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Research Article

Non-native freshwater fish escaped from aquaculture in China: too much of a good thing is not always the best

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Abstract

China has the world's largest aquaculture production that partly benefits from the introduction of high-quality germplasm from both abroad and within the country. However, the rivers, lakes and reservoirs of China face a high risk of invasion by non-native freshwater fish associated with aquaculture. In this study, we used peer reviewed and grey literature in combination with a field survey to investigate the status, pathways, mechanisms and management of non-native freshwater fish for aquaculture in China. Production of non-native freshwater fish accounts for 8% of total aquaculture in China and is dominated by tilapia, bass, ictalurid, pirapitinga, salmon, trout and sturgeon. However, the escape of non-native fish resulting from unstrict farming management, fishery stocking and mercy release has been frequently reported. In total, 155 non-native freshwater fish species have escaped into natural waters. Among these species, 102 are aquacultural of which 59 translocated and 43 introduced from abroad. Introduced species have been mainly reported from southern China, whereas translocated species from the north and west of the country. Available data suggest that non-native fish associated with aquaculture have escaped into the main rivers of China. However, the real risk posed by non-native fish to native species and the ecosystem has been hardly evaluated due to the lack of basic information on population dynamics of non-native fish. Despite management strategies for non-native species having achieved substantial progress in recent years in China, development of a suitable transformation strategy for aquaculture to fulfil Sustainable Development Goals remains challenging. Academia, government and stakeholders should work jointly to develop management strategies to mitigate the risks posed by non-native species in aquaculture.

Key words: management, translocated, non-native aquaculture species, invasion process, sustainable aquaculture

Introduction

Following declines in wild fish stocks in response to climate change, aquaculture has come to play an essential role in providing a source of food rich in protein and micronutrients to sustain a growing global population (FAO 2022). In 2021, aquaculture production worldwide reached a record of 126 million tons live weight comprising 47% finfish, 28% seaweeds, 15% mollusks and 9% crustaceans, for an estimated value of USD 295.5 billion (FAO 2023). The aquaculture industry provides work opportunities for some 20.6 million producers, with 28% of them being women (Mair et al. 2023). Aquaculture therefore makes an important contribution to achieving the Sustainable Development Goals set by the United Nations (FAO 2022).

The use of non-native species represents an important contribution to aquaculture production, accounting for 9.7% of the total (FAO 2021). However, this practice is a double-edged sword, as it provides economic benefits but also represents a threat to biodiversity (Xiong et al. 2022). By way of example, carps and tilapias are the dominant aquaculture species worldwide that contribute to an increase in protein supply in both developing and less developed countries (FAO 2009a, b). However, the escape of these species from aquaculture facilities has led to ecological pressure on biodiversity, water quality, habitat suitability, conservation of native species and nutrient recycling (Gozlan et al. 2010a; Gallardo et al. 2015; Flood et al. 2020). At the same time, the relative scale of the negative (e.g. harm to the environment) and positive (e.g. socio-economic benefits) impacts of non-native species in aquaculture has been merely estimated (FAO 2022). Therefore, it is crucial to investigate these benefits and risks to facilitate the development of sustainable aquaculture practices in the future.

China has the world's largest aquaculture production, which partly benefits from the introduction of high-quality germplasm from both abroad and within the country (Lin et al. 2015). At the same time, aquatic ecosystems, and especially freshwater ones that are more vulnerable than terrestrial ecosystems, are exposed to threats by non-native species (Havel et al. 2015). Recent reviews have highlighted the historical context, scale and ecological impacts of freshwater fish introductions in China (Lin et al. 2015; Xiong et al. 2015; Kang et al. 2023). However, these studies have predominantly focused on non-native fish species cultivated in China from a broader perspective, without elaborating on the specific pathways, scale and consequences of non-native fish escapes into the wild. Using peer-reviewed and grey literature in combination with a field survey, the aim of this study was to: (1) investigate the status of freshwater fish introductions for aquaculture in China; (2) explore the mechanisms by which aquaculture fish species escape into the wild and establish self-sustaining populations; (3) investigate the scale and impact of escaped non-native aquaculture fish; and (4) evaluate appropriate management strategies supported by risk analysis. The findings of this study are expected to better inform the management of non-native species associated with aquaculture in China.

Status of freshwater fish introductions for aquaculture in China

China is one of the countries with the largest number of rivers, lakes and reservoirs, which are conducive to the development of aquaculture. Aquatic

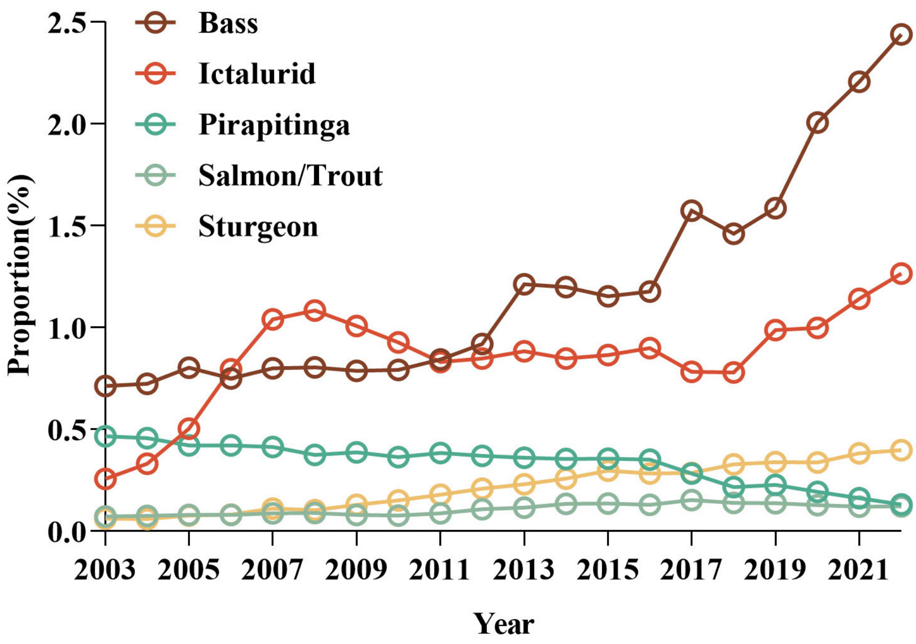

Figure 1. Proportion of bass, ictalurid, pirapitinga, salmon/trout and sturgeon accounting for total production of freshwater aquaculture (i.e. fish, shrimp, crab, shellfish) from 1980 to 2022 (data from China Fisheries Statistical Yearbook 1980–2022).

animal production in China has been growing fast in the past decades, from 12% of the world total production in the late 1980s to 37% in 2020 (China Fisheries Statistical Yearbook 1980–2022). The import of aquatic products has also increased steadily from 1.87 million tons in 1980 to 5.68 million tons in 2020 (China Fisheries Statistical Yearbook 1980–2022). At the same time, many fish species have been introduced from abroad or translocated from within China to satisfy the demand of aquatic products diversification (Xiong et al. 2015). In this respect, a total of 111 fish species have been introduced for aquaculture purposes, including 91 freshwater fish (Lin et al. 2015; Xiong et al. 2015). Non-native freshwater fish account for 8% of total aquaculture production in China (China Fisheries Statistical Yearbook 1980–2022). Production of bass, ictalurids and sturgeons has increased rapidly, whereas that of pirapitinga has decreased in recent years, and of salmon and trout has increased slowly (Figure 1). Despite several native species being part of such production, non-native species are dominant and include *Acipenser baerii* Brandt, 1869, *Ictalurus punctatus* (Rafinesque, 1818), *Micropterus salmoides* (Lacepède, 1802) and *Oncorhynchus mykiss* (Walbaum, 1792) (Li 2008; Sun and Wang 2010; Bai and Li 2013; Dai et al. 2019). Tilapia is the most frequently farmed non-native fish in China with production having increased from 2% in the 1990s to about 5% at present (Figure 2; Dai et al. 2020). Tilapia has important economic and social values and represents a billion-dollar industry that includes export trade, aquafeed industry, fish processing and other industrial clusters (Zhang 2017). Tilapia production in the southern provinces of China (i.e. Fujian, Guangdong, Guangxi, Hainan and Yunnan) accounts for 95% of

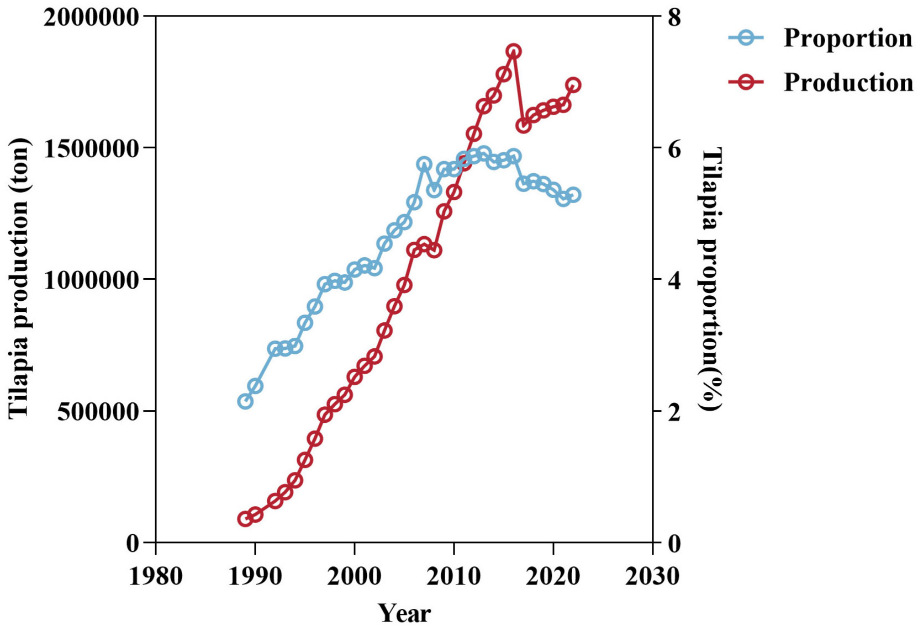

Figure 2. Production of tilapia and proportion accounting for total production of freshwater aquaculture (i.e. fish, shrimp, crab, shellfish) from 1980 to 2022 (data source from China Fisheries Statistical Yearbook 1980–2022).

the national production (Dai et al. 2020). However, tilapia has become the main catch in rivers of these provinces, where it has caused negative ecological impacts on biodiversity and ecosystem function (Gu et al. 2019; Shuai et al. 2023).

To maximise aquatic food yield, fish species native to China have been introduced to lakes and reservoirs to compensate the decline in wild resources (Kang et al. 2015). Translocated fish in China that are native to one basin but do not naturally occur in other basins are another important source of fish introduction (Lin et al. 2015). Fish species exchange within China is also efficient owing to facilitated conditions of transport. A recent survey has indicated that the number of translocated species has exceeded that of introduced species in Yunnan Province (Wang et al. 2023). The four Chinese carps [bighead carp *Hypophthalmichthys nobilis* (Richardson, 1845), grass carp *Ctenopharyngodon idellus* (Valenciennes, 1844), silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844), black carp *Mylopharyngodon piceus* (Richardson, 1846)] have a long farming history and are widely distributed in most rivers and lakes of China (Mao et al. 2010). These fish species are also translocated to the Yunnan-Guizhou Plateau, the Qinghai-Tibet Plateau, as well as to northeastern and northwestern China (Lin et al. 2015). Native to eastern and southern China, icefish (Salangidae) has been commercially exploited and translocated to lakes within China for a long time (Kang et al. 2015). Amongst icefish, *Neosalanx taihuensi* (Chen, 1956) was mainly translocated to southern China, whereas *Protosalanx chinensis* (Basilewsky, 1855) was mainly translocated to northern China owing to differences in the species' temperature tolerance (Kang et al. 2015). Some small body fish such as topmouth gudgeon *Pseudorasbora* *parva* (Schlegel, 1842), were introduced as a result of the translocation of economic important fish among the basins (Gozlan et al. 2010b). However, it is difficult to identify whether this translocated species was non-native due to the lack of documented historical distribution records.

Overall, translocated species can lead to negative impacts similar to that of introduced species, including biotic homogenization (Leprieur et al. 2008; Liu et al. 2017a). Therefore, further studies should be conducted to clarify the impact of translocated or reintroduced fish on the recipient communities.

How do non-native aquaculture fish become invasive in China?

Improved technologies for transportation of living fish facilitate the movement of non-native fish beyond their geographical barriers (Havel et al. 2015; Figure 3). The escape and establishment of non-native aquaculture fish can be facilitated by the release of propagules with high fitness to adapt to new environments and by suitable biotic and abiotic conditions for establishment (Figure 3). Firstly, the escape of seedling and adults from aquaculture facilities provides massive amounts of propagules, which is the base for the establishment of non-native fish populations (Gu et al. 2022). Whether aquaculture facilities could prevent the introduction of fish and pathogens escaping into natural water bodies is a crucial factor that should be considered as part of any risk assessment of non-native aquaculture species (Copp et al. 2014). China's aquaculture is mainly based on extensive systems, with pond farming as the main mode (China Fisheries Statistical Yearbook 1980–2022). By the end of 2022, freshwater ponds reached 2,624.88 thousand hectares, accounting for 52.15% of the total farming area across the country. This is followed by reservoirs with 1,447.73 thousand hectares and accounting for 28.76% of the farming area, and by factory farming accounting for only 0.12% (China Fisheries Statistical Yearbook 1980–2022).

Extensive aquaculture facilities are susceptible to extreme climate events (e.g. floods and tropical storms). For example, in 2016 nearly ten thousand tons of non-native sturgeons [i.e. *Acipenser baerii*, *Acipenser gueldenstaedtii* (Brandt & Ratzeburg, 1833), *Acipenser schrenckii* (Brandt, 1869), *Huso dauricus* (Georgi, 1775), *Polyodon spathula* (Walbaum, 1792), and a hybrid sturgeon] escaped from aquaculture cages into reservoirs of the Qingjiang River in Hubei Province due to flooding caused by extreme rainfall (Gao et al. 2017). This event caused a lot of concerns, as the escaped sturgeons were expected to exert a high threat to native endangered sturgeon *Acipenser sinensis* (Gray, 1835) (Gao et al. 2017). A recent risk analysis found that *Polyodon spathula* and *Acipenser baerii* could pose a high risk of invasion in the Changjiang River (Li et al. 2023). On the other hand, the aquaculture equipment of extensive farming is mainly used for oxygenation and feeding, with little equipment dedicated to the monitoring of fish diseases and water quality (Huang et al. 2020). Tailwater from fish farms is

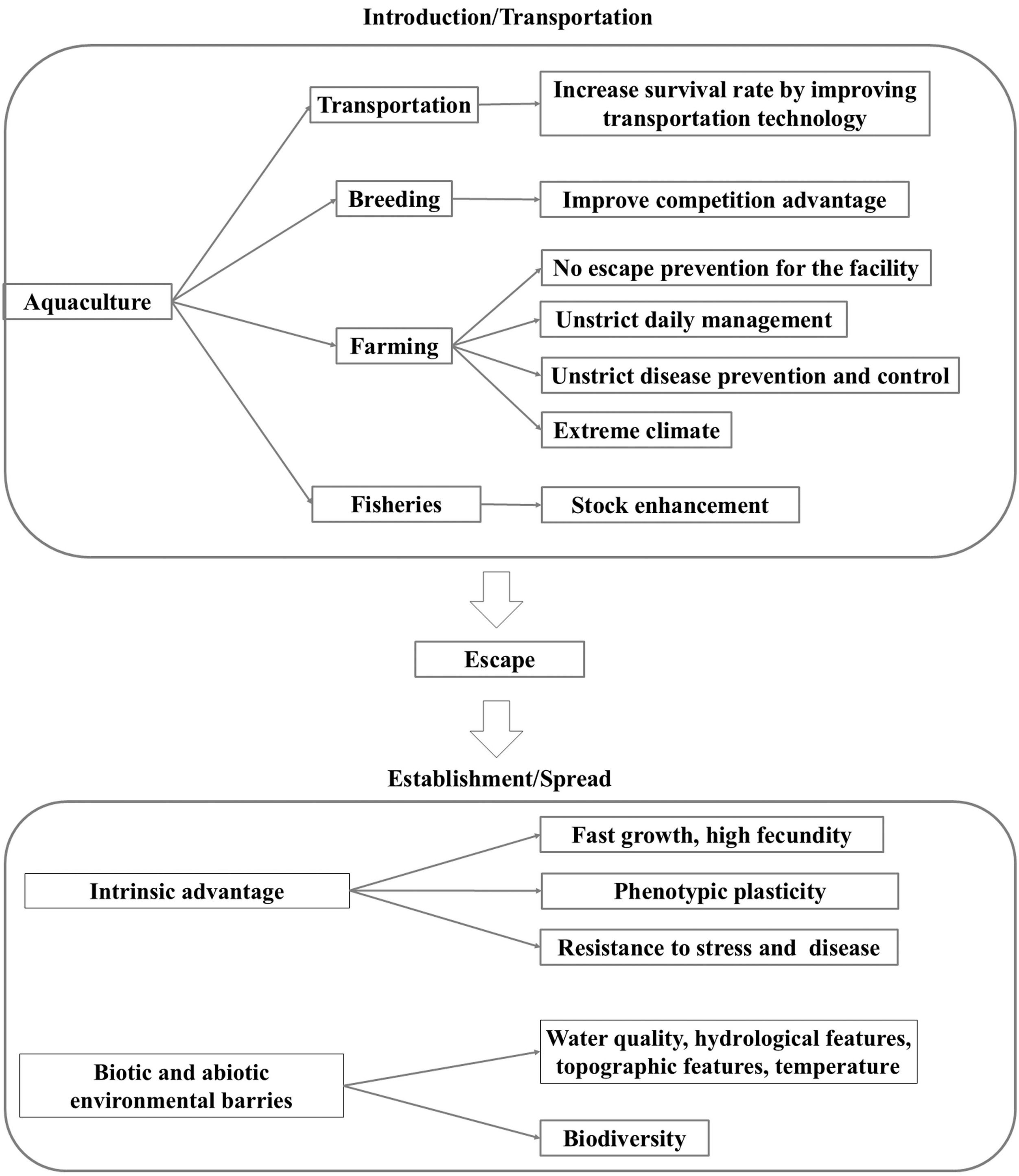

Figure 3. Schematic illustration of the process by which non-native fish escape from aquaculture to the wild.

discharged directly into natural water bodies, making it difficult to monitor and prevent fish and pathogens from escaping the facilities. Thus, the upgrade of farming facilities and related equipment and the improvement of daily management practices could reduce the risk of non-native fish escaping into water bodies.

Stock enhancement is another important pathway by which non-native fish enter natural waters (Kang et al. 2015). A few decades ago, several non-native fish were released into rivers, lakes and reservoirs for natural proliferation due to low awareness of biosecurity, unsound management measures and the need for economic benefits (Li et al. 2020). For example, tilapia and largemouth bass were released into natural water bodies to compensate for the decline of natural fishery resources in earlier years. Some non-native fish, including carps and tilapia, have also been released into natural waters to control water pollution (e.g. eutrophication and algal blooms). Additionally, religious groups have the practice of releasing animals, which is one of the dominant sources of non-native fish propagules in natural water bodies (Du et al. 2024). Although these activities have released massive amounts of non-native propagules, whether these non-native fish are able to establish self-sustaining populations in the wild depends on the biological characteristics and adaptive capacity of the recipient environment.

Individuals with life-history traits including fast growth rate and resistance to environmental stress and diseases are generally selected to maximize production with low economic and time costs (Liu et al. 2023). Non-native fish can also benefit from these traits to overcome abiotic and biotic barriers in their introduced ranges (Liu et al. 2023). Numerous studies have indicated that invasive fish typically possess undesirable traits such as omnivory, fast growth, high fecundity, short time to sexual maturity, ability to colonize various habitats, tolerance to stress, and high phenotypic plasticity (Cucherousset et al. 2009; Liu et al. 2017b). For example, *Coptodon zillii* (Gervais, 1848), which has established populations and has spread in southern China, reaches sexual maturity after six months and can tolerate hypoxic and eutrophic water conditions (Gu et al. 2020). As one of the IUCN 100 Worst Invasive Species, *Onchorynchus mykiss* is easy to breed, has high fecundity and can tolerate a wide range of environmental conditions (Froese and Pauly 2024). Another IUCN 100 Worst Invasive Species, namely *Micropterus salmoides*, has traits including fast growth, high fecundity, high genetic diversity and high environmental tolerance (Froese and Pauly 2024). *Oxyeleotris marmorata* (Bleeker, 1852), which has established self-sustaining populations in the rivers of Hainan Island, has similar characteristics, such as high fecundity and reproductive frequency, parental care, tolerance to hypoxia and starvation, and high population resilience (Zheng and Pan 1989; Froese and Pauly 2024). These characteristics allow these non-native fishes to adapt to new environments for their establishment and expansion.

Another aspect is whether biotic and abiotic environments may be favourable for the survival and population establishment of non-native species. Temperature is the main factor affecting the distribution of non-native fish. Fish species originating from tropical or sub-tropical regions are more likely to colonize and establish populations in southern China, whereas non-native cold-water fish are more likely to invade northern China (Xiong et al. 2015). *Micropterus salmoides*, which originates from North America, is a good example. Although this species is farmed at large commercial scales in Guangdong and Jiangsu Provinces, it could survive only in the latter, likely as a result of higher temperatures during the spawning season in Guangdong relative to Jiangsu (Li and Wei obs.). A recent study has demonstrated that this species has higher survival rates at 21 °C than at 24 °C and 27 °C (Aguilar et al. 2023).

Habitat characteristics (cf. "environmental filters": Bajer et al. 2015; Kirk et al. 2022) such as water quality, hydrological features, topographic features and vegetation can also affect the survival, spawning, population establishment and spread of non-native fish. Additionally, the functional traits of native fish can also affect the invasion success of non-native fish through interspecific interaction, such as competition and predation (Comte et al. 2017; Su et al. 2020). Despite the relationship between biodiversity and community invasibility having been well studied, no consensus has been reached regarding this relationship. For example, some studies have argued that non-native species with similar traits as native species could be more successful in the invaded communities (cf. "preadaptation": Kraft et al. 2015). Whereas other studies have proposed that the traits of non-native species should be distinct from those of native species to avoid interspecific competition, (cf. "Darwin's naturalization": Park and Potter 2013). A recent meta-analysis has demonstrated that invasive fish with similar evolutionary history but distinct functional traits are more successful (Xu et al. 2022). Overall, the invasion process of non-native fish is complex and cannot be determined by a single or a few factors. Further studies should include more factors to understand how non-native aquaculture fish become invasive in their introduced range.

Scale and impact of escaped non-native aquaculture fish species in China

We relied on an exhaustive data collection to investigate the scale of non-native fish escaped from aquaculture facilities into natural water bodies across China using peer-reviewed and grey literature combined with a field survey (see Supplementary material). We searched databases including the China National Knowledge Infrastructure (CNKI: https://www.lib.u-tokyo.ac.jp/en/library/contents/database/63), Web of Science (https://webofknowledge.com) and Google scholar (https://scholar.google.com/), using the keywords "fish community", "fishery survey", "fish diversity", and "China". A total of 115 literature sources were selected to compile the list of non-native freshwater fish by counting the records of non-native fish from fish communities in rivers, lakes, reservoirs and wetlands based on the terminology of non-native species in Kang et al. (2023) (Table S1). This list might not be consistent with previous reviews (e.g. Kang et al. 2023), which combined escaped and unescaped non-native freshwater fish species. Thus, the number of species was lower in this study relative to previous reviews. However, most of the species in our list were included in the lists of previous reviews.

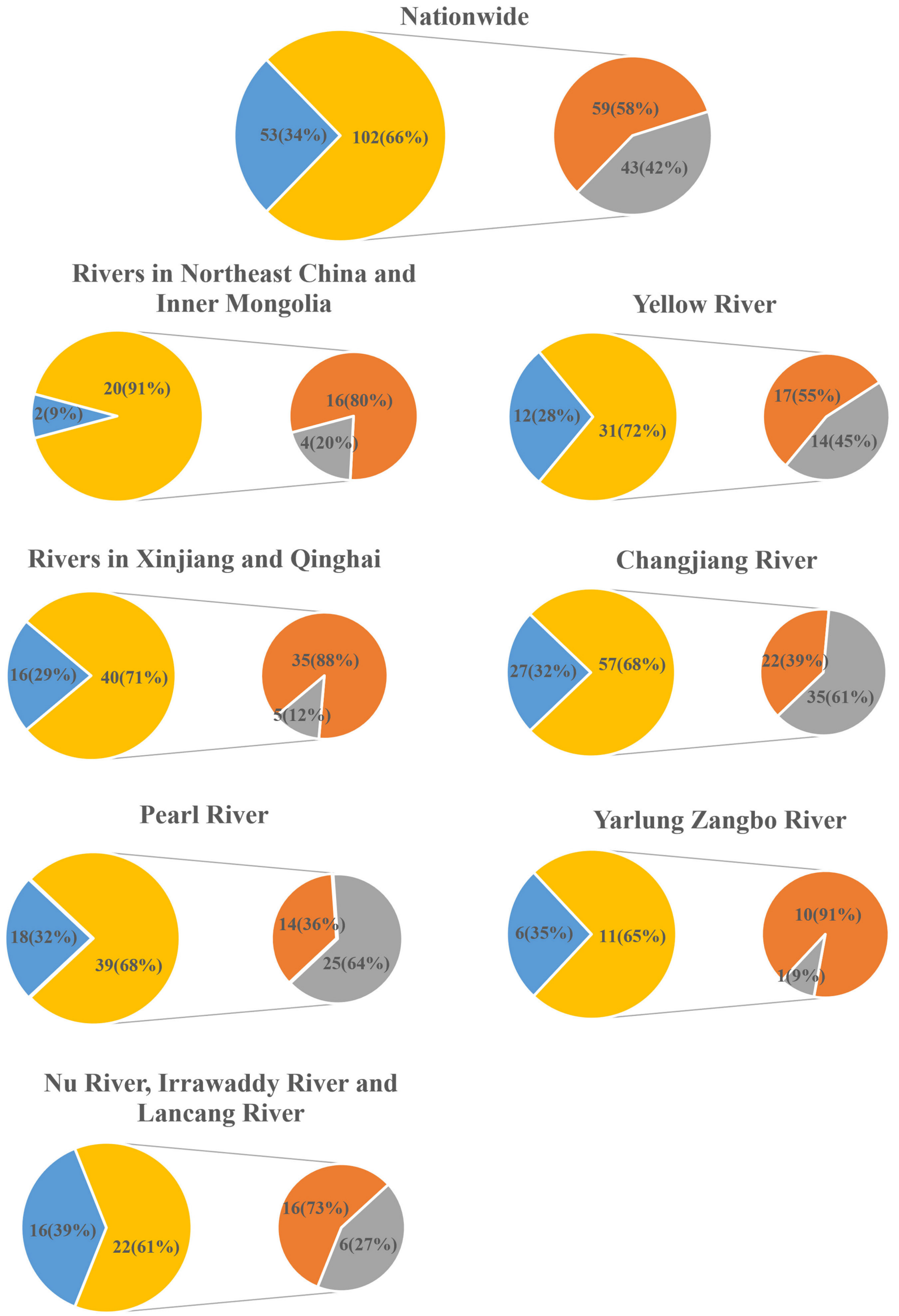

Figure 4. Number and percentage of non-native fish associated with aquaculture (yellow) and other pathways (blue) escaping into the main rivers of China, and numbers and percentage of non-native aquaculture species translocated (orange) or introduced (grey) from the abroad. Percentages in the parentheses indicated the proportion of non-native fish accounting for the total number of non-native fish species.

In total, 155 non-native fish have escaped into natural waters and 102 are aquaculture species, including 59 translocated and 43 introduced from abroad (Figure 4). Further analysis has suggested that the proportion of non-native aquaculture species accounting for the total number of non-native fish species has exceeded 50% in the main river basins of China, i.e. the rivers in Northeast China and Inner Mongolia (91%), the Yellow River (72%), rivers in Xinjiang and Qinghai Provinces (71%), the Changjiang River (68%), the Pearl River (68%) and the Yarlung Zangbo River (65%), as well as the Nu and Irrawaddy rivers (61%). Overall, more introduced species are found in southern China and more translocated species in northern China (Figure 4).

The Pearl River has the highest proportion of introduced fish, whereas the Yarlung Zangbo River harbors the highest proportion of translocated fish (Figure 4). Southern China is at the forefront of reforms and "opening" with more frequent exchanges with foreign countries, which could facilitate species introductions (Wei et al. 2019). Additionally, southern China, which is characterized by warm temperatures and abundant water courses, is suitable for the development of aquaculture (Wei et al. 2019). In this regard, many non-native aquatic species were introduced to China in the early period of reform and "opening" (1980s–1990s: Lin et al. 2015). Among them, a large-scale introduction and promotion was conducted for tilapia, *Ictalurus punctatus*, *Micropterus salmoides* and *Piaractus brachypomus* (Cuvier, 1818) (China Fisheries Statistical Yearbook 1980–2022). Conversely, aquaculture is less developed in north and west China, where it is affected by cold temperatures and water shortages. Fish species with wide ecological amplitude and cold-water fish are the main farmed species in north and west China. For example, four Chinese carps, icefish and *Megalobrama amblycephala* (Yih, 1955) were translocated from southern or eastern China. *Onchorhyncus mykiss* introduced from North America and sturgeon from Siberia. All these fish species can be found in natural water bodies, with tilapia and *Cirrhinus mrigala* (Hamilton, 1822) being common in the Pearl River (Gu et al. 2020), *Cirrhinus mrigala* and sunfish common in the lower reaches of the Changjiang River (Yang et al. 2023), and icefish, four Chinese carps as well as salmon and trout being common in the Yellow River (Zhao et al. 2020). This suggests that non-native fish associated with aquaculture have escaped into the main rivers of China. However, understanding of the ecological and socio-economic impacts of these non-native fish is overall limited.

From a biogeographic perspective, the introduction of fish species could lead to biotic homogenization to which translocated species contribute more than introduced species (Liu et al. 2017 a). Specifically, non-native fish could interact with native species (i.e. competition and predation), which could reduce fitness of native species, resulting in population decline or extinction (Yu et al. 2019; Parvez et al. 2023; Shuai et al. 2023). For example, non-native piscivorous fish, such as *Salmo trutta* (Linnaeus, 1758), could prey on native fish, leading to destructive effects on the native fish community (Alvarez and Ward 2019; Orlandi et al. 2024). The invasion of omnivorous fish, such as *Oreochromis niloticus* (Linnaeus, 1758), could affect nutrient cycling and phytoplankton community of the recipient ecosystem (Figueredo and Giani 2005). There is accumulating evidence based on stable isotope analysis suggesting that the invasion of non-native species can result in trophic overlap with native species (Cordova-Tapia et al. 2015; Balzani and Haubrock 2022). However, trophic overlap does not always equate to interspecific competition. In this respect, a dynamic consequence of multiple fish invasion (e.g. neutral and negative) due to trophic plasticity of fish species has been recently investigated (Wei et al. 2024). More efforts should be made to understand the dynamic process by which non-native fish interact with native species.

Risk analysis and management of non-native aquatic species in China

In the past few years, the Chinese Government has been paying increasing attention to non-native species than ever before, including the implementation of rules and legislation. In 2020, the Biosecurity Law of the People's Republic of China was promulgated. This is the first basic, comprehensive and overarching law of biosecurity in China. Additionally, the Criminal Law of the People's Republic of China (2021 edition) stipulates the penalties associated with the illegal introduction, release or discard of invasive species. The Measures for the Management of Alien Invasive Species, implemented on 1 August 2022, provide specific measures for the implementation of these laws. However, the management of non-native species still has a long way to go, and especially for non-native fish, which play an important role in socio-economic development.

The risks posed by non-native species are different throughout the process of aquaculture production, namely import, breeding, farming and destinate use each of which requires specific management strategies:

- At the import stage, the Government has imposed strong regulations including the Biosecurity Law and Law of the People's Republic of China on the Entry and Exit Animal and Plant Quarantine. This has been issued to enhance inspection, quarantine and risk assessment of non-native species. Although risk assessment used to focus on fish diseases, recent policy has required a full risk analysis (including an evaluation of the transmission of pathogens and of the ecological and economic impacts) of introduced species after the enactment of the Biosafety Law.
- At the breeding stage, farmers prefer to raise unisexual and sterile varieties as they have higher production relative to normal ones. This practice could prevent non-native fish from establishing sustaining populations in natural waters. This agrees with the FAO, which has recommended selecting sterile varieties for aquaculture to reduce the risk of introductions (FAO 2022).
- At the farming stage, the aquaculture mode of China, which is semi-natural and connected to natural water bodies, is easily affected by environmental conditions (e.g. extreme climate events: Gu et al. 2022). For this reason, non-native fish can easily escape into natural water

bodies via tailwaters or floods. Strict daily inspections should therefore be implemented to ensure that facilities can prevent the escape of non-native fish. Further, tailwaters should be disinfected before being discharged into natural waters to reduce the risk of fish escapees.

- At the destinate use stage, processed fish is usually destined for export, whereas people in China prefer live fish. These fish are sold in fish markets, which carries a risk of escape. The popularity of pre-made meals may reduce the sale of live fish, hence help to mitigate the risks associated with non-native fish at this stage. However, all these management measures could increase the costs by enterprises and farmers. A good strategy could be to establish a systematic mechanism to share the costs for the prevention and control of non-native fish with the Government, consumers and other stakeholders.

Fishery stocking is an important source of fish invasion. Regulations on the Enhancement and Release of Aquatic Species, enacted by the Ministry of Agriculture and Rural Affairs of the People's Republic of China, stipulate that the use of non-native, hybrid and genetically modified species is prohibited in practice. According to the regulation, translocated species could not be released, in particular carp and crucian carp, which have numerous local varieties. For better implementation, in 2022 the Ministry of Agriculture and Rural Affairs issued a guide for the enhancement and release of aquatic species as part of the 14th Five-Year Plan. The guideline has listed 126 aquatic organisms that are prohibited from being released nationally or locally. These schemes could mitigate the risk of non-native fish being released in natural waters.

Unlike fishery stocking, which is led by the Government, mercy release is mainly done by individual citizens or religious groups, hence it is more difficult to be prevented. In this respect, public education represents an important way to reduce the release of non-native species. Fortunately, in recent years, scientific researchers and civilian teams have joined public education to reduce the events of non-native species release. For example, the China Fisheries Association has set up a team of experts for fish release in a scientific manner, which consists of both researchers and amateurs. This team wrote a blog about the list of aquatic species not suitable for fishery stocking and release, and reposted using news media (e.g., blog, WeChat, Tik Tok), which had more than 50 million views. These facts suggest that news media has stepped forward in terms of popular science, which could help people to understand the risks of non-native fish, thereby reducing their release.

Conclusions

The rivers, lakes and reservoirs of China face a high risk of invasion by non-native freshwater fish associated with aquaculture (Kang et al. 2023). Several non-native freshwater fish have been introduced into China to promote aquatic production for feeding some 1.4 billion people, making for a most important socio-economic contribution. However, the escape of non-native fish, resulting from unstrict farming management, fishery stocking and mercy release, has been frequently reported and has aroused extensive concern in recent years. Despite massive investigations conducted to monitor the number and distribution of non-native fish, their real impact has been hardly assessed in the invaded ecosystems.

The benefits *vs* risks of fish introductions in aquaculture have been widely discussed in recent years (Lin et al. 2015; Gu et al. 2019; Xiong et al. 2022). These studies have emphasized the importance of developing an eco-friendly aquaculture system to mitigate the risk of fish introductions and of strengthening management strategies through collaboration with academia, government and stakeholders. This includes risk assessment, early warning, contingency and eradication plans, as well as cost sharing for non-native fish. In the past, stakeholders always avoided to mention "invasive species" in aquaculture to reduce economic loss due to Government supervision, which might make the management of non-native species difficult. This dilemma is common in the sustainable development of other industrial fields, such as carbon emission and sewage discharge *vs* capacity growth, which have well-developed strategies to meet environmental needs. For aquaculture, transformation and upgrade of the production system to minimize the impact of non-native species is an urgent task to build a "Beautiful China", which has been a main concept of governance in China since 2012. We urge academia, the Government and stakeholders to work together to develop more acceptable and moderate transformation strategies for aquaculture, in combination with more practical management strategies to mitigate the risk posed by non-native species associated with aquaculture.

Authors' contribution

HW, SL and DG – research conceptualization, data collection, funding provision and writing – original draft; MX, MF, FY, LS, XW – data collection and writing – review and editing.

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Supplementary material

The following supplementary material is available for this article:

Table S1. The references for the records of non-native aquaculture fish in China.

This material is available as part of online article from:
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