Doctoral Dissertation
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Habitat modeling in perennial and non-perennial rivers: developments and applications

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Summary

Rivers provide essential ecosystem services for human well-being and supply habitat for a vast multitude of animal species. However, river ecosystems are facing degradation and biodiversity loss due to significant pressures from hydrological and morphological alterations caused by water abstractions and hydropower generation. To preserve freshwater ecosystems and enhance water resource management, meso-scale Habitat Suitability Models (HSMs) are increasingly recognized as valuable tools. In particular, the MesoHABitat SImulation Model (MesoHABSIM) has proven effective for assessing the impact of water abstraction and designing ecological flows (e-flows) in regulated rivers, promoting more sustainable water use while preserving river ecosystems and the services they provide. MesoHABSIM uses geomorphic units (GUs or mesohabitats) and their local hydro- (e.g., water depth and flow velocity) morphological (e.g., substrate, channel geometry) attributes to quantify the physical habitat availability for freshwater species. Habitat assessments rely on habitat suitability criteria (HSC, or species distribution models), which link hydro-morphological features to species' habitat preferences. However, broader implementation of MesoHABSIM is hindered by gaps in knowledge regarding habitat preferences of freshwater species and, consequently, in the availability of validated HSC. Additionally, river habitat modeling have traditionally focused on perennial rivers, neglecting non-perennial rivers (NPRs), which constitute over half of the global stream network. Main constraints include limited knowledge on the spatio-temporal distribution of flow intermittency within river networks and the lack of theoretical approaches and analytical tools to properly model habitat evolution when discharge is close or equal to zero (i.e., during non-flowing periods).

This thesis focuses on advancing meso-scale habitat modeling for both perennial and non-perennial rivers, enhancing the applicability of the MesoHABSIM approach, particularly in Italy.

Part I focuses on developing new HSC for Italian endemic and threatened freshwater species in perennial rivers. A systematic literature review compiled physical habitat preferences for 31 freshwater fish species and 3 freshwater lampreys, representing 75% of Italy's endemic freshwater fish community. This review highlighted significant information deficits for over 30% of these species, particularly during critical spawning periods. To address these gaps, meso-scale HSC were developed and tested for the Italian vairone (*Telestes muticellus*) and applied to a regulated river reach, demonstrating practical application of collected literature information. According to the findings from the literature review, further studies were conducted to develop new empirical meso-scale HSC for two Italian threatened freshwater species, for which little quantitative data existed. Specifically, data on habitat preferences for the Po brook lamprey (*Lampetra zanandreai*), an autochthonous freshwater lamprey, were gathered, identifying significant mesohabitat attributes and sediment requirements for species distribution. The analysis was performed by training a Random Forest (RF) model which allowed the definition of the first meso-scale HSC in literature for considered lamprey. The results indicated that lamprey ammocoetes can play a crucial role as indicators of river ecosystem quality within the Po river basin, offering insights for more targeted investigations. Meso-scale HSC were also developed for the spawning period of the anadromous Twaite shad (*Alosa fallax*). The study was conducted in the Tagliamento river (Northeastern Italy), using Uncrewed Aerial Systems (UAS) and a two-dimensional (2D) hydrodynamic model to characterize local hydro-morphological features. Key spawning mesohabitat requirements were again identified using a RF model, which allowed the definition of the first meso-scale HSC in literature for an anadromous species during the spawning period. To observe and record the mating behaviour of the monitored *Alosa fallax* population, infrared cameras were deployed over two consecutive nights. Analysis of the video revealed mating behaviour consistent with previously reported findings in the literature, thereby enhancing the understanding of the reproductive ecology of Mediterranean populations of shads. These findings can contribute to developing effective conservation strategies and fisheries management practices for this species. Finally, meso-scale HSC for five fish species, previously developed and made available for applications of the MesoHABSIM approach in Italy, were tested in terms of transferability across different rivers. HSC predictions were compared with field data on fish distribution within GUs from nine rivers distributed in Northern Italy. The study demonstrated high predictive performance for considered HSC, suggesting effective transferability among streams.

Part II of this thesis concentrated on NPRs. An innovative approach to assess the spatio-temporal distribution of flow intermittency within river networks is presented. It is based on the use of multispectral Sentinel-2 images to monitor changes in water surface presence along NPRs. By identifying the main hydrological conditions (flowing, ponding and dry conditions) which mark NPRs using a supervised classification of satellite images, and developing RF models to predict these conditions on a daily scale, the study demonstrated a high-accuracy method with significant potential for the identification and hydrological characterization of NPRs. In the last study, the new module of the MesoHABSIM approach dedicated to NPRs (i.e., NPRs-module) is introduced using a practical application. Specifically, by integrating the new NPRs-module with remote sensing information and locally recorded hydrological data it was effectively possible to assess the aquatic habitat availability during both flowing and non-flowing conditions in a regulated and non-perennial reach of the Sangone river (Northwestern Italy). This new NPRs-module represents a significant advancement in river habitat modeling tools for preserving aquatic ecosystems and biodiversity in non-perennial streams.