

Evaluation on Restoration Effects of Coastal Protection Forest Safety Systems: A Case Study of the Ecological Restoration Shoreline Project in Fanhe Harbor and Kaozhou Bay, Huidong County, Huizhou City, China

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Abstract The coastal zone ecological restoration project has successfully restored a cumulative shoreline length of 76 km in Fanhe Harbor and Kaozhou Bay ecological restoration shoreline (mangrove forest) located in Huidong County, Huizhou City. Additionally, 5 619.5 m of artificial shoreline has been developed as part of the ecological restoration efforts. Various methods, including UAV remote sensing, orthophoto acquisition, and analysis using ArcGIS software, were employed to assess the length, width, coverage, and other relevant indicators of the newly established ecologically restored shoreline. The findings indicate that the average width, coverage, and ecosystem stability of mangrove forests in the restored area satisfy the criteria for the acceptance of ecological shoreline restoration. Furthermore, a relatively stable ecosystem has been established for over two years. This study offers a scientific foundation for the ecological restoration of mangrove forests and holds considerable significance for the conservation and utilization of mangrove forest resources.

Key words Mangrove forest, Ecological restoration, Shoreline, Ecological evaluation

1 Introduction

Huizhou, situated in the southeastern region of Guangdong Province, is abundant in marine resources and mangrove forest ecosystems. Historically, the extent of mangrove forests in this area has significantly diminished. In recent years, Huidong County has made concerted efforts to rehabilitate degraded shorelines and mangrove forest ecosystems by implementing various ecological restoration projects. The objective of this study is to assess the effectiveness of the implementation of these projects and to establish a scientific foundation for mangrove forest conservation and ecological restoration.

2 Research background

2.1 Natural background Huidong County, situated in the southeastern region of Guangdong Province, lies south of the Tropic of Cancer and east of the South China Sea. This area is characterized by abundant marine resources and distinctive mangrove forest ecosystems. Mangrove forests, as a significant coastal wetland ecosystem, provide a range of ecological functions, including wave attenuation, dyke stabilization, environmental purification, and provision of habitat for the breeding of marine organisms. However, the industrial restructuring and the rapid advancement of mariculture during the 1990s have resulted in substantial damage to the mudflat regions that support mangrove growth. This has led to a marked decrease in the extent of mangrove forests and a deterioration of their ecosystem service functions.

To safeguard and rehabilitate mangrove forest resources, the People's Government of Huidong County sanctioned the establish-

ment of the Mangrove County Nature Reserve in 1999, subsequently elevating its status to a municipal nature reserve in 2000. Building upon this foundation, Huidong County has proactively addressed the national initiative for the conservation and restoration of mangrove forests by executing a series of projects aimed at the protection and restoration of these vital ecosystems.

2.2 Project background According to the *Special Action Plan for the Protection and Restoration of Mangrove Forests (2020–2025)* and the *Implementation Plan for the Special Action Plan for the Protection and Restoration of Mangrove Forests in Guangdong Province*, Huidong County has established specific objectives for the protection and restoration of mangrove forests. The ecological restoration project for the Pinghai Inner Harbor and the Fanhe Harbor Daputun coastal zone was initiated in 2019. The primary objective of this project is to rehabilitate the degraded shoreline utilizing techniques such as the artificial planting of mangroves and the reestablishment of wetlands. Additionally, the project aims to accomplish tasks related to shoreline organization, vegetation restoration, and ecological reconstruction. The ecological restoration project for the Fanhe Harbor Daputun coastal zone was initiated in 2020. This project aims to enhance the restoration of mangrove forests and facilitate the ecological rehabilitation of the coastal zone, supported by marine resource management funds. The construction project for the coastal protection forest system, which encompasses mangrove forest restoration and afforestation, was initiated in 2019. This project aims to enhance the ecological protective functions of the coastline through the restoration and afforestation of mangrove forest ecosystems. The construction project for the coastal protection forest security system, which focuses on mangrove forest restoration and afforestation, was initiated in 2020. Building upon the efforts of the previous year, the scope of mangrove forest restoration has been significantly expanded, and the ecological service functions of mangrove forests have been enhanced.

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Through the execution of the aforementioned projects, Huidong County has successfully restored a cumulative total of 76 km of shoreline across various marine areas, including Fanhe Harbor, Kaozhou Bay, and Pinghai Inner Harbor. Notably, 5 619.5 m of artificial shoreline has been established as part of the ecological restoration efforts. The implementation of these projects not only restores the ecological functions of mangrove forests, but also provides significant support for the conservation of local biodiversity and enhances the disaster prevention and mitigation capacity of coastal areas.

3 Data collection and analysis methods

To conduct a thorough assessment of the ecological restoration effects of the mangrove forest shoreline in Fanhe Harbor and Kaozhou Bay, Huidong County, Huizhou City, this study employed a diverse array of data collection and analytical methods to ensure the accuracy and scientificity of the findings.

3.1 Unmanned aerial vehicle (UAV) remote sensing and orthophoto acquisition UAV remote sensing technology was employed to obtain high-resolution orthophoto of newly established ecological restoration shorelines in Fanhe Harbor and Kaozhou Bay. These images provided valuable visual data regarding the distribution, coverage, and growth of mangrove forests. The flight paths of UAVs and the associated shooting parameters were meticulously designed to guarantee comprehensive coverage of all target areas, while ensuring that the resolution of the captured images was adequate for the identification of intricate features of the mangrove ecosystems. Subsequently, the acquired image data were imported into a geographic information system (GIS) for advanced analysis.

3.2 ArcGIS software analysis The orthophotos obtained from the UAV were analyzed utilizing ArcGIS software to ascertain the geographical coordinates and dimensions of the starting and ending points of the newly established ecological restoration shoreline. The image processing capabilities of the software facilitated the calculation of both the area of mangrove growth and the ground projection area of the mangrove forest, which subsequently enabled the determination of the average width and coverage of the mangrove forest ecosystem. The specific steps involved in this process encompassed image pre-processing, which includes image correction, enhancement, and segmentation; feature extraction, which entails identifying and delineating the boundaries and coverage areas of the mangrove forests; area calculation, which utilizes the spatial analysis tool within ArcGIS to determine the growth areas and ground projection areas of the mangrove forests; and index calculation, which involves computing the average width and coverage of the mangrove forests based on the aforementioned data.

3.3 Growth survey of mangrove forest Fixed sample plots were established in areas where mangrove forests are located, and regular field surveys were conducted to document the species of mangroves, their population numbers, and growth conditions, which included measurements of plant height, ground diameter, crown diameter, and coverage. These data were utilized to evaluate the growth trends and health status of the mangrove forest.

3.4 Macrobenthos and bird monitoring Monitoring sample lines and points were established within and surrounding mangrove forests, where macrobenthos and birds were observed through visual counting and catch sampling methods. The data obtained from these monitoring activities contributed to the assessment of biodiversity and the ecological service functions provided by mangrove forest ecosystems.

3.5 Data statistics and analysis The data collected were analyzed using statistical software, which included descriptive statistics, the calculation of diversity indicators, and analyses of species richness and evenness. These analyses facilitated the assessment of the stability of mangrove forest ecosystems and the effectiveness of restoration efforts.

4 Evaluation of newly formed ecologically restored shorelines

4.1 Geographic location and length The newly established ecological restoration shoreline is situated in Fanhe Harbor and Kaozhou Bay, within Huidong County, Huizhou City. Based on the findings from the 2022 shoreline revision survey and associated shoreline restoration projects, the total length of the approved shoreline measures 5 619.5 m, encompassing a total of 10 distinct shoreline segments.

4.2 Ecological function The newly established ecologically restored shoreline serves not only as a physical barrier that reduces shoreline erosion caused by wind and waves, but also offers critical habitat and breeding sites for marine organisms. The root systems of mangrove trees play a crucial role in stabilizing sediments and mitigating coastal erosion. Additionally, their intricate structure offers habitat and protection for various marine organisms, including fish, crustaceans, and other aquatic life. Furthermore, mangrove forests serve critical functions in water purification and carbon dioxide absorption, which are essential for maintaining the ecological balance of the region and addressing the challenges posed by climate change.

4.3 Habitat stability The stability analyses conducted on the newly established ecologically restored shorelines indicate that these areas have developed relatively stable ecosystems, achieving a stability duration of over two years. The observed outcomes can primarily be attributed to the effective implementation of several key factors: mangrove forest coverage, where the coverage in all coastal sections has surpassed 30%, signifying the successful establishment of a stable community structure within the mangrove forests; ecosystem services, as mangrove forests offer a diverse array of ecological services, including coastal protection, maintenance of biodiversity, and water purification; and biodiversity, evidenced by the presence of a wide variety of benthic organisms and bird species recorded within the mangrove forest ecosystems, which highlights the biodiversity and complexity inherent to these environments.

4.4 Analysis of specific shoreline segments As illustrated in Table 1, the implementation of the ecological restoration project in Huidong County has effectively restored degraded coastlines and established mangrove restoration shorelines that possess considera-

ble ecological value. These shorelines not only enhance the ecological stability of the coastal environment but also serve as a robust foundation for the protection and preservation of local biodiversity.

Table 1 Status of newly formed ecologically restored shorelines

No. of shorelines	Length of shoreline segment//m	Average width of mangrove forests//m	Coverage of mangrove forests//%
44132300207-01	403.8	190.8	47.16
44132300207-02	741.1	247.3	35.14
44132300206-03	289.4	195.0	44.00
44132300204-04	388.5	307.7	30.61
44132300203101-05	143.1	82.8	63.05
44132300202-06	2 129.9	123.9	31.22
44132300202-07	633.5	258.7	42.44
44132300200-08	323.5	176.9	30.12
44132300271101-44132300270-09	321.2	170.4	30.44
44132300024-10	245.5	245.5	35.16

5 Ecosystem stability analysis

Ecosystem stability analysis is a critical component in evaluating the effectiveness of ecological shoreline restoration projects. This study offers a thorough assessment of the stability of mangrove forest ecosystems in Fanhe Harbor and Kaozhou Bay, located in Huidong County, by examining mangrove growth, macrobenthic biodiversity, and bird habitat.

5.1 Growth of mangrove forests Through field investigations and monitoring, it was determined that the average planting density of mangrove forests was 20 295 plants/hm², accompanied by a high survival rate. This finding suggests that the mangrove forests have undergone successful restoration. Furthermore, both the crown diameter and height of the mangrove plants exhibited significant growth, with some specimens developing additional strutting roots, indicative of a healthy growth and development trend. Additionally, the vegetation cover of the mangrove forests increased from 0% on the bare beach prior to restoration to approximately 10% in 2021, and subsequently to about 90% in 2022. This progression signifies that the ecosystem is evolving towards a more mature and stable state.

5.2 Macrobenthic biodiversity A survey of macrobenthic organisms in Fanhe Harbor and Kaozhou Bay revealed that both the species composition and abundance of macrobenthic organisms underwent significant changes following restoration efforts. This suggests a reconfiguration of the ecosystem structure and an enhancement of the biological habitat. The macrobenthic diversity indicators observed in spring and autumn indicated a predominance of annelids during the spring season, while arthropods were more prevalent in the autumn. This pattern reflects the impact of seasonal variations on the benthic community. Additionally, the findings from the sediment quality assessment revealed low levels of total carbon and total nitrogen, which align with national standards for class I sediment quality. This suggests that the environmental quality of the sediment is favorable and supports the survival of

benthic organisms.

5.3 Bird habitat Birds serve as significant bio-indicators within ecosystems, as their diversity and abundance can provide insights into the overall health of these environments. An analysis of the bird surveys conducted in Fanhe Harbor and Kaozhou Bay revealed a diverse array of bird species, including numerous nationally protected wildlife and species covered by migratory bird conservation agreements. This finding underscores the significant biodiversity present in the region. Seasonal variations in the abundance and species of bird species suggest that the region serves as a significant migratory stopover and overwintering habitat for birds. An analysis of the residency patterns and geographic distribution of these species indicates that the region is not only a habitat for a diverse array of bird species but also a critical area for the conservation of biodiversity.

5.4 Integrated assessment of ecosystem stability The stability of the mangrove forest ecosystem has been markedly enhanced, resulting in the formation of a relatively stable ecological system and the successful attainment of ecological restoration objectives. The increased biodiversity and the enhancement of ecosystem service functions underscore the considerable importance of establishing ecological restoration shorelines for the preservation of regional ecological balance and biodiversity. Ongoing monitoring and management are essential for maintaining and further enhancing ecosystem stability. Additionally, long-term conservation and management measures are necessary to ensure the sustained benefits of ecologically restored shorelines.

The stability analyses conducted on the ecological restoration shorelines of Fanhe Harbor and Kaozhou Bay in Huidong County underscore the significance of effectively implementing ecological restoration initiatives for the rehabilitation and conservation of coastal zone ecosystems. These findings offer valuable insights and serve as a reference for future ecological restoration projects of a similar nature.

6 Conclusions and discussion

6.1 Effectiveness of ecological restoration The implementation of a series of ecological restoration projects in Huidong County has successfully rehabilitated the damaged coastline, resulting in a notable increase in both mangrove forest coverage and biodiversity. This outcome substantiates the efficacy of the ecological restoration projects in enhancing the health and functionality of the coastal zone ecosystem. Notably, the average width and coverage of mangrove forests have surpassed the established criteria for the acceptance of ecologically restored shorelines, thereby illustrating the success of the restoration efforts.

6.2 Restoration of biodiversity The restoration of mangrove ecosystems has not only enhanced vegetation coverage but has also contributed to an increase in the diversity of macrobenthic organisms and bird species. This observation underscores the significance of mangrove forests as vital habitats for a diverse array of organisms, thereby playing a crucial role in the maintenance of regional biodiversity. Despite the observed recovery of biodiversity,

The G9 variety exhibits the following characteristics: a reproductive period of approximately 116 d, an average of 6.7 bolls per plant, a single boll weight of 5.7 g, a lint percentage of 43.5%, a pre-frost flowering rate of 100%, an average length of the upper part of the HVICC measuring 30.4 mm, a neatness index of 85.8%, a specific strength at break of 30.3 cN/tex, a micronaire value of 4.6, an elongation percentage of 6.6%, a reflectivity of 79.5%, a yellowness index of 7.5, and a spinning consistency in-

ongoing monitoring and protective measures are essential to ensure the long-term stability and survival of these species.

6.4 Challenges and future directions

Despite the achievements of ecological restoration projects, several challenges persist. For instance, the long-term stability of mangrove forests must be addressed in light of both natural and anthropogenic pressures, which include climate change, rising sea levels, pollution, and overexploitation. Consequently, future research and management efforts should prioritize the following areas: continuous monitoring, which entails the long-term assessment of the growth status, biodiversity, and ecosystem service functions of mangrove forests to evaluate the sustainability and stability of restoration outcomes; adaptive management, wherein management strategies are adjusted based on monitoring results to address environmental changes and emerging threats; community participation, aimed at enhancing local communities' awareness and involvement in mangrove conservation, as well as educating them on the significance of ecological restoration; and policy support, which involves strengthening

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