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Freshwater Fish Biodiversity in Liangzi Lake

Ke Li[1,2], Hai Liu[1], Jiangang Zhou[1], Hongbing Chen[1] and Zhengxiang Wang[1,2]*

[1]Faculty of Resources and Environmental Science, Hubei University, Wuhan 430062, People's Republic of China
[2]Regional Development and Environmental Response, Key Laboratory of Hubei Province, Hubei University, Wuhan 430062, People's Republic of China

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Key words
Aquaculture, Fish biodiversity, Sustainable fishery, Wetlands, Yangtze River

ABSTRACT

Liangzi Lake is the second largest freshwater lake in Hubei Province and the eighth largest lake in China. It is located in the central Yangtze River drainage, which is categorized as a priority region for biodiversity conservation. The Lake is lies within an important fishery region, but research-based information about its freshwater fishes is very limited. We summarize and update the freshwater species list of fish in Liangzi Lake. Based upon our field investigations and literature review, there are 95 freshwater fish species belonging to 12 orders, 28 families and 61 genera in Liangzi Lake. In recent years, the fisheries resources have declined because of waterway disconnections, overfishing, habitats destruction and non-native species. To recover and sustain the fishery we recommend fishing bans, artificial propagation and stocking of native fish species, and the control and management of non-native species. This study is first to present the Lake's fish fauna and provide some recommendations for the conservation of its fish biodiversity and the development of sustainable fisheries. We hope that this study provides a scientific basis and strategy for sustaining aquatic biodiversity conservation and for other large lakes in China.

INTRODUCTION

Global biodiversity has declined significantly in the recently forty years (Hautier *et al*., 2015; Fluet-Chouin *et al*., 2023). The rate of biodiversity loss in freshwater ecosystems exceeds that of terrestrial and marine ecosystems (Dudgeon *et al*., 2006; Strayer and Dudgeon, 2010). Freshwater fishes are the second most threatened animal groups and the degree of threat has changed more severely because of anthropogenic uses of water resources (Reid *et al*., 2019). Unfortunately, accurate and current information regarding freshwater fishes is very scattered and limited (He *et al*., 2020). China is a biodiversity hotspot and sustains a rich freshwater fish fauna (He *et al*., 2020). The Yangtze River is the third largest river of the world and supports a rich aquatic biodiversity (Chen *et al*., 2020). Various studies have reported the fish diversity in a few sites such as the Poyang Lake (Huang *et al*., 2013) and Dongting Lake (Chen *et al*., 2022), but little is known about fish biodiversity in other important lakes with significant aquatic resources.

Liangzi Lake is the second largest lacustrine setting in Hubei Province, and is the eighth greatest in China. It is one of the important aquaculture sites in China (JFARI, 1979) and sustains a rich biodiversity of freshwater organisms, including 71 algae, 331 higher plants, 89 zooplankton, 49 benthonic macrofauna, eight amphibians, 15 reptiles, 166 birds, and 21 mammals species (Ge *et al*., 2003). Unfortunately, prior to this study there has been little knowledge about the Lake's fish fauna.

The purpose of this study is to provide a current, data-based update of the fish fauna with recommendations to make the fishery and ecosystem more sustainable in Liangzi Lake.

MATERIALS AND METHODS

Study region

Liangzi Lake is located in the south of the central Yangtze River (114°21′- 114°39′E, 30° 05′-30°18′N, Fig. 1). The greatest recorded lake surface area occurred in

* Corresponding author: wangzx66@hubu.edu.cn
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1953 and encompassed 454.6km^2 with a water capacity of 12.65 ×10^8 m^3. Until the 1980s, the lake surface area and capacity were decreased to 304.3 km^2 and 10.83×10^8 m^3 because of water diversion and usage for large scale reclamation. The mean water depth is 4.16 m and the greatest water depth recorded was 6.2 m (Wang and Du, 1998).

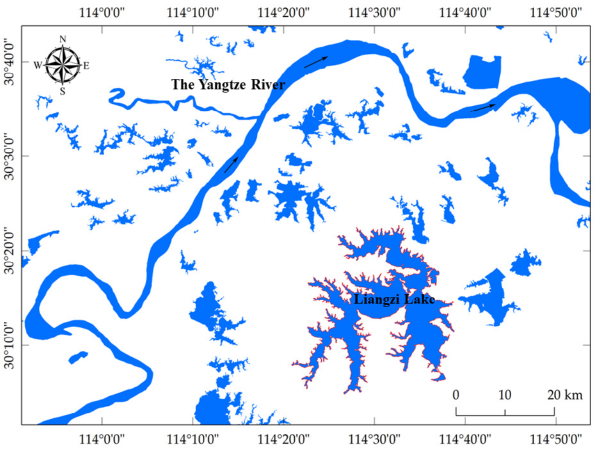

Fig. 1. Map of Liangzi Lake in China.

The water level usually begins to rise in April following the start of the annual rainfall reason, and the water level increases rapidly from May to June due to the rising water level of Yangtze River. The Lake is at its deepest from July to September. The average annual water temperature is 17.4°C, the average water temperature in January is 4.6°C, and the average water temperature in August is 29.8°C.

Liangzi Lake has a typical northern subtropical monsoonal climate. The annual mean atmospheric temperature is 16.8°C with a mean temperature of 29.2°C in July. Its highest temperature is 40.7°C with a mean temperature of 4°C in January and the lowest temperatures reach -12.4°C. The annual mean rainfall is 1263.4 mm, and nearly three quarters of it occurs between March and September. The highest rainfall is 1862.6 mm and the lowest rainfall is 889.2 mm. There are over thirty rivers that flow in the Lake, including the Jingniugang and Gaoqiaohe Rivers. The annual mean runoff into the Lake is 10.92×10^8 m^3, and precipitation on the lake surface is 3.84×10^8 m^3, and the total water intake is 14.76×10^8 m^3.

Aquatic biodiversity

There are six primary groups of phytoplankton in Liangzi Lake, including Bacillariophyta, Pyrroptata, Cyanophyta, Chlorophyta, Euglenophyta and Chrysophyta, with an annual average quantity of 47175.0 individuals per liter (ind/L). The dominant species is *Ceratium hirundinell*, which has its highest presence in autumn. The zooplankton assemblage is very rich, with the annual average quantities of protozoa 114.5ind/L, rotifers 318ind/L, cladocerans 58.9ind/L, and copepods 75.7ind/L. The dominant species include *Difflugia corona*, *Polyarthra trigla*, and *Vorticella* spp., with the highest populations occurring in the spring and autumn. The benthic animals are mainly mollusks, particularly lake snails and yellow clams. *Hydrilla verticillata*, *Vallisneria natans*, *Najas marina* and *Najas minor* are the primary aquatic plants present in the Lake. The biomass is the greatest for *Hydrilla verticillata*, accounting for more than 40% of the aquatic plant biomass in the Lake. The important economic fish species includes *Megalobrama amblycephala*, *Megalobrama terminalis*, *Cyprinus carpio, Chanodichthys erythropterus, Chanodichthys dabryi, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis, Elopichthys bambusa, Ochetobius elongatus, Siniperca chuatsi,* and *Xenocypris davidi*. It is well known that Lake Liangzi sustains a significant population of *Megalobrama amblycephala* (Wuchang bream).

Data collected

We collected freshwater fish diversity data using field investigations and a review of peretinent literature. Fifteen fishery surveys were conducted during different seasons from 2016 to 2021. Fish samples were collected using gillnets, cage nets, and dip net in different habitats (lake, ponds, wetlands, and canals). We sampled lake and pond habitats using gillnets (15×5 m, mesh size 5 mm) and cage nets (15 m length, 25×25 cm, mesh size 5 mm) over approximately 14-h intervals (20:00-10:00). In wetland and canal habitats, fish were surveyed using dip nets (1.5 m handle, 0.5 m diameter, mesh size 5 mm) for 15 minutes intervals. For detailed fish sampling methods see Xiong *et al*. (2015a, 2019a). Literature information was acquired from two databases, i.e., the Web of Science, http://www.webofknowledge.com/ and the China National Knowledge Infrastructure, http://www.cnki.net. We searched for the combination of words freshwater fish and Liangzi Lake in the title, abstract and keywords. The scientific names of fish species were identified as found in the catalog of fishes (http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp, accessed on January 20, 2023). These efforts allowed us to develop an updated inventory of freshwater fish species for the Lake. Threatened status fish species were identified according to the latest standards in China (Jiang *et al*., 2016).

RESULTS

In this study, we report a total of 95 freshwater fish species belonging to 12 orders, 28 families and 61 genera in the Liangzi Lake (Table I). The Cyprinidae are the most species-rich family, accounting for 62.22% of total native fish species.

It is noting that seven non-native fish species, including *Anguilla australis, Gambusia affinis*, *Lepomis macrochirus, Oreochromis niloticus*, *Micropterus salmoides, Clarias gariepinus, Ictalurus punctatus* that occurred in Liangzi Lake (Table I). Therein, *G. affinis* is the most widely distributed in Liangzi Lake and around waterbodies, such as ponds, rivers, wetlands, and paddies.

Table I. The list of fishes in Liangzi Lake. 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	IUCN
Order: Acipenseriformes		
Family: Acipenseridae	1. *Acipenser sinensis* Gray, 1835	CR
Polyodontidae	2. *Psephurus gladius* (Martens, 1862)	CR
Order: Anguilliformes		
Family: Anguillidae	3. *Anguilla australis* Richardson, 1841	EN
	4. *Anguilla japonica* Temminck and Schlegel, 1846	EN
	5. *Anguilla marmorata* Quoy and Gaimard 1824	EN
Order: Beloniformes		
Family: Engraulidae	6. *Coilia nasus* Temminck and Schlegel 1846	LC
Adrianichthyidae	7. *Oryzias latipes (Temminck and Schlegel, 1846)*	LC
Hemiramphidae	8. *Hyporhamphus intermedius* (Cantor, 1842)	LC
	9. *Tylosurus acus melanotus* (Bleeker, 1850)	LC
Order: Clupiformes		
Family: Clupeidae	10. *Tenualosa reevesii* (Richardson, 1846)	CR
Order: Clupeiformes		
Family: Engraulidae	11. *Coilia brachygnathus* Kreyenberg and Pappenheim, 1908	LC
Order: Cypriniformes		
Family: Bagridae	12. *Cobitis sinensis* Sauvage and Dabry de Thiersant, 1874	LC
Catostomidae	13. *Myxocyprinus asiaticus (Bleeker, 1864)*	CR
Cobitidae	14. *Parabotia banarescui* Nalbant 1965	LC
	15. *Parabotia fasciatus* Dabry de Thiersant 1872	LC
	16. *Parabotia maculosa* (Wu, 1939)	LC
	17. *Paramisgurnus dabryanus* Dabry de Thiersant 1872	LC
Cyprinidae	18. *Abbottina rivularis* (Basilewsky, 1855)	LC
	19. *Acheilognathus macropterus* (Bleeker, 1871)	LC
	20. *Acheilognathus taenianalis* (Günther, 1873)	LC
	21. *Acheilognathus barbatulus* Günther, 1873	LC
	22. *Acheilognathus gracilis* Nichols, 1926	LC
	23. *Acheilognathus imberbis* Günther, 1868	LC
	24. *Carassius auratus* (Linnaeus, 1758)	LC
	25. *Carassius carassius* (Linnaeus, 1758)	LC
	26. *Coreius guichenoti* (Sauvage and Dabry de Thiersant, 1874)	CR

Table continues on next page................

Order/ Family	Scientific name	IUCN
	27. *Coreius heterodon* (Bleeker, 1864)	LC
	28. *Chanodichthys dabryi* (Bleeker, 1871)	LC
	29. *Chanodichthys erythropterus* (Basilewsky, 1855)	LC
	30. *Chanodichthys mongolicus* (Basilewsky, 1855)	LC
	31. *Ctenopharyngodon idella* (Valenciennes, 1844)	LC
	32. *Cyprinus carpio* Linnaeus, 1758	LC
	33. *Culter alburnus* Basilewsky, 1855	LC
	34. *Culter oxycephaloides* Kreyenberg and Pappenheim, 1908	LC
	35. *Elopichthys bambusa* (Richardson, 1845)	LC
	36. *Hemibarbus maculatus* Bleeker 1871	LC
	37. *Hemiculter bleekeri* Warpachowski, 1888	LC
	38. *Hemiculter leucisculus* (Basilewsky, 1855)	LC
	39. *Hypophthalmichthys molitrix* (Valenciennes, 1844)	LC
	40. *Hypophthalmichthys nobilis* (Richardson, 1845)	LC
	41. *Luciobrama macrocephalus* (Lacepède, 1803)	CR
	42. *Megalobrama amblycephala* Yih, 1955	LC
	43. *Megalobrama mantschuricus* (Basilewsky, 1855)	LC
	44. *Megalobrama terminalis* (Richardson, 1846)	LC
	45. *Mylopharyngodon piceus* (Richardson, 1846)	LC
	46. *Ochetobius elongatus* (Kner, 1867)	CR
	47. *Onychostoma fangi* Kottelat, 2000	LC
	48. *Onychostoma simum* (Sauvage and Dabry de Thiersant, 1874)	LC
	49. *Opsariichthys bidens* Günther, 1873	LC
	50. *Plagiognathops microlepis* (Bleeker, 1871)	LC
	51. *Pseudorasbora parva* (Temminck and Schlegel, 1846)	LC
	52. *Rhinogobio ventralis* Sauvage and Dabry de Thiersant, 1874	EN
	53. *Rhinogobio cylindricus* Günther, 1888	LC
	54. *Rhodeus sinensis* Günther, 1868	LC
	55. *Rhodeus ocellatus* (Kner, 1866)	LC
	56. *Rhodeus lighti* (Wu, 1931)	LC
	57. *Sarcocheilichthys nigripinnis* (Günther, 1873)	LC
	58. *Sarcocheilichthys parvus* Nichols 1930	LC
	59. *Saurogobio dabryi* Bleeker, 1871	LC
	60. *Saurogobio dumerili* Bleeker, 1871	LC
	61. *Saurogobio gymnocheilus* Lo, Yao and Chen, 1998	LC
	62. *Spinibarbus sinensis* (Bleeker, 1871)	LC
	63. *Squaliobarbus curriculus* Richardson 1846	LC
	64. *Xenocypris davidi* Bleeker, 1871	LC
	65. *Xenocypris hupeinensis* (Yih, 1964)	DD
	66. *Zacco platypus* Temminck and Schlegel 1846	LC
Order: Cyprinodontiformes		
Family: Poeciliidae	67. *Gambusia affinis* (Baird and Girard, 1853)	LC

Table continues on next page................

Order/ Family	Scientific name	IUCN
Order: Perciformes		
Family: Channidae	68. *Channa argus* (Cantor, 1842)	LC
Centrarchidae	69. *Lepomis macrochirus* Rafinesque, 1819	LC
Osphronemidae	70. *Macropodus opercularis* (Linnaeus, 1758)	LC
Centrarchidae	71. *Micropterus salmoides* (Lacepède, 1802)	LC
Odontobutidae	72. *Micropercops swinhonis* (Günther, 1873)	LC
	73. *Odontobutis obscurus* (Temminck and Schlegel, 1845)	LC
	74. *Odontobutis sinensis* Wu, Chen and Chong, 2002	LC
Cichlidae	75. *Oreochromis niloticus* (Linnaeus, 1758)	LC
Gobiidae	76. *Rhinogobius giurinus* (Rutter, 1897)	LC
Serranidae	77. *Siniperca chuatsi* (Basilewsky, 1855)	LC
Percichthyidae	78. *Siniperca knerii* Garman, 1912	LC
Order: Salmoniformes		
Family: Salangidae	79. *Neosalanx oligodontis* Chen, 1956	DD
	80. *Neosalanx taihuensis*(Chen, 1956)	LC
	81. *Salanx prognathus* (Regan, 1908)	EN
	82. *Hemisalanx brachyrostralis* (Fang, 1934)	VU
	83. *Neosalanx pseudotaihuensis* Zhang, 1987	DD
Order: Siluriformes		
Family: Chacidae	84. *Clarias fuscus* Lacepède 1803	LC
	85. *Clarias gariepinus* (Burchell, 1822)	LC
Ictaluridae	86. *Ictalurus punctatus* (Rafinesque, 1818)	LC
Siluridae	87. *Silurus asotus* Linnaeus, 1758	LC
	88. *Silurus meridionalis* Chen, 1977	LC
Bagridae	89. *Tachysurus dumerili* (Bleeker, 1864)	LC
	90. *Tachysurus fulvidraco* (Richardson, 1846)	LC
	91. *Tachysurus nitidus* (Sauvage and Dabry de Thiersant, 1874)	LC
	92. *Pelteobagrus eupogon* (Boulenger, 1892)	
Order: Synbranchiformes		LC
Family: Synbranchidae	93. *Monopterus albus* (Zuiew, 1793)	LC
Mastacembelidae	94. *Macrognathus aculeatus* (Bloch, 1786)	LC
Order: Tetraodontiformes		
Family: Tetraodontidae	95. *Takifugu obscurus* (Abe, 1949)	LC

DISCUSSION

Threats to freshwater fish biodiversity

Chinese aquatic biodiversity has declined in the past four decades due to ongoing impacts from hydrological changes, pollution, climate change, and non-native species (Fu *et al*., 2003). Fish biodiversity and fisheries catch has decreased sharply in many waterbodies of China (He *et al*., 2020). Liangzi Lake is one of the most important fish habitats in the central Yangtze River basin and the health of its fishery is of great concern because of its significant role in the local economy.

Disconnecting lakes from rives causes a decrease in their fish biodiversityand this alteration can be seen in many lakes linked to the Yangtze River (Fu *et al*., 2003; Xiong *et al*., 2023b, c). Migratory fish species declined after 1980s because of the installation of dikes that severed existing river-lake connnections (Liu and Wang, 2018). Many migratory fishes, such as *Ochetobius elongatus* (Kner, 1867), *Tenualosa reevesii* (Richardson, 1846), and *Anguilla japonica* (Temminck and Schlegel, 1846), were nearly extirpated because of the establishment of a sluice in 1967.

Overfishing is a primary factor that can cause a decline in native fish biodiversity and can alter the composition of the fish community (He *et al*., 2020). As has been the case in many other regions of China, overfishing in Liangzi Lake triggered a rapid decline in its fishery resources (Xiong *et al*., 2018b, 2019b). Its fishery production reached about 4000 tons per year in the 1980s to 1990s (JFARI, 1979), then dropped rapidly to less 1000 tons. Predatory fish species are declining and the migratory and fluvial species are depleted or are disappearing with the increase in human harvest (Ye *et al*., 2012). Because of the low populations of many species, artificial breeding and stocking are important in replenishing the predatory fishes. Because of these efforts, aquaculture production and fishery catch reached about 85000 tons in 2021 (Website, 2022). Overfishing leads to the prevalence of smaller fish, which currently comprise 50-70% of the total fish community. Most fishes are lacustrine species with high adaptability to human disturbance and environmental changes (Ye *et al*., 2012).

Submerged macrophytes provide important habitats for juvenile fishes (Xie *et al*., 2001). Aquatic vegetation is undergoing substantive changes because of hydrologic modifications, climate change and other direct and indirect anthropogenic disturbances (Ge *et al*., 2004; Zhang, 2014). Historically emergent and submergent macrophytes covered more than 90% of the Lake surface, however, the cover of macrophytes nearly disappeared in 1956 and 2010 because of flooding and inundation by high water levels (Liu *et al*., 2006). It well known that many Cyprinid fish lay eggs on the submerged macrophytes, and the reduction of macrophytes inevitably caused the decline of fish biodiversity and fishery resources.

Invasions by non-native species is an important threat to native aquatic biodiversity (Sala *et al*., 2000), and China is well known as a hotspot of invasion of non-native aquatic species (Xiong *et al*., 2015b; Wang *et al*., 2016). The Yangtze River basin experiences an exceptionally high and ongoing rate of invasion (Xiong *et al*., 2018a). Some researchers have recorded a great number of non-native plants (such as parrot's feather (*Myriophyllum aquaticum*), fanwort (*Cabomba caroliniana*), and delta arrowhead (*Sagittaria platyphylla*) and fishes (such as mosquitofish (*Gambusia affinis*) and some tilapia species) have successfully established large naturalized populations throughout the Yangtze River basin (Wang *et al*., 2020; Xiong *et al*., 2019a, 2021, 2022, 2023a). These non-native species initiated a large-scale decline in native aquatic plant and fish biodiversity in the Yangtze River (Fang *et al*., 2006). Over the past twenty years, alligator weed (*Alternanthera philoxeroides*), water hyacinth (*Eichhornia crassipes*), Canadian waterweed (*Elodea canadensis*), fanwort and parrot's feather established extensive monospecific stands, effectively replacing native aquatic plants in many areas of the Lake and the surrounding wetlands (Xiong *et al*., 2008). On the one hand, vegetation covers by non-native aquatic plants produces suitable habitats for various small fishes (Xie *et al*., 2001) and thus, non-native aquatic plants facilitate invasion by non-native fishes, such as western mosquitofish (Xiong *et al*., 2019a; 2021). On the other hand, these non-native aquatic plants displace native submerged macrophytes and cause the decline of native fish biodiversity because of the reduction of suitable spawning ground (native submerged macrophytes) for many native carp fish species (Xiong *et al*., 2020, 2021, 2022). This is particularly marked in many cyprinid species that preferentially lay eggs on native submerged plants, such as *Hydrilla verticillate* and *Potamogeton pectinatus*. Theses submerged vegetation disappeared because of displaced by invasive non-native aquatic plants and eventually caused significantly decline of native fishery resource. Meanwhile, Liangzi Lake remains an important aquaculture region and rearing area for introduced some non-native fishes, such as Nile tilapia (*Oreochromis niloticus*) and largemouth black bass (*Micropterus salmoides*). Unfortunately, these non-native fishes inevitably escape from enclosures into lake and cause decline of native fish species by competition and predation (Xiong *et al*., 2015b; 2023a).

Conservation of freshwater fish biodiversity

China's wetland habitats have a rich aquatic biodiversity (He *et al*., 2020) and the Yangtze River is recognized as a high priority region for conservation (Fang *et al*., 2006; Xiong *et al*., 2023b). Recent studies have shown that there is a high degree of endemism and species richness in the Yangtze River's native fish fauna (Fu *et al*., 2003; Huang *et al*., 2013; Xiong *et al*., 2023c). Our study is the first to record the number of species and endemism of the fish fauna in Liangzi Lake, one of the important fisheries lakes in the Yangtze River. There are 13 endangered species (*Acipenser sinensis, Psephurus gladius, Anguilla australis, Anguilla japonica, Anguilla marmorata, Tenualosa reevesii, Coreius guichenoti, Luciobrama macrocephalus, Myxocyprinus asiaticus, Ochetobius elongatus, Rhinogobio ventralis, Salanx prognathous, Hemisalanx brachyrostralis*) were listed in endangered species (Jiang *et al*., 2016). Thus, the Liangzi Lake is important biodiversity hotspot and should be more conservation in the Yangtze River.

Fishing bans are always one of the most effective measures for the conservation of fish biodiversity (Xiong *et al*., 2018b, 2019b). A ten-year ban (2020–2030) on fishing has been established in sensitive areas of the mainstem Yangtze River and related wetlands, and there has been a rapid response in their fishery resources (Jin *et al*., 2022). A ban on fishing in Liangzi Lake from April 25 to September 23 has been instituted, as well, and it is hoped that the fishery at this sensitive site will also recover.

Artificial propagation and the release of juvenile fish are popular measures often implemented to restore damaged fishery resources (Kitada, 2018). In the past twenty years, local governments have conducted artificial propagation and release programs for a great number of small or fry fish, crayfish, and crabs. For example, over 3.66 million individuals of fry fish (*Megalobrama amblycephala, Cyprinus carpio, Hypophthalmichthys molitrix, Hypophthalmichthys nobilis*) were released into the Liangzi Lake between 8-10 May 2019 (BAR Website, 2019). The potential and feasibility of artificial propagation and stocking of some of the Lake's endangered or endemic species such as *Ochetobius elongatus* needs to studied and a strategy should be developed to use this promising approach on sensitive species.

Non-native species and their accompanying impacts are the primary threat to aquatic biodiversity in Liangzi Lake (Sala *et al*., 2000). It is extremely difficult to eliminate non-natives once they become established at a site such as this (Xiong *et al*., 2015a, 2019a) and early detection followed by immediate control measures are critical to curtail them during their period of invasion and naturalization (Xiong *et al*., 2017; Wang *et al*., 2021). The Yangtze River is a hotspot of invasion by non-native aquatic species, and it should have on-going field investigations to detect new invaders and help gain data to support the development of management strategies for non-indigenous species already building populations in the wild (Xiong *et al*., 2018a, 2022, 2023c).

CONCLUSIONS

Liangzi Lake supports a rich fish fauna and is one of the most important fisheries in China. The fishery and fish biodiversity have experienced a severe decline in the past forty years due to the Lake's disconnection with the Yangzte River, overfishing, habitat loss and the impacts of non-native species. Fisheries resources have responded quickly following a ten-year fishing ban in the adjacent Yangtze River. There is a need for additional ongoing research to gain more data-based information regarding the life-histories of endemic fish species, population dynamics of important fishery species, and monitoring and management efforts to control non-native species.

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IRB approval

All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities

Ethical approval

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

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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