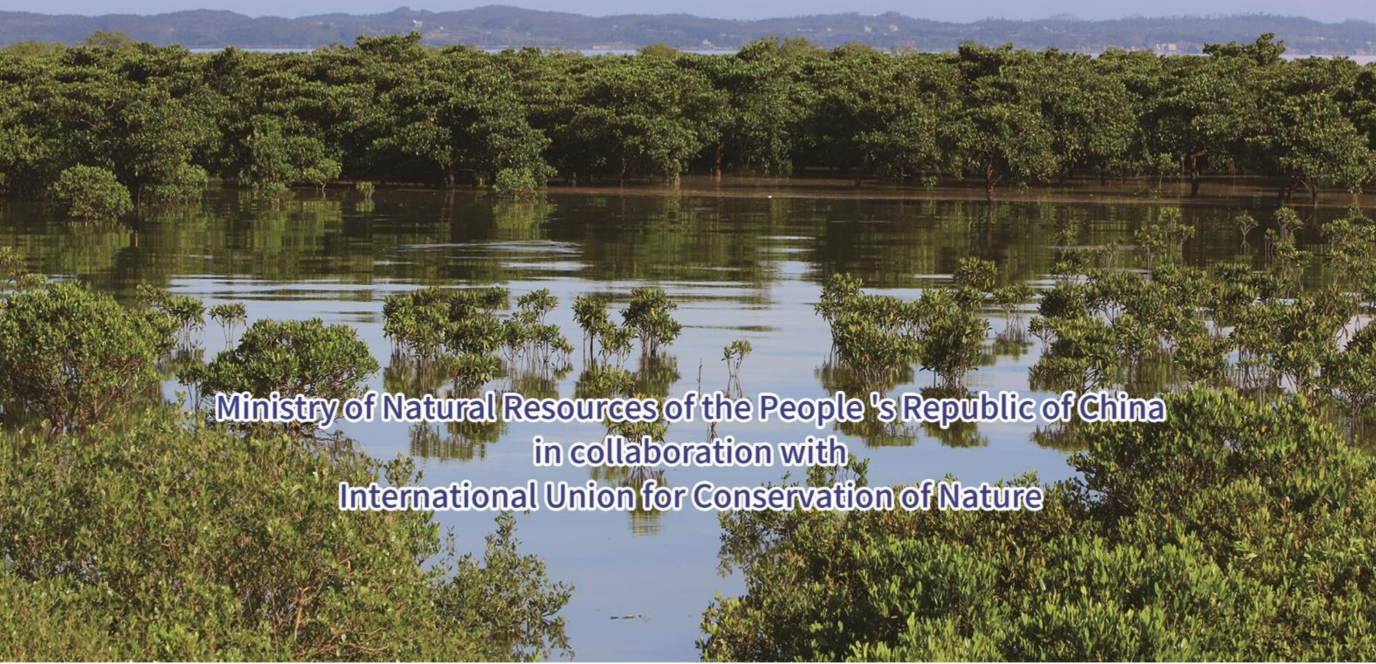
International Applications of Ecosystem-based Disaster Risk Reduction in Coastal Areas



Ministry of Natural Resources of the People 's Republic of China
in collaboration with
International Union for Conservation of Nature

PREFACE

Natural disasters are one of the most pressing global issues to humankind. To cost-effectively address the severe impacts of disasters on human lives and properties, ecosystem approaches such as Nature-based Solutions (NbS) and Ecosystem-based Disaster Risk Reduction (Eco-DRR) have garnered worldwide recognition these days. The ideas are to reduce disaster risks by enhancing ecosystem services through their effective management, conservation and restoration while at the same time generating the co-benefits in addressing other societal challenges to ultimately achieve sustainable and resilient development. These concepts are very much in line with China's philosophy of Ecological Civilisation and the guiding principles of disaster prevention, mitigation and recovery in the coming decade.

In the context of global climate change, the risks of marine disasters from typhoons, storm surges and other phenomena have escalated, posing a serious threat to the safety of people and properties in coastal areas and the sustainability of socio-economic development. Compared to the high costs and sustainability constraints of traditional grey infrastructure, marine ecosystems such as mangroves, salt marshes and seagrass beds are proven effective in attenuating waves and currents, promoting nourishment and protecting beaches. As guardians of the ocean, coastal ecosystems play a crucial role in reducing the risk of marine disasters.

In recent years, a number of good practices have emerged around the world that have demonstrated the synergistic delivery of the ecosystem enhancement and disaster risk reduction. Capturing and sharing good practices in practical application of Eco-DRR within and beyond the community of practice is a most recent endeavour of Ministry of Natural Resources (MNR) of China and International Union for Conservation of Nature (IUCN), culminating in the selection of eight case studies for sharing. The practical application of Eco-DRR, as demonstrated in these case studies, is expected to promote the achievement of co-benefits of ecosystem integrity, coastal resilience and sustainable economic development in coastal areas, which are consistent with our vision of living in harmony with the coasts and caring for the Earth.

Our heartfelt thanks go to those practitioners and professionals contributing to the management, conservation and restoration of coastal ecosystems who have made possible the co-benefits as exemplified in these case studies. Immense appreciation is also extended to National Development and Reform Commission, Ministry of Finance, Ministry of Water Resources, French Development Agency, European Union and the China Biodiversity Facility for their enthusiastic support to the research, review and compilation of the eight case studies.

Research and practical application of NbS and Eco-DRR in coastal areas with the objectives of generating multiple co-benefits are still at an early stage in many countries. In view of this, we welcome comments, suggestions and further development of the knowledge base for broader sharing, learning and application.

Editorial Team
September 2023

CONTENTS

PART 1

EXECUTIVE SUMMARIES

This publication contains eight case studies of the practical application of ecosystem-based disaster risk reduction (Eco-DRR) in coastal areas of China, Kenya, Sri Lanka and the United Kingdom. Approaches are being applied at scale in the management, conservation and restoration of mangroves, salt marshes, sandy coasts, estuaries and seawalls with demonstrated co-benefits of disaster risk reduction, biodiversity and ecosystem net-gains, climate change mitigation and adaptation, improvements in water and food security and human health, and social and economic development. Below are summaries of each case study.

Esturaine Disaster Risk Reduction in China-Singapore Tianjin Eco-city, Tianjin, China

Tianjin Eco-city is located at the estuary of the Yongding New River in the north of the Binhai New District of Tianjin Municipality. The major safety concerns in the New City are flood discharge and tidal resistance at the river-sea confluence, weak absorbing capacity of water systems inland due to poor connectivity, and the effectiveness of seawalls. A 'three lines of defence' has been developed to stratify existing seawalls to create a functional green infrastructure through salt marshes, seawalls and wetland parks. The newly-built culvert and sluice outside the seawalls is connected to the water system in the City that flows into the sea. An integrated underground rainwater pumping station has been built with the absorbing capacity of 300,000 m^3, thus increasing the resilience to urban flood risks. The cultural value of the old seawall and coastlines are tapped with connection to urban outdoor trails to preserve the historical monument. Following these interventions, the water exchange and tidal flood absorption capacity have been improved, and the restored vegetation creates new wetland habitat for birds and outdoor activities for the public. The case has created a characteristic coastal ecological space, in harmony with people and shared by the people, and a living example of the management of estuaries, coastal wetlands and coastal beaches.

Ecosystem-based Disaster Risk Reduction: A Case Study of the South Coast of the Yellow River Estuary, Dongying, China

The case is located in the south of the Yellow River Estuary in Dongying City, Shandong Province, which represents a major demonstration in protecting the ecosystems of the Yellow River Delta in China. Prior to the restoration, the region had experienced various ecological problems and disaster risks, such as the severe decline of the coastal salt marsh ecosystem, the reduction of the seawater exchange capacity, and destruction of the natural barrier of shoreline protection. In response to these problems, restoration works have been carried out, including tidal gully dredging, coastal salt marsh vegetation restoration, oyster reefs building, and transplantation for restoration of seagrass beds along the 20 km long coastline. Through the interventions, nearly 2,200 hectares of coastal intertidal flats were restored with vegetation, and the ‘1+N’ working model has been implemented, which stands for one-year restoration and long-term management and maintenance. Improvements are observed in the capacity of resistance to temperate storm surges with an increase in the areas of “red beach” painted by the native plant species *Suaeda salsa*, an expansion of the sea areas accessibility to the public, and new opportunities for ecological economy provided by a more stable and healthy coastal wetland ecosystem.

Sand Coast Revegetation and Restoration of Binhai New City, Fuzhou, China

The case is located in Binhai New City, Fuzhou City, Fujian Province. Faced with the problems of a high incidence of marine disasters, damage to the integrity of the sandy coastal landform, intensified coastal erosion, and the reduction in the windbreak and sand fixation function of the forest shelter belt in this region, an ecosystem approach of prioritising ecological services and green development was adopted as responses. Interventions have focused on beach regulation and maintenance, restoration and construction of the coastal shelter belt, and restoration of wetland habitat beyond the embankment. The average width of the dry beach has been enlarged by 30 metres along a 7.5 km long beach, and a coastal shelter belt of 5.5 km long and 500 metres wide have been built. A 3.2 km long beach has been re-vegetated, and 274.9 hectares of wetlands have been restored. Through the above measures, the coastal new town characterized by the green barrier of "sheltered forest - vegetated shoreline - beach" is in shape. The stratified green barrier with enlarged hydrophilic space has enhanced the capacity to mitigate marine disaster risks from typhoons and storm surges and reduce beach erosion from wind, thus scaling up the ecological advantage and strategic value of the coastal new town.

Restoring Mangroves to Reduce Coastal Risks in Xiatanwei, Xiamen, China

The case is located in a semi-enclosed bay of Xiatawei, Tong'an Bay of Xiang'an District in Xiamen City, Fujian Province. In view of the decline of the mangrove ecosystem, the frequent occurrence of red tides, the intensified invasion of Spartina, and the frequent occurrence of natural and man-made marine disasters, the mangrove restoration plan for the purposes of disaster risk reduction was implemented from 2005 to 2020. Through the implementation of coastal beach regulation measures, scientific mangrove planting, and the rebuilding of the "forest-beach-sea" mangrove wetland, an area of 180 hectares was returned from aquaculture for mangrove restoration, with 85 hectares of mangroves planted. The spatial layout of restored mangroves, connected water systems, vegetation as a natural buffer zone and hydrophilic space are the key features of the developed natural infrastructure for disaster risk reduction. Inseparable from the infrastructure development is the support of a marine biological breeding centre, a marine ecological environment monitoring station, a popular science research exhibition hall and a variety of ecological facilities to support research on mangrove restoration and long-term monitoring, science education and awareness raising, providing a model for actively promoting the sustainable use of coastal mangrove resources and realising the harmonious coexistence between people and nature.

Ecological Stratification of Hongshahuan Seawall in Fangchenggang, China

The case is located in Hongshahuan of West Bay area, Fangchenggang City, Guangxi Zhuang Autonomous Region. Serious coastal erosion, threats to the safety of the seawalls, the obstruction of ecological connectivity between land and sea, and the poor environmental quality of the coastal wetlands are the main environmental and safety constraints faced by local people. The approaches are to construct an ecological Hongshahuan seawall by restoring mangroves in the tidal flats and vegetate the rear embankment, constructing a dam and using hinge slope protection bricks, deploying a reef at the bottom of sea dyke, and vegetating sea and land transition zone. After completion of the project, mangrove area increased by 45.23%, dike body vegetation coverage has increased from 4.25% to 90%, forming a "mangrove-seawall-coastal vegetation" ecological seawall pattern with increased capacity to effectively curb the beach erosion, protect seawall soil from erosion and mitigate risks of the typhoon, and realise the co-benefits of improved ecosystem services and disaster risk reduction.

Integrating Climate Adaptation, Poverty Reduction and Environmental Conservation in natural resources management in Kwale County, Kenya

The case is located in Kwale County, Kenya, one of the six counties in Kenya's coast region, which is endowed with a wide variety of natural resources. The area suffers from persistent development constraints, marginalisation of women and children, environmental degradation, loss of biodiversity, climate threats and declining fisheries production. The Conservation and Sustainable Use of Marine Ecosystems project (COSME Project phase I and phase II) aimed to improve the lives and livelihoods of coastal communities (especially women) through the conservation and sustainable management of marine ecosystems, the adoption of a people-centred approach to address the triple crisis at the local level, the strengthening of local environmental stewardship and women's inclusion and agency and support to pro-poor responsible value chain development. The project has diversified and improved existing livelihoods, especially through seaweed farming and raised awareness at school and community level. By the end of the project, 91 functioning seaweed farms were producing 10.73-20.3 tonnes of seaweeds per year, providing economic opportunities for both men and women in the community. Eight mangrove groups replanted 293,320 mangrove trees across 59.4 hectares with a survival rate of around 70-75%. These activities have helped to protect coastlines from flooding, storm surges and erosion. Women reported investing their income in children's school fees, and health costs, and improving their quality of life, with improvements in children's well-being noted in the end-of-project survey.

Mangroves for Ecosystem-based -Disaster Risk Reduction: A Case Study of Kala Oya Estuary, Sri Lanka

The case is located in the Kala Oya estuary in Sri Lanka, a mangrove hotspot that is home to a third of the world's mangrove diversity. However, the mangrove ecosystems and biodiversity of the Kala Oya estuary are under severe threat from continued population pressure, increased infrastructure and industrial activity, poor governance, unsustainable local livelihoods, natural disasters and the effects of climate change. As small island states and developing countries highly vulnerable to coastal hazards, the associated post-disaster reconstruction costs are a heavy economic burden. In this context, specific local plans for mangrove protection have been developed. Based on the three pillars of mitigation, protection and strengthening of governance by local communities, the development of mangrove disaster preparedness and mitigation strategies are being developed, including demarcation of social boundaries to reduce encroachment, introduction and adoption of the concept of Environmentally Sensitive Areas (ESAs), promotion of co-management, reforestation of mangrove forests. The promotion of sustainable livelihoods, capacity building and public awareness has led to the restoration and protection of mangrove forests with the full participation of the community and the strengthening of community and ecosystem resilience to cope with the impacts of climate change, as well as the capacity for disaster risk reduction.

Coastal Realignment Scheme, Medmerry, United Kingdom

This case is located at Medmerry, England, a coastal wetland nature reserve between the towns of Selsey and Bracklesham in West Sussex, England. The area has historically been protected only by shingle embankments, which could only withstand minimal coastal storms. Climate change has exacerbated the increase in coastal flooding events and the existing shingle embankments are inadequate to withstand flooding, causing damage to homes, infrastructure and coastal habitats. At a cost of £28 million, the project is one of the largest open sea defenses in Europe. Waves were effectively dissipated by breaching or removing existing flood defenses, or by using culverts and tide gates to reintroduce tidal systems into previously reclaimed low-lying areas, creating a range of mudflat, saltmarsh and transitional habitats. The project provided cost-effective flood risk management for the local community, while restoring 183 hectares of intertidal habitat. The project was completed in 2013 and since 2014 Medmerry has been managed as a nature reserve by the Royal Society for the Protection of Birds, with the creation of new habitats resulting in a significant increase in bird numbers. The project also includes a network of footpaths and cycle paths to provide public open space, allowing visitors to enjoy the natural beauty of the area while protecting the habitats from disturbance. The Medmerry Coastal Zone Reorganisation Programme has been recognised by IUCN as a successful example of a nature-based solution that reduces the impacts and risks of climate change on coastal communities, while improving biodiversity, enhancing ecosystem services and providing recreational opportunities for local communities.

PART 2

CASE STUDIES

Esturaine Disaster Risk Reduction in China-Singapore Tianjin Eco-city,Tianjin, China

Introduction

The China-Singapore Tianjin Eco-city is located in the north of Binhai New District of Tianjin Municipality and on the west coast of the Bohai Sea, 45 km away from the central urban area of Tianjin, with a planned total area of 15,000 hectares (including 10,000 hectares of land area and 5,000 hectares of sea area) and a planned population of about 404,000 people. With 36 km of coastline dominated by sandy silt, the China-Singapore Tianjin Eco-city is a major cooperation project between the governments of China and Singapore. It represents the world's first eco-city jointly developed by two countries through cooperation. The China-Singapore Tianjin Eco-city aims to promote the integration of green and ecological development of industries and the eco-city, and highlights industries that take people's wisdom as productivity and people's health and happiness as the key, thus forming three leading industries: intelligent science and

Figure 1 Schematic Diagram of Case Location.

technology services, cultural and health tourism, and green buildings and development. In the past ten years, the number of market players has surged from 853 entities to 26,000 entities, the proportion of industrial tax revenue has reached 76%, and the job-housing balance index has reached 50%.

This case is located at the estuary of Yongding New River **(Figure 1)**, which is the connecting point between the eco-city and the sea, the connecting hub of marine and terrestrial ecology, the landmark of the eco-city's entrance, as well as the portal of the eco-city. Yongding New River is the common seaward channel of Yongding River, North Canal, Chaobaixin River and Ji Canal in the northern system of the Haihe River Basin. It is a flood control barrier in northern Tianjin and an important part of maintaining the stability of area-based ecosystems. But at the same time, because of its location at the top of Bohai Bay, it is a historical area of frequent and severe marine disasters, especially storm surge disasters. In recent years, influenced by global warming, extreme weather events have occurred frequently, and the frequency and intensity of storm surge have increased significantly, which has become one of the key disasters that threatens the safety of Binhai New District and restricts economic development. In addition, storm surges are often accompanied by violent winds and waves, and travel upstream through rivers and floods, thus often causing tidal surge and seawater backflow in the coastal areas. Tidal waves even wash away the seawalls, and devour docks, factories, towns and villages, thus causing great disasters. In order to further strengthen the protection of coastal wetlands, enhance the ecological service function and build an ecological security barrier system, the China-Singapore Tianjin Eco-city has launched marine ecological disaster reduction and remediation measures in this area.

The overarching considerations of this case is to showcase the building of harmonious relations between people, the harmonious coexistence between people and economic activities, between people and environment, and the development of a resource-saving and environment-friendly society. To this end, the marine ecological disaster reduction and remediation measures have been implemented for the China-Singapore Tianjin Eco-city have been implemented, and the wetland remediation in the sea area outside the seawalls and the construction of an urban ecological park inside the seawalls have been carried out as a whole at the estuary of the Yongding New River **(Figure 2)**.

Figure 2 Schematic Diagram of the Overall Layout of Case Location.

The wetland remediation area outside the seawalls covers 138 hectares, which is subject to four measures **(Figure 3)**, i.e., cutting the corner on the east side of the southern mudflat, with a project scope of 2.1 hectares; combing the terrain of the strip mudflat on the west side of the southern mudflat; elevating the mudflat adjacent to the seawall in the north; as well as garbage clearance [2]. After the remediation, the water exchange and tidal flood absorption have been obviously improved, and the vegetation has been restored, thus providing a suitable habitat for birds. With the old seawall as the skeleton, the design concept of "Green Leaf Ark" is formed by comprehensively using coastal ecological elements and combining the water system with the greenway system, and 35 hectares of ecological park and green space for urban safety protection are built **(Figure 4)**. The construction contents include soil remediation, vegetation construction, water system connectivity, trails along the seawalls, landscape nodes, service-supporting buildings and facilities, etc., with the aim of enhancing the composite functions of the coastline and creating a public activity space for ecological experience and marine observation.

Figure 3 Distribution Map of Engineering Measures in Wetland Remediation Area outside the Seawalls.

Figure 4 Plan of Wetland Park inside the Seawalls.

Issues

Under the joint influence of human disturbance and natural power, the original habitats in the land and sea areas around the region were partially destroyed, and the biological species were scarce, and the carrying capacity of the environment was weak **(Figure 5)**. There was an urgent need to adjust and restore the harmonious relationship between man and nature, city and security, and sea and land through nature-based solutions (NbS).

Figure 5 Satellite Map of the Site in 2016.

There were three main problems in the case of marine ecological disaster reduction for the China-Singapore Tianjin Eco-city before remediation. First, there was a prominent safety problem in terms of tidal resistance and flood discharge at the confluence of river and sea. Due to its location at the estuary area of Yongding New River, the site of the eco-city was supported by the land-based water at the confluence of the river and the sea, and the flow velocity dropped sharply, thus forming a certain amount of siltation, and there was a convex corner on the flood-discharging route **(Figure 5)**, which affected the flood-discharge safety at the estuary and caused the flood-discharge safety hazard between the eco-city and the seawalls. Second, the water system in the south of the eco-city was not interconnected, and the flood control and drainage capacity was insufficient; before the remediation, it was a barren mudflat inside the South Seawall **(Figure 6)**, with poor water fluidity, weak water exchange capacity, high and unstable groundwater level, as well as high soil salinity. The original soil was mainly silty clay, with a total salt content of 7.04~126.44 (g/kg) and a PH value of 7.8~8.1; and the soil had high bulk density and poor permeability. Third, the seawalls were monolithic in shape, and the mudflat blocked the land-sea connection. As a coastal flood control infrastructure, the South Seawall had a single form and monotonous function, and the mudflat inside the seawall blocked the accessibility and organic connection between the eco-city and the sea area, so it was difficult to meet people's demands for sea and sea proximity **(Figure 7)**.

Figure 6 Deserted Mudflat before Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2016)

Figure 7: High Hard Protective Seawall Blocking the Land-Sea Connection.
(China-Singapore Tianjin Eco-city Administrative Committee, 2016)

Approaches

Building "three lines of defence" with multi-functional composite ecological seawalls

From the perspective of ensuring tide-resistance safety, and giving consideration to urban development, humanity and ecological protection, it is proposed to combine "multi-functional composite ecological seawalls" with coastal wetlands, form coastal buffer green infrastructure, build up "three lines of defence" **(Figure 8)**, and establish a three-dimensional comprehensive protection system from sea to land, which greatly improves the tide-resistance and wave-proof standards of the original coastal protection infrastructure.

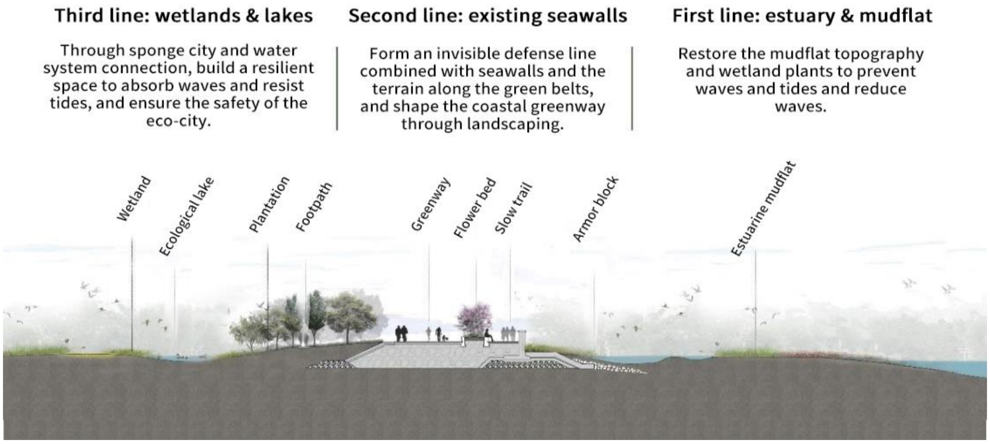


Figure 8 "Three Lines of Defense" for Coastal Protection.

The first line of defence is composed of salt marsh wetland and native mudflat plant communities outside the seawalls **(Figure 9)**, and its main function is to prevent waves and tides and reduce waves. The second line of defence is mainly based on the existing seawalls; combined with the terrain of the elevated green belts behind the seawalls, an invisible line of defence can be formed; and at the same time, the seawall section can be transformed through ecological landscaping, so as to form a coastal greenway that can meet the diverse needs of tourists **(Figure 10)**, which is effectively connected to the slow trail system of the eco-city. The third line of defence is the wetland park and lake bodies **(Figure 11)**, which can absorb waves and resist tides through sponge infrastructure and meet the tide resistance requirements in combination with area-based water system connectivity and corresponding management measures.

Figure 9 Plant Communities in Salt Marsh Wetlands and Native Mudflats outside the Seawalls. (China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Figure 10 Coastal Greenway Mainly Reconstructed along Existing Seawalls. (China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Figure 11 Wetland Park and Lake Bodies inside the Seawalls. (China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Creating a demonstration of coast with sustainable ecological resilience

The newly-built culvert and sluice outside the seawalls is connected with the Nanwan Water System and flows into the sea **(Figure 12)**. At the same time, the flood and waterlog of the southern water system can be automatically discharged by using the existing inner culvert and sluice of Shell Ridge Park, thus realising the connection of the southern water system, and the total storage capacity of the recirculating water system can reach 860,000 m^3. In this case, an integrated underground rainwater pumping station has been built to transport 300,000 m^3 of rainwater to the wetland park every year, providing greater flexibility and resilience to urban rainfall flood management.

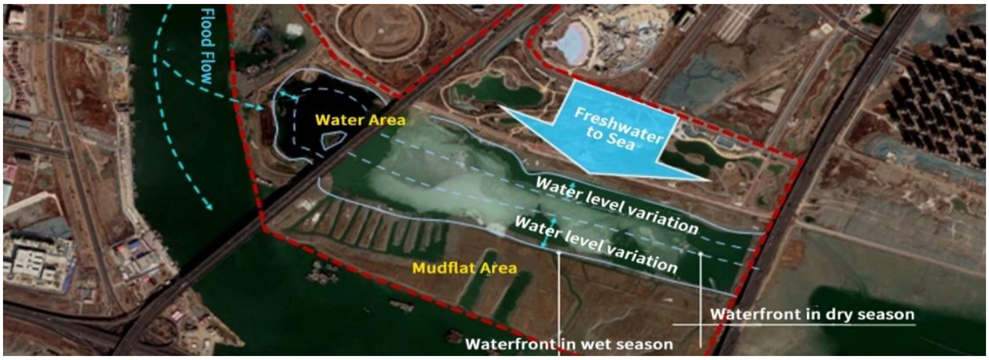


Figure 12 Schematic Diagram of Water System Connectivity outside the Seawalls.

The interior of the South Seawall Coastal Trail Park inside the seawalls is connected with pipelines and buried culverts, thus forming an ecological circulation in the water system **(Figure 13)**. Through permeable pavement, rainwater wetland, rainwater pumping station, rainwater purification and sedimentation pond and other facilities, a “rainwater purification system” **(Figure 14)** can be constructed by planting suitable aquatic plants, so as to create a green space with multiple functions of infiltration, adsorption and slow release.

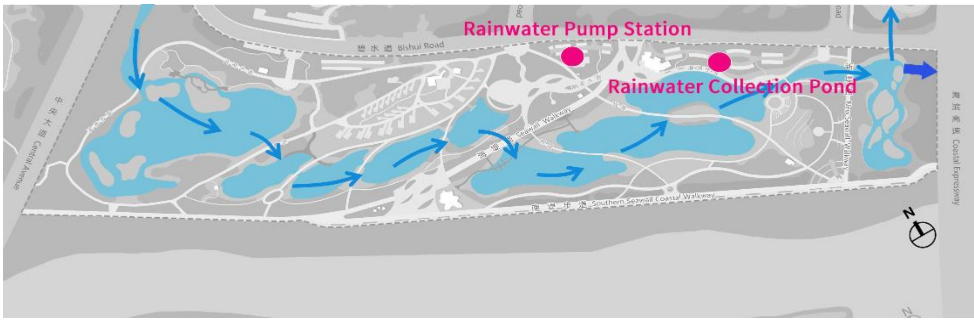


Figure 13 Schematic Diagram of Ecological Circulation in Water System.

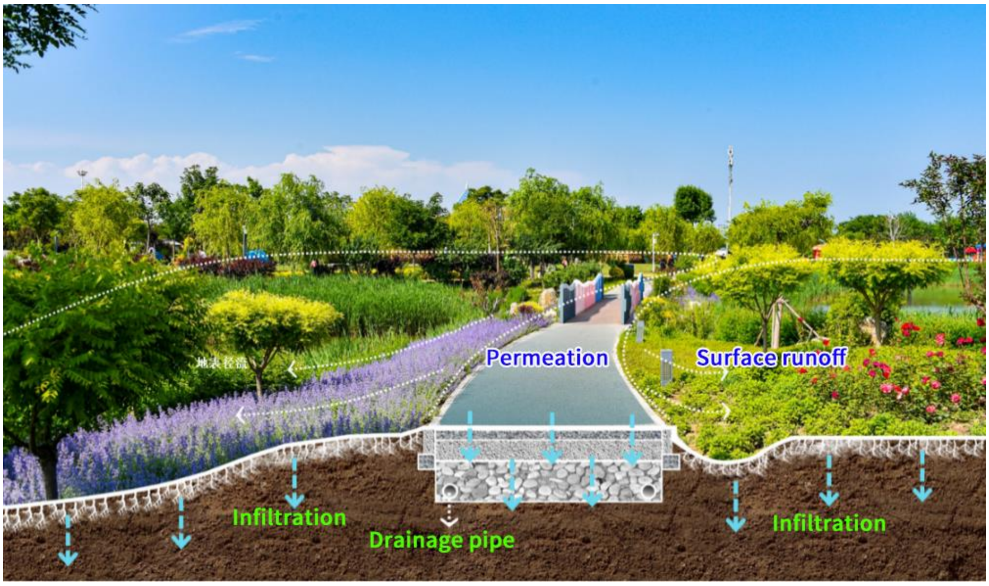


Figure 14 Schematic Diagram of Rainwater Purification System.

Protection, transformation and utilisation of new coastal heritages

The old seawall of the South Seawall built in 1950s is a precious historical and cultural memory of Tianjin coast. In this case, the planning and construction of the South Seawall Trail is based on the old seawall **(Figure 15)**. On the basis of respecting historical and realistic conditions, the value of utilizing and protecting the old seawall and the original shoreline cultural resources should be emphasised. Firstly, “greenway carriers” of urban space have been created by making use of tide-resistance seawalls and seawall patrol roads. After the transformation, the old seawall has formed a slow trail recreation system that permeates the eco-city through the links with urban greenways, railwayc stations, surrounding parks and aquatic tourism lines **(Figure 16)**, forming links and extensions to urban open spaces such as living spaces, waterfront spaces and public green spaces, so as to realise the perfection and construction of green space network and improve the value of urban public space. Second, with ancient coastal resources as the background and the sea as the theme, an “outdoor marine museum system” has been established for cultural tourism services.

Figure 15 Location Diagram of the Old Seawall and the New Seawall.

Figure 16 The New and Old Seawalls Connecting the Urban Slow Trail System after Their Construction. (China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Accomplishments

Under the policy background of Marine Ecological Civilisation construction, the construction of this case started in 2017, and was successfully completed in 2020 after three years. At the same time, according to the types and characteristics of coastal wetland remediation on the left bank of Yongding New River estuary for the China-Singapore Tianjin Eco-city, the remediation effect of the case was assessed, which met the technical requirements of the after-effect assessment of ecological remediation cases and could scientifically evaluate the effect of the coastal wetland remediation after the completion of the implementation of the case.

Linking the ecological interface between the eco-city and the sea, and comprehensively improving the capacity of marine disaster reduction

First, the multi-functional composite seawalls seamlessly link the city texture, improve the sea-loving space, and enhance the coastal ecological interface **(Figure 17)**. A certain width of space has been left for the sea lovers on the land side of the artificially-created coastline, thus building a water-friendly and sea-friendly space, and enhancing the ecological effect. At the same time, according to the multi-level needs of the public and on the basis of safety protection, a full-service and humanised ecological recreational space has been created in the construction of this case **(Figure 18** and **Figure 19)**, thus enhancing the area-based safety protection and the value of the landscape environment; and this will have a good and far-reaching impact on improving the living environment and life quality of surrounding residents.

Figure 17 Coastal Ecological Interface after Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Figure 18 Before the Completion of Ecological Recreation Space Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2016)

Figure 19 After the Completion of Ecological Recreation Space Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Secondly, after the water system in the southern part inside the seawalls is interconnected, the water storage capacity of the southern recirculating water system reaches 860,000 m3, thus enhancing the functions of flood control and drainage and rainwater regulation and storage. At the same time, the construction of a sponge city has been implemented, and the control rate of rainwater runoff reaches 90%; combined with rainwater pumping stations, storage tanks and other facilities, aquatic plants have been used to purify water bodies, thus enhancing the resilience of the eco-city and the benefits as a sponge city. In addition, it can avoid the flood relief pressure caused by the increase of instantaneous rainfall, reserve time for the discharge into the sea, ensure safety, and increase the purification by aquatic plants before the discharge into the sea, thus better meeting the water quality indicators of the discharge into the sea. Through the construction of three lines of defence with multi-functional composite ecological seawalls, the coastal buffer green infrastructure can be formed **(Figure 20** and **Figure 21)**; and the “three lines of defence” are constructed to ensure the disaster prevention and mitigation function of the coastline, eliminate the impact energy of waves through hierarchical reduction, and comprehensively improve the marine disaster reduction capability **(Figure 22** and **Figure 23)**.

Figure 20 Before the Completion of Ecological Seawall Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2016)

Figure 21 After the Completion of Ecological Seawall Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

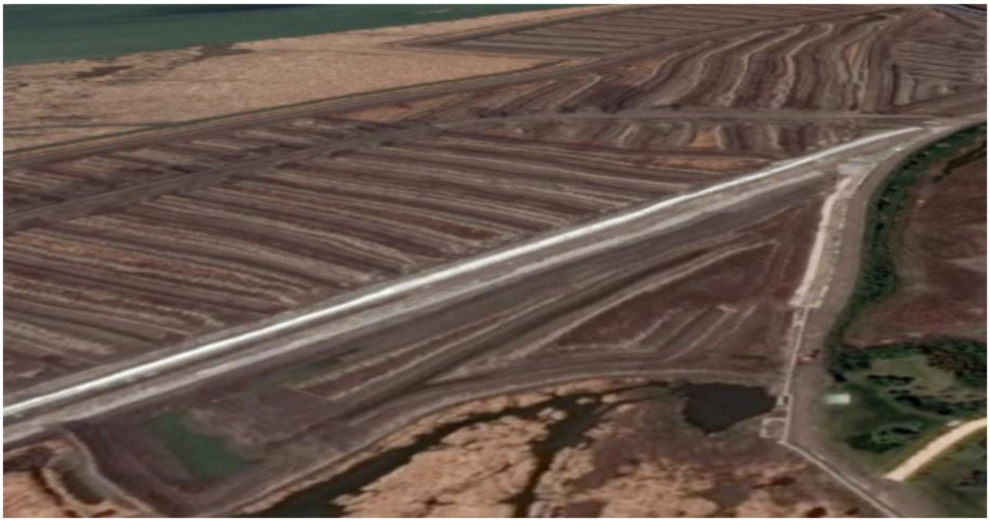


Figure 22 Land-based Satellite Image before Construction.

Figure 23 Land-based Photo after Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Habitat restoration, water environmental improvement, and significantly enhanced biodiversity

In this case, the wetland space inside the seawalls is interconnected and circulated through the water system, thus improving the self-purification ability of the water body and the regulation ability under different water levels, and restoring the natural form of the wetlands. In addition to the reserved estuarine mudflats, there are also various newly-added habitat types such as wetlands, woodlands and lakes **(Figure 24 and Figure 25)**.

Figure 24 Satellite Image before Construction.

Figure 25 Increased Diversity of Habitat Types in the Wetland Space inside the Seawalls after Construction. (China-Singapore Tianjin Eco-city Administrative Committee, 2021)

In this case, the water exchange and tidal flood absorption capacities of the estuarine wetlands outside the seawalls have been improved, and the wetland environment has also been improved **(Figure 26)**. According to the monitoring, 24 species of plants belonging to 12 Families have been found, all of which are angiosperms, with herbaceous plants accounting for 66.7% of the total species, and trees and shrubs accounting for 33.3%. The diversity index of phytoplankton has risen to 3.3, the diversity index of macro zooplankton is 1.5, and the diversity index of macro benthos is 1.6; a total of 10 species of birds belonging to 4 Orders and 7 Families have been found[1], and swimming birds and wading birds are dominant. The remediation of the coastal ecology in the case area uses nature to reshape nature in the way of natural planning, which improves the self-regulation ability and ecological resilience of the wetland system **(Figure 27)**, demonstrating the maximum value of ecological remediation and disaster prevention and reduction.

Figure 26 The Improved Wetland Environment outside the Seawalls after Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

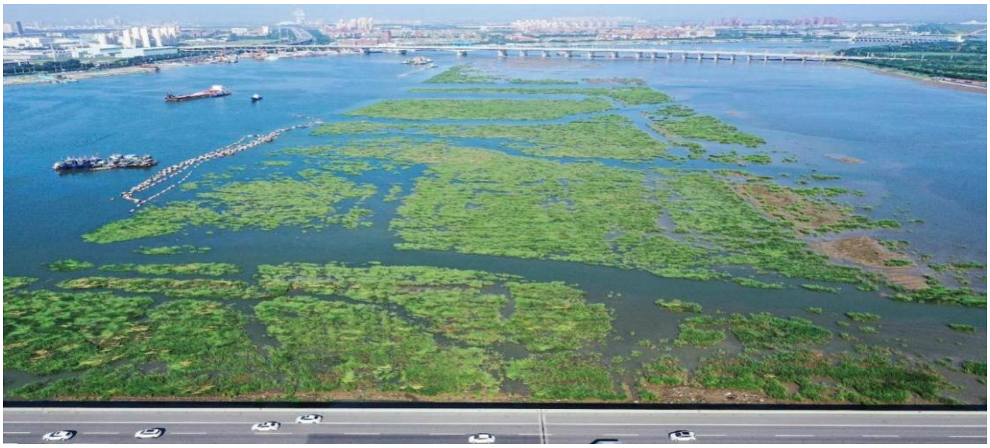


Figure 27 Wetland Environment outside the Seawalls after Construction.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Highlighting the historical and cultural value of seawalls, and enhancing the experience of public participation

On the one hand, the new and old seawalls are urban memories built on the basis of craftsman spirit, and they are also important natural, historical and cultural heritages. Through the construction, upgrading and ecology-oriented development of the new and old seawalls, the single tide-resistance function of seawalls has been expanded into urban leisure trails and coastal water-loving spaces, so that the historical context of seawall culture is organically integrated into the construction of wetland parks, the content of historical science popularisation is increased, and the historical memory rings of Tianjin people's symbiosis with the sea are preserved. Characteristic elements have been explored from the ancient coast and the historical changes of the coast, the protection and renovation of the old seawall, and the social living environment, then transformed and upgraded them into a new type of recreation space **(Figure 28)**. Combined with the local history and environmental conditions, the new concept of “new coastal heritage” protection, transformation and utilization has been put forward first in China and put into practice, which has an important demonstration effect for the modern coastal cultural heritage preservation, activation and protection.

Figure 28 Transformation and Upgrading of the Old and New Seawalls into Recreation Space. (China-Singapore Tianjin Eco-city Administrative Committee, 2021)

On the other hand, the communities' experience of public participation has been improved, and a green space shared by the masses has been created. First, the Nandi Coastal Trail is an important section of the sea-watching fitness theme route in the greenway system of the China-Singapore Tianjin Eco-city. By using the southern seawall, tide-resistant seawalls and park roads, a fitness trail of about 8 km has been created, thus providing various functions such as walking, jogging and cycling; and it has become a public space for citizens' fitness, sports and recreation **(Figure 29)**. Second, a tourist station and a service centre for the convenience of people **(Figure 30)**, Kid's Park, Grass-Stepped Stage, Qiulan Pavilion and other activity places have been established, and convenient facilities for people such as guide maps, information desks, light catering and outdoor camping have been arranged, thus further enriching people's public activity space, meeting the diverse needs of tourists and citizens, integrating rich cultural activity scenarios, and promoting the construction of healthy cities and communities.

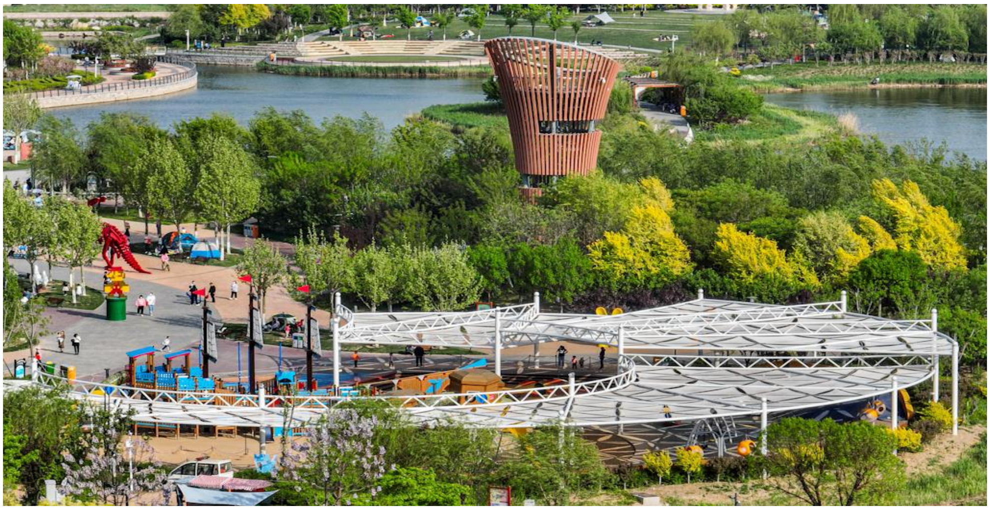


Figure 29 Public Space for Citizens' Fitness, Sports and Recreation.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Figure 30 Service Center for the Convenience of People.
(China-Singapore Tianjin Eco-city Administrative Committee, 2021)

Extensive Support of Experts, Scholars and All Sectors of Society

The implementation of this case integrates the functions of urban safety protection, coastal ecological conservation and coastal leisure and recreation. Since its opening to the outside world, it has been widely praised by social media, experts, scholars, and the public. Xinhuanet, CCTV-1, CCTV-13, people.com.cn, Xinhua News Agency, Tianjin Daily, People's Daily and many other media reported and reprinted related news **(Figure 31)**. The case planning and design scheme won the Second Prize of Science and Technology (Planning and Design) of the Chinese Society of Landscape Architecture in 2020, the third Prize of National Excellent Urban and Rural Planning and Design in 2017, and the first Prize of Tianjin Municipal Excellent Urban and Rural Planning and Design, and was included in the 2021 Tianjin Municipal Collection of Excellent Cases in Planning Sector. The project’s construction won the Second Prize of Science and Technology (Landscape Engineering) of the Chinese Society of Landscape Architecture in 2020.

Figure 31 Related Media Reports.

Alignment with IUCN Nature-based Solution Global Standard

The project has carried out self-assessment according to the *IUCN Global Standard for Nature-based Solutions (NbS)* officially issued by IUCN in 2020, and the assessment results are as follows (**Figure 32**):

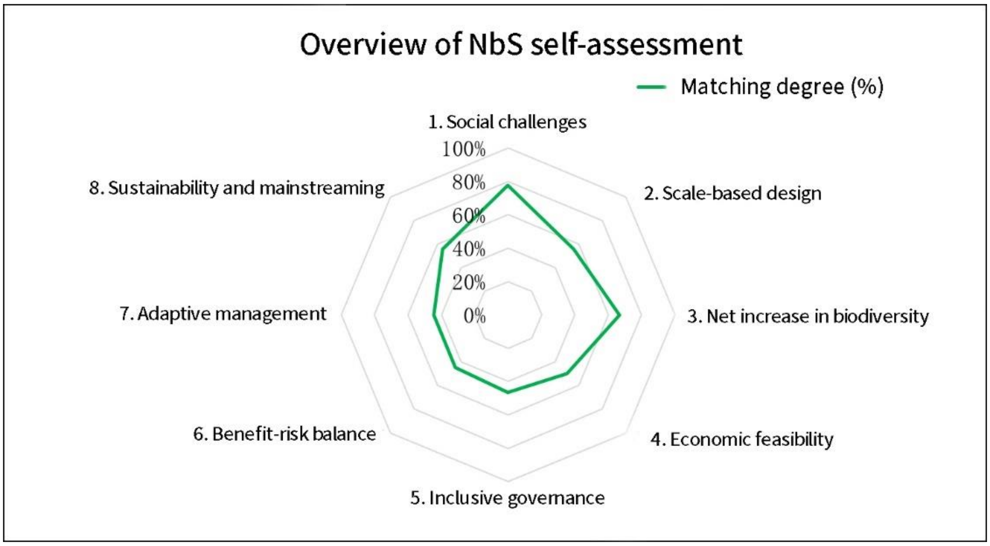


Figure 32 Alignment with NbS standard self-assessment.

Several social challenges, including disaster prevention and reduction, economic and social development, and environmental degradation and biodiversity loss, have been effectively identified and addressed. In line with the policy of constructing a marine ecological civilisation, the project has actively sought innovative approaches for marine ecological protection and remediation. This has involved coordinating the remediation of coastal wetlands, the construction of the South Seawall Coastal Trail Park, and the establishment of a composite land-sea ecological buffer zone.

As a result, a coastal space has been created wherein people can harmoniously coexist with nature, aligning with the criterion set for addressing social challenges (Criterion 1). The present situation has been properly assessed in time and space scales; in the process of implementation, a monitoring and assessment system has been established; specific measurable indicators have been set up; the “three lines of defense” consisting of mudflats outside the seawalls, seawalls and wetlands inside the seawalls has been constructed; a three-dimensional comprehensive protection system has been established from sea to land; and the connectivity of ecosystems has been identified and strengthened; it is basically consistent with the net increase criterion of biodiversity (Criterion 3).

The interactions among economy, society and ecosystem have been identified, and the multi-functional composite landscape seawalls have been constructed from the perspective of “ensuring tide-resistance safety and giving consideration to urban development, humanities and ecological protection”. However, the project did not specify cross-sectoral synergy or related complementary interventions, so it basically matched with the scale-based design criterion (Criterion 2).

As the world's first eco-city jointly developed between two countries, the China-Singapore Tianjin Eco-city provides a demonstration and leading role for the governance and remediation of esturaine bays, coastal wetlands, and shorelines, which basically matches with the sustainability and mainstreaming criterion (Criterion 8). The direct costs of the project have been identified, and the value of ecological civilization brought about by implementation indirectly indicates its cost-effectiveness, which basically matches with the economic feasibility criterion (Criterion 4).

Although the decision-making process has been documented, stakeholders have only been identified to a limited extent, and there is no feedback or grievance mechanism, partially matching with the inclusive governance criterion (Criterion 5).

While potential benefits of the project have been identified, no detailed cost-benefit analysis has been performed. The project ensures the stability of ecosystems and landscape by regularly checking safeguard measures, but it lacks specific analysis on the rights and responsibilities of stakeholders on land and natural resources, which partially matches with the benefit-risk balance criterion (Criterion 6). Although area-based biodiversity has been monitored and evaluated during implementation, it is not clear if an iterative learning framework has been established to improve and adjust the intervention measures, which partially matches with the adaptive management criterion (Criterion 7).

Recommended by: Tianjin Municipal Bureau of Planning and Natural Resources

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Ecosystem-based Disaster Risk Reduction: A Case Study of the South Coast of the Yellow River Estuary, Dongying, China

Introduction

Dongying is situated in the middle of the Yellow River Delta, located in the northern part of Shandong Province. The city encompasses the Yellow River estuarine area within its boundaries. The terrain of Dongying follows the southwest to northeast course of the Yellow River, and the region experiences a warm temperate continental monsoon climate. As of the end of 2022, the city has a population of approximately 2,209,000 residents. Currently, Dongying has established five distinctive industries, namely petrochemicals, rubber, petroleum equipment, non-ferrous metals and new materials. In addition, the city has developed two advantageous industries, modern efficient agriculture, and cultural tourism, along with two high-tech sectors, biomedicine, and aerospace. In 2022, Dongying's GDP reached CNY 360 billion.

The Yellow River estuary region, situated at the intersection of Bohai Bay and Laizhou Bay, encompasses the near-estuary segment of the river, the delta, and the coastal area. This region boasts the most comprehensive, typical, and youthful coastal wetland ecosystem in China and even globally. It serves as a crucial indicator of the ecological health of the Yellow River basin and acts as a valuable germplasm resource bank. Additionally, it functions as a spawning and breeding area for marine creatures in the Yellow River-Bohai Sea region. Moreover, it serves as an important stopover site along the West Pacific Flyway and the East Asian-Australasian Flyway. The estuarine and coastal wetland protection in this area is vital for maintaining the ecological security of the Yellow River basin and the surrounding region.

Marine disasters in the Yellow River estuary region are dominated by storm surges, waves and sea ice. There are clear seasonal patterns in their occurrence, with storm surge and wave disasters occurring more frequently in spring and autumn when cold air is active, and sea ice disasters occurring more frequently in mid-winter. Since 2018, two to five storm surge disasters and 10 to 15 wave disasters have occurred annually in

Dongying. Regional storm surge disasters have high intensity and destructive power. For example, Super Typhoon Lekima in 2019 caused economic losses of CNY917 million while passing Dongying, of which CNY594 million was lost in marine fisheries, CNY35 million in coastal protection works, and CNY288 million in other losses.

The Chinese Government attaches great importance to the ecological protection of the Yellow River basin. President Xi Jinping has repeatedly given important instructions on the ecological protection of the Yellow River Delta, pointing out that "the downstream of Yellow River Delta is the most complete wetland ecosystem in China's warm temperate zone, and it is necessary to protect the region to assure promoted health of the river ecosystem and improved biodiversity " [1].

In order to further enhance the regional marine ecological environment and strengthen disaster risk reduction capacity, Dongying has carried out the ecosystem-based disaster risk reduction (Eco-DRR) project for the coastal salt marshes on the south of the Yellow River estuary since 2019. The specific location of the restoration is the coastal area on the south of the Yellow River estuary **(Figure 1)**.

According to the different restoration sites and measures, the area is divided into three subzones, namely the Kendong Salt Marsh Subzone, the Xiaodaohe River North Subzone and the Yongfenghe River-Xiaodaohe River Bank Subzone. Through a package of differentiated restoration measures, such as restoring fisheries wetlands, dredging tidal ditches, modifying micro-topography, restoring coastal salt marsh vegetation, constructing oyster reefs, transplanting seagrass beds and ecological treatment of aquaculture effluent, a total area of nearly 2,200 hectares has been restored, with 18 km of tidal ditches dredged and 13 km of wetlands restored. 13 km of tidal ditches were dredged and 5.33 km of shoreline was restored, improving the ecosystems and biodiversity of the region. It has achieved the expected synergy between ecology protection and disaster risk reduction, and a new situation of harmonious coexistence between human beings and the sea.

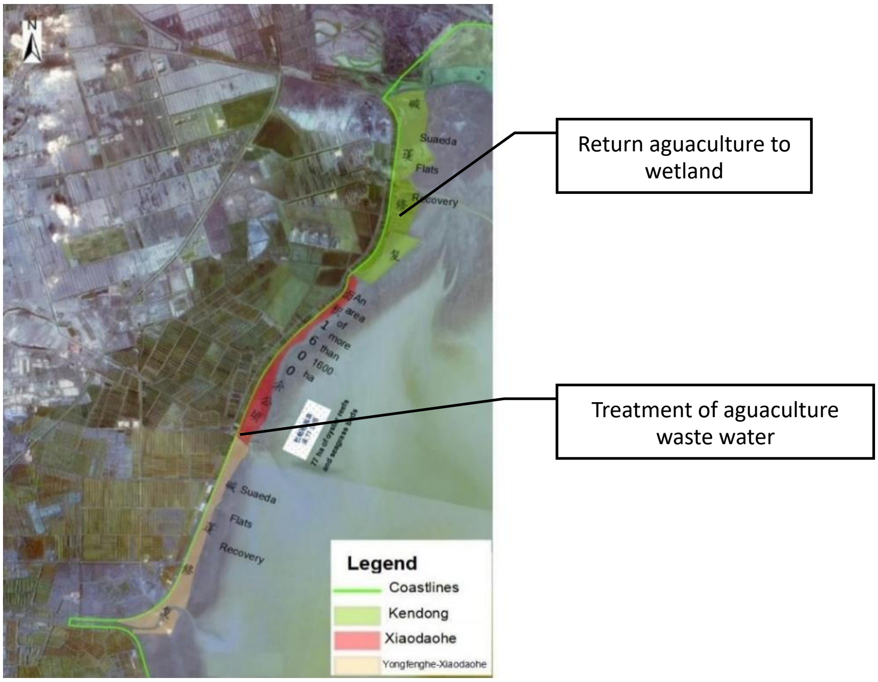

Figure 1 The overall regional landscape in the case.

Issues

Along the south coast of the Yellow River estuary in Dongying, *Suaeda salsa* was distributed over large areas, forming a typical “red carpet”, and oyster reefs and seagrass beds were concentrated in some parts of the coast, with a variety of ecosystems and a rich biodiversity of birds and other organisms. The area not only has high ecological value, but also provides a natural barrier against marine disasters such as storm surges, waves and red tides.

During the 1980s and 1990s, the deserted beaches in the region underwent gradual development and utilization, leading to an increase in the area of aquaculture ponds. While this promoted the growth of marine fisheries and the income of fishers, it also brought to light ecological issues and heightened disaster risks. The natural shoreline suffered damage, resulting in an elevated vulnerability to marine disasters. Since 2012, Dongying has actively put in place the concept of marine ecological conservation, and has witnessed the regional function shift from fishery production to ecological protection with initial improvements in ecosystem services.

However, Dongying still faced obstacles in ecological conservation and disaster risk reduction. Firstly, numerous abandoned aquaculture facilities remained, and the tidal channel in the region became silted and disappeared, leading to a reduced seawater exchange capacity (**Figure 2)**. Secondly, the encroachment of aquaculture ponds on the coastal wetland caused visible degradation of vegetation in the coastal area, resulting in shrinking "red carpet" areas and the emergence of bare beaches. Thirdly, human activities such as fishery and harbour construction led to the gradual disappearance of oyster reefs and seagrass beds, posing serious threats to ecosystem health and species diversity. (**Figure 3**). Thirdly, oyster reefs, seagrass beds and other ecosystems gradually vanished as a result of human activities such as fishery and harbour construction, posing serious threats to ecosystems and species diversity. Fourthly, the degradation or even disappearance of various ecosystems damaged the natural barrier of shoreline protection, making nearshore ecosystems more fragile and bringing a greater risk of marine disasters.

Figure 2 Abandoned aquaculture farms. (Pan Guangdao, 2019)

Figure 3 The wetland vegetation was heavily damaged. (Pan Guangdao, 2019)

Approaches

Building an integrated protection system of seawalls-vegetation-tidal flats

To address these challenges, Dongying undertook restoration efforts, including the creation of over 500 hectares of wetlands, dredging 18.13 km of tidal ditches, and implementing microtopography modifications. Leveraging the suitable conditions of vegetation habitats in different ecosystems, Dongying carried out three-dimensional vegetation restoration and recovery, resulting in increased vegetation coverage through native seed planting, specifically Suaeda salsa. More than 1,600 hectares of native salt marsh vegetation were restored, and oyster reefs and seagrass beds were established in a 77-hectare region. These efforts significantly contributed to the recovery of ecosystem diversity and stability, fostering a gradient pattern of multi-level ecosystem restoration. Ultimately, an integrated protection system combining seawalls, vegetation, and tidal flats was established. (**Figure 4**).

Figure 4 An integrated protection system of seawalls-vegetation-tidal flats.
(Zhao Yingli, 2021)

Strengthening technology-led restoration for a promoted eco-DRR of the native salt marshes

The case focuses on the research and development of marine eco-DRR technology and application, involving a number of scientific research organisations to have participated in the restoration and disaster risk reduction technology for breakthroughs. Their input served as strong support for the success of the coastal salt marsh restoration including native *Suaeda salsa* recovery.

Firstly, Dongying prioritized the selection and breeding of *Suaeda salsa* vegetation, following the concept of native ecological restoration. By collecting, selecting and retaining local suitable germplasm resources in similar ecological areas, it solved the problem of seedling resilience, significantly improving the survival rate of vegetation in the restoration area. Secondly, it implemented the measure of “grass square” which greatly reduced the impact of wind and waves, and created a suitable micro-ecological environment for retaining seeds and seedlings of the *Suaeda salsa* vegetation. Thirdly, in response to the extreme weather conditions in late spring and early summer, the region adopted responsive seawater sprinkler to ensure the irrigation water of the *Suaeda salsa* and improved the survival rate of seedlings.

Innovating “1+N” long-term model of management and conservation

In order to ensure the effectiveness of eco-DRR, Dongying has developed an innovative approach called the "1+N" model for long-term management and conservation. This model, guided by eco-DRR principles, involves one year of restoration ("1") followed by long-term conservation efforts ("N").

Under this model, a yearly budget is allocated and approved by local finance authorities. Scientific research organizations and enterprises involved in the restoration project are mobilized to carry out post-restoration maintenance work, establishing a long-term stable mechanism.

For example, to address the vulnerability of *Suaeda salsa* vegetation to tidal waves, Dongying collects germplasm resources of the plants in the same location and year. These resources are then replanted the following spring, with timely irrigation using sprinkler facilities to ensure a high seedling and survival rate. This approach maintains a higher level of ecological indicators such as vegetation cover, density, and height, leading to long-term stability in the vegetation condition.

Through the implementation of the "1+N" model, the effectiveness of marine eco-DRR is strengthened, and the ecosystem's ability to self-regulate and naturally recover is enhanced. This ultimately achieves long-term, stable, and natural ecological protection and disaster risk reduction in the region.

Accomplishments

Creating synergy between marine biodiversity conservation and disaster risk reduction

The 20-km vegetated area, mainly consisting of *Suaeda salsa*, has played a crucial role in protecting dikes and beaches from tides and waves. With an average width of about 800 meters and a plant density of 30 plants per square meter, it effectively reduces the impact on seawalls and improves the resilience of the coastal area in preventing and mitigating disasters. In the high tide area of the intertidal zone, where *Suaeda salsa* is located, the water depth at normal tide level is generally below 1 meter, and the attenuation rate of wave height can reach more than 50%.

The implementation of regional eco-DRR in Dongying has garnered valuable experience in efficient disaster mitigation, setting an example for future marine disaster risk reduction endeavors.

Substantial increase in biodiversity and carbon sequestration

With the restoration of the area, the landscape of the coastal area, which was originally fragmented by fishery facilities, has been completely changed (**Figure 5** and **Figure 6**): The ecosystems of coastal salt marshes, oyster reefs and seagrass beds have been effectively restored, and the biodiversity has been significantly improved. In recent years, the number of bird species in the Yellow River estuary has increased to nearly 400, and national-level protected animals such as Oriental White Stork (*Ciconia boyciana*) and

Black Storks (*Ciconia nigra*), as well as geese, sea cormorants and trumpeter swans in large groups often appear in the restored area (**Figure 7**). After restoration, the effect of carbon sequestration sees a significant enhancement [2]. It is estimated that the annual carbon sink of the coastal salt marshes in the region has increased by about 5,000 tonnes of carbon dioxide, which has greatly improved the carbon sink capacity of the region.

Figure 5 Pre-restoration of the Kendong saltwater ditch. (Zhao Yingli, 2019)

Figure 6 Restored Kendong saltwater ditch. (Zhao Yingli, 2019)

Figure 7 Sea cormorants in a large group appeared in the restored area.
(Zhao Yingli, 2019)

Expanded access to seas and a booming recreation industry

The implementation of regional eco-DRR has brought back the endless and spectacular red beach wetland (**Figure 8**). Against the blue sky and white clouds, flocks of birds soar through the crystal clear waters and ruby-colored beaches. This picturesque scenery has transformed the restored area into a paradise for photography enthusiasts and birdwatchers, attracting a growing number of visitors seeking leisure and holiday experiences. The improved regional ecology has not only enhanced the aesthetic appeal but also expanded public access to the sea, significantly boosting the influence of the tourism and leisure fishery industry in the area and its surroundings. As a result, the area has become a sought-after destination for eco-tourism.

The recognition and publicity of the restored area have been widespread, with China Central Television (CCTV), local TV stations, and online media featuring numerous reports on the region's transformation. The efforts in regional marine eco-DRR have garnered extensive support and assistance from all sectors of society.

Full public participation and raising awareness of marine eco-DRR

The restored area has emerged as a vital sampling and survey site for various scientific institutions and social organizations. These entities conduct bird censuses and study foraging behaviors, providing essential baseline data for bird sightings, habitats, conservation measures, and management effectiveness.

Furthermore, Dongying has established a "National Marine Science Education Base" to actively disseminate knowledge about marine organisms, habitat interdependencies, and the ecological and social values of local habitats. The role of local vegetation in mitigating disaster risk is also emphasized, promoting awareness and education about the importance of marine ecosystems to the public.

Figure 8 The restored “Red Carpet” on the Yongfenghe River-Xiaodaohe River bank. (Zhao Yingli, 2019)

Alignment with IUCN Nature-based Solution Global Standard

The project team has performed a self-assessment of alignment with IUCN Global Standard for Nature-based Solutions (NbS) officially released in 2020. The results are as follows (**Figure 9**).

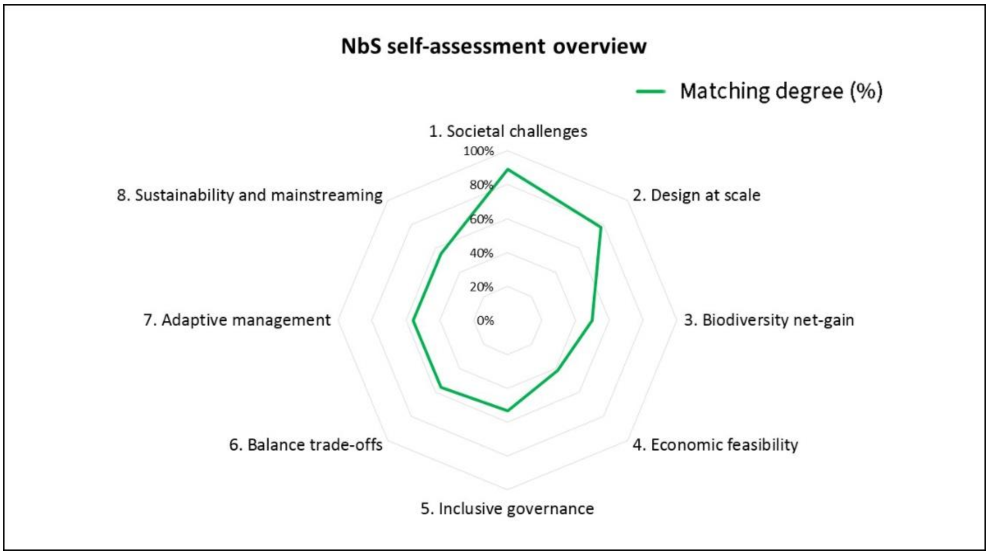

Figure 9 Alignment with NbS standard self-assessment.

The case study offers valuable insights into the complex social challenges faced in the coastal area of Dongying, encompassing climate change mitigation and adaptation, disaster risk reduction, human health, ecological degradation, and biodiversity loss. It provides a comprehensive understanding of the drivers and responses to these challenges.

Significant achievements in human well-being, including the overall enhancement of disaster risk reduction capacity and improved public access to the sea, demonstrate a strong adherence to Criterion 1, which focuses on addressing social challenges. The project recognizes marine hazards and effectively achieves disaster risk reduction effects through its implementation. Collaboration with the Shandong Yellow River Delta National Nature Reserve and scientific research institutes has facilitated monitoring, assessment, disaster prevention, and mitigation efforts, as well as expanded public sea access, anticipating unanticipated changes. This aligns with Criterion 2, facilitating a design at various scales.

Detailed mappings of ecological status and drivers of ecosystem degradation, along with improvements in biodiversity resulting from the project, demonstrate compliance with Criterion 3, which emphasizes biodiversity net gain. Extensive consultation with stakeholders and the establishment of feedback and complaint mechanisms ensure that the interests of all affected parties are considered. The decision-making process takes into account the perspectives and concerns of participating and related stakeholders.

Additionally, the areas of intervention are identified based on jurisdictional boundaries, promoting inclusive governance in line with Criterion 5.

The project incorporates a comprehensive cost-benefit analysis, considering temporal and spatial dimensions, rights, land, resource use, access, and responsibilities. Trade-offs are agreed upon and respected, meeting the trade-off criterion (Criterion 6). An eco-DRR strategy with clear expected outcomes, actions, and assumptions guides monitoring and assessment during both the design and implementation phases. The project employs an adaptive management approach, as evidenced by the development of an eco-DRR monitoring and evaluation plan, ensuring a complete learning hierarchy framework (Criterion 7).

The experiences and lessons learned in marine disaster risk reduction are effectively shared with relevant audiences. The project design incorporates relevant policies, regulations, and laws, while aligning with national and global targets related to regional populations, climate change, and biodiversity. This demonstrates a commitment to sustainability and mainstreaming (Criterion 8).

Consideration of direct and indirect costs and benefits, alongside cost-effectiveness analysis and identification of viable alternatives, aligns with the economic feasibility criterion (Criterion 4). While primary long-term funding sources and additional resources are identified, securing them remains a pending task.

Overall, the project demonstrates a strong commitment to adhering to the standards outlined, highlighting its efforts to address societal challenges, achieve sustainability, and ensure effective economic feasibility.

Recommended by: Oceanic Administration of Shandong Province

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Sand Coast Revegetation and Restoration of Binhai New City, Fuzhou, China

Introduction

Fuzhou Coastal New City is located on the eastern coast of Fujian, bordering the west coast of Taiwan Strait. It connects Fuzhou International Airport to the north and Songxia Port to the south. The city spans a total planning area of 188 km^2, and is expected to accommodate 1.3 million residents. The surrounding area boasts abundant natural resources, including 55 km of coastline and 25 km of sandy beaches. The Min River Estuary National Wetland Reserve has an area of 21 km^2, the East Lake Wetland with an area of 15 km^2, and the Zhanggang Mussel Enhancement Reserve of 207 km^2. These reserves serve as critical wintering grounds and habitats for rare bird species such as the Chinese Crested Tern and Black-faced Spoonbill.

Currently, Fuzhou Coastal New City is steadily progressing in line with President Xi Jinping's strategic direction of "moving eastward and going southward, heading towards the sea along the river." The city adheres to a development policy centered around creating an "innovation highland, open gateway, livable home, and ecological green city." In 2021, Fuzhou New District achieved significant economic growth, with a gross domestic product of CNY271.2 billion, marking a 9.8% increase from the previous year. Additionally, fixed asset investment amounted to CNY177.8 billion, reflecting a 15.1% increase from the previous year. The living environment in the Coastal New City has notably improved, benefiting over 300,000 residents [1].

Geographically, Coastal New City is highly vulnerable to marine disasters due to its open coasts and direct access from the Pacific Ocean. The region experiences severe natural disasters, including winds, floods, and droughts. The storm surge hazard level of the Fuzhou Coastal New Area is classified as Class I[2]. In 2018 alone, the city was affected by nine tropical cyclones, with Typhoon Maria No. 8 resulting in direct economic losses of approximately CNY360 million. The Coastal New City is also susceptible to wind and sand disasters, as demonstrated by the burial of the historic Xianying Palace, unearthed during the construction of Fuzhou Changle International Airport in 1992. The degradation of the coastal zone's disaster prevention and mitigation capabilities is a pressing issue that significantly impacts economic activities and the livelihoods of the region's residents, who face marine disasters throughout the year. Industries such as agriculture, forestry, animal husbandry, fishery, and transportation experience substantial economic losses, particularly during typhoons and heavy rainfall events.

To enhance the ecological services and disaster prevention capabilities of the coastal zones, Fuzhou City launched a coastal zone protection and restoration program in the Coastal New City in August 2020. The program comprises three major projects: forest restoration and construction for coastal defense, beach consolidation and maintenance, and restoration of wetland habitats behind the embankment. Its goals include the restoration and construction of 215 hectares of forest belts for coastal defense north of Changle County, conservation efforts for 5.3 hectares of beaches north of Changle Airport, invasive plant removal encompassing 129.3 hectares in the wetland behind the Waiwenwu seawall, the restoration of 61 hectares of wetland and forests to support bird habitats in Donghu Lake, and the revitalization and consolidation of 84.6 hectares of deserted sandy land. (**Figure 1**) [4].

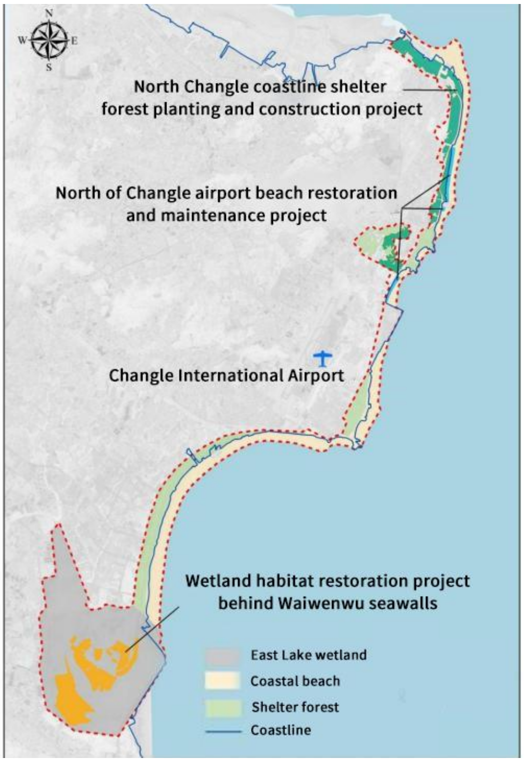

Figure 1 Spatial layout of a coastal ecological barrier with defense forest, restored beaches and wetland.

Issues

The coastline of Coastal New City is dominated by natural shorelines, with sandy beaches covering more than 80% of its length. Stressors from human activities and natural processes have resulted in the degradation of coastal forest quality, beach erosion, wetland ecological degradation and other related problems. Specifically, the impact of human activities and the reduction of sand carried downstream by the Min River have led to the disappearance of the geomorphological features of sand dunes and the retreat and loss of sand-based shorelines (**Figure 2**). In the past 10 years, 23 km of sandy coastline has eroded, with an average retreat or setback of 39 metres. The tree species of the coastal shelter forest in the northern coastal New City, Casuarina equisetifolia, mostly planted in the 1970s and 1980s, is characterised by old age, monoculture, simple structure and forest belt hierarchy, low quality forest stands and a significant decline in ecological integrity, wind protection and sand fixation **(Figure 3)**. In the East Lake wetland, uncontrolled and poorly planned development and land use has resulted in the establishment of numerous aquaculture ponds and associated severe environmental impacts. Spartina alterniflora has invaded 129.3 hectares in areas with serious encroachment on native species habitats and consequent degradation of some wetland ecological functions. (**Figure 4**).

Figure 2 Degradation and destruction of beach resources.
(Fuzhou New District Administrative Committee, 2020)

Figure 3 The aging shelter belts.
(Fuzhou New District Administrative Committee, 2020)

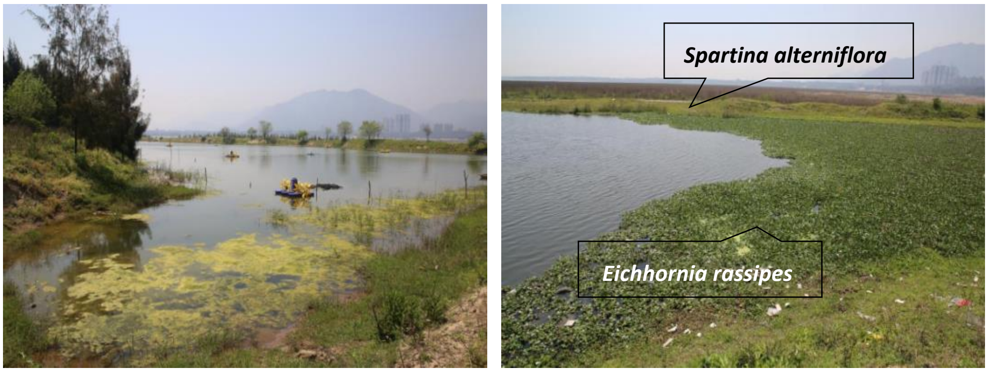

Figure 4 Eutrophication of wetland water bodies and invasion of exotic species.
(Fuzhou New District Administrative Committee, 2020)

Approaches

Stratifying nature-based wind defense system

Respecting laws of nature is adopted as a principle in stratifying the wind defense system. In practice, the land beyond the beach was replenished with the flagship tree species *Casuarina equisetifolia* to strengthen the existing shelter-forest belt mixed with suitable plant species to optimize the community structure. Hierarchically, an integrated shelter-forest wind defense system consisting of *Casuarina equisetifolia* and mixed forests (*Casuarina equisetifolia* and *Araucaria cunninghamii*) (**Figure 5**) was built with enhanced self-regulating capacity and biodiversity. On the coast, an artificial beach restoration method was implemented to stabilize the beach structure through engineering measures, including replenishing beach sand and revegetating the backshore. Through this method, sand accumulates slowly on the seaward side of the shelter forest, thereby ensuring the beach remains stable. Through implementing the stratification concept of intercepting sands with backshore vegetation and maintaining sands with shelter-forest, it is possible to avoid the historical tragedy of the “burial by sand of Xianying Palace” while constructing an ecological seawall that comprises of stable beaches, backshore vegetation and shelter-forests, respecting the natural shoreline. This approach has significantly enhanced the ability of coastal green infrastructure to defend against wind and attenuate waves. It serves as a model for marine disaster mitigation, providing reliable ecosystem services and abundant biodiversity.

Resource use efficiency

A series of surveys and scientific research were conducted on the ecological suitability of the substrate, stability of the beach and costs and benefits of restoration options. In addition, the issue of sedimentation and the need for regular dredging in the Min River channel was examined. Based on the research findings, sands with a mesh size of 0.2-1mm from the Min River estuary were dredged from the river channel and used to replenish the beach. A total of 15.3 hectares of beach restored and maintained by replenishing 486,000 cubic metres of sand, including 210,000 cubic metres dredged from the river channels. The restored beaches have achieved a dynamic balance in natural evolution and human impact was minimized as much as possible.

Selecting suitable and mixed plant species

Research and experimentation are required to identify species that are tolerant and resistant to wind, salt, drought, and low nutrition to establish vegetation on sandy ground. The target species for the restoration of vegetation on the sandy layer behind Changle beach as a barrier to prevent wind, fix sand and enhance the coastal landscape are *Sesuvium portulacastrum* and *Ipomoea pes-caprae*. Based on the historical record of the distribution and growth characteristics of tamarisk in Fujian Province, the first innovative research on tamarisk introduction was conducted and demonstrated in a sandy coastal zone. The research began by establishing a tamarisk introduction demonstration base to investigate the planting of various tamarisk species, and was followed by research on the survival rate of the reintroduced species. The reintroduced flora attained a 90% survival rate, displayed good growth overall, and is anticipated to serve as another pioneer species for planting alongside *Casuarina equisetifolia* to establish a coastal defence system using a blend of trees and shrubs.

Figure 5 The sandy plant species before and after the introduction of tamarisk.
(Fuzhou New District Administrative Committee, 2023）

Returning land use to wetland for natural recovery

The backshore wetland of the Waiwenwu seawall was enlarged by 61 hectare through returning aquaculture farms to wetlands supported by alternative livelihood programs to form the East Lake wetland forest as bird habitats. A further 84.6 hectares of abandoned sandy land was transformed into vegetated areas while 129.3 hectares of coastal wetlands were cleared to eradicate invasive species such as Spartina alterniflora and Eichhornia crassipes. Originally, separate fishponds were connected to integrate the water systems, transforming them into cohesive living bodies of water with enhanced water quality achieved through self-regulation. This fosters the natural recovery of ecological habitats without any development or exploitation activities. Efforts have also been taken to bolster the safeguarding of biodiversity and the management of the developed region to ensure the sound ecological growth of the East Lake wetlands and habitats for migratory birds (Figure 10). Connection between land and sea has been established by making use of defense facilities and increasing the exchange capacity of land and sea.

Public consultation and participation

Before construction, local governments, enterprises, villagers and other relevant stakeholders were fully consulted and their opinions were solicited. A long-term mechanism for joint construction and results sharing was also established. In terms of the authorities, Fuzhou New District has consistently adhered to the principle of "disaster preparedness with consideration of local requirements" during the entire urban planning and development process. The needs of various stakeholder groups were taken into account to the extent feasible. The New District has set aside a strip of land with a width of 300-500 metres along the coast for the purpose of constructing coastal defence forests. With consent of enterprises and villagers, 167 hectare of farms and 15.7 hectare of buildings were developed into forested areas along the coastal zone. Upon completion of the program, a coastal disaster reduction achievement display platform will be built to integrate achievements, science education, data utilization and ecological and cultural promotion. It is anticipated that by means of diverse publicity and educational campaigns, the general public, including tourists, will be drawn to the cause, with a greater appreciation of nature's role, leading to increased support for marine disaster reduction. This should lead to reduced losses for people and property.

Accomplishments

Stratified green infrastructure against wind and coastal erosion

Through sand replenishment and maintenance of the beach and construction of a coastal shelter-forest belt, a 7.5-km-long stable beach with an average increase of 30 meters of dry beach landward and a 5.5-km-long, 500-m-wide coastal shelter-forest belt were restored, which have significantly improved the capacity to resist marine disaster risks from typhoons and storm surges, and to attenuate wind and sandstorms. According to post-program modelling, the wave height attenuation rate has increased significantly, and the erosion of the beach has been markedly declined. The attenuation rates of the 1.5m and 2.5m incident wave height have improved from 63.3% to 94.0% and from 58.0% to 82.4% respectively [5], and the average monitored wind force value was reduced from 4.30 m/s to 2.93 m/s [6]. These achievements will contribute to the rapid development of tourism in Fuzhou New District's waterfront and coastal areas.

Figure 6 Bird’s eye view of the composite green infrastructure.
(Zhao Mafeng, 2022）

Figure 7 beaches before and after sand replenishment.
(Fuzhou New District Administrative Committee, 2021)

Biodiversity-friendly Coastal New City

Planting trees in 221 hectares of coastal areas, replenishing sand for 135.3 hectares of beaches, revegetating 3.2 km of sandy zones along the back shores, and restoring 274.9 hectares of wetland habitat have collectively created a green barrier of shelter forest, backshore vegetation, and beach, as well as a haven for birds in Coastal New City. The compliance rate with standards for coastal defense forests has increased from 68% to 94%[6]. The number of plant species in the sandy vegetation has also increased, from 64 families, 114 genera and 166 species to 73 families, 127 genera, and 182 species. In addition, the number of plant species in vegetation on the back shore has increased from 16 families, 24 genera and 24 species to 21 families, 32 genera and 33 species. One year after the restoration of the East Lake wetland, the number of plant species has increased from 74 families, 166 genera and 202 species to 80 families, 176 genera and 221 species respectively. The total number and diversity index of recorded avian species have increased by 22.8% and 13.6% respectively, and the proportion of recorded birds in the List of Terrestrial Wildlife with Beneficial, Economic or Scientific Research Value under National Protection has increased from 81.4% to 85.7%. The Common Buzzard (*Buteo japonicus*) and Eurasian Skylark (*Alauda arvensis*), both under National Class II protection, were newly recorded in the restoration areas.

Figure 8 Shelter forest before and after restoration.

Figure 9 Wetland before and after natural recovery and restoration.
(Fuzhou New District Administrative Committee, 2023）

High public satisfaction and economic opportunities

The program has developed several water-loving areas to enhance the coastal living environment and transformed the remaining spaces into the garden of East Lake Digital Town. This town incorporates investment, entrepreneurship, research, residency, employment, recreation, and tourism. The establishment of an eco-friendly and resilient environment has attracted around 500 high-tech digital companies, scientific research institutes, and colleges to settle in Coastal New

City. This groundwork sets the stage for the development of Fuzhou Coastal New City as a globally recognized first-class city, boasting a picturesque ecological coastal zone.

Figure 10 Beach visitors in the project area.
(Fuzhou New District Administrative Committee, 2023）

Alignment with IUCN Nature-based Solution Global Standard

According to the IUCN Global Standards for Nature-Based Solutions (NbS) [9] officially released by IUCN in 2020, the self-assessment of the program performance was conducted with the following results (**Figure 11**):

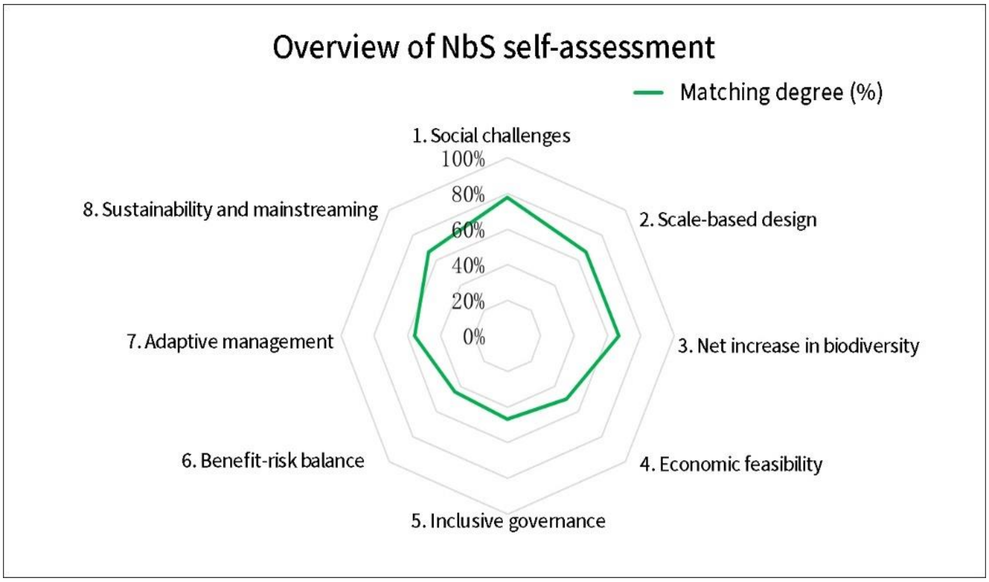

Figure 11 Alignment with NbS standard self-assessment.

The coastal zone protection and restoration program of Coastal New City is closely related with the needs of human habitat and ecological security. It aims at addressing the societal challenges of increasing risks of marine disasters, degradation of wetland ecosystems and biodiversity loss, and human health risks, and therefore is highly compliant (Criterion 1).

The Coastal New City implements three major projects: coastal defense forest restoration, beach consolidation and maintenance, and the restoration of wetland habitat backshore. These projects effectively enhance the coastal area's capacity to withstand the risk of marine disasters, mitigate erosion of sandy coastal ecosystems, and restore biodiversity in coastal wetlands. The results are quantitatively measurable, aligning with the criterion of net increase in biodiversity (Criterion 3).

The program follows comprehensive management measures that involve "respecting nature, conserving resources, exploring through experiments, and adopting classified measures." It has established a spatial coastal zone ecological disaster mitigation system, which includes a comprehensive shelter (defense) forest belt, dynamic and stable beaches, and interconnected wetland waterways as buffers. This system conforms to the criterion of design at scale. (Criterion 2).

The combination of protection of coastal zones and development of tourism has not only significantly improved the quality of the overall ecological environment of the coastal zone but also formed an ecological barrier, a green corridor and a sea-friendly paradise with the functions of windbreak and sand fixation, leisure and fitness, vacation tourism and other public services. It has strengthened the ecological advantages, investment opportunities and development competitiveness of the Coastal New City, and guaranteed the safety of lives and properties of the coastal people. However, it does not specifically elaborate the indirect costs as well as the resource allocation program, and therefore is rated as basically compliant with the economic viability criterion (Criterion 4).

The project has established a comprehensive long-term mechanism for assessing the restoration results, and formulated the Integrated Implementation Program for Planning, Construction, Protection, Conservation and Industrial Development, which serves as the basis for post-implementation assessment of performance and restoration outcomes. This approach aligns with adaptive management criterions (Criterion 7).

Through extensive media publicity and inter-regional research and exchanges, the project has served as a demonstration and model for other coastal cities in China. It showcases the synergy between enhancing ecosystem services and reducing disaster risks in the coastal zone. This achievement closely aligns with the mainstream criteria for sustainable development (Criterion 8).

The case demonstrates the implementation efforts of management authorities working in collaboration with a professional team. There are defined decision-making processes and a clear division of responsibilities. Although the affected stakeholders have been identified, the decision-making process is not thoroughly documented in detail. As a result, the project partially complies with the inclusive management criterion (Criterion 5).

The program has identified potential benefits but has not put in place relevant safeguards nor explicitly indicated stakeholder trade-offs in benefits to land and natural resources, and accordingly, is only rated as partially compliant with the trade-offs of benefits criterion (Criterion 6).

Recommended by: Department of Natural Resources of Fujian Province

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Restoring Mangroves to Reduce Coastal Risks in Xiatanwei, Xiamen, China

Introduction

Xiatanwei lies in the Xiang'an District of Xiamen City, north of Tong'an Bay and at the estuary of Xun Jiang River (**Figure 1**). It connects Zhongzhou Bridge to the North, Haixiang Road to the south, Binhai East Road to the east, and Binhai West Road to the west. The Torch Bridge passes over the entire Xiatanwei estuary. The Tong'an Bay area has a resident population of 107,000. Land area around Xiatanwei is earmarked for use as urban wetlands, surrounded by urban settlements and public green area based on functional development planning for East Sea Area of Xiamen City. Xiatanwei also connects with highly developed areas of Xiamen City, such as Tong'an and Xiang'an Hi-Tech New City and Yinchengzhigu Industrial plaza.

Xiatawei is classified as an estuarine coastal wetland that receives freshwater from Xixi Creek. This area serves as a connection between low-lying land and well-developed open sand gravels or tidal flats, which are formed through mild hydrodynamic and tidal influences. It represents one of the typical semi-enclosed bays in Xiamen City.

Since 2005, a successful cultivation and planting of a 5-hectare experimental forest in Xiatanwei Bay has taken place. Building upon this achievement, the Xiamen Municipal Government has supported the restoration of mangroves as an ecosystem-based approach for disaster risk reduction in two phases. This initiative has received designated funding from the central government as well as local co-funding. During the first phase, a total of 44 hectares of mangroves were restored through beach clearing and closure of aquaculture farms, waterway dredging, beach landscaping and planting of mangrove species, primarily *Kandelia candel*, *Aegiceras coniallatum*, *Bruguiera gymnorhiza*, *Avicennia marina, etc. In the second phase,* the mangrove plantation area was further expanded based on the achievements of the first phase. An additional 36 hectares were planted with Avicennia marina, *Aegiceras coniallatum, Kandelia candel*, *Bruguiera gymnorhiza and Rhizophora stylosa*. By 2020, a total of 404 hectares of coastal areas had been consolidated in Xiatanwei for the purposes of reducing disaster risks. This includes the mobilization of 180 hectares of sea areas that were previously used for aquaculture. In total, 85 hectares of mangroves were planted involving the consolidation of 4,500 metres of coastlines and dredging of 7 km of waterways [1].

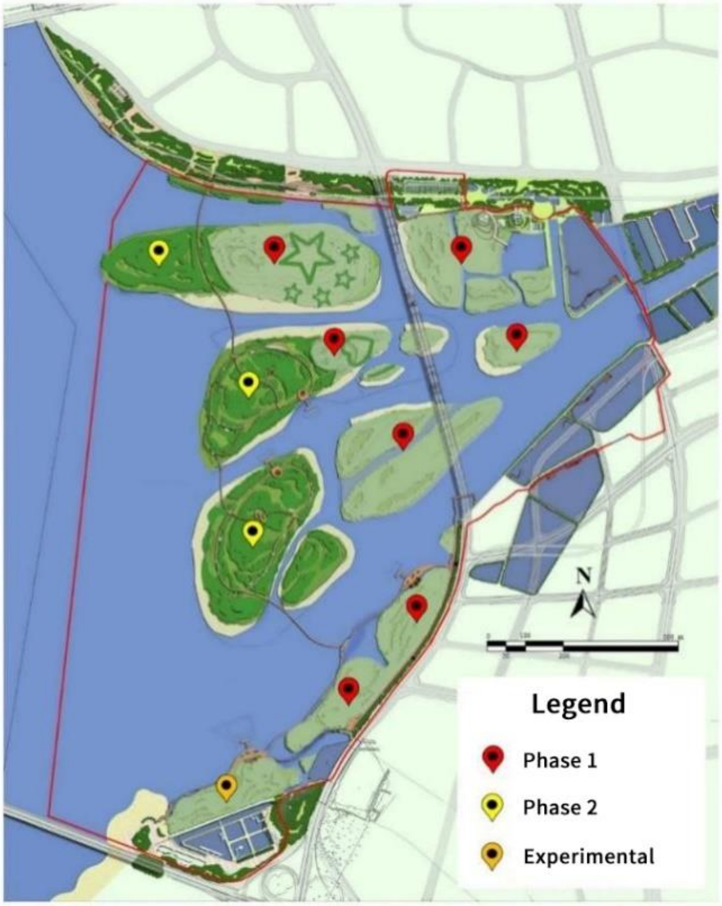

Figure 1 Mangroves areas restored in Xiatanwei, Tong'an Bay.

Issues

The reduction in the area covered by mangrove ecosystems and the degradation of wetland ecological services can be attributed to several factors, including human activities and natural processes. In the case of Xiatanwei, there are specific reasons behind these phenomena. Firstly, the native mangroves in Xiatanwei were subjected to severe destruction and a decline in services during the 1950s, primarily due to human disturbances, such as coastal reclamation and unregulated expansion of aquaculture farming (**Figure 2**). The discharge of land-based pollutants into the bay area, as well as unregulated waste water discharge from aquaculture activities, have contributed to eutrophication. This, in turn, has led to the deterioration of the ecological environment and regulating services of the bay areas. As a consequence of these factors, red tides occurred at a rate of 2.5 times per year in Tong'an Bay between 2001 and 2010. [2, 3 , 4]

Figure 2 Reclamation and unregulated aquaculture.
(Yang Shengchang, 2012).

Another contributing factor to the reduction and degradation of the mangrove ecosystems in Xiatanwei is the semi-enclosed nature of Tong'an Bay. With weak tidal effects and a small volume of tidal influx, sedimentation has become a significant issue, leading to a decline in the flood discharge capacity and navigation functions of waterways. This further exacerbates the challenges faced by the ecosystem.

Additionally, Xiamen city is frequently affected by typhoons, with the Pacific airflow causing direct or indirect impacts 4 to 5 times annually from July to September. These typhoons, accompanied by storm surges, pose significant threats to the life and property of coastal residents. For example, the landfall of Super Typhoon Moranti on 15 September 2016 brought maximum wind speeds of up to 52 metres per second, resulting in significant losses to the local population.

The invasion of the exotic species *Spartina alterniflora* (**Figure 3**) is another problem contributing to the ecological challenges at Xiatanwei. By occupying the ecological niche of native species, *Spartina alterniflora* is gradually undermining local biological security and ecosystem stability. This invasion has a significant impact on the ecological environment and economic development of the region.

Figure 3 invasion of Spartina alterniflora.
(Yang Shengchang, 2013)

Approaches

Mangrove restoration in Xiatanwei aims to reduce local disaster risks by enhancing the ecological services and benefits of coastal zones and coordinating ecological restoration, social benefits and local economic benefits. This goal is to be achieved based on the guidelines of "invigorating inclusiveness, transparency and empowerment in the governance process" and "striking an equitable balance between the primary objectives and multiple benefits". [5]

Micro-reshaping of landscapes

According to the specific conditions of Xiatanwei Bay, sediments dredged from waterways and tidal channels were used to create suitable higher tidal areas for mangrove planting, while leaving the shallow beach intact. This micro-sculpting of the landscape (**Figure 4**) to create suitable areas for mangrove planting has fully taken into account the topographical and geomorphological conditions of Xiatanwei and reduced the cost of dredging and habitat reshaping, while maintaining the hydrological connection with minimal human intervention. In less fortified coastal areas, a 500-metre-long coastal greenbelt and natural mangrove infrastructure was established with landward plantings of *Kandelia candel*, *Avicennia marina*, *Aegiceras coniallatum*, *Bruguiera gymnorrhiza* and *Acanths ilicifolius* to stratify the beach and attenuate winds (**Figure 5**). The micro-sculpture of the landscape respects the characteristics of the coastal areas and has fostered a community of marine life from mangroves, beach and sea, contextualised to the local topographical and geomorphological conditions.

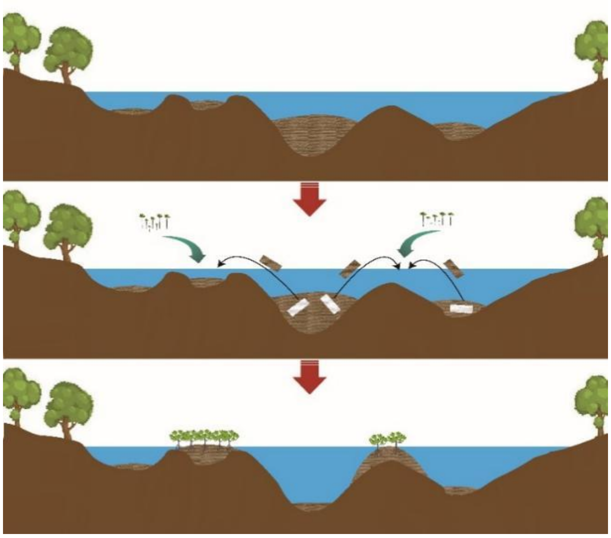

Figure 4 the concept of micro-reshaping of landscapes.

Figure 5 belt distribution of mangroves as coastal green infrastructure.
(Yang Changsheng, 2022)

Application of sediment-dredging technology

During the mangrove restoration project, a "sediment dredging technology" was used to remove approximately 726,800 cubic metres of beach mud, resulting in the creation of 80 hectares of beach area[1] (**Figure 6**). This technology involves the use of pontoons and amphibious excavators to excavate beach sediment, which is then transported either directly or by mud pumps. This method minimises disturbance to coastal habitats, benthic organisms and deep sediment texture. In addition, the timing of the work is carefully planned to coincide with the peak season for plankton, fish eggs and juvenile fish growth, ensuring that the construction has minimal ecological impact on marine life.

Figure 6 Operation sites of creating habitat for mangrove restoration.
(Yu Yanfeng, 2018).

The dynamic monitoring results from 2017 to 2021 showed that [6,7,8,9]: (1) the overall water quality and sediment quantity in adjacent waters remained unchanged, and the contents of active phosphate and inorganic nitrogen were maintained at an average level of 0.085 mg and 1.025 mg per litre respectively (**Figure 7**); (2) large benthic species in adjacent sea areas showed high diversity and the community structure was relatively stable. The abundance of gastropods and crustaceans reached 199 and 48 individuals per square metre, respectively, and the biomass of gastropods and sipuncularia reached 65.16 and 26.02 grams per square metre respectively.

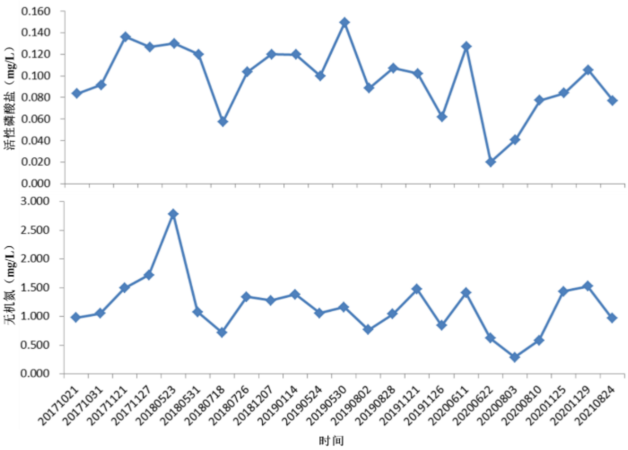

Figure 7 Temporal change of active phosphate content and inorganic nitrogen content in waters of Xiatanwei. (Top: active phosphate; Bottom: inorganic nitrogen)

Improving survival rate of planted mangrove seedlings

The implementation of a patented technology has significantly improved the survival rate of planted mangrove seedlings, reaching over 75% even in unsuitable planting areas.

Known as the 'chopstick seedling' technology, the mangrove hypocotyls are securely attached to chopsticks using rubber bands. This innovative approach ensures that the hypocotyls remain firmly embedded in the sand or mud, preventing them from being washed away by the sea. It also keeps the hypocotyls above water level, allowing for optimal photosynthesis.

By maintaining a controlled plant spacing of 0.5 to 0.75 metres, the rate of mangrove forest formation can exceed 85%. In addition, the combination of tree and shrub planting improves the overall plant community structure, resulting in a 76% increase in solar energy and biomass use efficiency per unit area. This approach also increases the carbon sequestration capacity of the mangrove wetland.

Adaptive management facilitated by long-term monitoring programs

The successful establishment of an experimental forest in 2005 led to the implementation of a robust monitoring and evaluation system [10]. This process enabled the timely identification of problems and the subsequent proposal and implementation of effective solutions. A long-term adaptive management mechanism was also established and put into operation. Continuous monitoring tracks the ecological disaster risk reduction achieved through restoration efforts. The dynamic ecological environment is closely monitored, with data collected on various elements of the mangrove ecosystem, including water, sediment and living organisms. This comprehensive monitoring provides valuable information to assess the health of the mangrove ecosystem and inform management decisions. An evidence-based adaptive management approach ensures that the development of the mangrove ecosystem, food chain structure and ecological functions remain healthy. As a result, the provision of ecosystem services by mangroves in Xiatanwei has improved significantly.

Nature education and fish stock enhancement

Annual outreach events are organised on major occasions such as World Ocean Day on 8 June, Disaster Prevention and Reduction Day on May 12, National Fish Release Day on June 6 and World Ocean Week in early November. These events aim to educate the public about the science and practice of marine disaster prevention and reduction and biodiversity conservation. Fish stock enhancement activities are carried out regularly with the active participation of the public. These initiatives include the release of fingerlings of various species such as blue crab, black seabream, yellowfin seabream, red seabream and others (**Figure 8**). These efforts not only contribute to improving ecological restoration outcomes, but also help protect the genetic resources of native species. Private sector funding is being mobilised to further strengthen mangrove research and science education. This support plays a crucial role in advancing scientific knowledge and promoting educational initiatives related to mangroves.

Figure 8 Regular fish fingerling release activities to enhance fish.
(Wang Huoyan, 2022)

Accomplishments

Increased extent of mangrove forests as ecological barriers to disaster risks

In the Xiatanwei marine area, a systematic community of life has been established, linking the mangrove forest, the beach and the sea. This development has resulted in an improved biological chain and food web structure within the mangrove ecosystem. It has also improved hydrological connections and functional waterways for navigation. Research has shown that mangrove forests with sufficient canopy cover can effectively reduce storm surges and wave energy by up to 70%. They act as natural barriers, reducing the height of wind and waves during typhoons and storm surges, thereby reducing the risk of disasters. The restoration of 85 hectares of mangroves in Xiatanwei has not only contributed to disaster risk reduction, but has also facilitated water purification and reduced the occurrence of red tides (**Figure 9**). In addition, the restoration efforts have been effective in reducing the invasion of exotic species in areas previously dominated by *Spartina alterniflora*.

Figure 9 Green buffer serviced by Mangrove in Xiatanwei area.
(Wang Huoyan, 2022)

Improved marine biodiversity

The establishment of a fully structured and functionally enhanced mangrove ecosystem has significantly improved marine biodiversity and ecosystem services. According to survey data [9], there has been a significant increase in the number and biomass of fish, shellfish and crustaceans such as shrimps and crabs in the mangrove restoration area. The number of species of these organisms has increased by 2.4 times, while their biomass has increased even more, with fish increasing by 2.99 times, shellfish by 4.76 times and crustaceans by 1.19 times. Restoration efforts have also led to an increase in the number of bird species in the area. Plovers dominate the area and over the years there has been a steady increase in woodland birds. Egrets, Chinese Pond Heron, Grey Heron, Pacific Golden Plover, Little Ringed Plover, White-faced Plover, Common Sandpiper, Common Greenshank, Little Tern, Common Kingfisher, Black-collared Starling, Light-vented Bulbul and others have become more common.

Potential of blue carbon fully harnessed

Launched in August 2017, the carbon neutrality project is in line with the new development concept of innovation, coordination, green, open and sharing. It aims to achieve net-zero emissions by the BRIC Leaders' Meeting in Xiamen. The second phase of the Xiatanwei Mangrove Restoration Project (**Figure 10**) plays a critical role in this effort. Carbon accounting has shown that the restored mangrove forest has an annual carbon sink capacity equivalent to 4.30 tonnes of carbon dioxide per hectare. This means that the mangroves are absorbing and storing a significant amount of carbon dioxide from the atmosphere, effectively reducing greenhouse gas emissions.

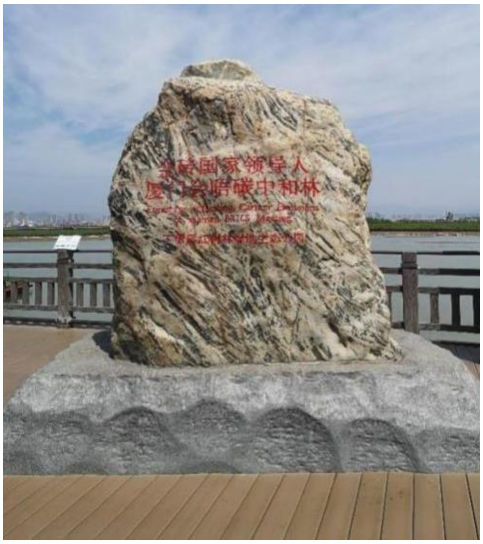

Figure 10 Statute to recognize carbon neutrality of BRIC leaders Xiamen Summit.
(Yang Shengchang, 2023)

The UN Secretary-General's Special Envoy for Oceans visited Xiatanwei in 2018. At the meeting of the first segment of the 15th Conference of the Parties to the Convention on Biological Diversity in Kunming on 11 October 2021, the Special Envoy told Xiahua News Agency that he was very impressed by Xiamen's tremendous efforts in mangrove conservation and restoration since the 1990s, and the scientific management of its coastal areas.

Areas for recreation and nature education

The restoration of the mangroves in Xiatanwei has brought about a remarkable transformation of the area. Previously characterised by chaotic beaches and heavy human intervention, it is now a picturesque and accessible recreational and educational area with lush forests and clean water. In partnership with the media and the private sector, several nature-related facilities have been established and operational at Xiatanwei. These include a marine biology introduction and breeding centre, a marine ecological environment monitoring station and a science education museum. These facilities serve as platforms to showcase the value of Xiatanwei's mangroves for scientific research, nature education and outdoor recreation. The nature education and recreation efforts have effectively demonstrated concrete examples of green and low-carbon development, as well as the sustainable development philosophy of clean water and green mountains. Xiatanwei has become a living manifestation of these concepts, contributing to Xiamen's status as a high-quality and international modern city (**Figure 11** and **Figure 12**). The popularity and success of Xiatanwei as a nature garden can be seen in the number of visitors. In a single day, the mangrove area has received up to 50,000 visitors, demonstrating its appeal and the appreciation of the local community.

The media, including China Central Television, Xinhua News Agency, and provincial and municipal media, have repeatedly reported on Xiatanwei as the city's "green lung" on a blue bay. These reports highlight how the restoration efforts have allowed the people of Xiamen to enjoy the tangible fruits benefits of ecological governance and an improved environment.

Figure 11 views of the Xiatanwei and mangrove.
(Wang Huoyan, 2023)

Figure 12 Scientific research, nature education and various nature-based facilities.
(Wang Huoyan, 2023)

Opportunities generated for social and economic development

The restoration of mangroves in Xiatanwei not only brings ecological and recreational benefits, but also enjoys the full support of local coastal users. This support has been achieved through effective communication and a shared understanding of the potential benefits of the project to local communities. To ensure the inclusiveness of the restoration effort, economic compensation schemes were designed and implemented based on principles of consultation and inclusiveness. This approach helped to address the concerns and needs of the local communities and fostered a sense of ownership and participation in the restoration project. The improvements in environmental quality and access to nature resulting from the restoration have created new opportunities for investment in the Xiang'an and Tong'an districts. As a result, there is growing interest in developing high-tech industries and establishing new cities in these districts. The landing of the Yinchengzhigu industrial platform, the presence of several unicorns, and the attraction of the world's top 500 enterprises to nearby areas have further promoted Xiatanwei as a catalyst for regional economic development.

Alignment with IUCN Nature-based Solution Global Standard

An assessment of the alignment with the eight global standards of Nature-Based Solutions (NbS) officially released by IUCN in 2020 was conducted, with the following conclusions (**Figure 13**):

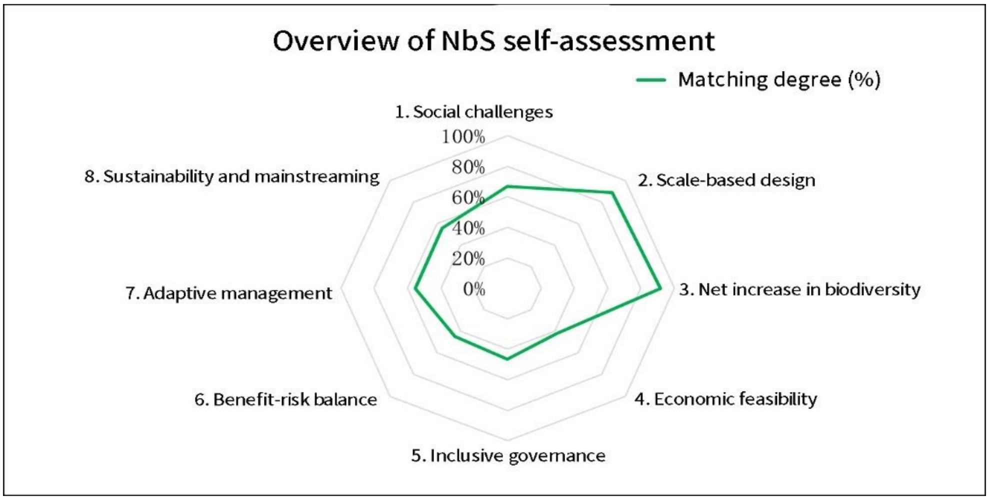

Figure 13 Alignment with NbS standard self-assessment.

Criterion 1 is basically consistent with addressing the societal challenges of climate change, human health, water security, environmental degradation and biodiversity loss. A long-term mechanism for monitoring and evaluating the full cycle of interventions, with learning from experimental restoration in small areas applied to subsequent phases of restoration.

This case study has demonstrated the importance given to the management of bare beaches and marine areas, the breeding and growth environment for mangrove species, with the identification of risks within and outside the restoration areas and the implementation of proposed solutions to mitigate identified risks. Therefore, criterion 2 is fully met (Criterion 2).

A situation analysis was carried out at temporal and spatial scales, and monitoring and evaluation systems were developed and implemented. The phased planting of different mangrove species and the artificial replenishment of fish stocks in intertidal areas have significantly improved biodiversity in the intervention areas, with evidence of net gains that are highly consistent with net biodiversity gains (Criterion 3).

Interventions have clearly demonstrated long-term financial sustainability with identification of direct and indirect costs and resource allocation schemes. Although a detailed analysis of costs and benefits was not provided, the concrete benefits to regional economic development and the obvious value in articulating an ecological civilisation have indirectly demonstrated the cost-effectiveness and economic feasibility of the interventions. It is basically consistent with economic feasibility (Criterion 4).

The interventions are basically consistent with criterion 5 on inclusiveness. The impact of the restoration work on the water quality of adjacent areas and biodiversity has been regularly monitored and tracked, together with an assessment of the impact on surrounding areas. Interventions were implemented jointly by management authorities and technical teams in accordance with assigned responsibilities and decision-making processes, and in consultation with identified stakeholders.

Trade-offs of interventions were not fully analysed to balance the interests of different stakeholder groups, thus partially meeting Criterion 6.

Real-time monitoring has been carried out to allow timely adjustment of management approaches and the use of technologies and implementation plans. In this respect, the team judged the interventions to be basically consistent with adaptive management (Criterion 7).

The case in point is basically in line with Criterion 8, justified by the implementation of scientific research, monitoring and science education programmes, sharing of results and experiences, and supporting studies to provide scientific basis for restoration, sustainable use of mangrove wetlands and compilation of case studies for learning. In addition, Xiatanwei restoration has also provided practitioners with the concrete examples of the application of Ecological Civilisation, carbon peaking and carbon neutrality target, which the Chinese government has committed to the international community. The experience can greatly help to promote the development and adoption of policies and management measures to support the application of development concepts and targets, so as to contribute to economic, social and environmental development.

Recommended by: Xiamen Municipal Bureau of Ocean Development

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Ecological Stratification of Hongshahuan Seawall in Fangchenggang, China

Introduction

Fangchenggang City is located on the northern coast of Beibu Gulf in Guangxi, China. It has a unique geographical position as it is both a coastal city and a border city. It serves as the starting point of China's southwest region and marks the coastline of the mainland. Separated from Vietnam by a single river, the city is well connected to the ASEAN region by sea, land and river routes. In addition, Fangchenggang City has the largest port in western China and a convenient estuary.

The coastal areas of Xiwan in Fangchenggang City are mainly for residential and tourism purposes. With its stunning landscape of intertwined islands and bays, and mountains facing the sea, the area has been transformed into a picturesque city that seamlessly integrates the urban environment with the natural surroundings. The concept of "the city in the sea, the sea in the city and the people in the landscape" encapsulates its unique charm. A notable area in Xiwan is the Hongshahuan area, which features an ecological sea wall. It serves as the administrative centre of Fangchenggang City, Guangxi, and is an important coastal segment connecting the port and central districts.

Fangchenggang City is located in the low-latitude region south of the Tropic of Cancer, with a subtropical maritime monsoon climate. Winters are mild, and summers are rainy, with the monsoon being significantly affected by disasters such as typhoons, storm surges, and large waves. The annual average temperature is 23.0°C, the average atmospheric pressure is 1009.6 hPa, the average annual precipitation is 2503.8 mm, and the average annual wind speed is 3.4 m/s. Over the past five years, Fangchenggang City has experienced 10 typhoon storm surge disasters along the coast, averaging 2 per year. Among them, there were 8 incidents with water levels rising by more than 50 cm, with the highest rise of 91 cm occurring during the storm surge of typhoon “Ma’an” 2209. There were 3 exceedances of the yellow warning tide level and 3 exceedances of the blue warning tide level, with an average of 1.2 exceedances of the warning level per year.

The Hongshahuan area of Fangchenggang City has a permanent population of 78,000. In terms of its stratigraphic structure, the site of the ecological embankment consists of two main layers. The upper layer is known as the Quaternary Sea-Land Interaction Deposit (Qmc), which is characterised by a mixture of fine, medium and coarse sand with a small amount of silt. The intertidal zone in this area experiences a range of tidal levels. The maximum high tide reaches up to 3.41 metres, while the minimum low tide reaches -2.22 metres.

The Xiwan Hongshahuan, Fangchenggang City ecological embankment improvement project takes into account the diverse geographical and hydrological conditions by using different embankment construction methods along different shorelines. The project will be implemented in three phases, covering a total of 3.2 km of shoreline restoration (**Figure 1**). The first phase will focus on the restoration of 803 metres of shoreline, followed by the second phase which will restore 900 metres, and finally the third phase which will restore 1,497 metres. Several structures will be constructed as part of the project, including a 282-metre-long submerged cofferdam, a 561-square-metre waterfront platform and a 1,675-metre-long boardwalk. In addition, efforts will be made to restore 1 hectare of mangrove forest and construct a seawall covering an area of 10,645 square metres. To enhance the marine ecosystem, 750 sets of artificial fish reefs will be installed at the base of the seawall. The total land area used for the ecological seawall project is 20.69 hectares.

Figure 1 Schematic Diagram of the Overall Layout of the Case Study Area.

Issues

Prior to 2012, the ecological degradation in the area was severe due to the impact of waves and storm surges, and the area was virtually uninhabited. The main issues were:

(i) Poor disaster prevention and reduction capabilities of simple seawall. The revetments were long overdue for maintenance, resulting in reduced durability and safety. Severe coastal erosion reaching down to the bottom of the revetment directly threatened its safety. Sparse vegetation on the revetment and exposed stone masonry exacerbated the situation. Soil erosion from the land side led directly to sedimentation in the waterway, increasing the flood pressure during the flood season.

(ii) Parallel tidal channels in front of the seawall posed a serious threat to the survival of the mangroves due to their depth and fast flowing nature. On the landward side of the seawall, the absence of vegetation and the exposure of loose surface soil resulted in significant soil erosion. Sewage discharges from the coastal outfalls directly eroded the tidal flats, creating low-lying mudflats and triggering the collapse of the surrounding mangroves. As a result, the environmental quality of the coastal wetlands has been severely compromised.

(iii) The exposed and hard physical seawall disrupted the regional land-sea ecological connectivity, with no biological passage along the shoreline, earning it the nickname 'the coast where the sea is invisible and the water's edge where the deck is missing'. (**Figure 2**)

Figure 2 Existing Problems Before Ecological Improvement in Xiwan Hongshahuan. Top-left: Exposed seawall. Top-right: Eroded mudflats. Bottom-left: Urban sewage outlet. Bottom-right: Exposed mudflats and shoreline. (Wang Xin, 2012)

Approaches

Building a layered ecological seawall that allows land-sea biological connectivity

The coastal zone is characterised by significant spatial heterogeneity as it encompasses a variety of habitats in close proximity. To follow the natural biological succession principles of the land-sea transition zone, the Xiwan Hongshahuan ecological embankment model incorporates five different biological layers in vertical space. [1] (see **Figure 3**).

The first layer is mangroves, which act as 'coastal guards'. The second layer consists of fish reefs at the bottom of the seawall, which provide shelter and breeding grounds for coastal fish, shrimp, crabs, shellfish and algae. The third layer, between the bottom of the seawall fish reefs and the average high tide level, includes salt-tolerant, submergence-tolerant liana for slope protection or semi-mangrove restoration areas, forming a land-sea ecological transition corridor. The fourth layer is between the extreme high tide level and the standard urban level and includes bidirectional slope protection lianas, terraced flowering slopes or grassed slope protection. The fifth layer is at the standard urban elevation and is used to re-establish zonal monsoon rainforests. Layers four and five together form an urban ecosystem, providing shelter and breeding grounds for terrestrial organisms and birds. In both vertical and planar space, the functional blocks of each layer are connected by paths, steps and platforms, making the tidal flats, seawall and land a unified whole.

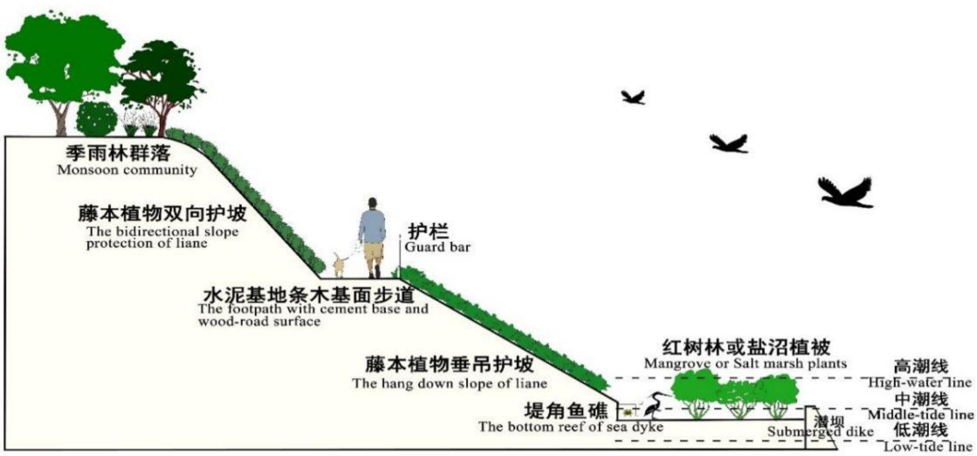

Figure 3 Profile of the main body of the Ecological Seawall. Top: Schematic profile. Bottom: On-site view of the completed seawall. (Wang Xin, 2021)

The Xiwan Hongshahuan seawall has undergone ecological restoration based on the ecological niche distribution patterns of local land-sea transition zone vegetation species. This restoration involved the selection of 33 indigenous coastal plants to establish a "marine higher plant community → coastal thorny shrubland → monsoon rainforest stable community in the land-sea transition zone." This helps connect the land-sea biological channels. After ecological restoration, the Xiwan Hongshahuan embankment is green and ecological all around. In some sections, gentle slopes extend into the sea, providing a waterfront deck that was missing from the old seawall. The seawall promenade and path organically connect elements such as the seawall, mangroves, tidal flats, water storage wetlands and urban roads to form a staggered coastal transition corridor.

Constructing submerged dams to prevent mudflat erosion and create land suitable for mangroves

To prevent further erosion of the damaged riverbed and the collapse of the mangrove tidal flats at the front, underwater embankments were constructed outside the seawall. The reclamation of the tidal flats created mangrove-suitable areas, allowing for the transplantation and restoration of mangroves, thus achieving synergies between disaster mitigation and ecology (**Figure 4**). The construction of underwater embankments helps to attenuate waves and prevent soil from flowing into the sea, while at the same time facilitating the creation of suitable areas for forests with appropriate elevation and reduced water flow outside the embankment. This allows for the rapid establishment or restoration of mangroves, gradually restoring the originality and integrity of the coastal ecosystem.

The submerged dam is 1.5 metres high (0.5 metres above the exposed mudflat) and 0.5 metres wide at the top. It significantly reduces the velocity of the water in the tidal channel, promotes sediment deposition in the water and raises the elevation of the local mudflats. This will create the conditions for planting mangrove seedlings on previously unforested tidal flats and rebuilding the community. By 2020, the submerged dam will have increased the survival rate of newly planted *Kandelia candela* mangroves from 0% to 65% and increased the mangrove area by 45.23% [2], significantly improving the ecological function of resisting erosion from wind, waves and currents in the region.

Figure 4 Schematic Diagram of Submerged Dam, with water channel at the outer side of the submerged dam and mudflat at the inner side of the submerged dam. (Wang Xin, 2021)

Using ArmorFlex to achieve synergistic effect of physical defense and ecological restoration

To enhance the protection and ecological restoration of the exposed seawall, a method using ArmorFlex was implemented. This involves laying ArmorFlex, a precast concrete material, on the surface of the seawall and filling the gaps between the stones with soil. Coastal lianas were planted in this soil (**Figure 5**). This approach has successfully increased the vegetation cover on the seawall, resulting in a synergistic effect between physical seawall defence and ecological restoration. The use of ArmorFlex has significantly improved the seawall's ability to prevent and mitigate disasters. Over time, the vegetation cover on the seawall has increased from an initial 4.25% [3] to an impressive 90% by 2020 [3].

 

Figure 5 Before and After Construction of ArmorFlex on the Seawall.
Left: Construction process of ArmorFlex (Wang Xin, 2015). Right: Seawall surface after planting vegetation (Wang Xin, 2021).

Enriching habitat for nearshore marine organisms

A total of 750 sets of small fish reefs, equivalent to 1,336 m³, have been strategically placed around the seawall, submerged dams and boardwalks. (**Figure 6**) These specially designed fish reefs, which are hollow hexahedrons and square prisms with open bottoms and three small holes at the top, serve multiple purposes. As well as providing wave-breaking capacity, they create diverse habitats for near-shore marine organisms, helping to restore intertidal wetland ecosystems. The reefs have been carefully designed to meet the specific habitat requirements of benthic fish, crabs, crustaceans and algae. Remarkably, the presence of these fish reefs at the bottom of the seawall has resulted in a significant increase in the number of species (31.94%), density (62.99%) and biomass (555.16%) of macrozoobenthos on the mudflats compared to 2012. This has effectively enriched the biodiversity of the seawall and mudflats, restoring the natural ecological functions of the shoreline.

 

Figure 6 Schematic Diagram of Fish Reefs at the Bottom of the Sea dyke. Left: Fish reefs next to the boardwalk. Right: Local residents collecting shellfish on the fish reefs. (Wang Xin, 2017)

Operationalising a quality assurance and feedback mechanism

Throughout the project, the integration of environmental principles has been consistently prioritised. A comprehensive management approach was implemented to ensure that these principles were mainstreamed into the overall design, engineering facilities, dynamic monitoring and long-term feedback of the project. This approach involved several stages, including "top-level environmental planning → engineering design → environmental compliance review → construction guidance". This approach effectively ensured the implementation of ecological principles. Throughout the project implementation process, continuous monitoring, evaluation, feedback and management were carried out to assess the project's compliance with ecological principles. After completion and acceptance of the project, a thorough analysis of the compliance with the ecological concept was carried out. This analysis considered both functional and structural aspects of the project, including protective function, landscape impact, recreational function, functional zones and restoration of tree species. The aim was to assess the extent to which the implementation of the project was consistent with the original conceptual plan in terms of ecological principles.

Environmental monitoring was implemented to ensure timely identification of environmental issues during project design and construction, allowing for continuous and dynamic feedback adjustments. A comprehensive engineering impact assessment technical system was established to assess both the short-term performance and the long-term overall impact of the project. Based on the identification of these ecological issues, appropriate improvement strategies were proposed, leading to the development of the concept and engineering demonstration technical system for mangrove coastal ecological seawalls. This system effectively supported decision making in engineering construction management and facilitated the implementation of environmentally sound practices. Careful ecological monitoring proactively addressed potential ecological challenges, resulting in improved project outcomes and informed decision making in line with ecological principles.

Since 2012, a comprehensive and systematic study of the natural, ecological and social conditions of the region has been carried out. An evaluation index system consisting of four elements: physical effects, ecological effects, landscape effects and socio-economic effects, and eleven indicators [5] has been established to determine evaluation standards and methods, forming a technical system for evaluating the ecological effects of sea dikes. This system validates and optimises the effectiveness of ecological design and project implementation, and provides a scientific basis for further promotion and application.

Accomplishments

Improved defence effectiveness of ecological sea dikes

Since the completion of the Hongshahuan ecological seawall, the area of restored tidal flat mangroves in front of the seawall has increased by 9,913 m², an increase of 45.23% compared to pre-restoration levels (**Figure 7**). Mangrove cover has increased from 5% to 85%, further enhancing the role of mangroves in wave attenuation and shoreline protection [1]. By restoring native vegetation to the seawall, the ecological stability of the seawall has gradually increased. Plant growth, new shoots and root systems will improve the seawall's ability to withstand wind and waves, control coastal soil erosion and strengthen the structural stability of the coast.

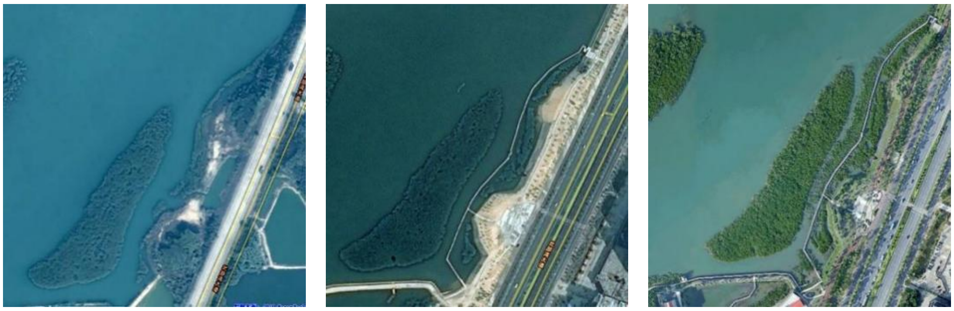

Figure 7 Comparison of remote sensing images before and after interventions.
(Left: 2011, Middle: 2013, Right: 2020)

Since the completion of the Hongshahuan ecological sea dike in 2015, the Guangxi coast has faced ten storm surges, resulting in around 28.93 km of damage to coastal protection projects. These incidents caused significant losses, estimated at around CNY 983 million. The Hongshahuan ecological sea wall was designed to withstand tidal surges up to a 20-year event. Remarkably, since its completion, it has withstood ten typhoon tests, including a maximum wind force of 14 in 2018, and remained resilient and undamaged [6]. The integration of mangroves, seawalls and vegetated revetments in the ecological seawall model significantly enhances its protective capabilities. Recognising its strength, local fishing communities have come to rely on the seawall as a shelter for their fishing boats, with approximately 200 boats seeking refuge there each year.

Enhanced coastal biodiversity

Since the completion of the Hongshahuan ecological seawall, there has been a significant net increase in biomass carbon sinks, totalling 18.23 Tc/ha^2, with an estimated total carbon increase of 18.07 Tc [1]. In the newly planted mangroves, there was significant regeneration of *Aegiceras corniculatum*, with a reduced presence of *Avicennia marina*. In particular, the seedlings of *Kandelia candel* and *Aegiceras corniculatum* show a capacity for self-reproduction, which promotes the formation of a resilient and stable community (**Figure 8**).

The establishment of fish reefs in front of the sea wall has caused remarkable changes in the population characteristics of the macrozoobenthos community in the tidal flat area. In 2018, there were significant changes in benthic communities, with increases of 31.94% in species richness, 62.99% in density, 555.16% in biomass, and 12.05% in H'. In addition, the average weight of individuals has tripled, from 0.33 in 2012 to 1.32 in 2018. This suggests a gradual increase in the proportion of larger populations and a corresponding increase in community stability.[2]

Figure 8 Newly Added Mangroves and Inhabiting Organisms. Top-left: Aerial view of newly added mangroves (Wang Xin, 2021). Top-right: Newly added mangroves (Wang Xin, 2021). Bottom-left: Egrets in the mangroves (Luo Sheng, 2023). Bottom-right: Fiddler crabs in the mangroves (Yao Weidong, 2023)

Enlarged public green and blue space

The scenic coastal landscape of Hongshahuan Ecological Sea Dike has attracted the attention of local residents and domestic and international tourists who visit the area for its breathtaking views. (**Figure 9**) It has gained wide recognition from society and has become a showcase of marine ecology and a popular tourist attraction in Fangchenggang City. It is not only a favourite recreational spot for locals, but has also become a must-see destination for visitors. In an article entitled "Ecological sea dike construction in Fangchenggang City highly aligns with global standards"[7], as reported in the Fangchenggang Daily, Johnsson Fuwafu, an American visitor experiencing Fangchenggang for the first time, I feel like I've arrived in Seattle, USA, where the sea surrounds us, lush greenery abounds, sunlight is abundant, the sky is clear, the seawater is refreshing, the sea breeze is cool, and there are golden beaches. Life embraces green, and it's a rare green and eco-friendly city! CHENG Feng, a visitor from Sanya, Hainan Province, remarked, "If Switzerland is considered the happiest country in the world, then Fangchenggang City should be the only place that can rival it".

Figure 9 Aerial View of the Surroundings of the Xiwan Hongshahuan Ecological Sea dyke.
(Wang Xin, 2021)

A proven case for promoting eco-economic development

The eastern bank of Hongshahuan Bay is characterised by the ecological sea dyke, while the western bank has a traditional dyke structure. In 2019, property prices around the ecological sea dyke showed a market premium rate of 56.76% compared to similar locations with comparable environmental and socio-economic conditions [4]. Furthermore, the ecological premium was an impressive 70.5 times the total investment cost of the ecological sea dyke. In 2022, the Hongshahuan ecological sea dike attracted about 70,000 domestic tourists, contributing to a total domestic tourism consumption of about CNY 70 million. The construction of the ecological sea dike has brought significant ecological, social and economic benefits, and has promising prospects for further promotion and application.

Lessons learned scaled up for national roll-out

The Xiwan Hongshahuan Ecological Sea Dike is designed to integrate ecology and disaster mitigation, with morphological features and ecological functions that resemble a natural coastline. It has achieved remarkable original breakthroughs and has the potential for replication and scalability. In recognition of its achievements, the State Oceanic Administration selected it in 2017 as a case for the national large-scale achievement exhibition called 'Five-Year Achievements by Forging Ahead'. The success of the Hongshahuan ecological sea dike model led to its adoption in the Action Plan (2019-2022) for Marine Ecological and Environmental Restoration in Guangxi, issued by the Oceanic Administration of Guangxi Zhuang Autonomous Region in 2019. This model has been instrumental in guiding the ecological transformation of 16 sea dikes with a total length of 78.50 km in Guangxi. It serves as a valuable reference for coastal areas across the country.

Alignment with IUCN Nature-based Solution Global Standard

Self-assessment was conducted based on the eight criteria of Nature-based Solutions (NbS), and the conclusion was that it aligns with IUCN NbS Global Standards. The radar chart for the self-assessment of this case is shown in **Figure 10**.

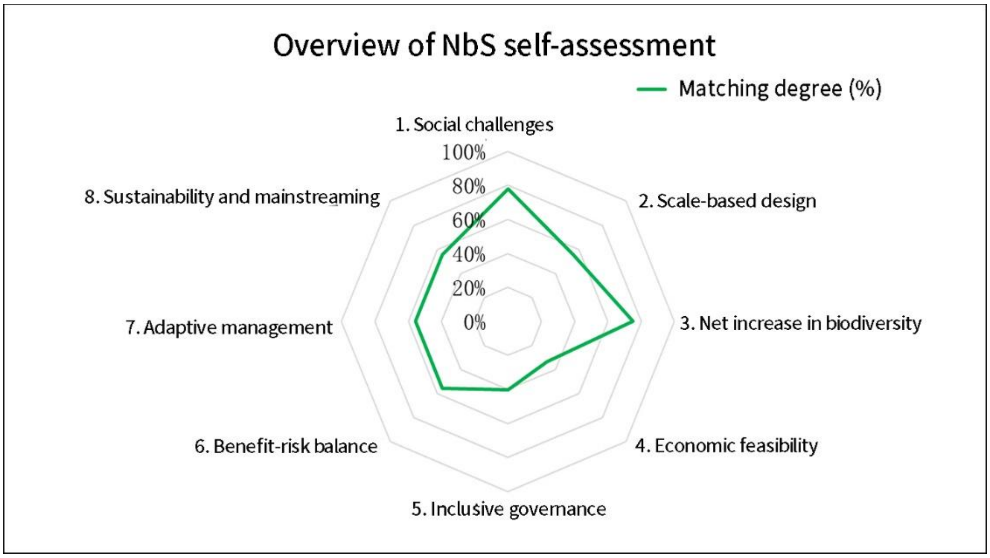

Figure 10 Alignment with NbS standard self-assessment.

The Xiwan Hongshahuan Ecological Sea Dike Project effectively identifies and addresses disaster prevention and mitigation, economic and social development, and environmental degradation and biodiversity loss. It is highly consistent with the societal challenge criterion (Criterion 1).

Guided by an ecological approach, the project combines disaster prevention and mitigation, environmental protection, cultural and recreational approaches to sea dike construction, enhancing the dike's disaster prevention and mitigation capabilities, improving coastal biodiversity, achieving synergy between ecology and disaster prevention, and significantly improving the well-being of local people. A proper assessment of the status quo has been carried out in terms of temporal and spatial scales (Criterion 2).

Measures such as the construction of underwater sills, the establishment of fish reefs at the bottom of the sea dike and the creation of land-sea transition zones have been implemented to form a multi-level, multifunctional ecological sea dike that enhances overall ecosystem integrity and biodiversity. It is closely aligned with the net biodiversity gain criterion (Criterion 3).

The project clearly identified direct costs, but did not specify indirect costs or resource allocation plans, nor did it conduct a cost-benefit analysis, and is partially aligned with the economic viability criterion (Criterion 4).

Environmental monitoring was carried out, monitoring the implementation of environmental concepts throughout the process, assessing short-term technical performance and long-term overall impacts, and proposing appropriate improvement actions based on identified issues. However, the project did not identify stakeholders, did not specify whether it was influenced by or involved stakeholders in project implementation, and did not establish a feedback and complaints mechanism. It partially meets the criterion for inclusive management (Criterion 5).

The project has identified potential benefits, ensured ecosystem and landscape stability through regular monitoring of safeguards, and is broadly in line with the criterion for balancing benefits (Criterion 6).

Throughout the life cycle of the project, robust monitoring and evaluation plans were developed and implemented, establishing a multi-factorial evaluation indicator system, defining evaluation criteria and methods, and promptly adjusting and optimising them based on actual monitoring results. This is broadly in line with the adaptive management criterion (Criterion 7).

The project summarised the experience of ecological sea dike construction and was selected by the State Oceanic Administration for the national large-scale achievement exhibition entitled "Five-Year Achievements by Forging Ahead", and served as a demonstration case to guide the ecological transformation of sea dikes in several regions. The project contributes to global goals such as improving human well-being, addressing climate change and conserving biodiversity. It is broadly consistent with the mainstreaming of sustainability criterion (Criterion 8).

Recommended by: Ocean Bureau of Guangxi Zhuang Autonomous Region

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Integrating Climate Adaptation, Poverty Reduction and Environmental Conservation into Natural Resources Management in Kwale County, Kenya

Introduction

Location and map

Kwale County is one of the six counties in the Coast region of Kenya. The county is located at the southern tip of Kenya (**Figure 1**), between latitudes 30.05º to 40.75º south and longitudes 38.52º to 39.51º east. Kwale County covers an area of approximately 8,270.2 km^2, of which 62 is water. The area excludes the 200-mile coastal strip known as the Exclusive Economic Zones (EEZ).

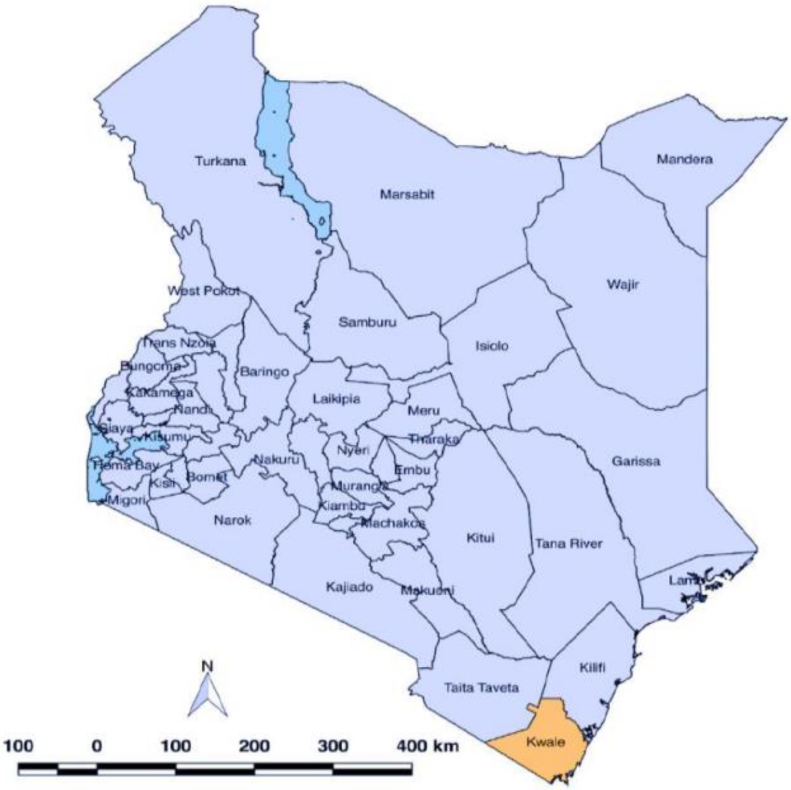

Figure 1 Location of Kwale County in Kenya.
(Independent Electoral and Boundaries Commission (IEBC))

Physical and Topographical Characteristics

Geologically, the county is underlain by the Karoo Sediments, also called Duruma Sandstones, which cover the central strip of the county to the foot of the Shimba Hills [1]. The district has the following major topographic features: 1) the Coastal Plain consisting of coral, sand, and alluvial deposits; 2) the Foot Plateau. It is located between 60 and 135 meters above sea level on a flat surface with a high potential of permeable sand hills and clay soils. This is the sugar cane zone of the region; 3) The Coastal Range is made up of many sandstone hills. This is an area of medium to high agricultural potential; 4) The Nyika Plateau is underlain by a basement rock system with the exception of reddish sandy soils. Occupying more than half of the region, it is semi-arid except for occasional patches of reddish sandy soils and is therefore generally poor [1]. The main activity in the area is livestock farming.

In general, the county is well-drained by seven major rivers and numerous minor streams as shown in **Figure 2**. Of the seven 7 rivers, 3 are perennial and drain into the Indian Ocean.

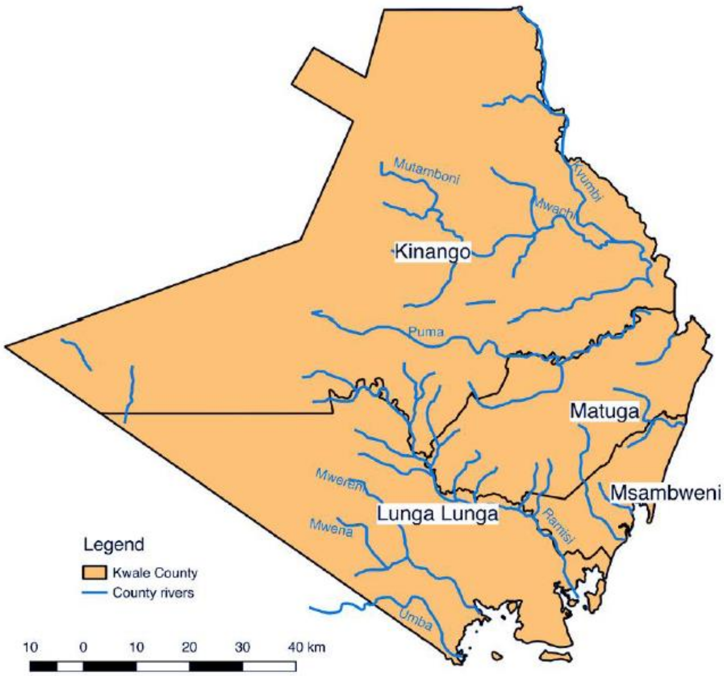

Figure 2 Distribution of rivers in the County.
(Geo-Water RCMRD SERVIR (2015))

Ecological and Climate Conditions

Kwale has a wide variety of natural resources ranging from mangrove forests, marine products and mining to diverse land resources including agriculture, lime production and food crops. There is evidence of increasing land pressure as large tracts of land are taken over by large-scale agriculture, large-scale mining and open-pit sand mining. The county is divided into agroecological zones in terms of agricultural potential. Medium potential and marginal lands constitute 15% and 18% of the total land area, respectively. The remaining 67% is pasture, arid and semi-arid land suitable only for livestock and limited cultivation of drought-resistant crops. Annual rainfall averages less than 800 mm and is extremely unreliable.

The county has a tropical climate with monsoon seasons, an average temperature of 23ºC, and bimodal rainfall. The short rains occur from October to December, while the long rains occur from March/April to July. There is a strong gradient of decreasing rainfall from east to west, with coastal areas receiving more than 1000 mm of rainfall per year and the western areas receiving less than 500 mm per year.

As such, heat stress, dry spells and drought are hazards that greatly contribute to agricultural risks in the county, especially in its central. However, flooding due to heavy rainfall has also occurred historically and is a risk to the county, especially in the central to eastern (including coastal) parts of the county.

Gender considerations

Women and girls in Kwale County relate differently to natural resources like forests, rivers, and land than men do. While gender considerations have been included in recent Kenyan government policies, the link between gender and climate change, as well as environmental concerns, is still not well established. According to Ambrosino *et al.* [2] (2021), economic activities like fishing and tourism pose child protection risks, with "sex-for-fish" being a widely reported phenomenon in recent years. Additionally, poverty and a lack of income-generating activities have led to children dropping out of school and being forced into mangrove cutting, charcoal production, and agricultural activities. Fisheries research, management, and policy have traditionally ignored women's indirect, informal, and/or unpaid roles in fishing activities that are dominated by men. Women's involvement in fisheries value chains is largely marginalized to post-harvest processing and retailing, with low profit margins. Women engage in these activities due to a lack of alternative income-generating opportunities, as the work does not require much education or skills. The traditional gender division of labor and power reinforces the system of male dominance in economic activities associated with fisheries value chains.

Livelihood

The county is one of the poorest and youngest in Kenya: in 2013, 48% of Kwale County's population was aged 0-14, and the poverty rate was 71% (UNICEF 2013) - with high levels of unemployment or underemployment (30% of the total labor force aged 15-64) [1].

Agriculture is one of the main economic activities in Kwale County, with 85% of farmers practicing subsistence agriculture. The agricultural sector plays a critical role in ensuring food security, poverty reduction, and employment generation in the county. Despite the importance of agriculture, food insecurity is still a challenge in the county. Most farmers in the county practice mixed farming.

Forestry is an important source of income, food and medicine for local communities. The many indigenous forests facilitate ecotourism by providing tourists with nature trails, scenic attractions, animal viewing, and bird and butterfly watching. They also provide timber for construction and charcoal, on which more than 90 percent of rural households depend. Mangrove forests support beekeeping, which produces high-quality honey, and provide shelter for some species of fish and oysters. In addition, mangrove poles are used to make fishing traps and in construction. The forests also provide raw materials for the manufacture of mosquito repellents, toothbrushes, glue, dyes, shampoos, soaps, and ropes.

Policy support

According to Ambrosino *et al*. [2], several policies and laws were developed to address poverty, the environment, and climate change, including the Environmental Management and Coordination Act of 1999 and the Poverty Environment Initiative launched in 2005. The country has also launched national climate change response strategies, action plans, and submitted its Intended Nationally Determined Contributions. In Kwale County, there has been a significant increase in average temperatures over the past 20 years, and extreme precipitation events are expected to become more frequent. Recent national policies and frameworks address specific components of Kenya's environmental policy, including the Forests Act of 2005, the National Climate Change Framework Policy of 2016, and the National Mangrove Ecosystem Management Plan of 2017 [2].

Issues

Environmental Degradation

According to FAO LADA/WOCAT[1], there are six types of environmental degradation in Kwale:

- Biological/vegetation degradation - the reduction of vegetation cover, loss of vegetation species and habitats, and decline in biomass;
- Soil erosion by water - the loss of topsoil due to runoff or overland flow, characterized by topsoil loss by water, gully erosion, highland landslides, and streambank erosion. Water erosion is the most common type of erosion in Kenya;
- Wind erosion - commonly associated with degraded lands prone to strong winds and light soils;
- Degradation of water resources - includes processes such as changes in the quantity and quality of surface water, acidification, and lowering of groundwater levels. It also includes a systematic decrease in soil moisture;
- Chemical degradation - manifested in the decline of soil fertility and organic matter content, leaching, nutrient mining, acidification/lowering of soil pH, soil pollution by pesticides, industrial effluents and soil contamination by toxic substances, salinization, which causes a net increase in the salt content of the (top) soil, leading to a decline in productivity; and
- Physical degradation - includes loss of natural or aesthetic physical conditions of the land, such as quarrying, mining, scarification, soil compaction, sealing and crusting: clogging of pores with fine soil material and creation of an impervious soil surface layer that prevents rainwater infiltration.

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[1] LADA-WOCAT QM is an evaluation tool for land degradation and the conservation activities undertaken in a country or provinces/regions within a country with the added ability to link to a country-level LUS spatial database, thus allowing the production of thematic maps and area calculations on various aspects of land degradation and conservation.

Biodiversity Loss

Mangrove forests in Kwale have been subject to alarming levels of destruction over recent decades, mainly due to demand from charcoal production and timber use. Mangrove loss reduces coastal protection from extreme weather and shrinks the breeding habitats for a diverse array of marine species. According to the National Mangrove Ecosystem Management Plan, the mangroves of Kwale County comprise the Vanga-Funzi, Gazi Bay, and Ukunda areas, covering an area of approximately 8,354 hectares, with 45% of this area consisting of mangroves requiring rehabilitation. Overfishing, illegal fishing (using dragnets and poisoning) and destruction of coral reefs (caused by pollution from unregulated and inadequate sewage systems) also have a deleterious effect on the local coastal ecology.

Since coastal communities suffer from high income inequality, and fishing communities are highly impoverished, artisanal fishers earn around $3-4/day and keep a portion of their catch for food. According to Global Coral Reef Monitoring Network, the low level of economic returns has contributed to the emergence of fishing practices that are destructive to coral reef habitats and fisheries resources. Outside of the four marine parks (fully protected) and six marine reserves (partially protected), fishing has been difficult to regulate. Beach Management Units (BMUs), established under The National Kenyan Fisheries Act of 2007, were introduced to increase community participation in coastal marine management. This relatively new initiative still has a long way to go and requires additional support in the areas of reporting, record keeping, financial sustainability, resources, and cooperation (SmartFish 2011). The lack of resources and the pursuit of short-term goals prevalent in most fishing communities means that harmful practices persist.

Since 2000, Kwale County has also witnessed the loss of 20% of its tree cover. Local communities engage in deforestation for a variety of reasons: agricultural expansion, rapid population growth, charcoal production, over-reliance on wood energy, and, to a lesser extent, mining - exacerbated by weak governance (Ministry of Forestry and Wildlife 2013). Deforestation contributes to soil erosion by water, wind, and activities associated with land-use change, increasing soil degradation and loss of water resources, and exposing vulnerable populations to more extreme climate and weather events.

Climate-related disaster

According to Kwale County Government (2018), Kwale County in Kenya is located in an arid and semi-arid region, which makes it vulnerable to various disasters caused by both natural and human factors. These disasters, including droughts, land degradation, diseases, conflicts, floods, as well as minor hazards like fire, winds, and landslides, have led to acute suffering, loss of development assets, and food insecurity in the area. Such challenges have resulted in conflicts, displacement, and millions of casualties. Long-term solutions are needed to address these issues and ensure the well-being of the county.

Within the county, major droughts occur every 10-15 years while minor droughts occur every 2-4 years (Makoti *et al*, 2015). A food security forecast conducted by the Kenya Food Security Steering Group (KFSSG) in Kwale in July 2016 indicated that Lunga-Lunga and Kinango had experienced 70-100% crop failure.

Livelihoods

Before the project began, the most recent data showed that Kwale County had an estimated population of 783,261, of which 74.9% lived in poverty. The coastal community is highly dependent on natural resources (agriculture and fisheries), which are negatively affected by climate change and environmental degradation. Coastal communities reported a declining trend in fish productivity and diversity, and low levels of income diversification among coastal households. This has increased their vulnerability to climate-related events, household-specific shocks such as injury and disease, and economic stress.

Approaches

Conservation and Sustainable Management of Marine Ecosystems

In 2016, the COSME project was developed by Plan International Kenya and Plan International UK in response to the lack of viable income-generating activities, increasing environmental degradation, climate threats, and dwindling fisheries yields along the southernmost coast of Kwale County. The project aimed to improve the lives and livelihoods of coastal communities, particularly women, through participatory and sustainable development (including the introduction of diversified, responsible economic opportunities), promoting environmental conservation and management of environmental risks, and building resilience to climate-related extremes.

The project formally started in January 2017 and ended in May 2019, with a final evaluation completed in June 2019. An ex-post evaluation was conducted in February-April 2020. The COSME project mobilized groups in Lunga-Lunga and Msambweni constituencies, reaching 4,145 people. During the last seasons survival rate has been affected by the 2020-2023 drought affecting Kenya and the Horn of Africa survival of around 70-75%. 8 mangrove groups – Mwazaro Beach Management Unit (BMU), Kibuyuni BMU, Majoreni BMU, Mwambao/Mkuyuni Youth, Daima Women, Mtimbwani BMU, Mwandamo and Chete Cha Kale took part in the planting, on their mapped mangrove sites with 435 (333F, 102M) members participating, of which 27 (10 women, 17 men) were youth.

The second phase also contributed to the establishment of 14 groups, (8 mangrove groups and 6 seaweed groups) and VSLAs in 8 communities to help the financing of the seaweed and mangrove groups and successfully led to the launch of the Pongwe-Kidimu Community Forest Association and the formalization of the Pongwe-Kidimu Participatory Mangrove Forest Management Plan (PFMP).

The Pongwe-Kidimu Community Forest Association (CFA) is a legally recognized entity under the Kenya Forests Service (KFS) Act, which is mandated to manage community forests on behalf of the KFS. The PFMP is the legal agreement between the KFS and the CFA and guides the CFA in running its affairs on forests and forest resources management and utilization. With the PFMP, the CFA can approach donors/development partners to support in the implementation of any of the interventions listed in the document, supervised by KFS. This gives the community the legal authority to manage the mangrove forest and forest-based resources in a sustainable manner for their livelihoods under the Kenya Forest Services watch.

In partnership with the Kenya Marine and Fisheries Research Institute (KMFRI), the project aimed to introduce improved and environmentally sustainable fishing techniques and promote alternative and supplementary income-generating activities (seaweed farming being the most prominent and successful intervention) among communities heavily dependent on fishing - and to reduce pressure on stressed fishing waters. Activities were informed by research into current and alternative livelihood practices, the viability of local fisheries, child protection and gender dynamics in the local coastal economy.

Interventions also included awareness-raising and education in local schools and communities to increase knowledge and capacity in natural resource management and environmental protection - with a particular focus on the impacts of illegal logging, mangrove destruction and unsustainable fishing practices. As noted above, engagement in illegal practices and natural resource degradation is partly a result of negative coping mechanisms of community members and fishing groups when the returns from fishing are inadequate. With technical support from the Kenya Forestry Service (KFS), the project worked with schools and community-based organizations to promote the production of tree and mangrove seedlings with the long-term goal of promoting the rejuvenation of fish stocks, restoring natural flood defences, and promoting soil and water resource management.

A People-Centered Approach to Address the Triple Crisis at Local Level

The main activities of the project and their contributions are listed in the center of **Figure 3**, under the domain of the main challenge they explicitly aim to address. The integrated nature of the project means that ancillary outcomes of the activities will contribute to addressing other challenges and was a key project objective.

The diagram also shows the components of the approach that promote community ownership and leadership, facilitated by working with self-governing community groups.

These components have been grouped into three categories, represented by icons in **Figure 3**: (i) local environmental stewardship, (ii) women's empowerment and agency, (iii) pro-poor responsible value chain development.

The role of local communities in catalyzing social, economic and environmental change is central to the approach, which promotes ownership of local natural capital and transparency in management while valuing and strengthening traditional knowledge and capacity to identify solutions. Local communities are critical to the design and implementation of interventions because of their wealth of knowledge and experience in dealing with localized climate and environmental risks, and their role as long-term stewards of natural resources. Local ownership is also central to ensuring the long-term sustainability and scale-up of project interventions.

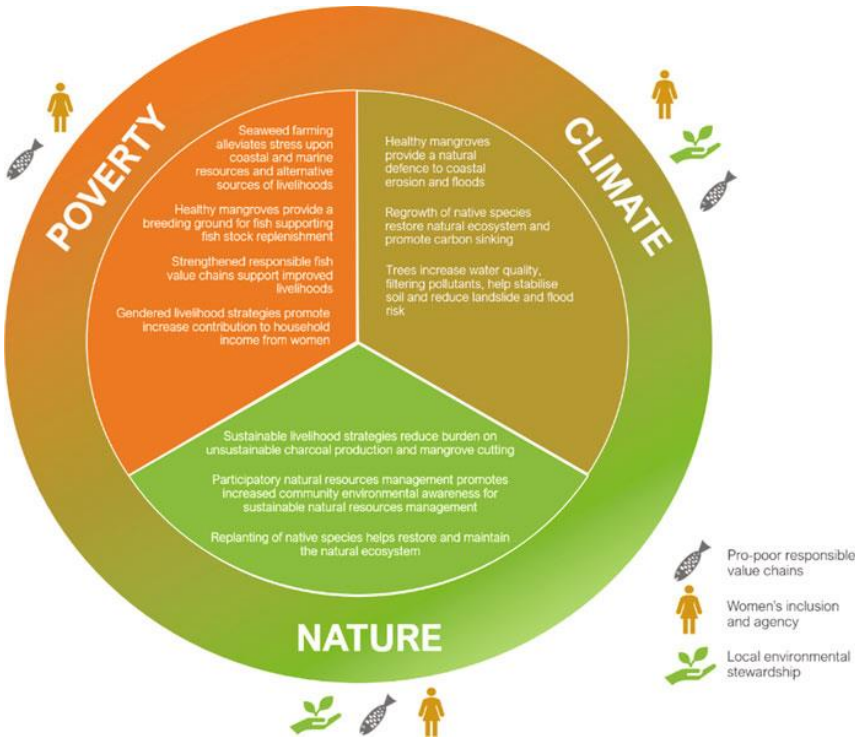

Figure 3 People-centered approach to address the triple crisis in coastal Kwale County, Kenya. (WWF-UK 2018)

Local Environmental Stewardship

Local environmental stewardship is defined as the sum of actions taken by individuals, groups, or networks of actors with varying motivations and levels of capacity to protect or responsibly use the environment in pursuit of environmental and/or social outcomes (Bennett *et al*. 2018).

Over the years, illegal logging, charcoal production, forest encroachment, overgrazing, and other human activities have contributed to forest loss and degradation. Community groups have demonstrated a high level of understanding of the relevance of the activities, the expected positive ecological and disaster risk reduction outcomes, and the resulting positive impacts on their well-being and livelihoods.

Since project completion, 80% of the groups have remained active. In addition, independent of the project, a number of mangrove groups have started saving money through village savings schemes to invest in project-related activities. Individuals contribute funds that have been used to secure the formal registration of the savings group, which will allow the group to access additional funds and purchase products to continue and expand their activities - including signs to identify the areas to be rehabilitated, seedlings, record keeping materials, and a boat to reach the areas to be rehabilitated. The involvement of the fisherfolk through the community BMUs and mangrove groups has been crucial in securing the commitment of the wider community and demonstrating the benefits of a healthy mangrove forest to the local economy and livelihoods. These activities were complemented by raising awareness of the negative impacts of illegal fishing practices, particularly the use of explosives, seine nets and poisons. Educating fishing groups about destructive fishing practices that have a negative impact on the ecological balance of the reef and seabed has been complemented by the promotion of responsible fishing techniques that contribute to long-term environmental benefits associated with an important economic activity.

Women's Inclusion and Agency

In coastal communities, gender considerations are crucial for two main reasons. Firstly, promoting responsible management and utilization of marine and coastal resources can serve as a means to empower women economically and socially. This approach not only strengthens resource governance and conservation but also provides opportunities for women's empowerment. Secondly, it is important to acknowledge that gender-based violence (GBV) is a significant issue in the fisheries sector. According to Siles *et al*. (2019), the FAO estimates that over 15% of individuals directly involved in fisheries and aquaculture are women, with the majority of them participating in processing activities. Despite their significant contributions to the fisheries value chain and their role in supporting the industry, women often face limited decision-making power and are underrepresented in leadership positions (FAO 2016a). This exclusion of women from management efforts, coupled with their vital role as environmental stewards, hinders the improvement of conservation practices and sustainable management of natural resources. This is especially critical as these resources form the basis of livelihoods for communities in these areas.

Integrating gender considerations into conservation and development interventions increases the likelihood that they will achieve their intended outcomes of poverty reduction and improved food security in coastal communities (Matthews *et al*. 2012). Findings from the project highlighted the high vulnerability of women and girls to GBV, particularly exacerbated by declining fisheries resources-women and girls are at greater risk of GBV from fish sellers and traders in order to sell or buy fish (Siles *et al*. 2019). Women reported supplementing household income through activities such as soap making, animal husbandry, farming, and selling firewood.

By analyzing women's unique contributions to the local economy, their capacities, needs, and constraints, the project identified strategies to better engage women and uphold women's interests at different stages of the intervention.

Pro-poor Responsible Value Chain Development

Value chain development refers to improving the productive operations of a value chain and generating social benefits such as poverty reduction, income generation, economic growth, environmental performance, and gender equity. The COSME project conducted research on viable alternative and complementary livelihoods for coastal communities to reduce vulnerability to climatic, idiosyncratic and economic stresses. Seaweed farming emerged as one of the preferred supplementary livelihoods, providing an opportunity for women to contribute to household income. Initial investment costs are low and there is a supportive environment for seaweed farming among communities. Women participating in seaweed farming have increased their base of consumer and household assets, including purchasing land and building permanent homes, paying school fees, and covering medical expenses. However, the project observed an increase in the popularity of seaweed farming among men, which may reflect gender inequalities in fisheries value chains and needs to be monitored. The project aimed to identify sustainable livelihood options in partnership with local communities, while addressing gender inequalities within households and communities.

Accomplishments

Livelihoods and well-being

The project has created jobs for participating community members, who earn from sales of seaweed. A total of 514 community members (342 women and 172 men) are participating at different stages, earning varying amounts depending on the crop cycle. 312 members (214 women, 98 men) earned a total of KES 1,957,000 (US$16,308) from sale of dried seaweed in 2022. The Kibuyuni Seaweed Cooperative, one of the entities the project has been working with, has moved into value addition and employs two staff on a permanent basis. They produce liquid and bar soaps, shower gels, body lotions among other products from seaweed, which fetch higher prices. For instance, while a kilo of seaweed goes for about US$0.35, a 100ml of shower gel which takes less than 10 grams of seaweed costs US$1 from the group. Through seaweed farming, the participating community members are able to meet their daily dietary needs, access to health service and education opportunities for their children as well as purchase assets.

Mangrove forest restoration: The project has created 476 jobs (232 female and 244 male) for community members who are involved in the establishment of a commercial seedling nursery. Through formal group structures, the groups set up the nursery and sell seedlings to partners who are implementing mangrove restoration activities.

With the introduction of VSLA, members of these groups have a means to save and access small loans when they are in need. The loans are paid back with a small interest of 10%, thus helping the fund to grow and fully meet members' financial investment needs over time.

With these interventions on income, members are better able to address household needs such food, medical expenses, school needs among other considerations than before because from time to time they earn from the sale of seaweed and seaweed products, mangrove seedlings and from mangrove planting and have a fall back within their VSLA in case they face emergencies.

Biodiversity and ecosystem benefits

The project has helped improve the restoration of local mangrove forests and fish populations by preserving existing mangroves and rehabilitating degraded sites.

Led by coastal community mangrove groups and upstream community tree planting groups, COSME's planting activities have yielded increasing results in terms of the number of trees growing and their survival rate. Over the past 2-year period, 127 people in 4 groups, of which 50% are women, planted 137,000 mangrove seedlings. In addition, 820 people (women, girls, boys and men - with 50% female participation) planted 7940 seedlings for reforestation of fruit trees, native forest species and sustainable charcoal replacement trees. Although there was some attrition at the beginning of the project, with seedlings being lost due to poor management, the survival rate has since increased and stabilized at an average of 80%. In addition, one of the groups involved in tree production and planting - a charcoal cooperative - has decided to stop charcoal production altogether and is now focusing its income-generating activities on goat rearing and beekeeping. The group now hopes to work with local government partners to identify and receive training in additional alternative and sustainable income-generating activities.

Gender equality

The project has been largely successful in reaching women and girls through awareness-raising and education initiatives - where they have been prominently involved in promoting reforestation activities and in school education. Women were also supported and heavily involved in seaweed farming and in monitoring, managing and promoting environmental conservation activities.

According to Ambrosino *et al.* [2] the project evaluation also found reports of improvements in issues related to the welfare of children and girls at the local level, including a reduction in reported cases of child trafficking, a reduction in reported child pregnancies in fishing communities, a reduction in girls dropping out of school to engage in fish processing and marketing, a reduction in children (especially boys) dropping out of school to engage in local tourism activities, and a reduction in children assisting parents in boat and local furniture making and mangrove harvesting.

Gender inclusion in the value chain promotes women's empowerment and increases their contribution to household income. At the end of the COSME project, women reported investing their income in paying for their children's school fees and health-related expenses and in improving their quality of life (e.g., access to safe water, home improvements), with clear outcomes for the broader household and community, including risk diversification at the household level, children's well-being, and a shift to more sustainable livelihoods.

Alignment with IUCN Nature-based Solution Global Standard

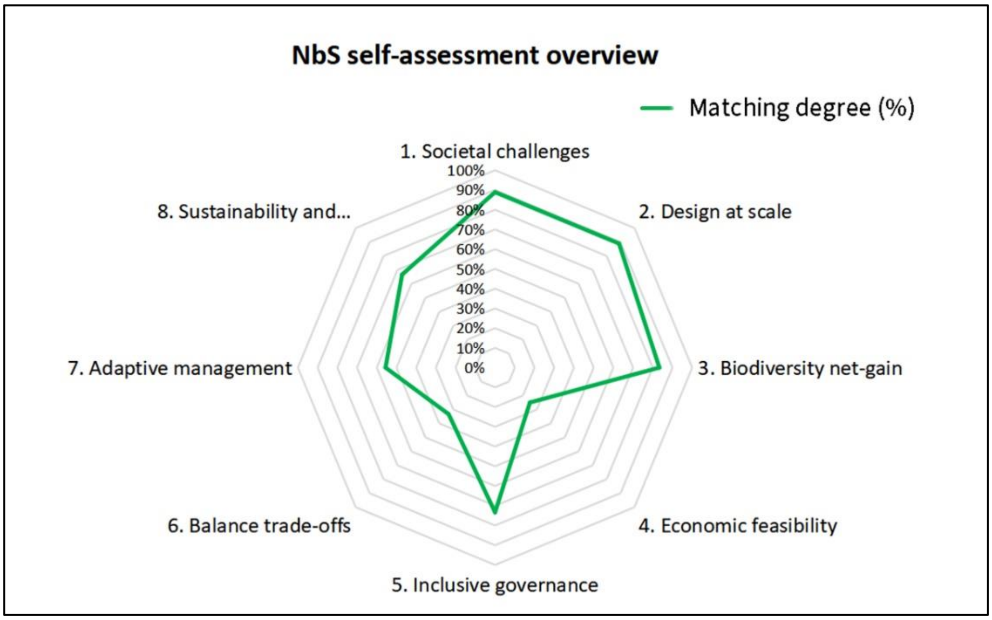

Figure 4 Alignment with NbS standard self-assessment.

After having assessed the case study with the NbS Global Standard's 8 criteria, we summarise the areas in which the case study strongly meets the Standard's criteria and those in which it met them partially or weakly (**Figure 4**). The latter helps identify what aspects are to be improved, which may be of considerable importance for practitioners.

The project focuses on mitigating and adaptation to climate change, reducing disaster risk, and safeguard food and water security. It manages to restore the mangrove ecosystems to enhance the ecosystem functions and services of climate regulation, water regulation, erosion control and sediment retention.

According to the Standard, the project has adequately met some of the criteria, while others are partially or weakly met based on available information. It has clear objectives to improve climate resilience and livelihoods (Criterion 1). In particular, the project incorporates gender considerations to strengthen the role of women in environmental management (Criterion 5).

However, the project needs to consider monitoring and evaluation strategies and adaptive management to improve sustainability (Criterion 7). In addition, the project team can develop a communication strategy in order to share knowledge and experience (Criterion 8).

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Mangroves for Ecosystem-based Disaster Risk Reduction: A Case Study of Kala Oya Estuary, Sri Lanka

Introduction

Sri Lanka is one of the world's premier biodiversity hotspots, renowned for its natural beauty across the island with a variety of ecosystems from coastal to mountain regions, despite the relatively small size of the tropical island.

Figure 1 Location of Kala Oya estuary. (Google Maps, 2023)

The Kala Oya estuary is located at the mouth of the Kala Oya where the freshwater from the river mixes with the saltwater from the sea. Particularly, Kala Oya and its tributaries (including the “Pan Oya", and “Lunu Oya” stream) discharge freshwater into Puttlamlagoon creating Kala Oya estuary with bar-built estuary characteristics. The Kala Oya estuarine system is relatively shallow, about 1.5-3m deep in most areas, and almost at the altitude of sea level. The estuary is located roughly 180 km northward of the capital city Colombo.

Two major components of the Kala Oya estuarine system can be distinguished based on the differences in depth, salinity, and biodiversity: the outer estuary and the inner estuary. The area between the river mouth and the brackish water area of the Kala Oya estuary is considered the inner estuary and the outer estuary is from the Dutch Bay and Puttalam lagoon area (National Wetland Directory Sri Lanka, 2022). As a bar-built estuary, the outer banks are approximately 7.5 km away from the river mouth, and that protects the inner coast area by sand barrier from direct waves and wind from the Indian Ocean. Kala Oya has low estuarine currents because dense saltwater has limited access to entering the estuary even during high tides.

These sandbars and islands in the estuary also protect fragile brackish ecosystems in the Kala Oya estuary. Beyond the outer boundary of the estuary, with unparalleled biodiversity significance and the largest coral reef of Sri Lanka (306 km^2), the famous Bar Reef marine sanctuary lies about 2 km in the Indian Ocean, parallel to the Kala Oya estuary (Perera et al., 2003). The Bar Reef Marine Sanctuary and nearby seagrass meadows display significant biodiversity in the country, home to porpoises, dolphins, Bottlenose and Spinner dolphins, dugongs, sea turtles, etc. (Dugong Conservation, 2023).

The Kala Oya is not a perennial river, as during certain months of the year some areas dry out. The volume of freshwater that reaches the estuary is mainly controlled by the Kala Oya-associated reservoirs – (the Kala Wewa and Rajanganaya) in the upper and mid catchment. The Kala Wewa reservoir in the dry zone receives continuous irrigation water from the Mahaweli River diverted project. Therefore, despite being in a semi-arid coastal region with relatively low annual rainfall, the Kala Oya estuary holds a considerable amount of water level all year long, providing perfect conditions for mangrove ecosystems. A variety of other coastal and marine ecosystems can also be found in the estuary, e.g., salt marshes located in high salinity areas within the outer estuary area, and seagrass found in the Dutch Bay.

The Kala Oya estuary is home to the most diverse mangrove ecosystems in Sri Lanka (**Figure 2**). According to the Biodiversity Baseline Survey for ESA Project, UNDP & Ministry of Environment Sri Lanka (2017), several true mangrove species as well as mangrove-associated species have been identified at the site. The area is home to endangered, vulnerable, and near-threatened species, some are listed but not limited to, endangered species of *Bruguiera cylindrica* (L.) (Bakau Putih), *Xylocarpus granatum* (mangrove cannonball), *Sonneratia alba*, Vulnerable species of *Bruguiera gymnorrhiza* (L.) Lamk (Oriental mangrove), and *Scyphiphora hydrophyllacea* Gaertn. f.) (Kalukadol), and Near Threaten species of *Avicennia Officinalis L* (Indian mangrove*), Lumnitzera racemosa* Willd. (Black mangrove), *Pemphis acidula* Forst., *Ceriops tagal* (Perr.) C.B. Robinson, *Rhizophora apiculata* Blume were identified (UNDP and MOE, 2017). Evidence shows that the Kala Oya estuary has the tallest mangrove trees in the country, with 20 m in height on average and more than 75 cm in stem girth (Ministry of Environment Sri Lanka & UNDP, 2016).

Figure 2 Mangroves in Kala Oya estuary. (ESA Project, UNDP Sri Lanka)

Mangroves at Kala Oya provide critical ecosystem services (**Figure 3**). Mangroves are located at the point where the sea meets the land, reducing flooding and providing a natural defense against waves and winds coming from the Indian Ocean. It also serves as a permeable dam that reduces storm surge damage and dampens the surge. Mangrove roots slow down wave energy before the surges reach the shoreline and mitigate coastal erosion (UNEP, 2013, FAO-Prasetya, 2007). The thick canopy of mangrove trees helps to dissipate storm surge energy, preventing it from reaching the shore with the same intensity. Mangrove forests reduce up to 66% of wave energy in their first 100 meters (Menéndez et al., 2020).

There is a substantial amount of blue carbon stored within living plants in mangroves as blue carbon ecosystems and its deep peat soils for millennia, it is estimated that over 21 gigatons of carbon are stored in mangroves across the globe and mangroves store 3 to 4 times more carbon than tropical forests (Spalding and Leal, 2021, IUCN, 2020). With most of the carbon stored in the soil, mangrove forests are one of the world's most carbon-dense ecosystems (Sanderman et al., 2018). Further, within the same estuary, soil carbon accounted for 78% of the total ecosystem carbon storage in tall mangroves and 96%–99% in medium and low stands of mangroves. Therefore, with this potential, climate mitigation targets can be achieved through mangrove protection and restoration. Besides carbon sequestration, ecosystems such as mangroves play a critical role in regulating the water cycle and extreme weather.

Mangrove ecosystems hold high biodiversity. Remarkably, the Kala Oya estuary and associated mangroves are a haven for a large variety of animal and plant species. This mangrove ecosystem is bountiful in biodiversity and provides habitats, feeding, and resting sites for a wide variety of aquatic, marine, terrestrial, and avifauna species. The area is rich in nutrients such as plankton, bacteria, and decomposing plant matter (detritus), which provides food for many species. This nutrient-rich area is an invaluable nursery, breeding, and feeding ground for numerous fish, shrimp, crabs, shellfish, and bird species and supports the complex food web in the mangrove forest. The calm, shallow waters provide a safe environment for small fish, shellfish, migratory birds, and shore animals.

It is estimated that over 80% of small-scale fishers in many countries depend on mangroves due to the structure and productivity of mangroves (Spalding and Leal, 2021, UNEP, 2013). 55 fish species and 8 shellfish species have been recorded in the Kala Oya estuary within Puttalam Lagoon (Ministry of Environment Sri Lanka & UNDP, 2020). Kala Oya mangrove forests are an important source of income and livelihood for coastal communities (Ministry of Environment Sri Lanka & UNDP, 2020). National budgets typically have no provision for the economic value of mangroves as a flood protection system (Menéndez et al.,2020). They provide fuelwood, food, construction wood for houses and boats, traditional medicine, as well as livelihoods for fishing, aquaculture, recreation, and eco-tourism (Katupotha, 2016). Most importantly, the mangrove ecosystem supports eco-tourism. Therefore, the conservation of Kala Oya mangroves can have a positive and lasting impact on local communities at the national and global levels.

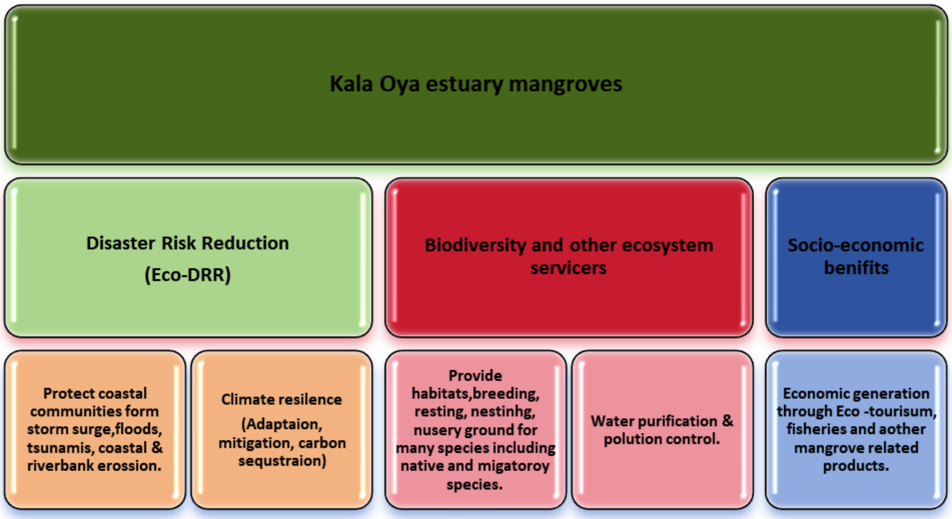

Figure 3 Benefits of Kala Oya estuary mangroves. (Padmi Ranasinghe)

Issues

Even though threats to the Kala Oya estuary mangrove ecosystems within the Wilpattu National Park (a legally protected area for conservation) are significantly lower than other mangrove sites in the country, mangroves in the area outside the protected area (the southern bank particularly) are highly exposed to fragmentation, degradation, and habitat loss due to increased population pressure, infrastructure, and industrial activity (**Figure 4**). As mentioned, the northern riverbank associated riparian zone and river mouth are under the Wilpattu National Park protected area; the opposite bank is not. As a result, the southern bank-associated riverine and mangroves are subjected to greater degradation due to human destruction.

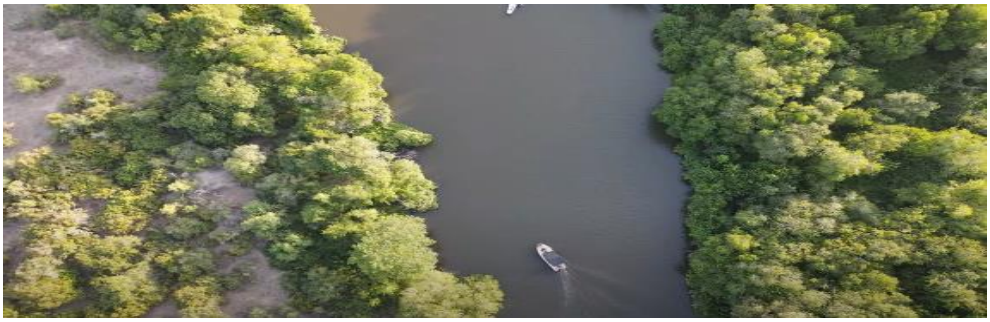

Figure 4 Changes in mangrove distribution on the northern and southern banks of the Kala River at Kala Oya estuary.

Threats to the Kala Oya estuary mangrove include anthropogenic and natural causes as listed below (also refer to **Figure 5**). Poor governance was identified as one of the most significant causes of fragile ecosystems in the Kala Oya estuary. This is particularly due to the absence of laws, policies, and a unique authority or mechanism for the conservation of highly biodiverse areas outside of protected areas. With these loopholes, the southern bank of the Kala Oya River and the river mouth are highly susceptible to exploitation, deforestation, overharvesting, poaching, and other illegal activities.

Figure 5 Threats to Kala Oya mangroves (Padmi Ranasinghe)

Unsustainable livelihoods: Economically disadvantaged communities, mostly fishermen live in the rural villages near the estuary and rely heavily on the Kala Oya mangrove ecosystems for their livelihood activities. Mangroves are heavily harvested for fuelwood and construction wood for houses and boats. Small-scale fishermen still employ destructive fishing gear (Ministry of Environment Sri Lanka & UNDP, 2020). At low tide, it is easy to overharvest clams, shellfish, crabs, shrimps, etc. The growing pressure to establish commercial prawn farms in the tidal zone hinders the tidal exchange and destroys mangroves. Prawn farms require a large area of enclosed space to be built to prevent the free flow of water and increase the salinity of water, as well as pollution.

Land conversion for infrastructure development and agriculture: It is not uncommon that mangroves are filled, ditched, and dredged in coastal infrastructure development such as ports, hotels, industries, and housing developments (Ministry of Environment Sri Lanka & UNDP, 2020).

The growing concern of the tourism industry: Tourism activities at the site are not monitored or regulated, and a major issue for the sustainable management of mangroves in the area. Several unsustainable tourism activities damage the mangrove ecosystem, contributing to mangrove degradation, fragmentation, and deforestation.

Natural hazard impact: Low-lying areas of Kala Oya are highly susceptible to coastal, flash, and fluvial flooding. Floods cause high deposition of sediment/sand near the river mouth, blocking the river and making fisheries unusable. It has been estimated that the depth of the river mouth has decreased from 15 feet to 2 feet within the last 30 years (Ministry of Environment Sri Lanka & UNDP, 2020). During the past few decades, the hydrology of the Lower Kala Oya basin has changed due to the Mahaweli River water diversion (Ministry of Environment Sri Lanka & UNDP, 2020). This increases the volume of freshwater in the estuary and reduces salinity. As a sensitive salinity-tolerant species, mangroves are highly vulnerable to such situations.

Natural phenomena like Climate change are a major threat: There is no doubt, that a greater likelihood of climate change adversely affecting the delicate ecosystems of the Kala Oya Estuary. Hence, species abundance, distribution, habitats, phenology, community composition, processes, functions, and ecosystem services can be further altered (Weiskopf et al., 2020).

Approaches

Conservation and restoration measures and activities

Even though Kala Oya estuary is home to the largest intact mangrove forest in the county and has a wide variety of unique species and ecosystem diversity, there was no specific mangrove conservation plan for "Gangewadiya" area or outside the protected areas in the country until 2020 (Ministry of Environment Sri Lanka & UNDP, 2020). It was crucial to implement a flexible, adaptive, and specific Eco-DRR strategy in order to ensure the conservation and restoration of the mangrove ecosystem, and other coastal and marine ecosystems, especially for environmentally sensitive areas outside of the protected areas.

Figure 6 below illustrates the Eco-DRR strategies implemented for the sustainable restoration and protection of mangrove forests in the Kalaoa estuary.

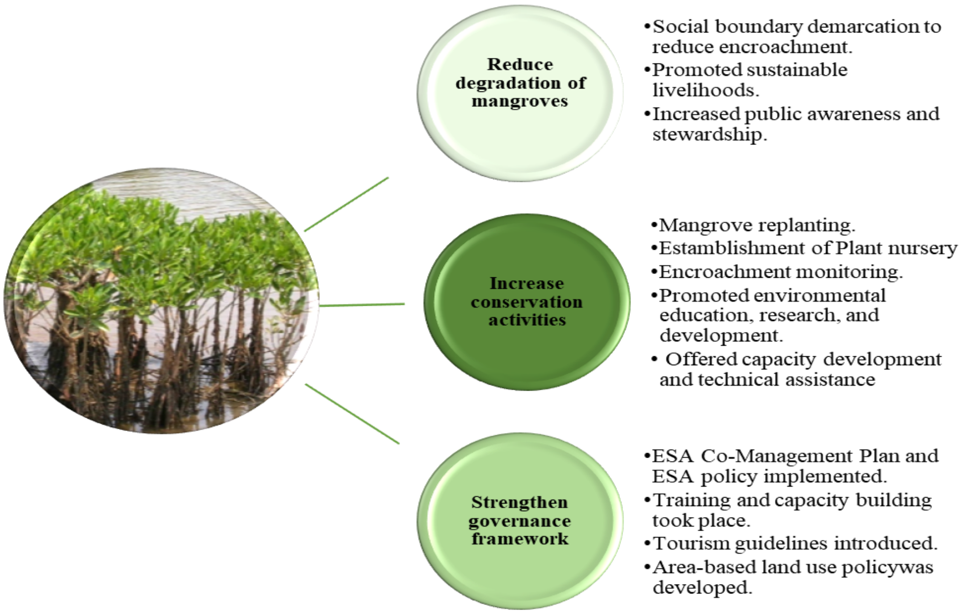

Figure 6 Eco-DRR and NbS strategic approach for mangrove conservation. (Padmi Ranasinghe)

Eco-DRR activities fall into three main categories: mitigation, protection and improved governance. A number of measures have been taken to reduce mangrove degradation. These include demarcation of social boundaries of mangrove forests to prevent encroachment, promotion of sustainable livelihoods, public awareness and ownership of mangrove forests by local communities. In addition to replanting mangroves, technical assistance, capacity building, monitoring of mangrove encroachment and promotion of research have been provided. Through the Environmentally Sensitive Areas Management Plan (ESAMP), the governance framework has been strengthened and policies implemented; training and capacity building activities have been conducted; tourism guidelines have been issued; and area-based land use policies have been developed. The aim of these activities is to protect mangrove ecosystems and promote the sustainable use of their resources. It has also ensured that all tourism activities in the area are conducted in a responsible manner to support conservation efforts.

Figure 7 below showcase the mangrove nursery at the initial stage, demonstrating how to make mangrove saplings and promoting awareness and capacity building through educational programs at the Kala Oya estuary – “Gangewadiya” Environmental Sensitive Area.

Figure 7 Mangrove Planting at Kala Oya estuary- Gangewadiya site.
(UNDP Sri Lanka-ESA Project)

With the support of the community and authorities, boundary demarcations for the mangrove areas were prioritized. These demarcations are mainly social demarcations. Many locals respected and protected the demarcation. During the demarcation process, the local community was allowed to participate in decision-making and a sense of ownership over the environmentally sensitive area, thus encouraging them to take responsibility for their maintenance.

Involvement of multiple government agencies and stakeholders including local community and collaboration were the key to success. Kala Oya mangroves are legally bound to different government agencies and mandates, therefore clear communication and a better understanding of responsibilities among different entities remained highly important (Ministry of Environment Sri Lanka & UNDP, 2020). It was also prioritized to engage stakeholders with local government agencies and the national level early in the process

In the context of the degradation of mangroves at the Kala Oya estuary, adaptive management involves analysis of knowledge of impacts and uncertainties. It involves the design of actions, monitoring species, habitats, and ecosystem services, evaluating management effectiveness, redesigning, and implementing improved (or new) management strategies if necessary. Monitoring results were integrated into management processes to ensure that management decisions are continuously improved. In addition, lessons learned were based on current experiences and other similar activities locally, regionally, nationally, and internationally.

Innovative mechanisms

A concept known as Environmentally Sensitive Areas (ESA) can serve as an innovative approach. An environmentally Sensitive Area (ESA) is a landscape element or an area with high biodiversity value, located outside of a protected area, and which needs to be managed through a co-management modality to conserve biodiversity and sustain ecological, environmental, and socioeconomic benefits to the local communities as well as the nation and the globe at large (Ministry of Environment Sri Lanka & UNDP, 2020). The ESA concept is fully consistent with the concept of Eco-DRR. Although environmental disaster mitigation may not be the primary focus of ESA, its actions still have the desired effect of reducing disaster risk.

Practice of Gangewadiya ESA

The southern bank within the Kala Oya estuary has a high biodiversity significance and is considered a conservation priority due to the importance of conserving ecosystems along the estuary and southern bank. The Gangewadiya area is located in the Vanathavilluwa Divisional Secretariat Division of Puttlam District. Based on its significance outside protected areas, "Gangewadiya" was designated as Sri Lanka's first environmentally sensitive area (ESA) in 2018 (**Figure 8**).

Figure 8 Gangewadiya ESA in Kala Oya Basin. (Padmi Ranasinghe)

Further, the Gangewadiya mangrove ecosystem at the Kala Oya estuary is one of the largest intact mangrove ecosystems in Sri Lanka with the presence of threatened mangroves with associated mangrove species and other flora and fauna species (Ministry of Environment Sri Lanka & UNDP, 2020). The Wilpattu Ramsar Wetland Cluster is located within the Wilpattu National Park and borders the Gangewadiya ESA (Ramsar.org, 2013). As it is located on the periphery of Wilpattu National Park and serves as an influential zone of the Bar Reef Marine Sanctuary, Gangewadiya, the ESA area is a landing site for migratory birds. Also, the area is the main fishing ground for the local community and Kala Oya is the main source of potable water for the Gangewadiya community.

Process of ESA Co-management

The Co-Management approach has been selected as the most effective method of managing ESAs because it combines environmental, ecological, and socio-economic factors with long-term biodiversity management goals. The process of co-management has three main components: 1) Biodiversity assessment; 2) Threats and trends assessment; 3) Participatory planning.(**Figure 9**) To oversee the planning, implementation, and monitoring of Gangewadiya ESA within the 'Vanathavilluwa' Divisional Secretariat Division[2], a Local Management Committee (LMC) was formed under the chairpersonship of the Divisional Secretary and with participation from relevant government institutions and community representatives. The figure below demonstrates the ESA Co-Management Plan Development Process.

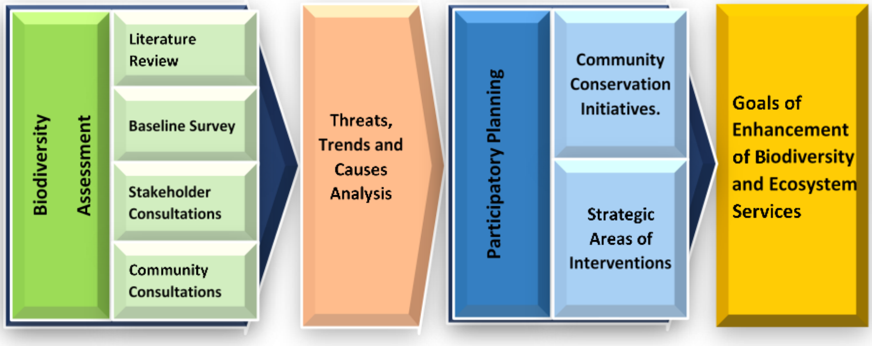

Figure 9 ESA Co-Management Plan Development Process (Padmi Ranasinghe, 2020)

Numerous stakeholder meetings, including meetings with government officials and other stakeholders, training, awareness missions, and capacity-building exercises taken during the process in 2019. (**Figure 10**) These activities have been instrumental in helping to build an understanding of the project and its potential impact.

Figure 10 Stakeholder consultations in the Kala Oya estuary area (UNDP Sri Lanka-ESA Project)

The picture below showcases different community consultation meetings that took place at the "Gangewadiya" area, within the Vanathavilluwa DS division. (**Figure 11**) These community meetings generally took place in schools and religious institutions in different rural villages in and adjacent to the "Gangewadiya" ESA.

[2] Divisional secretariats are the third-level administrative divisions in Sri Lanka. Provinces (9) are divided into districts (25), which are further divided into divisional secretariats (331) within the country.

Figure 11 Community consultations at rural villages near Kala Oya Estuary (UNDP Sri Lanka-ESA Project)

Accomplishments

Gangewadiya ESA co-management plan developed

Under the direction of the divisional Local Co-Management Committee, which was established in 2017, the Gangewadiya ESA Co-Management Plan was developed in 2019 with several conservation mandates. The Co-Management Plan is a composite of the geographical, demographic, and climatic conditions of "Gangewadiya", biodiversity profile, threat and trend assessment, objectives and implementation strategies, the conservation plan with a policy framework, the operationalizing plan with the responsible actors and resources required, and participatory monitoring and evaluation framework to assure adaptive learning and management.

The plan also includes the management of mangrove nurseries and mangrove replanting activities. The co-management plan recommends and approves the demarcation of protected areas and the adoption of bylaws to regulate development activities. Guidelines are proposed to ensure the demarcation of protected areas, the rational use of natural resources, the development of a farmer information system and the promotion of sustainable tourism. Biodiversity conservation, net biodiversity gain, economic viability and trade-offs, adaptive management and sustainability mainstreaming have been considered in the planning of environmental disaster prevention and mitigation approaches.

The Eco-DRR strategy has achieved remarkable results

The replanting of mangroves at the Kala Oya estuary was among the most successful and widely practiced activities. Mangrove restoration and replanting activities were led by the Sri Lankan Navy with the Forest Department, community members, different organizations, academia, and students. Initially, a nursery was constructed to accommodate about 400 mangrove saplings, and then it was expanded to accommodate more than 1,000 seedlings. To avoid monocultures, several mangrove species were housed in the nursery.

The COVID-19 pandemic, travel restrictions, and financial constraints due to the country's devastating economic crisis at the same time have curtailed the mangrove replanting process. Due to a severe economic crisis, it was difficult to obtain the necessary resources, and travel restrictions were imposed. The community made significant efforts to continue planting mangroves despite these challenges. Dedicated volunteers ensured the success of these initiatives. The Forest Department, especially, continues to monitor the newly planted mangroves on the site.

Attach importance to the development of eco-tourism

The ESA Co-Management Plan included a strong emphasis on ecotourism development in recognition of tourism as one of the potential economic development activities and potential threats to the Gangewadiya ESA and mangrove ecosystem. The Co-Management Plan has identified several specific strategies for developing ecotourism in the area, including promoting sustainable tourism practices, developing infrastructure for visitors, and providing training and education to local people in hospitality, tour guiding, and other skills related to tourism to provide economic opportunities to locals while protecting the natural environment through development and implementation of ecotourism guidelines.

Promote the implementation of policies

The National Environmentally Sensitive Areas Policy was adopted by the Government of Sri Lanka in December 2022 based on the practice of Gangewadiya ESA. The policy provides for the identification, declaration and management of environmentally sensitive areas such as the Kala Oya estuary. The policy will protect environmentally sensitive areas by providing a framework for their protection, rehabilitation and sustainable management. Measures include regulating land use practices, managing water resources, controlling pollution and protecting biodiversity in environmentally sensitive areas. To ensure compliance with these measures and to protect the environment, a monitoring and enforcement system has been established and relevant education programmes have been developed to promote environmental stewardship and to increase public awareness and participation in environmental protection. The policy contributes to the overall protection of the lush mangrove ecosystem of the Kala Oya estuary and beyond along with the national mangrove policy and the national environmental policy.

Alignment with IUCN Nature-based Solution Global Standard

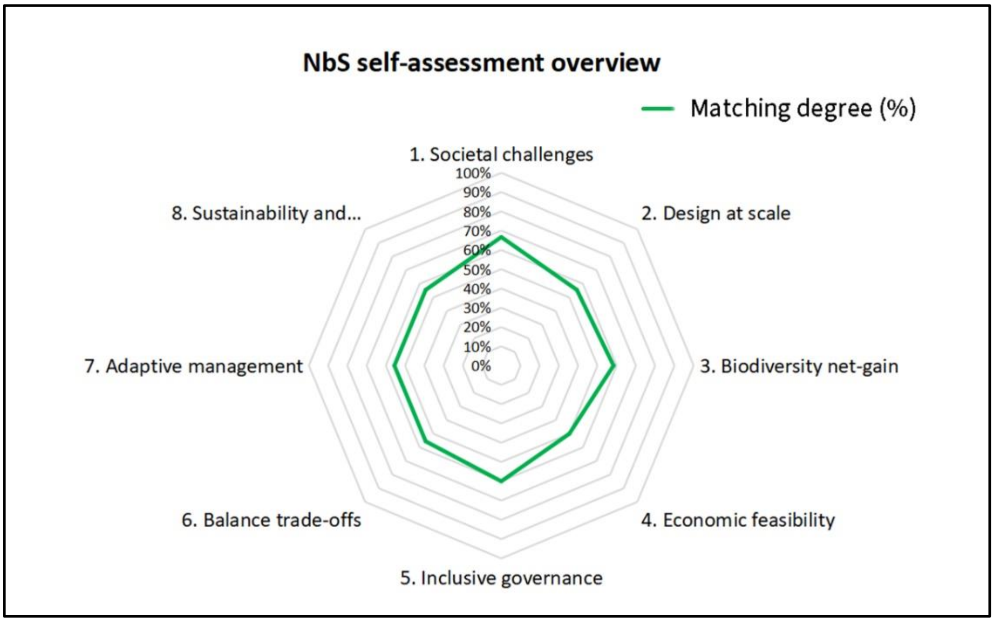

Figure 12 Alignment with NbS Standard self-assessment.

The IUCN Global Standard for Nature-based Solutions ensures that there are clear parameters defining Nature-based Solutions and a common framework from which to work. It is essential to develop such a framework to increase the impact and scale of the Eco-DRR approach; prevent unforeseen adverse outcomes or misuse, and to funding agencies, policymakers, and other stakeholders to assess the effectiveness of interventions. For this case study, Co-Management Plan actions along with mangrove conservation are compared with the IUCN Global Standards for Nature-based Solutions (NbS): Design at scale (local- manageable size), Biodiversity conservation, and net gain, Economic feasibility, balance tradeoffs, adaptive management, and sustainability mainstreaming.

Table 1 NbS criterion self-assessment overview.

Criterion	**FINAL OUTPUT**
1. Societal challenges	67%
2. Design at scale	56%
3. Biodiversity net-gain	58%
4. Economic feasibility	50%
5. Inclusive governance	60%
6. Balance trade-offs	56%
7. Adaptive management	56%
8. Sustainability and mainstreaming	56%
Total percentage match	57%

After having assessed the case study with the NbS Global Standard's 8 criteria, we have summarized the areas in which the case study strongly meets the Standard's criteria and those in which it met them partially or weakly.(**Figure 12** and **Table 1**) The latter helps identify what aspects are to be improved, which may be of considerable importance for practitioners.

The Gangewadiya ESA case focuses on mitigating and adapting to climate change, reducing disaster risk, and achieving water security while mainstreaming biodiversity. It manages to restore the mangrove ecosystems to enhance the ecosystem functions and services of climate regulation, disturbance regulation, erosion control and sediment retention, refugia, and recreation.

In line with criterion 1 of the NbS global standards, the case study was designed scientifically and community-centrically with a clear objective to address both natural and anthropogenic threats to mangroves in the Kala Oya estuary. The case study activities extended up to the local level integrating conservation aspects into development, and to the national level providing evidence for the formation of the National Environmentally Sensitive Area Policy (criterion 2).
By implementing conservation activities such as nursery management, replanting, and reducing degradation, the ESA supports mitigating climate change through Eco-DRR,

thereby restoring biodiversity (Criterion 3). The project was co-funded by GEF, UNDP, and the government, and the community provided their services for replanting and maintaining new plantations, which ensured the sustainability of the interventions (Criterion 4).

In addition, a local management committee has been formed in collaboration with the relevant government agencies and community representatives to adopt a co-management approach to land and sector management to promote inclusive governance. The Co-Management Plan and the Ecotourism Guideline officially acknowledge equal rights (Criterion 5).

The ESA clarifies costs and benefits and respects stakeholder rights through inclusive engagement. However, it needs to consider ecosystem trade-offs and relative interests. Local communities have been made aware of the benefits of non-harmful practices in fishing, tourism, and agriculture and have been facilitated for alternative, sustainable, and resilient livelihoods (Criterion 6).

The Gangewadiya ESA Co-Management Plan encompasses adaptive management strategies that involve iterative management actions followed by participatory and inclusive target monitoring and lessons-learned practices (Criterion 7).

Last but not least, Gangewadiya ESA management, including mangrove conservation activities, have been mainstreamed into the area-based development plans and sectoral plans (criterion 8). Accordingly, the mangrove conservation activities of the Gangewadiya ESA project have Satisfied all the criteria of the NbS Global standard. However, it requires continuous monitoring of conservation status as well as community behavior changes, and financial flows to continue such activities.

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Coastal Realignment Scheme, Medmerry, United Kingdom

Introduction

Location and Map

Medmerry Nature Reserve is a coastal wetland area located in West Sussex, England, between the towns of Selsey and Bracklesham, whose frontage was until 2013 a narrow shingle embankment ('barrier beach').(**Figure 1**) This acted as the flood defense protecting low-lying farmland behind it plus a significant number of residential properties in Selsey, the B2145 Chichester to Selsey road, the main wastewater treatment works of the area, and holiday chalets and associated infrastructure.

The frontage was considered to be the one most at risk in South East England of flooding from the sea, with a predicted level of risk of '1 in 1' (ie it was predicted that the sea would be likely to breach the barrier beach every year if remedial action wasn't taken). The barrier beach was artificially maintained, with a significant amount of public money spent each year (mainly in winter), recycling and re-profiling it with a fleet of diggers. In 2008, the defenses were breached during a storm which led to widespread flooding inland, showing how vulnerable the coast was at Medmerry.

Figure 1 Location of Medmerry. (Google Maps, n.d)

Socioeconomic Factors

In England and Wales, the central Government plays a key role in setting the policy framework for flood and coastal defense. According to Esteves [1], a strategic approach has been implemented through a three-level hierarchy of Shoreline Management Plans (SMPs), strategy plans, and schemes. The idealized route for a flood risk management scheme would therefore be: (1) for the SMP to recommend this as a policy, (2) a strategy to confirm the policy and to identify the type of scheme that will deliver the policy, and (3) a scheme to carry out the detailed design, seek necessary approvals (e.g. planning permission, etc.) and implement the works. Strategies typically investigate net gains and losses of existing habitats and make recommendations about how and where managed realignment should be implemented.

Discussion about managed realignment started in the UK in the late 1980s. At the time practitioners were questioning the need for ongoing maintenance of flood defences in some locations around the coast due to rising costs. In particular, consideration was given to locations where there were relatively self-contained rural areas of land, rising in elevation from the floodplain with no people, property or infrastructure. At the same time, coastal squeeze had been identified as an issue, and saltmarsh habitat was in decline so there were calls to recreate intertidal habitat areas. By the mid-late 1990s, the selection of early managed realignment sites was based on the conditions of the flood defenses and challenges faced to maintain them (e.g. exposure to high wave energy or undercutting by tidal currents) and the willingness of landowners to the new approach.

Issues

Coastal Flooding Risks

Medmerry was historically protected by a narrow shingle embankment, holding back only the very smallest coastal storms. An increase in the number of coastal flooding events, exacerbated by sea level rise and climate change, established that the existing shingle bank was insufficient to protect against floods. This posed significant actual and potential risks to life and caused damage to property and infrastructure. Additionally, coastal squeeze caused losses of coastal habitat. The most serious recent flood event before the start of the project occurred in 2008 and caused over GBP 5 million in economic damage and required evacuation due to risk to life. Therefore, the main societal challenge addressed by the Nature-based Solution was disaster risk reduction.

Ecosystem Degradation and Biodiversity Loss

Another issue in the wider region of The Solent has been the loss of environmentally important coastal habitat, as a result of coastal squeeze. The impacts of development and flood defense infrastructure around the large, urbanized areas of Southampton and Portsmouth have meant wetland and intertidal habitats are being lost to the sea. Some of the most important places for birds in Britain are the south coast estuaries, but these are under threat from climate change-driven sea level rise and increased coastal erosion.

To address these issues, a strategic view is needed, both to deliver the most cost-effective managed realignment and to maximize opportunities to create habitats from the start of the planning process. Biodiversity is at the center of both legal and policy drivers leading to the implementation of managed realignment.

Climate Change

Over the past century, the UK has experienced sea level rise and more intense winter rainfall. Seasonal rainfall is highly variable and appears to have decreased in summer and increased in winter, although the overall amount of winter precipitation has changed little over the past 50 years. While some of these changes may be influenced by natural factors, the overall patterns observed are consistent with climate change predictions from climate models.

The increased levels of greenhouse gases (GHGs) in the atmosphere are expected to contribute to higher winter rainfall in the future. Due to past GHG emissions, some degree of climate change is inevitable over the next 20-30 years. However, reducing emissions could mitigate the extent of climate change in the long term. Nevertheless, projections indicate that climate change will continue until at least the 2080s.

There are enough reasons to plan for change based on large-scale climate models. There is more uncertainty at a local scale, but model results can still help us plan to adapt. By the 2080s, the latest UK climate projections (UKCP18) are that there could be around three times as many days in winter with heavy rainfall (defined as more than 25mm in a day). It is plausible that the amount of rain in extreme storms (with a 1 in 5 annual chance, or rarer) could increase locally by 40%.

Approaches

Managed Realignment

Managed realignment refers to a common approach to restoring tidal patterns to previously reclaimed low-lying areas. This is achieved by breaching or removing existing flood defences, or by using structures such as culverts and tidal gates to regulate tidal exchange. The result is the creation of diverse habitats such as mudflats, salt marshes and transitional zones. Managed realignment serves as a strategy to reduce flood and erosion risks by allowing coastal habitats to adapt and move inland in response to climate change and rising sea levels. In doing so, it helps to limit the projected increase in the long-term costs of coastal defence, making it an integral part of coastal management.

Following detailed planning and public consultation, as part of the development of the Pagham to East Head Coastal Defence Strategy (2008), it was concluded that the best flood risk management solution for the Medmerry frontage would be managed realignment. In 2010, the Environment Agency secured planning permission for the scheme, and during 2011-2013, a very detailed and modeled design, constructed 7km of inland banks to a height of 5.6m Above Ordnance Datum (AOD). The clay to build the banks was extracted from shallow 'borrow pits' within the site, and two rock revetments (eastern and western rock armours) were created to strengthen the bank where it meets the coast.(**Figure 2**)

Figure 2 Rock revetment at seaward end of new embankment. (Harvey, 2021)

The managed realignment was implemented by constructing clay embankments on a retired alignment, tying into high ground where possible and defending all residential and commercial properties in the hinterland.(**Figure 3**) The seaward ends of the embankment are protected and tied in with rocks. The scheme links to adjacent private defenses built around the same time by Bunn Leisure's holiday park. New outfalls were provided within the clay bank, along with fluvial flood storage landwards of the bank to ensure that fluvial flood risk does not become worse. The provision of green infrastructure includes footpaths, cycleways, bridleways and disabled access. The existing coastal access route existing coastal access route was replaced with footpaths on a retreated line (to accord with Marine and Coastal Access Act). The design sought to achieve a balance between conservation and recreation by allowing some areas of the site to remain relatively undisturbed. Extensive stakeholder and community engagement was required.

Figure 3 Aerial photo of Medmerry looking south on 19 September 2013.
(Environment Agency, 2016)

Fundamental to the scheme was the creation of a breach in the existing shingle bank to allow the sea to reclaim an area of land close to the shore. New flood banks were built around the perimeter of this new flood inundation zone, and while they sit much closer to the surrounding communities than the previous shingle bank, the result is significantly increased flood protection. The inundation zone absorbs the energy and impact of the waves while also offering important new habitats.

Fundamental to the scheme was the creation of a breach in the existing shingle bank to allow the sea to reclaim an area of land close to the shore. New flood banks were built around the perimeter of this new flood inundation zone, and while they sit much closer to the surrounding communities than the previous shingle bank, the result is significantly increased flood protection.(**Figure 4** and **Figure 5**)

The project was achieved by:

- Constructing a new 7km embankment using clay from within the area. The embankment created a new intertidal zone, protecting properties behind it from coastal flooding.
- A channel was built behind the embankment to collect draining water. This water is taken back into the intertidal zone via four outfall structures.
- Sixty thousand tonnes of rock from Norway was used to build up rock armour on the seaward edges of the embankment, linking to the remaining ridge.
- Once the rock amour and embankment were complete, a 110-meter breach was made in the shingle bank on the beach, allowing the sea to flood the land and creating the new intertidal zone.

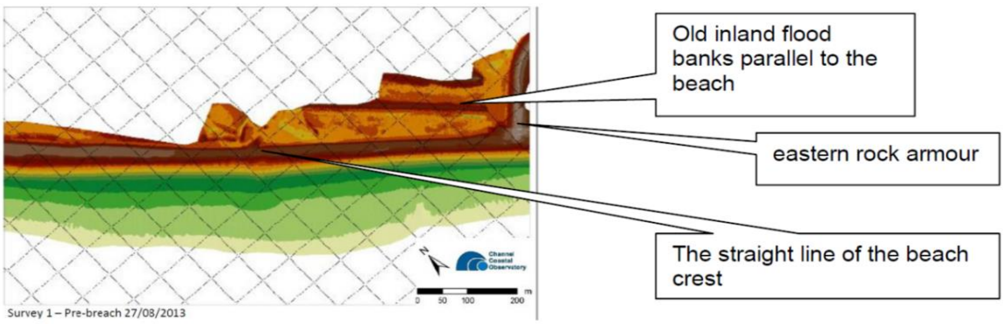

Figure 4 Medmerry pre-breach. (Environment Agency, 2016)

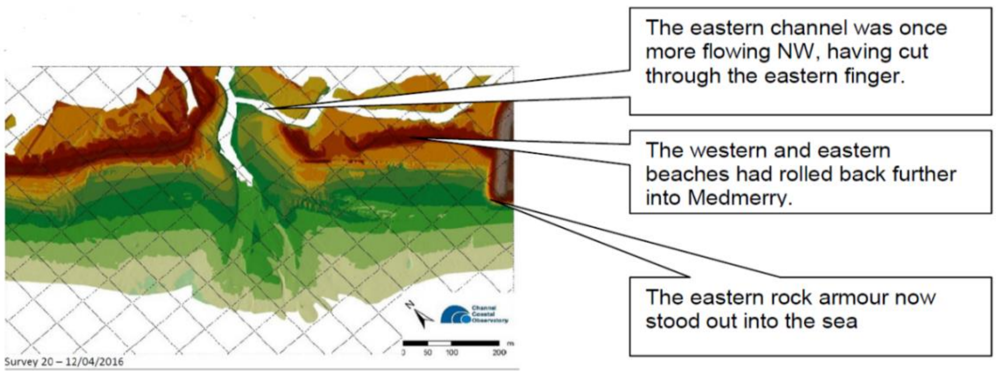

Figure 5 Medmerry post-breach. (Environment Agency, 2016)

Legal and Policy Drivers for Managed Realignment

In order to discuss whether managed realignment is sustainable in the long term, it is necessary to understand the main policy drivers to date and the direct or indirect influencing factors at the strategic and implementation levels. In the UK, two main drivers lead to the implementation of managed realignment:

The Habitats Directive and the Birds Directive

Provision of compensatory habitats required under European legislation: The Habitats Directive and the Birds Directive have been important drivers for restoring coastal habitats in Europe. Port expansion projects reclaiming intertidal mudflat habitat, or construction of sea defenses on the existing salt marsh, commonly need to provide compensatory habitat, including for indirect losses arising from coastal squeeze. In the UK, compensation measures have commonly been delivered by recreating new habitats within managed realignment schemes.

Department for Environment, Food and Rural Affairs (Defra)'s biodiversity policy

Defra's biodiversity policy sets as a minimum standard that all flood risk management works must be environmentally acceptable [1]. The Environment Agency (EA) is required to seek opportunities for environmental enhancement when selecting flood and coastal defense options both at the strategic and project level. Defra's biodiversity outcome measures are reflected in the EA's corporate strategy as performance targets. To achieve these targets, a strategic view is needed, both to deliver the most cost-effective managed realignment and to maximize opportunities to create habitats from the start of the planning process. Biodiversity is at the center of both legal and policy drivers leading to the implementation of managed realignment.

UK Government Policy on Flood Risk Management and Habitat Creation

Defra encourages a strategic (e.g. estuary-wide) approach to deliver intertidal habitat re-creation, including compensation for sea-level rise. As the EA manages several thousand km of flood defenses around the coast of England, coastal squeeze is an issue that must be addressed to meet environmental obligations. A strategic approach helps to conserve sites subject to long-term habitat loss and avoid delays in implementing justified flood management works. River basin management plans (RBMPs) [3] and shoreline management plans (SMPs) are best placed to provide the necessary business case, strategic framework and rationale for undertaking habitat creation for compensation and environmental enhancement. The creation of larger areas of new habitat, rather than several isolated smaller areas, is encouraged as a more sustainable approach both ecologically and economically.

Regional Habitat Creation Programmes (RHCP) proactively seek willing landowners to develop managed realignment projects ahead of capital projects and ongoing maintenance needs of EA's flood defenses. The EA then acquire sites, as and when they become available. This strategic approach helps reduce land purchase costs to the taxpayer and allows planning, in collaboration with landowners and partners, to maximize project outcomes. The RHCP approach was first implemented in the Anglian region in 2003 and has since been replicated across EA's regions.

These regional programs have a system of recording, reporting, and accounting for habitat created and provide a national view of habitat gains and losses. The recording system allows for identifying whether there is a pipeline of projects in place to balance current and future coastal change. The RHCP system is auditable and transparent to clarify the links with the statutory drivers and outcomes.

Community Engag6ement

A critical success factor for managed realignment is effective community engagement. Initially, local residents were very concerned about a strategy that allowed the sea to reclaim previously protected land. Medmerry residents had concerns that the scheme would have a negative impact on the local economy.

A stakeholder group was set up to be a point of engagement with the community and engaged a broad cross-section of community members including representatives from local authorities, parishes, businesses, and residents. The group was involved in decision-making at all stages of the project, from agreeing to project objectives to designing how the new area would work to create attractions and services for tourists (e.g. access routes, viewpoints, and parking infrastructure). A dedicated liaison officer

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[3] River basin management plans, a management tool in integrated water resources management. They generally contain descriptions of the water resources in a drainage basin and water allocation plans.

was employed. Communication strategies included workshops, guided walks, and public displays.

The partnership worked closely with local residents, the wider community, and their elected representatives. This participatory approach ensured that as many people as possible were kept informed throughout, and that the work was more productive and proactive. The knowledge, experience, views, and ideas of a range of stakeholders were integrated. The Medmerry Stakeholders Advisory Group was formed for this purpose, which included representatives of a wide range of community interests, from residents' groups and local authorities to tourism providers, access groups, farmers, business owners, and environmental groups. It also meant that the concerns of the local community, especially the flood risks to their homes and businesses, were able to be dealt with alongside educating them about how the area was being improved for wildlife and for climate change mitigation and adaptation.

Ecological and biodiversity conservation

According to Esteves [2], the scheme involved building a new sea wall further inland and breaching the old one, allowing the sea to flood the area behind it. This created a new intertidal habitat that provides valuable feeding and nesting grounds for a range of bird species, and new salt marshes, mudflats, and other habitats for wildlife.

The agricultural land within the area is also managed for nature, with approximately 24 ha of arable land managed specifically for wildlife (with wild bird seed mixes, nectar flower mixes, and cultivated uncropped areas for nesting birds) and a further 129 ha of arable land sustainably farmed by tenants (with commercial crops being grown, either as part of a countryside stewardship option such as for spring cereals, or with features like grassy margins for wildlife surrounding the fields).

Also, Medmerry has developed a fish 'index of diversity' comparable to long-established sites, despite being less than three years old, showing how quickly a managed realignment site can develop a healthy population of fish and become an important nursery for marine species.

Accomplishments

Disaster-Risk Reduction

This invention has protected 348 properties, the local water treatment facility, and the only road to a local town servicing 5,000 residents from flooding. This natural 'buffer zone' absorbs strong waves to reduce the strength and length of peak water levels and erosion from storm surges. The Scheme also reduced the need for traditional flood defense measures, which were expensive and subject to regular breaches. Selsey now has the best protection from coastal flooding, with only a 1 in 1000 chance of coastal flooding. 348 properties and sewage works are now protected to a standard of 1 in 100 years (previously just 1 in 1 year). The scheme avoided a possible breach during severe winter storms.

Biodiversity conservation

The site contains 300 ha of habitat of principal importance, including mudflats, reed beds, saline lagoons, and grassland. This includes 183 ha of newly created intertidal habitat important to wildlife on an international level, and crucial in compensating for losses due to development around The Solent, allowing the region to meet its European directive targets. The creation of a natural salt marsh and mudflat provides a sanctuary for many habitats and wildlife to flourish, offering valuable feeding and nesting grounds for a range of bird species, including lapwing, redshank, and avocet. The area is also home to several rare and protected species, such as the water vole and otter. The project has improved the ecological connectivity between different habitats, enabling wildlife to move more freely across the landscape. The increase in biodiversity has also resulted in improved ecosystem services, such as pollination and pest control.

Livelihoods and Well-being

Public access routes were incorporated into the scheme to allow the local community and visitors to enjoy nature whilst minimizing disturbance to wildlife. A network of footpaths and cycleways was created within the reserve aimed to increase access to green space for local communities and visitors. This helps to improve mental and physical health outcomes for those who use the site while providing opportunities for education and recreation. This new, easily accessible green space is helping to encourage more local residents to spend time outdoors. It is estimated that 22,000 people visit Medmerry each year.

Ecosystem Services

The reserve has boosted the local economy by creating new jobs and generating income for local businesses. It also provides ecosystem services such as flood protection, which can help to reduce the costs associated with damage from flooding. A report published in 2017 by the Environment Agency, titled ‘Medmerry Ecosystem Services Valuation’, aimed to estimate the financial value of the ecosystem services provided by the scheme. The approach has estimated the value of ecosystem service impacts of the scheme to be £2.95 million per year, with a present value (PV[4]) of £89.7 million over 100 years. This excludes the economic benefits of flood protection, estimated within the business case for the scheme at £78.2 million in PV terms over 100 years.

Climate Change Mitigation

The restoration and enhancement of wetland habitats have resulted in increased carbon sequestration, which helps to mitigate the effects of greenhouse gas emissions on the atmosphere.

Alignment with IUCN Nature-based Solution Global Standard

After having assessed the case study with the NbS Global Standard’s 8 criteria, (**Figure 6**) we summarise the results below. The Medmerry case study has also been reviewed against these criteria previously, and presented as a key NbS example at the IUCN World Conservation Congress in 2016.

[4] Present value (PV) is the current value of a future sum of money or stream of cash flows given a specified rate of return.

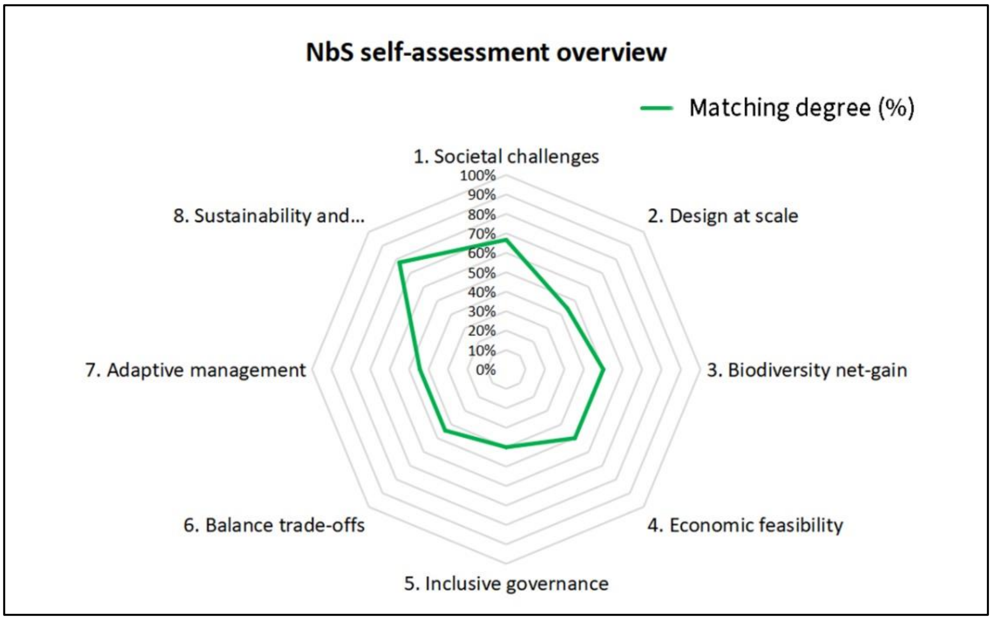

Figure 6 Alignment with NbS standard self-assessment.

The project scores best under Standard 8 in relation to sustainability and mainstreaming. The learnings from Medmerry have been widely recognized, and the project has received over 16 major national and international awards for engineering, environmental enhancement and community engagement. A highlight was winning the prestigious Prime Minister's Better Public Building Award in 2014, where the scheme was described by the panel as "ground-breaking" and "innovative. It is even part of the English school curriculum as an example of coastal management and climate change adaptation. The project has been used as a case study of NbS working in harmony with nature and people at many events, including at side events at UNFCCC COPs.

The project also took strong actions to tackle multiple societal challenges (Criterion 1), including disaster risk reduction, climate change mitigation and adaptation, economic and social development, biodiversity loss, and human health. It was designed at scale and sought synergies with other sectors (Criterion 2) such as working with tenant farmers to sustainably manage the agricultural land.

The project was determined to be economically viable (Criterion 4) and maintenance costs are now far less than for the old shingle bank. The value of the area has also increased substantially for wildlife, especially birds (Criterion 3), and monitoring continues. Results of this monitoring are published, including through annual reports.

Development of the project was founded on a participatory approach, and the knowledge, experience, views and ideas of a wide range of stakeholders were integrated (Criterion 5).

Trade-offs between primary goals and the continued provision of multiple benefits (Criterion 6) can be a challenge, with for example some sensitive species potentially at risk from recreational disturbance if visitors stray from the main paths. This remains a focus for the continued management of the reserve, in partnership with the variety of local groups that run walks, talks and surveys in the reserve.

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