Ecological Modelling 385 (2018) 65–77

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Prediction of suitable feeding habitat for fishes in a stream using physical habitat simulations

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ARTICLE INFO

Keywords:
Suitable feeding habitat
Physical habitat simulation
Feeding condition
Macroinvertebrate
Weighted epi-benthic feeding area

ABSTRACT

This study presented the suitable feeding habitat for target fish species using physical habitat simulations for both fishes and macroinvertebrates. The suitable feeding habitat is a novel concept for the fish habitat that guarantees a certain level of feeding condition as well as the suitability of the physical habitat. The study site is a 0.9 km long reach of the Gongneung-cheon Stream, which is a tributary of the Han-gang River in Korea. Three dominant fish species were selected as target fishes such as *Rhinogobius brunneus*, *Zacco platypus*, and *Pseudogobio esocinus*. In order to consider the feeding condition of these fishes, *Hydropsyche kozhantschikovi*, *Chironomidae*, *Baetis fuscatus*, and *Cheumatopsyche brevilineata* were selected as target macroinvertebrates. Physical habitat simulations were carried out for both fishes and macroinvertebrates, and the distributions of the suitable feeding habitat for the target fishes were provided. It was shown that the suitable feeding habitat properly represents the quality of the target fishes' habitats. Then, the Weighted Usable Area (WUA) and Weighted epi-Benthic Feeding Area (WBFA) for target fishes were compared, and the results indicated that WBFA predicts fish abundance better than WUA.

1. Introduction

Physical Habitat Simulation (PHS) is a numerical tool that quantifies the quality of habitats for target fish species in a stream. PHS evaluates the suitability of physical habitat in terms of flow depth, velocity, and substrate at a particular rate of discharge (Bovee, 1982; Booker and Dunbar, 2004). The outputs of PHS are the Composite Suitability Index (CSI) and the Weighted Usable Area (WUA), which indicate the quality of habitats for target fish species in the study area.

The PHS was originally developed for estimating instream flows downstream of large dams in North America (Milhous, 1999) and has been applied to various problems in river management. Examples include the estimation of environmental flows (Papadaki et al., 2014; Nikghalb et al., 2016) and the investigation of the effects of river restoration schemes, particularly, the effects of removing weirs (Im et al., 2011) and dams (Gillenwater et al., 2006; Tomsic et al., 2007). PHS has also been applied to identify the impact of constructing hydraulic installations, such as dams (Valentin et al., 1996; Yi et al., 2014; Boavida et al., 2015), large wood structures (He et al., 2009), and spur dykes (Chang et al., 2013). Although previous applications of PHS seem to have been successful, it has often been criticized because its assessment of habitat quality is only affected by the physical habitat variables. Roussel et al. (1999) pointed out that the conventional PHS does not reflect fishes' feeding condition. Rosenfeld and Ptolemy (2012) also argued that PHS, which focuses on changes in available habitat at different discharge rates, normally neglects prey abundance.

Macroinvertebrates serve as a major source of food to fishes in streams. Food availability is known to directly affect the growth, distribution, and population of fishes (Jones, 1986; Muotka, 1993; Rosenfeld and Boss, 2001; Devlin et al., 2004; Graeb et al., 2004). Moreover, imbalances between the fish and macroinvertebrate communities can incur the degradation of fishes' habitats (Brusven et al., 1974). Therefore, the quality of fish habitats is determined not only by the physical habitat variables but also by prey abundance.

Previous studies have indicated that the abundance of macroinvertebrates is affected by hydraulic parameters such as the Froude number, shear velocity, flow velocity, and substrate (Statzner, 1981; Culp et al., 1983; Brooks et al., 2005; Duan et al., 2008). Based on this, various PHSs for macroinvertebrates have been carried out just as they have for fishes. Gore et al. (1998) performed PHS for macroinvertebrates to investigate the effect of artificial riffles in a stream. Gore et al. used Physical Habitat Simulation System (PHABSIM) and Habitat Suitability Curves (HSCs) for macroinvertebrates. The simulation results showed that the benthic community's diversity had improved after the construction of artificial riffles. Waddle and Holmquist (2013) carried out PHSs for rarefied number of species, EPT

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https://doi.org/10.1016/j.ecolmodel.2018.07.014
Received 13 February 2018; Received in revised form 17 July 2018; Accepted 17 July 2018

(*Ephemeroptera-Plecoptera-Tricoptera*), and *Plecoptera* in the Tuolumme River, US. Multivariate suitability curves were used for habitat simulations. They found that water abstraction can degrade macroinvertebrate populations as a result of reducing the available wetted area. Kelly et al. (2015) performed PHSs for *Deleatidium spp*., and EPT in braided rivers in New Zealand. They found that downstream diversion decreased the biomass of macroinvertebrates. These previous studies provide a possibility of predicting the prey abundance for fishes using the PHSs for macroinvertebrates.

This study proposed a method to predict the suitable feeding habitat for target fishes in a stream. Here, a suitable feeding habitat refers to a suitable physical habitat with the favorable feeding condition for fishes. The main challenge is that the conventional PHSs predict the suitability of fish habitat based only on the physical habitat condition. The suitable feeding habitat is expected to represent the habitat quality better than the habitat predicted by the conventional PHSs.

The study site was selected as the Gongneung-cheon Stream, which is a tributary of the Han-gang River, Korea. For the same study area, Im et al. (2011) investigated the change in the physical habitat after a weir removal using the PHS for the dominant fish. Later, Kim and Choi (2017) carried out PHSs with HSCs generated in the same study reach, and presented CSI distributions for both fishes and macroinvertebrates. In the present study, the suitable feeding habitat, a novel concept for habitat quality, is presented. The target fishes were *Rhinogobius brunneus*, *Zacco platypus*, and *Pseudogobio esocinus*, and the target macroinvertebrates were *Hydropsyche kozhantschikovi*, *Chironomidae*, *Baetis fuscatus*, and *Cheumatopsyche brevilineata*. HSCs for the target macroinvertebrates were constructed based on monitoring data from the Han-gang River basin. PHSs for target macroinvertebrates and fishes were carried out, and the CSI distributions for both were presented. The product of the CSI for the target fishes and the CSI for the target macroinvertebrates, called CSI the for epi-Benthic Feeding (CSI_{BF}), was obtained and used as an indicator for the suitable feeding habitat. The WUA and Weighted epi-Benthic Feeding Area (WBFA) for target fishes were compared and discussed.

Fig. 1 shows a procedure of computing the suitable feeding habitat for fishes in the stream. First, habitat variables such as the flow depth, velocity, and substrate are obtained for a particular discharge via the hydraulic simulation. Using the results from the hydraulic simulation, the habitat simulations are performed for both macroinvertebrates and fishes. At this stage, the composite suitability indices for macroinvertebrates and fishes are evaluated over the study area. Then, the composite suitability index for the epi-benthic feeding, which is the

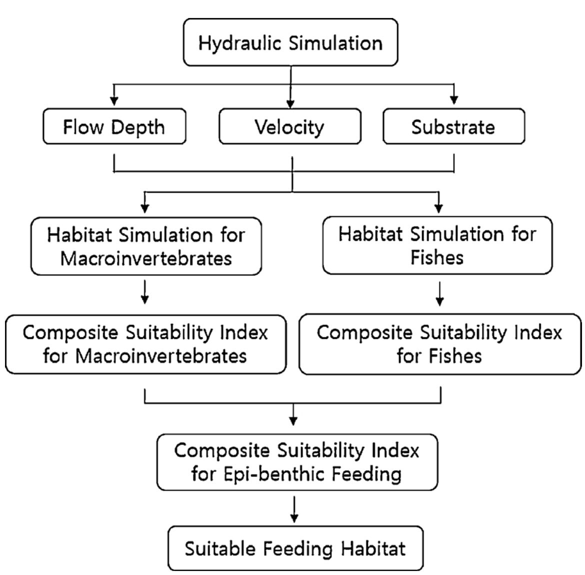

Fig. 1. Procedure of predicting the suitable feeding habitat.

product of the CSI for the macroinvertebrates and the CSI for fishes is computed. Finally, the suitable feeding habitat, defined by the habitat whose CSI for epi-benthic feeding is sufficiently high, is predicted.

2. Materials and methods

2.1. Study area and monitoring data

Fig. 2 shows the study site, which is a reach about 0.9 km long reach located at the upstream portion of the Gongneung-cheon Stream. The Gongneung-cheon Stream, a tributary of the Han-gang River, is located in the Kyeonggi Province in the north-western part of Korea. The Gongneung-cheon Stream is 45.0 km long and has a watershed area of 253.1 km^2. The discharge rates for drought flow (Q_{355}), low flow (Q_{275}), normal flow (Q_{185}), and averaged-wet flow (Q_{95}) are 0.28, 0.51, 0.91, and 1.73 m^3/s, respectively (Korea Institute of Construction and Technology, 2008). Here, Q_n denotes the average flow discharge that is exceeded on n days of the year. As shown in Fig. 2, the study reach includes pool and riffle sequences, whose bed elevation profiles are shown in the following figure in the longitudinal direction.

Fig. 3 shows the changes of the thalweg and the median size of the bed sediment with the longitudinal distance. The thalweg and sediment size profiles show the presence of pool and riffle sequences more evidently. That is, riffles are located about 200 m and 400 m from the upstream end, and pools are about 330 m and 650 m from the upstream end. Interestingly, the bed materials are coarse and fine in the riffles and pools, respectively.

The locations of the macroinvertebrate monitoring stations are also plotted in Fig. 2. As can be seen in the figure, St. 1 and St. 3 are located in the riffles, and St. 2 in a pool. St. 4 is located in a run, an intermediate zone with a wavy water surface between the pool and riffle, and a pool is located downstream from St. 4. The median sizes of the bed sediment at St. 1 – St. 4 are 6.0, 0.9, 5.5, and 2.0 mm, respectively.

Fig. 4 shows the distribution of dominant fishes and macroinvertebrates obtained by field monitorings in the study site. The field monitoring for fishes was conducted for the entire study reach in August 2006. It was found that *Rhinogobius brunneus* was the most dominant fish, followed by *Zacco platypus* and *Peudogobio esocinus*, as shown in Fig. 4(a) (Korea Institute of Construction and Technology, 2008). In this study, these three dominant fishes were selected as the target fishes. Fig. 4(b) shows the distribution of the dominant macroinvertebrates in the study site. The field monitoring for macroinvertebrates was conducted at the four monitoring sites shown in Fig. 3 in June 2006. Field monitoring revealed that four macroinvertebrates were dominant in the study reach, namely *Hydropsyche kozhantschikovi*, *Chironomidae*, *Baetis fuscatus*, and *Cheumatopsyche brevilineata*, and they accounted for 80% of the total macroinvertebrate community. Previous studies have found that these four macroinvertebrates serve as the main food sources for the three target fishes in the study site (Sone et al., 2001; Inoue et al., 2005; Chang et al., 2008; Katano, 2011).

2.2. Hydraulic simulation

In the present study, the River2D model developed by Steffler and Blackburn (2002) was used for the flow computation. The 2D hydraulic models have been used widely in the PHSs because of their acceptable accuracy and resolution with reasonable computational costs (Leclerc et al., 1995; Ghanem et al., 1996). The River2D model solves 2D shallow water equations using the finite element method. The shallow water equations consist of the following continuity and x- and y-momentum equations, respectively:

$$\frac{\partial H}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \quad (1)$$