Using habitat indices to quantify the impact of hydromorphological alterations

Utilisation d'indices d'habitat pour quantifier les altérations hydromorphologiques

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RÉSUMÉ

Ce papier vise à proposer des indices d'habitat développés sur la base d'un modèle de simulation de mésohabitat (MesoHABSIM) et d'une analyse de séries temporelles d'habitat. Ces indices représentent des métriques qui quantifient l'impact des modifications hydro-morphologiques sur les communautés aquatiques. Deux indices d'habitat sont définis pour évaluer l'altération spatiale et temporelle des habitats de rivière. L'indice de disponibilité spatiale d'habitat (ISH) est utilisé pour évaluer la perte relative moyenne d'habitat et l'indice de disponibilité temporelle d'habitat (ITH) est utilisé pour mesurer l'augmentation de la durée ininterrompue d'événements qui représentent des goulets d'étranglement de l'habitat créant du stress pour la faune. Des études de cas provenant des zones montagneuses du nord de l'Italie sont présentées pour fournir des exemples d'application. Les résultats obtenus indiquent que (i) la méso-échelle peut être considérée comme une résolution appropriée pour relier les exigences de la faune en termes d'habitat aux caractéristiques hydromorphologiques des cours d'eau et des outils flexibles et que (ii) les indices proposés peuvent être considérés comme capables de capturer à la fois l'altération spatiale et temporelle de la structure d'habitat et peuvent être développés pour différents types de pressions (par exemple, les prélèvements d'eau pour la production hydroélectrique, les éclusées, etc.).

ABSTRACT

The present work aims at proposing habitat indices developed with the support of a mesohabitat simulation model (i.e. MesoHABSIM) and the habitat time series analysis. Such indices represents metrics which quantify the impact of hydro-morphological alterations on the aquatic communities. Two habitat indices are defined to evaluate the spatial and temporal alteration of instream habitats. The Index of Spatial Habitat availability (ISH) is used to describe the relative amount of habitat loss; the Index of Temporal Habitat availability (ITH) is used to measure the increase of continuous duration of events when habitat bottlenecks create stress to the fauna. Case studies from the mountainous areas of Northern Italy are presented to provide example of applications. The results obtained indicate that (i) the meso-scale can be considered as an appropriate resolution to link habitat requirements of fauna to fluvial morphological characteristics and (ii) the proposed indices can be considered flexible tools since they can capture both spatial and temporal alteration of habitat structure and can be developed for different kind of pressures (e.g. water withdrawals for hydropower generation, hydropeaking, etc.).

KEYWORDS

Habitat indices, Mesohabitat, Fish community, Alpine streams, Hydropower

1 INTRODUCTION

The impact of water abstractions and hydro-morphological alterations on the aquatic ecosystems can be measured by assessing the effects on the biota or on its habitats. The former is difficult to accomplish because of the following: (i) the natural biological variability can increase the field data uncertainty; (ii) collection of field data for certain biotic component, such as fish, con be difficult due to their spatial and temporal mobility; (iii) after an hydro-morphological disruption, the time-lag required for populations recruitment can be long; and (iv) the instream hydro-morphological characteristics may not be the only drivers of species distribution (e.g. influence of restocking, angling, presence of alien species, etc.). Therefore, the use of a spatial unit of habitat suitable for the desired aquatic community can be seen as a more pragmatic and accurate metric in describing the impact of hydro-morphological alterations on biota [1].

The present work proposes two new habitat indices to quantify the impact of hydro-morphological alterations on the fish community, through the support of a mesohabitat simulation model (MesoHABSIM) and the habitat time series analysis. The MesoHABSIM model [2, 3] refers to mesohabitats or hydro-morphological units (HMU, such as pools, riffles or rapids) to integrate system-scale assessment of ecological integrity in flowing waters with quantitative information on instream habitat distribution and to simulate habitat changes over a range of discharges. The habitat time series represent how habitat changes through time and their statistical analysis can be useful to identify stress conditions created by persistent limitation in habitat availability. To quantify spatial and temporal alteration of habitat structure, we propose the Index of Spatial Habitat availability (ISH) to define the amount of habitat loss, and the Index of Temporal Habitat availability (ITH) to measure the increase of continuous duration of habitat events, which are stressful for the fauna.

2 METHODOLOGICAL DESCRIPTION

The starting point in establishing reference habitat for the fish community is the determination of hydro-geomorphic needs of all fish species. Habitat suitability models use this information to quantify the amount of suitable habitats under specific environmental conditions (figure 1). Because in rivers water flow is a primary factor influencing habitat availability, this relation is captured with the help of habitat-flow rating curves. The rating curves are then used to convert flow time series into habitat time series, which are statistically analysed using the Uniform Continuous Under Threshold (UCUT) curves [3]. UCUT curves describe magnitude, frequency and duration of habitat events and each curve represents the cumulative duration of events when habitat is lower than a specified quantity for a continuous duration of days. Details on UCUT curves construction and interpretation are reported in [3].

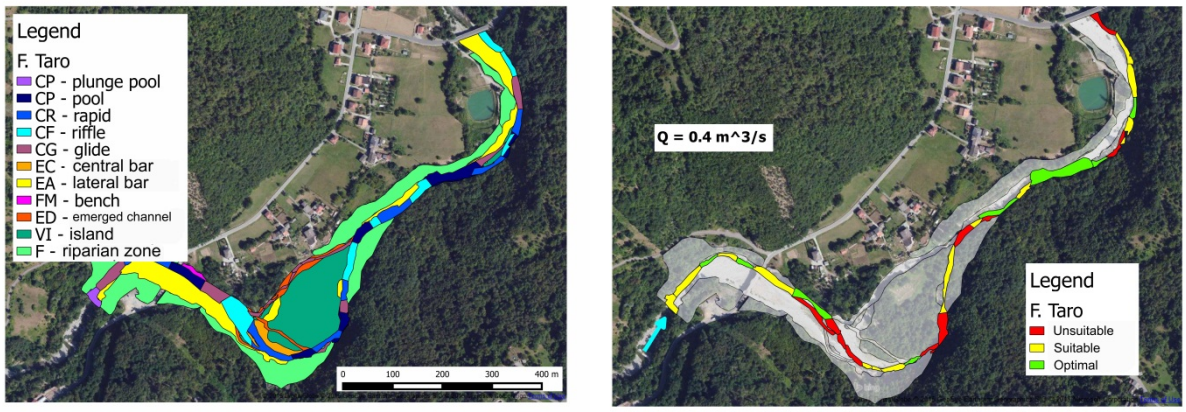

Figure 1 – River Taro (Italy): example of identification of spatial distribution, for a specific flow discharge (0.4 m^3/s in this case), of hydro-morphological units (left) and associated habitat suitability (right), through the application of a habitat suitability model

The Index of Spatial Habitat availability (ISH) (Eq. 1) represents the average habitat alteration in a defined period. Using the obtained habitat time series, it can be calculated at the annual scale as the

ratio between the average available habitat area (expressed in m^2) in reference hydro-morphological conditions ($A_{H,r}$) and altered conditions (A_H). Hydro-morphological reference conditions are calculated in the absence of the considered water abstraction. Finally, ISH value for the entire fish community is defined by the minimum value among all target fish species (and possibly life stages) in the river section.

$$ISH = min\left(\begin{cases} 1 - \frac{|A_{H,r} - A_H|}{A_{H,r}}, & \frac{|A_{H,r} - A_H|}{A_{H,r}} \leq 1 \\ 0, & \frac{|A_{H,r} - A_H|}{A_{H,r}} > 1 \end{cases}\right)_{species} \qquad \text{(eq. 1)}$$

The UCUT analysis is based on the assumption that habitat is a limiting factor, and events occurring rarely in nature create stress to aquatic fauna and shape the community. For each habitat threshold (expressed in m^2), one can calculate the number of habitat stress days (HSD) that occur under those desired conditions and use it as a benchmark for comparative analysis. Thus, The Index of Spatial Habitat availability (ITH) compares duration of under-threshold events in both reference and altered conditions. In this paper, the calculation of ITH is related to low flows to investigate duration and frequency of minimum habitat availability. Q_{97} (the flow value exceed 97% of the time) is then used to represent the low flow regime and to define the rare habitat stressor threshold (A_{Q97}, expressed in m^2). As an indicator of stress days alteration, i_{SDA} reports the average distance between two UCUT curves representing cumulative duration of habitat under-threshold events in reference ($d_{c,r,AQ97}$) and altered ($d_{c,AQ97}$) conditions. This average distance is calculated for each target species (and life stages) over the entire range of durations below threshold (i.e., between 1 and $d_{max,r}$, eq. 2).

$$i_{SDA} = \frac{1}{k} \cdot \sum_{k=1}^{k=d_{max,r}} \left(\frac{|d_{c,AQ97} - d_{c,r,AQ97}|}{d_{c,r,AQ97}}\right) \qquad \text{(eq. 2)}$$

The ITH index is finally calculated using the value function expressed in eq. 3, in which an exponential was preferred to a linear relationship, in order to give more importance to low stress days alteration. As for ISH, ITH community value is given by the minimum value among target species.

$$\mathrm{ITH} = \min\left(e^{-0.38\, i_{SDA}}\right)_{species} \qquad \text{(eq. 3)}$$

3 RESULTS AND DISCUSSION

The approach presented was applied in Italy in mountainous areas of the Alps and Apennines and the two indices demonstrated the adequacy of such habitat metrics to describe and evaluate the impact of water abstractions and hydro-morphological alterations. The proposed indices can be considered flexible tools since they can capture both spatial and temporal alteration of habitat structure and they can quantify the effect of both hydrological and morphological alteration on the aquatic habitat; moreover the analysis can be carried out for different kind of pressures. Further applications and testing of the indices are foreseen for water bodies affected by hydropower production, including hydropeaking and reservoir sediment management.

REFERENCES

[1] Parasiewicz P, Ryan K, Vezza P, Comoglio C, Ballestero T, Rogers JN (2012). Use of quantitative habitat models for establishing performance metrics in river restoration planning, *Ecohydrology,* 6, 4, 668–678

[2] Parasiewicz P (2007). The MesoHABSIM model revisited, *River Research and Applications,* 23, 8, 893-903

[3] Parasiewicz P, Rogers JN, Vezza P, Gortazar J, Seager T, Pegg M, Wiśniewolski W, Comoglio C (2013). Applications of the MesoHABSIM Simulation Model. In: *Ecohydraulics: an integrated approach: 2013*: John Wiley & Sons Ltd; 109-124