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Two-dimensional habitat modeling of Chinese sturgeon spawning sites

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ABSTRACT

Since the construction of the Gezhouba Dam in the 1980s, the number of Chinese sturgeon in the Yangtze River has been rapidly declining. The Gezhouba Dam has cutoff the migration path of these sturgeon, resulting in an overall reduction of suitable sturgeon habitat. This paper describes a habitat suitability index model that is used to evaluate the impacts of the Gezhouba Dam and Three Gorges Project on Chinese sturgeon spawning sites. Based on research concerning the reproduction characteristics of Chinese sturgeon, ten major ecological factors that influence reproduction were analyzed, including: water temperature, velocity, water depth, substrate, suspended sediment concentration, and the amount of egg predatory fish. The suitability index (*SI*) curves based on these ten ecological factors were obtained, and a habitat suitability function was developed. A two-dimensional mathematical model was also created to simulate and predict physical habitat situation (such as hydraulic, sediment, and substrate) of the Chinese sturgeon. By coupling the habitat suitability function and a two-dimensional mathematical model, a habitat suitability index model for Chinese sturgeon was established. The habitat suitability index model was validated by comparing measured data with predictions from the model. These comparisons showed that the computed results agreed well with the measured results, and the high calculated habitat suitability index (HSI) corresponded to high measured quantity of eggs per unit (1000 m^3) discharge ($CPUE_d$). The calculated habitat suitability index for Chinese sturgeon also showed that the habitat suitability index was better in 1999, before the impoundment of the Three Gorges Project, compared with the habitat suitability in 2003. Simulation results of different discharges from Gezhouba Dam predicted that flow discharges between 10,000 and 30,000 m^3/s were most suitable for sturgeon spawning.

1. Introduction

Dams bring great benefits to modern society which includes power generation, flood control, navigation and so on, but these benefits are not without downsides. Dams also can affect their surrounding environments causing changes to hydrological processes, reservoir siltation, channel erosion of downstream reaches, reduced water quality, cutoff of fish migration paths, and damage to aquatic habitats (Ligon et al., 1995; McCully, 1996; Wu et al., 2003). Therefore, there is a need for the development of research tools to analyze, assess, and quantify the impact of dam construction and operation on surrounding habitats and environments.

Since the late 1970s, aquatic habitat simulation models have been used to analyze fish habitats in water resource management (Bovee, 1982; Jowett, 1997; Parasiewicz and Dunbar, 2001). The models are used to evaluate habitat suitability for aquatic organisms, based on physical variables, such as water depth, flow velocity and substrate (Bovee, 1986). Physical habitat models are particularly useful for assessing the impact of hydropower projects, analyzing water abstraction on river ecology, and determining the minimum flow requirements of aquatic populations. These models may also be used to simulate and evaluate the impact of restoration projects on surrounding environments (Shuler and Nehring, 1994; Shields et al., 1997; Maddock, 1999).

Since the 1980s, physical habitat models have become an important tool for river management (Armour and Taylor, 1991; Bockelmann et al., 2004; Adriaenssens et al., 2006). The Physical Habitat Simulation (PHABSIM) model (Bovee, 1986; Nagaya et al., 2008), which uses Instream Flow Incremental Methodology (IFIM), was the first fish habitat model and is now being used worldwide. Other models that were based on PHABSIM include the Norwegian River System Simulator (Alfredsen and Killingtveit, 1996), RHYHABSIM (Jowett, 1996), EVHA (Ginot, 1995), and Mesohabitat (Parasiewicz, 2001). All these models link physical variables to habitat suitability by means of uni- or multivariate preference functions (Bovee, 1982).

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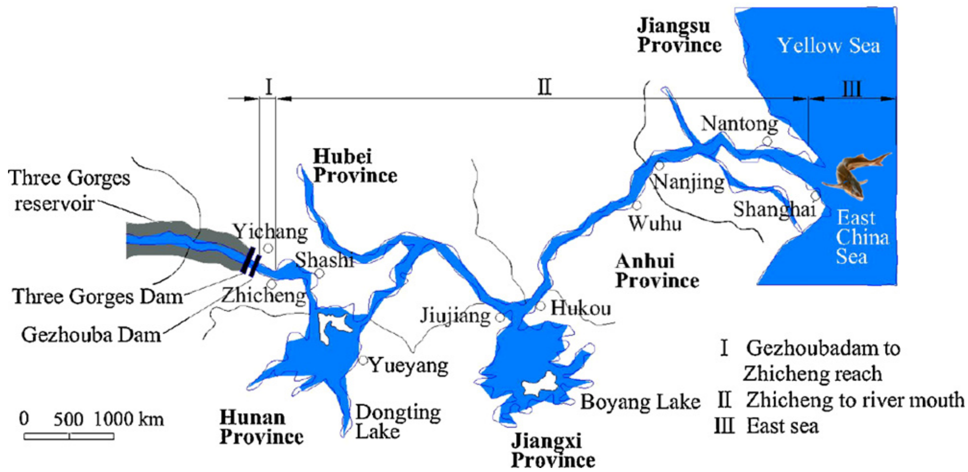

Fig. 1. Conceptual diagram of Chinese sturgeon (I: Chinese sturgeon spawn and hatch in this area from early October to mid-November; II: juvenile sturgeon look for food in this reach and arrive at the estuary the following June or July; III: juvenile sturgeon stay in the river mouth for a few months, and eventually migrate to the East Sea, living up to 15 years).

Two-dimensional models (RIVER 2D) have been developed for detailed hydraulic analysis of spatially explicit habitat units at the micro-habitat scale (Steffler and Waddle, 2002). The equations used in RIVER 2D can reach a steady-state solution without compromising accuracy. The aquatic habitat simulation models (AHSMs) generally have 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 and instream flow linkage with floodplain 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 fish habitats (Mouton et al., 2007; Jorde, 1996). CASiMiR, which is based on the input of experienced marine biologists and analysis of monitored data, can predict adequately the habitat selection of several species. It is observed that habitat requirements of species depend on life stage and river type (Jungwirth et al., 2000).

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 the researchers to evaluate the effects of dams on their surrounding environments (Mouton et al., 2008). The lack of attention paid to the effects of artificial embankments and dams on their surrounding habitats have resulted in a significant disturbance of the ecosystems of several rivers in China. In addition to being a significant migration barrier, these dams and artificial embankments alter their respective habitat's ecological conditions (depth, flow velocity, width and substrate). Moreover, the effects of Dams and artificial embankments are enhanced, causing downstream riverbed erosion, decreasing water quality and loss of habitat for some species. Due to the construction of large dams on the Yangtze River, the spawning sites of the Chinese sturgeon have been obstructed, and the survival of this species is in danger (Yi et al., 2007). There is still no adapted model of habitat suitability to evaluate the damage to fish habitats in the Yangtze River. This paper aims to:

- Develop a model in order to investigate the impact of dams on habitat suitability index (HSI) for Chinese sturgeon.
- Use this newly created model to simulate and compare the habitat suitability for Chinese sturgeon at different flow discharges released from the Three Gorges Project (TGP) and the Gezhouba Dam.
- Use the calculated results to provide a base for better reservoir management to mitigate the impact of these structures on the habitats of Chinese sturgeon.

2. The Chinese sturgeon

The Chinese sturgeon (*Acipenser sinensis Gray*, see Fig. 1) is a typical anadromous migratory fish. This species dates back 1.4 million years, thus it is called a "living fossil".

At one time, Chinese sturgeons mainly inhabited the Yangtze River, Pearl River, Minjiang River, and Yellow River. In the 1970s, the Chinese sturgeon was one of the four main species of fish caught in the Hangzhou Bay. During this period, around 400 Chinese sturgeons were harvested in the Yangtze River annually, each weighing more than 50 kg. Currently, the Chinese sturgeon has disappeared from the Yellow River and Minjiang River. There are now only several thousand sturgeons in the Pearl River and the Yangtze River.

Before the construction of the Gezhouba Dam, the harvest season of Chinese sturgeon occurred from September to November. Many fishermen in the provinces of Hubei and Sichuan lived on fishing sturgeon. From April to June, sexually mature sturgeons migrated from the East China Sea to the Yangtze River. These fish swam to spawning grounds, reproducing in early October to mid-November. Eggs attached to rocks and gravel in the riverbed and were hatched approximately 5–7 days later (Wang et al., 2002). Juvenile fish left the spawning sites for feeding in shallow waters. These fish arrived at the estuary the following June or July. Juvenile sturgeon stayed in the river mouth for a few months, and eventually migrated to the sea, living up to 15 years.

In January of 1981, with the enclosure of Gezhouba Dam, the migration path of sexually mature sturgeon to spawning grounds in the Yangtze River was obstructed. The overall result of this obstruction was a significant size reduction of sturgeon spawning grounds. When the Gezhouba Dam was first enclosed, a large number of sturgeons gathered at the Yichang reach just nearby the dam and were caught by fishermen. In total 1163 sexually mature sturgeons were caught, including 161 fishes upstream of the dam (see Fig. 2). Ke et al. (1992) estimated the amount of sexually mature Chinese sturgeon that migrated in 1983 and 1984 by using mathematical statistics methods. The number of sexual mature sturgeon that migrated during this period was 2176 sturgeon.

The rapid depletion of Chinese sturgeon has brought concern to the Chinese government and relevant departments. Since 1983, the Chinese sturgeon has been listed on the endangered species