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Fish Biodiversity, Endemism, Threats and Conservation in the Qiantang River, China

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Key words
Biodiversity conservation, Fishery resource, Freshwater fish, Global change, Invasive alien species

ABSTRACT

Freshwater fish diversity is imperiled by multiple stressors with global change, including invasive species and habitat loss. There is an urgent need to establish synthesized baseline information pertaining to current ecological communities to quantify future change and identify habitats to protect. The Qiantang River is the largest river in the Zhejiang Province, located in the southeast of China, with extensive fishery and aquaculture sectors. However, synthetic information on freshwater fish biodiversity and invasions in this region is lacking, impeding conservation efforts. We compile published information and empirical surveys to comprehensively discern the fish community of the Qiantang River. There are 184 (167 native and 17 non-native) freshwater fish species or subspecies, belonging to 15 orders, 38 families and 105 genera in the Qiantang River, including species listed as among the '100 world's worst invasive species. Therein, 24 species are endemic to China and 14 species are classed as endangered by the IUCN. We identify and discuss habitat loss, pollution, sand mining, over-fishing and non-native species as the major threats to freshwater fish biodiversity in this system. Thus, we propose that protected areas and bans on fish introductions, should be adopted and better enforced in this and other freshwater systems.

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INTRODUCTION

Rivers are important freshwater habitats, which comprise some of the most biodiverse areas on the planet (Reid *et al*., 2019). However, multiple anthropogenic pressures, such as invasive species and habitat loss or fragmentation (e.g., from dam construction, levees, weirs), threaten most lotic habitats (Grill *et al*., 2019; Haubrock *et al*., 2021). As a result, over one fifth of freshwater fish species have been listed as endangered or extinct, mainly due to flow

modification, overfishing, pollution, and non-native species (Dudgeon *et al*., 2006). Urgently, monitoring efforts are needed to establish comprehensive community composition information for key rivers, to inform future conservation efforts and quantify invasion risk (Guo *et al*., 2019).

China is a country with very high aquatic biodiversity, supporting as very rich diversity of freshwater fish (He *et al*., 2020). In the past one hundred years, many researchers have investigated the freshwater fish biodiversity in China. These efforts have resulted in the identification of hotspots with high fish biodiversity, such as the Pearl River (He *et al*., 2020), Yangtze River (Fu *et al*., 2003), Hainan Island (Xiong *et al*., 2018b) and Leizhou Peninsula (Xiong *et al*., 2019a). However, ecological information for many regions and systems is lacking, such as Qiantang River, hampering present and future conservation efforts (He *et al*., 2020).

Qiantang River is the largest river in the Zhejiang Province of China, and is an important freshwater fishery and aquaculture area nationally (Chen, 1990). Since 1930s, investigations into the fish fauna in the Qiantang River have reported information on fish biodiversity; however, the results have been equivocal and are dated, with the number of fish species in the Qiantang River varying considerably among studies, with values of 32 (Wu, 1964), 86 (Lin, 1936), 50 (Mao, 1959), 112 (Lu *et al*., 1960) reported. However, in recent years, over 300 new species of fish have reported in China (He *et al*., 2020) and 439 non-native freshwater fish species have been introduced in China (Xiong *et al*., 2015), necessitating more up-to date accounts of the conservation and invasion status of key freshwater systems. Currently, synthesis, analysis and assessment of fish biodiversity and fishery resources are limited, which in turn limits conservation of freshwater fish and the sustainability of fisheries in the Qiantang River and elsewhere. In this study, we thus compiled and analyzed comprehensive fish data in the Qiantang River. Our main purpose were to (1) provide an updated inventory of fish species in the Qiantang River; (2) identify the endemic and threatened species in the Qiantang River; and (3) to review the main threats to fish biodiversity and provide conservation recommendations.

MATERIALS AND METHODS

Study area

The Qiantang River is situated in the northwestern part of the Zhejiang Province, China (117°30′- 120°30′E, 28° 00′-30°30′N). The Qiantang River has two important sources: a south source and a north source. The south source is Lan River, originating from the Lianhua Mountain (located at the junction between the Kaihua County of Zhejiang Province and Xiuning County of Anhui Province), and is 530 km in length. The north source is Xin'an River, originating from the Huangshan Mountain, which is over 600 km in length. These two important sources (Lan River and Xin'an River) confluence in the Koumen as Qiantang River and flow north through the Hangzhou Bay, and eventually drain into the East Sea (Fig. 1).

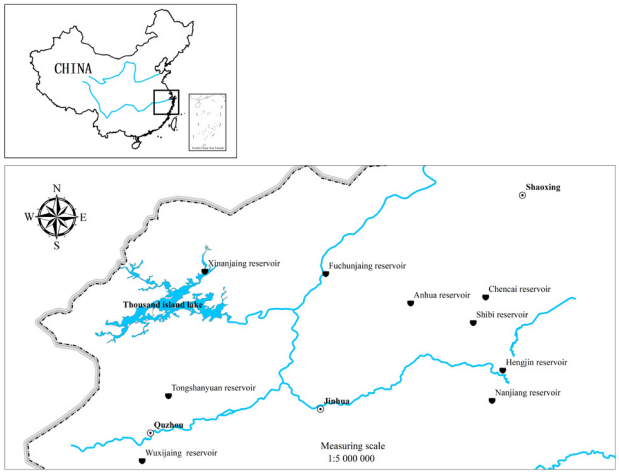

Fig. 1. Location of Qiantang River in China

The geographical range of the Qiantang River basin is divided into three sub-basins. The upstream from the Meicheng comprise the upper reaches, with a narrow valley and rocky channel and a high gradient. The middle reaches are from Meicheng to Fuyang, and the main stream broadens out from Long River. From Fucheng downward to the estuary of the Qiantang River are the lower reaches; the total area of the Qiantang River is 54349 km^2.

The prevailing climate around the Qiantang River is subtropical monsoon, with annual mean temperature of 17°C and annual precipitation approximately 2000 mm; over 60% of rain falls in the April to September period. Furthermore, interannual fluctuations in precipitation are marked, with 'wet' and 'dry' years varying by two-to-three times.

Sources of information

We collected and collated information about fish biodiversity in the Qiantang River from field investigation and comprehensive literature review. On the one hand, we conducted over 20 fishery surveys in different seasons from 2010 to 2018. Fish samples were collected with gillnets, cage nets, and electrofishing. Detailed sampling methods are presented in Xiong *et al*. (2017). On the other hand, the information about fish in the Qiantang River was mainly obtained from two database: We searched for combination of words "freshwater fish" and "Qiangtang

River" in the Web of Science (ISI, http://www.isiknoledge.com) and the China National Knowledge Infrastructure (http://www.cnki.net). Furthermore, we opportunistically collected information from Chinese books, such as Fish Resources of Qiantang River (Chen, 1990). These field investigations and literature reviews allowed for the inventorying of the fish species in the Qiantang River. Threatened species were identified according to the red list categories of the International Union for Conservation of Nature (IUCN, www.iucnlist.org) and the China's Red List of Biodiversity: Vertebrates, Volume V, Freshwater Fishes (Zhang and Cao, 2021).

RESULTS

We identified a total of 184 freshwater fish species or subspecies, belonging to 15 orders, 38 families and 105 genera in the Qiantang River. The full inventory of fish compiled in the Qiantang River is presented in Table I, alongside taxonomic information, non-native species, migratory species, and IUCN statuses. Cyprinidae are the most species rich and endemic families, accounting for 52.1% and 34.7% of total native species and total endemic species of Qiantang River, respectively. More precisely, *Psephurus gladius, Formosania stigmata, Niwaella laterimaculata, Acheilognathus imberbis, Acrossocheilus kreyenbergii, Acrossocheilus parallens, Gobiobotia longibarba, Hemiculterella sauvagei, Hemiculterella wui, Pseudorasbora elongate, Saurogobio dumerili, Sinibrama macrops, Salanx longianalis, Rhinogobius cliffordpopei, Siniperca knerii, Siniperca obscura, Siniperca roulei, Siniperca undulata, Hemibagrus macropterus, Tachysurus eupogon, Pseudobagrus albomarginatus, Pseudobagrus ondon, Pseudobagrus tenuifurcatus,* and *Silurus meridionalis*, are endemic to China. Despite the Qiantang River amounting to only 0.5% of the total Chinese land area, it provides suitable habitat for 167 native fishes (about 10% of the total number of Chinese freshwater fishes), including the 24 species endemic to China.

The conservation status of fish species in the Qiantang River has been identified in Table I. A total of 14 fish species are listed as threatened according to IUCN red list criteria or are listed as endangered species in China. We also identified 42 migratory fish species.

In total, we detected 17 non-native fish species, including *Cirrhinus molitorella, Cirrhinus mrigala, Labeo rohita, Tinca tinca, Gambusia affinis, Lepomis macrochirus, Micropterus salmoides, Oreochromis niloticus, Oreochromis aureus, Oreochromis mossambicus, Clarias batrachus, Clarias gariepinus, Hypostomus Plecostomus, Ictalurus punctatus, Ameiurus nebulosus, Lepisosteus osseus* and *Piaractus brachypomus*, that occurred in the Qiantang River (Table I). In particular, *G. affinis*, *Oreochromis* sp., *P. brachypomus*, are widely distributed in the diverse freshwater ecosystems of the area (such as wetlands, ponds, rivers, reservoirs and paddies).

DISCUSSION

Threat to fish biodiversity

Freshwater fish species are one of the most threatened animal groups worldwide (Olden *et al*., 2010; Reid *et al*., 2019). In China in particular, largely due to habitat loss and biological invasions, freshwater fishes are severely threatened (Xiong *et al*., 2018b, 2019a); fish biodiversity and fisheries resources have significantly decreased in many waterbodies (Fu *et al*., 2003; He *et al*., 2020). The study area, Qiantang River basin, is located in the Zhejiang Province, which is one the fastest growing economic regions in China (NBS, 2020). As a result, many human activities have seriously threatened fish biodiversity in the Qiantang River, including through damming, pollution, sand mining, over-exploitation and non-native species.

The Qiantang River is an important river for many migratory fish species of China. There are 42 migratory fish (36 native and 8 non-native) that have been found in the Qiantang River. Starting with Xin'an Reservoir in 1958 and, nine other large reservoirs thereafter (Fuchunjiang, Wuxijiang, Tongshanyuan, Hengjin, Nanjiang, Chencai, Shibi, Anhua, and Wanyao reservoir), dams were built in the Qiantang River for control flood and the development of hydropower. Then in the 1980s-2000s, a great number of small hydropower stations were built in the upper section of the Qiantang River. These dam and water conservancy projects (sluice gates, dykes, diversion canals etc.) have fragmented the Qiantang River, causing some migratory fish populations to decrease and even go extinct. For example, reeves shad (*Tenualosa reevesii*) is a high valuable anadromous spawning fish in China; every spring and summer, reeves shad swim upstream from the ocean into the spawning grounds of the Qiantang River for breeding. The highest previous catch of reeves shad was 1574 tonnes in China, however, the catch of this fish species has now reduced to less than 1 tonne nationally and the species has become extinct in the Qiantang River because of damming (Liu *et al*., 2002). Furthermore, many fish spawning and growth opportunities could be reduced because of low water temperatures (Hao *et al*., 2017, 2019). For example, the most important Chinese commercial carps (*Ctenopharyngodon idella, Hypophthalmichthys molitrix, Mylopharyngodon piceus* and *Hypophthalmichthys nobilis*) have declined after damming in the largest Chinese rivers (Zhang *et al*., 2012). Thus, water conservancy projects are a primary threat to fish in the Qiantang River.

Table I. The list of freshwater fishes in the Qiantang River. a mean non-native freshwater fish species in the Qiantang River; b mean freshwater fish species endemic to China; c mean migratory fish species. IUCN: CR mean Critically Endangered; DD mean Data Deficient; EN mean Endangered; LC mean Least Concern; NE mean Not Evaluated; NT mean Near Threatened; VU mean Vulnerable.

Order/ Family	Scientific name of species	IUCN
Acipenseriformes		
Acipenseridae	*Acipenser sinensis* Gray 1835[c]	CR
Polyodontidae	*Psephurus gladius* Martens 1861[c]	CR
Anguilliformes		
Anguillidae	*Anguilla japonica* Temminck and Schlegel 1846[c]	EN
	Anguilla marmorata Quoy and Gaimard 1824[c]	EN
Beloniformes		
Hemiramphidae	*Hyporhamphus intermedius* Cantor 1842[c]	LC
Clupeidae	*Tenualosa reevesii* Richardson 1846[c]	CR
Engraulidae	*Coilia nasus* Temminck and Schlegel 1846[c]	LC
	Coilia mystus Linnaeus 1758[c]	LC
Characiformes		
Serrasalmidae	*Piaractus brachypomus* (Cuvier, 1818)[a]	NE
Cypriniformes		
Balitoridae	*Formosania stigmata* Nichols 1926[b]	DD
	Vanmanenia stenosoma Boulenger 1901	DD
Cobitidae	*Cobitis rarus* Chen 1981	LC
	Cobitis sinensis Sauvage and Dabry de Thiersant 1874	LC
	Niwaella laterimaculata Yan and Zheng 1984b	DD
	Leptobotia pellegrini Fang 1936	LC
	Leptobotia tchangi Fang 1936	DD
	Misgurnus anguillicaudatus Cantor 1842	LC
	Parabotia banarescui Nalbant 1965	LC
	Parabotia fasciatus Dabry de Thiersant 1872	LC
	Parabotia maculosa (Wu, 1939)	LC
	Paramisgurnus dabryanus Dabry de Thiersant 1872	LC
Cyprinidae	*Abbottina rivularis* Basilewsky 1855	LC
	Acheilognathus barbatulus Günther 1873	LC
	Acheilognathus chankaensis Dybowski 1872	LC
	Acheilognathus hypselonotus Bleeker 1871	LC
	Acheilognathus imberbis Günther 1868b	LC
	Acheilognathus macropterus Bleeker 1871	LC
	Acheilognathus meridianus Wu 1939	LC
	Acheilognathus polylepis Wu 1964	LC
	Acheilognathus taenianalis Günther 1873	LC
	Acheilognathus tonkinensis Vaillant 1892	LC
	Acrossocheilus fasciatus Steindachner 1892	LC
	Acrossocheilus kreyenbergii Regan 1908[b]	LC
	Acrossocheilus parallens Nichols 1931[b]	LC
	Acrossocheilus wenchowensis Wang 1935	LC
	Aphyocypris chinensis Günther 1868	LC
	Atrilinea roulei Wu 1931	VU
	Belligobio nummifer Boulenger 1901	LC
	Carassius auratus Linnaeus 1758	LC
	Chanodichthys dabryi Bleeker 1871	LC
	Chanodichthys erythropterus Basilewsky 1855	LC
	Chanodichthys mongolicus mongolicus Basilewsky 1855	LC
	Coreius heterodon Bleeker 1864	LC
	Ctenopharyngodon idella Valenciennes 1844[c]	LC
	Culter alburnus Basilewsky 1855	LC
	Cyprinus carpio Linnaeus 1758[c]	LC
	Cirrhinus molitorella (Valenciennes, 1844)[ac]	NT
	Cirrhinus mrigala (Hamilton, 1822)[a]	LC
	Distoechodon tumirostris Peters 1881	LC
	Elopichthys bambusa Richardson 1845[c]	LC
	Gnathopogon taeniellus Nichols 1925	LC
	Gobiobotia longibarba Fang and Wang 1931[b]	DD
	Gobiobotia paucirastella Zheng and Yan 1986	DD
	Gobiobotia tungi Fang 1933	DD
	Hemibarbus labeo Pallas 1776[c]	LC
	Hemibarbus longirostris Regan 1908	LC
	Hemibarbus maculatus Bleeker 1871	LC
	Hemibarbus qianjiangensis Yu 1990	LC
	Hemiculter leucisculus Basilewsky 1855	LC
	Hemiculter lucidus Dybowski 1872	LC
	Hemiculterella sauvagei Warpachowski 1888[b]	LC
	Hemiculterella wui Wang 1935	LC
	Hypophthalmichthys molitrix Valenciennes 1844[c]	LC
	Hypophthalmichthys nobilis Richardson 1845[c]	LC
	Labeo rohita (Hamilton, 1822)[ac]	LC
	Megalobrama mantschuricus Basilewsky 1855	LC
	Microphysogobio chenhsienensis Fang 1938	LC
	Microphysogobio fukiensis Nichols 1926	DD

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Order/ Family	Scientific name	IUCN
	Microphysogobio kiatingensis Wu 1930	DD
	Microphysogobio tafangensis Wang 1935	DD
	Mylopharyngodon piceus Richardson 1846[c]	LC
	Nipponocypris temminckii Temminck and Schlegel 1846	DD
	Ochetobius elongatus Kner 1867	CR
	Onychostoma barbatulum Pellegrin 1908	NT
	Opsariichthys bidens Günther 1873	LC
	Parabramis pekinensis Basilewsky 1855[c]	LC
	Plagiognathops microlepis Bleeker 1871	LC
	Pseudobrama simoni Bleeker 1864	LC
	Pseudogobio vaillanti Sauvage 1878	LC
	Pseudohemiculter dispar Peters 1881	LC
	Pseudohemiculter hainanensis Boulenger 1900	LC
	Pseudolaubuca engraulis Nichols 1925	LC
	Pseudolaubuca sinensis Bleeker 1864	LC
	Pseudorasbora elongata Wu 1939[b]	VU
	Pseudorasbora parva Temminck and Schlegel 1846	LC
	Rhodeus lighti Wu 1931	LC
	Rhodeus ocellatus ocellatus Kner 1866	LC
	Rhodeus sinensis Günther 1868	LC
	Rhynchocypris oxycephalus Sauvage and Dabry de Thiersant 1874	LC
	Sarcocheilichthys kiangsiensis Nichols 1930	LC
	Sarcocheilichthys nigripinnis nigripinnis Günther 1873	LC
	Sarcocheilichthys parvus Nichols 1930	LC
	Sarcocheilichthys sinensis sinensis Bleeker 1871	LC
	Saurogobio dabryi dabryi Bleeker 1871	LC
	Saurogobio dumerili Bleeker 1871[b]	LC
	Saurogobio lissilabris Bănărescu and Nalbant 1973	LC
	Sinibrama macrops Günther 1868[b]	LC
	Spinibarbus denticulatus Oshima 1926	LC
	Spinibarbus hollandi Oshima 1919	LC
	Squalidus argentatus Sauvage and Dabry de Thiersant 1874	LC
	Squalidus nitens Günther 1873	LC
	Squalidus wolterstorffi Regan 1908	LC
	Squaliobarbus curriculus Richardson 1846	LC
	Tinca tinca (Linnaeus, 1758)[ac]	LC
	Toxabramis swinhonis Günther 1873	LC
	Xenocypris davidi Bleeker 1871	LC
	Xenocypris macrolepis Bleeker 1871	LC
	Zacco platypus Temminck and Schlegel 1846	LC
Cyprinodontiformes		
Adrianichthyidae	*Oryzias latipes* Temminck and Schlegel 1846	LC
Poeciliidae	*Gambusia affinis* (Baird and Girard, 1853)[a]	LC
Lepisosteiformes		
Lepisosteidae	*Lepisosteus osseus* (Linnaeus, 1758)[a]	LC
Mugiliformes		
Mugilidae	*Planiliza haematocheila* (Temminck and Schlegel, 1845)[c]	NE
	Mugil cephalus Linnaeus 1758[c]	LC
Polynemidae	*Eleutheronema tetradactylum* Shaw 1804[c]	NE
Osmeriformes		
Salangidae	*Neosalanx tangkahkeii* Wu 1931	LC
	Protosalanx chinensis Basilewsky 1855[c]	DD
	Salanx ariakensis Kishinouye 1902[c]	DD
	Salanx longianalis Regan 1908[bc]	DD
Perciformes		
Centrarchidae	*Lepomis macrochirus* Rafinesque, 1819[a]	LC
	Micropterus salmoides (Lacepède, 1802)[a]	LC
Channidae	*Channa argus* Cantor 1842	LC
Cichlidae	*Oreochromis niloticus* (Linnaeus, 1758)[ac]	LC
	Oreochromis aureus (Steindachner, 1864)[ac]	NE
	Oreochromis mossambicus (Peters, 1852)[ac]	NT
Eleotridae	*Eleotris oxycephala* Temminck and Schlegel 1845[c]	LC
Gobiidae	*Acanthogobius hasta* Temminck and Schlegel 1845[c]	NE
	Ctenogobius clarki Evermann and Shaw 1927	NE
	Ctenogobius shennongensis Yang and Xie, 1983	NE
	Glossogobius olivaceus Temminck and Schlegel 1845[c]	LC
	Mugilogobius abei Jordan and Snyder 1901	LC
	Odontamblyopus lacepedii (Temminck and Schlegel 1845)	NE
	Rhinogobius brunneus (Temminck and Schlegel, 1845)[c]	DD
	Rhinogobius cliffordpopei Nichols 1925[b]	LC
	Rhinogobius giurinus Rutter 1897[c]	LC
	Rhinogobius lentiginis Wu and Zheng 1985	LC
	Taenioides cirratus (Blyth 1860)[c]	NE
	Tridentiger trigonocephalus Gill 1859	DD

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Order/ Family	Scientific name	IUCN
Lateolabracidae	*Lateolabrax japonicus* Cuvier 1828[c]	NE
Odontobutidae	*Micropercops swinhonis* Günther 1873	DD
	Odontobutis obscura Temminck and Schlegel 1845	NE
	Odontobutis potamophila Günther 1861	LC
Osphronemidae	*Macropodus chinensis* Bloch 1790	LC
	Macropodus opercularis Linnaeus 1758	LC
Percichthyidae	*Coreoperca whiteheadi* Boulenger 1900	NT
	Coreoperca liui Cao and Liang 2013	DD
	Siniperca chuatsi Basilewsky 1855	LC
	Siniperca knerii Garman 1912[b]	LC
	Siniperca obscura Nichols 1930[b]	NT
	Siniperca roulei Wu 1930[b]	VU
	Siniperca scherzeri Steindachner 1892	LC
	Siniperca undulata Fang and Chong 1932[b]	NT
Pleuronectiformes		
Cynoglossidae	*Cynoglossus trigrammus* Günther 1862	LC
	Cynoglossus semilaevis Günther 1873	LC
Scorpaeniformes		
Cottidae	*Trachidermus fasciatus* Heckel 1839[c]	EN
Siluriformes		
Amblycipitidae	*Liobagrus anguillicauda* Nichols 1926	DD
	Liobagrus styani Regan 1908	CR
Bagridae	*Leiocassis longirostris* Günther 1864	DD
	Hemibagrus guttatus Lacepède 1803	LC
	Hemibagrus macropterus Bleeker 1870[b]	LC
	Tachysurus eupogon Boulenger 1892[b]	LC
	Tachysurus fulvidraco Richardson 1846	LC
	Tachysurus nitidus Sauvage and Dabry de Thiersant 1874	NE
	Tachysurus vachellii Richardson 1846	DD
	Tachysurus truncatus Regan 1913	DD
	Pseudobagrus albomarginatus (Rendahl, 1928)[b]	LC
	Pseudobagrus brevicaudatus (Wu, 1930)	DD
	Pseudobagrus crassilabris (Günther, 1864)	LC
	Pseudobagrus ondon Shaw, 1930b	LC
	Pseudobagrus tenuifurcatus (Nichols, 1931)[b]	NE
	Pseudobagrus tenuis (Günther, 1873)	DD
Clariidae	*Clarias batrachus* (Linnaeus, 1758)[ac]	LC
	Clarias fuscus Lacepède 1803	LC
	Clarias gariepinus (Burchell, 1822)[ac]	LC
Ictaluridae	*Ictalurus punctatus* (Rafinesque, 1818)[a]	LC
	Ameiurus nebulosus (Lesueur, 1819)[a]	LC
Loricariidae	*Hypostomus plecostomus* (Linnaeus, 1758)[a]	NE
Sisoridae	*Glyptothorax fokiensis* Rendahl 1925	LC
Siluridae	*Silurus asotus* Linnaeus 1758	LC
	Silurus meridionalis Chen 1977[b]	LC
Synbranchiformes		
Mastacembelidae	*Macrognathus aculeatu* Bloch 1786[c]	LC
	Sinobdella sinensis Bleeker 1870	DD
Synbranchidae	*Monopterus albus* Zuiew 1793[c]	LC
Tetraonontiformes		
Tetraodontidae	*Takifugu ocellatus* Linnaeus 1758[c]	LC
	Takifugu obscurus Abe 1949[c]	LC

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Water pollution is additionally a very serious environmental problem in China (Yu *et al*., 2019). Over the last forty years, vast amounts of contaminants (organochlorine pesticides, heavy metal, microplastics) have polluted water of the Qiantang River (Zhou *et al*., 2006; Su *et al*., 2013; Shi *et al*., 2017). The partial reach of the Qiantang River was particularly seriously polluted in 1990s-2010s (Website, 2020). Further, eutrophication and extreme weather events have induced algae blooms in the Qiantang River (Guo *et al*., 2018). Nonetheless, over the last ten years, the water quality of the Qiantang River improved slightly (MARA, 2018), but lethal fish events have been still recurrent in the Qiantang River every year (Jia *et al*., 2010).

Sand mining is an important threat to freshwater biodiversity in the region (Reid *et al*., 2019). Zhejiang is one of the fastest growing economic regions in China (NBS, 2020). In the past thirty years, the urban area increased by about six times (Cui, 2013). During this time, many illegal sand mining operations were initiated in the upper reach of the Qiantang River and destroyed stream habitats for small fish, such as *Ctenogobius shennongensis*, *Microphysogobio kiatingensis* and *Cobitis rarus*. Moreover, as many small fish (*Rhodeus* sp. and *Acheilognathus* sp.) spawn in the gills of freshwater mussels (Mills and Reynolds, 2003), sand dredgers have disrupted spawning habitats and impeded development. As a result, these small fish have been extirpated from the upper reaches of the Qiantang River.

Over-exploitation is a serious and widespread threat to global freshwater biodiversity (Reid *et al*., 2019). In long term, overexploitation of fisheries resources increasingly common in China (Xiong *et al*., 2018b; 2019a). The total catch of Qiantang River has increased from 9044 tonnes

in 1978 to 159809 tonnes in 2019 (Fig. 2), and almost doubled in the last four years alone. In the Hangzhou reach of the Qiantang River, there are nearly 1000 fishing boats which have registered in the fishery administration. Further there are many illegal fishing boats which catch undocumented fish at night, and these can often employ illegal fishing gear (such as electrofishing and poison) (Xiong *et al*., 2018b, 2019a). In addition to population declines, the proportion of small individual fish in the catch is increasing and is up to over 70% in some regions of the Qiantang River, illustrating the demographic effects of overexploitation (Hao *et al*., 2017, 2019).

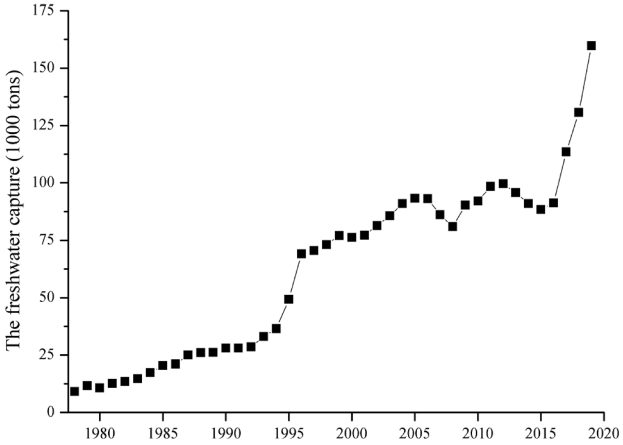

Fig 2. The freshwater capture in the Qiantang River through time.

Non-native species are another important threat to freshwater biodiversity (Xiong *et al*., 2015, 2017; Wang *et al*., 2016; Reid *et al*., 2019) Many Chinese waterbodies have experienced very high invasion rates by non-native aquatic species (Xiong *et al*., 2018a; Wang *et al*., 2021). In recent years, numerous non-native species were introduced in the Qiantang River for aquaculture. Inevitably, some non-native species have escaped and established invasive populations in the Qiantang River. In particular, *P. brachypomus* and *Oreochromis* sp. have become very widely distributed in the Qiantang River. Furthermore, *G. affinis* has a very long history (over 100 years) in the Qiantang River (Cheng *et al*., 2018), and this species has become very widespread in adjacent freshwater habitats. The invasion by these non-native fish species has caused the significant decline of native fish species (Xiong *et al*., 2022). Meanwhile, some non-native aquatic plant species (such as *Sagittaria platyphylla* and *Myriophyllum aquaticum*) have formed dense monocultures, decreasing the oxygen in waterbodies and deteriorating water quality (Wang *et al*., 2020; Xiong *et al*., 2021). Ultimately, the invasion of these non-native aquatic plants has caused mortality of a great number of fish, while some invasive aquatic plants (such as *Alternanthera philoxeroides*) provide suitable habitats for some non-native fishes (e.g. *G. affinis*), thus further facilitating the invasion by non-native fish (Xiong *et al*., 2019b).

Conservation of fish biodiversity

In total, there have been 1651 freshwater fish species recorded the China (He *et al*., 2020). Our study system, Qiantang River, while amounting for only 0.5% of the total Chinese land area, provides suitable habitats for 167 native fishes (about 10% of the total number of Chinese freshwater fishes), with 24 species endemic. Therefore, this suggests that Qiantang River is a very important biodiversity hotspot for Chinese freshwater fish.

Approximately one fourth of the total number of fishes is migratory (11 amphidromous fish, nine anadromous fish, six catadromous fish, and 16 potamodromous fish) in the Qiantang River. Thus, the development of conservation measures should give full consideration to the life history strategies of migratory fish species and their habitats transitions. Therein, *A. sinensis, P. gladius, A. japonica, C. carpio, H. molitrix, O. mossambicus* and *T. ocellatus* in particular were listed as endangered species by IUCN (Fishbase, 2020), and *A. marmorat* and *T. fasciatus* were added to the endangered species of China in 2016. The establishment of conservation areas is the primary measure to protect spawning ground and habitats for these migratory species. This has been seen in other systems with 32 nature reserves having been established for the conservation of the Chinese alligator, bird, and golden monkey, as well as forests, marine ecosystems and, geologic relics in the Zhejiang Province (MEE, 2020), but freshwater river designations are still lacking.

The artificial propagation and release of fish fry is an effective measure to restore and enhance of fishery resources (Kitada, 2018). From 1983, more than 3.5 million individuals of artificially propagated juveniles have been released in the Qiantang River every year, with the main released species including *C. auratus, C. dabryi, C. carpio, H. labeo, H. molitrix, H. nobilis, P. pekinensis, H. maculatus, L. longirostris, P. microlepis and A. fasciatus*. In the future, further studies should devote attention to the artificial propagation of declining migratory fish (such as *Tenualosa reevesii* and *Trachidermus fasciatus*), which are both ecologically-significant and highly valuable fish species, but almost extinct in the Qiantang River.

Fishing bans have been proven as an effective measure for conservation and restoration of fish biodiversity and fishery resources (Li *et al*., 2014). Fishing bans were promulgated in the Qiantang River for several months

in 2019, however, the fishing ban period was very short and many fish fry were caught by fisherman just after the breeding period in July and August. In other areas, however, fishing bans have been established for longer, such as in the Yangtze River, where they have been implemented for over ten years prior to 2020. In turn, fish biodiversity and fishery resources in some regions of the Yangtze River have recovered quickly. Thus, we call on the local government to prolong the fishing bans in the Qiantang River for several years at a time.

CONCLUSIONS

Based on our study, the Qiantang River supports a very high freshwater fish biodiversity and a great number of endemic or endangered species. Without action, we anticipate that the number of endangered species will increase in the future, particularly as many fish species have not been evaluated or have been data deficient for a long time. Overall, habitat loss, pollution, sand mining, over-exploitation and non-native species are important threats to local fish biodiversity. Thus, further research and conservation actions should be considered, including establishing nature reserves, artificial propagation and release of declining native fish fry, and fishing bans.

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DECLARATIONS

Ethical approval

This research was conducted in accordance with ethics committee procedures of animal experiments.

Sampling and field studies

All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgements, if applicable.

Data availability

All data generated or analyzed during this study are included in this article.

Statement of conflict of interest

The authors have declared no conflict of interest.

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