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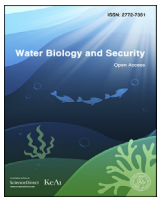

Research Article

Spatial distribution and introduction pathways of non-native freshwater fish species in China

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ABSTRACT

Non-native freshwater fish species are regarded as a key factor responsible for the degradation of freshwater ecosystems. Although research on China's non-native freshwater fish species has been conducted at the national scale, the spatial distribution and introduction pathways of these species in China remain unclear. To address this knowledge gap, this study compiled a dataset of non-native freshwater fish species across administrative regions in China. We first assessed the number of non-native freshwater fish species by taxonomy, geographical origin, introduction pathway, and province. There were 177 non-native freshwater fish species, belonging to 17 orders, 48 families, and 118 genera. The orders Cypriniformes (33.3%), Perciformes (28.2%), Siluriformes (10.2%), and Salmoniformes (6.2%) accounted for the largest proportion of non-native freshwater fish species. Eighty-nine non-native species were introduced from other countries or regions, mostly from North America (31 species; 34.8%), Asia (20 species; 22.5%), Africa (13 species; 14.6%), Europe (11 species; 12.4%), and South America (10 species; 11.2%). Aquaculture was the most common introduction pathway. Non-native freshwater fish species were more widely distributed in southwest China. Our study showed that there were obvious differences in the number and composition of non-native freshwater fish species across various provinces in China. The variation in the number of non-native freshwater fish species across provinces in China was attributed to distinct geographical features, development of the aquaculture industry, and efforts to study non-native freshwater fish species. Therefore, comprehensive surveys and studies of non-native freshwater fish species are needed, which are of great importance for the management and control of non-native species invasions.

1. Introduction

Biological invasion is the phenomenon related to the intentional and unintentional introductions of numerous species to new areas by human activities, the successful establishment and proliferation of non-native species under new environments (Blackburn et al., 2011). Biological invasions are widely regarded as a substantial threat to the diversity of native species and ecosystems, leading to serious ecological and economic losses on a global scale (Mack et al., 2000; Pyšek et al., 2020; Diagne et al., 2021). Biological invasions are a global issue and are widespread throughout terrestrial, freshwater, and marine ecosystems (Mačić et al., 2018; Vantarová et al., 2023). Freshwater ecosystems are the most affected by biological invasions (Gallardo et al., 2016; Reid et al., 2019). Previous studies have demonstrated that non-native species are widespread in freshwater ecosystems (Strayer, 2010). Fish are the main group of introduced species in freshwater ecosystems, and non-native freshwater fish species are regarded as a key factor in the degradation of freshwater ecosystems (Clavero and García-Berthou, 2005; Vitule et al., 2009; Gozlan et al., 2010). Therefore, it is crucial to study the status of non-native freshwater fish species.

China, the third largest country in the world with expansive land and diverse ecosystems, grapples with substantial challenges posed by biological invasions, and economic globalization and trade have increased the impact of these invasions on China (Lin et al., 2015; Xiong et al.,

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2015; Du et al., 2022; Liu et al., 2022). As the world's largest producer and exporter of aquatic products, China has introduced many non-native freshwater fish species through aquaculture and the aquarium trade (Cao et al., 2015; Xiong et al., 2015). However, many non-native freshwater fish species escape (through multiple pathways), establishing wild populations, and competing with native fishes, posing a decline in native species diversity (Xie and Chen, 1999; Hulme, 2015). Previous studies have compiled a comprehensive list of non-native fish species in China, sorted the species composition and distribution patterns of non-native fishes at the watershed scale, and summarized the status and impacts of non-native fish invasions for only one province (Xiong et al., 2015; Wei et al., 2017; Gu et al., 2019, 2020; Liu et al., 2021). Geographical distribution and introduction pathways are critical information for compiling a non-native species list at the provincial scale (Bernery et al., 2022, 2024; Arianoutsou et al., 2023; Xu et al., 2024). However, there is a lack of detailed studies on non-native freshwater fish species at the provincial scale. This gap hinders the investigation of invasion of non-native aquatic organisms in the country and the development of effective prevention and management strategies for non-native freshwater fish species. Therefore, investigating the spatial distribution of non-native freshwater fish species across various provinces in China is a crucial step for effective management of biological invasions.

This study compiled and assessed distribution data related to non-native freshwater fish species in China. The objectives of this study were: (1) to compile comprehensive information on the spatial distribution of non-native freshwater fish species in China, (2) to summarize their classification information and geographical origin, and (3) to characterize the introduction pathways and proportions of non-native freshwater fish species. This study serves as a valuable reference and data source for related research by elucidating the spatial distribution and introduction pathways of non-native freshwater fish species in China. Additionally, this study provides suggestions on the management, prevention, and control of invasions of non-native freshwater fish species in China.

2. Materials and methods

2.1. Classification and definition

We defined freshwater species as those that live in or migrate to freshwater for most of their life history (excluding marine and amphidromous fish families), in accordance with previous studies (Leroy et al., 2019). Previous studies have defined non-native species as those introduced to areas beyond their native range (Kolar and Lodge, 2001; Guo and Ricklefs, 2010). This study mainly focuses on non-native freshwater fish species, which are divided into two groups: (1) alien species introduced from other countries, and (2) translocated species introduced from regions within China.

2.2. Data collection

We conducted a literature search using a combination of the keywords "invade OR alien" and "China OR fish" in the title, abstract, and keywords. The search was performed on the Web of Science (WoS) and Chinese National Knowledge Infrastructure (CNKI). These keywords primarily identified published Chinese and English literature including Hong Kong, Macao, and Taiwan up to 2022. After identifying literature based on keywords, individual articles were filtered for relevance. The abstract was first reviewed for relevance, followed by the main text. For each article, the following information was recorded: (1) Species name: correct the Latin name according to the species name in the literature; (2) Province: confirm the province of the sampling site or the study area; (3) Introduction pathways: assign an introduction pathway as one of aquaculture, aquarium, biological control, or unintentional; (4) Species group: evaluate whether an alien species or translocated species; (5) Taxonomic information: add the information of class, order, family, and genus based on FishBase (http://www.fishbase.cn/search.php); (6) Geographical origin: classify the geographical origin of non-native freshwater fish species based on FishBase (http://www.fishbase.cn/search.php). Further information on China's freshwater fish species and the world's non-native freshwater fish species can be found in the following literature (He et al., 2020; Su et al., 2021).

2.3. Data analysis

We estimated the number of non-native freshwater fish species based on taxonomy, native continent, introduction pathway, and province. The number of native and non-native freshwater fish species in China and the world's non-native freshwater fish species in various fish orders were calculated (Table 1). We selected the six fish orders with the highest number of introduced species in China (Cypriniformes, Perciformes, Siluriformes, Salmoniformes, Osmeriformes, Cyprinodontiformes) and assessed differences in the proportion and number of non-native freshwater fish species between various orders in China and the world using the Pearson-Chi squared test in R 4.3.2 (MacFarland and Yates, 2016). We visualized the number and proportion of non-native freshwater fish species in China from various fish orders, native continents, and introduction pathways using the "ggplot2" package in R 4.3.2 (Wickham, 2009), and estimated differences in the number and proportion of non-native freshwater fish species. We also visualized the distribution of non-native freshwater fish species in various provinces of China using the Scientific and Research plot tool (SRplot) (Tang et al., 2023).

3. Results

3.1. Taxonomic statistics

There were a total of 177 non-native freshwater fish species reported in the wild, distributed in 118 genera, 48 families, and 17 orders. A total of 1651 species in 360 genera, 55 families, and 20 orders were identified as native freshwater fishes from the previous study (Table 1).

It is noteworthy that four orders: Cypriniformes (59 species), Perciformes (50 species), Siluriformes (18 species), and Salmoniformes (11

Table 1
Order composition of native and non-native freshwater fish species in China and the world's non-native freshwater fish species.

Order	China (Native)	China (Non-native)	China (A)	China (T)	World (Non-native)
Cypriniformes	1226	59	15	44	196
Perciformes	130	50	33	17	147
Siluriformes	199	18	13	5	42
Salmoniformes	22	11	8	3	32
Osmeriformes	6	9	2	7	9
Cyprinodontiformes	4	5	5	0	36
Acipenseriformes	8	4	2	2	8
Anguilliformes	5	3	2	1	1
Beloniformes	4	3	0	3	2
Characiformes	0	3	3	0	27
Pleuronectiformes	2	3	3	0	2
Lepisosteiformes	0	2	2	0	4
Osteoglossiformes	2	2	1	1	6
Synbranchiformes	10	2	0	2	2
Clupeiformes	5	1	0	1	8
Esociformes	2	1	0	1	7
Tetraodontiformes	7	1	0	1	0
Others	19	0	0	0	1
Total	1651	177	89	88	530

Note: China (Native) represents the number of native freshwater fish species in China; China (Non-native) represents the number of non-native freshwater fish species in China; China (A) represents the number of alien species in China; China (T) represents the number of translocated species in China; World (Non-native) represents the number of non-native freshwater fish species in the world.

species) stand out with more than ten species each, collectively representing over 75% of the total. Specifically, these orders account for 33.3%, 28.2%, 10.2%, and 6.2% of the total non-native freshwater fish species in China (Table 1). The remaining thirteen orders had relatively low fish species richness, each comprising fewer than ten species. Remarkably, three orders-Esociformes, Clupeiformes, and Tetraodontiformes-were each represented by only a single species within the documented non-native freshwater fish species in China (Table 1). Non-native freshwater fish species in China and the world showed variance in the number and proportion of fish orders ($\chi^2 = 18.08$, $p \leq 0.01$).

3.2. Geographical origin

The current study revealed that 88 non-native species were introduced from regions within China (translocated species), while 89 non-native species were introduced from other countries (alien species) (Table 1). In terms of geographical origin, there was an obvious difference in the number of non-native freshwater fish species originating from each continent. The highest number of non-native freshwater fish species originated from North America with 31 species (34.8%), followed by Asia with 20 species (22.5%), Africa with 13 species (14.6%), Europe with 11 species (12.4%), South America with 10 species (11.2%), and Oceania with 4 species (4.5%) (Fig. 1).

In China, non-native freshwater fish species native to different continents showed variations in fish orders. The non-native freshwater fish species introduced from other countries were mainly of four fish orders. Perciformes (33 species; 37.1%) constituted the predominant non-native freshwater fish species, followed by Cypriniformes (15 species; 16.9%), Siluriformes (13 species; 14.6%), and Salmoniformes (8 species; 9.0%), which collectively represented more than three-quarters of the total (Table 1). The other eight orders accounted for only a quarter of the total. There were many non-native freshwater fish species introduced from Asia, Europe, and the Americas, with more than three fish orders from each continent. The major non-native freshwater fish species introduced from Africa belonged to the orders Perciformes and Siluriformes. In contrast, only one fish order was introduced from Oceania (Fig. 1).

3.3. Introduction pathways

Non-native freshwater fish species were introduced into China through multiple pathways, including aquaculture, aquarium, biological control, and unintentional. Aquaculture (90 species; 50.8%) stood out as the main pathway for the introduction of non-native freshwater fish species, followed by unintentional (25 species; 14.1%), aquarium (15 species; 8.5%), and biological control (1 species; 0.6%) (Table 2). The results showed that unintentional introduction has become an important pathway, accounting for one quarter of the total introductions of non-native freshwater fish species.

3.4. Distribution status

The spatial distribution of non-native freshwater fish species in China was uneven (Fig. 2; Table 3). From a regional perspective, non-native freshwater fish species had a wide distribution in southwest China. Beyond Hubei Province, non-native freshwater fish species had a limited distribution in the central, northern, and eastern coastal areas. From a provincial perspective, there was an obvious difference in the number of non-native freshwater fish species in each province. Non-native freshwater fish species had a wide distribution in Yunnan (58 species) and Qinghai (42 species), followed by Hubei (40 species), and Xinjiang (36

Table 2
Species composition and proportion of non-native freshwater fish species across different introduction pathways in China.

Introduction pathways	Numbers	Proportion (%)
Aquaculture	90	50.8
Unintentional	25	14.1
Aquarium	15	8.5
Biological control	1	0.6
Unknown	46	26.0
Total	177	100.0

Note: Unknown represents non-native species with no information about the introduction pathway.

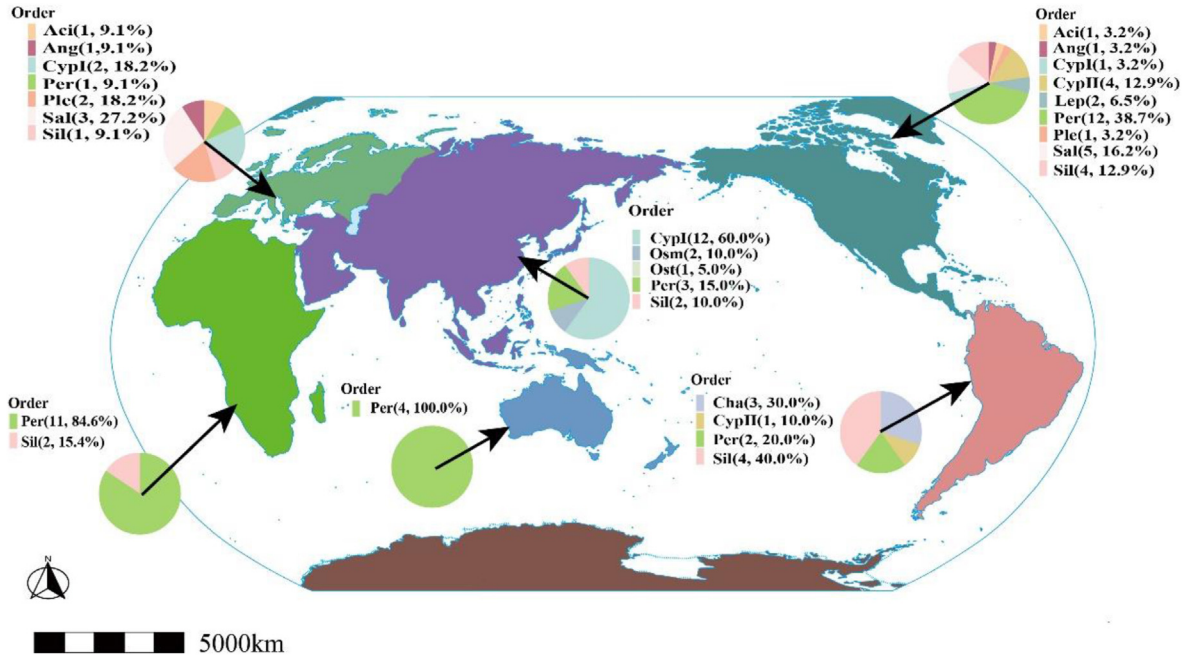

Fig. 1. Geographical origin of alien freshwater fish species into China. The pie plots in different continents indicate the composition of orders for alien species, while the number and percentage of species in each order are shown in parentheses after the order name (Aci: Acipenseriformes; Ang: Anguilliformes; Cha: Characiformes; CypI: Cypriniformes; CypII: Cyprinodontiformes; Lep: Lepisosteiformes; Osm: Osmeriformes; Ost: Osteoglossiformes; Per: Perciformes; Ple: Pleuronectiformes; Sal: Salmoniformes; Sil: Siluriformes) **Basemap source: GS (2016) 1567 No.**

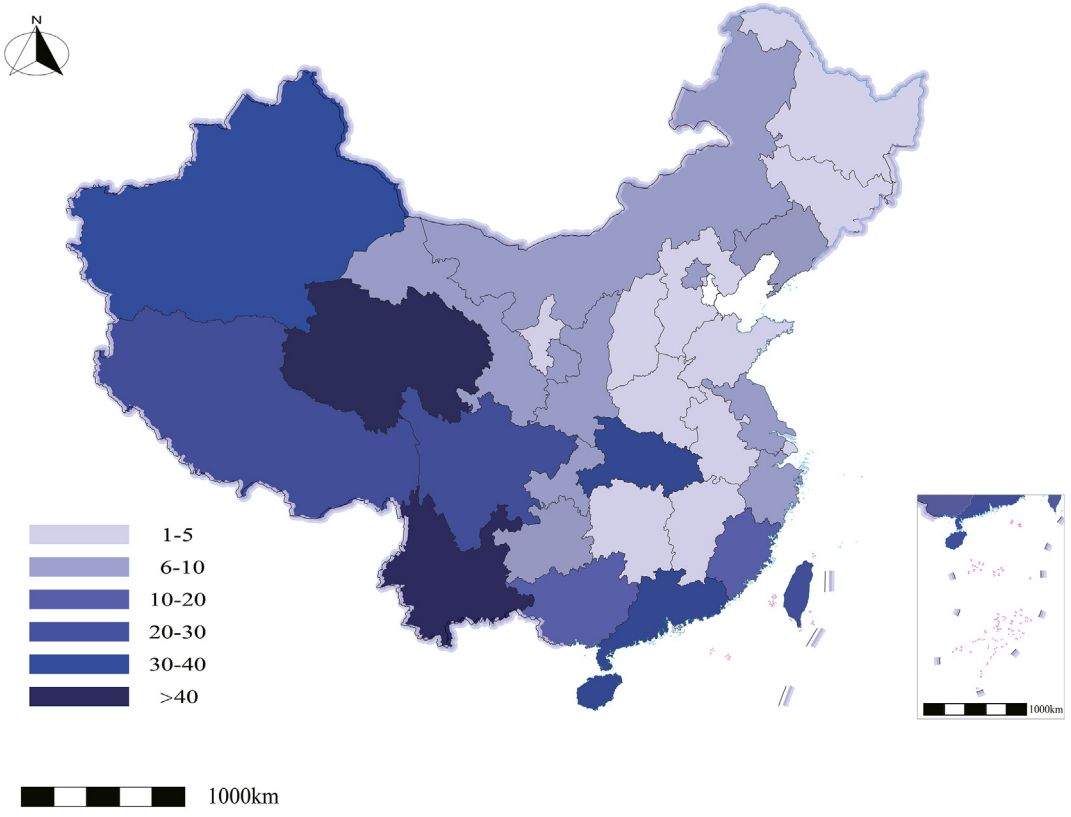

Fig. 2. Distribution of the number of introduced non-native species by province in China **Basemap source: GS (2022) 4316 No.**

species), followed by the southern coastal provinces (Hainan, 32 species; Guangdong, 30 species; Taiwan, 21 species; Guangxi, 19 species; Fujian, 16 species), Sichuan (21 species), and Xizang (20 species). Non-native freshwater fish species had a limited distribution in the other provinces (less than 20 species), though no data records were found in Tianjin and Macao (Fig. 2; Table 3).

The composition of non-native freshwater fish species among orders, introduction pathways, and provinces was markedly inconsistent (Fig. 3). Almost all fish orders were introduced to China through aquaculture. Fish species introduced through aquarium and biological control were mainly concentrated in a few relatively large fish orders. The number of unintentionally introduced species lies between aquaculture and aquarium became the second largest introduction pathway after aquaculture (Fig. 3; Table 3).

The introduction pathways of many non-native species introduced to various provinces in China were unclear, and non-native freshwater fish species with no recorded introduction were present in several provinces (Table 3). Several provinces had no records of non-native freshwater fish species introduced through various pathways. Most of the recorded introduction pathways were found in provinces with abundant water resources or well-developed aquaculture industries. In contrast, other provinces had few records or insufficient data (Fig. 3; Table 3).

4. Discussion

4.1. Taxonomic statistics

Previous studies have shown that the introduction of non-native species reduces species richness and has serious impacts on native diversity (Alidoost Salimi et al., 2021). For example, Brazil is one of the countries with the highest diversity of freshwater fish species in the world, and the introduction of a large number of non-native freshwater fish species has caused serious ecological impacts (Agostinho et al., 2005; Vitule et al., 2012; Queiroz-Sousa et al., 2018; Rocha et al., 2023). Therefore, the study of non-native freshwater fish species is an important step for global ecological conservation (Bernery et al., 2022).

China's freshwater fish species exhibit a remarkable diversity, comprising 20 orders of freshwater fish, over 90% of these species are concentrated in Cypriniformes, Perciformes, Siluriformes, and Salmoniformes, with only 30 species being part of other orders (He et al., 2020). This is consistent with the orders of non-native freshwater fish species in the study (Table 1), suggesting that non-native freshwater fish species that are taxonomically similar to native species are more likely to be introduced in China (Xu et al., 2024). Geographical and climatic conditions of various regions are often regarded as key factors contributing to differences in freshwater fish species in various countries or regions (Griffiths et al., 2014; Griffiths, 2018). Situated in both the northern temperate zone and the tropics, China features a distinctive climate environment. This unique environment not only provides habitats for non-native freshwater fish species but also enhances the environmental adaptability and survival capabilities of these species. Freshwater fish species exhibit a high degree of endemism across different regions (Leroy et al., 2019). Therefore, specific geography is a major factor in the difference between China's non-native freshwater fish species and global freshwater fish species (Leroy et al., 2019).

Previous studies on the number of non-native freshwater fish species reported 439 species (Xiong et al., 2015), 506 species (Luo et al., 2019), 200 species (Xiang et al., 2021), and 111 species (Lin et al., 2015), respectively. This study included 177 species, differing from previous studies. Firstly, there are certain differences across study objectives. In this study, we focused on freshwater fish species only reported to be found in the natural environment, which is different from previous studies that included both species in the natural environment and those in captivity (e.g., aquarium store). Including species in captivity largely increased the number of non-native species. Secondly, there are differences in the study years considered. In the context of economic

Table 3
Species composition and differences in introduction pathways for non-native freshwater fish species across various provinces in China.

Province	Non-native	Non-native (A)	Non-native (T)	Non-native (pathways)	Difference
Yunnan	58	24	34	23	35
Qinghai	42	11	31	1	41
Hubei	40	31	9	29	11
Xinjiang	36	7	29	20	16
Hainan	32	27	5	25	7
Guangdong	30	25	5	25	5
Sichuan	21	12	9	10	11
Taiwan	21	19	2	8	13
Xizang	20	3	17	20	0
Guangxi	19	15	4	14	5
Fujian	16	12	4	7	9
Guizhou	10	5	5	10	0
Liaoning	10	6	4	0	10
Gansu	9	7	2	0	9
Jiangsu	7	4	3	3	4
Shaanxi	7	5	2	1	6
Zhejiang	7	6	1	6	1
Beijing	7	6	1	3	4
Chongqing	6	3	3	0	6
Inner Mongolia	6	1	5	0	6
Henan	5	4	1	0	5
Hunan	5	3	2	0	5
Shandong	5	4	1	0	5
Heilongjiang	4	3	1	4	0
Ningxia	4	3	1	0	4
Shanxi	4	3	1	0	4
Anhui	3	2	1	1	2
Hong Kong	3	2	1	2	1
Jiangxi	3	2	1	0	3
Hebei	1	1	0	1	0
Jilin	1	1	0	1	0
Shanghai	1	0	1	0	1
Macao	0	0	0	0	0
Tianjin	0	0	0	0	0

Note: Non-native represents the number of non-native freshwater fish species across various provinces (including species with no clear introduction pathways); Non-native (A) represents the number of alien species in China across various provinces; Non-native (T) represents the number of translocated species in China across various provinces; Non-native (pathways) represents the number of non-native freshwater fish species through different introduction pathways across various provinces (excluding species with no clear introduction pathways); Difference represents the difference between Non-native and Non-native (pathways).

globalization, there is an increasing number of trades between regions increasing the probability and number of non-native freshwater fish introduced each year. Finally, there are differences in the methods used to obtain information. For example, there are differences between the data obtained from the literature and the data obtained from databases. A previous study reported 147 species based on a comprehensive review of the literature (Liu et al., 2017).

4.2. Geographical origin

In fact, non-native species including plants and freshwater fish originate from all continents except Antarctica (Jiang et al., 2011; Xiong et al., 2015). Similarly, the current study demonstrates that non-native freshwater fish species originate from all continents. Previous studies have shown that international trade is an important factor in the introduction of non-native species, and the trade between China and other countries may have facilitated the shipment of non-native freshwater fish species into China (Essl et al., 2011; Seebens et al., 2015; Xiong et al., 2015; Pyšek et al., 2020). According to The State of World Fisheries and Aquaculture (2022), the trade of fisheries and aquaculture products occurs frequently between continents, with Asia accounting for a large proportion of imports and exports (FAO, 2022). As the largest trader of aquaculture products globally, China has had an influx of farmed fish from all continents (Cao et al., 2015; FAO, 2022).

Apart from international trade, differences in climate and species composition contribute to variations in the number of species native to each continent (Griffiths et al., 2014; Su et al., 2021, 2023). For instance, North America has the largest number of post-Pleistocene freshwater fish species of any temperate region in the world, and is located at a similar latitudinal range as China (Knouft and Page, 2011; Qian et al., 2021), which makes China and North America have many similarities in the composition of freshwater fish species and their natural environments (Su et al., 2021; Zhao et al., 2023). Consequently, North American fish species are more invasive and easier to introduce into China than species from other continents (Su et al., 2023).

4.3. Introduction pathways

Previous studies have demonstrated that non-native freshwater fish species are introduced from their countries or regions through aquaculture, aquarium trade, and biological control (Lin et al., 2015; Xiong et al., 2015; Kang et al., 2023). Firstly, aquaculture represents a key solution to the challenge of food supply in the context of climate change, with developing countries on all continents introducing non-native freshwater

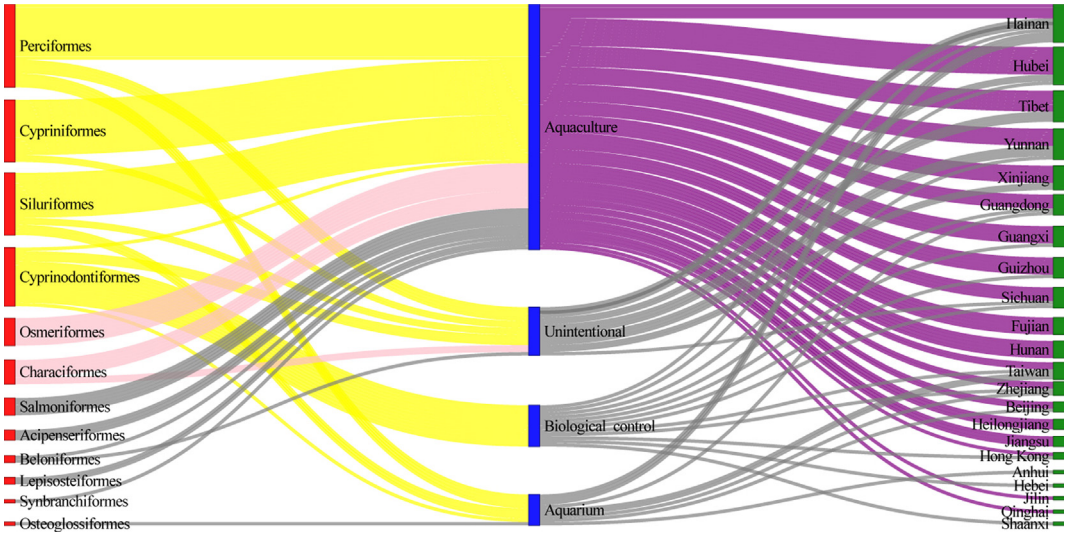

Fig. 3. Network showing the composition of non-native freshwater fish species in China among orders, introduction pathways, and provinces.

fish species to increase economic production (Naylor et al., 2000; Bush et al., 2013; Kang et al., 2017; Ju et al., 2020). Currently, over a quarter of China's aquaculture products originate from non-native species, and it will continue to increase in the future (Casal, 2006; Kang et al., 2023).

The aquarium trade is an important pathway for the introduction of non-native freshwater fish species. Many non-native freshwater fish species are introduced into China as ornamental fish, which promotes the development of ornamental fish (Novák et al., 2020; Wei et al., 2021). Currently, biological control is a limited applicable introduction pathways and many non-native freshwater fish species have not been introduced through this pathway (Gao et al., 2017; Cheng et al., 2018). In contrast, this study demonstrates that many species are introduced to China through unintentional introduction. The absence of adequate management systems has resulted in the unintentional introduction of many non-native freshwater fish species into natural water bodies, including escape and release (Xiong et al., 2015). Previous studies have demonstrated that the costs of species introduced unintentionally were higher than that of species introduced intentionally (Turbelin et al., 2022). Given the economic impacts outlined here, managing unintentional pathways should be a priority in future biosecurity efforts and this approach must adapt to the increasing trends in global shipping (Sardain et al., 2019).

In contrast to previous studies, aquaculture is the most common pathway of introduction (Xiong et al., 2015, 2017; Wang et al., 2016). Over the past three decades, aquaculture has emerged as one of the fastest-growing segments of the Chinese food economy (Zhong and Power, 1997; Wang et al., 2015). Many non-native species have been introduced with the objective of enhancing the cultivation of specific species and increasing the overall value of aquaculture in China (Lin et al., 2015).

4.4. Distribution status

Non-native freshwater fish species have a wide distribution and a high proportion of aquaculture production in south China, particularly in Guangxi, Guangdong, and Fujian (Xiong et al., 2015; Gu et al., 2018, 2022). The relatively warm climate conditions and intricate river systems in south China provide an optimal environment for the cultivation and introduction of non-native freshwater fish species, enabling their survival and spread in natural water bodies (Gu et al., 2019, 2020). For instance, Guangdong is a prominent aquaculture province endowed with abundant water resources, capable of ensuring comfortable temperatures for non-native freshwater fish species. Moreover, Guangdong's proximity to a seaport facilitates the import and export of non-native freshwater fish species, thereby creating an environment conducive to the introduction of non-native freshwater fish species (Wei et al., 2017, 2019). Guangxi, situated on the southern border of China, features diverse climatic conditions spanning three climate zones—northern tropical, southern subtropical, and central subtropical. With rivers in multiple basins, including the Pearl River and Yangtze River, Guangxi boasts the highest aquatic biodiversity globally. It is a hotspot and a major province for freshwater fisheries farming, which is a key factor contributing to the introduction of non-native freshwater fishes in this region (Zhang et al., 2019; He et al., 2022).

The current study shows that non-native freshwater fish species have a wide distribution in west China. For instance, Yunnan situated in southwest China, features 30 natural lakes, an average altitude exceeding 2000 m, a distinctive monsoon climate, and a high average annual temperature (15 °C) and precipitation (1000 mm). The favorable combination of complex geographical conditions and moisture conditions in Yunnan has enriched the number of non-native freshwater fish species (Ye et al., 2015). Xizang is severely affected by the global climate, and many non-native freshwater fish species have been introduced due to the vulnerability of the ecosystem to damage (Kang et al., 2010; Tao et al., 2015; Holt and Jørgensen, 2015). Altitude plays an important role in the introduction of non-native freshwater fish in plateau areas such as Xinjiang, Xizang, Qinghai, and Sichuan (He et al., 2017; Costa et al., 2018; Liu et al., 2021). For instance, temperatures at high altitudes tend to be cooler, providing an environment conducive to the survival and reproduction of cold-water fish species. Conversely, areas at higher altitudes may experience warmer subtropical or tropical climates, which are favorable for the growth of warm-water fish species.

In central China, Hubei is known as the "Province of a Thousand Lakes" due to its abundance of water resources. Surveys showed that consumer demands were extensive as their spending power increased, facilitated indirectly by the introduction of non-native freshwater fish species (Newton et al., 2021). Moreover, similar to Shandong in north China, Hubei is the primary province for the introduction of non-native freshwater fish species as it has several scientific research institutions focusing on freshwater fisheries, including Huazhong Agricultural University, Yangtze River Fisheries Research Institute of the Chinese Academy of Fishery Sciences, and the Institute of Hydrobiology of the Chinese Academy of Sciences (Kang et al., 2023). Conversely, the limited number of non-native freshwater fish species in other central provinces can be attributed to several factors. Firstly, aquaculture is mostly concentrated in coastal or water resource-rich provinces, the limited development of the aquaculture industry in these provinces may contribute to a lack of emphasis on research related to non-native freshwater fishes (Lv et al., 2017). Secondly, there may be limited surveys and studies conducted in these provinces, resulting in a dearth of data on non-native freshwater fish species. In northeast China, climatic and geographical features make it the survival of just a few non-native freshwater fish species, with sturgeon and salmon being the main introduced species (Kang et al., 2023). In contrast to non-native marine species, non-native freshwater species are mainly distributed in south China (Wu et al., 2010; Xu et al., 2012). However, the number of non-native freshwater fish species in the northern sea is lower than that in the southern sea (Fig. 2). This difference may be attributed to the fact that most marine fisheries research institutions are located in northern China, and non-native marine species are introduced to northern provinces for aquaculture (Lin et al., 2015; Xiong et al., 2017). The marine institutions prioritize studies on marine fish species rather than freshwater fish species, contributing to the limited number of non-native freshwater fish species (Kang et al., 2023).

5. Conclusions

Non-native freshwater fish species from various provinces in China show obvious differences in distribution status. Non-native freshwater fish species are widely distributed in western and southern China with the exception of Hubei. These differences can be attributed to several factors. Firstly, climate and geographical features play an important role in the distribution of non-native freshwater fish species in China. Secondly, the development of the aquaculture industry in various provinces is uneven. Finally, there are obvious differences across various provinces, leading to a lack of data on non-native freshwater fish species across provinces.

Based on this study, attention should be paid to increasing research on the distribution status of non-native freshwater fish species in various provinces, and establishing a more comprehensive distribution dataset of non-native freshwater fish species across various provinces in China. This is of great significance for the management and control of non-native species invasions.

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CRediT authorship contribution statement

Liuxin Qiao: Writing – original draft, Visualization, Resources, Formal analysis, Conceptualization. **Chunlong Liu:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Guohuan Su:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Yuning Zhang:** Writing – review & editing, Resources, Conceptualization. **Jiayuan Xie:** Writing – review & editing, Resources, Conceptualization. **Min Zhang:** Writing – review & editing, Methodology, Conceptualization. **Jun Xu:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Jun Xu is an editorial board member for *Water Biology and Security* and was not involved in the editorial review or the decision to publish this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.watbs.2024.100276.

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