Pakistan J. Zool., vol. 56(6), pp 2953-2962, 2024 **DOI**: https://dx.doi.org/10.17582/journal.pjz/20231111073345

Review Article

Freshwater Fish Biodiversity and Fisheries in Honghu Lake: Status, Threat and Conservation

Wen Xiong[1], Yifan Huang[1], Yue Liu[1], Shuyin Li[2]* and Baoqiang Wang[3]*

[1]*College of Life Sciences, Hubei Normal University, Huangshi 435002, China*
[2]*Yangtze River Basin Ecological Environment Monitoring and Scientific Research Center, Yangtze River Basin Ecological Environment Supervision and Administration Bureau, Ministry of Ecological Environment, Wuhan 430010, China*
[3]*Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China*

ABSTRACT

Honghu Lake is the seventh largest freshwater lake in China, and located in the centre of Yangtze River, which is the protection priority. Meanwhile, Honghu Lake is one of the most important regions of Chinese Fisheries. However, fish biodiversity and fisheries in the Honghu Lake have remained relatively undocumented. In this study, we reviewed data about freshwater fish biodiversity and fisheries in the Honghu Lake. In total of 96 species belonging to 7 orders, 26 families and 65 genera were listed in the Honghu Lake in past seventy years. And the fisheries resource decreased quickly due to hydrological disconnected, overfishing, and non-native species. In order to protect freshwater fish biodiversity and fisheries in Honghu Lake, some measures including establishment of protect area, artificial propagation and artificial releasing and fishing ban, were implemented in Honghu Lake. We hope that this study should provide more management recommendations that will be useful for freshwater fish biodiversity conservation and fishery management in the Yangtze River.

Article Information
Received 11 November 2023
Revised 15 December 2023
Accepted 26 December 2023
Available online 04 April 2024
(early access)
Published 08 November 2024

Authors' Contribution
WX: Conceptualization, data collection, writing original draft;
YH and YL: Fish sampling, data collection;
SL: Conceptualization, writing review and editing;
BW: Conceptualization, funding acquisition.

Key words
Conservation, Fish fauna, Fishery resource, Non-native species, Sustainable fishery, Water project, Yangtze River

INTRODUCTION

Freshwater ecosystems only cover very a small percentage of Earth's surface, but supports very high biodiversity (Strayer and Dudgeon, 2010). However, freshwater ecosystems are also the most endangered habitats in this planet (Reid *et al*., 2019), because the extinction rate in freshwater ecosystems are obvious higher than those in terrestrial and marine ecosystems (Abell, 2002). Freshwater fish is one of the most threatened animal group because of its extinction rate just after amphibians (Olden *et al*., 2010). However, information about freshwater fishes taxonomy and distribution are very scarce (Abell *et al*., 2008). Thus, researchers should pay more attention on conservation of freshwater fishes (Abell *et al*., 2008; Olden *et al*., 2010).

China is one of the mega biodiversity countries with greatest freshwater fish diversity (McAllister *et al*., 1997). There are nearly 10% freshwater fish species were occurred in Chinese freshwater ecosystems (He *et al*., 2020). Therein, the Yangtze River is an important biodiversity hotspot that is listed in 200 protection priority regions in this planet (Olson and Dinerstein, 1998), and is also the most important fishery and aquaculture region support over 50% inland aquaculture production in China (Wang *et al*., 2015). Some studies have reported the taxonomy and distribution of freshwater fishes in some regions or total of the Yangtze River (Fu *et al*., 2003; Huang *et al*., 2013). However, the important regions that support high freshwater fish biodiversity, such as the Honghu Lake, have received little attention.

The Honghu Lake is the only large freshwater lake in China with well-preserved ecosystem and overall water quality that meets class II standards. It is listed in the "List of Important wetlands in China" and "Action Plan for the Protection of Wetlands in China". In 2008, Honghu Lake was listed as a national nature reserve and in the Ramsar Convention. It is the home of 92 aquatic plants, 167 birds, 29 mollusc, and more than forty species, such as sacred lotus (*Nelumbo nucifera*), white stork (*Ciconia ciconia*), black stork (*C. nigra*), red-breasted merganser (*Mergus serrator*) and African fish eagle (*Haliaeetus vocifer*), were

* Corresponding author: wangbq@ihb.ac.cn
0030-9923/2024/0006-2953 $ 9.00/00

listed as first or second class national protected plants and animals (Lu and Jiang, 2003). Meanwhile, Honghu Lakes is one of the important bases of freshwater fisheries in China. Now, annual fishery production in Honghu Lake reaches over 200000 tonnes. However, there is little information available in the Honghu Lake.

In present study, we summarize a comprehensive data of the freshwater fish diversity in the Honghu Lake in the different period of past seventy years and use these data to: (1) to characterize patterns of freshwater fish diversity and fisheries in different period; (2) to summarize the main threats to freshwater fish biodiversity; and (3) to provide recommendation for fish biodiversity conservation and fisheries.

HONGHU LAKE

Honghu Lake is the largest lake in the Jianghan plain of Hubei province and the seventh largest freshwater lake in China. It is located in the middle reach of the Yangtze River (29°42′-29°58′N, 113°13′-113°29′E, Fig. 1). It is polygon shape with a water area about 344 km^2 and drains a catchment area about 3000 km^2 with population of about 1.5 million (Yuan *et al*., 2013). The average water depth of Honghu Lake is 1.34 m and the maximum depth is 6.5m. During the Flooding of the Yangtze River period (April-October), the water depth keeps 0.3-1.5m. In the drought period (November-March), most lake surface keep sediment surface exposed.

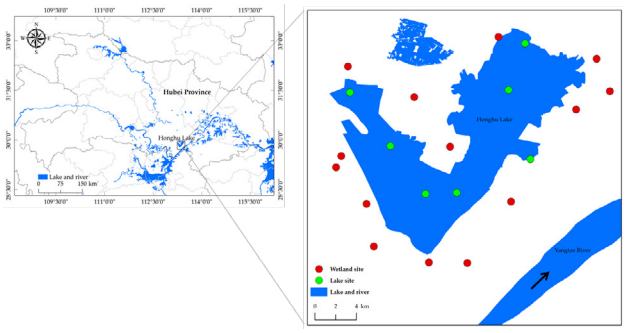

Fig. 1. Map of Honghu Lake in the Yangtze River, China. Red points mean sample sites in wetlands, green points mean sample sites in lake.

A typical northern subtropical humid monsoon climate occurred in Honghu Lake, with hot and rainy in summer with southeast winds and cold winter with northeast winds. The climate of Honghu Lake is warm and humid, with abundant precipitation, which is concentrated in the April to August. The annual evaporation is 1385.6mm, and average annual temperature is 16.8°C. The average temperature in summer is higher than other regions at the same latitude.

FISHERIES RESOURCE

There are very rich of fishery resources in the Honghu Lake. The highest aquatic plant cover in Honghu lake was 98% in 1982. The most main aquatic plants are Manchurian wild rice (*Zizania latifolia*), (*Potamogeton maackianus*), Eurasian watermilfoil (*Myriophyllum spicatum*), hornwort (*Ceratophyllum demersum*), waterthyme (*Hydrilla verticillata*). The biomass of aquatic plants was 1.57 million tonnes, and the average biomass was 4.4 kg/m^2 (Chen, 1988). According to investigation, there are 92 genera of phytoplankton occurred in the Honghu Lake, with an average annual population of 1.08 million/L and a biomass 2.43 mg/L. Therein, diatoms are the dominant species, accounting for 37.57% of the total phytoplankton population and 32.34% of the total biomass. There are 29 molluscs, the dominant species include *Alocinma longicornis, Parafossarulus striatulus, Gyraulus convexiusculus, Radix swinhoei, Bellamya purificata, Semisulcospira cancellate, Cipangopaludina chinensis, Limnoperna fortune, Unio douglasiae, Sinanodonta woodiana, Lanceolaria grayana, Hyriopsis cumingii,* and *Cristaria plicata* occurred in the Honghu Lake. The average density was 697 molluscs/m^2 with average biomass was 126 mg/m^2 (Wu and Lu, 1996). The crustace consists of seven species, and the dominant species are *Neocaridina denticulata sinensis, Caridina nilotica, Palaemonetes sinensis*, and *Eriocheir sinensis.*

Data collection

Both fish sampling and literature review were used to collecting information of freshwater fish species in the Honghu Lake. More than 20 ichthyological survey have been conducted in Honghu in different seasons, 2012-2018. Fish samples used dip nets, gillnets, and electroshock fishing techniques. For detailed sampling methods see Xiong *et al*. (2015b, 2017). Meanwhile, we conducted a literature search that contained the following combination of words: “Honghu Lake” and “fish or ichthyo*” in the title, abstract, or keywords from the WoS database (ISI, http://www.isiknowledge.com) and CNKI database (http://www.cnki.net). The CNKI (China National Knowledge Infrastructure) is the largest Chinese database which contain over 7000 natural and/or social science journal in China. Meanwhile, we collected information from Chinese books, such as Integrated Development of Biological Productivity and Lake Ecology of Honghu Lake (IHB, 1991). All scientific names of fish were identified as found in the Cataloge of Fishes (http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp).

FISH BIODIVERSITY

In history, there are a total of 96 freshwater fish species (84 native and 12 non-native species), belonging to seven orders, 26 families and 65 genera are found in Honghu Lake. Therein, 84 native freshwater species belonging to four orders, 18 families and 56 genera (Table I). In total four freshwater fishes, Chinese sturgeon (*Acipenser sinensis*), Chinese paddlefish (*Psephurus gladius*), Chinese sucker (*Myxocyprinus asiaticus*), giant mottled eel (*Anguilla marmorata*), of Honghu Lake were classified as endangered (Table I).

Table I. List of fish species in Honghu Lake.

Order/ Family	No	Scientific name	IUCN
Order: Acipenseriformes			
Family: Acipenseridae	1	*Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833*	CR
	2	*Acipenser baerii* Brandt, 1869*	EN
Family: Polyodontidae	3	*Polyodon spathula* (Walbaum, 1792)*	VU
Order: Anguilliformes			
Family: Anguillidae	4	*Anguilla japonica* Temminck & Schlegel, 1846#*	EN
Order: Beloniformes			
Family: Adrianichthyidae	5	*Oryzias latipes* (Temminck & Schlegel, 1846)#*	NE
Family: Hemiramphidae	6	*Hyporhamphus intermedius* (Cantor, 1842)#	NE
	7	*Tylosurus acus melanotus* (Bleeker, 1850)#	NE
Order: Characiformes			
Family: Serrasalmidae	8	*Piaractus brachypomus* (Cuvier, 1818)*	NE
Order: Clupeiformes			
Family: Engraulidae	9	*Coilia nasus* Temminck & Schlegel, 1846#	EN
Order: Cypriniformes			
Family: Cyprinidae	10	*Opsariichthys bidens* Günther, 1873#	LC
	11	*Elopichthys bambusa* (Richardson, 1845)#	DD
	12	*Squaliobarbus curriculus* (Richardson, 1846)#*	DD
	13	*Hemisalanx brachyrostralis* (Fang, 1934)#	DD
	14	*Ochetobius elongatus* (Kner, 1867)#	LC
	15	*Mylopharyngodon piceus* (Richardson, 1846)#*	DD
	16	*Ctenopharyngodon idella* (Valenciennes, 1844)#*	NE
	17	*Parabramis pekinensis* (Basilewsky, 1855)#*	NE
	18	*Megalobrama amblycephala* Yih, 1955#*	LC
	19	*Megalobrama mantschuricus* (Basilewsky, 1855)#*	NE
	20	*Toxabramis swinhonis* Günther, 1873#	NE
	21	*Hemiculter bleekeri* Warpachowski, 1888#*	NE
	22	*Hemiculter leucisculus* (Basilewsky, 1855)#*	LC
	23	*Chanodichthys erythropterus* (Basilewsky, 1855)#*	LC
	24	*Chanodichthys mongolicus* (Basilewsky, 1855)#*	LC
	25	*Chanodichthys dabryi* (Bleeker, 1871)#*	LC
	26	*Chanodichthys dabryi* (Bleeker, 1871)#*	LC
	27	*Culter oxycephaloides* Kreyonberg & Pappenheim, 1908#*	NE

Table continued on next page.....

Order/ Family	No	Scientific name	IUCN
	28	*Culter alburnus* Basilewsky, 18555#*	NE
	29	*Pseudolaubuca sinensis* Bleeker, 1864#*	LC
	30	*Xenocypris davidi* Bleeker, 1871#*	NE
	31	*Xenocypris macrolepis* Bleeker, 1871#*	LC
	32	*Plagiognathops microlepis* (Bleeker, 1871)#	LC
	33	*Pseudobrama simoni* (Bleeker, 1864)#*	NE
	34	*Acheilognathus macropterus* (Bleeker, 1871)#*	DD
	35	*Acheilognathus taenianalis* (Günther, 1873)*	LC
	36	*Acheilognathus barbatulus* Günther, 1873*	LC
	37	*Acheilognathus gracilis* Nichols, 1926#*	NE
	38	*Acheilognathus imberbis* Günther, 1868#*	NE
	39	*Rhodeus sinensis* Günther, 1868#*	LC
	40	*Rhodeus ocellatus* (Kner, 1866)#*	DD
	41	*Rhodeus lighti* (Wu, 1931)#*	LC
	42	*Cyprinus carpio* Linnaeus, 1758#*	VU
	43	*Carassius auratus* (Linnaeus, 1758)#*	LC
	44	*Hypophthalmichthys molitrix* (Valenciennes, 1844)#*	NT
	45	*Hypophthalmichthys nobilis* (Richardson, 1845)#*	LC
	46	*Abbottina rivularis* (Basilewsky, 1855)#*	NE
	47	*Pseudorasbora parva* (Temminck & Schlegel, 1846)#*	LC
	48	*Sarcocheilichthys sinensis* Bleeker, 1871#*	LC
	49	*Sarcocheilichthys nigripinnis* (Günther, 1873)#	NE
	50	*Squalidus argentatus* (Sauvage & Dabry de Thiersant, 1874)#	DD
	51	*Paracanthobrama guichenoti* Bleeker, 1864#	NE
	52	*Rhinogobio typus* Bleeker, 1871#*	NE
	53	*Coreius heterodon* (Bleeker, 1864)#*	NE
	54	*Coreius guichenoti* (Sauvage & Dabry de Thiersant, 1874)#	NE
	55	*Hemibarbus labeo* (Pallas, 1776)#*	NE
	56	*Hemibarbus maculatus* Bleeker, 1871#*	NE
	57	*Saurogobio dabryi* Bleeker, 1871#*	NE
	58	*Saurogobio dumerili* Bleeker, 1871#*	NE
	59	*Spinibarbus sinensis* (Bleeker, 1871)#*	NE
Family: Catostomidae	60	*Myxocyprinus asiaticus* (Bleeker, 1864)#*	NE
Family: Cobitidae	61	*Leptobotia taeniops* (Sauvage, 1878)#	NE
	62	*Parabotia fasciata* Dabry de Thiersant, 1872#*	LC
	63	*Cobitis sinensis* Sauvage & Dabry de Thiersant, 1874#	LC
	64	*Misgurnus anguillicaudatus* (Cantor, 1842)#*	LC
Family: Bagridae	65	*Tachysurus dumerili* (Bleeker, 1864)#	DD
	66	*Pelteobagrus ussuriensis* (Dybowski, 1872)#*	NE
	67	*Pseudobagrus crassilabris* (Günther, 1864)#*	NE
	68	*Hemibagrus macropterus* Bleeker, 1870#*	LC
	69	*Tachysurus fulvidraco* (Richardson, 1846)#*	LC

Table continued on next page.....

Order/ Family	No	Scientific name	IUCN
Order: Cyprinodontiformes			
Family: Poeciliidae	70	*Gambusia affinis* (Baird & Girard, 1853)*	LC
Order: Osmeriformes			
Family: Salangidae	71	*Hemisalanx brachyrostralis* (Fang, 1934)#*	NE
	72	*Neosalanx taihuensis* Chen, 1956#	NE
Order: Perciformes			
Family: Centrarchidae	73	*Lepomis macrochirus* Rafinesque, 1819*	LC
	74	*Micropterus salmoides* (Lacepède, 1802)*	LC
Family: Cichlidae	75	*Oreochromis niloticus* (Linnaeus, 1758)*	LC
	76	*Oreochromis aureus* (Steindachner, 1864)*	NE
	77	*Oreochromis mossambicus* (Peters, 1852)*	NT
Family: Percichthyidae	78	*Siniperca chuatsi* (Basilewsky, 1855)#*	NE
	79	*Siniperca knerii* Garman, 1912#*	DD
Family: Odontobutidae	80	*Micropercops swinhonis* (Günther, 1873)#*	NE
	81	*Odontobutis obscura* (Temminck & Schlegel, 1845)#*	NE
Family: Gobiidae	82	*Rhinogobius giurinus* (Rutter, 1897)#*	LC
Family: Channidae	83	*Channa argus* (Cantor, 1842)#*	NE
Family: Osphronemidae	84	*Macropodus opercularis* (Linnaeus, 1758)#*	LC
Order: Salmoniformes			
Family: Engraulidae	85	*Coilia brachygnathus* Kreyenberg & Pappenheim, 1908#	NE
Order: Siluriformes			
Family: Clariidae	86	*Clarias gariepinus* (Burchell, 1822)*	LC
Family: Ictaluridae	87	*Ictalurus punctatus* (Rafinesque, 1818)*	LC
Family: Siluridae	88	*Silurus asotus* Linnaeus, 1758#*	LC
	89	*Silurus meridionalis* Chen, 1977#*	LC
Family: Bagridae	90	*Pseudobagrus vachellii* (Richardson, 1846)#*	DD
	91	*Tachysurus dumerili* (Bleeker, 1864)#*	DD
	92	*Tachysurus nitidus* (Sauvage & Dabry de Thiersant, 1874)#*	NE
	93	*Pelteobagrus eupogon* (Boulenger, 1892)#*	NE
Order: Synbranchiformes			
Family: Sybranchidae	94	*Monopterus albus* (Zuiew, 1793)#*	LC
Order: Synbranchiformes			
Family: Mastacembelidae	95	*Macrognathus aculeatus* (Bloch, 1786)#*	NE
Order: Tetraodontiformes			
Family: Tetraodontidae	96	*Takifugu obscurus* (Abe, 1949)#*	LC

IUCN: DD, data deficient; LC, least concern; NE, not evaluated; NT, near threatened; VU, vulnerable; CR, critically endangered; EN, endangered. #, mean literature review; *, mean field investigation.

According to our investigation, there are 12 non-native freshwater fish species occur in Honghu Lake, including Danube sturgeon (*Acipenser gueldenstaedtii*), Siberian sturgeon (*A. baerii*), Mississippi paddlefish (*Polyodon spathula*), pirapitinga (*Piaractus brachypomus*), western mosquitofish (Gambusia affinis), bluegill (*Lepomis macrochirus*), largemouth black bass (*Micropterus salmoides*), Nile tilapia (*Oreochromis niloticus*), blue tilapia (*O. aureus*), Mozambique tilapia (*O. mossambicus*), North African catfish (*Clarias gariepinus*), channel catfish (*Ictalurus punctatus*).

Fisheries

The Honghu Lake is one of the most important lakes of Chinese fisheries (IHB, 1991). The fisheries in Honghu Lake have four stages. The initial stage (before 1960), the annual average fisheries catch is 10000 tonnes, lotus seeds 900 toones, water chestnut (*Trapa bispinosa*) 4000 tones (Chen, 1988). The main fisheries production including Black carp (*Mylopharyngodon piceus*), Grass carp (*Ctenopharyngodon idella*), Silver carp (*Hypophthalmichthys molitrix*), Bighead carp (*Hypophthalmichthys nobilis*), Yellowcheek (*Elopichthys bambusa*), which accounts for about 40% of the total fisheries production of Honghu Lake (Li, 1983). The second stage (1960-1982), the annual average fisheries catch is deceased to about 3500 tonnes quickly. The main fisheries production including small fishes, such as Chinese false gudgeon (*Abbottina rivularis*), Stone moroko (*Pseudorasbora parva*), and some commercial fishes less to 100 g, such as goldfish (*Carassius auratus)*, yellow catfish *(Tachysurus fulvidraco*) and predatory carp (*Chanodichthys erythropterus*). Because the sluices and dams built about the Honghu Lake, which become the controlled lake. The larvae of many migratory fish species could not entry into Honghu Lake. The fisheries catch of Honghu Lake is deceased quickly because of lack of supplement (IHB, 1991). The third stage (1983-2018), Chinese researchers and local government development extensive work to improve fishery production in Honghu Lake. On the one hand, local government artificial propagation and releasing a large number of fish fry and crab fry into Honghu Lake every year (Song *et al*., 1999). On the other hand, researchers conducted research on various aquaculture models to improve fishery production in Honghu Lake, including fence farming, dyke-net farming etc (IHB, 1991). The main fishery production are goldfish, Chinese mitten crab (*Eriocheir sinensis*), and giant river prawn (*Macrobrachium rosenbergii*). The fourth stage (after 2018), according to propose of Chinese government, all fishing activities were banned in order to protected fisheries resource (Government Website, 2020).

THREATS TO FISH BIODIVERSITY

Freshwater fishes are the most serious endangered animal group because of its high endemism (Olden *et al*., 2010; Reid *et al*., 2019). Honghu Lake, only accounting for about 0.003% of Chinese area, supports 84 native freshwater fish species (about 5.8% of the total number of China). Therein, 10 native freshwater fish species were listed in China red list (Table I). Thus, the freshwater fish biodiversity of Honghu Lake is very important for the Yangtze River, which is one of the protected priority regions in the World (Olson and Dinerstein, 1998). Following are threats to fish biodiversity.

Hydrological disconnection

Hydrological disconnection of the Yangtze River floodplain is the most top vector threatening river-floodplain ecosystems (Liu and Wang, 2010). After sluice was built in the canal linking the Honghu Lake with the Yangtze River in 1958, the fishery catch was continuous decreased from about 10000 tonnes to 7400 tonnes in 1960s, 5330 tonnes in 1970s, 3500 tonnes in 1980s (Li, 1983; IHB, 1991). Before 1958, the fishery catches of migratory and semi-migration fishes accounts for 70% of the total fishery production in Honghu Lake. The fishery catches of migratory fishes, such as Japanese eel (*Anguilla japonica*), black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*), yellowcheek (*Elopichthys bambusa*), sale niglask (*Ochetobius elongatus*), White amur bream (*Parabramis pekinensis*), are significant decreased 44% after 1959 (BWREPHC, 1974). Now, some migratory fishes, such as Japanese eel, Japanese grenadier anchovy (*Coilia nasus*), Hauglatik (*Luciobrama macrocephalus*), Obscure pufferfish (*Takifugu obscurus*), have disappeared in the Honghu Lake now.

Habitat destruction

Honghu Lake as a natural dammed lake formed about 2500 years ago. The area of Honghu Lake is about 760 km^2. In 1959, a sluice was built between Honghu Lake and the Yangtze River, the area of the lake is decreased to 653 km^2. In 1965, Sihu main canal were built about 30 kilometers across the north part of lake, the area of the lake decreased to 553 km^2. In 1971, a 28-kimometers drainage canal were constructed in the western part of the lake, the area of the lake decreased to 438 km^2. Between 1970s to 1980s, the area of the lake decreased to 354 km^2 because of human reclamation (Li, 1983). For a long time after sluice was built, Honghu Lake maintained very low water level (< 0.3 m) in the winter for agriculture utilization (Li, 1983). These results lead to the loss of habitat for many native fish species and the capture of large number of fishes during the winter. However, the fishery resources in the Honghu Lake were not being replenished from the Yangtze River. Meanwhile, a large area of shallow habitats as refugia and spawning ground for native fishes were destroyed. Thus, some native fishes, such as Japanese rice fish (*Oryzias latipes*), sharpbelly (*Hemiculter leucisculus*), stone moroko (*Pseudorasbora parva*), zilingwen goby (*Rhinogobius giurinus*), were decreased quickly. Meanwhile, embankment and canal were built around the

Honghu Lake from 1955 to 1970, and Honghu Lake has become an entire controlled lake since 1975. Meanwhile, some non-native species, such as western mosquitofish have successful invaded and occupied blank ecological niche because of land type changed. The synergistic effect by land changed and non-native species lead to many native fish species, which occupy marginal lake habitats, decreased quickly.

NON-NATIVE SPECIES

China is one the most hotspot regions for non-native aquatic species introduction (Xiong *et al*., 2015a, 2017a; Wang *et al*., 2016, 2021). The Yangtze River is the most important aquaculture region, which accounted for over 50% of the inland aquaculture production in China (Wang *et al*., 2015). A great number of non-native aquatic species were introduced in the Yangtze River, which recorded the highest invasion rates by non-native aquatic species (Xiong *et al*., 2018a, 2023b). Some non-native species, such as Nile tilapia, largemouth bass, channel catfish, red swamp crayfish (*Procambarus clarkii*) were widely used as aquaculture species in the Honghu Lake (Xiong *et al*., 2015, 2018, 2023a, b). Inevitably, these non-native fish species have established feral populations and caused great threat to native fish species. For example, largemouth bass and channel catfish prey on many native small fish or fish eggs (Xiong *et al*., 2015a). Western mosquitofish was introduced into China over a century and into Honghu Lake over forty years (Xiong *et al*., 2015a). It widely occurred in all suitable habitats (lake bey, wetlands, ponds, rivers, and ditches), become the most popular non-native fish species in the Honghu Lake. And this species has caused serious environment problems, including deterioration of water quality and native biodiversity loss, including fish, amphibian, invertebrates (Cheng *et al*., 2018; Xiong *et al*., 2018b, 2019a, b). Some worst non-native species, such as red swamp crayfish, water hyacinth (*Eichhornia crassipes*), were listed in 100 worst invasive species, have established feral populations and caused great threat to native biodiversity (Wang *et al*., 2016).

The Yangtze River is one of the hotspots of invasion by non-native aquatic species (Xiong *et al*., 2018a, 2023b). Recently, many non-native aquatic species have successfully invaded the Yangtze River basin (Cheng *et al*., 2018; Wang *et al*., 2020). Honghu Lake, locate in the centre of the Yangtze River, is the most main aquaculture production region of crab and crayfish in China (Xiong *et al*., 2021). A great number of non-native aquatic plants, such as Parrotfeather (*Myriopyllum aquaticum)* and Waterweed (*Elodea canadensis and E. nuttallii*), have widely planted in ponds, lakes and reservoirs for aquaculture of crayfish and crab (Xiong *et al*., 2021). However, synergistic effect of some non-native species facilitates the invasion of other non-native species and caused ecosystems change (Simberloff and Von Holle, 1999). For example, a non-native aquatic plant (*Alternanthera philoxeroides*) facilitates the invasion of western mosquitofish (*Gambusia affinis*) in Yangtze River (Xiong *et al*., 2019b). Thus, monitoring, controlling and managing non-native aquatic species are important work for researchers, environmental protection organizations and local government (Xiong *et al*., 2018a).

CONSERVATION OF FISH BIODIVERSITY

The establishment of protection areas is an important measure for freshwater fish biodiversity conservation (Xiong *et al*., 2018b; 2019a). Since 2010, Honghu Lake were listed in the Chinese National Protected Areas for Aquatic Germplasm Resources (FEEMC, 2010) and All fishery catch (including fish, snail, clam, crayfish, crab, shellfish) were forbid from 15 July 2018 (Jingzhou Government Announcement, 2018). Since 2020, the Now, the fishery resource of Honghu Lake and the Yangtze River reach around the Lake were entire protected and all fishing banns in the future 10 years. The fishery resource in the Honghu Lake have recovery quickly.

Over two third of fishes in the Honghu Lake are migratory and contributed 70% of the total fisheries (BWREPHC, 1974), Therefore conservation measures must give consideration for the life cycle of migratory fishes. Now, Honghu Lake become a controlled lake, with both incoming and outgoing water regulated by sluice. Thus, how to supplement migratory fish species is an important measure to keep fishery sustainability of Honghu Lake. Open sluice between Honghu Lake and the Yangtze River in the March- July, which is breeding period of these important migratory fishes (including carp, Japanese eel, black carp, grass carp, silver carp, bighead carp, yellowcheek, sale niglask, white amur bream).

Fishing bans is a very effective means for conservation and restoration of fishery resources and have been proven in many studies (Xiong *et al*., 2018b, 2019a). Since 2006, all fishing activities have been banned from 1 April to 31 July throughout the entire Honghu Lake (Website, 2006). Since 2021, all fishing are banned in the mainstream of the Yangtze River. And local government has stepped up patrol and inspection to clamp down on a large of illegal fishing gears, such as electrofishing.

CONCLUSION

Honghu Lake, which supports very high freshwater

fish biodiversity, is also one of the most important fishery regions in China. Habitat destruction, illegal fishing, and non-native species are main threat to native fish biodiversity and fishery production. Thus, some effective protection and conservation, including establishment of protection areas, period connect lake-river, illegal fishing banns, applied in the Honghu Lake. And control of non-native species and scientific study about artificial reproduction of native endangered and/or endemism fish species, are required. Finally, a network for monitoring fishery resources should be established.

ACKNOWLEDGMENT

We are grateful to anonymous reviewers for their helpful comments on earlier versions for this paper.

DECLARATIONS

Funding

This research was supported by the Second Tibetan Plateau Scientific Expedition and Research program (STEP), Grant No. 2019 QZKK0501.

Statement of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abell, R., 2002. Conservation biology for the biodiversity crisis: A freshwater follow-up. *Conserv. Biol.*, **16**: 1435-1437. https://doi.org/10.1046/j.1523-1739.2002.01532.x

Abell, R., Thieme, M.L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S.C., Bussing, W., Stiassny, M.L.J., Skelton, P., Allen, G.R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J.V., Heibel, T.J., Wikramanayake, E., Olson, D., López, H.L., Reis, R.E., Lundberg, J.G., Pērez, M.H.S. and Petry, P., 2008. Freshwater ecoregions of the world: A new map of biogeographic units for freshwater biodiversity conservation. *Bioscience*, **58**: 403-414. https://doi.org/10.1641/B580507

BWREPHC (Bureau of Water Resources and Electric Power of Honghu County, Hubei Province), 1974. Impacts of water conservancy construction on fishery resources and remedial measures in Honghu Lake. *Freshw. Fish.,* **7**: 17-19.

Chen, Y.J., 1988. A tentative analyse about the ecosystem of fishery in Honghu Lake. *J. Fish. China,* **7**: 331-342.

Cheng, Y., Xiong, W., Tao, J., He, D.K., Chen, K. and Chen, Y.F., 2018. Life-history traits of the invasive mosquitofish (*Gambusia affinis* Baird and Girard, 1853) in the central Yangtze River, China. *BioInvasions Rec*., **7**: 309-318. https://doi.org/10.3391/bir.2018.7.3.13

FEEMC (Fishery Eco-Environment Monitoring Center, Chinese Academy of Fishery Sciences), 2010. *Report on the State of the Fishery Eco-Environment in China*.

Fu, C., Wu, J., Chen, J., Wu, Q. and Lei, G., 2003. Freshwater fish biodiversity in the Yangtze River basin of China: Patterns, threats and conservation. *Biodivers. Conserv*., **12**: 1649-1685. https://doi.org/10.1023/A:1023697714517

Government website, 2020. http://www.cjyzbgs.moa.gov.cn/zcjd/202011/t20201117_6356382.htm. (access December 5 2020).

He, D.K., Sui, X.Y., Sun, H.Y., Tao, J., Ding, C.Z., Chen, Y.F. and Chen, Y.Y., 2020. Diversity, pattern and ecological drivers of freshwater fish in China and adjacent areas. *Rev. Fish Biol. Fisher*., **30**: 387-404. https://doi.org/10.1007/s11160-020-09600-4

Huang, L.L., Wu, Z.Q. and Li, J.H., 2013. Fish fauna, biogeography and conservation of freshwater fish in Poyang Lake Basin, China. *Environ. Biol. Fish*., **96**: 1229-1243. https://doi.org/10.1007/s10641-011-9806-2

IHB (Institute of Hydrobiology, Chinese Academy of Sciences), 1991. *Studies on Comprehensive exploitation of aquatic biological productivity and improvement of ecological environment in lake Honghu*. China Ocean Press, Beijing.

Jingzhou Government Announcement, 2018. Jingzhou Municipal People's Government Announcement about Fishing Ban in the National Aquatic Life Reserve. https://zwgk.jingzhou.gov.cn/40/202209/t20220928/136710.shtml (available in October 7 2018).

Li, K.L., 1983. Investigation of fishery catch in Honghu lake. *Issues Agric. Econ.,* **2**: 56-58.

Liu, X.Q. and Wang, H.Z., 2010. Estimation of minimum area requirement of river-connected lakes for fish diversity conservation in the Yangtze River floodplain. *Divers. Distrib*., **16**: 932-940. https://doi.org/10.1111/j.1472-4642.2010.00706.x

Lu, S. and Jiang, J.H., 2003. The wetland resources of Honghu Lake and countermeasures of its protection. *J. Lake Sci.,* **15**: 281-284. https://doi.org/10.18307/2003.0314

McAllister, D.E., Hamilton, A.L. and Harvery, B., 1997. *Global freshwater biodiversity*. Sea Wind, Cemex,

Mexico City.
Olden, J.D., Kennard, M.J., Leprieur, F., Tedesco, P.A., Winemiller, K.O. and García-Berthou, E., 2010. Conservation biogeography of freshwater fishes: Recent progress and future challenges. *Divers. Distrib.,* **16**: 496-513. https://doi.org/10.1111/j.1472-4642.2010.00655.x
Olson, D. and Dinerstein, E., 1998. The Global 200: A representation approach to conserving the earth's most biologically valuable ecoregions. *Conserv. Biol*., **12**: 502-515. https://doi.org/10.1046/j.1523-1739.1998.012003502.x
Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.Y., Olden, J.D., Ormerod, S.J., Smol, J.P., Taylor, W.W., Tockner, K., Vermaire, J.C., Dudgeon, D. and Cooke, S.J., 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol. Rev*., **94**: 849-873. https://doi.org/10.1111/brv.12480
Simberloff, D. and Von Holle, B., 1999. Positive interactions of nonindigenous species: Invasional meltdown? *Biol. Invasions*, **1**: 21-32. https://doi.org/10.1023/A:1010086329619
Song, T.X., Zhang, G.H., Chang, J.B., Miao, Z.G. and Deng, Z., 1999. Fish diversity in Honghu Lake. *Chin. J. appl. Ecol.,* **10**: 86-90.
Strayer, D.L. and Dudgeon, D., 2010. Freshwater biodiversity conservation: recent progress and future challenges. *J. N. Am. Benthol. Soc*., **29**: 344-358. https://doi.org/10.1899/08-171.1
Wang, H., Wang, Q., Bowler, P.A. and Xiong, W., 2016. Invasive aquatic plants in China. *Aquat. Invasions*, **11**: 1-9. https://doi.org/10.3391/ai.2016.11.1.01
Wang, H., Xiao, K.Y., Wu, Z.G., Chen, J.F., Xiong, W., Wang, Z.X., Wang, Q., Zhu, H. and Bowler, P.A., 2020. Delta arrowhead (*Sagittaria platyphylla*) in the Yangtze River: An invasive aquatic plant and the potential ecological consequences. *BioInvasions Rec*., **9**: 618-626. https://doi.org/10.3391/bir.2020.9.3.17
Wang, H., Xie, D., Bowler, P.A., Zeng, Z.F., Xiong, W. and Liu, C.L., 2021. Non-indigenous species in marine and coastal habitats of the South China Sea. *Sci. Total Environ*., **759**: 143465. https://doi.org/10.1016/j.scitotenv.2020.143465
Wang, Q.D., Cheng, L., Liu, J.S., Li, Z.J., Xie, S.Q. and De Silva, S.S., 2015. Freshwater aquaculture in PR China: Trends and prospects. *Rev. Aquacult*., **7**: 283-302. https://doi.org/10.1111/raq.12086
Website, 2006. http://news.sohu.com/20060406/n242657712.shtml (available in December 2 2002).
Wu, B.C. and Lu, J.F., 1996. Elementary analysis of aquatic resources development and ecological protection in Honghu Lake. *Yunnan Environ. Sci.*, **15**: 36-39.
Xiong, W., Sui, X.Y., Liang, S. and Chen, Y.F., 2015a. Non-native freshwater fish species in China. *Rev. Fish Biol. Fisher*., **25**: 651-687. https://doi.org/10.1007/s11160-015-9396-8
Xiong, W., Tao, J., Zhang, D.C., Liu, C.L., He, D.K. and Chen, Y.F., 2015b. Length–weight relationships for four small fish species caught in wetlands of central Yangtze River, China. *J. appl. Ichthyol*., **31**: 219-220. https://doi.org/10.1111/jai.12484
Xiong, W., Shen, C.Y., Wu, Z.X., Lu, H.S. and Yan, Y.R., 2017a. A brief overview of known introductions of non-native marine and coastal species into China. *Aquat. Invasions*, **12**: 109-115. https://doi.org/10.3391/ai.2017.12.1.11
Xiong, W., Zhu, J., Jin, L. and Zhang, J.Q., 2017b. Length–weight relationships of seven fish species from the Yuan River, China. *J. appl. Ichthyol*., **33**: 1240-1241. https://doi.org/10.1111/jai.13439
Xiong, W., Wang, H., Wang, Q., Tang, J.F., Bowler, P.A., Xie, D., Pan, L. and Wang, Z.X., 2018a. Non-native species in the Three Gorges Dam Reservoir: Status and risks. *BioInvasions Rec*., **7**: 153-158. https://doi.org/10.3391/bir.2018.7.2.06
Xiong, W., Wang, Q., Xie, D., Fletcher, D.H. and He, D.K., 2018b. Factors influencing tropical Island freshwater fishes: species, status, threats and conservation in Hainan Island. *Knowl. Manage. Aquat. Ec*., **419**: 6. https://doi.org/10.1051/kmae/2017054
Xiong, W., Xie, D., Chen, G. and He, D.K., 2019a. Freshwater fish biodiversity in the Leizhou Peninsula of China. *Aquat. Ecosyst. Hlth.*, **22**: 160-170. https://doi.org/10.1080/14634988.2019.1632666
Xiong, W., Tao, J., Liu, C.L., Liang, Y.Y., Sun, H.Y., Chen, K., Cheng, Y. and Chen, Y.F., 2019b. Invasive aquatic plant (*Alternanthera philoxeroides*) facilitates the invasion of western mosquitofish (*Gambusia affinis*) in Yangtze River, China. *Aquat. Ecosyst. Hlth.*, **22**: 408-416. https://doi.org/10.1080/14634988.2019.1700090
Xiong, W., Zhu, J., Zhu, S.Q., Yang, L.T., Du, S.M., Wu, Y.W., Wu, T.F., Xiao, K.Y., Chen, J., Jiang, Y.P., Wang, Q., Wang, H., Tang, W., Pan, L. and Bowler, P.A., 2021. Distribution and impacts of invasive aquatic plant parrot's feather (*Myriophyllum aquaticum*) in China. *BioInvasions Rec*., **10**: 796-804. https://doi.org/10.3391/bir.2021.10.4.04

Xiong, W., Guo, C.B., Gozlan, R.E. and Liu, J.S., 2023a. Tilapia introduction in China: Economic boom in aquaculture versus ecological threats to ecosystems. *Rev. Aquacult.* **15**: 179-197. https://doi.org/10.1111/raq.12710

Xiong, W., Xie, D., Wang, Q., Wang, H., Wu, Z., Sun, H., Li, T. and Bowler, P.A., 2023b. Non-native species in Poyang Lake Basin: Status, threats and management. *Aquat. Invasions,* **18**: 119–134. https://doi.org/10.3391/ai.2023.18.1.103610

Yuan, L., Qi, S., Wu, X., Wu, C., Xing, X. and Gong, X., 2013. Spatial and temporal variations of organochlorine pesticides (OCPs) in water and sediments from Honghu Lake, China. *J. Geochem. Explor*., **132**: 181-187. https://doi.org/10.1016/j.gexplo.2013.07.002