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Changes in Fisheries Resources in the Hanjiang River and Danjiangkou Reservoir, China

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Abstract.—The Hanjiang River is the largest tributary of the Yangtze River and contains Danjiangkou Dam, which forms Danjiangkou Reservoir in the middle and upper reaches of the river. During the past 50 years, fisheries resources have changed significantly in the middle and lower Hanjiang River and in Danjiangkou Reservoir. Spawning grounds for major carps and other commercially important fishes have disappeared. Downstream of Danjiangkou Dam, total egg quantity spawned by major carps and other commercially im-

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portant fishes have decreased while similar measures from small-bodied fishes have increased. Important commercial fishes have experienced delayed spawning times and decreased growth. Overall catches of commercial fishes have decreased downstream of the dam, though increased upstream. Some exotic fishes captured in the Danjiangkou Reservoir were likely escapees from cage-culture fish farms in the reservoir or from land-based fish farms around the reservoir. Changes in fisheries resources were presumed related to reservoir management strategies, which produced a narrower range of year-round water temperatures and caused decreases in seasonal water flow variation downstream, overfishing, and eutrophication in the reservoir. To implement a national water diversion policy in central China, the height of the Danjiangkou Dam was increased 15 m in 2012, which significantly increased the impoundment area of the Danjiangkou Reservoir at the end of 2014. Further changes in fisheries resources can be expected in the future. At the present time, management and conservation strategies for fisheries resources need to be developed to ensure future fisheries sustainability for both the Hanjiang River and the Danjiangkou Reservoir.

Introduction

The Yangtze River is the longest river in China and contains numerous large tributaries. The Hanjiang River originates in the Qingling Mountains and flows through the Shaanxi and Hubei provinces. The Hanjiang River is the largest tributary of the Yangtze River, having a total length of 1,557 km and a watershed area of 159,000 km^2 (Du et al. 2005). Historically, the middle and lower reaches of the Hanjiang River contained fish faunas similar to the middle and lower reaches of the Yangtze River (HPIH 1976; Yu et al. 1981). In 1959, the middle reach of the Hanjiang River was dammed at Danjiangkou, just downstream of the confluence with the Danjiang River. When the hydroelectric project was completed in 1973, the dam height was 162 m above sea level and the impounded area was called Danjiangkou Reservoir. This reservoir, with an original surface area of 846 km^2 and storage volume of 1.745×10^{10} m^3, is now the second largest reservoir in China following the Three Gorges Reservoir, which was impounded at a height of 175 m in 2008. Since construction of Danjiangkou Reservoir, fisheries resources in the middle and lower reaches of the Hanjiang River have changed significantly. These fisheries changes have included the species composition of fish catches, species abundances, and the availability of suitable spawning habitats.

In order to relieve water shortages in the municipal cities of Beijing and Tianjin in northern China, the Chinese government developed the South–North Water Diversion Project in 2002, the largest water-diversion project in the world. This ambitious project consists of three diversion routes: eastern, middle, and western. The diversion route from Danjiangkou Reservoir to northern China is called the middle route. During 2005–2009, the dam's height was increased 15 m from 162 to 177 m above sea level in order to implement the South–North Water Diversion Project, which was finished in October 2014. After the Danjiangkou Dam's height was increased, water in the Danjiangkou Reservoir could flow naturally to Beijing and Tianjin through the Henan and Hebei provinces. This project also increased the impounded area of Danjiangkou Reservoir from 846 to nearly 1,000 km^2. It is expected that further effects on fish fauna in the Hanjiang River are likely, given that 9.5×10^9 m^3 of water is diverted north from Danjiangkou Reservoir annually, equaling 23% of the total inflow of 4.11×10^{10} m^3 upstream of Danjiangkou Dam (Shen and Liu 1998; Gao and Gao 2010). Fish faunal changes are believed more likely downstream of Danjiangkou Dam due to the expected decreases in water quantity associated with the water-diversion project.

Fish Community Composition Changes in the Hanjiang River

A total of 84 fish species were recorded in the middle and lower reaches of the Hanjiang River from the 1970s to the present (Table 1). However, fish community composition, as reflected by patterns of species presence and absence over time, had become slightly less similar through the three sampling periods (1976–1978, 2003–2004, and 2012–2013). Jaccard's index, which describes the similarity of two communities (Jaccard 1912; Taylor 2004), was 95% when comparing 1976–1978 and 2003–2004 but decreased to 90% when comparing 1976–1978 and 2012–2013 (Table 2). Although 90% still reflects relatively high similarity, Jaccard's values are based only on presence–absence data and do not reflect shifts in fish community structure. For instance, two large-sized piscivorous fishes frequently collected historically, *Ochetobius elongates* and Long Spiky-head Carp *Luciobrama macrocephalus*, were not collected in the two more recent investigations in 2003–2004 and 2012–2013 (Table 1). Similarly, the Chinese Longsnout Catfish *Leiocassis longirostris* was not collected in the most recent investigation (2012–2013) after having been collected in 1976–1978 and 2003–2004 (Table 1). Conversely, several exotic fishes, including Channel Catfish *Ictalurus punctatus*, Largemouth Bass *Micropterus salmoides*, and Paddlefish *Polyodon spathula*, have been recently found in Danjiangkou Reservoir and are occasionally collected in the middle and lower reaches of the Hanjiang River. All of these exotic fishes have undoubtedly escaped from cage-culture farms in the region of Danjiangkou Reservoir or from commercial aquaculture facilities along the Hanjiang River.

Temporal patterns in fish species abundances have indicated several notable changes in fish community composition that have occurred during the past few decades. In 1976–1977, the most abundant fishes in the catch in the Hanjiang River were Grass Carp *Ctenopharyngodon idella*, Bronze Gudgeon *Coreius heterodon*, White Amur Bream *Parabramis pekinensis*, Common Carp *Cyprinus carpio*, Mongolian Redfin *Culter mongolicus*, Smallscale Yellowfin *Xenocypris microlepis*, *Rhinogobio typus*, and *R. cylindricus*, respectively (Yu et al. 1981; Yu 1982). However, nearly 30 years later in 2003–2004, the most abundant fishes in catch ranked as Common Carp, Goldfish *Carassius auratus*, White Amur Bream, Yellow Catfish *Pelteobagrus fulvidraco*, Grass Carp, and Barbel Chub *Squaliobarbus curriculus*, which comprised 86% of the total catch (Li et al. 2005). Spearman's rank correlation coefficient (Nash et al. 2013) correlating species abundances from 2003–2004 with those from 1976–1978 was only 0.31 ($P = 0.24$). This finding indicated some structural differences in fish communities through time, probably being driven by the more abundant species. In addition, some species consistently exhibited the trends of decreasing ages and smaller sizes between 1976–1978 and 2003–2004. For example, the average ages of Grass Carp, Common Carp, White Amur Bream, Barbel Chub, Goldfish, and Yellow Catfish collected during 1976–1978 (Yu et al. 1981) were noticeably younger than those collected during 2003–2004 (Li et al. 2005) (Table 3).

Changes in Spawning Fish Composition, Spawning Habitat, and Egg Quantity in the Hanjiang River

Fishes that spawn drifting eggs are the most important group of commercial fishes in both the Yangtze and Hanjiang rivers (Li et al. 2010; Wan et al. 2011). There were 25 fish species that spawn drifting eggs collected in the middle and lower reaches of the Hanjiang River during the 1976–1978 surveys (Zhou et al. 1980). These species belonged to the families Cyprinidae, Homalopteridae, Cobitidae, and Serranidae, of which 17 species were commercially harvested (Zhou et al. 1980). However, by 2004, only 16 species from two families were recorded that spawn drifting eggs in the same area of the Hanjiang

Table 1. Changes in fish species composition in the middle and lower Hanjiang River across three time periods: 1976–1978 (Zhou et al. 1980; Yu et al. 1981), 2003–2004 (Li et al. 2005), and 2012–2013 (present study).

No.	Order	Family	Species	1976–1978	2003–2004	2012–2013
1	Acipenseriformes	Polydontidae	Paddlefish *Polyodon spathula*	–	–	+
2	Clupeiforms	Engraulidae	Shortjaw Tapertail Anchovy *Coilia brachygnathus*	+	+	+
3	Salmoniforms	Salangidae	Clearhead Icefish *Protosalanx hyalocranius*	+	+	+
4			Icefish *Neosalanx taihuensis*	–	+	+
5	Anguilliforms	Anguilidae	Japonese Eel *Anguilla japonica*	+	+	+
6		Cobitidae	Chinese Spined Loach *Botia superciliaris*	–	+	–
7			Barred Loach *Parabotia fasciata*	+	+	+
8			*Leptobotia taeniaps*	+	+	+
9			Pond Loach *Misgurnus anguillicaubatus*	+	+	+
10	Cypriniformes	Homalopteridae	*Lepturichthys fimbriata*	+	+	+
11		Cyprinidae	Chinese False Gudgeon *Abbottina rivularis*	+	+	+
12			*Acheilognathus macropterus*	+	+	+
13			Chinese Bleak *Aphyocypris chinensis*	+	+	+
14			Goldfish *Carassius auratus*	+	+	+
15			Bronze Gudgeon *Coreius heterodon*	+	+	+
16			Grass Carp *Ctenopharyngodon idella*	+	+	+
17			Topmouth Culter *Culter erythropterus*	+	+	+
18			Mongolian Redfin *C. mongolicus*	+	+	+
19			*Culter ilishaeformis*	+	+	+
20			*Culter dabryi*	+	+	+
21			*Culter oxycephaloides*	+	+	+
22			Common Carp *Cyprinus carpio*	+	+	+
23			*Distoechodon tunirostris*	+	+	+
24			*Gobiobotia filifer*	+	+	+
25			Yellowcheek *Elopichthys bambusa*	+	+	+
26			Barbel Steed *Hemibarbus labeo*	+	+	+
27			Spotted Steed *H. maculatus*	+	+	+
28			*Hemiculter bleekeri*	+	+	+
29			Sharpbelly *H. leucisculus*	+	+	+
30			Bighead Carp *Hypophthalmichthys nobi1is*	+	+	+
31			Silver Carp *H. molitrix*	+	+	+
32			Long Spiky-head Carp *Luciobrama macrocephalus*	+	_	_
33			Black Bream *Megalobrama skolkevii*	+	+	+
34			Bluntnose Black Bream *M. amblycephala*	+	+	+

Table 1. Continued.

No.	Order	Family	Species	1976–1978	2003–2004	2012–2013
35	Cypriniformes	Cyprinidae	Black Carp *Mylopharyngodon piceus*	+	+	+
36			*Ochetobius elongatus*	+	–	–
37			Chinese Hooksnout Carp *Opsariichthys bidens*	+	+	+
38			White Amur Bream *Parabramis pekinensis*	+	+	+
39			*Pseudobrama simoni*	+	+	+
40			*Pseudogobio vaillanti*	+	+	+
41			*Pseudolaubuca sinensis*	+	+	+
42			*Pseudolaubuca engrauliss*	+	+	+
43			Stone Moroko *Pseudorasbora parva*	+	+	+
44			*Rhinogobio typus*	+	+	+
45			*Rhinogobio cylindricus*	+	+	+
46			Rose Bitterling *Rhodeus ocellatus*	+	+	+
47			Chinese Fat Minnow *Sarcocheilichthys sinensis*	+	+	+
48			*Sarcocheilichthys nigripinnis*	+	+	+
49			Longnose Gudgeon *Saurogobio dabryi*	+	+	+
50			*Saurogobio gracilicaudatus*	+	+	+
51			Largescale Shoveljaw Fish *Scaphesthes macrolepis*	+	+	+
52			*Sinibrama wui*	+	+	+
53			*Squalidus argentatus*	+	+	+
54			Barbel Chub *Squaliobarbus curriculus*	+	+	+
55			*Toxabramis swinhonis*	+	+	+
56			*Xenocypris davidi*	+	+	+
57			Smallscale Yellowfin *X. microlepis*	+	+	+
58			Freshwater Yellowfin *X. argentea*	+	+	+
59			Freshwater Minnow *Zacco platypus*	+	+	+
60	Silurifomes	Siluridae	Amur Catfish *Silurus asotus*	+	+	+
61			Southern Catfish *S. meridionalis*	–	–	+
62		Bagridae	*Leiocassis crassilabris*	+	+	+
63			Chinese Longsnout Catfish *L. longirostris*	+	+	–
64			Largefin Longbarbel Catfish *Mystus macropterus*	+	+	+
65			Yellow Catfish *Pelteobagrus fulvidraco*	+	+	+
66			Darkbarbel Catfish *P. vachelli*	+	+	+
67			Shining Catfish *P. nitidus*	+	+	+
68			*Pseudobagrus truncatus*	+	+	+
69			Roundtail Bullhead *Pseudobagrus tenuis*	+	+	+

Table 1. Continued.

No,	Order	Family	Species	1976–1978	2003–2004	2012–2013
70	Silurifomes	Amblycitidae	Liobargrus marginatus	+	+	+
71		Ictaluridae	Channel Catfish *Ictalurus punctatus*	–	–	+
72		Sisoridae	*Glyptothorax sinensis*	+	+	+
73	Beloniformes	Hemirhamphidae	*Hemirhamphus kurumeus*	+	+	+
74	Synbranchiformes	Synbranchidae	Asian Swamp Eel *Monopterus albus*	+	+	+
75	Perciformes	Serranidae	Big-eye Mandarin Fish *Siniperca knerii*	+	+	+
76			Mandarin Fish *S. chuatsi*	+	+	+
77			Golden Mandarin Fish *S. scherzeri*	+	+	+
78		Centrarchidae	Largemouth Bass *Micropterus salmoides*	+	–	+
79		Eleotridae	*Hypseleotris swinhonis*	+	+	+
80			Dark Sleeper *Odontobutis obscura*	+	+	+
81		Gobiidae	*Ctenogobius giurinus*	+	+	+
82		Belontiidae	Roundtail Paradise Fish *Macropodus ocellatus*	+	+	+
83		Channidae	Northern Snakehead *Channa argus*	+	+	+
84		Mastacembelidae	Lesser Spiny Eel *Mastacembelus aculeatus*	+	+	+

Table 2. Jaccard's index computed for faunal similarity of the middle and lower Hanjiang River during the 1976–1978, 2003–2004, and 2012–2013 time periods.

Year	1976–1978	2003–2004	2012–2013
1976–1978	–	95%	90%
2003–2004	–	–	93%
2012–2013	–	–	–

River (Li et al. 2006). Among these 16 species, only eight species were classified as commercially harvested (Li et al. 2006). Similarly, in 1976, there were nine well-known spawning grounds for fishes that spawned drifting eggs in the middle and lower reaches of the Hanjiang River (Zhou et al. 1980). In 2004, the spawning grounds of the major Chinese carps, namely Grass Carp, Black Carp, Silver Carp, and Bighead Carp, had disappeared in five of these nine known spawning grounds. Over the same time period, the number of spawning grounds for small-bodied fishes increased substantially (Li et al. 2006). The fry percentages of *Rhodeus sinensis*, *Pseudolaubuca engraulis*, and Stone Moroko, three small-bodied fishes, reached 26%, 19%, and 19% of the total fry number, respectively, and spawning grounds of these small-bodied fishes were distributed along the entire river in the middle reaches (Li et al. 2006).

The total quantity of drifting eggs in the middle reaches of the Hanjiang River increased 1.5-fold between 1976 and 2004 (Zhou et al. 1980; Li et al. 2006). However, the total egg quantity of the four major carps and other economically important fishes decreased from 3.14×10^9 in 1976 to 0.46×10^9 in 2004 while the total egg quantity of small-bodied fishes increased from 1.56×10^9 to 1.632×10^{10} during the same time period (Zhou et al. 1980; Li et al. 2006).

Changes in Fisheries Resources and Commercial Harvest Production in Danjiangkou Reservoir

Prior to dam construction, 34 fish species were found in the Hanjiang River reach that would later become Danjiangkou Reservoir (Bolotskiy et al. 1959). Following construction of the dam, a total of 70 fish species have been recorded, including 67 native species (Yuan and Huang 1989) and three exotic species (i.e., Channel Catfish, Largemouth Bass, and Paddlefish). The fishes collected represented five orders, 13 families, and 54 genera. Among these species, 44 species were from the family Cyprinidae (comprising 63% of the total species), nine species from Bagridae, three species each from Cobitidae and Serranidae, two species each from Siluridae and Salangidae, and one species each from Homalopteridae, Synbranchidae, Engraulidae, Eleotridae, Gobiidae, Channidae, and Mastacembelidae.

During the past 30 years, commercial fish harvest production in Danjiangkou Reservoir has gradually increased from about 20 kg/ha to about 75 kg/ha (Figure 1). The major fishes harvested were *Culter* spp., Silver Carp, Bighead Carp, Common Carp, Goldfish, and Icefish, which is a small, transpar-

Table 3. Comparison of average ages of fishes in catches collected from the middle and lower Hanjiang River during the 1976–1978 (Yu et al. 1981) and 2003–2004 (Li et al. 2005) time periods.

	Average ages					
Sampling time (reference)	Grass Carp	Common Carp	White Amur Bream	Barbel Chub	Goldfish	Yellow Catfish
1976–1978	3.7	3.3	3.6	3.6	2.3	2.4
2003–2004	2.9	2.1	2.7	3.2	1.2	1.4

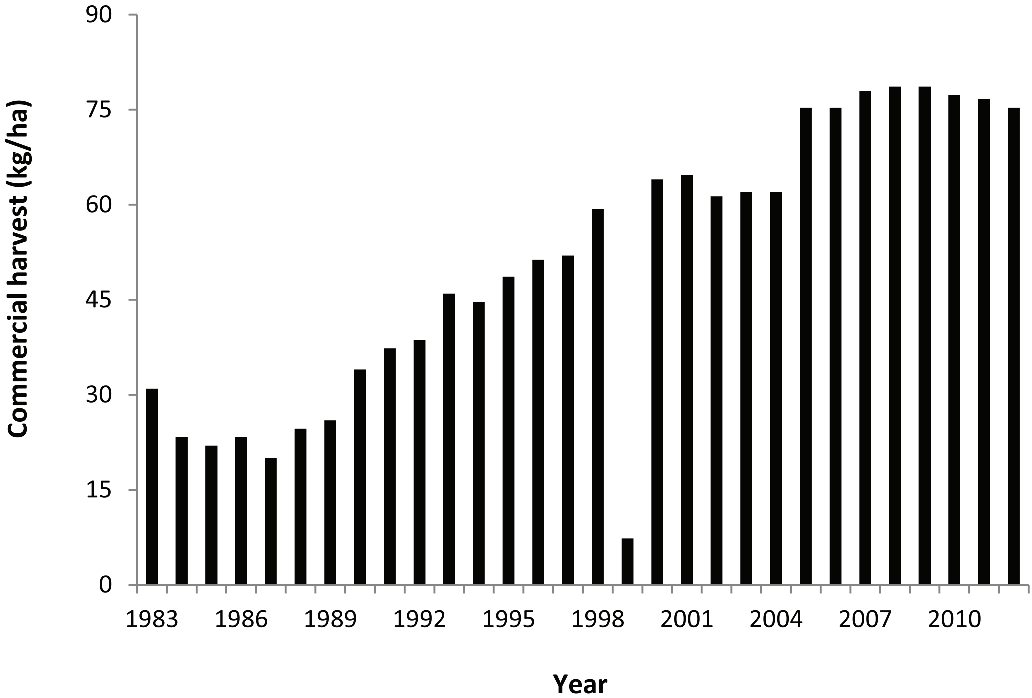

Figure 1. Commercial fisheries production as reflected by harvests in Danjiangkou Reservoir, 1983–2012.

ent species introduced to the reservoir in the late 1990s that has become commercially important (Yang et al. 2012). Cage-fish culture is an increasing industry within the Danjiangkou Reservoir (Figure 2). Fish production associated with cage-culture farms has increased from less than 200 metric tons in 1983 to more than 30,000 metric tons by 2011 (Figure 3). The main cage-cultured species included *Culter ilishaeformis*, Yellowcheek, Channel Catfish, and Largemouth Bass. In these cage-culture systems, small, low-valued fishes, such as Silver Carp, or frozen fishes are used as feeds for *C. ilishaeformis* and Yellowcheek. By contrast, Channel Catfish and Largemouth Bass are commonly fed formulated feeds. Fish production from these cage-culture systems typically ranges from 50 to 80 kg/m^3 (Hua Zhang, Fisheries Bureau of Danjiankou City, Hubei Province, P. R. China, unpublished data). This production is in the average level for cage culture in China (Liu and Huang 1998; Wang et al. 2014), but the value from the cage culture is much higher than those in other places since the price of *C. ilishaeformis* and Yellowcheek is about 3–5 times that of major carp species (Zhang, personal communication).

Possible Reasons for Fisheries Resources Changes in the Hanjiang River

Large dams impact river ecosystems and services worldwide (Dynesius and Nilsson 1994). Fisheries resources are impacted most by flow and temperature alterations, water chemistry changes, and migration blockage produced by dam construction (McAllister et al. 2001; Nilsson et al. 2005; Xie et al. 2007). A decade ago, Fu et al. (2003) warned that large water-diversion projects, such as the South–North Water Diversion Project, were likely to affect a broad array of native species throughout the Yangtze River basin. Following dam construction, the total egg quantity spawned by the four major commercial carp species (Grass Carp, Black Carp, Silver Carp,

Figure 2. Cage-fish culture facility in Danjiangkou Reservoir, China.

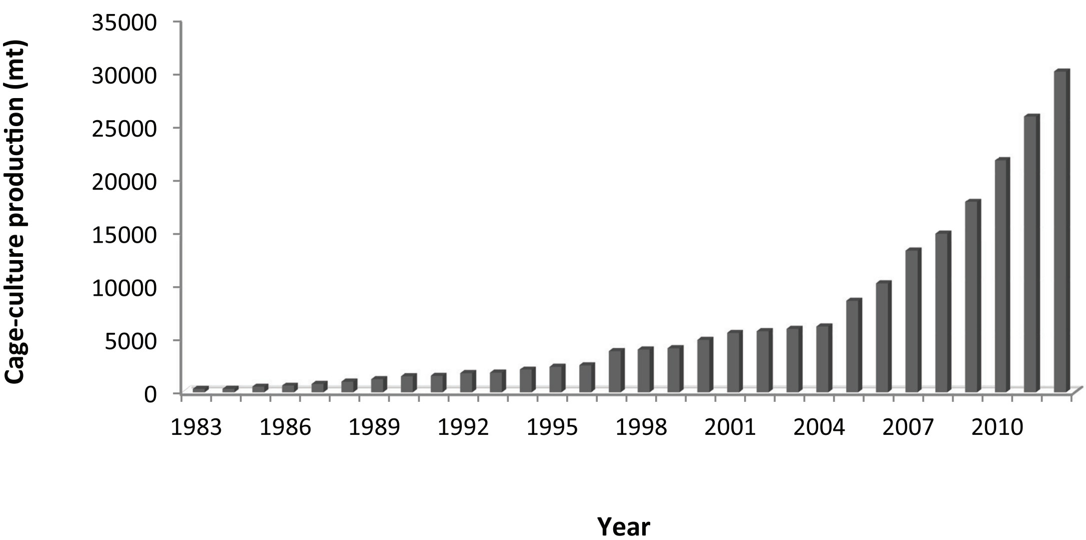

Figure 3. Cage-culture fisheries production in Danjiangkou Reservoir, 1983–2012.

and Bighead Carp) in the middle and lower Hanjiang River decreased significantly, which was consistent with the predictions of Fu et al. (2003). Spawning success of these carps is being negatively impacted, likely due to the narrower range of year-round water temperatures and water levels downstream of Danjiangkou Dam. Lack of spawning success for carps also may be related to the decreased range of flow fluctuations during the spawning season downstream of the dam, as has been observed at the Three Gorges Dam (Xie et al. 2007).

To implement the South–North Water Division Project, it was necessary to raise the height of Danjiangkou Dam 15 m during 2005–2009. Completed in late 2014, this project diverts 9.5×10^9 m^3 of water north from Danjiangkou Reservoir every year, which is equivalent to nearly one-fourth of the total flow of the Hanjiang and Danjiang rivers above the dam. With further decreases in water flow of the middle and lower reaches of the Hanjiang River, resources for the four major carps are predicted to continue decreasing. The habitat losses for these economically important carps must be fully considered and appropriate conservation strategies must be adopted. Given that sexual maturation of these carp species occurs in 5–7 years (Liu and He 1992), we suggest that establishment of conservation areas aimed at restoring major carp spawning habitats be prioritized for the reaches downstream of Danjiangkou Dam.

There are other factors that may have affected fisheries in the Hanjiang River. During the past few decades, modification of powered fishing boats and advanced fishing facilities have translated into significantly increased fishing effort and fish harvests. Li et al. (2006) estimated that there were at least 174 motor-powered fishing boats working from six locations along the Hanjiang River. Although there is a closed fishing season in the Hanjiang River from early April through late June, and government regulations prohibit harmful fishing techniques such as bombing, toxic fishing, and electric fishing, fishing effort and minimum harvest sizes are not strongly regulated. Thus, overfishing is another possible reason for decreases in abundances and sizes of many commercially important fishes. We strongly suggest implementation and enforcement of fisheries regulations that restrict total harvest, effort, and minimum harvest size for each boat and species along the entire Hanjiang River. These regulations combined with the closed fishing season will aid the restoration and protection of these valuable fisheries resources.

Another possibility for the decline of the four carp species is fragmentation of their habitats throughout the Hanjiang River. In the Hanjiang River basin, there are many natural lakes that were historically connected to the river. The four major carps regularly used these lakes for overwintering and growth, followed each year by migrations back to the main river for spawning during late spring and early summer (Liu and He 1992). However, widespread construction of sluice gates in the 1960–1970s has largely disconnected these lakes from the Hanjiang River main channel. Although obvious that disconnection blocks fish movements between lakes and the river, it is theorized that broodstock recruitment also has been affected, which is suspected to be further inhibiting the fisheries resources (Zhou et al. 1987; Chang and Cao 1999). We suggest the opening of the sluice gates during the spawning season of the major carps to allow broodstock spawning migrations between the lakes and Hanjiang River main channel. Opening of these gates also will facilitate movement of carp fry and juveniles from main river channel back to nursery habitats contained in these lakes (Zhou et al. 1987).

Eutrophication in the middle and lower reaches of the Hanjiang River is another potential threat to fisheries resources. During the past few decades, the frequency of reported algal blooms has increased from zero prior to the 1980s to once or twice during the 1990s. However, several dozen algal blooms have occurred since 2000 (Xie et al. 2006; Zhan Yin, Institute of Hydrobiology, Chinese Academy of Sciences, unpublished data). Eutrophication can increase fish production within limits, with a corresponding increase in system primary productivity (Liu and He 1992). Eutrophication may partly explain the significant increases of many small-bodied fishes such as *Rhodeus sinensis*, *Pseudolaubuca engraulis*, and Stone Moroku throughout the Hanjiang River. With the initiation of the South–North Water Diversion Project, further water pollution and subsequent eutrophication could affect future fisheries conservation efforts. The effects are predicted more for the middle and lower reaches of the Hanjiang River in light of the expected decreases in water flows.

Although exotic species are important to Chinese aquaculture (Liu and Li 2010), they may create ecological disasters in some natural waters (Liu 2014). Three exotic species common to Chinese aquaculture (Channel Catfish, Largemouth Bass, and Paddlefish) are being more routinely collected in Danjiangkou Reservoir and the Hanjiang River. Because the Hanjiang River provides an easy corridor to the Yangtze River, the potential ecosystem-level effects of these three exotic species on the Yangtze River should not be neglected. Furthermore, each species represents a different trophic guild, with Channel Catfish being an omnivore, Largemouth Bass a piscivore, and Paddlefish a planktivore. Stricter regulations and farm inspection programs should be developed that minimize the escape potential of these exotic species into the wild.

In conclusion, fisheries resources have changed significantly in the middle and lower Hanjiang River during the past 50 years. In particular, spawning grounds for the four major economically important carps and several other large-bodied fishes have significantly decreased. While total egg quantity spawned by the major carps and other commercially important fishes has decreased, production by small-bodied, economically less important fishes has increased downstream of Danjiangkou Dam. Important commercial fishes have experienced delayed spawning times and decreased growth. Overall catches of commercial fishes have decreased downstream of the Danjiangkou Dam, though they have increased upstream of the dam in Danjiangkou Reservoir. Changes in Hanjiang River fisheries resources also have presumably been affected by several factors, including Danjiangkou Dam, sluice gates separating floodplain lakes and the main river, overharvest, and eutrophication. With the decreased inflows in the middle and lower Hanjiang River due to the implementation of the South–North Water Diversion Project finished in late 2014, further changes in fisheries resources are expected in the future. Management and conservation strategies for fisheries resources need to be developed to ensure future fisheries sustainability both for the Hanjiang River and the Danjiangkou Reservoir.

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