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Effects of upstream reservoir regulation on the hydrological regime and fish habitats of the Lijiang River, China

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ABSTRACT

Dam construction may alter the hydrological regime of rivers, and thus may cause profound and accumulative impacts on a river ecosystem. Therefore, research on hydrological and ecological response to river regulation has received increasing interest. This research, takes the middle reach of the Lijiang River as a case and an indigenous cyprinid fish *Spinibarbus hollandi* (*S. hollandi*) as a target species for the development of an integrated hydro-environmental-habitat model. In contrast to previous studies focusing only on habitat suitability, this research takes into account habitat quality such as habitat fragmentation. The model analyses the effects of flow regime changes due to upstream reservoir operation on habitats for juvenile fish. Unregulated flow (UF) and regulated flow (RF) were simulated, and the corresponding effects on habitat of *S. hollandi* were analysed and discussed. Using the developed model, an ecologically-based flow regime was derived ensuring several conservation levels for *S. hollandi* habitats. Based on the recommended ecological flow regime, rules for reservoir operation are suggested.

1. Introduction

Changes in climate, land use and land cover due to human activities have been significantly altering precipitation patterns (Merritt et al., 2006; Thanapakpawin et al., 2007; Steele et al., 2008; Bi et al., 2009; Li et al., 2009; Boyer et al., 2010; Bao et al., 2012). River training and water management, which may include the construction of single and cascade reservoirs and water diversion tunnels, have further altered the hydrology and water quality of rivers. After several decades of development, hydropower has recently become a major portion in China energy structure (Lu, 2005). Constructions of large hydropower plants have raised serious ecological problems, including eutrophication of backwater zones as within the Three Gorges Reservoir (Zeng et al., 2006; Huang et al., 2012), decrease of fish stocks, like the Chinese Carps along the Yangtze River (Yi et al., 2010a,b), and reduction of fish habitat like that of the Yangtze sturgeon (Wang and Xia, 2009; Li et al., 2012; Yi et al., 2013).

Therefore, research on hydrological and ecological responses to stream flow management has received great attention from the scientific and managerial community. Research has shown that hydro-environmental changes due to human alterations of natural flows may significantly influence hydrological regimes and thus the ecology of rivers, too. Graf (1999) reported that dams cause a strong fragmentation of riverine habitats, and that such impacts on river discharge are several times greater than those expected as a result of global climate change. Karr (1991) and Pof and Hart (2002) found that reservoir impoundment leads to rising of groundwater level, which may create swamps in the land surrounding the reservoir. Conversely, groundwater recharge decreases downstream the reservoir, leading to water shortage. Kurunc et al. (2006) evaluated the effects of Kilickaya dam on the water quality of Kelkit stream, and concluded that Kilickaya dam strongly affected stream water quality. Müller et al. (2008) updated and extended the chemical database available for the Yangtze River below the Three Gorges dam. They compared the concentrations and loads of anthropogenically altered parameters of the lower Yangtze River before and after the dam construction, and evaluated the effects induced by the project.

With respect to impacts on river ecosystem, Ward (1979) and Saito et al. (2001) have studied the relationships among

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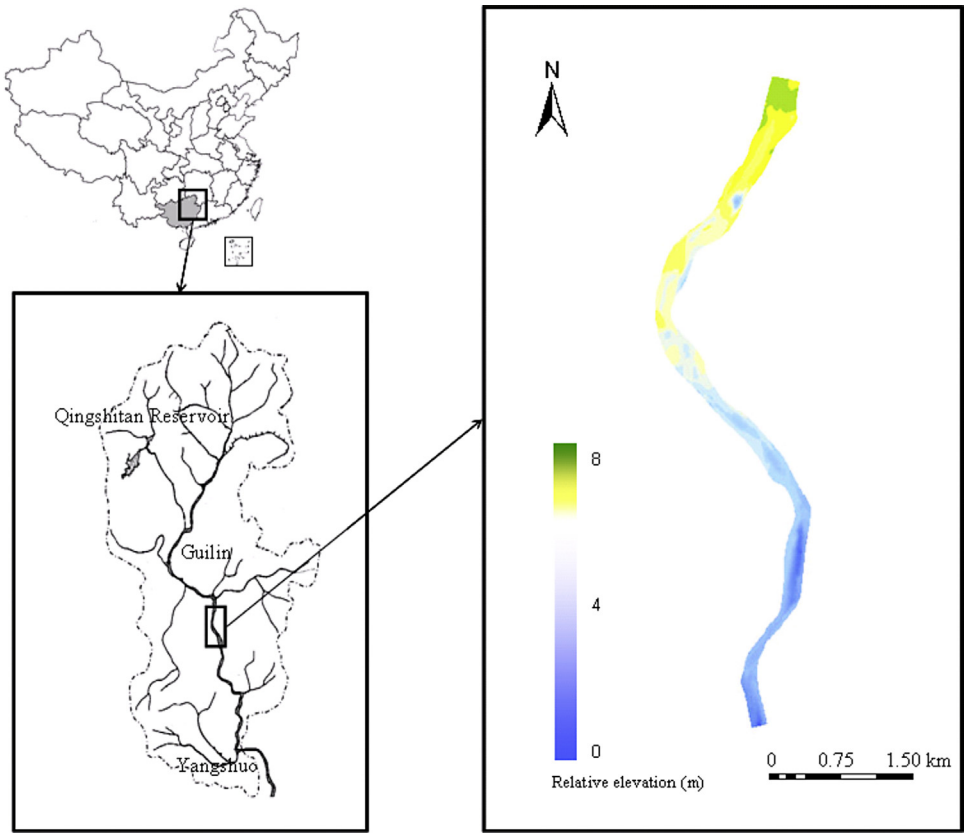

Fig. 1. The location of Lijiang River and the studied river reach.

hydrological regime, flow condition and physicochemical feature variations and their influence on stream communities and habitats. Ye et al. (2010, 2013) have investigated the effects of reservoir operation on downstream riparian dynamics, and Li et al. (2010) and Han et al. (2013) have studied the impacts on downstream fish population dynamics. Li et al. (2010) have studied the effect of altered flow regime on downstream fish habitat and proposed an ecological flow regime for habitat conservation (Li, 2012). Zhai et al. (2010) analysed the relationship between cascade dam construction and river ecosystem integrity in the Longitudinal Range Gorge Region (LRGR) in southwest China. Benjankar et al. (2012) used a dynamic vegetation model to analyse succession processes of riparian vegetation occurring as the consequence of river modification and dam operation. Wang et al. (2012) examined the difference in microbial diversity in various seasons and locations of Three Gorges Reservoir, and analysed the responses of microbial communities to hydro-environmental changes due to the dam construction.

To alleviate the adverse impacts of stream flow management, methodologies and management strategies for ecological river restoration and remediation have been explored by a number of studies. Dong et al. (2009) have summarized the factors for contributing to successful ecological river restoration, in which the primary and fundamental component is to maintain a suitable discharge in the stream for habitat conservation. Wohl (2012) has emphasized that the direct impact caused by dams consist in the reduction of riverine physical diversity and connectivity, which creates detrimental effects on river biodiversity and ecosystem functions. Thus the critical requirement for successful restoration of physical diversity and biodiversity is to maintain ecological flows, which may conflict with the social-economic benefits of the projects. To balance the social–economic and ecological interests, Chen et al. (2012, 2013) proposed an optimization model for eco-friendly reservoir operation, in which the accurate determination of ecological flows is crucial.

This study has been conducted on the Lijiang River for which we developed an improved habitat model to estimate suitable ecological flows. The objectives include: (1) the development of a habitat model by taking into account habitat quality to assess the response of fish habitat to reservoir operation; (2) the estimation of ecological flow regime for fish habitat conservation; (3) the recommendation of a suitable ecological flow for the studied river section.

2. Materials and methods

2.1. Study site and target species

The developed method was applied to the Lijiang River, which lies in Guangxi Province, southwest China (Fig. 1). The river originates from Mao'er Mountain and is famous for statuesque mountains with karst topography and limpid water with rich aquatic biodiversity. The drainage area is 2173.29 km^2 and mean bed-slope of 0.58‰. The sediment is consist of gravel and cobble with median sediment size of 0.03–0.06 m (Yang, 2012). Lijiang has typical rain source characteristics and the bankfull flow is 7810 m^3/s usually occurring in May and June. Strong seasonal oscillations of river low affect the water features and aquatic ecosystem quality during the dry period, which occurs between October and March with about 20% flow in annual runoff. The low flows of approximately 12 m^3/s also suspend the navigation of recreational cruise ships. To improve the water conditions during the dry season, a three-stage water recharge program has been suggested. The minimum flow will be increased to 30 m^3/s after stage I, to 42 m^3/s after stage II and to 60 m^3/s after the final stage. At present, stage I

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