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The Impact Effect of Introducing Exotic Mangrove Vegetation on Mitigating Coastal Erosion: A Case Study of Qi 'ao Island in Zhuhai

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ABSTRACT
In the context of global climate change, the intensification of coastal erosion has become a major threat to coastal ecological security, and mangroves as natural protective barriers have received widespread attention. However, problems such as the long recovery period and insufficient resilience of native mangroves have led to the introduction of exotic mangrove plants as an exploration direction for ecological restoration, but their ecological effects remain controversial. Since the introduction of the flowerless sea mulberry in Qiao Island, Zhuhai in 1999, this exotic mangrove plant has shown remarkable results in mitigating coastal erosion, making it a typical case of mangrove ecological restoration along the South China coast. Based on literature review and multi-source data (remote sensing images), this paper systematically analyzes the ecological functions of the anisorrhizia and its mitigating effect on coastal erosion, and explores its ecological benefits and potential risks. The results showed that the introduction of sea mulberry significantly increased the mangrove area on Qiao Island, Zhuhai, and effectively reduced typhoon waves and suppressed the invasion of Spartina alterniflora. The case of Qi 'ao Island in Zhuhai provides a theoretical basis and practical reference for the scientific introduction of alien species in coastal ecological restoration.

KEYWORDS
Mangrove vegetation; Coastal erosion; Sea mulberry without petals; Qiao Island, Zhuhai; Ecological restoration

1 Introduction

Mangroves are crucial to blue carbon, with their carbon sink capacity per unit area far exceeding that of land forests. In the context of global climate change, rising sea levels and frequent extreme weather events have exacerbated the problem of coastal erosion, threatening the ecological security and socio-economic development of coastal areas. Mangroves, as natural coastal protection barriers, have multiple functions such as wave dissipation, beach stabilization, carbon sequestration and storage, and maintaining biodiversity, and are regarded as the core ecosystem for resisting coastal erosion. However, native mangroves have difficulty responding quickly to the danger of erosion due to their long growth cycle and limited resilience. The invasion of Spartina alterniflora poses a threat to native plants and benthic animals, seriously affects the ecosystem of coastal wetlands in our country, and occupies waterways and hinders the passage of ships, urgently requiring ecological restoration[1]. The mangrove wetland on Qiao Island in Zhuhai, as a typical case of artificial restoration in the Guangdong-Hong Kong-Macao Greater Bay Area, has significant research value in terms of its ecological restoration process and challenges. Since the 1990s, the mangroves on Qi 'ao Island in Zhuhai have suffered severe damage due to factors such as land reclamation from the sea and the invasion of Spartina alterniflora, and the area of native mangroves has sharply declined from 112.2 hectares in 1984 to less than 32 hectares. In response to the ecological crisis of mangroves on the island, Qiao Island in Zhuhai has successfully controlled the invasion of Spartina alterniflora and restored the mangrove area to 500 hectares[9] by introducing invasive mangrove species such as the thornless sea mulberry, setting an example of successful artificial mangrove restoration. However, while the ecological model of introducing invasive mangrove species has achieved remarkable results, it has also exposed many ecological problems, leading to serious threats such as reduced biodiversity and degradation of ecosystem service functions. The introduction of a large number of invasive mangrove species, such as the broadleaf sea mulberry, will make the population structure in the area more uniform and the biodiversity more fragile. Against this backdrop, how to scientifically analyze the ecological benefits and risks that invasive mangrove plants bring to Qiao Island in Zhuhai and explore the impact of invasive mangrove plants on coastal erosion in the area have become important issues for achieving sustainable development of the coastal zone. This study mainly focuses on Qiao Island, Zhuhai, and comprehensively reviews literature, multi-source data and remote sensing images to analyze the shore stabilization and wave suppression effects of mangrove vegetation in coastal protection, the ecological diversity stabilization effect and the potential risks of the local ecosystem, providing a scientific approach for the ecological benefits of mangroves on Qiao Island, Zhuhai and the response to coastal erosion.

2 Overview of the study area

Zhuhai Qi 'ao Island is located in the northeastern part of Xiangzhou District, Zhuhai City, Guangdong Province (22° 24.9 'N, 113° 38.1' E), opposite Humen to the north, on the inner west side of the Pearl River estuary, 13 kilometers east of

Neilingding Island, and connected to Tangjiawan of Zhuhai City via a cross-sea bridge. Qi 'ao Island is a comprehensive type of nature reserve that integrates forests, wildlife and wetland ecosystems, and is an important coastal wetland ecosystem in the Pearl River Delta. The Good Forest wetland within the Qi 'ao - Danggan Island Provincial Nature Reserve, covering an area of about 500 hectares, is one of the largest and best-preserved artificial restored mangrove areas in China.

Due to factors such as the rapid development of the coastal economy since the mid-20th century, reclamation of land from the sea, aquaculture, excessive development of tourism and leisure activities, large amounts of direct discharge of pollutants into the sea, and frequent extreme weather, the mangrove ecosystem on the island deteriorated continuously between 1973 and 2000, reducing its area by about 62[2] percent. At the same time, the invasive species Spartina alterniflora grew wildly, taking up a large amount of living space and thus destroying the habitat of nearshore organisms. Due to the fact that spartina alterniflora occupies a large area of tidal flats in the mangrove forest of Qi 'ao Island, only 32 hectares of native mangroves remained on the island in 1998, causing severe damage to the ecological environment. In response to the ecological crisis, Zhuhai City carried out a large-scale restoration project of the mangroves on the island in 1999. The Tropical Forestry Research Institute of the Chinese Academy of Forestry, in collaboration with local authorities, introduced mangrove plants such as the leafless sea mulberry and sea mulberry, and used their biomass and density to effectively control the growth and spread[3] of Spartina interniflora. Between 2000 and 2020, the area of mangroves increased by 6.36 km^2[4]By 2023, the area of mangroves on Qi 'ao Island had recovered to 500 hectares, and Spartina alterniflora coverage had dropped to 1 percent, successfully reversing the trend of ecosystem degradation. The restored mangroves have seen a significant increase in biodiversity. But there are still ecological and environmental issues that need to be studied after the introduction of the exotic thornless sea mulberry forest vegetation.

3 The effects of introducing foreign mangrove vegetation

3.1 The wave-breaking and shore stabilization effects of the thornless sea tree and coastal zone protection

The broadleaf sea mulberry can form tall tree communities in a short period of time and is a typical fast-growing tree species. With lush branches and leaves and a thick trunk that is cylindrical in shape, it can effectively weaken and block wave energy. It can also form enough green to resist wind invasion, which can effectively break the damage caused by waves to beach afforestation. The mulberry has a well-developed root system that can penetrate deep into the soil to form a stable support structure. These roots not only hold their plants in place but also reinforce coastal slopes[5] by entwining and fixing sediment to enhance the soil's resistance to erosion. The mangroves of the thornless sea mulberry, with their dense trunks and branched leaves, can effectively block and disperse wave energy. When waves pass through mangrove areas, the wave height is significantly reduced. Studies have shown that the average wave dissipation coefficient of the 30-meter-wide thornless sea mulberry mangrove belt is 0.13 during typhoon-free periods, and the maximum wave dissipation coefficient can reach 0.47. During storm surges, the average wave dissipation coefficient increased to 0.18 and the maximum wave dissipation coefficient reached 0.33, with a 38% improvement in wave dissipation capacity.

3.2 Effects on native tree species (in the case of autumn solanum)

Autumn mangrove is one of the native species of the mangroves on Qiao Island, Zhuhai, and is a typical true mangrove plant. It thrives in the intertidal zone, especially in the intertidal muddy tidal flats where salinity changes significantly. Qi 'ao Island, located at the mouth of the Pearl River, provides an ideal habitat for autumn solanum due to its estuarine beaches and marshes. The salt and flood resistance of the autumn eggplant team can thrive in the low tide zone of Qi 'ao Island. Nightshade is a small tree or evergreen shrub that can grow up to 3 meters tall. The root system of the autumn plant is intricate, with columnar roots and aerial roots interwoven and penetrating into the beach mud to form a strong support structure. This root structure effectively holds the beach soil in place, preventing it from being washed away by the waves, and strengthens the coastal slope[6]. The autumn solanum forest also slows down the current, making it easier for the sediment and silt in the current to settle and accumulate, further consolidating the coast and increasing the thickness and stability of the tidal flats. Its roots and branches can also effectively slow down the impact of waves and tides, absorbing and dispersing the energy brought by the waves. Since the introduction of the exotic mangrove vegetation, the area of the broadleaf sea mulberry forest has expanded rapidly due to its fast growth characteristics, making it the dominant mangrove species[7] on Qi 'ao Island. The cultivation of mussels has had an inhibitory effect on the growth of local native tree species. In the case of autumn solanum, to some extent, the morphological plasticity and biomass of autumn solanum are controlled by mussels[8].

3.3 Enhance local biodiversity

As the mangrove area gradually recovered after the introduction of the thornless sea mulberry forest, ecological

diversity also improved[10]. Moreover, compared with the native mangrove vegetation on the island, the data indicators such as species diversity and species composition of the local mangrove community, such as the autumn mangrove, are lower than those of the unpetaled sea mulberry community[11]. Among them, the number of bird species increased from the original 99 to 182, and the number of families, orders, species and genera of birds increased to varying degrees before and after the recovery[9]. Among them, the number of 22 species of national second-class protected birds, such as the black-faced spoonbill, the brown-winged crow, the osprey and the black-eared kite, has also increased. In particular, along the outer edge of the mangroves and the areas covered by beaches, a spectacular sight of "thousands of birds flying together" is created, with tens of thousands of migratory birds stopping or wintering here every year. The broadless sea Forest wetland also provides a rich habitat and food source for the island's birds, bringing a large number of sandpipers, herons, ducks and other birds to Qi 'ao Island. Not only is the population of birds growing, but the number of benthic animals is also changing and increasing. The thornless sea mulberry forest vegetation is beneficial to the diversity of benthic animals and the distribution of benthic animals will be affected, with the large benthic animal species on the island increasing from 16 to 64. According to the study, different ages of mussels forests have an impact on large benthic animals, and various indices of benthic animals have shown an upward trend[12] at different ages of the forest. The habitat structure is complex, and habitat functional diversity is influenced by the complexity of the vegetation. The increase in complexity leads to an increase in habitat functional diversity, reaching a peak in the habitat. Therefore, the habitat is beneficial for the growth and survival[13] of large benthic animals.

4 The effectiveness and challenges of introducing Seabucs

4.1 The introduction of the flower-free sea mulberry inhibited the growth of Spartina alterniflora

Since the appearance of Spartina alterniflora mangrove vegetation on Qi 'ao Island, it has grown at a rapid rate, causing damage to the species diversity on the island. Because native plants grow more slowly compared to spartina alterniflora, the proliferation of spartina alterniflora deprives the island of much sunlight, causing many native mangrove plants to stop growing[15] and reducing the living space for native plants, resulting in a single vegetation population community on the island. And the species of birds, benthic animals and other species that depend on native plants have been dwindling due to the reduction of food sources and habitats. A series of chain effects have led to an ecological crisis[3] on the island. After planting the broadless sea mulberry on the island and using methods such as biological evolution to prevent the expansion of Spartina alterniflora vegetation, the area of spartina alterniflora vegetation decreased from 260hm^2 to 2hm^2[14] between 1999 and 2007. The thornless sea mulberry was able to grow at a faster rate, with tall and large canopies that could easily form dense shade layers, giving it an advantage over spartina alterniflora in competing for sunlight resources on the island. The study found that as the years of cultivation of the sea mulberry increased, the light-loving plant Spartina alterniflora received less and less light intensity and duration, which affected [16]factors such as plant height, frequency, stem-to-leaf ratio and biomass to varying degrees. The photosynthetic rate of Spartina alterniflora drops [14]significantly when the canopy density of the Spartina alterniflora forest reaches over 80 percent. The higher the stand density value of the unflowered sea mulberry forest, the lower the coverage rate and plant height of Spartina alterniflora in the upper part of the soil, as well as the photosynthetic rate and biomass in the lower [15]The litter or root system of the variegated sea mulberry can release a large amount of volatile allelogenic substances, which can destroy the cellular structure, photosynthesis and chlorophyll synthesis of the Spartina alterniflora, ultimately slowly inhibiting the growth of the Spartina alterniflora.

4.2 Risks and challenges of introducing the variegata

Although the introduction of the sea mulberry has restored the mangrove area and ecology of Qi 'ao Island to varying degrees, it still poses a potential threat of invasion. As an invasive species on the island, the seeds can spread far with the tides and have a strong diffusibility, and may suppress the growth of native mangrove vegetation, resulting in the diversification[17] of mangrove vegetation communities. The diversification of the acacia community could affect the original ecosystem function. Compared with native mangrove plants, the single-species pure forest ecosystem of the sea mulberry is less stable and prone to pest and disease risks, resulting in a reduced[20] diversity of large benthic animals. Moreover, studies have shown that although the colonies of the unblemishes grow very fast, their seedlings grow very slowly, making self-renewal particularly difficult[18]. Although the thornless sea mulberry can suppress Spartina alterniflora, it has a large number of high-density forests that affect the habitat of many birds. The cold resistance of the sea mulberry is weaker[19] than that of the native mangrove vegetation. During the 2008 southern ice and snow disaster, the sea mulberry vegetation largely died and the sea mulberry community suffered varying degrees of damage[3]. It can be known that there are still many challenges in the thornless sea mulberry forest.

5 Conclusions and remediation recommendations

Exotic mangrove plants such as the thornless sea mulberry forest are fast-growing plant forests that can effectively suppress the spread of Spartina alterniflora in a short period of time, and the results are remarkable. However, the single planting of exotic mangrove plants such as the unblemishes have a negative impact on native plants such as nightshade and olive, reducing their living space and leading to a decline in the quality of ecosystem services. Due to the dense canopies of the introduced mangroves, which block the light needed by the native vegetation, the undergrowth rate is not high. In the future, to prevent ecological and environmental problems caused by the excessive singling of exotic mangrove vegetation, better methods and models for introducing mangrove vegetation need to be proposed, such as the mixed planting strategy of "intercropping native vegetation + planting fast-growing vegetation first", which allows native vegetation and exotic mangrove vegetation to grow alternately, so that both can get sufficient sunlight and nutrients. Better survival, more complex vegetation communities on the island, more effective resistance to wind and waves, and mitigation of coastal erosion[21].

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