FROM MICROHABITAT ECOHYDRAULICS TO AN IMPROVED MANAGEMENT OF RIVER CATCHMENTS: BRIDGING THE GAP BETWEEN SCALES

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Ecohydraulic studies in rivers range from local-scale studies, which target a better understanding of the mechanisms underlying biological responses to microhabitat hydraulics, to large-scale studies, which address the influence of hydro-morphological management on catchment biodiversity. A major challenge in the field is to bridge the gap between local- and large-scale studies, in order to base the large-scale physical management of rivers on general and transferable ecohydraulic processes. This Special Issue includes ten articles that illustrate progresses and difficulties to bridge this gap. It gathers microhabitat-scale studies focused on the identification of major ecohydraulic mechanisms, reach-scale studies that typically target generality and transferability across reaches, and examples of catchment scale management based on general ecohydrological knowledge. The Special Issue illustrates how ecohydraulics have evolved to better integrate dynamic physical processes, ecological concepts and the consideration of ecosystem services. Although this remains challenging in practice, the Special Issue shows the need to integrate dynamic hydraulic descriptors of the environment for improving the cost-effectiveness of large-scale river management and restoration. These articles were presented at the 10th International Symposium on Ecohydraulics in Trondheim, Norway (2014), where the first symposium on ecohydraulics was organised 20 years before. The 10th issue of the symposium celebrated 20 years of ecohydraulic research and had about 300 delegates, giving 194 talks and presenting 86 posters.

UPSCALING MICROHABITAT ECOHYDRAULICS AT THE REACH-SCALE

The complex structure of microhabitat hydraulics has long been recognized as important for aquatic organisms (e.g. Statzner et al., 1988; Rice et al., 2010). Microhabitat hydraulics depends on complex combinations of catchment and local processes (e.g. Doyle et al., 2005), and are still difficult to model and take into account in ecohydraulic studies. In particular, the physics of interstitial microhabitats (e.g. hydraulic conductivity, water temperature and dissolved oxygen), their dynamics (e.g. colmation or de-colmation processes) and management (e.g. flushing flows) are of major importance for aquatic biota. Noack et al. (2017) present a habitat-based modelling approach for simulating an "interstitial habitat suitability" at the reach scale that considers dynamically varying interstitial microhabitat conditions during the egg and larval stages of gravel-spawning fish. Although this approach requires an important effort (combinations of field measurements and three-dimensional sediment transport modelling), it provides interesting ideas for considering hyporheic microhabitats in habitat models. Therefore, this research has been considered of great importance for future developments in habitat modelling for macroinvertebrates and lithophil fish.

Anderson et al. (2017) compare macroinvertebrate communities in habitat patches around the outlet of a run-of the-river hydropower scheme. They illustrate the influence of microhabitat hydraulics on aquatic assemblages in detail, and reveal independent effects of near-bed velocities and turbulence characteristics (Roy et al., 2010). Interestingly, considerations at the micro-scale and meso- or patch-scale were incorporated in the analyses, providing insights on the scale-dependent evaluation of impacts. One of the relevant outcomes of such analyses is the need to upscale the effect of microhabitat hydraulics at the meso- and reach-scale when inferring the impacts of hydropower schemes, because the impact of hydropower on macroinvertebrate assemblages (moderate in this study) often depends on the power plant configuration and operation. The reach-scale analysis of vegetation changes in regulated and unregulated river reaches shown by Martínez-Fernández et al. (2017), confirms that a better understanding of sediment-flow interactions with the riverbed substrate and the riverbanks are crucial to understand large-scale processes induced by afforestation changes, farmland abandonment and construction of dams. This is clear in their long-term analysis of ortho-photos over several decades since the 1950’s, from a morphological (e.g. narrowing, braiding index), hydrological and ecological perspective. They explain how these catchment-scale processes impact species composition and age structure in river and riparian vegetation. In regulated reaches, mature and late-seral species were much more abundant than in non-regulated reaches, where pioneer species also occurred. A relevant lack of recruitment of Salicacea pioneer species were found in regulated rivers, in coherence with hydrological changes such as flood disturbance decrease and summer minimum flows increase.

Egger et al. (2017) proposed reach-scale "time and intensity weighted" flow indices that can reflect the history of flood magnitudes (velocities and shear stresses) and durations. These indices are derived from dynamic combinations of one- and two-dimensional hydraulic models. Using demonstration reaches of the Kootenai River in USA and Canada, they show consistent links between their indices and differences in vegetation successional stages. Such methods can guide river restoration and mitigation measures, in order to reduce potential impacts from human alterations on river flows and riparian zones.

TOWARDS CATCHMENT-SCALE ECOHYDRAULIC MANAGEMENT

It is important to translate flow characteristics into hydraulic parameters. However, spatial and temporal extrapolations of hydrological characteristics are often difficult and uncertain (Lamouroux et al., 2014). Whereas most catchment-scale ecohydrological studies consider daily flow values, Hailegeorgis and Alfredsen (2017) investigated different methods to model unregulated hourly flow duration curves in ungauged rivers. This is an essential step for assessing hydrological alterations due to hydropeaking (rapid changes in flow rates below hydropower plants for addressing the needs of flexible electricity generation). They found that simple regression models relating flow duration curves to drainage areas, and transfer of streamflow time series information from nearby catchments, outperformed other methods to model ungauged rivers.

Macnaughton et al. (2017) used statistics of hourly and daily discharge variations to infer the impacts of hydrological alteration on fish communities in 10 regulated and 14 unregulated Canadian rivers.

They found that observed fish community alteration was particularly strong in hydropeaking reaches, although the key hydrologic or hydraulic variables responsible for fish response were still difficult to identify. This is very promising for management applications to allow rapid assessment of potential impacts of changes in the hydrological regime.

Martinez-Capel et al. (2017) also used flow indices to compare climate change scenarios and create flow-ecology relationships to assess environmental flows, in the Zambezi River, Namibia. Interestingly, they used remote sensing to translate some of their flow indices into flooding area and flood duration in the catchment, for critical habitats extracted from GIS. The extracted physical habitat descriptors, e.g. area-duration curves and estimated annual habitat, are important indicators for the quality of fisheries and many other ecosystem services provided by the river and its floodplain. Remote sensing, in combination with hydrological indices at a daily and monthly time scale, simulation of climate change scenarios and environmental flow components (Mathews and Richter, 2007), provide an example of flow-ecology models as a basis for environmental flow recommendations, monitoring and research programmes.

Seliger et al. (2016) developed a decision support tool that integrates energy-economic characteristics of planned hydropower plants and conservation needs of ecologically sensitive river reaches. The tool combines technical and economic data for hydropower development with ecological criteria and conservation scenarios to support planning and prioritisation among alternative hydropower plant locations. This tool is applicable at regional and national levels. The elements retained to describe the ecological sensitivity involve the degree of alteration of physical habitats and the knowledge on distribution and abundance of species sensitive to physical habitat alterations. Integrating hydraulic habitat issues is not an easy task in such holistic tools, but Seliger et al. (2016) has shown a good example of improved holistic decision-making for sustainable hydropower development at large spatial scales.

Parasiewicz et al. (2017) provide an example of efforts to upscale dwarf wedge mussels response to complex microhabitat characteristics (e.g. local Froude numbers and Reynolds numbers of bed particles) at the catchment scale in the Upper Delaware River, USA. For this purpose, they combine surveys of mesohabitats (e.g. pools, runs, riffles) in the catchment at different discharge rates, numerical modelling of selected reaches, and field surveys of mussel abundance. This illustrates the possibility to upscale responses to complex microhabitat hydraulics. Their case study shows that improving the duration of suitable habitats for dwarf wedge mussel would require morphological improvements rather than flow manipulations alone.

Although connectivity issues are poorly represented in this Special Issue, the study of Nzau Matondo et al. (2017) illustrates that local hydraulics (e.g. fish pass configurations) can have important consequences for connecting functional habitats at catchment scales (Vowles et al., 2013). They investigated the migration dynamics of eels in the Meuse River in Belgium, with interesting insights on the behaviour of the eels at a site far from the tidal limits, analyzing if different fish passes were effective to support their migration. They found that the significant period to evaluate fish passes efficiency for eels was short and probably influenced by temperature, but did not find differences among the targeted fish passes, suggesting a low efficiency that deserves further studies. Finally, this article provides key understanding for eel management, such as the importance of seasonal maintenance and improvement of fish pass design and the enhancement of monitoring methodologies in European rivers.

CONCLUSION

Hydraulic description of habitats at the catchment scale is still challenging due to the difficulty to obtain reliable hydraulic estimates at large scales. However, the articles in this Special Issue provide examples of progresses made in this direction. Ideally, future environmental flow assessments at large scale will focus on the key habitat descriptors for the communities of interest, expressed by hydraulic characteristics such as inundation magnitude and durations or hydraulic suitability rather than flow statistics alone. Such habitat descriptors need to be estimated for seasons and at time scales appropriate for organisms (e.g. accounting for sub-daily variations when studying hydropeaking). We hope that this Special Issue and as well as rapid progresses in the large-scale physical description of streams and their floodplain will stimulate research towards this goal.

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