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Review

An improved habitat model to evaluate the impact of water conservancy projects on Chinese sturgeon (*Acipenser sinensis*) spawning sites in the Yangtze River, China

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ABSTRACT

Construction of water conservation projects may change the transport of water and sediment, and nutrient and food web dynamics in river systems, thus impacting the ecological systems downstream, especially fish habitats. This study proposed an improved habitat model that consider both habitat quality and quantity and applied it to evaluate the impact of water conservancy projects on fish habitats. The indices of fragmentation, which emphasize the core habitat patch, and connectivity, based on the minimum spanning tree, appeared to be the most suitable indicators of fish habitat quality. Chinese Sturgeon (*Acipenser sinensis*) was used as an indicator species and spawning sites between the Gezhouba Dam and Yichang Station were selected as study areas. The relationships between habitat quality and water temperature and discharge were established in these areas. The results indicated that discharges from 13,100 m^3/s to 24,200 m^3/s and water temperatures from 17.1 °C to 20.0 °C are recommended for Chinese sturgeon spawning and hatching. The improved habitat model showed that the impoundment and operation of the Three Gorges Dam and the construction of the separation levee project both caused a decrease in the habitat quality of Chinese sturgeon spawning sites. Compared to previous studies, the improved habitat model provides a promising intermediate step to reduce the uncertainty in evaluating and quantifying the impact of water conservation projects on fish habitats.

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Abbreviations: HSI, habitat suitability index; HFI, habitat fragmentation index; HCI, habitat connectivity index; SLP, separation levee project; WUA, weighted usable area; IFIM, Instream Flow Incremental Methodology; MST, minimum spanning tree; $CPUE_d$, catch per unit effort; TGD, Three Gorges Dam; PHABSIM, physical habitat simulation.

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1. Introduction

Water conservancy projects bring great benefits to society, such as preventing flooding or drought, access to water resources, and optimizing the function of water systems (Prasuhn, 1987; Ligon et al., 1995). Due to increasing demand for water resources, water conservancy projects have increased during the last few decades, well-known examples being the Three Gorges Dam in the Yangtze River in China (Wu et al., 2003) and the Hoover Dam in the Colorado River in the United States (Stevens, 1990). Globally, there are over 45,000 large reservoirs with impoundments higher than 15 m, which reserve approximately 15% of the total river runoff every year (Nilsson et al., 2005). In China alone, there were 98,000 reservoirs by 2013 (Yang and Lu, 2014). However, as most water conservation projects were designed to facilitate flood control, power generation, transportation or agricultural irrigation, little attention has been paid to river ecological system (Petts, 1984; Bednarek, 2001). These projects may change water and sediment transport, obstruct fish migration paths, and alter water temperature and water quality, thus influencing downstream aquatic ecosystems, especially fish habitats (Ligon et al., 1995; Wu et al., 2003; Zalewski, 2012). Approximately 75% of eel (*Anguilla* spp.) and shad (*Alosa* spp.) inhabit heavily obstructed ecoregions, and 11% of sculpin (*Cottus* spp.) have been rapidly lost in heavily obstructed ecoregions. Other species, such as sturgeon (*Acipenser* spp.) and salmonids (*Salmo* and *Oncorhynchus* spp.) are also facing impacts from dam obstruction (Liermann et al., 2012). Following the construction of the Gezhouba Dam, the Chinese sturgeon (*Acipenser sinensis*) has lost almost all spawning sites, resulting in near localized extinction of this species (Gao et al., 2009). In the McKenzie River, the construction of two Army Corps of Engineers flood-control dams resulted in the development of mid channel bars and islands, which constrained this river to a single thread channel. This change was one of the major factors in the dramatic decrease in the population of native salmon (Ligon et al., 1995). The loss of freshwater species is faster than terrestrial or marine biota (Sala et al., 2000; Dudgeon et al., 2006; Arthington et al., 2010; Liermann et al., 2012). Therefore, quantifying the impact of water conservancy projects on fish habitat is crucial for protecting and/or restoring the impacted downstream ecosystems.

The aquatic habitat simulation model is an effective tool for evaluating the influence of river development or restoration on fish habitats (Jung and Choi, 2015). Instream Flow Incremental Methodology (IFIM) and its physical habitat simulation component (PHABSIM) is one of the most widely used models for assessing fish habitat (Tharme, 2003; Annear et al., 2004; Huckstorf et al., 2008). The PHABSIM model is divided into three groups: 1-D, 2-D and 3-D. The 1-D model is a cross section-averaged model that only considers the velocity in a streamwise direction (Choi et al., 2015). However, the 1-D model cannot adequately simulate hydrodynamic characteristics, thus, 2-D and 3-D hydrodynamic models have been used to study fish habitat since 2000 (Wentzel 2001). Mouton et al. (2007) used the fish habitat model to evaluate the impact of weirs on habitat suitability for bullhead (*Cottus gobio*) in Flanders, Belgium. Ban et al. (2011) developed a 2-D hydrodynamic model using River2D to simulate Chinese sturgeon spawning sites and calculated the optimal flow suitable for spawning of this species. Lee et al. (2010) used a 2-D habitat model to improve the weighted usable area using appropriate placement interval and boulder location.

There are two limitations in the PHABSIM model to evaluate the impact of conservancy projects on fish habitats. Firstly, most models only calculate the environmental flow for the downstream fish habitat whilst ignoring the water temperature, which is one of the key factors for fish metabolism and simulates the spawning and hatching of fish. In general, large reservoirs tend to become thermally stratified and the water temperature of released discharge differs from the water temperature of the natural river, resulting in a negative impact on fish spawning. Following the construction of several dams in lower peninsula of Michigan, mean summer temperature changed from 1 °C cooler to 5 °C hotter, resulting in lower mean populations of some cold-water fish species in 10 rivers, such as brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*) (Lessard and Hayes, 2003). Therefore, simulating both discharge and temperature of discharged water is necessary. Nevertheless, the PHABSIM model usually evaluates local habitat conditions using weighted usable area (WUA), which is calculated as the sum of all habitat grids that are the product of the habitat suitability index (HSI) and area values in the study area (Vismara et al., 2001; Mouton et al., 2007). WUA can only depict the quantity of habitat in the study area, and many fish habitat models based on WUA (Vilizzi et al., 2004; Goldberg and Waits, 2009; Yi et al., 2010) have been widely criticized for their lack of aspects of habitat quality, such as fragmentation and connectivity between habitat patches (Li et al., 2015b). For example, the model is misleading when the WUA of a habitat is large and the habitat patches are very fragmented or the poorly connected. Thus, WUA is not suitable for evaluating the habitat quality (Li et al., 2015b). Core habitat patch is very important to fish habitat and the distance between each habitat patch is a good indication of the connectivity of the habitat (Bojie et al., 2001). Therefore, a habitat