A SHORT REVIEW OF HYDRAULIC-HABITAT MODELLING FOR ENVIRONMENTAL FLOWS

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Abstract

This research is embedded into the FlowTech project which focuses on the estimation of river environmental flows. Human interventions to natural streamflow are rising; most of the time these disruptions do not consider environmental needs. Several methods of environmental flow estimation have been developed in different parts of the world addressing different goals and levels of protection. Due to the large number of streams involved and money-manpower limitations, methods developed and used must be simple and require little field investigation. The integration of in-stream fish habitat and hydraulic modelling is among the most advanced approaches for estimating environmental flows based on biological criteria. In this study we reviewed the current knowledge and literature developed to estimate fish habitat availability for environmental flow requirements. Among our main findings are that parameters such as the selection of fish species and their habitat preferences during their life cycles, their relationships within ecosystems, the spatial and temporal scales that represent habitat, and the validation strategies, are considered crucial for the estimation of the water required to sustain aquatic habitats and that those methods need to be used within a wider decision support framework to define a flow regime for both the environment and human health.

Keywords: flow regime, habitat, fish, hydraulic, modelling, ecohydraulic.

1. Introduction

Hydromorphological pressures alter the natural flow regime of rivers and can be directly linked to impacts on their physical and chemical attributes and processes. The environmental flow regime is a key element in determining river processes, affecting ecosystem health. Methods addressed to estimate environmental flows are classified into four different categories (Tharme, 2003): hydrological methods (e.g., Karimi *et al.,* 2012), hydraulic methods (e.g., Gippel & Stewardson, 1998), physical habitat methods (e.g., Papadaki *et al.,* 2016) and holistic methods (e.g., McClain *et al*., 2014).

A river ecosystem is affected by many parameters, so the delineation of different habitat types will facilitate comprehending the mechanisms by which the river operates as an ecosystem. Habitat simulation methods for environmental flow assessment and estimation attempt to interpret the importance for fish of these patterns of flow within channels, primarily resulting from the geometry of the channel. Simulated discharge through the means of a hydraulic model, aims to find an optimal flow such that the amount of physical habitat for the selected fish species does not decline beyond a subjectively determined conservation level (Linnansaari *et al.,* 2013).

Among the most widespread approaches for exploring the relationship between stream flow and physical habitat is the Physical Habitat Simulation System (PHABSIM), the Instream Flow Incremental Methodology (IFIM) and the Ecological Limits of Hydrologic Alteration (ELOHA) framework for determining and implementing environmental flows at the regional scale (Poff *et al*., 2010). IFIM methodology was designed by a multidisciplinary United States Fish and Wildlife Service team of biologists, hydrologists, engineers and computer scientists working together in Colorado in the 1980s. PHABSIM quantifies an aquatic habitat in terms of physical variables such as flow depth, velocity, and substrate (Bovee 1982). Apart from PHABSIM habitat hydraulic modelling methods have been applied by many countries either as physical habitat modelling or as independent approaches (Acreman & Dunbar, 2004). Instream physical habitat models were firstly introduced and developed to estimate flow requirements below dam constructions in North America (Bovee 1982). Later, those methods were applied to various relevant problems such as flow alteration caused by manmade hydromorphological changes, including instream channelization, and hydropeaking (Boavida *et al.,* 2012). Additionally, environmental flow or minimum flow was also estimated using physical habitat simulation (Heggenes *et al.*, 1996; Katopodis, 2005; Dunbar *et al.*, 2012; Papadaki *et al.*, 2016; Nikghalb *et al.*, 2016; Armas-Vargas *et al.*, 2017; Stamou *et al.*, 2018).

2. Important Parameters for applying habitat hydraulic simulation for environmental flow estimations

2.1 Ichthyofauna and habitat suitability

The fish fauna is considered as the most sensitive Biological Quality Element (BQE) to river flow changes and is a key factor of the inter-relations among many BQEs. The target species for conducting ecohydraulic modelling should reflect the environmental constraints on the overall community and their abundance should be dependent on environmental changes that affect specific habitat variables related to important life cycle events (e.g., spawning season). Many previous studies have focused on migratory species (Ferguson *et al*., 2011; Mendes *et al.,* 2021), headwater (rhithron) (Meyer *et al.,* 2007) and/or endangered species or particular fish species (e.g., salmonids) which have an important economic value and attract public attention. Techniques which have traditionally been used for fish habitat measurements are direct observations from the river banks, snorkeling, electrofishing (Heggenes *et al.,* 1991; Martínez-Capel *et al.,* 2009; Papadaki *et al.,* 2016), and various fish telemetry methods, including the use of acoustic or radio transmitters and Passive Integrated Transponder methods (Linnansaari *et al.,* 2009).

2.2 Relationships within ecosystems

All components of the flow regime are important for aquatic organisms. Relationships among streamflow, habitat conditions, temperature, and the distribution, growth, and abundance have been most extensively studied for summer months (Barbieri *et al*., 2021). Reference to anthropogenic pressures is also a rising research topic; and most sampling work is also during summer flows (Tachos *et al.,* 2022; Vavalidis *et al.,* 2021). Summer months represent the main growing season for most fishes, and changes to stream temperature may affect fish metabolism, feeding, and growth (Zorn *et al*., 2012). Moreover, previous studies have shown that high discharge is correlated with larger and more frequent movements, and that extreme low discharge could also induce movement if habitat is being de-watered (e.g., Taylor & Cooke 2012).

2.3 Spatial and temporal scales to represent the fish habitat

The spatial patterns of depth, velocity, and substrate are important factors for the habitat of river fishes. Research studies have aimed at quantifying and establishing hydro-physical variables in both microhabitats and a larger spatial scale (mesohabitat), such as the number of reaches or an entire drainage basin. In spite of technological advances that allow for more comprehensive data collection, hierarchical scaling procedures are often required to optimize the field work and data collection protocol. As well, upscaling is often required to extend results produced for single species to an entire community, and to select a regime associated with the proper time scale (Parasiewicz, 2003; Duel *et al*., 2003). Selection of representative river reaches are crucial for the estimation of environmental flows when applying the aforementioned methods, considering them to represent samples of healthy aquatic habitats. Delimitation of a section of a river down to smaller river sections, within which a representative river reach will be defined including important habitat types and Hydro-Morphological Unit types (HMU), according to their depth and flow characteristics. In situ studies conducted for fish habitat selection covering all likely spatial and temporal heterogeneity are not possible. Therefore, the ecohydraulic modelling at spatial and temporal scales relevant to the fish, and based on presumably representative samples of stream sections (Bovee, 1982; 1986). Moreover, habitat availability estimations of aquatic organisms in a natural, non-regulated river act as the reference condition for comparing the degree to which an environmental flow scenario deviates from the natural flow regime (Boavida *et al.,* 2012).

2.4 Modell and Validation

Validation is usually recognized as an essential step in any modelling effort. Model validation consists of ensuring that both the biological parameters in habitat models and the numerical modeling in the hydraulic models is adequate by comparing model results to observed values (Leclerc *et al.*, 2003). Inevitably modelling involves several sources of uncertainty such as the input data the model structure and the internal model parameters (Papadaki *et al.,* 2017; Papaioannou *et al.*, 2021). Moreover, previous studies showed that, in complex river topographies where flows have local variations, the use of a 2D model is important in the assessment of flow alteration effects associated with water resource projects and habitat modelling (Leclerc *et al.*, 1995; Jowett & Duncan, 2012) and the investigation of spatiotemporal variability of available habitats using 2D models can be affected by the data set and the methodology followed for the digital terrain model (DTM) generation, which therefore affects the hydraulic characteristics and the habitat availability.

4. Discussion/Conclusion

Incorporating fish species and their associations with the hydrologic regime, may provide flow prescriptions which can meet human water requirements. Ecohydraulic models provide researchers and managers with important tools for the evaluation of flow regime alterations on many aspects of the riverine environment, including riparian ecosystems, river connectivity, and managing flows according to either reference physical habitat conditions, thresholds, rates of change or minimum values (Dimitriou & Papadaki, 2021). Aspects that need improvements include: the range of abiotic variables considered; modelling of habitat preference; modelling strategies in the context of multi-specific use of rivers; fish behavior related to winter conditions and model validation strategies. Finally, recent improvements of technology can provide the necessary support to overcome the obstacles and produce reliable environmental information for the estimation of environmental water needs. Incorporation of cutting-edge technology (e.g., high-resolution bathymetric; habitat types and habitat availability maps) will significantly improve the amount and accuracy of information that is necessary for a scientific understanding of how changes in the natural flow regime affect ecological conditions (Papadaki, 2021). Additionally, possible human interactions and resource competition within aquatic ecosystems and water should be analyzed within a holistic approach. In conclusion, future research on environmental flows and ecohydraulic modelling should be carried out within an integrated approach in which instream flow will benefit the overall understanding of the ecological functioning of river systems, as well as the potentially changing environmental conditions such as climate change effects.

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