

# Coastal Zone Ecological Restoration and Blue Carbon Ecosystem in China

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**Abstract.** Coastal zones as critical nodes in the global carbon cycle, the coordinated development of environmental restoration and blue carbon sequestration has become a key pathway for responding climate change. This paper provides a comprehensive review of research on ecological restoration technologies and blue carbon ecosystems in China's coastal zones. Restoration techniques cover physical restoration, chemical restoration, and biological restoration. Physical restoration includes sediment mixing and dredging operations, and the Fixation and Isolation of Pollutants, chemical restoration includes pollutant neutralization and decomposition, biological restoration includes microbial, plant, and animal restoration. Blue carbon ecosystem research is based on typical ecosystem such as mangroves, seagrass beds, and salt marshes, focusing on its current condition of degradation and restoration measures. Research indicates, deep integration of coastal zone ecological restoration and blue carbon conservation, by improving ecosystem environments and enhancing ecosystem carbon fixation efficiency, achieving a double benefit of pollution control and carbon sink enhancement.

## 1 Introduction

Under the dual challenges of intensifying global climate change and deteriorating ecological environments, carbon peaking and carbon neutrality have become key strategies for sustainable development. The total area of the oceans is 360 million square kilometers, covering 71% of the Earth's surface area. The ocean as the largest dynamic carbon stock on Earth, enable the absorption, storage, and release of carbon dioxide, is a stabilizer and buffer for climate change [1, 2], is also the largest carbon sink system on Earth. The coastal zone, as a key area for the interaction between the ocean and the land, is a crucial node in the global carbon cycle. With the development of society, some human activities and natural environmental factors have large impacts on the coastal zone's ecological environment, according to monitoring data, 80% of pollutants in China's coastal zones originate from land-based sources [3], this has led to increasingly severe problems such as intensified coastal environmental pollution and degradation of blue carbon ecosystem. It has weakened the ocean's carbon sink capacity, also exacerbated global warming.

Monitoring data shows that, over 400 marine areas worldwide have been designated aseologically dead zones, at the same time, nearly half of coastal ecosystem will face the

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threat of further degradation. On the one hand, coastal environmental pollution not only impacts the survival environment of marine organisms, also accumulates through the food chain, posing risks to human health, coastal zone environmental restoration is a prerequisite for restoring its carbon sink function. On the other hand, blue carbon ecosystem, represented by mangroves, seagrass beds, and salt marshes, although it accounts for only 0.2% of the total ocean area, but its carbon storage is more than 50% of the ocean, degradation of blue carbon ecosystem directly leads to carbon loss, therefore, protecting and restoring coastal blue carbon ecosystem plays a crucial role in enhancing marine carbon sink capacity and alleviating the impacts of climate change.

With the advancement of science, Coastal ecological restoration technologies are gradually developing toward diversification and refinement. Physical restoration by dredging sediment and isolating pollutants, and controlling the scope of pollution. Chemical restoration reduces the toxicity of pollutants through neutralization and decomposition. Biological restoration purifies coastal environments through the inherent properties of microbes, plants, and animals. At the same time, the restoration of blue carbon ecosystem is gradually transforming from a singular focus on enhancing carbon sequestration to restoring degraded areas and enhancing carbon sink capacity. Within this context, systematically review research in coastal zone ecological restoration, coastal zone ecological restoration technologies through physical, chemical, and biological techniques, effectively improved the coastal environment, and better response to climate change. Meanwhile blue carbon ecosystem, exemplified by mangroves, salt marshes, and seagrass beds, by analyzing its current state of degradation, and proposing corresponding solutions, and improving the environmental conditions of blue carbon ecosystem, enhance carbon sink capacity. Deep integration of coastal zone ecological restoration and blue carbon conservation, this facilitates the integration of multidisciplinary technologies and provides a scientific basis for coastal zone ecological restoration, achieve a double benefit of pollution control and carbon sink enhancement, ultimately promoting a high-quality transition of coastal ecosystem from environmental restoration to enhanced carbon sequestration.

## **2 Coastal zone ecological restoration technology**

### **2.1 Physical restoration technology**

#### *2.1.1 Sediment mixing and dredging operations*

Sediment mixing breaks up sediment layers by bottom dragging equipment such as trawls and agitators. Dredging operations transfer loosened sediments for disposal using suction or grab dredgers. Purifying water quality and improving the coastal environment. Depending on different operational requirements, dredging operations can be categorized into surface dredging and deep dredging. During dredging operations, real-time monitoring of water depth changes is required, especially during the shallower stages of the project. Construction vessels require precise positioning of shallow points and their depths [4]. Sediment mixing and dredging operations pose certain environmental risks, the agitation process may cause secondary pollution to the water body, destroy the habitat of marine life. Therefore, water quality must be monitored after the operation, prevent secondary ecological risks, environmental impact assessments must also be required before implementation, and make a reasonable plan, ensure that the restoration work achieves maximum effectiveness, while minimizing the impact on the environment.

### *2.1.2 Pollutant fixation and isolation*

The fixation technique by adding solidifying agents such as lime and cement, reacts with pollutants to form stable and insoluble compounds, and reduces the risk of its diffusion into water bodies. Isolation technology by using materials such as clay or geomembranes covers contaminated sediments and prevents pollutants from coming into contact with the water body. When laying geomembranes, based on the range of temperature changes and product requirements, allowance for thermal deformation caused by temperature changes [5]. Fixed and isolated installations pose some environmental risks; the stability of insoluble compounds formed by fixation techniques may decrease due to changes in the pH of the environment, and pollutants may be dissolved again. However, isolation technology may be due to the aging of the covering material, damage, and biological disturbance reducing effectiveness. Therefore, long-range monitoring of chemical factors in fixed areas is required; at the same time, anti-aging, high-strength composite materials are selected for isolation to ensure the lasting effectiveness of the project.

## **2.2 Chemical restoration technology**

### *2.2.1 Pollutant neutralization*

Neutralization technology utilizes calcium hydroxide to neutralize acidic wastewater, and sedimentation removes heavy metals. Adding sodium hydroxide neutralizes wastewater containing organic acids, while reducing its corrosiveness, it also creates conditions for subsequent biological treatment. For example, for wastewater containing high concentrations of acetic acid, adjusting the pH to neutral by adding sodium hydroxide, microbial activity can be enhanced in subsequent biological treatment, and more effectively degrading organic matter [6]. The drawback of this method includes the likely generation of large amounts of chemical mud, causing secondary pollution to water bodies, and unsuitable input quantities, will cause fluctuations in pH, affect the treatment results. Therefore, long-term monitoring of water body environmental conditions is required, ensure inputs are appropriate, at the same time, the generated mud is transferred for treatment, avoid transfer of environmental risks.

### *2.2.2 Pollutant decomposition*

Decomposition technology utilizes catalysts such as platinum and various metal oxides, under controlled conditions, accelerate the degradation of persistent organic pollutants in coastal waters, convert them into low-toxicity or readily decomposable molecules. The core of this technology is the design of highly efficient catalysts, the key is accurate control of conditions such as pressure, pH, and temperature. For example, increasing the temperature generally enhances catalytic efficiency, but excessively high temperatures can easily damage the catalyst structure, affect its stability, may lead to catalyst deactivation [7]. The limitation of this method is its application is constrained by the high cost of catalysts, prone to intoxication and inactivation, with strict reaction conditions, etc, therefore, need to develop affordable metal catalysts that are resistant to contamination and recyclable, at the same time, long-term monitoring of water body environmental conditions will be conducted, ensure the catalyst has maximum effectiveness.

## **2.3 Biological Restoration Technology**

### *2.3.1 Microbiological restoration*

Microbiological restoration utilizes microbial metabolism, bioadsorption, and biotransformation to break down pollutants such as oil and heavy metals in coastal waters. In petroleum bioremediation, its core is the utilization of genetic engineering to modify highly efficient bacteria, such as bacillus, enhancing its ability to degrade specific pollutants like polycyclic aromatic hydrocarbons (PAHs), and improving repair efficiency. Genetically modified bacillus spores can reduce PAH concentrations by more than 50% within 24 hours [8]. In heavy metal bioremediation, such as ferrosulfate bacillus, through bioadsorption and biotransformation, soluble heavy metals can be converted into insoluble compounds, reducing their toxicity. Although microbiological restoration is environmentally friendly and highly efficient, but it is easily constrained by environmental factors. Engineering-modified bacteria pose ecological safety risks, therefore, the environmental behavior of the bacteria need to be strictly evaluated and monitored, using physical isolation measures when necessary, ensure the repair process is safe and reliable.

### *2.3.2 Flora and fauna restoration*

Animal restoration utilizes benthic mollusks to accumulate heavy metal in coastal waters, and purify water quality. Typical mollusks such as purple mussels and scallops, this type of benthic mollusk, can efficiently accumulate multiple heavy metals in water bodies, it has strong accumulation capacity for heavy metals such as Cu, Zn, and Pb. Plant restoration removes and stabilizes environmental pollutants through plants and their root-associated microorganisms, it is particularly suitable for treating heavy metals and organic pollutants in coastal wetlands and other water margins [9]. Such as reeds, it can absorb heavy metals from water bodies through its extensive root system, such as lead and cadmium, and Purify water quality. Although plant and animal restoration is an environmentally friendly economic approach, it requires a long restoration cycle. The accumulation of heavy metals in plants and animals may be transmitted through the food chain, trigger ecological risks. Therefore, it is necessary to regularly process organisms that have accumulated pollutants, conduct long-term ecological monitoring of the restoration area, and ensure that no secondary pollution is caused.

## **3 Blue carbon ecosystem research**

### **3.1 Mangrove ecosystem**

#### *3.1.1 Degradation of mangrove ecosystems*

Over the past 50 years, global mangrove forests have been affected by massive destruction and degradation, its area has declined sharply. Due to the persistent impact of irrational human activities such as large-scale land reclamation and coastal development in the mid-to-late 20th century, compounded by insufficient public awareness of its ecological value, leading to the endangerment of mangrove resources and environmental degradation. According to the 2002 survey of China's mangrove resources, the area of mangrove forests has shrunk to 22,600 square kilometers, accumulated losses of nearly 50% [10].

### *3.1.2 Mangrove ecosystem restoration*

At the end of the 20th century, people have realized the importance of restoring mangrove forests, started protecting and restoring mangrove forests. Mangrove restoration includes measures such as species colony construction and planting-farming ecological coupling. Species colony construction is achieved through the artificial planting of mangrove tree species such as *avicennia marina* or *rhizophora mucronata*, expand mangrove forest area. Planting-farming ecological coupling through scientific water level regulation, plant mangroves on upland areas such as the pond base and pile island, building forest-fishery ecological coupling system. Liao Baowen et al. Found that, the petalless sea mulberry, due to its own growth advantages, will displace native tree species such as the paulownia tree [11]. For colony such as petalless sea mulberry and paulownia trees, etc, conduct pruning and pest cleaning treatments, conduct pruning and pest control treatments, ensure the effective restoration of mangrove ecosystem.

## **3.2 Seagrass bed ecosystem**

### *3.2.1 Degradation of seagrass bed ecosystems*

In recent years, seagrass beds have suffered extensive damage, and both the species and area are showing a downward trend. For example, Wenchang in Hainan, China, in 2018 and 2020, xiaoxi saltwort was not found in any of the surveyed areas in Chang'p Port, it may be due to its location at the entrance of multiple rivers flowing into the sea, coastal shrimp pond farming drainage, seriously affected seagrass growth. Compounded by the impacts of human activities such as marine engineering and ground source pollution, the construction of the Gaolong Bay artificial island has directly led to the disappearance of seagrass within hundreds of meters of the surrounding area [12].

### *3.2.2 Seagrass bed ecosystem restoration*

In the early 21st century, people have begun undertaking systematic conservation and restoration of degraded seagrass beds. Seagrass bed restoration includes habitat restoration and artificial restoration methods. Habitat restoration methods rely on natural forces, through measures such as protecting and improving habitats, promoting the natural reproduction of seagrass, low cost but long periods. Artificial restoration methods with the help of artificial seeding or transplanting plants, etc, promote the growth of seagrass, short periods but high cost. Zhang Zhuangzhi et al. Found that, seeds of *eupatorium fortunei* treated with vernalization at 4 °C for 50 days can achieve a germination rate of 55.3%, when planted at a depth of 0.5 to 2.5 centimeters, its seedling emergence rate is significantly higher than at depths of 3 to 4.5 centimeters [13], ensure effective restoration of seagrass bed ecosystem.

## **3.3 Salt marsh ecosystem**

### *3.3.1 Degradation of salt marsh ecosystems*

In recent years, coastal wetlands have suffered extensive damage, its area has sharply decreased. Since the mid-20th century, the total area of China's coastal wetlands has decreased more than 50%, ecological functions continue to weaken, the area of salt marsh vegetation has decreased 59% [14]. Due to people pursuing rapid economic development, massive encroachment on tidal flats and wetlands for the construction of farmland, towns,

and other infrastructure, resulting in reduced freshwater inputs upstream, the wetland area has also decreased accordingly, the wetland water ecosystem has become completely unbalanced.

### 3.3.2 Salt marsh ecosystem restoration

In recent years, people have begun undertaking restoration and conservation tasks in response to the degradation of salt marshes. Salt marsh restoration methods include plant restoration and microbial restoration. Plant restoration utilizes the purification functions inherent to plants, such as their ability to absorb and accumulate pollutants, restoration of wetland water bodies and soil, rebuild its healthy vegetation colonies and habitats. Microbial restoration utilizes the degradation capabilities of indigenous or engineered microbial colonies, break down toxic substances in soil into non-toxic substances. REZANIA S et al. Found that, reed vegetation can not only directly adsorb and purify organic pollutants and oils in oily wastewater, but also activate soil microbial colonies, accelerate its rate of decomposition of pollutants [15], ensure the effective restoration of salt marsh ecosystem.

## 4 Conclusion

This paper systematically reviews the progress and achievements in China's coastal zone ecological restoration technologies and blue carbon ecosystem research. The dual tasks of pollution control and carbon sink enhancement in coastal zones have been clearly defined. Coastal ecological restoration technologies have formed a framework of synergistic development of physical, chemical, and biological techniques, it provides multiple technical pathways for pollution control and functional restoration of coastal environments. Blue carbon ecosystem research focuses on typical ecosystems such as mangroves, seagrass beds, and salt marshes, research into their current state of degradation and restoration techniques, it has established a scientific foundation for the conservation and restoration of blue carbon ecosystem. However, the synergistic mechanisms between coastal zone ecological restoration and the enhancement of blue carbon ecosystem functions are still weak, future research should further explore the coupling mechanisms between restoration technologies and blue carbon functions, promote the coordinated development of coastal ecological restoration and blue carbon resource development, provide a coastal pathway for achieving the dual carbon goals, and provide more focused and feasible coastal solutions for global climate regulation.

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