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Transferability of Mesohabitat Suitability Criteria in Northern Italy

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Abstract

In the framework of water resources planning and management, the MesoHABSIM (MesoHABitat SImulation Model) approach demonstrated high potential to assess suitable environmental conditions for freshwater fish species. In the present study, the transferability capabilities of mesohabitat suitability criteria were evaluated in nine streams across Northern Italy. In particular, the Random Forest (RF) technique was used to calibrate and validate suitability criteria for adult and juvenile life stages of brown trout (*Salmo trutta*), marble trout (*Salmo marmoratus*), bullhead (*Cottus gobio*) Italian barbel (*Barbus plebejus*), and Italian vairone (*Telestes muticellus*). Presence/absence binary models were calibrated at the mesohabitat scale (i.e., the geomorphic unit scale) using field data collected in reference sites, selected for their natural hydro-morphological conditions and habitat characteristics. Model transferability tests were performed in streams located in different regions within the distribution area of the fish and not included in the model calibration dataset. Predictive capacities of the models were very good in terms of accuracy (ranging from 75% to 82%) and true skill statistic (ranging from 52% to 75%). The high predictive performances can be related to (i) the use of an ecologically relevant spatial resolution (mesohabitat) to predict fish presence, (ii) a robust and adequate hydro-morphological characterization of the analyzed geomorphic units, and (iii) the large number of mesohabitat descriptors provided by the MesoHABSIM approach. Results showed that mesohabitat suitability criteria based on RF can be considered transferable among streams located in different regions of Northern Italy, especially when river channels are characterized by similar hydro-morphological characteristics.

Keywords: Habitat modelling; MesoHABSIM; Random Forest; Geomorphic Units; Freshwater fishes.

1. INTRODUCTION

Freshwater ecosystems are globally deemed to be one of the most threatened environment of the world (Dudgeon et al., 2006). Among the several pressures on these ecosystems, hydrological and morphological alterations related to hydropower generation and water abstraction are identified as high impact factors determining river ecosystems degradation and biodiversity loss (Renöfält et al., 2010).

In order to mitigate such impacts and to enhance water resource management, since 1980s, Habitat Suitability Models (HSMs) were proposed (Bovee, 1982) and widely used at the global scale. Despite a high number of different approaches, the most recent meso-scale models, such as the Meso-HABitat SImulation Model (MesoHABSIM, Parasiewicz, 2001), have proved to be adequate for assessing habitat availability for fish in rivers (Yi et al., 2017). MesoHABSIM is a methodological approach that utilizes geomorphic units (GUs or mesohabitats, Belletti et al., 2017) as spatial unit of analysis (about 10^{-1}-10^{3} m). MesoHABSIM includes a large range of biotic and abiotic habitat descriptors (e.g., hydraulic variables, substrate composition, covers and shelters for fish, water surface gradient) which are used to describe habitat availability for fish. For evaluating the amount of available habitat for a certain species or life stages, MesoHABSIM involves the use of binary models (absence/presence and presence/abundance), to distinguish between not suitable/suitable habitats and suitable/optimal habitats. Generally, the most reliable binary models are those developed by using sophisticated machine learning techniques able to analyze the empirical data collected in environmental

reference sites (Vezza et al., 2014a; Vezza et al., 2012). In particular, the use of Random Forest (RF, Breiman, 2001) classification algorithm has recently increased to identify most important variables that are related to species presence and abundance within mesohabitats (Muñoz-Mas et al., 2016; Vezza et al., 2015).

Since HSMs were proposed, freshwater ecologists argued on the possible transferability of microhabitat suitability criteria (HSC), developed in a particular context, to other streams (Williams et al., 1999). In this regard, several microhabitat-oriented studies, mostly carried out in Northern America, revealed some critical issues in applying a unique HSC to different hydro-morphological contexts, concluding that site-specific HSC are preferable (e.g., Bozek and Rahel, 1992). However, developing site-specific criteria is usually expensive and time-consuming, and, in cases of degraded habitat, may not be feasible. Mayor constraints to successfully allow the transferability of such HSC can be related to the spatial scale of analysis. The microhabitat scale does not consider hydro-morphological variables around each evaluated microhabitat (or point). This approach may have drawbacks on the habitat description. Indeed, environmental conditions around an organism, not only at the point where it is observed, are known to be important factors affecting habitat suitability (Allouche, 2002). For mobile animals, such as fish, a larger spatial extent may be used to describe their habitat preferences in order to increase the validity and reproducibility of a HSC in multiple contexts (Borsányi et al., 2004). The meso-scale HSMs have already proven their effectiveness in supporting biological model transferability between multiple European rivers (Borsányi et al., 2004). In particular, the MesoHABSIM approach coupled with a RF biological model, was recently used to assess the available habitat for the European crayfish (*Austropotamobius pallipes*) in different riverine contexts of Italy (Vezza et al., 2016).

With the aim of testing the transferability of meso-scale fish distribution models in Northern Italy, different field data collection campaigns were carried out over the last 10 years in reference sites (i.e., natural conditions of river morphology, flow regime, fish community composition, Vezza et al., 2014a, Vezza et al., 2014b). RF was used to build mesohabitat suitability criteria calibrated with field data collected in Piemonte and Valle d'Aosta regions. In this study, the calibrated mesohabitat models were applied to 9 river reaches located in other regions (Emilia-Romagna, ER; Liguria, L; Piemonte, P; Trentino-Alto-Adige, TAD; Valle d'Aosta, VDA) and not included in the model calibration dataset. Together with the application of the MesoHABSIM protocols (Vezza et al., 2017), quantitative fish data collection were carried out within each mesohabitat to describe fish species distribution in terms of presence/absence. Model transferability tests were achieved by comparing the predictions of considered RF models with fish species distribution assessed in the field in terms of accuracy, sensitivity, specificity and TSS (True Skill Statistic, Vezza et al., 2015; Allouche et al., 2006).

2. MATERIALS AND METHODS

2.1 Case study

The study sites consisted of nine river reaches, located in Alpine and Apennine catchments, distributed in five regions of Northern Italy (Figure 1). In particular, four reaches (Belbo, 2; Ghiandone, 3; Orco, 5; and Pellice, 6) were located in the Piemonte region, two reaches (Argentina, 1; and Malacqua, 4) in the Liguria region, and one reach (Rabbies, 7; Savara, 8; and Trebbia, 9) respectively in Trentino-Alto Adige, Valle d'Aosta, and Emilia-Romagna regions. The majority of them (2, 3, 5, 6, 8) were located in Alpine watersheds and belonged to the Po river drainage basin, the longest Italian river. Only reach 9, despite flowing into the Po river, it pertained to the Apennine area, whereas reach 7, positioned in the Alpine area, belonged to the Adige river basin. Furthermore, considering the study sites of Liguria region, both pertained to Tyrrhenian sea catchments, although reach 1 is located in the Alps, whereas reach 4 in the Apennines.

Despite a quite extensive spatial distribution, considered river reaches are characterized by similar hydro-morphological characteristics (Gumiero et al., 2022), resumed in Table 2. In particular, reaches 1, 4, 7, 8 belong to the landscape unit of mountain areas, whereas 3, 5, 6, 9 are located in the Po river plains, and 2 can be considered as part of the hilly areas. Although 1 and 4 are mountain streams, characterized by a confined straight-sinuous (C-SS, Gurnell et al., 2014) morphology, they are marked by gentler slopes and by a local fish fauna dominated by cyprinid fishes (e.g., *Barbus plebejus*, *Telestes muticellus*). On the other hand, reach 7 and 8 are typically Alpine high gradient streams (Vezza et al., 2014b), where exclusively brown and marble trout can be found. The remaining reaches (2, 3, 5, 6, 9) are mostly characterized by unconfined or partly confined valley edges and by a prevalent cyprinid fish community. Only in reach 5, due to the proximity to the mountainous area of its watershed, trout populations are present.
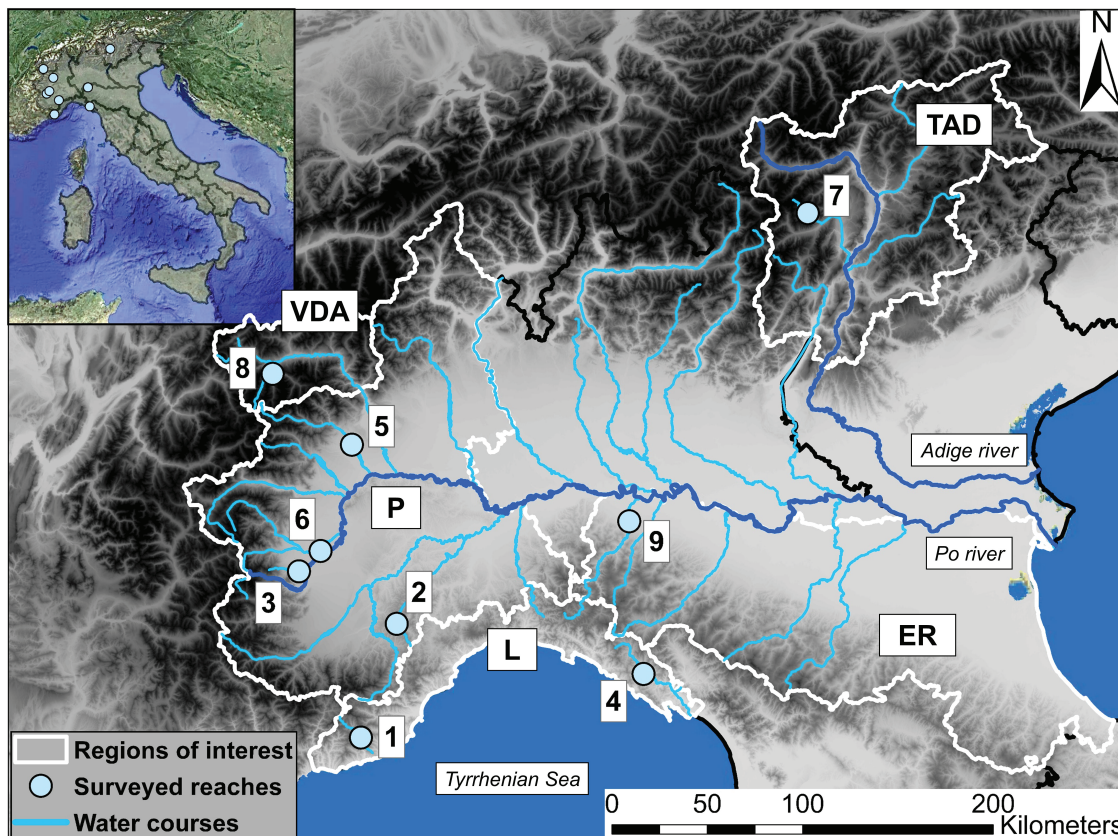
Figure 1. Location of the surveyed reaches considered in the study. Regions of interest: ER = Emilia-Romagna; L = Liguria; P = Piemonte; TAD = Trentino-Alto-Adige; VDA = Valle d'Aosta. Surveyed river reaches: 1 = Argentina; 2 = Belbo; 3 = Ghiandone; 4 = Malacqua; 5 = Orco; 6 = Pellice; 7 = Rabbies; 8 = Savara; 9 = Trebbia.

2.2 MesoHABSIM approach

MesoHABSIM is a methodological approach that models fluvial habitats based on a specific hierarchical structure of morphological classification (Gurnell et al., 2014). It allows the evaluation of available habitat for freshwater species using geomorphic units (GUs or mesohabitats, Belletti et al., 2017) as a primary metric. GUs are evaluated in terms of habitat suitability (suitable/not suitable) by the application of a biological model and accordingly to their local biophysical attributes. These riverine features (Table 1) involve both abiotic (flow velocity, depth and substrate composition) and biotic (biotic substrate, presence of aquatic or overhanging vegetation) factors, which mainly influence the patterns of habitat use by freshwater fishes (Parasiewicz, 2007).

Table 1. The biophysical habitat parameters of the MesoHABSIM model used for the GUs description in the field data collection campaigns. For each habitat parameter the corresponding categories are expressed as reported in Vezza et al. (2017).

Habitat parameter	Units	Number of Categories	Categories/Description
Geomorphic units (GUs)	yes/no	17	Pothole, Cascade, Rapid, Riffle, Step, Pool, Glide, Dune, Aquatic vegetation, Secondary channel, Flood lake, Wetland, Artificial element, Waterfall, Plunge pool, Backwater, Rock glide
GU gradient	%	1	bottom mean slope of the GU
GU longitudinal connectivity	yes/no	1	habitat binary attribute describing mesohabitats longitudinal river connectivity

Depth	percentage of random samples	9	categories in 15 cm increments (range 0-120 cm and above)
Velocity	percentage of random samples	9	categories in 15 cm/s increments (range 0-120 cm/s and above)
Substrate	percentage of random samples	12	Gigalithal (GI), Megalithal (ME), Macrolithal (MA), Mesolithal (MS), Microlithal (MI), Akal (AK), Psammal (PS), Pelal (PE), Detritus (DE), Xylal (XY), Sapropel (SA), Phytal (PH)
Cover	yes/no	11	Boulder (BD), Canopy shading (CS), Overhanging vegetation (OV), Roots (RO), Submerged vegetation (SV), Floating vegetation (FV), Emerging vegetation (EV), Undercut bank (UB), Woody debris (WD), Riprap (RI), Shallow margins (SM)
Froude number	(flow velocity)/(9.81 depth)$^{0.5}$	1	average over the GU area
Flow velocity standard deviation	cm/s	1	SD over GU area

2.3 Field data collection

GUs depiction and fish data collection were carried out following the MesoHABSIM protocols and standards (Vezza et al., 2017). In particular, by using a hierarchical structure of morphological classification (Belletti et al., 2017; Gurnell et al., 2014), it was possible to identify a morphologically homogeneous reach in each considered river with (i) limited hydrological and morphological alterations, and (ii) quite natural conditions of fish community composition. The study sites (Table 2, sub-reaches) were then selected and the GUs description was based on a mobile mapping technique defined in Vezza et al. (2017; 2014b). This mapping technique allowed the user to record the so called 'GUs mosaic', outlying the wetted perimeter of sampled mesohabitats and gathering all their abiotic and biotic factors (Table 1). It is based on the use of a rangefinder (LTI, Trupulse 360R), a rugged field computer (e.g., Panasonic Toughpad FZM1, with GPS positioning) and a geographic information system (GIS) software. In particular, by means of the rangefinder, the GU areas were delineated and stored in the GIS environment, and the mesohabitat-scale features (GU type, GU longitudinal connectivity, GU gradient, cover, shores characteristics) were recorded. Depth and velocity values were measured using a flow meter (e.g., Marsh McBirney Flo-Mate 2000) and substrate compositions were assessed from each of the mapped mesohabitats (Vezza et al., 2017). Moreover, at each river survey, flow discharge was measured at the beginning and the end of each study site. Finally, the recorded information was organized and processed with GIS software to produce detailed maps of the aquatic habitat in the study area. Fish data were collected by sampling each GUs within the study site with backpack electrofishing (i.e., two-pass removal method, Meador et al., 2003) before the GUs depiction. To ensure the direct association between sampled GUs and the captured fish species, each mesohabitat was kept separated by using nets (Vezza et al., 2014a). Collected fish were identified at species level and measured in terms of total length (TL) before being released within the same sampled mesohabitat. This latter measurement was then used to classify each specimen as adult or juvenile according to the length/age relationships reported in Vezza et al. (2012).

Table 2. Name, location, morphological classification, and characteristics of surveyed reaches. River morphology codes (according to Gurnell et al., 2014): C = confined; P = partly confined; U = unconfined; SS = straight-sinuous; M = meandering; PM = pseudo-meandering; B = braided. Reach width represents the mean value of the active river channel width in each surveyed reach.

River/Creek	Reach name	Region	UTM 32N coordinates	Catchment area [km^2]	Reach morphology	Reach length [m]	Reach width [m]
Argentina	1	Liguria	E: 359939.34 m; N: 5056504.41 m	209	C-SS	306	18
Belbo	2	Piemonte	E: 424991.19 m; N: 4925539.43 m	470	C-SS	92	8
Ghiandone	3	Piemonte	E: 406244.02 m; N: 4865984.92 m	100	U-M	160	15
Malacqua	4	Liguria	E: 373716.49 m; N: 4953060.71 m	30	C-SS	211	16
Orco	5	Piemonte	E: 401489.62 m; N: 5019384.86 m	913	P-PM	580	85
Pellice	6	Piemonte	E: 546950.03 m; N: 4979274.44 m	371	P-M	1500	105

Rabbies	7	Trentino-Alto Adige	E: 385031.57 m; N: 4963706.95 m	150	C-SS	132	9
Savara	8	Valle d'Aosta	E: 554450.8 m; N: 4899310.77 m	146	C-SS	235	20
Trebbia	9	Emilia-Romagna	E: 640563.97 m; N: 5140724.51 m	1070	U-B	760	400

2.4 Mesohabitat suitability criteria

Based on the available information about fish communities, as well as the data collected during the field campaigns, mesohabitat suitability criteria for 5 freshwater fish species were selected to test their transferability capabilities. These models were developed using the RF classification algorithm to distinguish between presence and absence of the fish, using field data collected at the meso-scale in several years of sampling in reference sites of the Italian Alps (Vezza et al., 2014a; Vezza et al., 2014b). For juvenile brown and marble trout a global model was considered since it's challenging to clearly identify the juvenile specimens from simple field recognition (Berrebi et al., 2000). Table 3 reports the species and the life stages for which the corresponding RF models were tested in terms of transferability among surveyed reaches.

Table 3. RF models of freshwater fish species and life stages considered in the study. For each model the reaches name in which it was applied with the corresponding total amount of sampled GUs are reported.

Species (Eng.)	Species (Lat.)	Life stage	Reach name	Sampled GUs
Brown trout	*Salmo trutta*	A	5, 8	72
Marble trout	*Salmo marmoratus*	A	5, 7	27
Juvenile trout	*Salmo trutta/marmoratus*	J	5, 7, 8	87
Bullhead	*Cottus gobio*	A	3, 6	16
Italian barbel	*Barbus plebejus*	A	1, 2, 3, 4, 5, 6, 9	105
Italian vairone	*Telestes muticellus*	A	1, 2, 3, 4, 5, 6, 9	105
		J	1, 2, 3, 4, 5, 6, 9	105

Models predictions in terms of GUs suitability were achieved by using SimStream-Web software (Vezza et al., 2017), a specific web service developed to apply the MesoHABSIM approach in Italy. The physical attributes of each GUs were taken into account in order to assess the rank of suitability (not suitable/suitable) of each sampled mesohabitats according to the application of a specific RF model. Models predictions were then compared with the observations collected during the field campaigns. Finally, to test model transferability, the predictive performances of considered RF models were assessed using four performance metrics, i.e. accuracy, sensitivity, specificity, and true skill statistic (TSS, Vezza et al., 2015; Allouche et al., 2006).

3. RESULTS

Field data consisted of 180 sampled mesohabitats distributed within the 9 study sites. In particular, most of the analyzed GUs were found to be as riffles (30% of total amount), followed by glides (21%), rapids (17%), and pools (14%). Whereas backwaters and cascades were respectively sampled only in the 6% and 5% of total GUs amount. In total, more than 5000 fish were captured within surveyed mesohabitats. Overall, the most common fish species was found to be the Italian vairone (*Telestes muticellus*), which represented 52% of total specimens. By way of example, in Figure 2 are represented (i) the GUs mosaic, and (ii) the observed and (iii) predicted distributions for adult brown trout (*Salmo trutta*) assessed in reach 8.
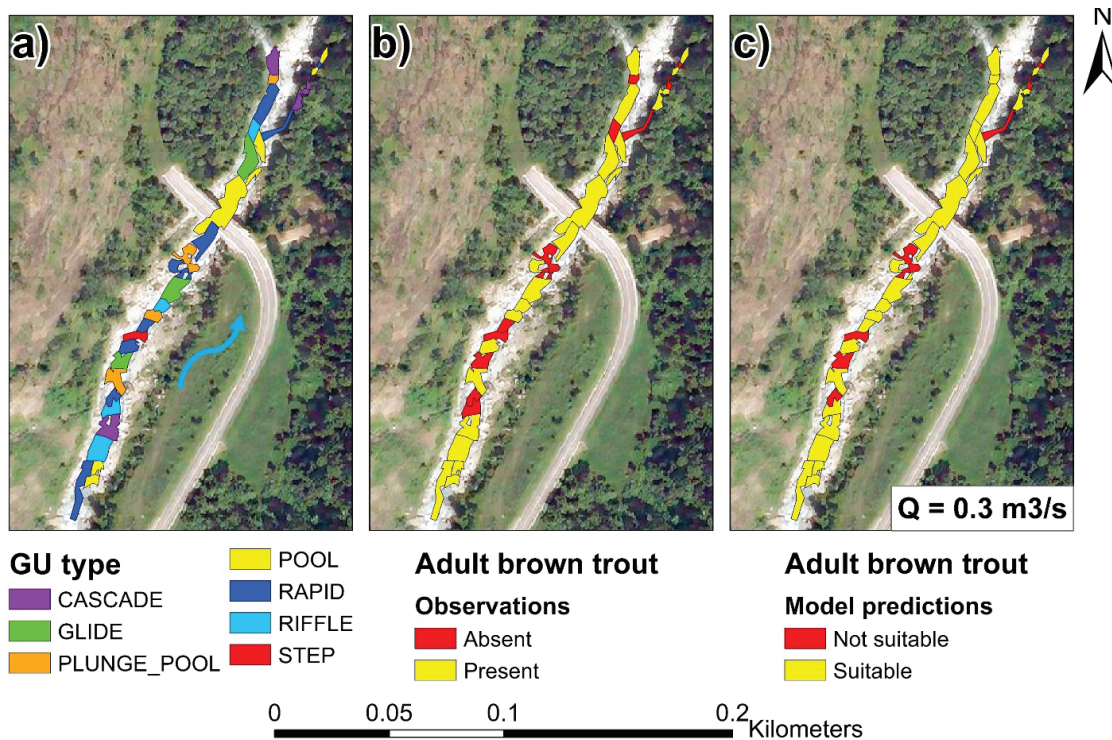
Figure 2. GUs, observed distribution, and habitat suitability map for reach 8. a) GUs mosaic and b) observed distribution for adult brown trout (*Salmo trutta*) assessed during the field campaign at 0.3 m³/s of discharge. c) predicted distribution for adult brown trout by the application of corresponding RF model.

The considered RF models showed quite high predictive performances for assessing the presence or absence of individuals within surveyed mesohabitats, with slight differences depending on the specific biological model (Table 4). Overall, models accuracy varied from 0.75 to 0.82 and TSS from 0.52 to 0.75, whereas sensitivity and specificity exhibited scores in range 0.75-1 and 0.72-1, respectively. Considering accuracy, the juvenile trout model showed the highest value (0.82), followed by the adult marble trout and bullhead models (0.81 each). These two latter models, furthermore, exhibited the highest TSS scores (0.75 for bullhead and 0.72 for marble trout). The Italian barbel model, on the contrary, resulted to be globally the least accurate (accuracy = 0.75 and TSS = 0.52). Finally, models sensitivity was generally assessed to be greater than specificity, except for bullhead, which exhibited the highest prevalence (0.75, ratio between fish presence and total observations).

Table 4. Predictive performances obtained for the considered RF models.

Species (Eng.)	Life stage	Prevalence	Accuracy	Sensitivity	Specificity	TSS
Brown trout	A	0.60	0.77	0.78	0.74	0.53
Marble trout	A	0.33	0.81	1.00	0.72	0.72
Juvenile trout	J	0.62	0.82	0.87	0.73	0.60
Bullhead	A	0.75	0.81	0.75	1.00	0.75
Italian barbel	A	0.40	0.75	0.80	0.72	0.52
Italian vairone	A	0.64	0.80	0.83	0.74	0.57
	J	0.68	0.78	0.80	0.72	0.53

4. DISCUSSIONS AND CONCLUSIONS

Results of the present application demonstrated that the considered mesohabitat suitability criteria based on RF can be considered transferable among streams of Northern Italy. In particular, we assessed quite high predictive performances for all analyzed models, no matter the considered life stage, the number of GUs used as validation dataset, and the spatial location of the surveyed river reaches. Such results, in our opinion, can be related to the structure of the MesoHABSIM approach, which (i) enables river habitat description using an ecologically relevant spatial scale, (ii) is based on a robust and adequate hydro-morphological

characterization of the analyzed geomorphic units, (iii) may include in the analysis a large range of biotic and abiotic environmental descriptors, not only at the point where the organism is observed.

Applying species distribution models to the entire Northern Italian territory should be of primary importance for environmental flow assessment and the design of habitat restoration measures. The use of validated mesohabitat suitability criteria can generate a robust habitat assessment for water abstraction licensing. Starting from 2017, MesoHABSIM has been increasingly used in Italy, as it was established as a reference method for environmental flows design and impact assessment of water abstractions (Vezza et al., 2017). In this regard, the present study can provide important insights for a wider application of this approach to the entire Italian context. Accordingly, further river sites, belonging for instance to the Center or Southern Italy, can be selected in order to increase the validation dataset and to verify models transferability in other regions. Furthermore, due to a general lack of knowledge on the habitat requirements for autochthonous Italian freshwater species (Negro et al., 2021), additional fish data collection and mesohabitat suitability criteria for different fish species should be developed and validated.

5. ACKNOWLEDGEMENTS

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