Habitat Indices for Rivers: Quantifying the Impact of Hydro-Morphological Alterations on the Fish Community

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Abstract

Habitat simulation models are effective tools which can be used to estimate spatial and temporal habitat availability for aquatic organisms, and to design and evaluate habitat restoration actions. Based on the meso-scale resolution, the present work proposes two indices to evaluate the spatial and temporal alteration of instream habitats. Firstly, the Index of Habitat Quantity (I_{HQ}) describes the relative amount of habitat loss due to flow diversion, and, secondly, the Index of Habitat Stress Days (I_{HSD}) measures the increase of continuous duration of events when habitat bottlenecks create stress to the fauna. Two case studies from the mountainous areas of Northern Italy are presented as applicatory examples. The achieved results indicate that (i) the meso-scale can be considered an appropriate scale resolution to link fish habitat requirements to fluvial morphological characteristics, and (ii) the proposed indices are flexible tools since they can capture both spatial and temporal alterations of habitat structure and can be applied to different kind of pressures (e.g., hydropower generation, hydropeaking).

Keywords

Habitat indices • Fish community • Mountainous streams • Hydropower

75.1 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 uncertainty of field data; (ii) the collection of field data for some biotic component, such as fish, can be difficult due to their spatial and temporal mobility; (iii) after an hydro-morphological

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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). Therefore, the use of a spatial unit of habitat suitable for the desired aquatic community may represent a more pragmatic and accurate metric to describe the impact of hydro-morphological alterations on biota (Parasiewicz et al. 2012).

The present work proposes two 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 (Parasiewicz 2007; Parasiewicz et al. 2013) 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 (Milhous et al. 1990). To quantify spatial and temporal alteration of habitat structure, we propose the Index of Habitat Quantity (I_{HQ}) to define the amount of habitat loss, and the Index of Habitat Stress Days (I_{HSD}) to measure the increase of continuous duration of habitat events, which are stressful for the fauna.

75.2 Study Area

The mountainous areas of northwestern (NW) Italy, located in Valle d'Aosta, Piemonte and Liguria Regions, are the study domain of this research. The climatic characteristics of this area range from the Apennine-Mediterranean climate of Liguria and southeastern hills of Piemonte, to the Alpine-Continental one in the NW Alps of Piemonte and Valle d'Aosta (Vezza et al. 2010). In the first zone, watersheds are characterized by little snowpack storage, high evapotranspiration and summer low flows, while in the second one, low flows occur in winter affected by freezing processes, presence of glaciers and snow cover accumulation (Vezza et al. 2014b).

In this paper, two case studies, located in the Alpine (case study #1) and in the Apennine (case study #2) mountain ranges, are reported as examples of application.

75.3 Methodological Description

The starting point in establishing reference habitat for fish community is the determination of the hydro-geomorphic needs of all fish species. Habitat suitability models use this information to quantify the amount of suitable habitats under specific environmental conditions (Parasiewicz et al. 2012; Vezza et al. 2014a). This allows in turn an adjustment of physical attributes of a stream or river to create a hydro-geomorphic structure that matches the biological structure (Parasiewicz et al. 2012). Because the amount of water in rivers (i.e. flow) is a primary factor influencing habitat availability, this relation is captured with the help of habitat-flow rating curves (Fig. 75.1). The Index of Habitat Quantity (I_{HQ}) uses this habitat-flow relationship to quantify the alteration of habitat availability under the most common discharge conditions (i.e., the mode value from the streamflow record, Q_{mode}). For each species, I_{HQ} is then estimated as the ratio between the available suitable area (expressed as planimetric area in m^2) in reference ($A_{Qmode,r}$) and altered conditions (A_{Qmode}, Eq. 75.1). Hydrological reference conditions ($Q_{mode,r}$) are calculated in the absence of the considered water abstraction. Finally, I_{HQ} 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.

$$I_{HQ} = min\left(1 - \frac{\left|A_{Qmode,r} - A_{Qmode}\right|}{A_{Qmode,r}}\right)_{species} \tag{75.1}$$

The rating curves are also used to convert flow time series into habitat time series, which are statistically analyzed using the Uniform Continuous Under Threshold (UCUT) curves. UCUT curves describe magnitude, frequency and duration of habitat events and are defined for a given period, in which the sum-length of all under-threshold events of the same duration is expressed as days per year, and duration values are plotted as a cumulative frequency. Details on UCUT curves construction and interpretation are reported in Parasiewicz (2008) and Vezza et al. (2014b). 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), the number of habitat stress days (HSD) that occur under those desired conditions can be calculated and used as a benchmark for comparative analysis. Thus, the Index of Habitat Stress Days (I_{HSD}) compares duration of under-threshold events in both reference and altered conditions. In this paper, the calculation of I_{HSD} 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 habitat stressor thresholds (AQ_{97}, 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 (Fig. 75.2). This average distance is calculated for each target species (and life

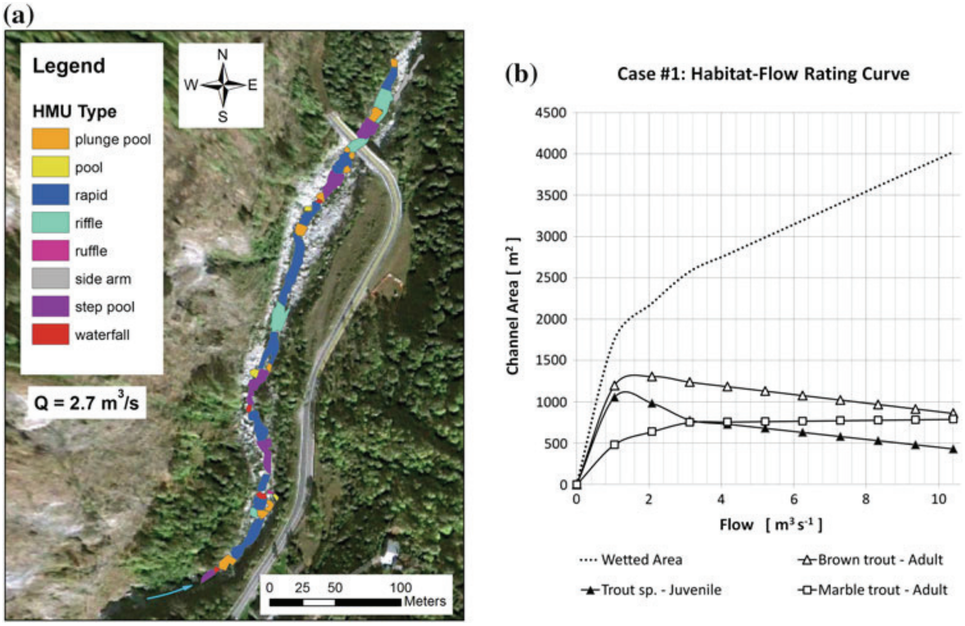

Fig. 75.1 **a** Mesohabitat distribution and **b** habitat-flow rating curve for case study #1. Both figures were obtained using the methodology reported in Vezza et al. (2014b). Mesohabitat classification is described in Parasiewicz (2007) and Vezza et al. (2012)

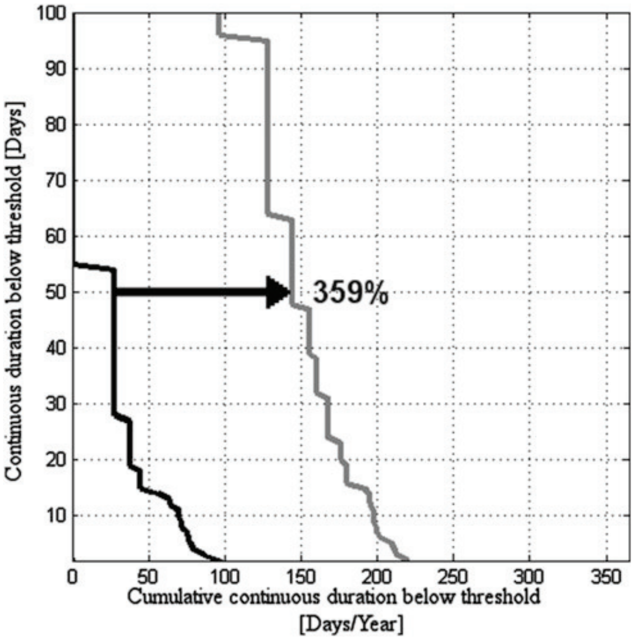

Fig. 75.2 UCUT curves for reference (*black solid line*) and altered (*grey solid line*) conditions for case study #1. Duration *curves* on the graph are related to the habitat threshold for adult *brown* trout during low flows in reference conditions ($AQ_{97} = 910\ m^2$, corresponding to $Q_{97} = 0.7\ m^3s^{-1}$). Mean alteration of habitat stress days (expressed as relative increase in %) is defined using the average horizontal distance between *curves* (details in, Parasiewicz et al. 2012)

stages) over the entire range of durations below threshold (i.e., between 1 and $d_{max,r}$, Eq. 75.2).

$$i_{SDA} = \frac{1}{d_{max,r}} \cdot \sum_{k=1}^{k=d_{max,r}} \left(\frac{\left| d_{c,AQ97} - d_{c,r,AQ97} \right|}{d_{c,r,AQ97}} \right) \qquad (75.2)$$

The index I_{HSD} is calculated using Eq. 75.3, in which the exponential shape of the curve was preferred to linear relationship to give more importance to low stress days alteration. As for I_{HQ}, I_{HSD} community value is given by the minimum value among target species.

$$I_{HSD} = min\left(e^{-0.38 i_{SDA}}\right)_{species} \qquad (75.3)$$

In case of alteration of river morphology, the construction (or simulation) of habitat-flow rating curves in morphological reference conditions is required. Parasiewicz et al. (2012) proposed a possible way to generate reference morphological characteristics through an iterative process, where the model simulates habitat conditions that offer the greatest gains in community habitat.

Depending on the study objectives, indices' calculation can be performed at both intra- and inter-annual scale, and using both daily and hourly discharge. Hourly streamflow records are considered suitable for rivers affected by hydropeaking, due to the particular time-scale of hydropower production and dam operations. Moreover, in areas where specific conservation objectives are required, index values can be calculated for single taxa, allowing restoration strategies to be focused on especially threatened species.

75.4 Results and Discussion

The presented concept of habitat indices is supported by two examples of application in the mountainous areas of Northern Italy. Figure 75.1a reports mesohabitat distribution and habitat-flow rating curves for the case study #1, which

Table 75.1 Values of index of habitat quantity (I_{HQ}), stress days alteration (i_{SDA}), and index of habitat stress Days (I_{HSD}) calculated for the case study # 2. Minimum values of the two indices are reported in bold

Species/life stage	I_{HQ}	i_{SDA}	I_{HSD}
Brown trour—adult	**0.95**	1.60	0.54
Trout spp.—juvenile	1.00	0.86	0.72
Vairone—adult	1.00	0.13	0.95
Vairone—juvenile	1.00	0.93	0.70
Barbel spp.	0.97	2.28	**0.42**
Chub—adult	1.00	0.83	0.72
Italian freshwater goby—adult	0.96	0.94	0.69

refers to a small hydropower plant without storage capacity. Daily annual Q_{mode}, estimated in 2007 upstream (reference conditions) and downstream (altered conditions) the water abstraction point, were estimated as 0.8 and 0.1 m^3s^{-1} respectively. These values were transformed in available amount of habitat for fish by the rating curves reported in Fig. 75.1b and the I_{HQ} index for adult brown trout (BT) was calculated as:

$$I_{HQ} = \left(1 - \frac{|1000 - 167|}{1000}\right)_{BT-adult} = 0.17 \qquad (75.4)$$

The same procedure was repeated for adult marble trout and juvenile trout, obtaining I_{HQ} equal to 0.21 and 0.19 respectively. The I_{HQ} community value was then estimated equal to 0.17.

The habitat threshold for brown trout related to low flows in reference conditions (Q_{97} = 0.7 m^3s^{-1}) was AQ_{97} = 910 m^2. UCUT curves for reference and altered conditions were then constructed (Fig. 75.2). The habitat stress days alteration, expressed as $i_{SDA} = 3.59$, indicated an increase in the number of habitat stress days equal to 359 %. The analysis was repeated for all target species, and, using Eq. 75.3 to transform i_{SDA}, I_{HSD} values were 0.26 for adult brown trout, 0.19 for adult marble trout and 0.78 for juvenile trout. The I_{HSD} community value was then estimated equal to 0.19. The same analysis was carried out in case study #2, in which water is diverted by a small weir and a lower hydrological alteration was detected in 2007 ($Q_{mode,r}$ = 0.9 m^3s^{-1}; Q_{mode} = 0.8 m^3s^{-1}). Table 75.1 summarizes the obtained results for case study #2. I_{HQ} and I_{HSD} were calculated for all the target species in the river section, and, compared to case study #1, obtained values underlines the lower impact of the considered water abstraction.

According to previous research studies carried in the mountainous areas of Northern Italy (Vezza et al. 2014a, 2014b), mesohabitat scale demonstrated its appropriateness to describe and evaluate the impact of water abstractions. The proposed indices can be considered flexible tools since they can capture both spatial and temporal alteration of habitat structure. These habitat indices can quantify the effect of both hydrological and morphological alteration on the aquatic habitat and the analysis can be carried out for different kind of pressures. Future indices' applications and testing will be carried for different hydropower facilities, hydropeaking and sediment flushing.

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