Study on the Invasion Mechanism of Alien Species through Ship Activities

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Abstract. This paper analyzes the harm of invasion of alien species caused by ship activities, and expounds the necessity and urgency of carrying out relevant research in China. This paper summarizes the research progress at home and abroad, analyzes the research defects, and proposes that the research on the invasion mechanism of alien species caused by ship activities in China should focus on solving the major scientific problems such as the process and evolution of the invasion disaster, the interaction between the invasion and the offshore ecological environment security. In addition, it is necessary to consider the different invasion stages of alien species, such as invasion-escape period, population establishment period, latent-lag period and spread-outbreak(disaster) period. Finally, the key technologies and implementation plans to solve major scientific problems are proposed. The results show that, the interpretation of the model is generally consistent with the actual situation. Through database construction and typical species experiments, the theoretical model of alien invasion mechanism introduced by ship activities is interpreted and proved.

1. Introduction
The invasion of alien species has become one of the four threats to the world's marine ecological environment. A large number of studies have shown that with the process of international trade and globalization, ship ballast water has become an important way and carrier for the invasion of alien species at sea[1]. The world exchanges about 12 billion tons of ballast water every year[2], and 7000 species of species survive in untreated ballast water every day[3]. According to the International Council for the Exploration of the Sea (ICES), 94% of the potentially harmful marine species are transmitted by ballast water[4]. Developed countries, such as Europe, America, Australia and Japan, have been harassed by the invasion disasters for many times[5]. China, as the largest developing country, has also suffered from the invasion disasters such as the red tide (HAB)[6].

IMO formulated the International Convention for the Control and Management of Ships Ballast Water and Sediments in 2004, which entered into force on September 8, 2017 and officially entered into force in China on January 22, 2019. The Convention requires that new ships (ships built on or after September 8, 2017) should meet the D-2 standard at the time of delivery and be equipped with ballast water treatment equipment. The Convention has made a phased arrangement in the implementation of standards for existing ships, which is required to be no later than September 8, 2024 at the latest.

China is the world's largest exporter and importer of ballast water, but at present, there is a lack of in-depth study on the invasion mechanism of marine alien species, especially those brought by ship
ballast water, which can not meet the requirements of our government departments for the prevention and control of ballast water alien species.

2. **Researches at home and abroad**

2.1 **Researches abroad**

In order to prevent the invasion of alien species in ballast water, the United States, Britain, Germany, Australia and other developed countries have invested a large amount of funds to support relevant research since the 1990s[7]. The United States Coast Guard, Naval Laboratory and other agencies continue to support research on the management techniques and rules of ballast water. In 2011, the German Federal Maritime and Hydro-logical Agency launched the project of “Effective new technologies for assessing compliance with ballast water management conventions” to study the technology of ship ballast water sampling and rapid analysis. Supported by “The national research and development program”, the Korean Institute of Shipping and Marine Engineering has developed a rapid biological detection technology and device for 10-50μm. At present, the U.S. Coast Guard, St. John's Innovation Center in Cambridge, Chelsea Property Group in Britain, BBE in Germany and other institutions are vigorously carrying out researches related to ballast water.

2.2 **Researches at home**

The invasion of foreign plankton through ballast water in China was first studied in Hong Kong[8]. In 1999, the ballast water of oceangoing ships was tested in mainland China, and microcystins were found to be positive, but no related algae was detected[9]. Since 2006, projects such as the national science and technology support plan of the Ministry of Science and Technology have supported ballast water research. The Ministry of Transport, the State Oceanic Administration and other departments have also initiated and carried out research on revision of the guidelines for the type approval of the ballast water convention, standards and specifications for the implementation of the ballast water convention, supervision and inspection of the port states of the ballast water convention, and investigation of the status quo of marine invasive species. In recent years, although many studies have been carried out in different areas, most of them are scattered and lack of sustainability. The researches on dinoflagellate and its sporangium are mainly focused on species composition and cell abundance. It is necessary to carry out experiments on its environmental adaptability, germination characteristics and population growth mechanism, so as to reveal the mechanism of its invasion disaster.

3. **On the major scientific problems to be solved**

3.1 **Invasion mechanism**

3.1.1 **Source of invasion.** The main reason for the invasion of alien species in China's offshore area is species transfer. Marine activities, bird migration, floating material, and off-site breeding can make species transfer happen in space, among which marine activities are the most common to cause biological invasion. According to statistics, 3000-4000 species of species are transferred through ballast water of ships every day. In recent years, different units in our country have done a lot of research on ballast water and ballast water sediment of international navigation ships, but no one studies it as a system, and most of them do not carry out a long-term continuous research. In this way, there is no perfect protection system to protect the ecological environment security of China's entry ports.

3.1.2 **Survival strategy for alien species through ship ballast water.** Before entering the ballast tank, ballast water will be filtered by a strainer, and most of the aquatic animals will be filtered. However, plankton, microorganisms, bacteria and even small fish, as well as eggs, larvae or spores of various
species, may enter ballast tanks. Most of the aquatic organisms entering the ballast tank can not bear the bad environment of no light, lack of oxygen and iron-rich environment in the ballast tank and die on the way. Yet a small number of aquatic species can survive when the ship arrives at the destination port, and its survival strategy is worthy of further study.

Take dinoflagellate as an example, which has caused red tide disaster. Many dinoflagellates can form cysts at a certain growth stage. Some dinoflagellates can also form two different types of cysts, such as temporary cysts and dormant cysts. The temporary cysts is a haploid cell formed in the bad environment. It can germinate as long as the environment is suitable. Dormant cysts is a diploid dormant zygote produced by sexual reproduction. Its germination must go through a compulsory dormancy period, otherwise it can not germinate even if the environment is suitable. Cysts plays an important role in the life of dinoflagellate, which is an important stage for dinoflagellate to survive adversity under adverse environmental conditions. It is of great significance for the conservation and continuation of population, but it can also trigger dinoflagellate red tide, which is also considered as one of the main sources of alien species. Most dinoflagellate cysts have resistant cell walls containing sporopollen analogues, which can be preserved in sediments at the bottom for a long time. When the environmental conditions are suitable, they can germinate into vegetative cells and release into water. Therefore, the environmental adaptability of invasive species in the process of invasion, the characteristics of sporangium germination and the mechanism of population growth during the outbreak of invasion disaster are the key revealing the mechanism of invasion disaster.

3.2 Evolution law and trend of invasion

Whether the invasive species enter a new area actively or passively, they will go through a series of processes to successfully establish the population and cause harm in this area. The process includes transferring from one area to another, a few individuals surviving in the new area, starting to reproduce and establish the population, forming the dominant population in the invasive area, spreading out, spreading in a large scale, forming a complex and multi link chain. The corresponding stages are called invasion-escape period, population establishment period, latent-lag period and spread-outbreak (disaster) period. Whether the invasion of alien species can be controlled successfully or not depends not only on the control technology and investment, but also on the stage of invasion when the control measures are taken.

The logistic curve equation proposed by Verhulst (1838), a biological mathematician, shows that the growth of biological population is characterized by a single peak curve, which specifically shows that the growth of biological population is slow at the beginning stage and explosive growth occurs when it exceeds the first turning point. With the increase of population level, the growth rate is forced to decline by environmental constraints. When it reaches the second turning point, its growth rate slows down again and reaches the saturation level after reaching the K point. In each stage of the spread of harmful species to other areas, the population growth rate is either fast or slow. After the incubation period, when the invasive biological population is found, it has a large scale, even has been very consolidated. It is very difficult to completely eradicate it, and the cost of management and control is very high.

3.3 The interaction between the process of invasion disaster and the safety of coastal ecological environment

Ship activities, especially the invasion of harmful alien species through ship ballast water, are extensive, covert and repetitive. With the global action to fight against the invasion of alien species, the species and quantity of alien species in ballast water of ships entering China's coastal waters have gradually declined. However, the invasion of alien species and the disasters caused by invasive species still have potential risks of marine environmental security, including weakening the community structure of marine ecosystem, reducing its biodiversity; changing the genetic diversity of marine ecosystem, reducing its genetic variability; affecting the stability of marine ecosystem, causing exogenous diseases; aggravating marine ecological disasters, etc.
4. Key technologies and implementation plans to be adopted to solve major scientific problems

In 2017, the national key research and development plan "marine environment security" special project, research and development of risk prevention and control technology and equipment for typical alien invasion disaster in offshore China, topic 1 “Research on the occurrence mechanism, ecological environment security impact and evolution trend of typical alien invasion disaster” (2017yfc1404601) proposed technical solutions in response to the above major scientific issues. The details are as follows.

4.1 Establishment of mechanism model

In the past, the study of alien invasion disaster only focused on the analysis of source term, process or consequence. This paper broke through their limitations and creatively put forward a theoretical model of disaster occurrence mechanism and evolution law, which included the invasion-escape period, population establishment period, latent-lag period and spread-outbreak period. See Figure 1.

4.2 Establishment of database

The database is established by carrying out the investigation and analysis of the long-term marine activities(port construction, loading and unloading of domestic and foreign cargo, ship route, loading and discharging of ballast water, generation and discharging of bilge sediment, implementation of ship anti-fouling bottom system, etc), the information of alien species carried by them and the invasion status of alien species(Environmental assessment, marine monitoring, investigation and cases of invasion disaster). The data mining model of typical invasive source terms is developed, and the temporal and spatial evolution database of invasive alien species in China's coastal waters is constructed based on GIS and existing data. In order to reveal the source, distribution, transmission route, colonization environment, diffusion mechanism and hazard status of the main invasive species, a statistical analysis method was established for the evolution laws of the characteristics of the invasion disaster and the suitable niche, the correlation between the invasion source term and the evolution of the disaster.

By using ArcGIS software, the data system of alien species invasion caused by ship activities in China's coastal waters is constructed. In other words, by integrating the data on main liner route activities, important ports at home and abroad, ballast water biological species, ballast water exchange area, ballast tank sedimentary species, fouling biological species as well as other possible alien species composition, alien species transmission, colonization and disaster conditions, etc., the basic database of offshore alien invasion in China is constructed. And through the secondary development of ArcGIS, we can realize the development and utilization of business such as economic loss caused by alien...
species invasion, alien species invasion early warning and environmental matching, etc. And we focus on the statistical analysis, query, graph number interaction and other functions of relevant data, so as to lay a foundation for the subsequent development of relevant policies and regulations on the prevention and control of offshore alien invasion in China.

![Figure 2. The structure of the basic database system of alien invasion in China's offshore based on ArcGIS software](image)

### 4.3 Study on the separation and germination mechanism of sporangia in ballast water and bilge sediment of ships

In the coastal areas of China, the typical invasive species from ballast water and bilge sediments of ships are selected to carry out physiological and ecological experiments such as interspecific competition, community succession process, sporangium germination mechanism and environmental adaptability. Combined with the previous experimental research results and the field observation and investigation of the port, the study reveals its environmental adaptation strategies, the niche characteristics of dominant species succession, nutrition supply, activity space, environmental adaptation conditions and scope in different adaptation stages to analyze the invasion mechanism and characteristics of typical species.

### 4.4 Construction of an analysis model for the impact of typical coastal ecological environment security

According to the different invasion stages of typical alien species in ship ballast water, this paper studies and analyzes the interaction between invasion disaster and coastal ecological environment security. By focusing on the changes of environmental conditions such as water eutrophication, biodiversity and ecosystem stability, this paper construct the analysis method and index system of interaction relationship. It try to reveal the impact of typical alien invasion disasters on marine ecological environment in important sea areas. This paper focuses on the analysis methods and models of interaction relationship from the aspects of water eutrophication and other environmental changes, biodiversity and ecosystem stability reduction.

### 5. Conclusion

The results show that, the interpretation of the model is generally consistent with the actual situation. The theoretical model of alien invasion mechanism introduced by ship activities is interpreted and proved, through carrying out the database construction of long-term series of ship activities in China's
coastal, the analysis of the characteristics of alien invasion disasters and the systematic experiment and observation analysis of typical invasive species.

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