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Promoting the restoration of China's marine ecology and the governance of marine disaster prevention and reduction

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Abstract

The oceans are a treasure trove of natural resources and an essential regulator of the global climate. Still, due to economic development and human activities in recent years, these ecosystems have suffered varying degrees of degradation, so the restoration of marine ecosystems is essential. At the same time, states should strengthen the synergy of marine disaster prevention and mitigation efforts and jointly defend against the impact of maritime disasters on human lives, property, and climate change. On June 28–29, 2023, the Forum on Restoration of Marine Ecological Environment Protection, Disaster Prevention, and Mitigation was held in Qingdao's West Coast New Area. The forum adopted a combination of "online and offline." Nearly 150 experts and scholars in marine-related environmental protection, disaster prevention, and mitigation from organizations, universities, and research institutes across multiple countries attended the event.

Keywords Marine ecosystems, Marine ecological restoration, Marine disaster prevention and mitigation, Global shared governance

Introduction

In December 2017, the UN General Assembly established the UN Decade of Marine Science for Sustainable Development (2021–2030) through its resolution 72/73 [1]. The UN General Assembly adopted the implementation plan for the decade in its resolution 75/239. The Ocean Decade aims to provide scientific solutions for global, regional, national, and local marine management by revolutionizing marine science [2]. Its goal is to halt the deterioration of the oceans and ensure that they continue to support sustainable development for mankind. The vision is to achieve 'the science we need for the ocean we want' [3–5].

In response to the initiative of the United Nations, on February 15, 2023, the Ministry of Natural Resources of China, the People's Government of Shandong Province, and the People's Government of Qingdao City jointly established the "Decade of Oceans" International Cooperation Center. On June 28, 2023, the 2023 East Asian Ocean Cooperation Platform Qingdao Forum, with the theme of "Ten Years of Oceans, Harmony, and Coexistence, opened in the West Coast New Area of Qingdao". More than 400 guests from over 30 countries and regions around the world discussed ocean cooperation plans and shared a vision for ocean development. Promoting the restoration of China's marine ecology and the governance of marine disaster prevention and reduction has become the central topic of the 2023 Qingdao Forum of the East Asian Ocean Cooperation Platform.

Marine ecological restoration and marine disaster prevention and reduction are complementary. The ocean is the natural environment for human survival, closely related to the fate of mankind as human

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beings, to survive, develop, and constantly improve marine resources. However, the development of marine resources has led to a series of environmental problems, including seawater eutrophication, decreased seawater power, reduced water self-purification ability, frequent marine disasters, declining coastal wetland areas, decreased ecosystem function, reduced natural shoreline, and significant shoreline damage [6–8].

Marine ecological restoration and marine disaster prevention and reduction are important components of marine environmental protection. The research on international marine ecological restoration began in the 1990s. During this period, marine ecological restoration mainly took the form of individual projects, focusing on typical marine ecosystems such as salt marshes, mangroves, seaweed, and coral reefs [9–11]. In the mid-to-late 1990s, developed countries began to formulate ecological restoration plans at the macro level, such as national strategic planning and regional planning. For example, the United States developed a national plan for coastal and estuarine habitat restoration in 2002, and in 2003–2004, it systematically compiled information on marine ecological restoration, for example, the "National Review of Coastal Habitat Restoration," the "Systematic Approach to Coastal Ecological Restoration," the "Scientific-Based Monitoring of Coastal Habitat Restoration," and so on [12–14].

In recent years, China's marine ecological environment has become increasingly serious; ecological protection and ecological restoration of the state attach great importance. Chinese marine ecological restoration began with mangrove plantations, algal bloom pollution control, artificial reef deployment, proliferation, and release. Following the promulgation of the "Outline of the National Marine Development Plan," coastal provinces, municipalities, and autonomous regions have also started to protect, restore, and restore typical marine habitats such as the Binhai wetland. At present, marine ecological restoration has also been listed as an important part of national ecological conservation and restoration, land and sea integrated development, and "Landscape Forest Lake Grass Sea" system protection and restoration [9, 15].

The research content of marine ecological restoration has changed from a unilateral study to a systematic study, which involves the monitoring and evaluation of ecological restoration, the methods and measures of ecological restoration, and the management of ecological restoration. Neckles et al. put forward a monitoring scheme suitable for any salt marsh ecological restoration project based on a series of main ecosystem structural parameters and a monitoring scheme of ecosystem function for individual restoration projects [16]. Nienhuis et al. summarized the results of ecological restoration in the Netherlands over the past 25 years [17]. Chapman et al. introduced the progress of coastal habitat restoration in the northern Gulf of Mexico [18]. Boesch introduced the scientific principles of ecosystem management in ecological restoration in the Chesapeake Bay and coastal Louisiana and put forward some suggestions on the application of ecosystem management in ecological restoration [19].

Of course, the research results of marine ecological restoration and marine disaster prevention and reduction are still few, and the practice is still groping. In recent years, faced with the deterioration of marine ecosystems and the frequent occurrence of marine disasters, China has been actively exploring the issues of promoting marine ecological restoration, disaster prevention, and mitigation in theory and practice.

Marine ecological restoration and marine disaster prevention and reduction are the subjects of international attention

The ocean has a remarkable capacity for self-purification. After entering the ocean, pollutants are constantly diffused, diluted, oxidized, reduced, and degraded by a combination of physical, chemical, biological, and geological processes. However, human consumption and production activities in the process of emissions of pollutants, by river transport or through atmospheric deposition, into the ocean, or as a result of human activities in the ocean (such as ship dumping, oil tanker accidents, and seabed mining) directly into the ocean, beyond the self-purification capacity of the ocean, will cause pollution in certain areas. Marine pollution has disrupted the balance of nature in the ocean, posing a constant threat to human health. Marine protection has received more and more attention.

International organizations such as the United Nations, the International Maritime Organization, and the United Nations Educational, Scientific, and Cultural Organization are dedicated to protecting the marine ecological environment, preventing and controlling marine disasters, and developing international conventions and agreements for marine ecological restoration and disaster prevention, see Table 1.

The concept, practice, and technology of marine ecological restoration

The marine ecosystem is part of the most valuable human resources, and more people depend on it along the coast. In particular, mangrove ecosystems, coral reef ecosystems, and seagrass-bed ecosystems are characterized by high biodiversity and productivity, provide spawning and breeding grounds for marine life, and protect the coasts from erosion by waves and hurricanes [33–35].

Table 1 International conventions and agreements related to marine ecological restoration and marine disaster prevention and reduction

No.	Voting approval time	Signing location	International convention name	Main content
1	May 12, 1954	London	International convention for the prevention of marine oil pollution [20]	Take measures to prevent seawater from being contaminated by oil discharged from ships
2	April 29, 1958	Geneva	Convention on fishing and conservation of the living resources of the high seas [21]	All countries have the right to allow their nationals to fish on the high seas and have a responsibility to take or cooperate with, necessary measures to conserve the living resources of the high seas
3	February 2, 1971	Ramsar, Iran	Convention on wetlands of international importance, especially as habitat for waterfowl [22]	Wetlands are an international resource; believing that a visionary national policy combined with coordinated international action can protect wetlands and their flora and fauna
4	November 16, 1972	Paris	Convention concerning the protection of the world cultural and natural heritage [23]	Establish a permanent and effective system based on modern scientific methods for the collective protection of cultural and natural heritage with outstanding universal value
5	December 29, 1972	London; Mexico City; Moscow and Washington	Convention on the prevention of marine pollution by dumping of waste and other matter [24]	The convention controls any intentional dumping of waste and other substances at sea from ships, aircraft, platforms, or other artificial structures at sea, and any intentional abandonment of ships, aircraft, platforms, or other artificial structures at sea
6	March 3, 1973	Washington D.C	The convention on international trade in endangered species of wild fauna and flora [25]	Regulate rather than completely ban international trade in wild species, it is achieved through species classification and licensing to achieve sustainable utilization of the wild species market
7	November 2, 1973	London	The 1973 international convention for the prevention of pollution from ships, as amended by the 1978 protocol [20]	Eliminate the pollution of oil and other toxic and harmful substances from ships to the ocean, and minimize marine pollution caused by daily ship operations and maritime accidents
8	June 23, 1979	Bonn	Convention for the protection of migratory species of wild animals [26]	The objects protected by the convention are wildlife migratory species that pass through national borders or areas beyond national borders
9	September 19, 1979	Bern, Switzerland	The conservation of European wildlife and natural habitats [27]	Ensure the protection of wildlife species and their habitats. Pay special attention to endangered and vulnerable species
10	December 10, 1982	Jamaica	United Nations convention on the law of the sea [28]	Territorial waters, adjacent zones, exclusive economic zones, continental shelves, straits used for international navigation, archipelagic countries, island systems, closed or semi-closed seas, the rights and freedom of transit of landlocked countries to enter and leave the sea, international seabed and marine scientific research, protection and security of the marine environment, development and transfer of marine technology, and so on
11	June 4–14, 1992	Rio de Janeiro	United Nations framework convention on climate change [29]	Recognizing the global nature of climate change requires all countries to cooperate as widely as possible based on their common but differentiated responsibilities and respective capabilities, as well as their social and economic conditions, and to participate in effective and appropriate international response actions to protect the climate system for present and future generations
12	June 5, 1992	Rio de Janeiro	Convention on biological diversity [30]	The convention has three main objectives: protecting biodiversity; Sustainable utilization of components of biodiversity; and Sharing the benefits of genetic resources fairly and reasonably

Table 1 (continued)

No.	Voting approval time	Signing location	International convention name	Main content
13	November 2, 2001	Paris	Convention for the protection of underwater cultural heritage [31]	Underwater cultural heritage is an integral part of human cultural heritage, and all countries should take responsibility for protecting underwater cultural heritage
14	June 19 and 20, 2023	New York	Agreement on the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction under the United Nations convention on the law of the sea [32]	The agreement provides for activities related to marine genetic resources in areas beyond national jurisdiction, benefit sharing, and the establishment of zoning management tools, including marine protected areas

The concept of marine ecological restoration

Marine ecological restoration involves utilizing the natural self-repair capacity of ecosystems, along with appropriate artificial measures, to restore the original or similar structure and functional state [36]. The goal is to facilitate continuous recovery of the ecosystem's structure and function, with the assistance of the damaged ecosystem. Marine ecological restoration is the comprehensive application of engineering, technical, economic, administrative, and legal means to protect and repair the structure of damaged marine ecosystems. The goal is to enhance the protection capacity of the ecosystem, regional ecological patterns, and ecosystem service functions. This will ultimately lead to the sustainability of marine ecosystems in the face of long-term or sudden natural or anthropogenic disturbances [9, 15].

According to the degree of artificial disturbance, marine ecological restoration can be divided into three categories: natural ecological restoration, artificial ecological restoration, and ecological reconstruction. Ecological restoration can be achieved through natural or artificial means. Natural restoration involves eliminating pressure and reducing the speed of ecosystem degradation to allow for recovery [37, 38]. Artificial restoration involves combining the ecosystem self-repair with human intervention, such as physical, chemical, and biological measures, to promote recovery [39–41]. Ecological reconstruction is the process of rebuilding a completely degraded or lost ecosystem, including the creation of new ecosystems in areas where they are not present. Ecological restoration is the process of ecosystem self-recovery, development, and improvement. In ecological restoration, ecosystem structure and its community go from simple to complex, from single-function to multi-function. Ecological restoration is not a simple restoration of a species but a comprehensive and effective restoration of the structure, function, biodiversity, and sustainability of the ecosystem [42–44].

The fundamental principles of marine ecological restoration are as follows: first, the nature of marine ecological conservation and restoration is the adjustment of the 'human–sea' relationship. The aim is to maintain the integrity and resilience of the marine ecosystem, ensure its health, improve the comprehensive efficiency and benefits of marine protection and utilization, and ultimately achieve harmony between humans and the sea [45]. Second, marine ecological protection and restoration should not only focus on ecological space but also production and living space. Marine ecological problems mainly arise from the unreasonable exploitation and utilization of the marine and its adjacent land resources and space. Therefore, if the pattern and mode of production and living space use do not change, the protection and restoration of the affected ecological space will not achieve the expected results [46, 47]. Third, the means of marine ecological protection and restoration are comprehensive. To achieve the goal of protection and restoration, not only the implementation of specific technical measures but also strict management measures and the establishment of a reasonable system and operation mechanism are necessary [48].

China's practice in marine ecological restoration

Marine ecosystems can be divided into coastal zone ecosystems (supra-tidal zone, intertidal zone, and subtidal zone), island ecosystems, shallow sea ecosystems, open sea and ocean ecosystems, and polar marine ecosystems. At present, the international protection of marine ecosystems has covered all types, including coastal zones, islands, and shallow seas. Many international conventions and protected areas have also been established for the protection of marine and polar biodiversity and its biological resources. As a sovereign state, marine ecological protection and restoration are mainly carried out in coastal zones and islands, two types of ecological restoration [49–51].

Comprehensive improvement of the coastal environment

The integrated environmental rehabilitation of the coastal zone of the sea area includes the comprehensive rehabilitation and rehabilitation of key bays and estuaries, a list of national parks in China, adjacent sea areas of important tourist areas, and adjacent sea areas of large and medium-sized cities. From the practical effect, through the demolition of abandoned docks, waste removal, sea areas, and measures such as dredging, reclaiming beaches, retreating dike to sea, natural shoreline restoration, artificial shoreline renovation, offshore submerged dike construction, tidal dike construction, coastal promenade construction, beach renovation, geological relic landscape restoration, etc. China's coastal environment has improved [52, 53].

Island rehabilitation

Island rehabilitation includes island ecological environment rehabilitation, island infrastructure construction, and island protection for special purposes. From the practical results, through island restoration, vegetation planting, shoreline remediation, beach restoration, the surrounding sea area dredging, as well as the removal of aquaculture ponds, abandoned facilities, and other measures, a large number of ecologically and landscape-damaged islands have been repaired, improving the island's ecological environment. By the end of 2022, nearly 90 islands had been rehabilitated nationwide, playing a major role in building an ecological civilization on the

islands, developing their economy and society, and safeguarding state maritime rights and interests [54, 55].

Conservation and restoration of typical ecosystems

Typical ecosystem protection and restoration includes the protection and restoration of important coastal wetlands, coral reefs, mangroves, and seagrass beds. The restoration and reconstruction of Suaeda salsa, Phragmites Australis, and Manchurian willows can effectively improve the ecological environment of coastal wetlands [56–58].

Capacity building for ecological conservation and restoration

Capacity building for ecological conservation and restoration includes marine protected area capacity enhancement, capacity building for dynamic marine surveillance, construction of an island video monitoring system, and upgrading of the marine early warning system. By purchasing patrol and law enforcement equipment, ecological monitoring equipment, and constructing management and protection facilities, as well as marine biology species protection facilities, the management level of national nature reserves (marine parks) such as Longkou, Shandong Province, has been effectively raised. Additionally, the dynamic monitoring capability in grassroots marine areas has been strengthened through measures such as the construction of dynamic management facilities at the county level. It is possible to monitor the base point of the territorial sea and its surrounding sea area all year through the construction of a video monitoring system and other measures. Through the upgrading of the marine early warning system and other measures to enhance marine prediction and disaster reduction capacity in some areas [59, 60].

Integration of biotechnology and marine ecosystem restoration

One notable characteristic of bioremediation technology is the analysis of the structure and function of the aquaculture ecosystem from an ecological perspective. To establish a new model of the mariculture ecosystem, marriage, fish, shrimp, and shellfish are selected and optimized. To reduce the impact of aquaculture wastewater on the environment, improve economic output, and decrease disease incidence in the aquaculture system, it is necessary to effectively absorb and utilize excess nitrogen, phosphorus, and other nutrients present in the environment. At the same time, large-scale algae, shellfish, and other organisms can fix carbon, produce oxygen, regulate the pH value of the water body, and achieve the biological repair of the aquaculture environment and ecological regulation to achieve the unity of economic and environmental benefits. In practice, some of these technologies have been widely used in marine ecosystem restoration. These include the proliferation and release of important fishery resources, the bioremediation of aquaculture environments in shallow water, the bioremediation of biological resources in typical marine areas, and the restoration of marine ecosystems. They have also been utilized for protecting and restoring fishery resources in island waters, remediating marriage in eutrophication environments in shallow seas, and bioremediation typically constructed wetlands in tidal flats [61–63].

Jin Ling, a professor at Hong Kong Polytechnic University, has explored the use of species-specific cell lines to identify major toxic pollutants in marine habitats, expanding the thinking for habitat protection [64]. Chen Bin, the Deputy Director of the Third Institute of Oceanography of the Ministry of Natural Resources, aims to protect and restore the ecology of the coastal zone. This is achieved through marine ecological assessment and degradation diagnosis, priority area selection for protection and restoration, identification of marine ecological corridors, and the construction of a protected area network. This paper explains the key technologies and applications of coastal ecological protection and restoration planning [65].

Early warning and risk prevention for marine disaster prevention and reduction

Capacity building for marine disaster prevention and mitigation

Marine disasters are those that occur in marine or coastal areas as a result of the intensity of a particular marine process exceeding a certain limit or as a result of local anomalies in the marine natural environment, including storm surge disasters, wave disasters, sea ice disasters, tsunami disasters, red tide disasters, sea level rise, coastal erosion, and so on [66–68]. Large Chinese cities and densely populated areas are concentrated in coastal areas that are most vulnerable to marine disasters, so marine disasters account for a larger proportion of total Natural disasters in China and marine disasters seriously threaten the safety of people's lives and property in coastal areas and the development of social and economic construction.

The development of big data, cloud computing, and other technologies is of huge significance to the early-warning capacity building of marine disaster prevention and reduction. Cloud computing ocean big data analysis technology can provide an accurate and reliable scientific basis for storm surge warnings, red tide prediction, auxiliary decision-making, disaster prevention and reduction, and disaster inversion. In-memory cloud computing technology is an effective means of big data analysis. The Stanford University research team built the Memory

Cloud" E as the main platform for big data computing through large-scale common server memory clusters. In the face of the high-efficiency computing demand of ocean big data processing, memory clouds provide a new research direction for fast and real-time analysis of ocean big data [68–70].

Wang Juncheng, a Chinese Academy of Engineering academician and director of the National Marine Monitoring Equipment Engineering and Technology Research Center, said the development of marine environment observation and detection equipment in China plays an important role in marine environment prediction, disaster prevention and reduction, and marine safety. After nearly 20 years of development, China's marine environment observation and detection technology has met the country's basic observation and detection needs. China has established several major ocean observation networks, such as the National Ocean Data Buoy Network, the Marine Automatic Observation Station network, and the Marine Resources Survey network, which have preliminarily realized operational observation in China's offshore waters. In the future, stability and reliability will need to be continuously enhanced to achieve industrial applications [71].

Risk prevention for marine disaster prevention and mitigation

To prevent and reduce the loss of human life and property caused by marine disasters, the construction of three major projects should be strengthened in practice. Firstly, the strengthening and reinforcement of sea embankments should be carried out, and a combination of biological and engineering methods should be adopted to control coastal erosion and improve coastal moisture engineering [72, 73]. Secondly, the construction project of the ocean observation, forecasting, and early warning network system. To enhance our capabilities in marine disaster prevention and reduction, we will strengthen the construction of basic infrastructure and increase monitoring stations in key areas. We aim to achieve routine monitoring of various marine disasters. Additionally, we will utilize the 'Digital Ocean' platform to accelerate the development of a basic geographic information system for marine space. This will help us establish and improve a warning and defense decision-making system for marine meteorology, storm surges, strong winds, floods, and other marine disasters. We will also accelerate the construction of a three-dimensional monitoring and forecasting network system for the ocean to improve our ability to prevent and reduce disasters and respond to sudden maritime accidents [74, 75]. Thirdly, the construction project of the coastal protective forest system. To enhance the ability of the coastal front to resist natural disasters such as typhoons and storm surges, it is recommended to increase the construction of national special protected forest belts. These belts should be constructed within the range of 200 m on rocky slopes and mud banks and 500 m on sandy banks in coastal areas. Additionally, existing protective forest trunk belts should be supplemented and updated. It is also suggested to construct forest belts within the range of 200 m along the coast, especially the windward section, as protective forest belts [76–78].

In addition, the emergency management mechanism for marine disasters needs to be further improved. Corresponding coastal cities and marine management departments should establish and improve disaster emergency plans. Since the release of the National Emergency Response Plan for Public Emergencies in 2003, China has successively formulated and introduced a large number of emergency plans under its requirements. In 2005, the former State Oceanic Administration issued the "Emergency Plan for Storm Tide, Tsunami, and Sea Ice Disasters" and "Emergency Plan for Red Tide Disasters," specifically targeting specific marine disasters; the National Maritime Search and Rescue Emergency Plan issued in 2006; and in 2018, the National Emergency Response Plan for Major Offshore Oil Spills was issued. To further improve the scientific and operability of marine disaster response work, the Ministry of Natural Resources revised and formed the Marine Disaster Emergency Plan based on the Emergency Plan for Storm Tides, Waves, Tsunamis, and Sea Ice Disasters, which was promulgated and implemented on December 31, 2019. After the release of a series of national overall emergency plans for different types of marine disasters, coastal areas have developed emergency plans for marine disasters at the provincial, municipal, and county levels under the guidance of these plans. These plans include both local overall disaster emergency plans and emergency plans for marine disasters with local characteristics, such as the Qingdao Storm Tide and Tsunami Emergency Plan. The introduction of these plans has formed a complete system of marine disaster emergency plans, which has effectively guided local marine disaster prevention and reduction work and played a positive role in practice [79, 80].

Conclusion

The ocean is a treasure trove of natural resources, an essential regulator of global climate, and a strategic highland for high-quality development. The convening of the Subforum on Marine Ecological Environment Protection, Restoration, and Disaster Prevention and Reduction will provide technological support for building a different pattern of coordinated development, protecting marine

ecological resources, and promoting the development of the marine economy.

As one of the important sections of the 2023 East Asian Ocean Cooperation Platform Qingdao Forum, the Forum on Marine Ecological Environment Protection, Restoration, and Disaster Prevention and Reduction showcases the latest research achievements in China's marine ecological environment protection, restoration, and disaster prevention and reduction in recent years. It also explores the ecological system degradation and frequent occurrence of ecological disasters faced by the ocean under the pressure of human activities, climate change, and other factors. There are numerous issues, such as decreased biodiversity, as well as future development directions. This forum has established a professional academic exchange platform for marine scientists around the world, which will further deepen and expand international ocean research exchanges and cooperation.

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Author contributions
QW determined the thesis's basic framework, clarified the paper's basic ideas and central thoughts, and revised and reviewed the thesis. LH and XW collected and organized the literature, wrote the first draft of the thesis, made the preliminary layout of the thesis, unified, and standardized the literature format, etc. All authors contributed to the article and approved the submitted version.

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Data availability
The data that support the findings of this study are available on request from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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