

## Research Article

# Non-native species in Poyang Lake Basin: status, threats and management

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## Abstract

Poyang Lake is the largest freshwater lake in China and sustains a high level of biodiversity in the mid-reach area of the Yangtze River watershed. Poyang Lake is also one of the most important aquaculture regions in China, and a great number of non-native species have been introduced into it. We present a current and well-documented list of the non-native species of plants, molluscs, crustaceans, fishes, reptiles, and amphibians currently found in Lake. We found that there are 103 non-native species (83 vascular plants, 12 fishes, three crustacea, two molluscs, two reptiles and one amphibian) that have invaded Poyang Lake Basin, of which 96 non-native species were introduced after 2000. The invasion rate of non-native species reached 4.36 species year<sup>-1</sup>, which is the highest invasion rate recorded in freshwater ecosystems. The primary pathways of introduction are through the ornamental trade and unintentional escapes (30 species each, respectively), followed by food (19), aquaculture (15), forage grass (four), medicinal and oil (two, respectively), and biocontrol (one). The origins of non-native species are North America (29.12%), Asia (25.24%), South America (20.38%), Africa (18.44%), Europe (5.82%) and Oceania (0.97%). Many non-native species provide significant support for the rapid development of the local economy (such as aquaculture). However, many non-native species pose a great threat to local biodiversity and societal development. More studies that include monitoring and the development of strategies for managing and eliminating non-native species in Poyang Lake are needed.

**Keywords:** Aquaculture, biological invasions, biological conservation, ecological impacts, hotspot, risk

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## Introduction

Biological invasions are one of the most serious threats to global biodiversity and ecosystem function (Mack et al. 2000). Freshwater ecosystems are considered to be the habitat most susceptible to invasive species (Strayer 2010; Vilà et al. 2010), and many invasive species are very difficult to eradicate once they have established feral populations in aquatic habitats (Reaser et al. 2020). Therefore, monitoring and management of invasive species in freshwater ecosystems have become significant research foci in the study of invasion biology (Xiong et al. 2015a).

One of the fundamental baselines that may be established when studying a habitat is to develop a list of native and non-native species within it (Pyšek et al. 2004). Most such studies have focused on non-native species in the developed countries and regions, such as North American and Europe (Pyšek et al. 2008). However, research has shown that a great number of non-native species have also been introduced in some rapidly developing countries (such as China and Brazil) in recent decades (Xie et al. 2001; Xu et al. 2012; Adelino et al. 2021). In some aquatic habitats in China the number and invasion rate of non-native species has increased sharply (Xiong et al. 2018b; Wang et al. 2021). Recent studies have shown that China is the country most seriously threatened by the invasion of non-native aquatic species and possesses a higher number of non-native aquatic species in its wetlands than any other throughout the world (Xiong et al. 2015a, 2017a; Wang et al. 2016, 2020a). Unfortunately, there has been little research of non-native species in some regions of biodiversity hotspots, such as Poyang Lake (Wang et al. 2020b; Xiong et al. 2021).

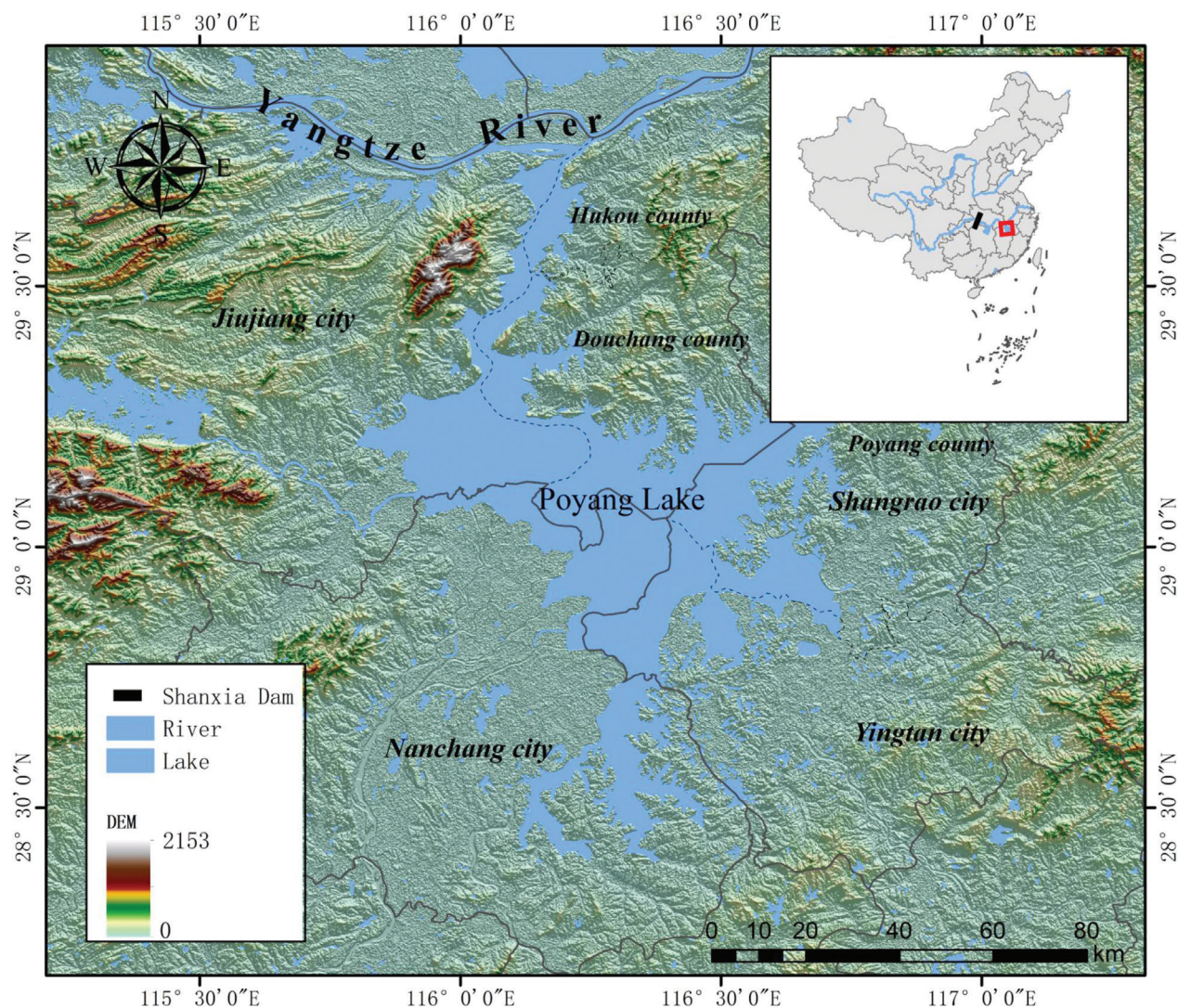
Poyang Lake is located in the middle reach area of the Yangtze River, one of the global biodiversity hotspots and regions that are ranked as a priority for conservation (Olson and Dinerstein 1998; Huang et al. 2013; Wu et al. 2019). The Lake has a native biodiversity that includes 127 plant species (Wu et al. 2019), 220 fishes (Huang et al. 2013), 60 molluscs, 74 reptiles, and 20 amphibians (Ding and Xu 2004; Tai et al. 2020). The biodiversity of Poyang Lake has decreased rapidly in the past forty years due to many factors, including invasion by non-native species (Fang et al. 2006). Poyang Lake is one of the important aquaculture and fishery harvest regions in China, which is the largest aquaculture producer in the world (Wang et al. 2015). A very high number of non-native species were introduced in Poyang Lake and they have caused great negative impacts on the Lake's ecosystem (Wang et al. 2020b; Xiong et al. 2021). Therefore, non-native species have become an important threat to native biodiversity and economic sustainability in the region.

The objectives of this study were: (1) to compile an updated list of non-native species in Poyang Lake; (2) to summarize their taxonomic status and origin; (3) to characterize the pathway of introduction; and (4) to review their ecological, economic, and social impacts of non-native species in Poyang Lake.

## Materials and methods

### Study area

Poyang Lake (Figure 1) is located in Jiangxi Province in the middle reaches of the Yangtze River drainage (113°34'36"–118°28'36"E, 24°29'14"–30°04'41"N). The periphery of Poyang Lake is about 1200 km and the lake surface is 3285 km<sup>2</sup> when the water level reaches 21.71 m. It extends 173 km from north to south and 74 km from east to west. Influenced by the subtropical monsoon climate, the area of Poyang Lake changes from 3000 km<sup>2</sup> during the wet season (April – September) to



**Figure 1.** The location of Poyang Lake.

less than 1000 km<sup>2</sup> during the dry season (October – March) (Wang et al. 2012). Recently, the water level of Poyang Lake has decreased markedly, and the duration of drought is prolonged because of the large dam upstream in the Yangtze River (Zhang et al. 2022).

## Sources of information

An updated list of non-native species in Poyang Lake was compiled based on field investigations and a review of pertinent literature (Suppl. material 1). The geobotanical investigations and fish sampling were conducted during 2002–2022. Over 30 botanical investigations were undertaken during the primary flowering period (May–September) for most aquatic plants. All inventory data were recorded and vouchers of non-native aquatic plants were collected. For details about the methods used in the botanical investigations see Wang et al. (2020b) and Xiong et al. (2021, 2022a). We carried out over 40 ichthyological studies in Poyang Lake and the wetlands around the Lake. Fish samples were collected using gillnets (20 × 10 m, mesh-size 5 mm), dip nets (0.5 m in diameter and a stretched mesh size of 1 mm) and electroshocking fish techniques (CWB-2000 P, 12V, 250 Hz). For details about the ichthyological investigation methodology used in this study see Xiong et

al. (2015b, 2017b, 2019b). We conducted a search for literature that contained the following combination of words: “alien OR exotic OR invas\* OR non-native OR non-native” and “Poyang Lake” in the title, abstract, and in keywords from the Web of Sciences (WOS, <https://www.webofscience.com/wos/alldb/basic-search>) and a Chinese database (CNKI, <http://www.cnki.net>). We also collected and incorporated information from various Chinese books, such as “Collection of Wetland Plants in Poyang Lake” (Wang and Xu 2016). Most information listed in Suppl. material 1 (including scientific name, taxonomic group, pathway, year of first record) came from references cited in Suppl. material 1 and some collected from other sources, like some Chinese books and Chinese invasive plant database (<http://www.nsii.org.cn/2017/minglu/ruqin.html>). To avoid possible confusion caused by synonyms and changes of common names, the scientific names of non-native fish species were applied as found in Catalog of Fishes (<http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp>), the scientific names of non-native plant species were applied as found in the Flora of China (<http://www.iplant.cn/frps>) or Plant list database (<http://www.theplantlist.org>), and the scientific names of other non-native species were applied as found in ITIS database (<http://www.itis.gov>).

## Results

### Taxonomy and time of introduction

According to our field investigations and a review of the literature, a total of 103 non-native species belonging to 43 orders, 53 families and 91 genera have been recorded in the Poyang Lake (Suppl. material 1). Plants are the most species-rich taxonomic group (83 species), followed by fishes (12 species), crustacea (three species), molluscs and reptiles (two species each), and amphibian (one species).

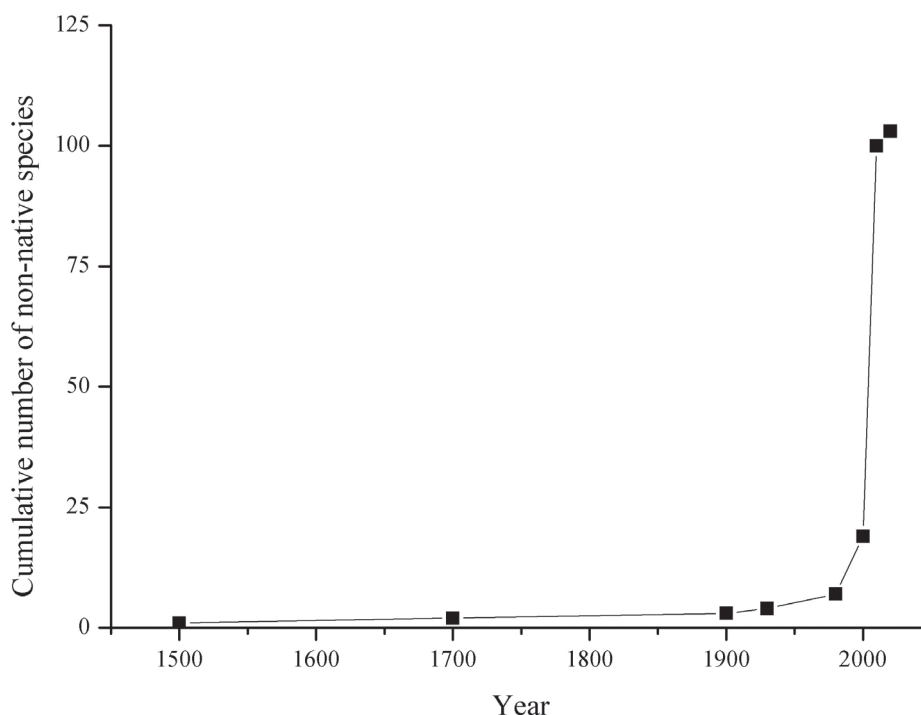
The first recorded non-native species was the peanut (*Arachis hypogaea*), which was recorded in Poyang Lake in the 1500s, followed by water lettuce (*Pistia stratiotes*) in the 1700s, and water hyacinth (*Eichhornia crassipes*) in the 1900s. In the 20<sup>th</sup> century, there were only four non-native species, alligator weed (*Alternanthera philoxeroides*), red swamp crayfish (*Procambarus clarkii*), golden apple snail (*Pomacea canaliculata*), and the bullfrog (*Lithobates catesbeiana*), that were recorded in Poyang Lake (Suppl. material 1). However, the number of non-native species increased to 103 in the first 22 years of 21 century (Figure 2).

### Origin

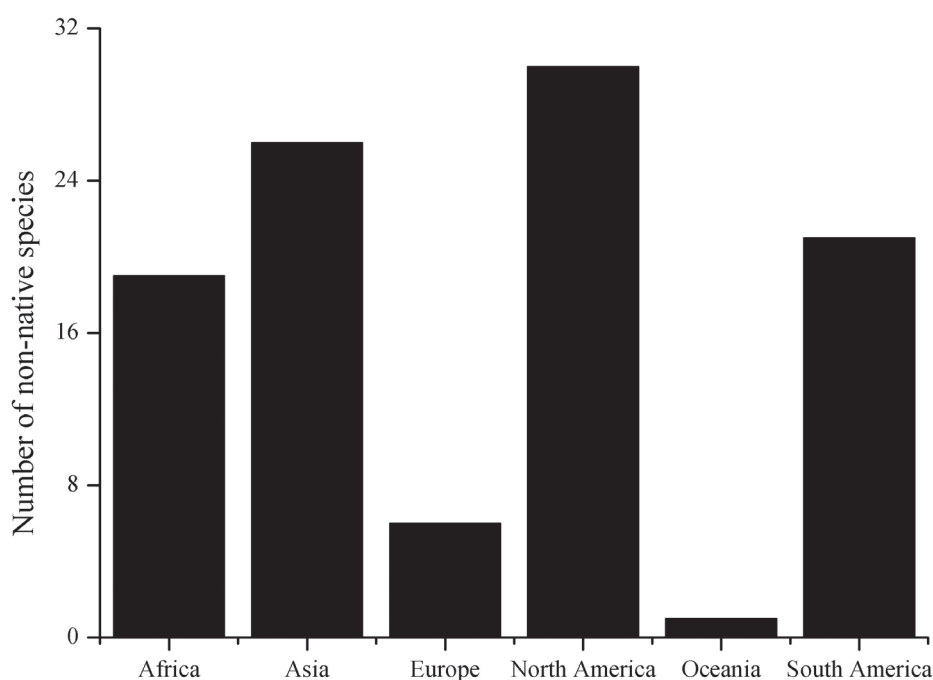
The origin of most of the non-native species was North America (30 species), followed by Asia (26 species), Central and South America (21 species), Africa (19 species), Europe (6 species), and Oceania (1 species). The origins of non-native species are shown in Figure 3.

### Pathways of introduction

Thirty non-native species (29.12% of total non-native species) were introduced through the ornamental trade and via unintentional escapees, respectively. Nineteen species (18.44%) were introduced for use as food. Other pathways of introduction included aquaculture (15 species, 14.56%), forage grasses (four species, 3.88%), medicinal and oil producing plants (two species, respectively, 1.94%), and for biocontrol (one species, 0.97%). All introduction pathways of non-native species are shown in the Figure 4.



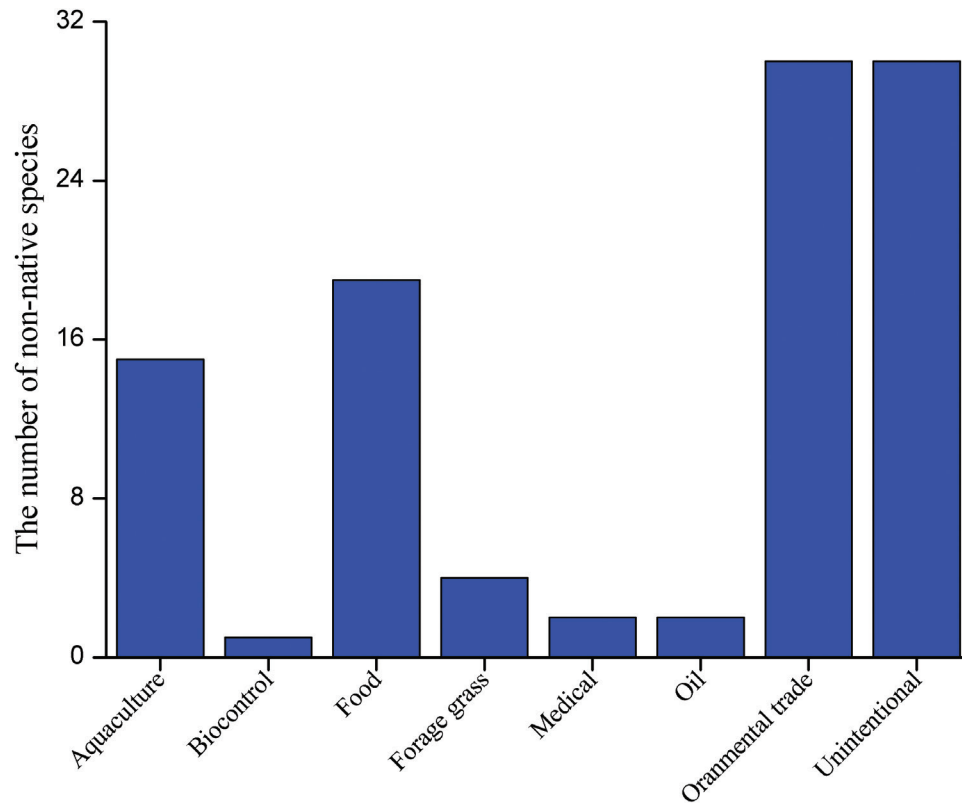
**Figure 2.** The cumulative number of non-native species in Poyang Lake.



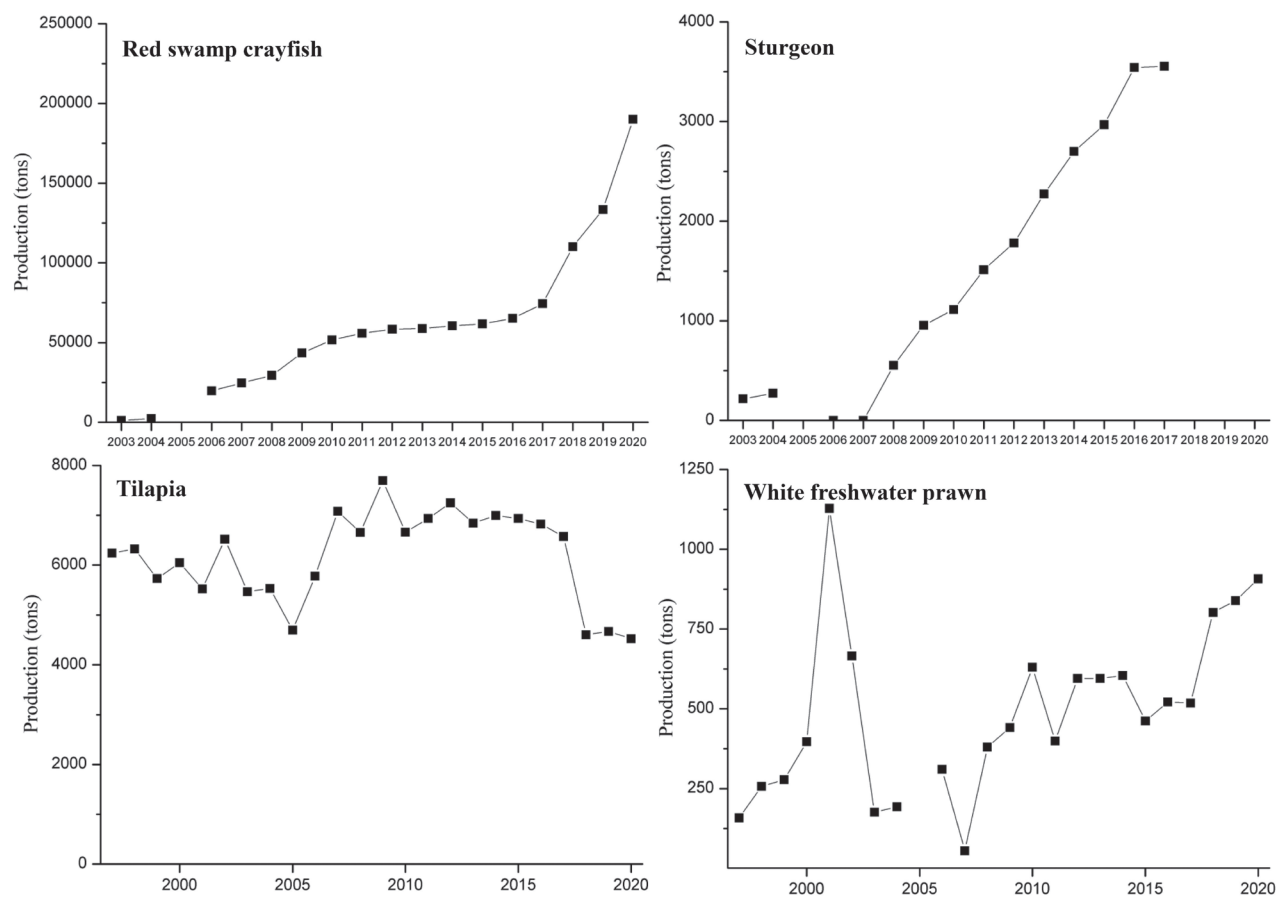
**Figure 3.** The numbers of non-native species from different regions now occurring in Poyang Lake.

## Ecological and economic impacts

Many non-native species are important in local agriculture and aquaculture. For example, the production of red swamp crayfish (*Procambarus clarkii*) increased from 1,222 tons in 2003 to 189,977 tons in 2020 (China Fisheries Statistical Yearbook 1989–2021). The production of tilapia (*Oreochromis niloticus*), and giant freshwater prawn (*Macrobrachium rosenbergii*) have also increased sharply in the past 25 years (Figure 5).



**Figure 4.** The number of non-native species introduced from different pathways into Poyang Lake.



**Figure 5.** The annual aquaculture production of main non-native species in Poyang Lake.

There are at least 48 non-native species that had caused negative ecological impacts in Poyang Lakes (Suppl. material 1). The initial negative impact is competition with native species (46 species), followed by predation upon native species (15 species), habitat and ecosystem alteration (10 species), introduction of a host of parasites (seven species), species poisonous to humans (four species), species producing human allergens (three species), and hybridization and genetic introgression (one species). The ecological and economic impacts of non-native species are presented in Suppl. material 1.

## Discussion

### Taxonomy and time of introduction

In this study we have shown that 103 non-native species have been successfully introduced and become established in Poyang Lake (Suppl. material 1). Compared with other large waterbodies (for example, 184 non-native species in the Great Lakes, Escobar et al. 2017; 100 non-native species in the Lake St. Clair, NOAA-GLANSIS 2023), the number of non-native species in Poyang Lake is much less. Nonetheless, the detection rate of non-native species has reached 4.36 species year<sup>-1</sup> in the past 22 years (96 species after 2000). This rate is much higher than the previous global record of 3.5 species year<sup>-1</sup> in the Three Gorges Reservoir (Xiong et al. 2018b). To our knowledge, this is the highest detection rate of invasion reported for freshwater habitats (Xiong et al. 2018b). We can't be certain all of these 96 non-native species successfully invaded Poyang Lake after 2000 because a few species, such as tilapia and white freshwater prawn were introduced for aquaculture in the 1990s (Figure 1). There may be time lags between reports of non-native species and the time of actual introduction of non-native species. Even so, the invasion rate of non-native species in Poyang Lake is very high.

In the past twenty years, China has become the country most seriously threatened by aquatic non-native species (Xiong et al. 2015a, 2017a; Wang et al. 2016). It is well known that high numbers of aquatic non-native species have invaded various regions and caused significant negative ecological and economic impacts (Xiong et al. 2018a, 2019a, 2023; Wang et al. 2020a, 2021). The Yangtze River is one of the largest invasive hotspots in the world, and it includes sites with the top two highest invasion rates (Poyang Lake and Three Gorges Reservoir, Xiong et al. 2018b). The Yangtze River watershed supports the most important agriculture and aquaculture regions in China (Wang et al. 2015; Chen et al. 2017; Wang et al. 2020b). Additional research and new management strategies are clearly needed to better understand and control the massive regional problem posed by non-native species.

Non-native plants are the primary biological group of non-native species in Poyang Lake. The vast majority of non-native plants are terrestrial due to the lake's low water level. A prolonged drought has been caused by the Three Gorges Dam upstream on the Yangtze River (Zhang et al. 2022). The Lake's water surface area has decreased to less than 600 km<sup>2</sup> (September 19, 2022), which is its lowest level ever recorded (website 2022). There is a strong probability that the duration of severe droughts in China will be longer due to global warming (Price et al. 2022). During severe droughts, human activity in and around the Lake is likely to increase dramatically and with the result of the introduction of even more non-native species. Thus, more wetland plants, mesophytes, and even xerophytes could be introduced and establish feral populations in Poyang Lake in the foreseeable future.

## Pathways of introduction

The aquarium trade has become one of the most important pathways for the introduction of non-native species (Padilla and Williams 2004; Cohen et al. 2007; Lockwood et al. 2019). China is one of the largest producers, users, and exporters of aquarium species (Xiong et al. 2015a, 2017a; Wang et al. 2016). To meet the market demand for novel and attractive aquarium species, a great number of non-native taxa (such as *Sagittaria platyphylla*, *Myriophyllum aquaticum*, *Cabomba caroliniana*, and *Protopterus annectens*) were introduced in China for farming and for the ornamental trade (Wang et al. 2020b; Xiong et al. 2021, 2022a; Wu et al. 2023). According to our investigations, there are over 400 pet or aquarium stores and over 300 online outlets that sell non-native species in Nanchang (the largest city around the Poyang Lake) (Taobao website 2021). These non-native species were farmed around or in Poyang Lake and inevitably escaped via flood, storm and involuntary releases by humans during transport of the species. Many non-native ornamental plants were intentionally planted with the intent of having them persist as established stands. A great number of non-native ornamental plants such as *Myriophyllum aquaticum* and *Eichhornia crassipes* were deliberately introduced in Poyang Lake to absorb nutrients and to help control algal blooms (Wang et al. 2020b; Xiong et al. 2021, 2022a). Some non-native ornamental plants such as *Myriophyllum aquaticum* and *Sagittaria platyphylla* have been widely planted for recreation and aesthetic enhancement (Wang et al. 2020b; Xiong et al. 2021). For example, an area of over 3000 km<sup>2</sup> in Poyang Lake was planted with ornamental plants to improve the aesthetics and beauty of aquatic-environment for visitors and residents of the area (China government website 2007). Because of these deliberate introductions some non-native aquatic plants, such as *Eichhornia crassipes*, *Myriophyllum aquaticum*, and *Sagittaria platyphylla*, have successfully established a large area of feral populations in Poyang Lake (Wang et al. 2020b; Xiong et al. 2021). Unfortunately, monitoring and management measures to control these non-native species are lacking (Xiong et al. 2015a, 2017a; Wang et al. 2016).

Accompanied by prolonged drought, increased human activity, and the unintentional introduction of non-native species, the seeds or clonal propagules of non-native plant species were transported unintentionally by humans and entered the Poyang Lake. Poyang County (around Poyang Lake), is the most populous County (over 1.6 million people) in Jiangxi Province, and it is the poorest County in Jiangxi Province (Statistical Yearbook of Jiangxi Province 2021). Many local residents have acted to reclaim the land for agricultural purposes and have introduced some non-native plant species as food during the drought. Some non-native plant species, such as *Solanum tuberosum*, *Phaseolus vulgaris*, and *Hordeum vulgare*, were widely planted around Poyang Lake. These non-native species have become important food sources for local residents. These terrestrial non-native plant species have established feral populations along the Lake periphery (Suppl. material 1). It is extremely likely that more non-native species will be introduced and become established in the area.

Aquaculture is another well-known and important introduction pathway for aquatic non-native species (Naylor et al. 2001). China is the largest aquaculture producer in the world (Wang et al. 2015), and Poyang Lake is one of its most important aquaculture regions (Wang et al. 2015; Wu et al. 2023). Many non-native fish, crustaceans, and amphibian species were introduced into Poyang Lake for aquaculture due to their rapid growth and economic value. Inevitably, some non-native species escaped and established feral populations (Xiong et al. 2015a). Fifteen non-native species (nine fish, three crustaceans, two molluscs, and one amphibian) have been introduced by aquaculture in Poyang Lake (Suppl. material 1). Since the 1980s, red

swamp crayfish (*Procambarus clarkii*) were introduced to the Lake via aquaculture, and subsequently, other high-valued non-native crayfish (such as *Cherax quadricarinatus* and *Macrobrachium rosenbergii*) were introduced to support the fast-growing demand for crayfish aquaculture (Li et al. 2007). Duchang County (adjacent to Poyang Lake) has become one of the top 30 crayfish production counties in China (unpublished data). After 2000, some non-native fishes (such as *Oreochromis niloticus*) with high growth rates and high market values were introduced (Xiong et al. 2023). In the past twenty years, the production of non-native species increased sharply, and farmed non-native species have become an important industry in Poyang Lake (Figure 5). We observed some newly introduced non-native species, such as flathead grey mullet (*Mugil cephalus*), whiteleg shrimp (*Litopenaeus Vannamei*), and trout (*Oncorhynchus* spp.), that are currently being intensively raised in aquaculture in Poyang Lake. Although we can't verify that these recently introduced non-native species have successfully established wild populations in Poyang Lake, the invasion risk of these non-native species should not be down-played.

## Potential ecological and economic impacts

Non-native aquatic species are significant elements in Chinese aquaculture, which is the largest and fastest-growing sector in China (Wang et al. 2015). Poyang Lake is one of the country's most important aquaculture regions (Wang et al. 2015), and the production of aquaculture and fishery capture in Poyang Lake rose sharply from 1,150,772 tons in 1997 to 2,626,904 tons in 2020 (China Fisheries Statistical Yearbook 1989–2021). The production of non-native species, such as *Procambarus clarkii*, *Macrobrachium rosenbergii*, *Piaractus brachypomus*, and *Oreochromis niloticus*, has also increased significantly in the past twenty years (Figure 5). The production of red swamp crayfish (*Procambarus clarkii*) rose from 1,222 tons in 2003 to 189,977 tons in 2020 (Figure 5). Poyang Lake has become one of the most important aquaculture regions for non-native crayfishes in China. Poyang Lake basin is the seventh largest rearing base of eggs for commercially high-value fishes and crayfish in China. The eggs of many economically important farmed non-native species, such as largemouth bass (*Micropterus salmoides*), Pirapitinga (*Piaractus brachypomus*), and red swamp crayfish (*Procambarus clarkii*), are cultivated and the hatchlings are grown in Poyang Lake. For example, the egg production of tilapia and non-native crayfish reached 0.283 billion and 2.51 billion eggs, respectively, in 2020 (China Fisheries Statistical Yearbook 1989–2021). The introduction of these non-native species has provided a diverse diet and improves the living standard for the local human population, and it is a significant contributor to local economic development.

By contrast, some non-native species cause significantly negative impacts on the local biodiversity, economic sustainability, and human health (Simberloff et al. 2013; Meyerson et al. 2019). Non-native plant species are the most widely introduced group in Poyang Lake (83 species), and many non-native plants have had significantly negative impacts on local biodiversity, local economies, and societal development (Wang et al. 2020b; Xiong et al. 2021). For example, parrot's feather (*Myriophyllum aquaticum*) has established large wild populations in Poyang Lake (Xiong et al. 2021) and it has displaced some native aquatic plants (such as *Myriophyllum spicatum* and *Trapa bispinosa*), facilitated the invasion of other non-native species (such as *Gambusia affinis* and *Procambarus clarkii*), increased the risk of disease carried by mosquitoes, and threatened agricultural production (Xiong et al. 2021). Another widely distributed non-native species that has caused great negative impacts is delta arrowhead (*Sagittaria platyphylla*), which forms dense monocultural stands that block irrigation canals and ditches (Wang et al. 2020b). The Poyang Lake basin is one

of important grain producing areas in China, and the production of grain reached 21.6388 million tons in 2020 (Statistical Yearbook of Jiangxi Province 2021). There are thousands of kilometers of irrigation channels that are distributed around Poyang Lake. These non-native plant species could pose a threat to local grain production by occluding irrigation systems (Wang et al. 2020b; Xiong et al. 2021).

Non-native fish species (12 species) are the second largest of the introduced groups and they have caused significantly negative impacts on other aquatic vertebrates. Western mosquitofish (*Gambusia affinis*) are the most abundant of the non-native fish species and have widely established naturalized populations throughout the Poyang Lake basin (Xiong et al. 2015b, 2019b). Mosquitofish have caused a sharp decline of native fish, amphibian and reptile biodiversity (Cheng et al. 2018). Another classical example of a particularly damaging non-native fish species is the omnivorous tilapia. The populations of some tilapia species including Nile tilapia (*Oreochromis niloticus*) and Mozambique tilapia (*Oreochromis mossambicus*) can grow quickly, and their predation on native small aquatic animals has resulted in a decrease of native fish and amphibian species and their populations (Xiong et al. 2022b, 2023). It is noteworthy that we caught two west African lungfish (*Protopterus annectens*) and observed that over twenty individuals of this species in Poyang Lake (Wu et al. 2023). West African lungfish secrete a thin slime around their bodies that dries into a fragile protective covering. This might be a way that they can survive for long periods of prolonged drought. This lungfish can prey on native fishes, molluscs, and even frogs (Reed et al. 1967). There has been little research focused on non-native fish impacts upon native biodiversity due to a lack of funding (Xiong et al. 2015a). More research on the ecological impacts of non-native fishes in the Lake is needed.

Poyang Lake is one of the most important aquaculture areas for the generation of red swamp crayfish (*Procambarus clarkii*) in China (China Fisheries Statistical Yearbook 1989–2021). The production of red swamp crayfish has increased quickly in the past thirty years (Figure 5). Inevitably, a great number of red swamp crayfish escaped into Poyang Lake and the wetlands surrounding the lake. This non-native species can carry the fungal pathogen *Batrachochytrium dendrobatidis* that causes lethal skin infections (chytridiomycosis) in amphibian species worldwide (McMahon et al. 2013). Poyang Lake has a high diversity of amphibians (Yu et al. 2005) that will be at risk with *Batrachochytrium dendrobatidis* present. This non-native species can cause serious ecological problems through its burrowing activity, modification of physical and chemical properties of the substrate and water, as a vector of diseases, consumption of aquatic plants and algae, predation upon macroinvertebrates, impacts on amphibians, interactions with fish and other crustaceans, and the bioaccumulation of toxic substances (Souty-Grosset et al. 2016).

## Monitoring and management

Poyang Lake is the largest freshwater lake in China and is also one of the most important aquaculture areas in China (China Fisheries Statistical Yearbook 1989–2021). In the future, more non-native species will inevitably be introduced as part of the ongoing effort to expand the production and quality of the Lake's aquaculture industry (Xiong et al. 2015a, 2023). Thus, an ongoing management program for non-native species and a rigorous assessment and monitoring of ecological and economic impacts in Poyang Lake is needed. Early detection and response are important measures for management and control of non-native species (Burgiel 2020; Cuthbert et al. 2022). However, identification of non-native species is a serious challenge, because there are few taxonomists and many researchers are not familiar with novel non-native species (Engel et al. 2021). For example, we spent over

one year seeking scientists to help with identifying a new non-native aquatic plant species, delta arrowhead (*Sagittaria platyphylla*) (Wang et al. 2020b). Researchers who encounter non-native species in the field may not recognize these unfamiliar taxa to be non-native species. Some new technology, such as environmental DNA and remote sensing, have been applied in monitoring non-native species (Tréguier et al. 2014; Vaz et al. 2018). However, these new methods need skilled professionals to correctly implement them. More species identification training programs, instruction in molecular biology and GIS should be provided to researchers and local environmental managers. Better and additional cooperation between administrative departments, non-governmental organizations and researchers is needed.

Finally, it is hard to eradicate non-native aquatic species once they have successfully established naturalized populations (Xiong et al. 2015a, 2017a). Some researchers tried to find optimal times and eradication methods to control invasions of non-native species (Liang et al. 2022). The appropriate timing and method of eradication differs among non-native species because of their varying habitat preferences and different biological traits (Xiong et al. 2021, 2023). In the future, more attention needs to be given to invasion risk assessment in introduced species, early detection and methods of eradication.

## Conclusions

Compiling an inventory of non-native species is a first and fundamental step for effective management of natural as well as constructed habitats (Pyšek et al. 2004). In this study, we provide the first multi-taxon list of non-native species in Poyang Lake, which can help in management efforts to protect the native biodiversity, sustainable agricultural uses, and in sustainably operated aquaculture developments (Wang et al. 2020b; Xiong et al. 2021). The primary pathways of introduction are through the ornamental trade and unintentional escapes from it (Suppl. material 1). Therefore, more monitoring and management of non-native species in the ornamental trade and human activities involved with it are primary measures that need to be developed to successfully manage and control non-native species in Poyang Lake. Poyang Lake is one the largest reproductive and rearing bases of a number of non-native species. It is inevitable that more non-native species and strains of species already introduced will be brought in to improve the genetics and range of selection in commercially important species. More strict management procedures, handling protocol, and regulation of introduced non-native species in aquaculture are needed to decrease the unintentional introduction of more non-native species in the already heavily impacted natural habitats of the Lake.

Poyang Lake is located in a biodiversity hotspot and also supports valuable agriculture and aquaculture development in China. The Lake is a good model for management approaches to non-native species that can be utilized in the control of non-native species in other large lakes of China. A great number of non-native species have been introduced in Poyang Lake and have caused vast negative ecological and economic effects. More measures of monitoring, controlling, and public education should be integrated to decrease the negative impacts of non-native species.

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## Authors' contribution

WX, HW and ZW conceived the idea and designed the study. WX designed the methodology. DX, QW, and HS carried out the searches and organized the occurrence and environmental datasets, performed the analyses, and prepared the figures. WX and HW interpreted the results. WX, HW, and ZW led the writing of the manuscript. WX, HW, TL, and PAB significantly contributed to the manuscript writing and critical review.

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## Supplementary material 1

### List of non-native species in Poyang Lake

Authors: Wen Xiong, Dong Xie, Qiang Wang, Hui Wang, Zhigang Wu, Heying Sun, Tao Li, Peter A. Bowler

Data type: Occurrences

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