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PERSPECTIVE

Challenges to saving China's freshwater biodiversity: Fishery exploitation and landscape pressures

Yushun Chen, Xiao Qu, Fangyuan Xiong, Ying Lu, Lizhu Wang, Robert M. Hughes

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Abstract China has over 1320 freshwater fish species, 877 of which are endemic. In recent decades, over-exploitation and landscape pressures have threatened them and led to a severe aquatic biodiversity crisis. In response, large-scale fishing bans have been promulgated to protect freshwater biodiversity in major Chinese rivers since the early 1980s. Here, we present the historical background and current challenges to the fishing bans. Implementing large-scale fishing bans may help improve China's current freshwater biological resources and biodiversity to some extent. But implementing fishing bans alone is not sufficient to solve the crisis because of shortcomings of the current bans and expanding human pressures in most river basins. Thus, we recommend regulating other anthropogenic pressures, expanding duration and extent of current fishing regulations, establishing a comprehensive monitoring program, and initiating basin-scale ecological rehabilitation. These programs are also needed in other developing countries facing similar biodiversity crises and human pressures.

Keywords Ecological rehabilitation · Freshwater biodiversity · Inland fishery regulations · Landscape pressures

INTRODUCTION

Freshwater fishes are under threat worldwide (Dudgeon et al. 2006; Vörösmarty et al. 2010), but the threat intensity in China is exceptionally severe because of China's large population size, booming economy, growing resource demand per capita, and the resulting degradation of aquatic ecosystems (Limburg et al. 2011; Chen et al. 2017a; Guo et al. 2019). Over 1320 freshwater fish species occur in China, and 877 of them, such as Chinese sturgeon (*Acipenser sinensis*) and Chinese paddlefish (*Psephurus gladius*) are found nowhere else in the world (Xing et al. 2016). The major threats to these fishes include water quality degradation, physical habitat modification, river fragmentation and dewatering, translocation of species outside of their native ranges, urbanization and agricultural development, and over-exploitation (Xie and Chen 1999; Fu et al. 2003; Dudgeon et al. 2006; Fang et al. 2006; Jelks et al. 2008; Vörösmarty et al. 2010; Chen et al. 2016, 2017a, b; Guo et al. 2019). These human threats have led to a severe aquatic biodiversity crisis in China. Many endemic aquatic species (fishes and freshwater mammals) are endangered or critically endangered (Xie and Chen 1999; Chen et al. 2017a), which calls for immediate actions for aquatic conservation in China.

Fishes, especially wild-caught fishes from natural rivers and lakes, are delicacy foods and important protein sources in Chinese diets. Therefore, fishes are heavily exploited, and over-exploitation is recognized as a critical threat to China's freshwater fishery resources and fish diversity (Allan et al. 2005; Chen et al. 2016). As China's government develops socioeconomic priorities and environmental protection policies, increased attention has been given to establishing policies and enforcement strategies to rehabilitate fisheries resources and promote biodiversity conservation (Chen et al. 2017a; Chen 2019).

However, water resource managers and policy-makers in China are largely relying on fishery regulations to solve the freshwater biodiversity crisis while paying less attention to other co-occurring, expanding, and even more imperative anthropogenic pressures (Dudgeon 2005; Chen et al. 2017a). Among the fishery regulations, fishing bans have been considered the most aggressive action and have received national attention (Chen 2018, 2019). Thus, we

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present the historical background and current challenges to Chinese fishing bans, but call for immediate actions on several other fronts for mitigating China's freshwater biodiversity crisis.

DECLINES IN FISHERIES AND ENDEMIC FISHES LEADING TO FISHING BANS

As the Chinese human population and wealth increased dramatically in recent decades, demand for fishes as food increased correspondingly. Between 1993 and 2013, Chinese per capita fish consumption increased an average of 5% annually (FAO 2016) and China consumed 38% of the total global fish production in 2015 (FAO 2018). This demand, along with co-occurring economic pressures, has resulted in the disappearance or decline of many traditional fisheries across China (Zhao et al. 2015). Historically, neither subsistence nor commercial harvests were well regulated (Chen et al. 2016). Such poorly regulated fish harvesting, in conjunction with other anthropogenic pressures, has resulted in dramatic declines in fishery resources, total catch, and biodiversity (Fig. 1). For instance, the total fish catch dramatically decreased from > 20 000 tons in the late 1990s to about 6000 tons in 2000, and to < 2000 tons since 2008 in the mainstem Yangtze River below Gezhouba Dam (Fig. 1a). This decreasing trend was consistent for total catches of economically important and commercially harvested fish species such as bronze gudgeon (*Coreius heterodon*) (Fig. 1b), yellow catfish (*Tachysurus fulvidraco*) (Fig. 1b), the four major carps, grass carp (*Ctenopharyngodon idellus*), black carp (*Mylopharyngodon piceus*), bighead carp (*Hypophthalmichthys nobilis*), and silver carp (*Hypophthalmichthys molitrix*) (Fig. 1c) and Osbeck's grenadier anchovy (*Coilia mystus*) (Fig. 1c). We used carp fry data here to indicate the status and trend of the wild population because the commercial carp catch data are a mixture of wild and stocked populations in the mainstem Yangtze River.

The unregulated fisheries and the Gezhouba Dam (the first mega-dam on the mainstem Yangtze, which began its first operation in 1981 and its full operation in 1988) have been linked to the extinction or endangerment of endemic fish species such as the Chinese sturgeon (Phelps et al. 2016). In addition to the previously mentioned fish species, the Chinese sturgeon and other endemic fish species were previously commercially harvested for food in the Yangtze River (Phelps et al. 2016). For instance, the annual commercial harvested number of Chinese sturgeon from the Yangtze River was around 400 to 600 during 1972–1980, and then reached 1163 in 1981 when large numbers of Chinese sturgeon were not able to pass the Gezhouba Dam and gathered below the dam (Fig. 2a; Phelps et al. 2016; Huang et al. 2017). Also, the pre-spawn population of Chinese sturgeon in the mainstem Yangtze River below Gezhouba Dam was about 2176 individuals in 1980, but was reduced to < 1000 in 1989, and then to only around 20 in 2017 (Fig. 2a; Zhu et al. 2009; Huang 2013; CMEE 2017; CMOA 2019). Likewise, the population of Chinese paddlefish in the mainstem Yangtze River below Gezhouba Dam dramatically decreased from about 32 individuals in 1985 to functional extinction. That is, the total existing population became too low to support natural reproduction around 1995 (Fig. 2b; Wei et al. 1997; Phelps et al. 2016; CMOA 2019).

Uncontrolled fish harvesting and other anthropogenic pressures also contributed to the extinction or endangerment of freshwater mammals as a result of increased mortality, morbidity, injury, and starvation (Chen et al. 2016). For instance, the population of Baiji or Yangtze river dolphin (*Lipotes vexillifer*) in the mainstem Yangtze River was around 300 individuals in 1983, but dropped dramatically in the 1990s, and became functionally extinct in 2006 (Fig. 3; Chen and Hua 1985; Chen et al. 1993; Zhang et al. 2003; Turvey et al. 2007; Chen et al. 2016). The population of the Yangtze finless porpoise (*Neophocaena asiaeorientalis*) in the mainstem Yangtze River decreased from about 3 000 in the late 1980s to about 1000 in 2006, and to only about 500 individuals in 2017 (Fig. 3; Zhang et al. 1993; Mei et al. 2014; Chen et al. 2016; CAS 2018).

The depressed fishery resources and endangered or extinct endemic fish species and freshwater mammals alarmed management agencies and the general public, leading to increased fishing bans in the Yangtze River and other river basins in China (Fig. 4). Although fishing bans had been implemented in the early 1980s, including the prohibition of commercial fishing of Chinese sturgeon and Yangtze sturgeon (*Acipenser dabryanus*), the recent fishing bans are unprecedented in duration and extent. Examples of these include expansion of spring fishing bans from the lower and middle reaches to the upper Yangtze River implemented between 2002 and 2016 and the expansion of year-long fishing bans from the Chishui River to all 332 aquatic biota reserves in the Yangtze River Basin during 2017–2018 (CMOA 2019). The year-long ban will be extended to all major natural water bodies in the Yangtze River Basin in 2020 (The State Council of China 2018; Fig. 4). Spring fishing bans have also been implemented in the entire Pearl River Basin since 2011, the mainstem Huai River since 2016, the entire Min River Basin and inland waters in Hainan province since 2017, the entire Yellow River Basin since 2018, and in the Liao, Hai, Songhua, and Qiantang River basins in 2019 (CMOA 2019).

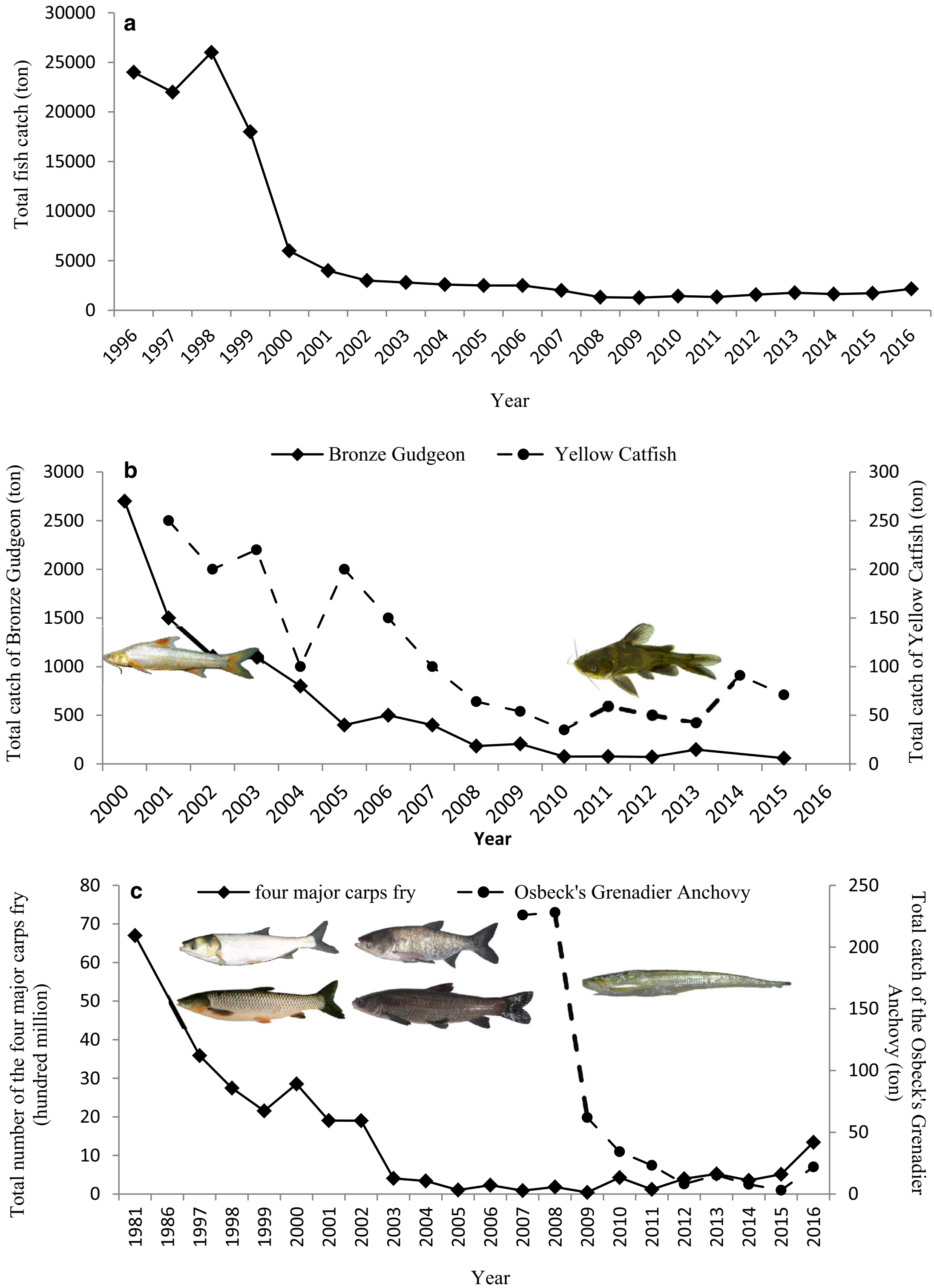

Fig. 1 Total catch of **a** all fish species, **b** bronze gudgeon *Coreius heterodon* and yellow catfish *Tachysurus fulvidraco*, and **c** the four major carp species fry and Osbeck's grenadier anchovy *Coilia mystus* below Gezhouba Dam in the mainstem Yangtze River. Note: All plotted fish species are commercially harvested and important economically in the Yangtze River. Osbeck's grenadier anchovy is the most important fish species in the Yangtze River estuary. The four major carp species are grass carp *Ctenopharyngodon idellus*, black carp *Mylopharyngodon piceus*, bighead carp *Hypophthalmichthys nobilis*, and silver carp *Hypophthalmichthys molitrix*. The four major carp fry were monitored to assess the total amount of these species that are naturally spawned and to indicate the wild population condition of those species. Data sources: Zhu et al. (2009) and CMEE (2017)

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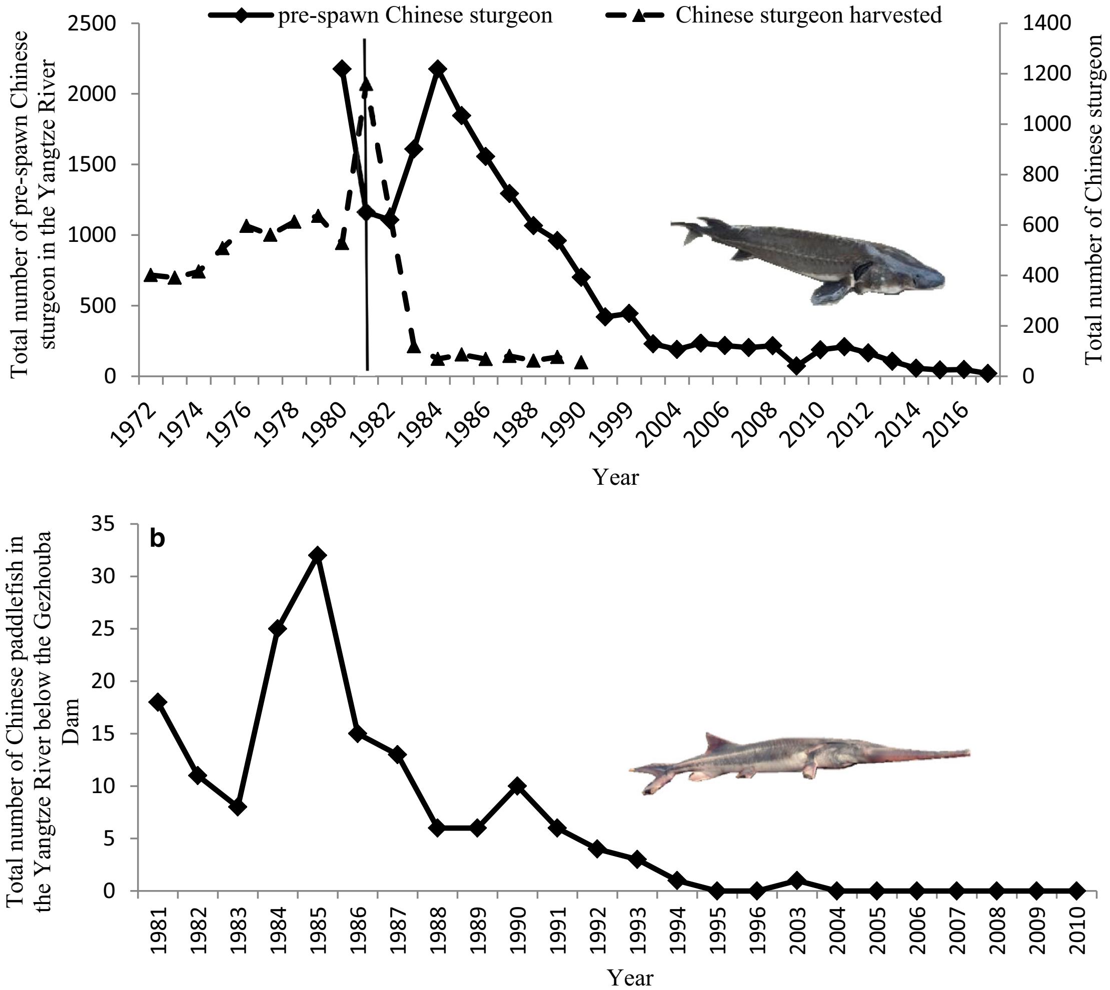

Fig. 2 **a** Total harvested number and pre-spawn of Chinese sturgeon *Acipenser sinensis* (the vertical line indicates the initial operation of the Gezhouba Dam in 1981) in the Yangtze River and **b** total estimated number of adult Chinese paddlefish *Psephurus gladius* below the Gezhouba Dam in the mainstem of the Yangtze River. Data sources: Wei et al. (1997), Zhu et al. (2009), Huang (2013), Phelps et al. (2016), Huang et al. (2017), CMEE (2017), and CMOA (2019)

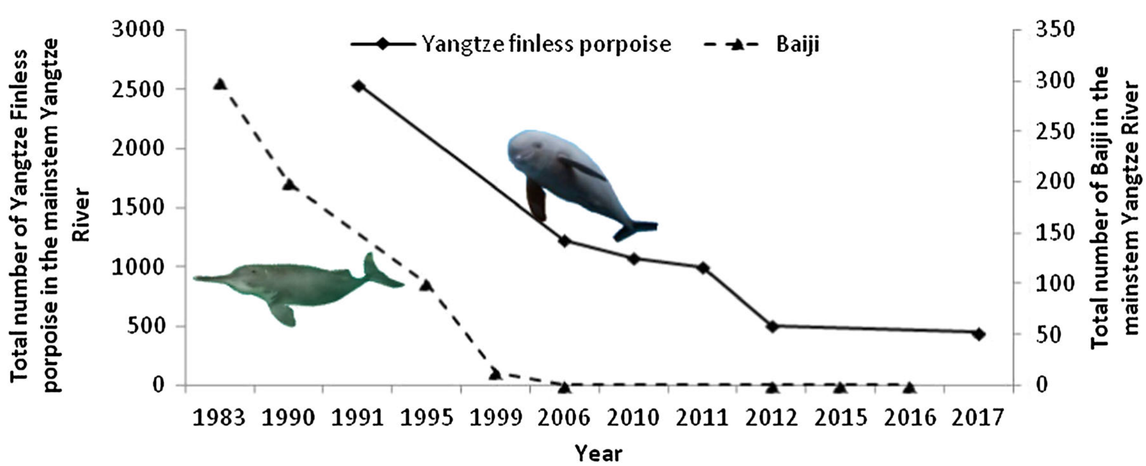

Fig. 3 Total estimated number of Baiji or Yangtze river dolphin *Lipotes vexillifer* and Yangtze finless porpoise *Neophocaena asiaeorientalis* in the mainstem of the Yangtze River. Data sources: Chen and Hua (1985), Chen et al. (1993), Zhang et al. (1993, 2003), Turvey et al. (2007), Mei et al. (2014), Chen et al. (2016), CMEE (2017), and CAS (2018)

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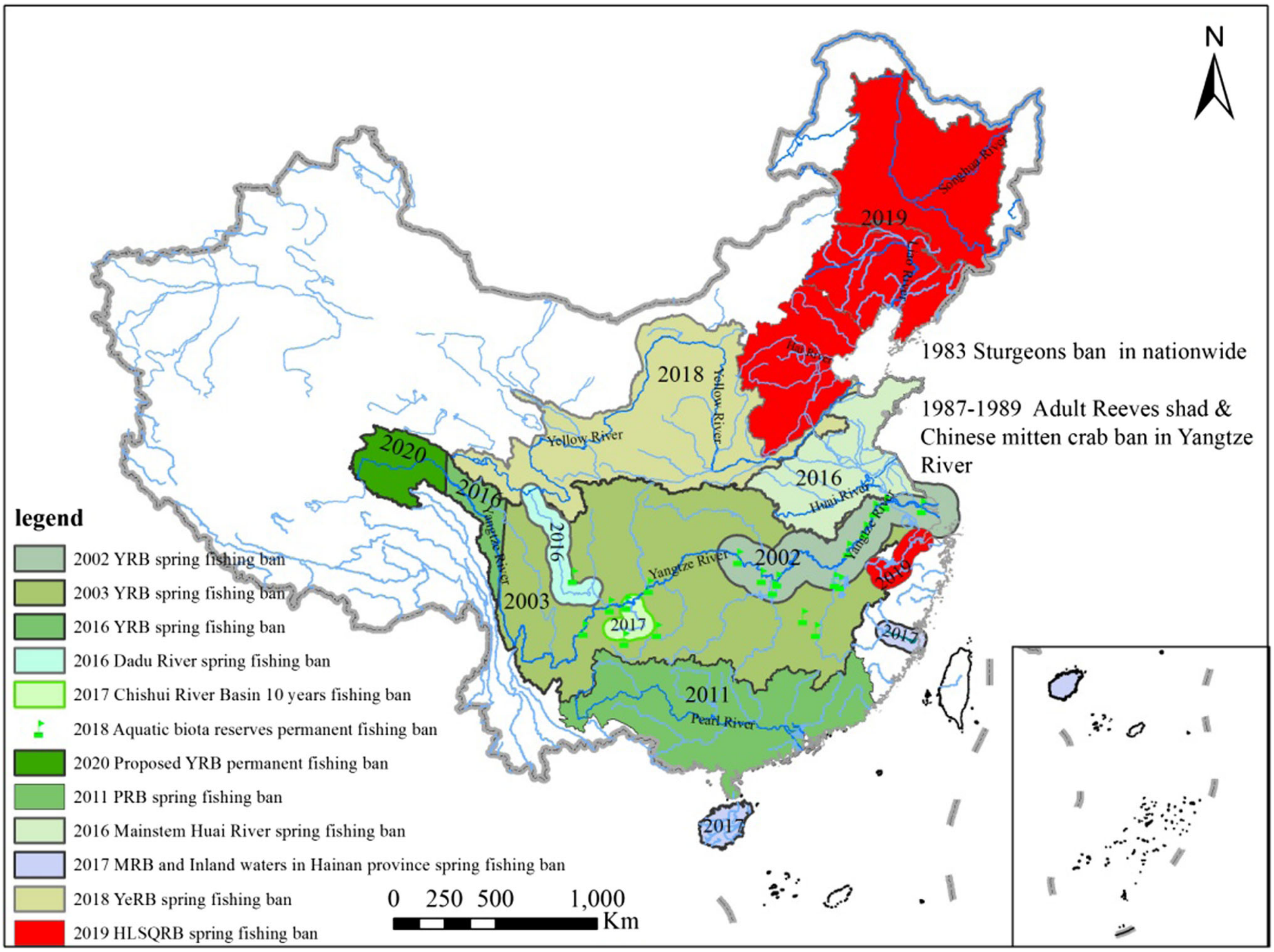

Fig. 4 Fishing bans in major Chinese river basins since the 1980s. YRB indicates the Yangtze River Basin; PRB indicates the Pearl River Basin; MRB indicates the Min River Basin; YeRB indicates the Yellow River Basin; HLSQRB indicates the Hai, Liao, Songhua, and Qiantang River Basins. Data source: CMOA (2019)

CHALLENGES TO THE SUCCESS OF FISHING BANS FOR RESTORING FISHERIES AND BIODIVERSITY

The effectiveness of the fishing bans for restoring the fisheries and fish biodiversity of China is limited by the combination of three factors:

(1) Strict law enforcement during the fishing ban seasons and post-ban fish harvest (i.e., the harvest or re-opening of commercial fishing after the spring fishing ban or closure period) regulation are critical to the success of the fishing bans to achieve the goal of restoration of fisheries and fish biodiversity for inland waters in China. As a result of fishing bans, thousands of fishers affected by the fishing bans will be compensated by the governments. As part of the 2018 spring fishing ban, a multi-agency (e.g., Fisheries Administration, Public Security, Water Police, Maritime Safety, Border Defense, Coast Guard) fishing law enforcement fleet was formed with a fleet of 1000 boats and 10 000 officers to patrol the 21 regulated provinces and municipalities (CMOA 2019). Although the fishing ban has yet to be completely enforced, over 60 000 illegal nets have been removed, and 405 people violating fishing regulations have been penalized over the past 3 years (http://www.xinhuanet.com/english/2019-03/01/c_137861381.htm, accessed June 2019).
Historically, post-ban harvests were unregulated or poorly regulated, resulting in exploitation of all fishes from fingerlings to adults in the months immediately after the bans (Chen et al. 2017a). Field surveys showed that this unregulated fishing practice was very common in the Yangtze River Basin, especially after the July 1 re-opening of the commercial harvest (Chen et al. unpubl.). Globally, historical fishery over-exploitation led to substantial

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fishery declines in large rivers and estuaries (FAO 2016, 2018). In North America and other regions, fisheries are now well regulated for fish species, length and number limits, and areas and seasons (Krueger et al. 2019). If modified and applied to waters in China and other developing countries, such regulations could help ensure that fishery resources would not be further depleted by fishers while still meeting their fishing needs.

(2) Many other co-occurring pressures, in addition to over-exploitation, in the Yangtze and other river basins directly or indirectly threaten fisheries and fish diversity (Chen et al. 2017a, b; Fig. 5) and limit the success of the fishing bans. These include hydropower dams, sand mining, commercial navigation, urban and agricultural land uses, harbor and riparian developments, industries and mining, river–lake fragmentation, and many others (Chen et al. 2017a, b). Although currently unquantified and unassessed, such pressures likely threaten fisheries and biodiversity at least as much as fishing, and they are still expanding (Chen et al. 2017a, b). Similar landscape and riverscape pressures continue to limit fisheries and aquatic biodiversity globally (Dudgeon et al. 2006; Jelks et al. 2008; Vörösmarty et al. 2010; Schinegger et al. 2013, 2016).

Total hydropower generated in the mainstem Yangtze River increased 10 times from 3000 MW in 1988 to 30 000 MW in 2011, reached 62 000 MW in 2016, and is expected to rise to 100 000 MW in the near future (Fig. 6a). These dams blocked migration routes for all long-distance migratory species such as sturgeon, paddlefish, and dolphin (Phelps et al. 2016; Chen 2018). Also, dam operations affected spawning of some fish species such as the four major carps (Chapman et al. 2016; Chen 2018). Moreover, the dam reservoirs accumulated sediments from upriver (Chen et al. 2017a; Chen 2018). Dams and flow regulation were reported to be major factors altering fish assemblages in large American rivers (Hughes et al. 2005).

Total sand mined in the middle and lower reaches of the Yangtze River increased from 23 MT in 2004 to 80 MT in 2013, and was limited to around 30 MT during 2015–2016 because of regulations on legal sand mining in the recent years (Fig. 6a). However, illegal and unreported sand mining is still poorly controlled (Chen et al. 2017b). Sand and other sediments are important materials for aquatic habitats, including river beds, riparian zones, and islands (Hughes et al. 2016). Sand mining increased the loss of these aquatic habitats in rivers and lakes, especially downstream of hydropower dams (Chen et al. 2017b).

Total cargo shipped on the Yangtze River increased from 0.5 million tons (MT) in 1998 to 2 MT in 2008, and then to 4 MT in 2017 (Fig. 6b). Navigation leads

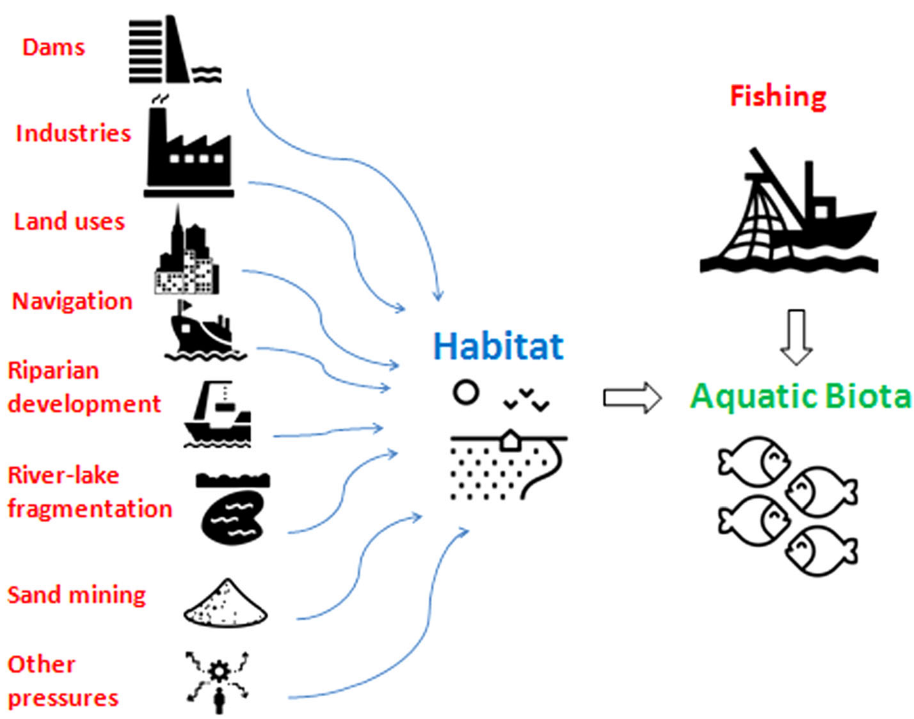

Fig. 5 Conceptual diagram illustrating the direct impacts of fishing and the indirect impacts of landscape pressures through habitat on freshwater biodiversity in Chinese rivers

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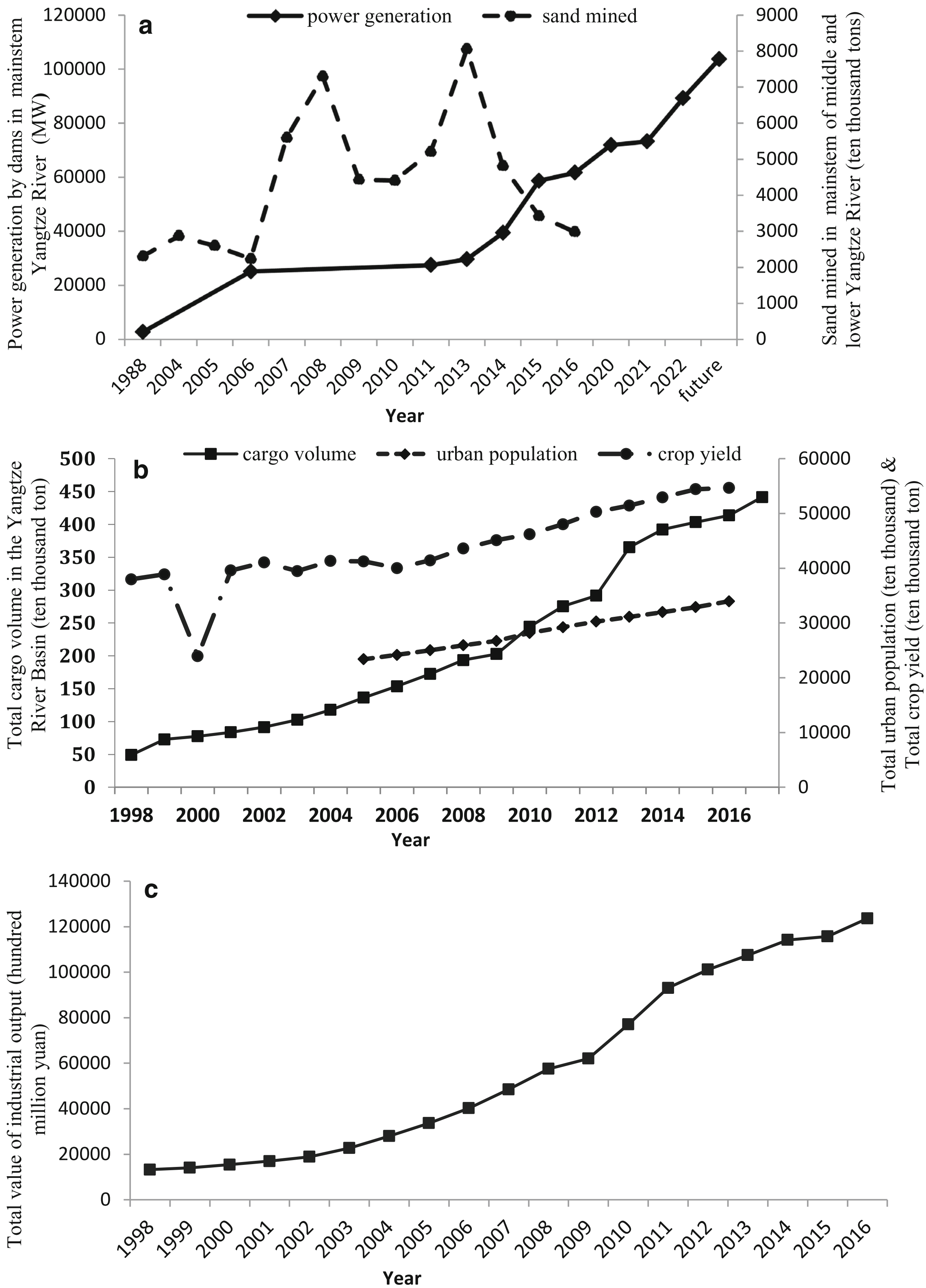

Fig. 6 Trends of total annual **a** power generations by mainstem dams and sand mined in the middle and lower mainstem, **b** cargo volume, urban population and crop yield, and **c** value of industrial output in the Yangtze River Basin. Data sources: China Ministry of Water Resources or MWR (http://www.mwr.gov.cn/); China Ministry of Transport or MOT (http://www.mot.gov.cn/); China Ministry of Natural Resources or MNR (http://www.mnr.gov.cn/); and China National Bureau of Statistics or NBS (http://www.stats.gov.cn/)

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to severe channel modifications by dredging and channelizing to maintain the required channel condition and reduce risks of accidents (Chen 2018). Moreover, the increased cargo volume reduces fish feeding and rearing zones and increases the possibility of injuries or deaths from ship collisions and propellers, thereby decreasing the abundance of several fish species (Chen 2018; Zajicek and Wolter 2019).

Total urban population increased from 234 million in 2005 to 340 million in 2016 in the Yangtze River Basin (Fig. 6b). There are three urban centers (i.e., Shanghai, Wuhan, and Chongqing-Chengdu) in the Yangtze River Basin and the urbanization rate has been projected to increase further around these centers (Chen et al. 2017a). One impact from urbanization is the occupation of tributaries, riparian zones, and floodplains of rivers and lakes near where most aquatic biota feed, breed, and rear (Yeakley et al. 2014; Chen et al. 2017a; Guo et al. 2019). In addition, urban sewage and impervious area runoff is untreated, leading to high loads of organic wastes, nutrients, and toxic contaminants (Yeakley et al. 2014).

Total crop yields increased from 380 MT in 1998, to 436 MT in 2008, and then to 547 MT in 2016 in the Yangtze River Basin (Fig. 6b). Additionally, confined animal feeding operations are an important component of agricultural development in the Yangtze River Basin (Chen et al. 2017a; Chen 2018). The major impacts from agricultural development are the discharge of nutrients (nitrogen and phosphorus), fine sediments, and biocides into adjacent rivers and lakes, together with the alteration of physical habitat structure (Chen et al. 2016; USEPA 2016; Leitão et al. 2018).

Total value of industrial output increased more than four times from 1 trillion Yuan (1 US Dollar is about 7 Chinese Yuan) in 1998 to 6 trillion Yuan in 2008, and then doubled to about 12 trillion Yuan in 2016 in the Yangtze River Basin (Fig. 6c). The major impacts of untreated or partially treated industrial wastes on rivers and lakes are contamination from toxic chemicals and increased temperatures (Chen et al. 2017a). Such wastes are known to eliminate sensitive fish species and increase the abundances of tolerant species (Hughes et al. 2005; Krueger et al. 2019).

The aforementioned anthropogenic impacts on river systems are recognized worldwide. Such issues have been addressed through federal and provincial legislations, such as the Water Framework Directive in Europe (Schinegger et al. 2016) and the Clean Water Act in the United States (Keller and Cavallaro 2008), which have been effectively implemented and much progress has been made in water protection and rehabilitation. In contrast, although China has established environmental statutes (e.g., the Chinese Biodiversity Conservation Action Plan and the Chinese Environmental Protection Action Plan), they have been either implemented ineffectively or complied with insufficiently. Restoring fishery and biodiversity by implementing fishing bans in combination with addressing other anthropogenic impacts is an added challenge for China and other developing countries where people largely depend on fish as food and face increased anthropogenic pressures. Some of the experiences from the western countries could be modified and applied to China and other developing countries for restoring fisheries and biodiversity.

(3) Evaluating the successfulness of the fishing bans is important so that fishing regulations can be adjusted to meet specific species and regional needs. Such evaluations also facilitate identifying pressures other than over-exploitation so that environmental regulation policies can be developed accordingly. However, fishery and aquatic resources have been poorly monitored and assessed before and after the current bans (Chen et al. 2002) precluding rigorous before-after and control-treatment assessment designs (Maas-Hebner et al. 2016). To date, no comprehensive national or provincial monitoring and assessment program has been established at basin scales, further hindering status and trend assessments such as those implemented for ecological assessments in the United States (e.g., USEPA 2016; Krueger et al. 2019), Europe (e.g., Pont et al. 2006; Schinegger et al. 2013), Australia (Robinson et al. 2019), and South Africa (DWAF 2008). Some of these monitoring and assessment programs could be modified and applied to Chinese rivers and lakes where large-scale fishing bans will be implemented (Chen 2019). Once these monitoring and assessment programs are implemented, fishery regulations could be further adjusted and modified to meet specific needs, especially in considering regional differences (Krueger et al. 2019). Such cost-effective monitoring and assessments are needed to better understand the status, trends, and major pressures regarding fisheries and biodiversity globally (FAO 2016, 2018; Hughes et al. 2019).

A CALL FOR ADDITIONAL ESSENTIAL ACTIONS

Thus, we argue that implementing the fishing ban only is not enough to save China's current freshwater fishery resources to address the biodiversity crisis. To make the

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fishing ban program more effective for fishery resource rehabilitation and biodiversity conservation in the future, and to help address China's freshwater biodiversity crisis in a comprehensive way, we suggest implementing six programs (Table 1).

(1) Promulgate legislation and regulations that set specific goals and quantitative targets for dischargers and receiving waters. Currently, land and water users and industrial and municipal dischargers are essentially unregulated in China, which has resulted in major chemical spills as well as chronic degradation of surface and ground waters (Qu and Fan 2010). The EU and the USA first focused on industrial and municipal discharges. Agricultural land use regulations have been less effective in most cases, but soil erosion rates and agricultural chemical releases have been reduced somewhat (USEPA 2016; Schinegger et al. 2013, 2016). To implement this in China, the central government needs to promulgate and maintain river basin legislation and regulations to control discharges of chemicals and other pollutants in each of the large river basins. Such regulations must be enforced by multiple provincial and local governmental agencies, but with the central government oversight.

(2) Implement comprehensive and effective adaptive management plans accompanied by ecological monitoring and assessment programs (Maas-Hebner et al. 2016) and make the monitoring and assessment data available to the public (e.g., USEPA 2016). Current project-based monitoring and assessment of fishery and aquatic resources is insufficient to assess the overall effectiveness of the fishing ban program, let alone the aquatic effects of the pressures listed above. This creates gaps and uncertainties for future implementation and optimization of regulatory activities (Krueger et al. 2019) and adaptive management (Maas-Hebner et al. 2016). A comprehensive monitoring program is especially needed in the Chishui River Sub-basin where those other human pressures are limited and the fishing ban lasts for 10 years. If the data and management actions are made transparent to the public, it will facilitate the fishing ban, adaptive management planning, and the monitoring and assessment. China has not yet established a nationwide ecological monitoring and assessment program nor adaptive management plans for aquatic ecosystems. Such a program and basin-specific adaptive management plans could help identify threatened water bodies, and better support the regulation of human-caused pressures over large spatial extents (e.g., within a large river basin such as the Yangtze). To implement this approach, integrating the current project-based monitoring and assessment of fishery

Table 1 Essential actions to rehabilitate China's freshwater biodiversity

Action	Benefits	Feasibility	Implementation
1. Promulgate statutes for all stressor-producing entities	Sets goals, objectives & quantitative targets for discharges & ambient levels	Based on US Clean Water Act & EU Water Framework Directive successes	China central government: Promulgate & coordinate river basin regulations
2. Develop comprehensive ecological implementation & effectiveness monitoring & assessment programs	Identify individual stressor-producing entities meeting or failing to meet targets Assess spatial extent of ecological effectiveness	Based on US Clean Water Act & EU Water Framework Directive successes	China Ministry of Ecology & Environment: Coordinate & integrate local programs into nationwide programs
3. Implement basin-scale long-term fishing bans	Provide sufficient time for aquatic biota to recover	Based on current seasonal closures; shift food sources to aquaculture	China Ministry of Agriculture & Rural Affairs: maintain & expand current fishing ban programs
4. Quantify impacts from multiple pressure types	Help focus additional regulatory efforts & adaptive management	Based on US Clean Water Act & EU Water Framework Directive successes	Research institutes, universities & government agencies: Quantify impacts & rank pressures
5. Regulate all anthropogenic pressures	Reduce physical, chemical & biological stressors; improve human health & quality of life	Based on US Clean Water Act & EU Water Framework Directive successes	China central government: Coordinate provincial & local governments to prioritize & regulate pressures
6. Conduct basin-scale physical habitat rehabilitation	Improve physical habitat conditions for aquatic & riparian biota	Technically doable and required by the China central government	China central government: Educate provincial & local governments to prioritize & conduct ecological rehabilitation

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and aquatic resources programs could be a good start. However, to extend those local programs to a nationwide monitoring and assessment program, quantitative indicators, monitoring protocols and assessment methodologies must be standardized (Pont et al. 2006; USEPA 2016; Hughes et al. 2019). In addition, a nationwide digital database of all stream channels, lakes, and wetlands is needed to facilitate extensive monitoring and assessment programs (Hughes et al. 2019). Implementation of this action will require that the China Ministry of Ecology and Environment coordinate research institutes, universities, and government agencies to integrate individual project-based programs, establish and manage a nationwide digital database, and initiate integrated nationwide monitoring and assessment programs.

(3) Promote basin- and sub-basin-scale long-term (e.g., 10–15 years) fishing regulation and enforcement in natural water bodies rather than short-term seasonal bans. The current 10-year ban in the Chishui River and the permanent ban in the Yangtze aquatic reserves are useful examples and tests for future fishing regulations. After sufficient long-term bans, fish and other aquatic resources may be returned to sustainable levels, then followed by more-refined regulated fisheries (e.g., fishing seasons and area closures; species, size, and number limits, and catch and release), which might be effective in China as they have been in Australia, Europe and North America. Many of the most enthusiastic advocates for fishery conservation and pollution controls in those cultures are the millions of anglers who treasure their waters and their biota and create billion-dollar recreational industries as well (Hughes 2015). The current regulated fishery policies and management strategies in North America and elsewhere may not be effective in China currently because many aquatic resources have been largely depleted. To help restore aquatic resources to a sustainable level in major Chinese river basins, the large-scale and long-term fishing ban could be direct management tools. If aquatic resources are restored and sustained, fishing can be re-opened but with strict management rules (such as limitations on angling gears, daily species sizes and numbers, and angling locales) instead of returns to overfishing as occurred in the past. Until that occurs, fish consumers must rely on aquaculture from ponds, rice fields, and other intensive culture facilities. The China Ministry of Agriculture and Rural Affairs will need to play a key role in maintaining and expanding the current fishing ban programs. Once the fisheries are restored, the Ministry must adopt fishery policies and management strategies that have been successful in other countries.

(4) Quantify impacts from multiple anthropogenic pressures and stressors (Pont et al. 2006; Schinegger et al. 2013; USEPA 2016; Hughes et al. 2019; Guo et al. 2019) because there is an urgent need to assess their individual and cumulative impacts. Despite uncertainties and data gaps, advanced modelling and statistical tools can be applied to quantify the relative contribution of each stressor or pressure in degrading fishery and aquatic resources (Krueger et al. 2019; Van Sickle and Paulsen 2008; Leitão et al. 2018; Hughes et al. 2019; Guo et al. 2019). This will be very useful for planning basin-wide management and rehabilitation efforts (Maas-Hebner et al. 2016). Within each large river basin of China, impacts from those individual anthropogenic pressures on aquatic resources have never been quantified. After their relative contributions are quantified, basin-wide planning strategies and regulations must be developed to target priority pressures and stressors and to track their management effectiveness (Maas-Hebner et al. 2016; Chen 2019; Krueger et al. 2019). To implement this assessment, research institutes, universities, and provincial and local environmental agencies (coordinated by the central government) will need to standardize how they quantify impacts and rank pressures for each river basin to pinpoint sources of stressors for subsequent management and regulation actions.

(5) Regulate all pressures and stressors. Fishing is just one of the many human pressures that have depressed fishery and aquatic resources in China's waters. Implementation of fishing bans alone will not fully rehabilitate the fishery and biodiversity of China's rivers and lakes if other anthropogenic pressures are not regulated as well (Chen et al. 2017a, b; Chen 2019). However, aquatic biota and fisheries can be rehabilitated by regulating anthropogenic pressures and stressors in conjunction with fishing regulations (Chen et al. 2016; Krueger et al. 2019). As indicated before, most landscape pressures have been expanding in major Chinese river basins. We know how those pressures affect aquatic biota, and we know how to limit their effects. If not regulated, these pressures will blur any benefits from fishing bans. To regulate landscape pressures, basin-wide plans need to be developed to prioritize corrective actions and a regulation timetable needs to be developed to minimize their social impacts (Maas-Hebner et al. 2016; Chen 2019). To implement this, the central government will need to work closely with provincial and local governments to establish priorities and targets

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for eliminating or minimizing the impacts of those sources.

(6) Initiate basin-scale ecological rehabilitation. To rehabilitate freshwater biological resources and biodiversity, basin-scale ecological rehabilitation is urgently needed in major Chinese river basins. To do so, successful examples and experiences from other regions of the world (e.g., Bernhardt et al. 2005; Palmer et al. 2005; Lake et al. 2007; Pander et al. 2014; Benjamin et al. 2016; Shrestha et al. 2017) should be examined, modified as needed, and applied to China's river basins. Those previous approaches are either to control or minimize negative impacts on aquatic resources, but ecological rehabilitation also needs to focus on improving habitat and overall ecosystem health. A list of priority sub-basins or aquatic biodiversity hotspots from each large river basin also need to be established for implementing ecological rehabilitation, perhaps beginning with China's global freshwater biodiversity hotspots such as the Yangtze River basin (Marchese 2015; Chen 2019). Again, this implementation will require that the central government coordinate provincial and local governments to determine priorities and targets for ecological rehabilitation in each river basin.

CONCLUSIONS

At least 877 Chinese fish species are endemic, including the iconic Chinese Sturgeon and Chinese Paddlefish. Those species, as well as China's 1320 other fish species are threatened by multiple anthropogenic pressures and the resulting aquatic habitat degradation. Implementing seasonal or regional year-long fishing bans alone is not enough to solve China's aquatic biodiversity crisis because of the unregulated harvests after spawning season bans are lifted and the many other co-occurring and expanding anthropogenic pressures. Thus, we recommend regulating all anthropogenic pressures and stressors, establishing a comprehensive monitoring program, expanding the duration and extent of current fishing regulations with strict enforcement, and initiating basin-scale ecological rehabilitation projects (Table 1). All these programs are needed to rehabilitate freshwater fisheries and biodiversity in China, and they are applicable to other nations where people largely depend on fish as food while facing biodiversity crises and expanding anthropogenic pressures. For instance, developing countries in Africa, Southeast Asia, and South America are experiencing similar economic development and rapid human population growth accompanied by ecological degradation of lakes and rivers. Those countries are facing similar problems and may or may not have implemented basin-scale fishing bans like those China is currently pursuing. Successful fishing regulation and addressing other anthropogenic impacts could be a joint learning experience for improving freshwater management and biodiversity conservation in both China and those countries. In doing so, China could take the lead in offering realistic examples of how developing countries can mitigate their fishery and aquatic biodiversity crises.

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AUTHOR BIOGRAPHIES

Yushun Chen (✉) is a professor at Institute of Hydrobiology & University of Chinese Academy of Sciences. His research interests include watershed anthropogenic pressures and aquatic ecosystems health, and fishery and aquatic biodiversity conservation in large river basins.
Address: Institute of Hydrobiology & State Key Laboratory of Freshwater Ecology and Biotechnology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan, Hubei 430072, China.
Address: University of Chinese Academy of Sciences, 19 Yuquan Road, Shijingshan, Beijing 100049, China.
e-mail: yushunchen@ihb.ac.cn

Xiao Qu is a Ph.D. student at Institute of Hydrobiology & University of Chinese Academy of Sciences. His research interests include GIS analysis and aquatic biodiversity conservation in large river basins.
Address: Institute of Hydrobiology & State Key Laboratory of Freshwater Ecology and Biotechnology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan, Hubei 430072, China.
Address: University of Chinese Academy of Sciences, 19 Yuquan Road, Shijingshan, Beijing 100049, China.
e-mail: quxiao@ihb.ac.cn

Fangyuan Xiong is a Ph.D. student at Institute of Hydrobiology & University of Chinese Academy of Sciences. Her research interests include fish communities and water quality in rivers and streams.
Address: Institute of Hydrobiology & State Key Laboratory of Freshwater Ecology and Biotechnology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan, Hubei 430072, China.
Address: University of Chinese Academy of Sciences, 19 Yuquan Road, Shijingshan, Beijing 100049, China.
e-mail: xiongfangyuan@ihb.ac.cn

Ying Lu is a M.S. student at Institute of Hydrobiology, Chinese Academy of Sciences. Her research interests include watershed land use and land cover analyses and aquatic habitat assessment.
Address: Institute of Hydrobiology & State Key Laboratory of Freshwater Ecology and Biotechnology, Chinese Academy of Sciences, 7 South Donghu Road, Wuhan, Hubei 430072, China.
e-mail: luying@ihb.ac.cn

Lizhu Wang is a senior scientist and fish biologist at International Joint Commission & School for Environment and Sustainability, University of Michigan. His research interests include watershed anthropogenic stressors and aquatic biodiversity conservation.
Address: International Joint Commission & University of Michigan School for Environment and Sustainability, 440 Church Street, Ann Arbor, MI 48109, USA.
e-mail: wangl@windsor.ijc.org

Robert M. Hughes is a courtesy associate professor at Department of Fisheries and Wildlife, Oregon State University and a senior research scientist with the Amnis Opes Institute. His research interests include fish assemblage ecology, landscape analysis, and global fisheries.
Address: Amnis Opes Institute & Department of Fisheries and Wildlife, Oregon State University, 104 Nash Hall, Corvallis, OR 97331-3803, USA.
e-mail: hughes.bob@amnisopes.com

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