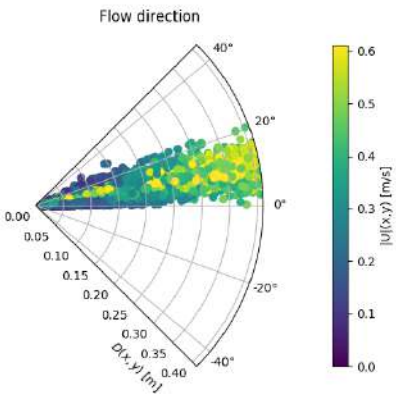
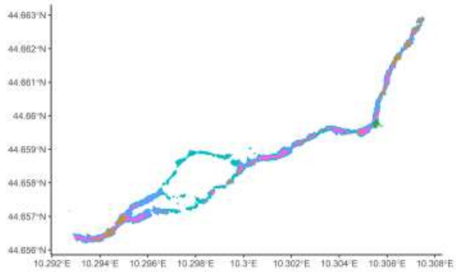


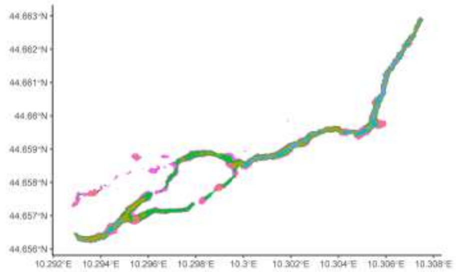
Figure 3.6: Flow depth (radial axis), velocity magnitude (color) and direction (angular axis) Q_2.

3.2 Modelled mesohabitats

In this section, the results for the mesohabitat extraction, and estimated habitat suitability are reported. In fig. 3.7, the application of the k-means clustering algorithm to the simulated flow data is reported, for a chosen k = 6, as described in step 1 of the procedure. In fig. 3.8, maps showing the mosaic of extracted mesohabitats (step 2), based on the clusterization of step 1 are shown. The number k = 6 was chosen, as it gave the best size distribution for simulated mesohabitats. The simplified biological models for common chub and Italian barbel were then applied. And example of resulting habitat suitability distribution for the common chub can be seen in fig. 3.9. Finally, the estimated habitat-flow rating curve, in the range of discharges modeled is presented in fig. 3.10.

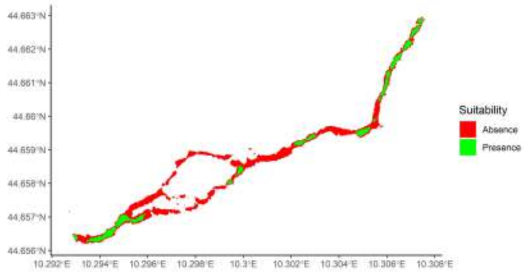


(a)

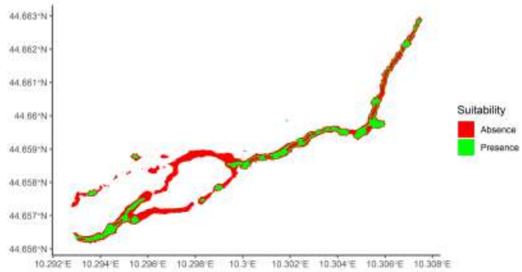


(b)

Figure 3.8: Step 1: Regionalization of contiguous patches of clusters into mesohabitats, for discharges $Q = 3.1m^3/s$ (a), and $Q = 6.2m^3/s$ (b), for k = 6



(a)



(b)

Figure 3.9: Step 1: Presence/absence habitat suitability map for the common chub (*Barbus plebejus*), for discharges $Q = 3.1m^3/s$ (a), and $Q = 6.2m^3/s$ (b),

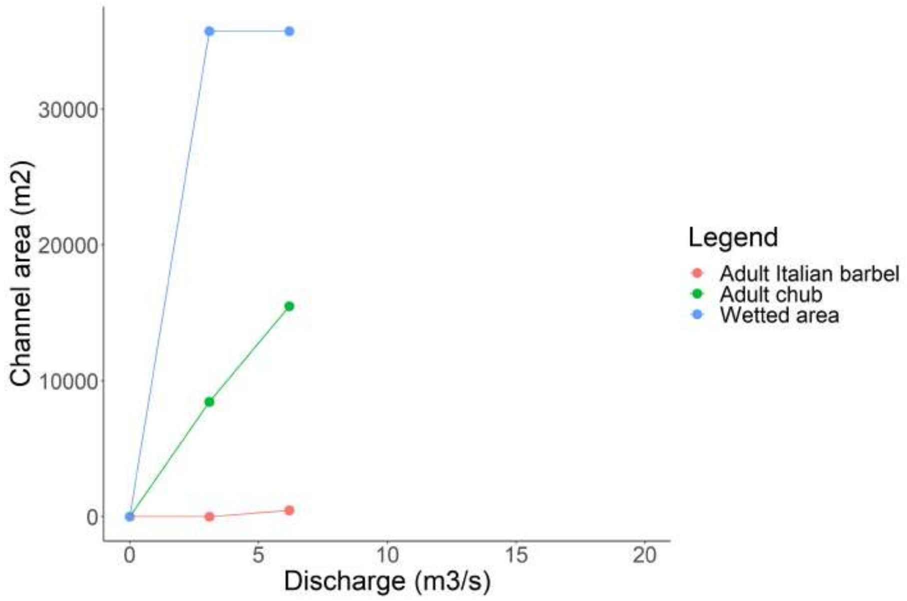


Figure 3.10: Habitat-flow rating curve for the species adult Italian Barbel and adult common chub

4 Conclusions

The present report has presented an innovative approach to habitat modelling at the mesoscale based on a combination of 2D hydraulic modelling and cluster analysis techniques. As previously remarked, results of the analysis have to be seen as preliminary outputs of a methodology that is presently under development, and has a high potential for future application. The employed method has some differences from the official version of the MesoHABSIM method that is routinely used in Italy for ordinary river management purposes, for which an approach based on hydraulic modelling is still under development. The biological models used in the present work are simplified versions of the actual biological models embedded in the SimStream software used by MesoHABSIM.

The results of this work demonstrate that it is possible to employ hydraulic modelling to estimate some of the envirnmental descriptors of river habitat at the mesoscale, namely flow depth and velocity, and that it is also possible to extract quantitative information of habitat availability at the mesoscale by the application of an iterative approach based on cluster analysis techniques. This allows to estimate the streamflow-habitat rating curve for a river reach, which can then be used to predict the habitat availability under future scenarios, including those associated with climate change.

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