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Evaluation of physical fish habitat quality enhancement designs in urban streams using a 2D hydrodynamic model

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ABSTRACT

Creating a habitat for a variety of forms of life, such as riparian plants and various fish, is a necessity for stressed river ecosystems. In this study, the hydraulic characteristics of a fish habitat in an urban channel were analyzed using River2D, which is a two-dimensional (2D) depth-averaged finite element hydrodynamic model, to improve the habitat of two target fish in the Daejeon Stream, Korea. These species are *Pseudopungtungia nigra*, which is an endangered species in the Daejeon Stream, and *Zacco platypus*, which is a dominant species. In addition, changes in the weighted usable area (WUA) were compared and reviewed as boulders were placed in the stream. The best method for improving the *P. nigra*'s habitat is proposed. A simulation analysis was performed on urban rivers for fish habitats. As a result, a straight and monotonous urban river flow was found to be an appropriate habitat environment for *Z. platypus*. The WUA for *Z. platypus* was about 20 times greater than that for *P. nigra*. Three different fish habitat enhancement methods were evaluated by calculating the WUA for the target fish in the study channel. By calculating the WUA to create fish habitats, the V-type riffle method was found to increase the usable area of the habitat environment for *P. nigra* by 360%, and the step stone method and single boulder method did so by 60% and 8%, respectively. For the single boulder method, boulders were placed in the channel bed at 3.5-m intervals, which significantly increased habitat availability. Moreover, centralizing the flow pattern in the channel among several types of boulder placements greatly expanded the habitat for *P. nigra*. Thus, an appropriate placement interval and boulder location that considers the characteristics of the riverbed and target fish species should be researched and implemented.

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1. Introduction

Rivers have an important role in sustaining riparian ecosystems and human communities. However, globally, rivers have been severely impacted by a variety of human activities that have resulted in the loss of many of their original ecosystem's functions. Preserving an ecological habitat is a key requirement for riparian species and fish species, both of which are greatly affected by rivers (Lee et al., 2006). Recreating and restoring the river habitat for riparian assets and endangered fish species is now an important aspect of ecohydrological research. A significant amount of research has been conducted on the habitat requirements of riparian and instream plants and animals; most studies are related to habitat modeling and generally focus on stable and natural channels (Hauer et al., 2007; Hauer et al., 2008). For example, Crowder and Diplas (2000) provided results that demonstrate the extent to which a boulder, or a series of boulders, can influence the predicted flow conditions and fish habitats in a natural stream using a two-dimensional (2D) hydraulic model. García and Gortazar (2006) evaluated the effectiveness of habitat enhancements, such as riffles and pools, with a 2D hydraulic model under different instream flow conditions in natural streams located in Spain.

Many researchers have demonstrated that improving the natural habitat of fish requires knowledge of the natural recovery process of river ecosystems (Cairns et al., 1977; Gore, 1985; Konrad, 2009; Nagaya et al., 2008; Shih et al., 2008). In particular, understanding the interaction between the physical habitat and the hydraulic habitat is essential to rehabilitate impaired river ecosystems. One approach to stream restoration that focuses on the physical fish habitat is the Instream Flow Incremental Methodology (IFIM), which is an example of how ecological characteristics can be applied to ecosystem restoration (Bovee, 1982; National Biological Service, 1995; Spence and Hickley, 2000; Lopes et al., 2004). In this approach, the Weighted Usable Area (WUA) for a fish habitat in

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Fig. 1. Photo of the study reach and topographic reach map of the Daejeon Stream. (a) Photo of straight trapezoidal reach looking upstream. (b) Photo of straight trapezoidal reach looking downstream. (c) Topographic reach map.

the stream is applied to assess the influences of different instream structures to provide a hydraulic habitat.

In urban streams and rivers, the amount of fish habitats is severely limited because of the use of traditional flood control methods for river management. Urban rivers have been managed and exploited with an emphasis on both flood control and instream water use, leading to tremendous damage to the riparian ecosystem and river environment. In this study, we assessed the effectiveness of different obstacles, such as boulders, to create a fish habitat using the River2D model. Several traditional methods that have been used to artificially create fish habitats were compared and analyzed. As an alternative to eco-friendly methods, hydraulic and ecologic characteristics were analyzed after boulders were placed on the river bed, and the WUA was estimated using micro-habitats (depth, velocity, riverbed materials) to protect and maintain fish habitats. Instead of using traditional standardized methods to maintain rivers, an alternative, forward-looking and detailed method is proposed to create an environment that provides an eco-friendly habitat for fish.

2. Methods

2.1. Study site

The study reach is situated in Daejeon Metropolitan City in Korea. The basin area of the Daejeon Stream is 89.38 km^2, and the total length of the stream is 23.08 km. The Daejeon Stream is a typical urban stream that flows through the heart of Daejeon City. Most of the reaches of the Daejeon Stream that pass through the urban area have unchanging, straight flow patterns. Urbanization of the Daejeon Stream's basin has not only changed the morphology of the stream but also has had a significant impact on the ichthyofauna of the river's ecosystem. *Pseudopungtungia nigra*, which is a native fish, became endangered due to the lack of a proper habitat and instream flow (Hur and Kim, 2009). As a result of habitat degradation and the decline of *P. nigra*, *Zacco platypus* is the dominant species in the basin (CGRBM, 2005).

In this study, typical straight sections of urban streams that consist of very monotonous flow patterns were selected and used as basic modeling to analyze the current issues for fish habitats in urban rivers. The selected study reach is 100-m long, while the average width of the channel is 17 m; it is located mid-downstream of the Daejeon Stream (Fig. 1).

2.2. Model employed in this study

2.2.1. River2D

A two-dimensional numerical model was selected for the hydraulic simulation with low flow in the study reach. The 2D numerical model was found to be very effective in comparison to the 1D model, especially for spatially distributed phenomena, such

Table 1
Natural flow regime of the Daejeon Stream (Daejeon Metropolitan City, 2008).

Basin area (km^2)	Averaged-wet flow (Q95) (m^3/s)	Normal flow (Q185) (m^3/s)	Low flow (Q275) (m^3/s)	Drought flow (Q355) (m^3/s)
89.38	1.73	1.15	0.75	0.45

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