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Influence of Manwan Reservoir on fish habitat in the middle reach of the Lancang River

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ABSTRACT

The Lancang–Mekong River is the most important international river in Southeast Asia. Where the river flows through China, it is called the Lancang River. The Lancang River basin has become the most abundant species resource and the most bio-diverse region of China and has significant potential as a source of hydropower. The construction of cascade hydropower dams on the main river has brought great economic benefit, but has also changed the river as a physical habitat. Many fishes, especially endemic species and those with economic value in this area, have been affected by these changes. An ESHIPPO-PPm model was established to evaluate the extinction risk of fish species in this area. Four endemic fish were evaluated, two of which (*Tor sinensis*, and *Cosmochilus cardinalis*) are classified as critical extinction risk. The habitat quality of *T. sinensis*, an endemic and economically important fish, was simulated using a habitat suitability index model. The habitat suitability index (HSI) model was developed by coupling a one-dimensional (1-D) hydraulic model with habitat suitability curves. Considering the spawning characteristics of the fish, habitat suitability curves were established for key factors influencing adult fish and spawning behavior of *T. sinensis*. A hydraulic model was developed to simulate and predict parameter of the physical habitat. Based on the simulated result of the HSI model, Weighted Usable Areas for adult (WUA_d) and spawning (WUA_s) were obtained. A Mann–Kendall test was used to analyze the variation trend of WUA_s and WUA_d before and after the construction of the Manwan dam. Abrupt change in WUA_d and WUA_s occurred during the dam construction and operation period, respectively. According to the simulation and analysis, habitat suitability has been changed during the construction and operation of Manwan Reservoir. For the spawning of *T. sinensis* (WUA_s), the dam has a visible influence on the minimal and medium level habitat, but little influence on the optimal habitat. For the adults habitat, the dam reduced the medium and optimal WUA_d. Optimal discharge for spawning is much greater than for adult. Different discharges for maintaining different degrees of habitat quality are suggested.

1. Introduction

The construction of dams on large rivers is important for societal development because dams bring great benefits to modern society, including power generation, flood control, and navigation. However, dam construction can reduce the connectivity of rivers, fragment watersheds, affect fish assemblages by interrupting fish migration, and reduce species diversity (Lee and An, 2014; Tiemann et al., 2004). Due to the construction of large dams on the Yangtze River, the spawning sites of the Chinese sturgeon have been obstructed, and this species is in danger (Yi et al., 2010a). At the same time, reservoirs cause direct changes to water depth, flow velocity, and hydrologic processes, resulting in downstream river channel erosion, and this can detrimentally alters the physical habitat and decrease water quality. Biological communities are interconnected with hydrologic processes (Pringle, 2003); for instance, flow fluctuations can potentially change the spawning habitat for Chinook salmon in USA (Tiffan et al., 2002) and for the four major Chinese carps in China (Yi et al., 2010b). Flow velocity is particularly important because it determines the rate at which nutrients and oxygen reach aquatic species, and it also affects the lift and drag force on aquatic species (McDonnell, 2000).

The U.S. Environmental Protection Agency (USEPA) noted that 70% of freshwater mussels, 55% of crayfish, 42% of amphibians,

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Table 1
Dams already constructed on mainstream of Lancang River.

Dam	Storage level (m)	Watershed area (km^2)	Water surface area (km^2)	Total storage (10^8 m^3)	Dead storage (10^8 m^3)	Active storage (10^8 m^3)	Installed capacity (MW)	Annual energy (GWh)	Dam height (m)	Building timing
Xiaowan	1236	113 300	189.1	151	47.5	99	4200	18 890	292	2001–2010
Manwan	994	114 500	23.6	9.2	6.3	2.6	1500	7805	126	1986–1995
Dachaoshan	895	121 000	26.25	9.4	7.20	3.67	1350	7021	111	1992–2003
Nuozhadu	812	144 700	320	227.41	114.06	113.35	5850	23 912	261.5	2004–
Jinghong	602	149 100	32.81	1233	810	249	1500	8059	118	2003–

and 40% of freshwater fishes in the United States are vulnerable, imperiled, or critically imperiled in the United States (USEPA, 2002). Similar problems also exist in the Lancang River. Cascade hydropower stations influence the hydrological condition and the river ecosystem. The underlying process has attracted the attention of many researchers (Kummu and Varis, 2007; Liu et al., 2011). However, there is still no research evaluating the damage to fish habitats in this area. There is a need for tools to analyze, assess, and quantify the impact of dam construction and reservoir operation on physical processes and ecological functions. One approach that can explicitly link hydro-geomorphic and ecological predictions in the design phase of river rehabilitation is the coupling of hydrodynamic models for predicting hydraulic processes and local habitat suitability functions for predicting physical habitat quality for organisms (Lee et al., 2010; Pasternack et al., 2008; Gard, 2006). These models are used to evaluate habitat suitability for aquatic organisms, and they are based on physical variables, such as water depth, flow velocity, and substrate (Bovee, 1986). Physical habitat models are particularly useful for impact assessment of hydropower projects, analysis of the effects of water abstraction on river ecology, and the determination of the minimum flow requirements of aquatic populations (Maeda, 2013; Shields et al., 1997; Jowett, 1997; Parasiewicz, 2001).

Since the 1980s, physical habitat models have become an important tool for river management (Armour and Taylor, 1991; Bockelmann et al., 2004). The Physical Habitat Simulation (PHABSIM) model (Bovee, 1986; Spence and Hickley, 2000; Nagaya et al., 2008), which uses the Instream Flow Incremental Methodology (IFIM), was the first fish habitat model and it is now used worldwide. Other models based on PHABSIM include the Norwegian River System Simulator (Alfredsen and Killingtveit, 1996), RHYHABSIM (Jowett, 1997), EVHA (Ginot, 1995), and Mesohabitat (Parasiewicz, 2001). All of these models link physical variables to habitat suitability by means of uni- or multi-variate preference functions (Bovee, 1986; Pasternack et al., 2008).

Two-dimensional models have been developed for detailed hydraulic analysis of spatially explicit habitat units at the microhabitat scale (Steffler and Waddle, 2002). The Aquatic Habitat Simulation Models (AHSMs) generally have both physical and biological modeling components. A general critique of AHSMs is that they have been widely used to model instream flow, but they are not able to model overbank flow or the linkage of instream flow with floodplains and tributaries (Hudson et al., 2003). The Computer Aided Simulation Model for Instream Flow Requirements (CASiMiR), developed at the University of Stuttgart's Institute for Hydraulic Engineering, is based on fuzzy sets and rules. CASiMiR, a surface-water habitat model, is used to investigate habitats of fish, benthos, and vegetation (Jorde, 1996). From fuzzy input from experienced aquatic biologists and analysis of monitoring data, this model can adequately predict the habitat selection of several species (Jungwirth et al., 2000). This model does not include a hydraulics module, but it provides an interface port with some hydraulic models.

Habitat suitability models are widely used to evaluate the ability of a habitat to support a particular species (Vincenzi et al., 2006; Fukuda, 2009). These models ultimately allow researchers to evaluate the effects of dams on their surrounding environments (Mouton et al., 2007). The Lancang–Mekong River is the most important international river in Southeast Asia. In the 1980s, the construction of cascade hydropower dams on the Lancang River was proposed. The dams constructed on the Lancang River are listed in Table 1. The Manwan Hydropower Dam is one of those proposed dams, located in the middle-reach of the Lancang River (24°37′ 50″ N, 100°26′ 50″ E), and its construction lasted from 1985 to 1998. Because of the typical characteristics of a significant potential hydropower source and of an abundant and unique biodiversity assemblage in the Lancang River, it is very important to find a solution that can minimize the negative influence of hydropower exploration on the ecosystem.

When asked about the most important factor affecting fish habitat in the Lancang River, many researchers gave their opinions (Ba et al., 2009; Lu et al., 2010; Zhai et al., 2010), but no quantitative evaluation of the influence of the dam on the ecosystem has been performed. A habitat suitability model was used in this paper to assess the degree of the influence exerted by the construction and operation of the Manwan dam on the fish habitat.

Fish species have evolved their living strategies primarily in direct response to flow regimes. This study surveyed the changes in the aquatic ecosystem and in fish species between the pre- and post-dam periods. An ESHIPPO-PPm model was used to evaluate the extinction risk of fish in Lancang River basin. An indicator fish species was selected based on these results. To address whether aquatic habitats clearly varied with the construction and operation of the Manwan dam, a habitat suitability model was identify to determine the fish response to the changing habitats between the pre- and post-dam periods in the downstream reach of the dam.

This paper primarily presents the following work:

- An ESHIPPO-PPm model was developed for assessing the extinction risk of the fish in Lancang River, and the extinction risks of four endemic fish species were evaluated. A typical economic and endemic fish, *Tor sinensis*, which is in critical extinct risk, was selected to model the habitat quality.
- To investigate the impact of dams on fish habitat, a one-dimensional habitat suitability index (HSI) model for *T. sinensis* was established. Based on the HSI model, the Weighted Usable Areas values for adult (WUA_d) and spawning (WUA_s) of *T. sinensis* during the pre- and post-dam periods were calculated.
- The Mann–Kendall method was used to analyze the time series of WUA_d and WUA_s. The development trend and abrupt changing point of WUA_d and WUA_s were calculated, and the degree of influence of the Manwan dam on the *WUA* was evaluated. A suitable discharge scheme was obtained to guarantee a certain habitat quality for *T. sinensis*.

2. Study area

The Lancang–Mekong River originates in the Tibetan highlands of China and extends 4500 km. The reach of the river in China is