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Effects of damming on the biological integrity of fish assemblages in the middle Lancang-Mekong River basin

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ABSTRACT

The Lancang-Mekong River basin contains a diverse assemblage of freshwater fish species; however, their populations are threatened by current and planned dam construction along the river. Fish assemblages are sensitive indicators of environmental degradation and can be used to assess aquatic ecosystem health. This research compared the fish fauna at the Xiaowan hydropower dam located on the middle reaches of the Lancang-Mekong River at three time periods: in 2008 (before impoundment), 2010 (water storage) and 2011 (full operation). A modified fish index of biological integrity (modified F-IBI) was developed and it synthesized information on the taxonomic composition, trophic guilds, and tolerance levels of the fish and habitat diversity to quantitatively assess the condition of fish populations before and after damming. This index also was used to assess the longitudinal diversity of the fish fauna along the river channel and could assess the barrier effect associated with the dam. Jaccard's index of similarity was used as a feasible tool to assess fish diversity loss and biotic homogenization. The analysis clearly showed a homogenization of the fish communities after damming, and the reservoir impoundment region showed much more serious homogenization than the downstream region. The Xiaowan dam had an immediate and profound effect on the fish fauna in this region of the Lancang-Mekong River. A total of eight cascading dams are planned for development in this region, and, unless conservation mitigation efforts are considered, the results could be devastating on the native fish populations of middle reaches of the Lancang-Mekong River basin.

1. Introduction

Biological integrity refers to the ability of an ecosystem to maintain its functionality and support a balanced and integrated assemblage of organisms similar to that of its natural state (Frey, 1975; Schiemer, 2000). The biological integrity of a system is directly impacted by human activities, and measuring biological integrity provides critical information for setting objectives and priorities for conserving and restoring aquatic ecosystems (Mercado-Silva et al., 2002). Quantifying the biological integrity of a system provides an integrated measure of ecological complexity and can overcome some of the limitations imposed by using only chemical and physical parameters for assessing the health of aquatic ecosystems (An et al., 2002). The Water Framework Directive (WFD) recently proposed that fish assemblages be used as one of four biological indicators for aquatic ecosystem assessment in the new EU water policy (Schmutz et al., 2000). Because they are at the top of aquatic food webs and have diverse trophic guilds, fish assemblages are sensitive to habitat alterations and can be used as indicators of aquatic environmental changes (Karr, 1981; Karr et al., 1986; Schmutz et al., 2000). In particular, fish assemblages are thought to be sensitive indicators of habitat and environmental degradation due to the construction and operation of dams (Petesse et al., 2007; Terra and Araújo, 2011).

The fish index of biological integrity (F-IBI), which was proposed by Karr (Karr, 1981; Karr et al., 1986), has been used worldwide to assess aquatic environmental conditions (Novotny et al., 2005; Terra and Araújo, 2011). Nevertheless, this index needs to be modified and calibrated for local use, because of the distinctive fish fauna of different regions (Kesminas and Virbickas, 2000). The Lancang-Mekong River basin, as one of the richest diversity of freshwater fish species in the world (Froese and Pauly, 2010; Ferguson et al., 2011), its unique and diverse fish fauna is greatly threatened by the large number of mainstem dams installed in recent years (Grumbine and Xu, 2011).

Abbreviations: Plankt, planktivorous; Pisc, piscivorous; Herb, herbivorous; Invert, invertivorous; Omni, omnivorous.

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Dams and reservoirs have been shown to have a profound effect on watersheds and aquatic ecosystems (Poff et al., 1997; He et al., 2004). Numerous studies (Marchetti and Moyle, 2001) have shown that fish assemblages are the most sensitive organisms affected by dam construction and flow regulation. In particular, migratory fish are affected most seriously, because longitudinal connections are disrupted by dams (Larinier, 2000; Wu et al., 2003). Dams also cause habitat fragmentation and loss (Wu et al., 2003; Wozney et al., 2011) leading to the loss of native fish species, the invasion of exotic fish species, the decline of fish beta-diversity and a resulting increase of faunal similarity or biotic homogenization (Mckinney and Lockwood, 1999; Olden and Rooney, 2006). However, most studies on the homogenization of fish populations have been conducted in North America and Europe and at very large scales (Rahel, 2000; Taylor, 2004; Leprieur et al., 2008). Until now, there have been no studies on the homogenization of fish fauna associated with dam construction and operation in the Lancang-Mekong River basin.

Hydropower dam construction and planning on the Lancang-Mekong River basin has received widespread attention and has sparked arguments among conservationists in recent years (Nilsson et al., 2005; Grumbine and Xu, 2011). In the section of the Lancang-Mekong River within China's borders, 224 native fish species have been recorded, which is greater than the 162 native fish species of the Yangtze River basin (Lu et al., 2010). In this fish-rich basin, eight cascading dams are in operation or planned in the middle and lower reaches of the Lancang-Mekong River in Yunnan Province, China (Fig. 1). The effects of hydropower dams on hydrological regimes, water quality and sediment accumulation in the Lancang-Mekong River have been documented (Kummu and Varis, 2007; Fu et al., 2008; Kummu et al., 2010; Zhao et al., 2010). Alterations in the hydrological regime, changes in water quality and sediment accumulation have the potential to harm native fish assemblages; however, few studies have been conducted to assess the impacts of dams on the fish fauna in this area. Because of the habitat transition from lotic to lentic condition, the assumption in this study was that the trophic guilds of pristine fish assemblages before damming are dominated by invertivorous and herbivorous that are determined by the lotic habitat and after damming the planktivorous fish increase significantly associated with the habitat variation and introduction of exotic species (Petesse et al., 2007; Terra and Araújo, 2011). To test this hypothesis, this study was conducted with the following objectives: (1) investigating the variation in fish assemblages, their trophic guilds and habitats before and after the Xiaowan hydropower dam impoundment and operation; (2) developing a modified fish index of biological integrity (F-IBI) to assess aquatic ecosystem changes associated with damming in the reservoir–river system; (3) comparing levels of biotic homogenization of the fish fauna pre- and post-damming and the mechanisms associated with this; and, (4) providing some insights as to the ecological effects of dam construction on fish assemblages in the Lancang-Mekong River basin.

2. Materials and methods

2.1. Study area

Xiaowan hydropower dam reservoir region, located at the middle reaches of the Lancang-Mekong River basin in Yunnan Province of China, was selected as study area (Fig. 1). The Lancang-Mekong River, one of the largest rivers in the world, is situated in the southeastern part of the Eurasian continent and originates from Guyong-Pudigao creek (5160 m above sea level in altitude) at the foot of Mt Jifu on Qinghai-Tibet Plateau spanning a length of 4909 km (Liu et al., 2007). Its watershed area is approximately 760,000 km^2 with a mean annual discharge of 457 km^3 at a rate of approximately 14,500 m^3/s (MRC, 2010). The trans-boundary river is generally divided into two parts, the Upper Mekong River basin, including the watersheds of parts of China and Myanmar, and the Lower Mekong Basin which includes the watersheds of parts of Laos, Thailand, Cambodia and Vietnam (Kummu and Varis, 2007; MRC, 2010). In the section which China's borders, the Lancang-Mekong River flows across Qinghai Province, Tibet Autonomous Region and Yunnan Province from upstream to downstream. In Yunnan Province, the river is 1240 km in length and drops 1780 m in height, flowing through deep, narrow valleys (Chen and He, 2000). Due to its rich hydrological resources, the middle and lower reaches of Lancang-Mekong River were planned as one of 12 key regions for hydropower exploitation in China (Dore and Yu, 2004). As shown in Fig. 1, eight cascading hydropower dams along the mainstem of the river will be completed and in full operation before 2020 (Chen and He, 2000).

The Xiaowan hydropower dam is one level of the eight cascading hydropower dams, and serves as a water storage reservoir to ensure the hydroelectricity production of downstream hydropower dams over the year. The dam is 292 m high and its crest length is 923 m. At normal water levels of 1240 m above sea level, the surface area of reservoir region is 189.10 km^2 and the reservoir capacity 151.32×10^8 m^3. The installed capacity of this dam is 4200 MW. The geographical features in this reservoir region are typically narrow and deep valleys. The climate in this region can be divided into two distinctive seasons: a rainy season dominated by the southwest monsoon from May to October and the dry season dominated by the mainland west monsoon from December to April. Construction of this dam began in 2002, and it commenced generating power in 2010. It is the second cascade dam in the middle and lower reaches of Lancang-Mekong River, but the first cascade dam located at Gongguoqiao is not yet been completed as of the end of 2011. This reservoir region can be divided into two parts, the mainstem backwater with a length of 178 km and the tributary backwater with a length of 122.7 km. The third cascade dam next to Xiaowan is Manwan hydropower dam, which was completed and began operation for hydropower generation in 1995 (Fig. 1).

2.2. Fish sampling procedures

Both temporal and spatial variation in the fish fauna were monitored as suggested by Zhang and He (1991). Surveys were conducted in 2008 (before water impoundment), 2010 (after water impoundment) and 2011 (after dam operation). Xiaowan dam is located 70 km upstream from Manwan dam. The 2008 surveys were conducted far upstream the Manwan dam so the river was not impacted by the backwater, and, since there were no dams in operation upstream, it was assumed that there were no effects of dams on the fish assemblages in the river where fish surveys were carried out. Thus, the 2008 measurements were regarded as the native condition of the fish assemblages. The fish assemblages surveyed in 2010 were considered to reflect water storage effects, and the 2011 survey included affects of both impoundment and operation of the dam on the fish fauna.

Spatial variation was assessed by sampling the fish fauna at four sampling sites (S1, S2, S3 and S4) upstream and downstream of the Xiaowan hydropower dam (Fig. 1). Site S1 was located downstream of the dam and represented the site influenced by riverflow regulated by the operation of the Xiaowan hydropower dam. Site S1 was investigated in 2010 and 2011 only as site S2, located just above the dam and in close proximity to S1 (3.68 km), was considered to be representative of both locations in the pre-dam period. Site S2 was located just above the dam in the reservoir at a maximum depth of 252 m after dam impoundment. Sites S3 and S4 were both located