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Research Article

A brief overview of known introductions of non-native marine and coastal species into China

Wen Xiong[1,2,*], Chunyan Shen[1,2], Zhongxin Wu[1,2], Huosheng Lu[1,2] and Yunrong Yan[1,2,*]

[1]*Faculty of Fisheries, Guangdong Ocean University, Zhanjiang 524088, China*
[2]*Center of South China Sea Fisheries Resources Monitoring and Assessment, Guangdong Ocean University, Zhanjiang 524088, China*
E-mail addresses: chinaxiongwen@gmail.com (WX), cyshen101@163.com (CS), wuzhongxin2007@126.com (ZW), luhs@gdou.edu.cn (HL), yanyr@gdou.edu.cn (YY)
**Corresponding author*

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Abstract

Non-native marine species have attracted a great deal of attention due to wide distribution and potential harmful impacts on ecosystems and economies. However, relatively little information exists about non-native marine species in China. This study provides an inventory of non-native marine and coastal species (213 species) reported to date in China (including the Bohai Sea, the Yellow Sea, the East China Sea, and the South China Sea). The main source regions were the Atlantic, Pacific, Indo-Pacific, and Indian Oceans (196 species in total, or 92.0% of species). Over one-third of non-native marine species (74 species) have established self-sustaining populations, and nearly half of the non-native species (93 species) caused negative ecological and economic impacts. The main introduction pathways of the known non-native species are ornamental trade (74 species, 34.7%), followed by aquaculture (69 species, 32.4%), shipping (65 species, 30.5%), and ecological restoration (5 species, 2.3%). The number of non-native marine species is higher in the northern sea than that in the southern sea of China. Non-native marine species have caused significant positive and negative impacts on China's environment and economy. Clearly, future studies need to focus on detecting and managing non-native marine species in China.

Key words: aquatic species introductions, aquaculture, China, invasive, biodiversity

Introduction

Biological invasions are recognized as serious threats to global species diversity and ecosystem function, causing great economic and environmental problems (Mack et al. 2000; Pimentel et al. 2005). Although the proportion of non-native marine species that have significant impacts is lower than that of freshwater species (Vilà et al. 2010), some invasive marine species cause very high economic loss and harm larger areas. Thus, non-native marine species are problematic for government managers and ecological researchers.

The eastern boundary of China is adjacent to the western Pacific Ocean. The entire coastline of China is measures over 32,000 km (including the coastlines of over 6000 islands). The Chinese seas cover an area of 4.73 million square kilometers. The Chinese coastline spans 38 degrees (3º–41ºN) latitude and covers three climate zones (temperate, subtropical, and tropical). There is a wide variety of marine and coastal habitats, including: estuaries, marine lagoons, mangroves, intertidal zone, coral reef, etc. Thus, non-native marine species may find suitable habitats for establishing feral populations once they are introduced to Chinese coastal waters. Earlier works have identified the many of the non-native fresh-water fish and aquatic plant species in China (Xiong et al. 2015; Wang et al. 2016); however, information on the identity and status of non-native species in China's marine and brackish water is rare.

Presently, China has become the world's largest producer, consumer, processor, and exporter of fisheries (in its broadest sense) products (Cao et al. 2015). Many non-native marine species (including fishes, molluscs, algae, crustaceans, ascidians, etc.) have been introduced into China's oceanic ecosystems for aquaculture (Lin et al. 2015). Meanwhile, along

with accelerated economic growth, a number of aquatic species were introduced to China for the ornamental trade (Mu et al. 2008; Xiong et al. 2015). Many non-native marine species have escaped and established feral populations throughout Chinese territorial seas and coastal habitats (Xu and Qiang 2011). Recently, researchers found that non-native aquatic organisms cause significant ecological and economic problems in China (Lin et al. 2005; Xu et al. 2006). Several non-native species, such as *Spartina anglica* C. E. Hubb and *S. alterniflora* Loisel, are highly invasive and have caused significant negative impacts on native biodiversity (An et al. 2007; Li et al. 2009). Consequently, policymakers and researchers need to become better informed about non-native marine species currently present in China.

In this study, the goals were: (1) to create an inventory of non-native marine species in China; (2) to summarize basic taxonomy, origins, and distribution status; (3) to identify the pathway of introduction, and (4) to briefly describe potential impacts of establishment on the marine ecosystems and fisheries.

Material and methods

For many years, the negative impacts of non-native aquatic species have received little attention from the government and the scientific community in China (Xiong et al. 2015). Hence, a national monitoring network for non-native aquatic species is currently nonexistent. In China, the definitions of "non-native" and "invasive" are often confusing (Xiong et al. 2015; Wang et al. 2016). In this study, we just attempted to compile a list of all species of non-native origin that have ever been recorded in Chinese marine and coastal environments, whether they established or not. In this study, an inventory of non-native marine species was developed from various sources, including: published literature, institutional reports (grey literature), and field and market investigations. We searched for literature that included the following words: "alien" or "exotic" or "invas*" or "non-native" or "non-indigenous" and "marin*" or "aquatic" or "coast*" in the title, abstract, or keywords from the Thomson institute for scientific information (ISI, http://www.isiknowledge.com) and CNKI (http://www.cnki.net). An inventory of the non-native marine species in China was created from the collected data (Supplementary material Table S1). For each non-native species, we documented its native range, year of introduction, pathway, status, distribution, and potential ecological impacts. Traditionally, the Chinese sea territory is divided in four parts: the Bohai Sea, Yellow Sea, East China Sea, and South China Sea. The Bohai Sea lies between the Liaodong and Shandong peninsula, enclosed by the North China plain, and is bordered by the provinces of Liaoning, Hebei, Tianjin and Shandong. The Yellow Sea is lies between the North Jiangsu Plain and Shandong Peninsula on the western side, and is bordered by the provinces of Shandong, Jiangsu, and Zhejiang. The East China Sea lies between the Korea Peninsula, Japan, and the Ryukyu Islands, and is bordered by the provinces of Zhejiang, Shanghai, and Fujian. The South China Sea connects with the East China Sea, Pacific Ocean, Sulu Sea, Java Sea, and Indian Ocean (Figure 1). The Latin names of the non-native marine species were used as found in the WoRMS (http://www.marinespecies.org). Species that live predominantly in freshwater were omitted, so some well-known invasive species are excluded from this study (e.g., *Oreochromis niloticus* (Linnaeus, 1758) occurred in some mangroves).

Results

At least 213 non-native marine species belonging to 52 orders, 89 families and 133 genera were found in China (Table S1). Actinopterygii is the class with the highest number of non-native marine species (113 species) in China, followed by Bacillariophyceae with 22 species, and Dinophyceae with 21 species. All other classes were represented by less than 10 species.

The vast majority of non-native species originated from the Atlantic Ocean (86 species, 40.3%), followed by the Pacific Ocean (62 species, 29.1%), Indo-Pacific Ocean (33 species, 15.5%), and Indian Ocean (15 species, 7.0%) (Table S1 and Figure 2). Each of the other origins (Mediterranean, unknown, Baltic Sea, Black Sea, and Arctic) were represented by less than 10 species (Figure 2).

The main pathways of non-native marine species introduction to China were ornamental trade (74 species, 34.7%), followed by aquaculture (69 species, 32.4%), shipping (65 species, 30.5%) and ecological restoration (5 species, 2.3%) (Table S1).

Consistent with similar studies (e.g. Wang et al. 2016), it was difficult to determine the precise date of introduction for each non-native marine species. Nearly all reports of introduced species were reported from the 1970s and onwards (Figure 3). The 1990s was the decade having the most reports of non-native species with a slight decline observed for the 2000s.

The status of most non-native marine species is uncertain. About one-third of non-native marine species (74) introduced into China have established feral populations. The Yellow Sea had the highest number of non-native marine species (86 species),

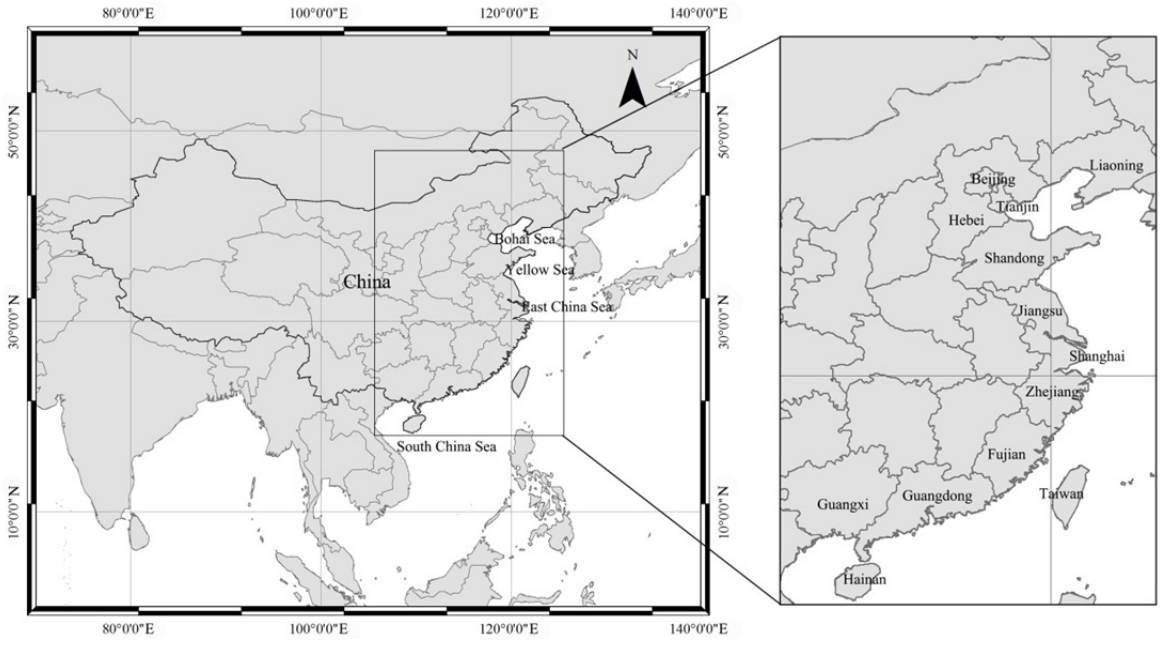

Figure 1. Map of China showing the territorial seas.

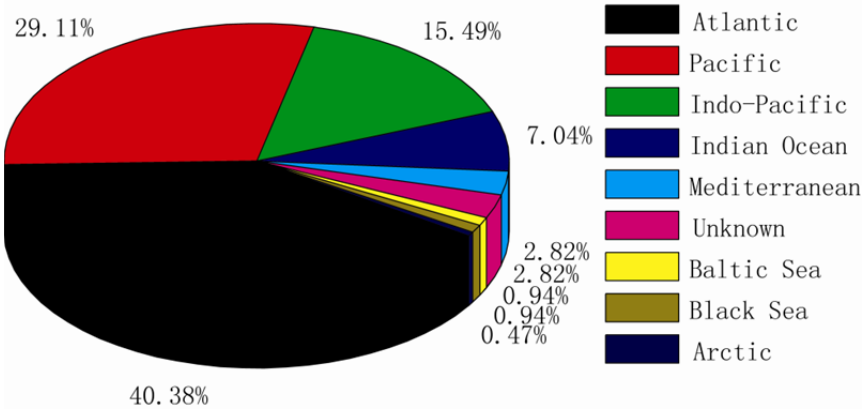

Figure 2. Origin regions of non-native marine species occurring on Chinese coastal waters.

followed by the Bohai Sea (72 species), the East China Sea (57 species), and the South China Sea (36 species). There are 93 non-native marine species that have shown negative impacts on China's marine ecosystems (Table S1).

Discussion

A total of 213 non-native marine species have been recognized as occurring in China (Table S1), by the end of 2016. And the number of non-native marine species in China could increase quickly (Lin et al. 2015) with additional field surveys designed to determine species composition of coastal ecosystems. China is one of the biodiversity hotspots in marine and brackish waters, with more than 22,629 known species (Liu 2013). Many studies have shown that non-native marine species have caused significant negative impacts on native biodiversity and economic development in other countries and regions (Bax et al. 2003; Molnar et al. 2008). Hence, there is an urgent need to address issue of non-native marine species and their effects of ecosystem structure and function in China.

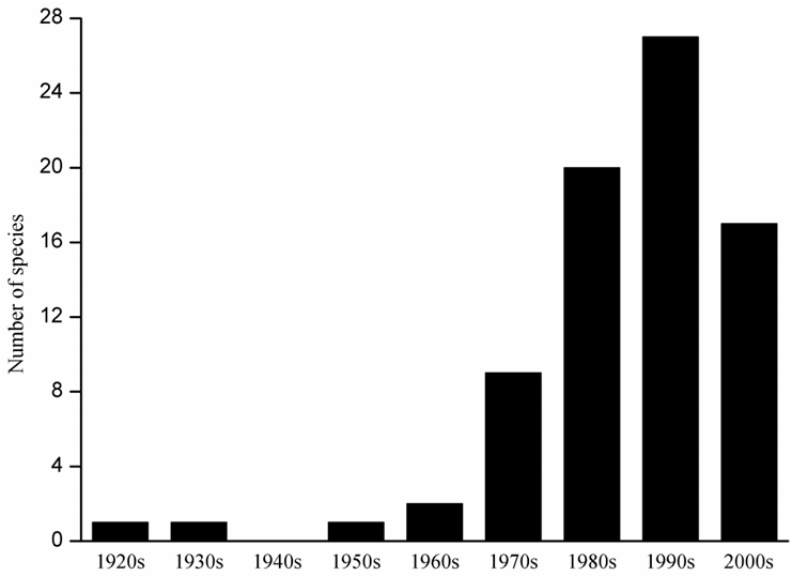

Figure 3. Decadal pattern in number of reports of non-native marine species introductions into China

Most non-native marine species in Chinese waters were introduced from Atlantic, Pacific, Indo-Pacific and Indian Oceans. This is mainly due to the fact that the countries (or regions) of main aquaculture and aquarium trade with China are adjacent to these three oceans. As one of the countries with the highest volume of international trade, China imported a large number of non-native marine species for aquaculture and ornamental purposes for many years. Russia, the United States of America, Peru, the Association of Southeast Asian Nations (ASEAN), Chile, Norway, Canada, New Zealand, the European Union (EU), and Japan are the top ten countries (or regions) that export aquaculture products to China (Xiong et al. 2015). Inevitably, some hitchhikers will accompany or mix with the live product. Thus, in all likelihood, more non-native marine species will be introduced into China in the foreseeable future (Wang et al. 2016).

Similar to the introduction of non-native freshwater species in China, the ornamental trade is the most common pathway of introduction (Xiong et al. 2015; Wang et al. 2016). After the year 2000, an increasing number of aquarium species (including fishes, shrimps, algae, crustaceans, aquatic plants, etc) were introduced in China. Currently, many large aquarium markets are located in the larger cities of China and escapees or intentional releases are inevitable. It has been found that a number of new non-native species are introduced in China on a daily basis (Wang et al. 2016). Thus, ornamental trade is expected to remain the main conduit for the introduction of non-native marine species in the foreseeable future.

Aquaculture is another frequent pathway for non-native marine species introductions (Naylor et al. 2001; De Silva et al. 2006; Grosholz et al. 2015). In the past two decades, aquaculture (marine and freshwater) has been one of the fastest-growing segments of the Chinese food economy (Zhong and Power 1997; Wang et al. 2015). Many non-native species were introduced for the purpose of improving the cultivation of species and the value of aquaculture in China (Lin et al. 2015). At first, some non-native marine species of high production and fast growth were introduced, such as the algae *Saccharina longissima* (Miyabe) C.E. Lane, C. Mayes, Druehl and G.W. Saunders, 2006 and *Macrocystis pyrifera* (Linnaeus) C. Agardh, 1820. Recently, with the accelerated economic growth in China, more non-native marine species with high economic value, such as the pufferfish *Takifugu rubripes* (Temminck and Schlegel, 1850) were introduced for the luxury food market.

Ballast water is one of the principal sources of non-native species in coastal and marine ecosystems (Drake and Lodge 2004). Today, China has the second largest economy in the world. Every year, hundreds of thousands of vessels frequently travel between China and other countries and regions. Many non-native marine species were inevitably introduced in China with ballast water (Chu et al. 1997). China currently lacks a ballast-water control protocol; therefore, additional introductions via this route are to be expected.

Finally, a few angiosperm species (four *Spartina* species and *Sonneratia apetala* Buch.-Ham.) were introduced to China for coastal wetland restoration (An et al. 2007). Some of these wetland-restoration

species have spread widely throughout several regions and have established feral populations (Ren et al. 2009; Wan et al. 2009).

For marine invasive species, one of the main differences between China and other countries is the intention of introduction. The introductions are mainly intentional (ornamental trade and aquaculture) in China, while introduction is mainly unintentional (shipping, fouling, etc) in other countries. The difference in the introduction pathway is likely due to two causes: (1) Chinese government and ecologists have underestimated the harm of non-native marine species in ballast water. Few studies focused on non-native species in ballast water (Chu et al. 1997). It is surprising that there is no act for management ballast water in China even today. (2) China has long coast and high biodiversity; therefore, it is difficult to detect unintentional introductions. Thus, our study almost certainly underestimates the number of non-native species introduced unintentionally and more attention and monitoring is needed with regards to routes of unintentional introduction because, by definition, they are less predictable and more difficult to manage.

In contrast to terrestrial non-native species, which are mainly distributed in south China (Wu et al. 2010; Xu et al. 2012), the number of non-native marine species is higher in the northern sea than the southern sea (Table S1). The difference in the distribution pattern of non-native species could be because that most institutions of marine and fishery research are located in northern China (such as the Dalian Ocean University in the Liaoning Province; Institute of Oceanology, Yellow Sea Fisheries Research Institute, the First Institute of Oceanography, and Ocean University of China in the Shandong Province). These institutions in northern China introduced many non-native marine species into adjacent sea for aquaculture (Lin et al. 2015). Therefore, there are more non-native marine species distributed in the Bohai Sea and Yellow Sea than in the East China Sea and South China Sea. Recently, however, some research institutions have been introducing increasing numbers of non-native marine species for aquaculture or ornamental trade in south China (Xiong et al. 2015). Moreover, the climate of south China facilitates the success of most invasive aquatic species (Liu et al. 2005). Thus, the number of non-native marine species in the south China likely will increase quickly in the foreseeable future.

The impact and consequences of non-native marine species introduction is very complex. On the one hand, many non-native marine species have been widely used to improve the production and value of aquaculture in China (Lin et al. 2015). Currently, China is the world's largest producer of aquaculture products, accounting for more than 60% of the global production (Cao et al. 2015). In that respect, non-native species account for over 25% of the total production of Chinese aquaculture. This proportion is significantly higher than the overall global rate of non-native species aquaculture, which is about 17% (Shelton and Rothbgard 2006). Some non-native marine species have become the most important aquaculture species in China. In terms of production, spotted seatrout *Cynoscion nebulosus* (Cuvier, 1830), plaice (*Hippoglossus hippoglossus* (Linnaeus, 1758), *Hippoglossus stenolepis* (Schmidt, 1904), and *Verasper moseri* (Jordan and Gilbert, 1898)), flounders (*Paralichthys dentatus* (Linnaeus, 1766), *Paralichthys lethostigma* (Jordan and Gilbert, 1884), and *Scophthalmus maximus* (Linnaeus, 1758)), shrimps (*Penaeus stylirostris* (Stimpson, 1871), *Penaeus vannamei* (Boone, 1931), *Penaeus japonicus* (Spence Bate, 1888), and *Penaeus monodon* (Fabricius, 1798)), molluscs (*Haliotis laevigata* (Donovan, 1808), *Haliotis discus discus* (Reeve, 1846), *Haliotis gigantean* (Gmelin, 1791), *Haliotis rufescens* (Swainson, 1822), *Haliotis fulgens* (Philippi, 1845), *Crepidula onyx* (G.B. Sowerby I, 1824), *Pecten maximus* (Linnaeus, 1758), *Argopecten irradians* (Lamarck, 1819), *Mizuhopecten yessoensis* (Jay, 1857), *Crassostrea gigas* (Thunberg, 1793), *Crassostrea virginica* (Gmelin, 1791), *Mercenaria mercenaria* (Linnaeus, 1758), *Mytilopsis sallei* (Récluz, 1849), and *Panopea abrupta* (Conrad, 1849)), and kelp (*Saccharina japonica* ((J.E. Areschoug) C.E. Lane, C.Mayes, Druehl and G.W. Saunders, 2006), *Saccharina longissima* ((Miyabe) C.E. Lane, C. Mayes, Druehl and G.W. Saunders, 2006), *Macrocystis pyrifera* ((Linnaeus) C. Agardh, 1820), and *Kappaphycus striatus* (F. Schmitz) Doty ex P.C. Silva, 1996)) are six groups among the top 20 mariculture groups in China (China Fisheries Statistical Yearbook 2015). From the 1960s to 1970s, kelp farming was the most important segment of mariculture in China, which accounted for over 80% of the total Chinese production of mariculture. Therein, the production of three non-native species (*S. japonica*, *S. longissima*, and *U. pinnatifida*) accounted for over 70% of the total production of kelp in China. Currently, the cultivation of three non-native shrimps (*L. vannamei*, *P. monodon*, and *M. japonicus*) accounts for over 95% of the total production of shrimp mariculture in China (China Fisheries Statistical Yearbook 2015). Many non-native species have escaped from the seawater cultural fence and farm (Liang and Wang 2001; Zhao et al. 2006). As a result, these non-native marine species have established feral populations. Some species, such as eels (*Anguilla anguilla* (Linnaeus, 1758), *Anguilla rostrata* (Lesueur, 1817)), spotted seatrout

(*C. nebulosus*), red drum *Sciaenops ocellatus* (Linnaeus, 1766), and American shad *Alosa sapidissima* (Wilson, 1811), have become valuable marine fishing species in China (China Fisheries Statistical Yearbook 2015). In contemporary China, an increasing number of non-native marine species have become part of the important mariculture and marine fishing species in China.

On the other hand, many non-native marine species have caused significant negative impacts on the native biodiversity (Bax et al. 2003; Molnar et al. 2008; De Silva et al. 2009). Firstly, some native endemic species have decreased due to competition with (predation or herbivory by) non-native marine species. For example, some native species, such as *Phragmites australis* (Cav.) Trin. ex Steud., *Scirpus* × *mariqueter* Tang et Wang, hybrid. nov. and some mangrove species, were displaced by non-native species *Spartina alterniflora* Loisel. (Chen et al. 2005; Li et al. 2009). Secondly, some native species were infected by new parasites carried by non-native marine species. One example is the Lymphocystis virus (LCV), which is often discovered in the flatfish of Europe and America. Following the introduction of flatfish in China, this pathogen was found in the native Chinese grouper, and spread rapidly throughout some important culture regions of Shandong Province, China, which led to the death of more than 60% of native flounders (Qu et al. 1999). Thirdly, some non-native marine species bring about genetic pollution through hybridization with native species. For example, native mollusca (*Haliotis discus* (Reeve, 1846), *Chlamys farreri* (Jones and Preston, 1904)) hybridized with some non-native species, such as *H. rufescens*, *H. fulgens* and *M. yessoensis*. Up to this day, it is hard to find pure native species of *Haliotis discus* in Chinese seas (Lin et al. 2005). Finally, many non-native marine species caused harmful red or brown tides. Many chromista were introduced in China with ship travel and have caused increasing incidents of red tides in the China seas (Liang and Wang 2001; Lin et al. 2005).

In conclusion, providing a first inventory of non-native species within a region is a first step to promote management strategies for non-native species (Pyšek et al. 2004). This is the first study to catalogue known non-native marine species in China and fills a wide geographic gap of knowledge about East Asia (Molnar et al. 2008). China clearly contains a large number of non-native marine species. Although many non-native marine species are important species for aquaculture and ornamental trade in China, some non-native marine species have caused significant negative impacts on native biodiversity, causing a considerable amount of social and economic harm. Therefore, more research on detecting and assessing the ecological impacts of non-native marine species in China is urgently needed. It has become crucial to establish a national network for monitoring non-native marine species in China.

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Supplementary material

The following supplementary material is available for this article:

Table S1. A list of all non-native marine species currently known in China.

This material is available as part of online article from:
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