NATURE-BASED SOLUTIONS FOR BEACH STABILIZATION

OPPORTUNITIES FOR THE TOURISM SECTOR

PROBLUE
HEALTHY OCEAN · HEALTHY ECONOMIES · HEALTHY COMMUNITIES

GLOBAL PROGRAM ON
NATURE-BASED SOLUTIONS
FOR CLIMATE RESILIENCE

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ABOUT THIS GUIDE

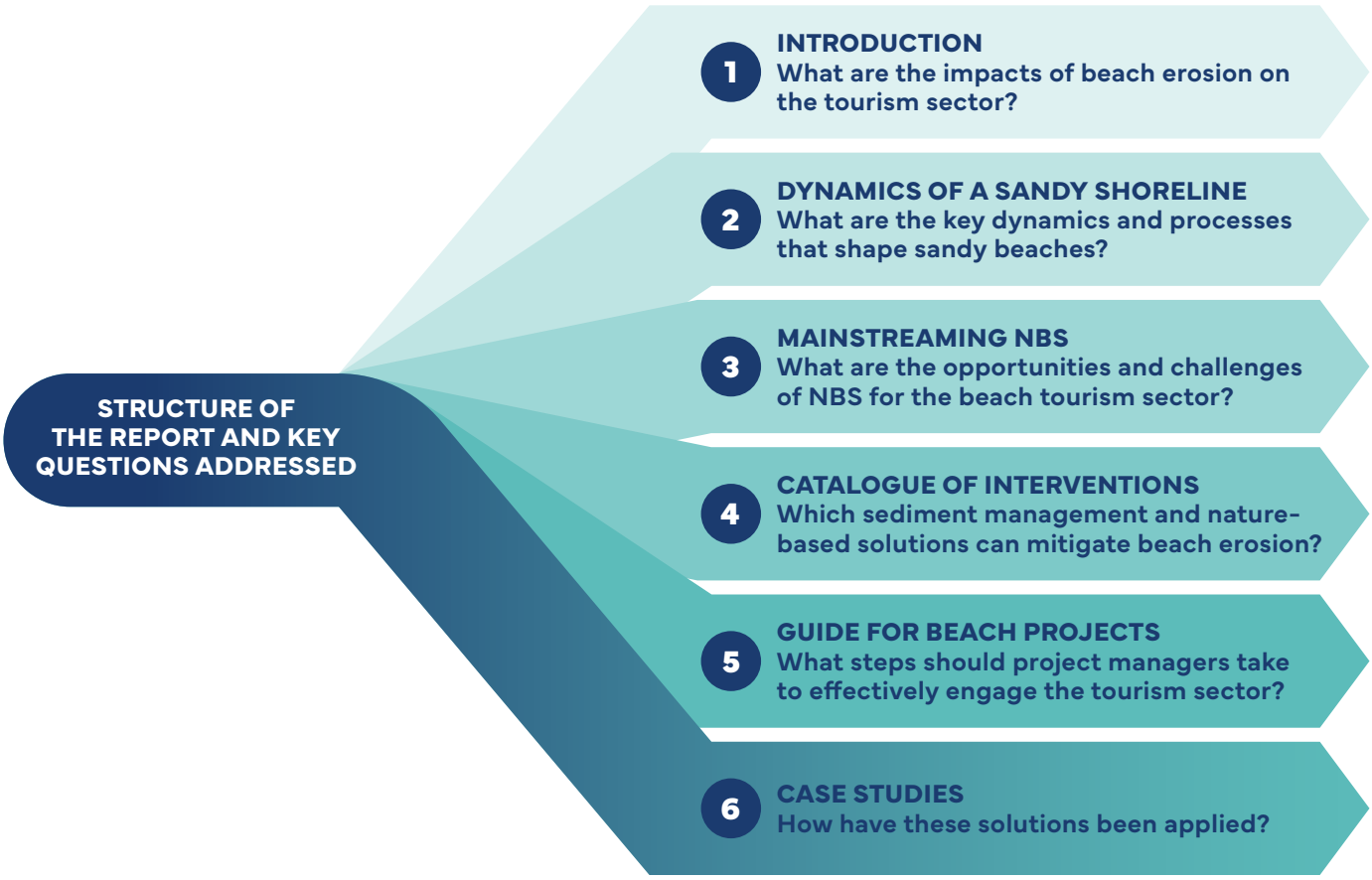
This report, *Nature-Based Solutions for Beach Stabilization: Opportunities for the Tourism Sector*, is framed within the broader vision of the Blue Economy, an approach that promotes the sustainable use of ocean resources for economic growth, improved livelihoods, and job creation while preserving the health of ocean ecosystems. As a key sector within the Blue Economy, coastal tourism plays a critical role in supporting local economies, especially in developing regions and Small Island Developing States (SIDS), where it contributes significantly to GDP, employment, and poverty reduction.

The document targets all levels of government, as well as project developers, managers, and owners of coastal tourism assets, offering practical strategies to address the challenge of sandy beach erosion and stabilization, a pressing issue for many communities that depend on healthy beaches for their livelihoods. While the strategies outlined in this report focus on coastal protection measures, they should only be considered in combination with other indirect approaches and after no-intervention and development avoidance strategies have also been evaluated and deemed unsuitable.

This document serves as an educational resource aimed at increasing the tourism sector's understanding of the synergistic opportunities that coastal nature-based solutions (NBS) can offer to enhance climate resilience while delivering tourism benefits. It provides an overview of key coastal erosion processes and effective methods, emphasizing the additional social, environmental, and economic advantages they can offer, especially for communities with limited resources and high vulnerability to climate hazards.

However, this guide is not intended to be a comprehensive technical manual or implementation guideline. Instead, it aims to raise awareness by offering case studies, investment entry points, strategic steps, and other insights from successful erosion defense projects. The examples provided are meant to inform and inspire coastal managers and tourism stakeholders to explore nature-based and hybrid solutions as a strategic choice to protect sandy beaches while promoting a more sustainable and climate-resilient coastal tourism development, aligned with the principles of a thriving Blue Economy. See figure 0.0.

FIGURE 0.0 STRUCTURE OF THE REPORT AND KEY QUESTIONS ADDRESSED



Source: Authors' elaboration.

ABBREVIATIONS AND ACRONYMS

CAPEX	Capital expenditure
CVA	Coastal Vulnerability Assessment
CVI	Coastal Vulnerability Index
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
GIS	Geographic information systems
ha	Hectare
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
NBS	Nature-based Solutions
NGO	Nongovernmental organization
OPEX	Operating expenditure
SIDS	Small Island Developing States
WACA	West Africa Coastal Areas Program

OVERVIEW

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0.1

THE BEACH EROSION CHALLENGE IN THE TOURISM SECTOR

COASTAL TOURISM'S RELIANCE ON BEACHES

Tourism serves as a vital engine for economic development in coastal areas, generating income, creating jobs, and supporting poverty reduction. This is particularly evident in SIDS and other developing coastal regions, where tourism provides direct benefits to millions of people. Sandy beaches, which line one-third of the world's ice-free shorelines, form some of the most iconic tourist destinations globally. Their recreational value attracts millions of visitors annually, but their significance extends beyond tourism. Beaches also act as natural protection systems, providing a critical buffer against coastal hazards such as erosion, storm surges, and flooding, challenges that are increasingly intensified by global climate change.

The stability of sandy beaches depends heavily on the health of adjacent coastal and marine ecosystems. Unfortunately, increasing degradation of these habitats, combined with global warming and sea-level rise, poses significant threats to beaches and the communities that rely on them. As habitats deteriorate and beaches erode, the sustainability of tourism and coastal livelihoods is placed at risk. Therefore, maintaining healthy beach ecosystems is essential to preserving tourism revenues and securing the livelihoods of those dependent on this sector.

THE BEACH EROSION CHALLENGE

A substantial proportion of the world's sandy coastlines is currently eroding, driven by climate change, coastal development, sand deficits, and ecosystem loss. Erosion often results in narrower and less accessible beaches, diminished natural beauty, and reduced appeal to tourists. This degradation negatively impacts tourism infrastructure and often requires costly engineering solutions to address the damage.

Additionally, unplanned urban development and traditional engineering structures exacerbate these challenges, reducing the ability of beaches and dunes to adapt and recover from extreme events. Coastal infrastructure often restricts natural sand movement, leading to chronic coastal retreat and the permanent loss of valuable beach surfaces.

The pressures of sea-level rise and increased storm intensity due to climate change further stress these already vulnerable systems. As beaches degrade, tourism-dependent economies face revenue losses, explaining why the preservation of beaches is intrinsically tied to the sustainability of the tourism sector.

0.2

TURNING THE BEACH EROSION CHALLENGE INTO AN OPPORTUNITY

COASTAL RESILIENCE THROUGH NBS

Sandy coastlines, supported by adjacent ecosystems, play an essential role in protecting coastal infrastructure and communities. Acting as natural buffers, beaches absorb and dissipate wave energy, reducing inland impacts during storms. Wide beach profiles, dunes, and other interconnected ecosystems provide a critical first line of defense, mitigating the effects of high waves and storm surges.

Despite their natural resilience, human interference often disrupts these processes. Traditional coastal engineering, commonly referred to as "gray infrastructure," such as seawalls, breakwaters, and groins—has long been used to manage erosion and protect infrastructure. While such structures may offer short-term protection, they often interfere with the dynamic processes that sustain beach systems. By locking beaches in place, they prevent the natural migration and replenishment of sand, leading to unintended effects such as increased erosion in adjacent areas, habitat degradation, and the loss of natural beach profiles. Moreover, these hard interventions are costly to maintain, fail to adapt to changing climate conditions, can negatively affect marine ecosystems, and reduce the aesthetic value of beaches.

Nature-based Solutions (NBS) offer adaptive, cost-effective, and ecologically sound alternatives that work with natural processes rather than against them. Techniques such as dune restoration, coastal vegetation planting, and the conservation or restoration of coastal habitats harness the protective functions of ecosystems to stabilize shorelines and trap sediments. By integrating green infrastructure with engineered solutions, coastal engineers and project managers are increasingly adopting hybrid approaches. This integration combines the immediate protection offered by gray infrastructure, such as artificial reefs or reinforced dunes, with the adaptability and co-benefits of natural systems, including biodiversity enhancement and aesthetic improvements.

In addition to mitigating erosion and coastal flooding, NBS protect other valuable ecosystem services. Healthy biodiverse beaches and adjacent coastal and marine habitats contribute directly to the success of coastal tourism. Tourists highly value pristine and accessible beaches, scenic sea views, clean water, and low disaster risks. Destinations reliant on recreational activities like water sports or seafood-based cuisine risk losing their appeal and reputation if these ecosystems degrade.

When implemented under favorable conditions, NBS present a sustainable and economically viable solution to beach erosion, ensuring long-term benefits for coastal communities. By restoring beaches naturally, these approaches sustain jobs and businesses that rely on the tourism industry while enhancing the resilience of coastal assets.

AN OPPORTUNITY FOR THE TOURISM SECTOR

Investing in NBS is not only an environmentally responsible choice but also a potential strategic move for the tourism sector. This timely opportunity arises from improved scientific understanding, evolving market preferences, and increasingly stringent environmental regulations.

Enhanced knowledge and growing experience in managing beach and dune systems have strengthened the case for adopting NBS. These strategies are increasingly supported by coastal engineers, governments, and research organizations as effective methods for erosion control and environmental preservation.

On the regulatory front, governments and international bodies are mandating stricter environmental standards. Even lower-income countries with tourism-dependent economies are adopting strategies to manage and protect coastal zones, reduce risks, and maintain healthy ecosystems. Early adoption of NBS by the tourism sector can ensure compliance with these regulations, reducing future liabilities while reinforcing sustainability credentials.

Market trends further support this shift. Tourists increasingly prioritize destinations that offer pristine, well-maintained environments and demonstrate tangible sustainability efforts. Studies reveal that natural and aesthetic beach resources significantly influence visitor satisfaction and willingness to pay. By embracing NBS, tourism destinations can position themselves as leaders in sustainable tourism, appealing to eco-conscious travelers and enhancing their competitive advantage.

However, the implementation of these natural approaches has its own challenges, and strong collaboration between different stakeholders at different levels is often required. The tourism sector is uniquely positioned to leverage its financial stability, established supplier networks, and sectorial associations to scale NBS initiatives. By engaging local communities and other stakeholders, tourism operators can empower clients, promote citizen science, and support sustainable economic development while minimizing their environmental impact.

By participating in beach stabilization efforts, the tourism sector not only ensures the continuity of its operations but also contributes to the health of coastal ecosystems and the well-being of local communities. Many of these communities, including those employed within the tourism industry, are essential for its success.

THE BUSINESS CASE FOR THE TOURISM INDUSTRY

NBS investments offer a compelling value proposition for the tourism sector by delivering multiple co-benefits beyond erosion control (see chapter 3). They have the potential to improve long-term cost efficiency, lower insurance premiums, diversify revenue through ecotourism, and enhance brand reputation. In parallel, aligning with evolving regulatory frameworks and sustainability standards can unlock access to emerging financial incentives. By investing in NBS, the tourism industry can safeguard its core assets, respond to stakeholder demands, and secure a competitive advantage in the highly dynamic tourism sector.

FIGURE O.1 RECAP OF BENEFITS PROVIDED BY NBS FOR BEACH STABILIZATION AND POTENTIAL IMPACTS FOR TOURISM SECTOR BUSINESSES DESCRIBED IN CHAPTER 3

BENEFITS OF NBS FOR BEACH STABILIZATION	TYPES OF BUSINESS IMPACTS		
	REDUCING COSTS	INCREASING REVENUE	IMPROVED RISK MANAGEMENT
Cost-effectiveness in the long term	✓		✓
Costs distribution over time	✓		✓
Enhancement of tourism experience		✓	
Regulatory compliance			✓
Brand reputation and credibility		✓	✓
Financing opportunities	✓		

Source: Authors' elaboration.

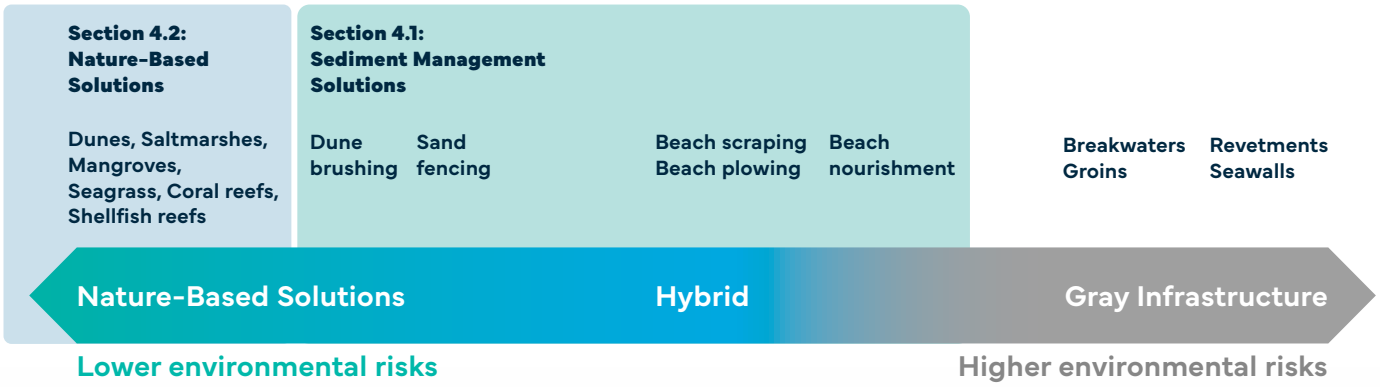
O.3

PRACTICAL APPLICATION TO MITIGATE EROSION AT BEACH LEVEL

BEACH INTERVENTIONS TO MITIGATE EROSION

Chapter 4 presents an inventory of strategies to mitigate beach erosion, categorized into two primary types of structural interventions (figure O.2). Section 4.1 focuses on **sediment management solutions**, emphasizing less intrusive engineering approaches that mimic natural coastal processes by using materials like sand, vegetation, and wood. Section 4.2 delves into **NBS for beach stabilization**, showcasing effective interventions proven successful in diverse contexts. For each intervention type, the catalogue provides an overview of its beach stabilization functions, benefits for the tourism sector, estimated cost ranges, and key considerations for implementation.

FIGURE 0.2 BEACH STABILIZATION METHODS WITHIN THE BLUE QUADRANTS INCLUDED IN CHAPTER 4, POSITIONED ON THE GREEN-HYBRID-GRAY SPECTRUM



Source: Authors' elaboration.

Note: This report focuses on structural or restoration methods when conservation or protection approaches are previously discarded and active beach restoration strategies become the most suitable options.

While these interventions can provide sustainable and efficient erosion control, their implementation requires careful planning and an in-depth understanding of the interconnected coastal systems. Beaches and dunes are dynamic environments where changes in one area can significantly impact others. Effective strategies must recognize these interdependencies and prioritize ecosystem conservation to avoid unintended consequences. Additionally, rehabilitation projects should consider human activities and societal needs, ensuring they address both environmental and community objectives. To maximize their success, these efforts must also align with broader national, regional, and local strategic objectives and be thoughtfully integrated into existing frameworks.

SEDIMENT MANAGEMENT SOLUTIONS

Soft engineering measures offer sustainable alternatives to traditional hard infrastructure, stabilizing sandy beaches without the need for rock or concrete structures. These solutions utilize natural materials and processes, often proving more cost-effective while maintaining the natural aesthetics of the coastline. Techniques such as sand fencing trap wind-blown sand to encourage dune formation, while methods like dune brushing and beach plowing promote vegetation growth, stabilizing the sand. Other more intensive measures such as beach scraping and nourishment can also be suitable when a main objective is to preserve the recreational value of beaches for tourists.

These interventions aim to create and maintain sand accumulations at the upper part of the beach, serving as physical barriers against storm waves and reservoirs during erosion events. While restoration of beach ecosystems often requires time, immediate stabilization efforts may be necessary in areas experiencing severe erosion. Combining stabilization with restoration practices, such as revegetation, can ensure longer-term success.

NATURE-BASED SOLUTIONS

Section 4.2 presents a list of NBS grouped into three main typologies: beach and dune ecosystems, intertidal wetlands, and submerged aquatic vegetation and reef habitats. Each typology contributes uniquely to maintaining beach stability, whether by directly stabilizing sand or indirectly regulating erosion through mechanisms such as sediment trapping or wave energy reduction. These approaches not only mitigate erosion but also enhance biodiversity, water quality, recreation uses and improve coastal resilience, making them particularly suitable for the tourism sector.

FIGURE O.3 NBS TYPOLOGIES FOR SANDY BEACH STABILIZATION DESCRIBED IN THIS REPORT

	UPPER BEACH AND DUNES	INTERTIDAL WETLANDS		AQUATIC ECOSYSTEMS		
	DUNE SYSTEMS	SALT MARSHES	MANGROVES	SEAGRASSES	CORAL REEFS	SHELLFISH REEFS
KEY RISK REDUCTION PROCESSES*:						
Mechanism 1	N/A	✓	✓	✓	✓	✓
Mechanism 2	N/A	✗	✗	✗	✓	✓
Mechanism 3	N/A	✓	✓	✓	✗	✗
OTHER KEY BENEFITS:						
PERFORMANCE FACTORS:	Height, Width, Volume, Shape, Vegetation cover, Density	Plant height, Bed width, Species, Density	Forest width, Species, Density	Plant height, Bed width, Species, Density	Depth, Width, Coral morphology	Height, Width, Density of shellfish
TIME TO EFFECTIVENESS:	≤ 1-10 years	≤ 1-25 years	≤ 1-25 years	≤ 1-10 years	≤ 1-10 years	≤ 1-5 years
TRACK RECORD:	High	Medium	High	Low	Medium	Medium
MAINTENANCE REQUIRED:	●●●	●●	●●	●●●	●●	●

OTHER KEY BENEFITS:

Biodiversity

Tourism and recreation

Resources production

Water quality

Social interaction

Cultural

Carbon storage and sequestration

NUMBER OF INTERVENTIONS NEEDING MAINTENANCE:

●●● All interventions need maintenance;

●● Most interventions need maintenance;

● Some interventions need maintenance.

Source: Adapted from Morris et al. 2021.

Note: * Mechanism 1: Wave attenuation due to roughness; Mechanism 2: Wave attenuation due to depth-induced breaking; Mechanism 3: Erosion mitigation within ecosystem; N/A: not applicable, the key mechanism for sandy systems is to provide a physical buffer that erodes and recovers in response to storm events.

Effective beach stabilization requires a holistic approach grounded in a deep understanding of the dynamic and interconnected nature of coastal systems. No single method can fully eliminate erosion. While this report introduces these solutions individually, their effective application often involves integrating multiple measures at various spatial and temporal scales. These efforts must also align with national and local strategies, respond to community needs, and be supported by regular maintenance and sound management practices to ensure long-term sustainability and minimize unintended impacts.

Photo by NEOM on Unsplash

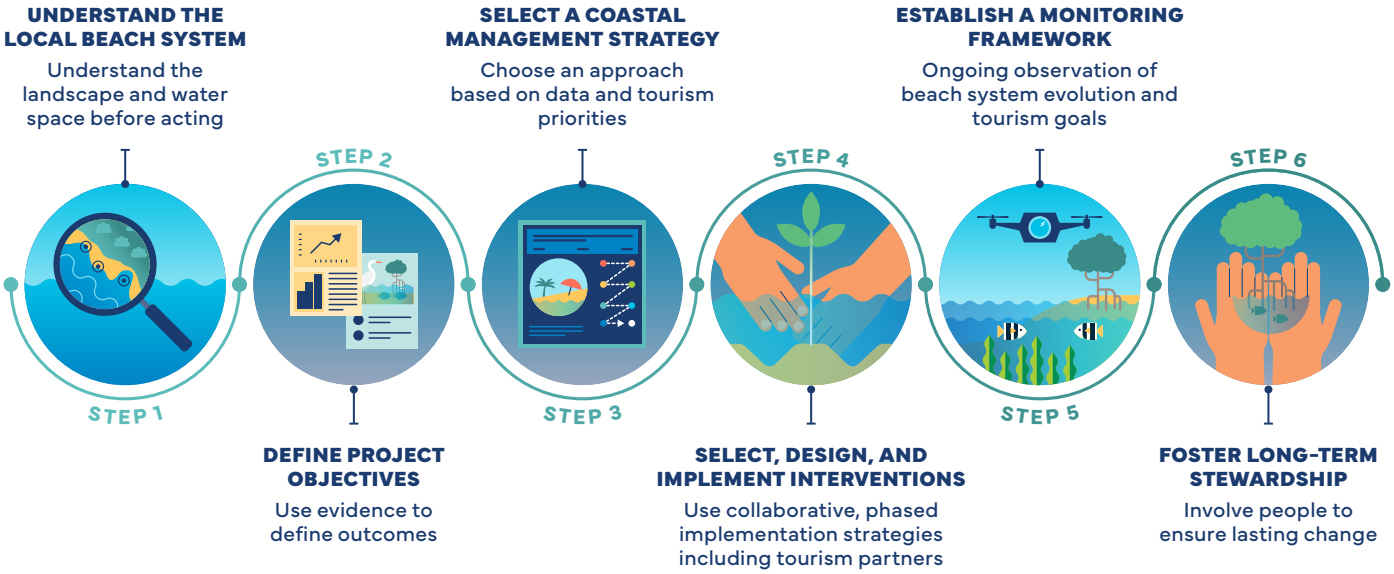
0.4

GUIDE TO BEACH MAINTENANCE WITH TOURISM SECTOR ENGAGEMENT

The report also provides a practical step-by-step approach for designing and implementing sustainable beach maintenance projects that integrate the tourism sector from the outset. It emphasizes participatory planning, long-term resilience, and the strategic role of tourism actors. Drawing on international best practices, the guide supports practitioners in developing tailored interventions that are effective in managing erosion and other climate risks while enhancing biodiversity and tourism experiences.

Structured around six practical steps, chapter 5 walks practitioners through the project life cycle, from understanding local beach systems to fostering long-term stewardship (figure O.4).

FIGURE 0.4 KEY STEPS FOR BEACH MAINTENANCE PROJECTS IN TOURISM AREAS



Source: Authors' elaboration.

O.5

CASE STUDIES TO INSPIRE ACTION

The five case studies at the end of this report illustrate how NBS have been strategically implemented in diverse settings to address beach erosion challenges. These examples help demonstrate how NBS can be integrated into coastal investments to protect sandy beaches while fostering long-term economic and climate resilience, ultimately promoting more sustainable tourism development.

In Mauritania (case study 1), a large-scale initiative is stabilizing the coastal dunes of Nouakchott using NBS, combining ecosystem restoration, sand stabilization techniques, and other traditional engineering measures. In Grenada (case study 2), a pilot project installed submerged breakwaters shaped like artificial reefs, providing a stable base substrate for coral growth while enhancing coastal resilience and restoring marine habitats.

In California (case study 3), a section of degraded beach was restored by promoting natural dune formation through passive interventions. This approach not only supported sand accumulation but also made the beach more appealing to visitors. In Uruguay (case study 4), dunes were regenerated using natural material fencing and native vegetation to protect the shoreline and improve the recreational experience. Lastly, the Integrated Coastal Zone Management (ICZM) Plan for the Marche Region in Italy (case study 5) offers an example of a long-term strategy addressing coastal erosion. The plan emphasizes soft engineering techniques to manage coastal retreat, protecting local settlements and supporting the tourism-dependent economy.

Photo by Mathilde Langevin on Unsplash

1 INTRODUCTION

Photo by Lorenzo Angeli on Unsplash

1.1

COASTAL TOURISM'S RELIANCE ON BEACHES

Tourism is a vital engine for economic development in coastal areas. It serves as a significant source of income, job creation, and poverty reduction, providing direct benefits to millions of people (UN Tourism 2024). The economic impact of tourism is particularly pronounced in SIDS and other developing coastal regions. For example, in the Maldives, tourism contributes nearly 60 percent of the nation's gross domestic product (GDP) and 90 percent of its government tax revenue[1] (Hampton and Jeyacheya 2020). In countries like the Bahamas and Fiji, tourism employs over 50 percent of the workforce and is the primary source of income for local communities (UNWTO 2019). This sector not only stimulates local economies but also plays a critical role in protecting vulnerable coastal communities from the impacts of climate change by driving investments in climate-resilient infrastructure.

In particular, the coastal and marine tourism sector constitutes approximately 50 percent of all global tourism, generating US$4.6 trillion or 5.2 percent of global GDP (Northrop et al. 2022). The popularity of "sun and sand" tourism is well documented, particularly across the tropics and subtropics. Additionally, the spectacular coastal scenes and wild ecosystems of cooler and sub-Arctic coastlines are emerging as powerful natural tourism attractions. Future economic projections for the sector estimate a global ocean-based economy of US$777 billion, employing 8.5 million people by 2030 (OECD 2016; Northrop et al. 2022). However, the future of the sector is highly dependent on natural assets that require space and careful management.

Sandy beaches, which fringe one-third of the world's ice-free shorelines (Luijendijk et al. 2018), form some of the most iconic tourist destinations globally and are highly valued by tourists (Dodds and Holmes 2019). The high aesthetic value and variety of natural amenities offered by coastal habitats associated with sandy shorelines generate a range of recreational activities such as surfing, scuba diving, fishing, swimming, and sunbathing (Barbier et al. 2011). Beyond these recreational services, beaches and dunes are crucial ecosystems offering direct economic value and natural coastal protection. By acting as buffers, they reduce the risks of coastal erosion, storm surges, and flooding, which are becoming more frequent due to climate change (Secaira Fajardo et al. 2017).

Sandy beaches, when preserved as intact coastal ecosystems, are capable of supporting both ecological processes and sustainable human use (Schlacher et al. 2008). However, the stability of sandy beaches depends greatly on the health of their associated coastal and marine habitats. The increasing degradation of beaches and habitats puts the sustainability of the tourism sector and coastal communities at risk (Northrop et al. 2022; Hulsen et al. 2023). Additionally, global warming and resulting sea level rise (estimated to be up to 1 m by 2100 in high-impact scenarios, according to Fox-Kemper et al. 2021) are key drivers of beach loss, further increasing the risk of beach erosion and habitat loss (FitzGerald et al. 2008).

1 See .worldbank.org/indicator/SP.POP.TOTL.

Despite its high reliance on the sustainability of beaches, tourism infrastructure and activities are often responsible for beach degradation, making the current tourism model inherently unsustainable (Northrop et al. 2022; Sun et al. 2019). Additionally, the tourism sector is responsible for 8–10 percent of global greenhouse gas (GHG) emissions (Lenzen et al. 2018), contributing to the degradation of global shorelines caused by climate change. Therefore, maintaining the health of beach ecosystems in the long term is crucial to sustaining tourism revenues and preserving the livelihoods of those dependent on the sector.

1.2

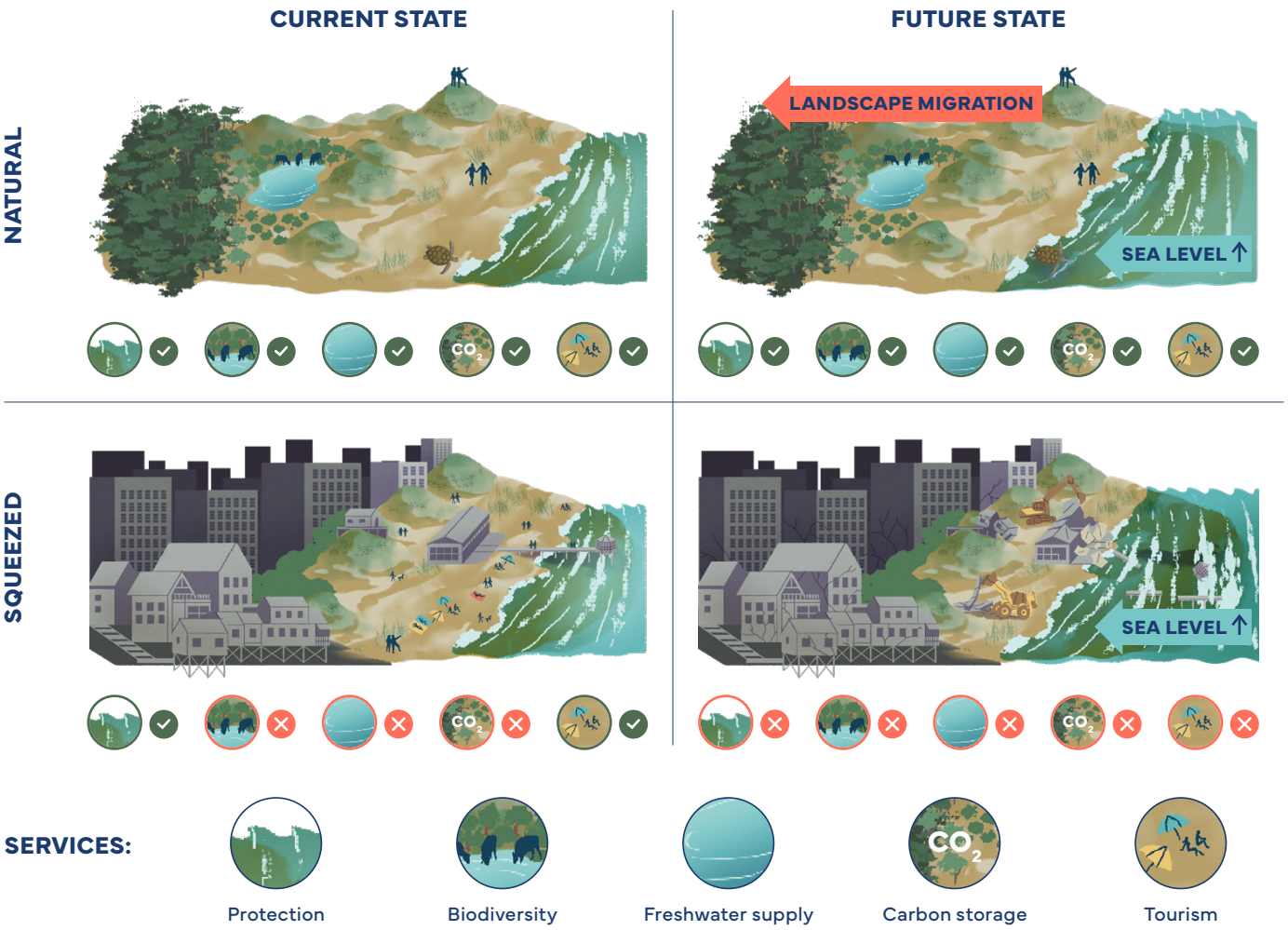
THE BEACH EROSION CHALLENGE IN THE TOURISM SECTOR

Coastal erosion alone affects 24 percent of the world's sandy beaches, with regions in Africa, Southeast Asia, and the Pacific Islands among the hardest hit (Luijendijk et al. 2018). The economic impact is significant, with coastal damage from flooding and erosion projected to cost more than $1 trillion annually by 2050, disproportionately affecting developing nations that depend heavily on tourism and coastal resources for livelihoods (World Bank 2013).

Climate change, coastal development, ecosystem loss, and sand deficits, among other factors, increasingly threaten sandy shorelines and have caused a substantial proportion of the world's sandy coastline to erode (Vousdoukas et al. 2020; Tavares et al. 2020). Beach erosion and the associated habitat loss are a growing concern in many coastal regions worldwide. Where erosion occurs, beaches become narrower, less accessible, and can lose their natural beauty, which can also negatively impact the tourism industry (Houston 2008; Houston 2018; Alexandrakis et al. 2015). This can result in the underutilization of tourism infrastructure or lead to expensive investments in coastal engineering interventions, traditionally large-scale reclamation, and engineering works (Landry et al. 2003).

The pressures of unplanned rapid development and engineering structures, combined with habitat loss, are decreasing the capacity of beaches worldwide to regenerate and leading to increased coastal erosion impacts (Bozzeda et al. 2023). Beaches are often squeezed between the ocean and urban infrastructure due to sand loss under erosion and scour processes (Lansu et al. 2024). Urban developments along the shoreline reduce the capacity of the beach and dune system to adapt and recover from extreme events, thereby reducing the beach surface to tourism and other amenities and often leading to chronic coastal retreat (figure 1.1). Further, climate change–induced sea-level rise and changes in storminess represent additional stressors, putting beaches under further strain with ever-increasing rates of erosion (Vousdoukas et al. 2020; Defeo et al. 2021). As an example, a study for the Maghreb region estimated an annual asset destruction cost from coastal erosion to the equivalent of 2.8 percent of GDP in Tunisia, 0.7 percent in Libya, 0.4 percent in Morocco, and 0.2 percent in Algeria (Heger et al. 2021).

FIGURE 1.1 A REPRESENTATION OF THE EFFECTS OF MALDEVELOPMENT ON COASTAL AREAS



Source: Adapted from Lansu et al. 2024.

Note: Maldevelopment and poor coastal management can result in coastal squeeze under increased sea levels and intensified storminess leading to disruption and shoreline retreat, threatens their natural capacity to adapt and recover, and collapse of its ecosystem services.

As beaches degrade and ecosystems deteriorate, the appeal to tourists can also diminish, leading to potential revenue losses for coastal economies. In Rio de Janeiro's iconic Ipanema Beach, coastal erosion has reduced the available beach area, directly impacting tourism revenues and increasing the cost of mitigation efforts such as beach nourishment and dune restoration projects (Lins-de-Barros and Parente-Ribeiro 2018). In the extreme case, disappearance of beaches could lead to massive losses should tourists decide not to visit the affected areas anymore. For instance, a survey conducted in the Hawaiian town of Waikiki revealed that the majority of respondents would not consider staying at a hotel if the nearby beach were to completely erode (Tarui et al. 2018). Similarly, more than three-quarters of tourists surveyed in Barbados indicated they would not return for the same price if the beaches largely disappeared, leading to an estimated 46 percent decline in tourism revenues (Schuhmann et al. 2016). These examples highlight the critical link between beach preservation and the sustainability of the tourism sector in coastal regions.

1.3

PREVENTING BEACH EROSION

Sandy coastlines, in combination with other coastal ecosystems, play a crucial role in protecting coastal infrastructure, assets, and land by acting as natural buffers against storm winds and wave energy. The gentle slope and loose sediment of sandy beaches absorb and dissipate the energy of incoming waves, reducing the force that reaches inland areas. During storms, dunes and wide beach profiles serve as a first line of defense, mitigating the impact of high waves and storm surges (Nordstrom et al. 2021). This natural buffering capacity helps prevent erosion and flooding of coastal properties and infrastructure, reducing the potential for costly damage and the need for artificial protective structures. These interconnected ecosystems have the ability to shield coastal communities from storms and help to prevent or better recover from erosion events.

When human activity disrupts natural beach processes, coastal engineering looks at preventative measures to stop coastal flooding and erosion. Traditional engineering structures are often referred to as "gray infrastructure" as they are typically constructed using rock or concrete. Gray structures like groins, seawalls, rock armoring, and detached breakwaters are designed to prevent coastal flooding, erosion, and wave action onshore by hardening and fixing the shoreline (see a list of traditional gray coastal measures at appendix A).

While gray infrastructure may be able to effectively mitigate erosion issues when properly designed, it typically comes with several social and ecological disadvantages and often with environmental impacts (Franzen et al. 2021; Gittman et al. 2016). Gray coastal measures do not allow coastal and marine ecosystems to adapt. The opportunity of retaining or enhancing natural ecosystems and the coastal protection these systems provide naturally is typically lost after installation. In addition, the associated tourism and livelihood benefits of natural beaches and habitats can sometimes decrease considerably.

Beaches naturally move and migrate with seasons and storms and the fixation of coastlines by these artificial structures alters their cyclical dynamic shifts, restricting their movement. Further, dunes act as "sand reservoirs," naturally renourishing beaches after extreme events while providing flood protection during storms (Nordstrom et al. 2021). Understanding how beaches are formed and how they respond to storms is at the root of an effective assessment of erosion causes and solutions. By characterizing beach processes, we can manage the coast more effectively and work with nature rather than against it. Sound understanding of the natural processes of a sandy shoreline, as well as the protective function of its coastal and marine ecosystems, offers the potential to better address beach erosion (see chapter 2).

1.4

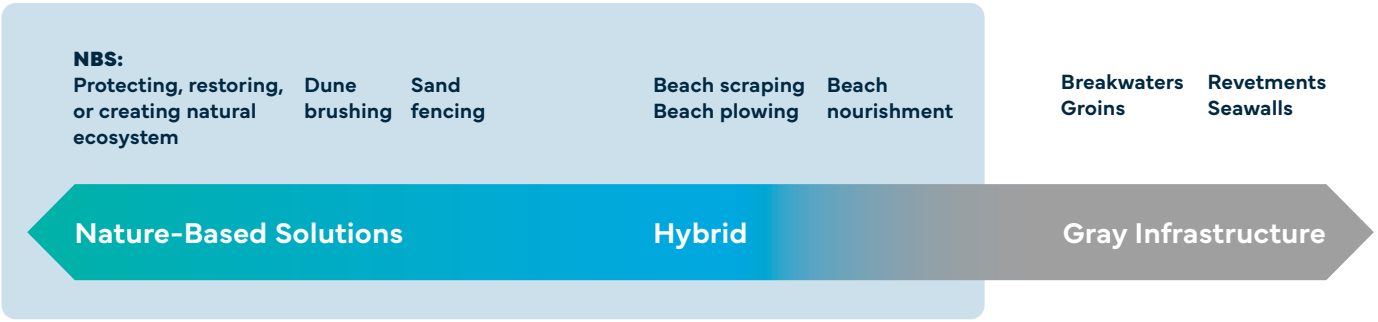
HOW NBS CAN PREVENT BEACH EROSION

NBS are actions to protect, conserve, restore, sustainably use, and manage natural or modified ecosystems that address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, and resilience and biodiversity benefits (UNEP 2022).
In the context of beach erosion, NBS offer adaptive and cost-effective approaches that maintain the cyclical dynamics of sandy beach ecosystems, which are vital for long-term coastal resilience and protection (Reguero et al. 2018).

NBS for beach erosion include a range of techniques that work with natural processes rather than against them (Masselink and Lazarus 2020; Van der Meulen et al. 2023). A growing body of evidence supports the effectiveness of these techniques in preventing beach erosion and supporting beach resilience. Examples include beach and dune restoration, coastal vegetation planting, and the protection of marine habitats such as seagrass meadows, salt marshes, and coral reefs (see figure 1.2 and chapter 4). These coastal ecosystems play a crucial role in buffering wave energy, trapping sediments, and stabilizing shorelines—for instance, planting coastal vegetation, such as dune grasses, enhances dune formation, which in turn acts as a natural barrier against storm surges and erosion (Gracia et al. 2018). Similarly, coral reefs and seagrass beds absorb wave energy, reducing its impact on sandy shorelines and contributing to beach stability (Perricone et al. 2023). Research also shows that these coastal ecosystems not only support the protection of shorelines (Gracia et al. 2018) but also recover surprisingly well from repeated storm exposure (Patrick et al. 2020).

Thanks to this new perspective, coastal engineers and project managers are increasingly recognizing the value of combining natural and engineered solutions to ensure the resilience of coastlines. This approach, known as hybrid infrastructure, integrates green infrastructure with gray structures such as artificial reefs or reinforced dunes. Hybrid solutions aim at capitalizing on the strengths of both approaches, with gray elements offering immediate protection and smaller spatial footprints, and green infrastructure providing long-term adaptability, aesthetics, and other benefits like biodiversity improvements.

FIGURE 1.2 BEACH STABILIZATION METHODS WITHIN THE BLUE QUADRANT INCLUDED IN THIS REPORT POSITIONED ON THE GREEN-HYBRID-GRAY SPECTRUM



Source: Authors' elaboration.

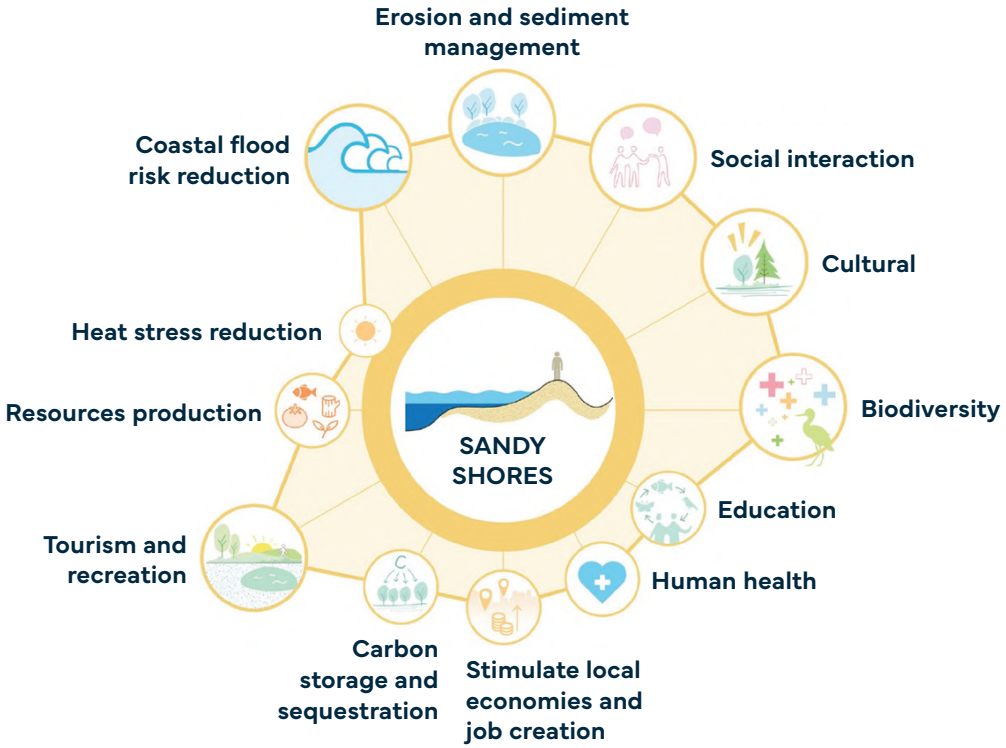
Note: See chapter 4. This report focuses on restoration methods when conservation or protection approaches are previously discarded, and active beach restoration strategies become most suitable options.

In addition to safeguarding the hinterland by mitigating erosion and coastal flooding impacts, NBS offer a range of additional benefits (Harris and Defeo 2022). Coastal habitats are globally recognized as the most valuable ecosystems in terms of the services provided to human activities (Culbertson et. al 2009; Harris and Defeo 2022) and by using NBS for beach stabilization, many of these services are protected and maximized. In particular, beaches and dunes provide essential habitats for a variety of species. Sea turtles, for example, rely on natural beaches to lay their eggs. Migratory birds also depend on beaches as critical stopover points during their annual journeys, supporting the growing birdwatching industry, which generates over $40 billion annually in the United States alone.

The health of the beach and connected coastal and marine ecosystems can also directly impact the success of coastal tourism as the key factors affecting the perceived value of tourist beaches include access to pristine and stable beaches, preservation of sea views, clean water, low pollution and odors, and low disaster risk (Boto-Garcia and Leoni 2023; Georgopoulou et al. 2019). Destinations that rely on water sports, recreational activities, or local seafood will also suffer reputationally over time if these coastal ecosystems are compromised.

Under favorable conditions and when implemented appropriately, NBS offer a sustainable approach to addressing beach erosion while preserving the tourism value of coastal areas in the long term (figure 1.3).

FIGURE 1.3 POTENTIAL BENEFITS PROVIDED BY SUSTAINABLY MANAGED AND HEALTHY SANDY SHORES



Source: World Bank 2021.

BOX 1.1 EXPLORE PRACTICAL EXAMPLES FOR BEACH MANAGEMENT WITH NBS

1. **Naturally Resilient Communities:** This guide offers a comprehensive collection of nature-based solutions and case studies from the United States and Europe. It is designed to help communities identify which solutions might be best suited to their local challenges. A dedicated section for beaches and coastal erosion is included. Explore the Guide
2. ***Engineering with Nature Atlas* Series:** *The Engineering with Nature Atlas* presents three volumes with more than 100 projects that combine natural and engineered systems to maximize environmental, social, and economic benefits. This resource provides inspiration and real-world examples of projects for beaches and dunes, wetlands, and reefs implemented globally. View the Atlas
3. **California Dune Science Network:** An online platform aiming to expand understanding of coastal dunes and their role in building a resilient, transitional, and adaptive coast. It showcases various dune restoration projects along the Californian coast. View the Atlas

2

DYNAMICS OF A SANDY SHORELINE

Photo by Radek Skrzypczak on Unsplash

Sandy shorelines are formed by beaches with relatively gentle slopes, often backed by single or multiple rows of sandy dunes. Beaches are formed through the accumulation of sand and other sediments, such as gravel, silt, and mud, along the shoreline. Sediment is carried to the shoreline by river flows, waves, and ocean currents. Once on the shore, wind, waves, and tides continually shape and reshape the beach, causing its size and form to change over time.

To effectively manage beach erosion and implement suitable mitigation strategies, it is crucial to understand the specific processes shaping a given beach. While the involvement of specialists, such as coastal engineers, marine geologists, or coastal oceanographers, is often necessary for in-depth analysis, this section aims to provide a high-level overview of the key factors that drive changes along sandy shorelines. For those interested in a more detailed technical understanding of beach and dune dynamics, refer to Lodder et al. (2021).

2.1

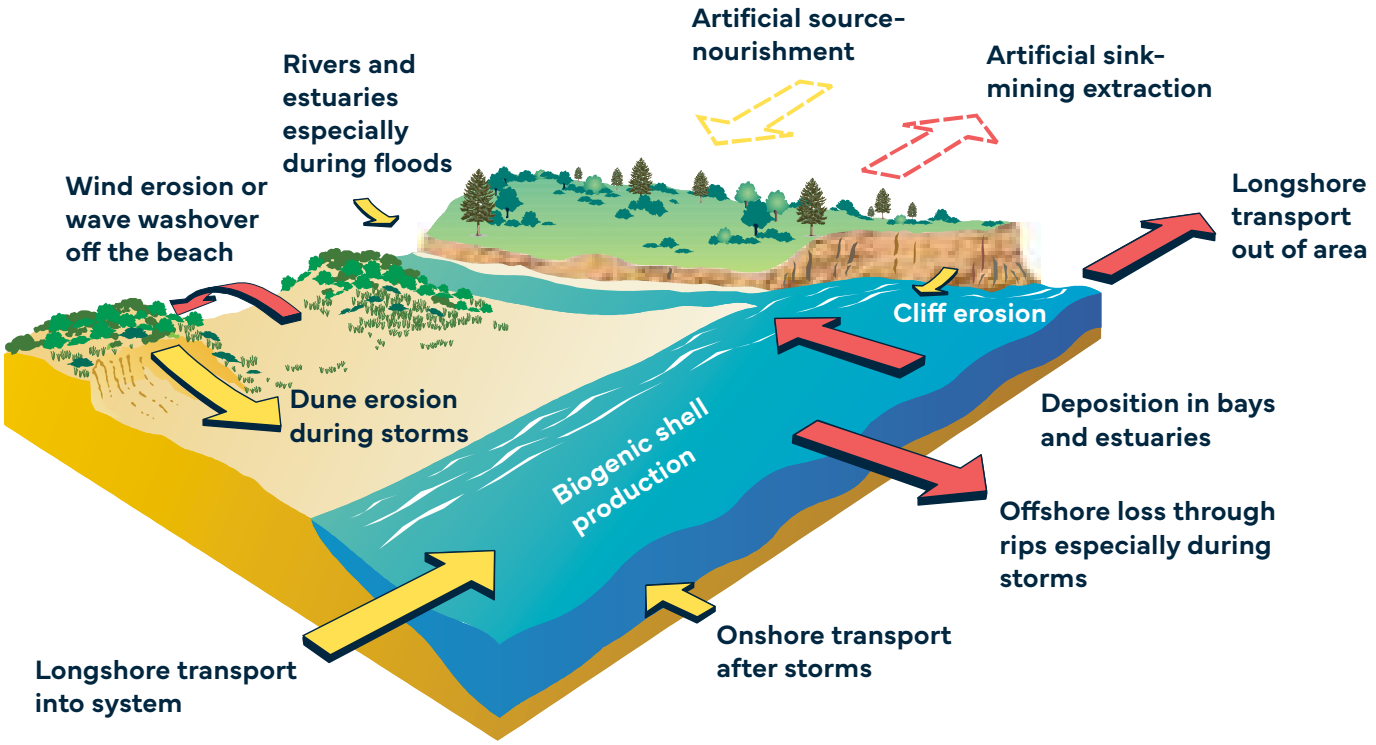
BEACH SAND SOURCES AND SINKS

Understanding the causes of erosion at a specific coastal location requires identifying both the sand sources (gains) and sand sinks (losses) in the area. Disruptions to the natural sources of sand can significantly affect the stability and volume of sediment along the shoreline. Coastal sand typically originates from rivers and estuaries, which carry sediment from inland areas and deposit it along the coast. Additionally, biogenic sources, such as fragments of shells, corals, and other marine organisms, contribute to the formation of sand. Another source is the erosion of coastal cliffs and rocks, where waves gradually break down solid structures into smaller particles that accumulate on the beach.

Once the sand reaches the beach, it is transported by several natural processes. Onshore-directed transport brings sand from the nearshore ocean onto the beach, while alongshore transport moves sand from adjacent coastal areas. Human intervention, such as beach nourishment, can also introduce sand artificially to replenish or expand a beach (figure 2.1).

Conversely, a major source of sand sink is artificial extraction (sand mining), which removes significant volumes of sediment, thereby reducing the beach's natural sand supply. Additionally, sand can be deposited in coastal bays and estuaries, where it becomes trapped and no longer contributes to the beach system. Offshore and longshore transport can also carry sand away from the beach, leading to a reduction in beach volume over time.

FIGURE 2.1 OVERVIEW OF POTENTIAL SAND SOURCES AND SINKS



Source: NSW Department of Land and Water Conservation 2001.

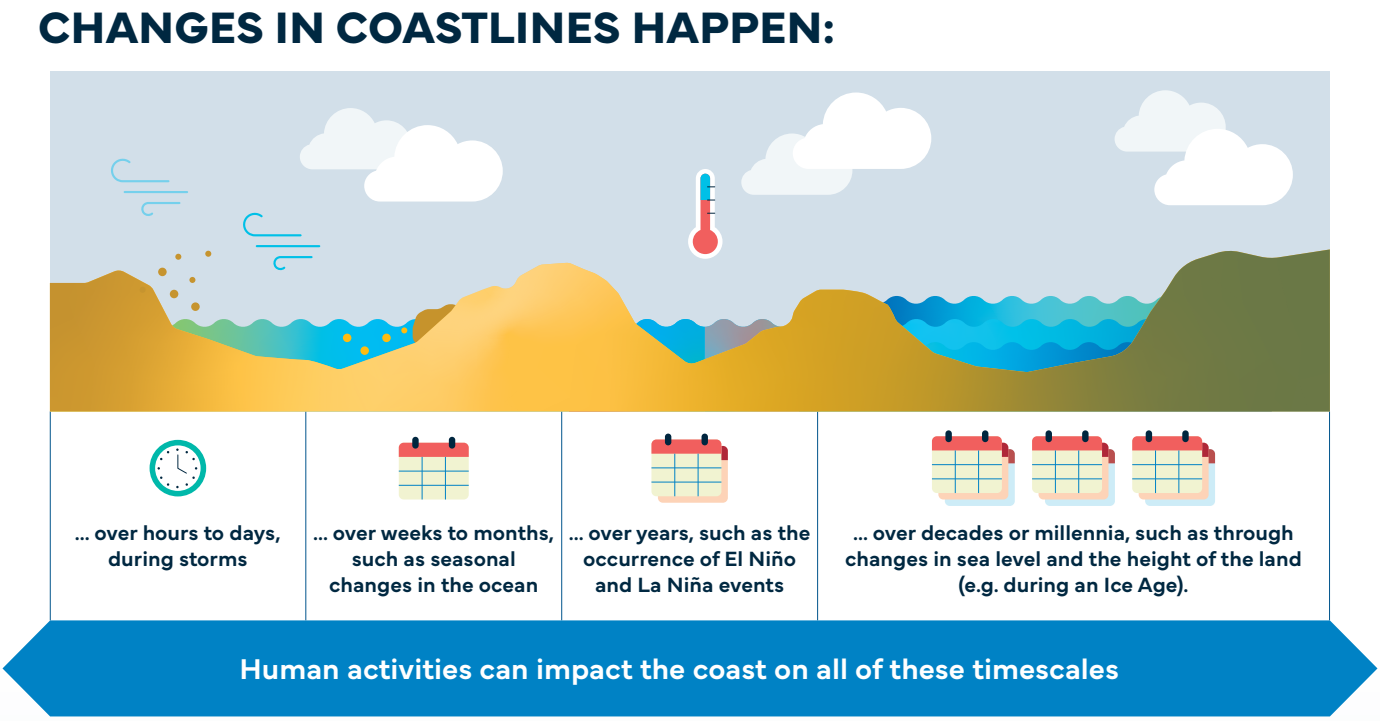
Note: Yellow arrows = sources; red arrows = sinks.

2.2

BEACH EROSION AND SHORELINE RETREAT

Beach erosion is the net loss of sediment volume from the shoreline and can be driven by both natural and/or human-induced causes (in other words, sand sink volumes are greater than the sand source volumes). It often occurs during high-energy events, such as storms, resulting in dramatic changes to the beach and dune over relatively short periods, but can also occur at a slower pace over much longer timescales (see figure 2.2).

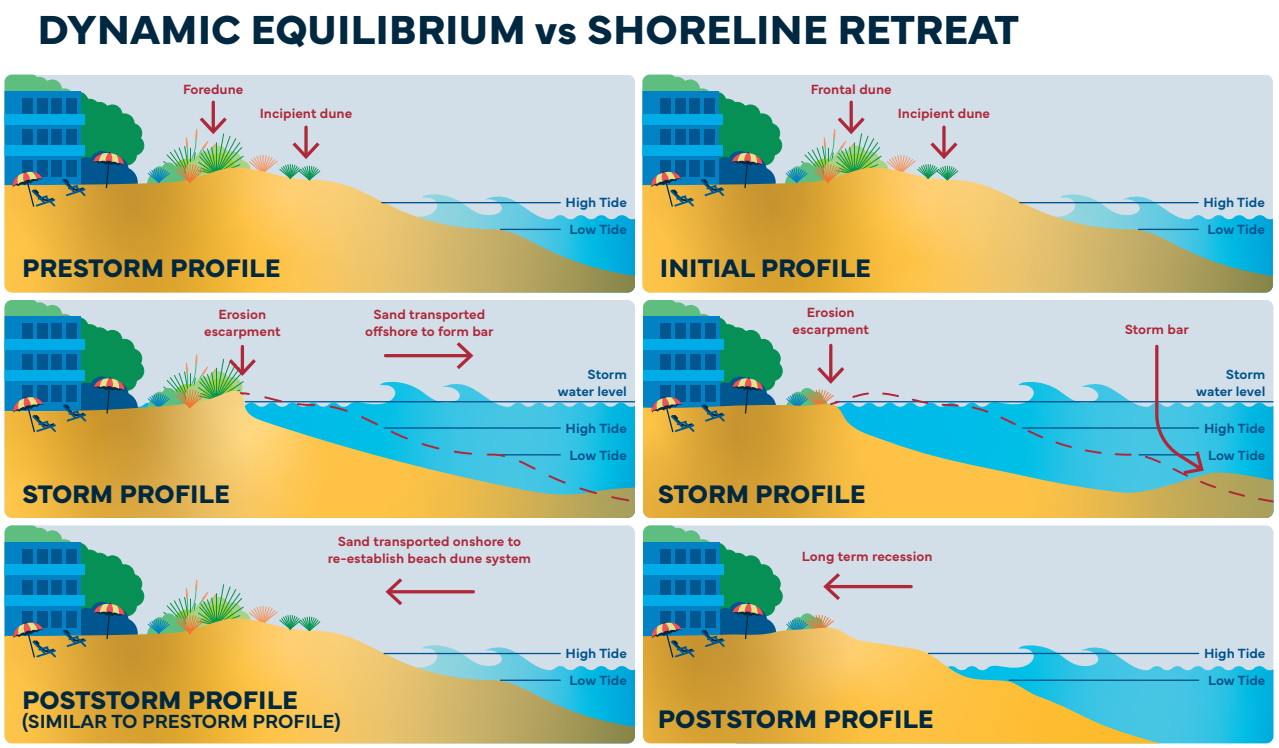
FIGURE 2.2 COASTLINE CHANGES OCCURRING OVER A WIDE RANGE OF TIMESCALES



Source: Adapted from CoastAdapt 2017.

Beach erosion is part of the natural dynamics of a sandy shoreline and may not be problematic when the beach is in dynamic equilibrium (figure 2.3, left). In this case, the beach is expected to naturally recover from erosion during calmer weather conditions. Most beaches worldwide go through cycles or erosion (for example, during energetic wave conditions or winter season) and recovery (during calmer conditions or summer season), without resulting in a lasting change of shoreline position.

FIGURE 2.2 EXAMPLE OF BEACH EROSION AS PART OF A DYNAMIC EQUILIBRIUM (LEFT) OR RESULTING IN SHORELINE RETREAT (RIGHT)



Source: Adapted from NSW Department of Land and Water Conservation 2001.

Beach erosion can become a serious issue when coastal infrastructure is located too close to the shore, leaving insufficient buffer space for the natural, dynamic movement of the beach. Without enough room for these natural processes, erosion may lead to significant damage to infrastructure. Over time, a net loss of beach sand volume can cause the shoreline to retreat landward, placing tourism facilities, coastal infrastructure, and beach amenities at risk. This ongoing process, known as shoreline retreat, often necessitates costly coastal management interventions to prevent further damage and protect these valuable assets (figure 2.3. right). For example, at the Kiyú coastline in Uruguay, coastal erosion was so severe that the roads along the coastline had to be relocated, and measures to protect the coast from further erosion where implemented (see case study 4).

While some cases of problematic beach erosion are natural, the far majority is caused by human developments and activities. Common contributors include coastal infrastructure, such as ports, roads, and buildings, which interfere with the natural movement of sand along the shoreline. Additionally, the construction of upstream dams can limit the supply of sediment that rivers transport to the coast, while sand mining and dredging physically remove sediment from the system (box 2.1). Human-induced degradation of coastal and marine ecosystems such as wetlands or reefs can also further exacerbate erosion. These factors often reduce the volume of sand available to a particular stretch of beach, leading to persistent erosion problems. Paradoxically, many coastal structures designed to mitigate erosion in one location, such as groins and breakwaters, can inadvertently cause or intensify erosion in adjacent areas (see appendix A).

BOX 2.1 THE HIDDEN COST OF SAND MINING

Sand extraction from beaches poses serious challenges for many developing countries. Unregulated sand mining is often driven by demand from the construction industry and the absence of affordable alternatives. However, this practice can lead to severe environmental consequences, including beach erosion, loss of biodiversity, saltwater intrusion, and the weakening of natural coastal defenses (see case study 1). These impacts not only threaten local ecosystems but also undermine the very beaches that sustain tourism economies.

Despite its short-term economic appeal, sand mining frequently results in long-term losses, particularly when the extraction is informal, illegal, or poorly monitored, causing public revenue leakage and environmental degradation. Addressing this issue requires stronger enforcement of regulations, improved land use planning, and the promotion of alternative materials or sustainable mining practices. It is equally important to raise awareness among local stakeholders and developers about the true costs of unregulated sand extraction. Recent efforts in countries such as São Tomé and Príncipe illustrate the potential of national strategies focused on minimizing coastal sand mining through a mix of legal reforms, community engagement, and technical guidance (Rego et al. 2023).

2.3 CROSS-SHORE BEACH AND DUNE PROCESSES

During winter or wet seasons, storm wave (high-energy) conditions are usually dominant. Large sand volumes can be rapidly eroded from the coast by destructive waves. This causes beaches to become narrow and steep, a process that can happen over several hours or more gradually throughout the season.

If the wind and waves are strong enough, the water may be able to reach the dune foot and start the erosion process. Due to the relatively steep slope of the dunes, erosion volumes are typically much larger than for the beach alone. Although dune erosion often leads to dramatic shoreline changes, the eroded sand normally remains close to the coast, often forming a sand bar. Sand bar formations help break high energy waves offshore. As such, they help slow down the erosion process and protect the beach-dune profile in subsequent storms (figure 2.3, left). This self-protecting mechanism is an important process and explains why a storm early in the winter season often has relatively substantial impact on the dunes, since it will be the first time in the season that the eroded sand will be used to form sand bars.

During calm, low-energy wave conditions, such as in the summer season, waves gradually transport sand back towards the coast. As a result, beaches become wider and steeper, and sand often accumulates in a berm on the dry beach face. Under the influence of wind, this sand is then further carried up the beach into the dunes.

Hence, it is common for beaches to show seasonal variation in width and steepness, and this does not mean the shoreline is retreating. In some cases, the seasonal variation is in a timescale of years or decades.

The speed of recovery of the beach after a storm depends on where the sand was deposited offshore as well as the wave and tide conditions post storm.

Dune vegetation plays a vital role in stabilizing dunes. The below-ground root systems help bind the loose sand, reducing the risk of wind and wave-induced erosion. Meanwhile, the above-ground parts of the plants act as barriers, reducing the impact of strong winds and high water levels, which helps prevent further erosion. The vegetation's ability to trap and accumulate wind-blown sand allows the dunes to recover over time (photo 2.1). As a natural coastal defense mechanism, dunes are essential for protecting both beaches and inland areas.

PHOTO 2.1 EXAMPLES OF DUNE VEGETATION

Source: *de Groot et al., 2017* © Martin Stock/LKN-SH (left) and Alma de Groot (right).

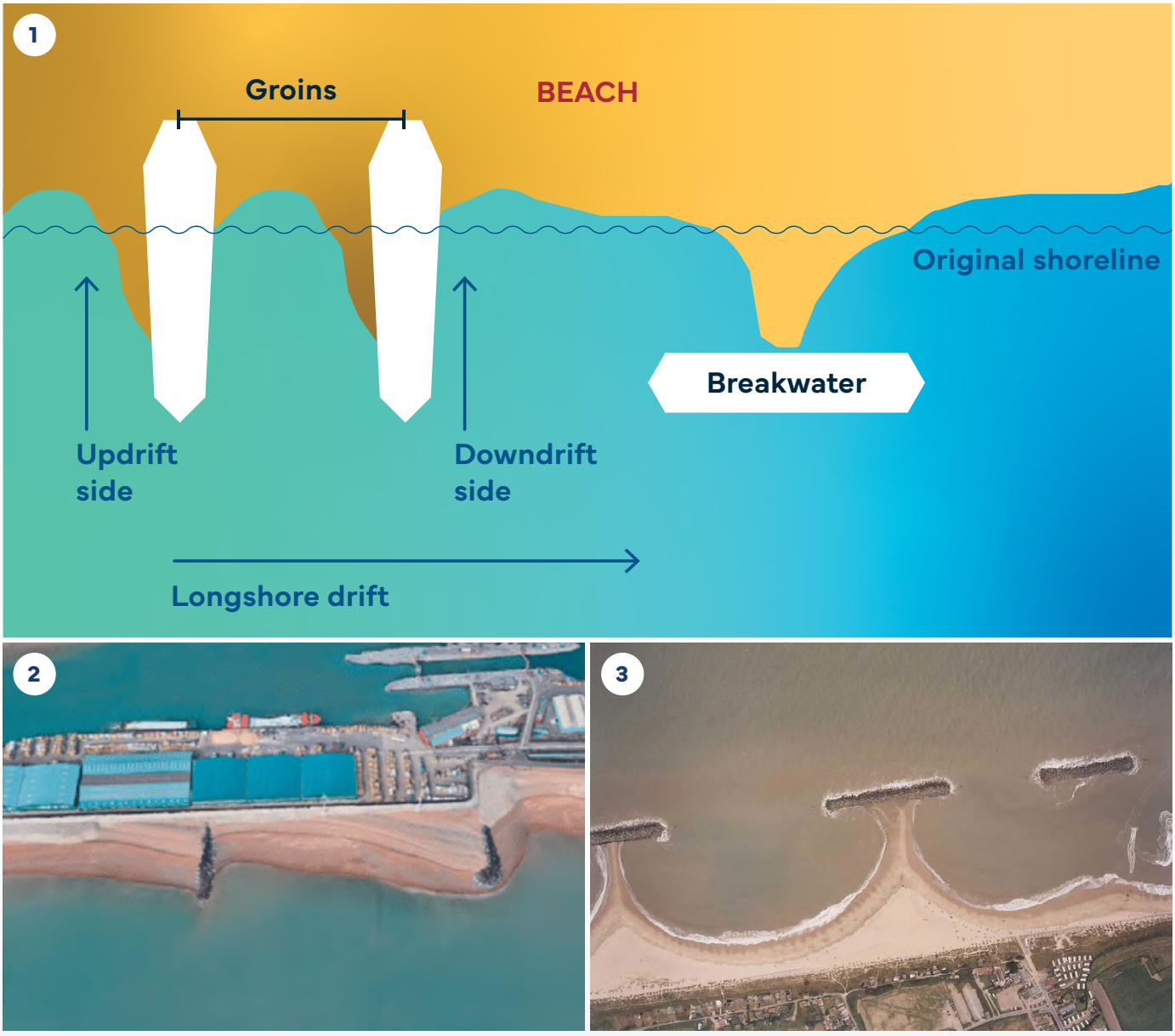
Note: Left – Dune Vegetation Retaining Sand During a Wind Event at Rømø Beach, Denmark. Right – White dunes on Ameland, Netherlands.

2.4 ALONGSHORE BEACH PROCESSES

Sand moves back and forth along (parallel to) the coast throughout the year without causing a net change in shoreline position, and the coast is in dynamic equilibrium. The rate and direction of transport depend on the ocean current speed and direction, which are directly influenced by the incoming waves. Transport can be interrupted or blocked by natural hard features, such as headlands and rocky outcrops, or human-made infrastructure such as ports, groins, and breakwaters (see appendix A). In some cases, sand transport along the beach is interrupted by coastal habitats such as mangroves or shellfish reefs.

Shoreline growth (accretion) typically occurs on the updrift side and shoreline retreat occurs on the downdrift side of the natural or human-made barriers (figure 2.4). This process continues until a new dynamic equilibrium is achieved. Along many coastlines, the placement of coastal structures causes downdrift erosion, which is mitigated with the placement of a subsequent structure, often leading to a series of hard structures (figure 2.4).

FIGURE 2.4 EXAMPLES OF SHORELINE GROWTH, SHORELINE RETREAT, AND COASTAL STRUCTURES



Sources: 1. Adapted from Ryzhakov et al. 2022; 2. © Valsamidis and Reeve 2020; 3. Brew et al. 2005, © UK Environment Agency.

Note: 1. The typical shoreline response for a coastal structure that interrupts or reduces the longshore drift with shoreline accretion (growth) on the updrift side and retreat (erosion) on the downdrift side. 2. Updrift and downdrift created by groins in Southwick beach (UK). 3. Tombolos created behind detached breakwaters at north-east Norfolk (UK).

Wave climates, including the predominant direction of wave action, often vary seasonally. These seasonal variations are particularly noticeable in enclosed or embayed beaches, also known as pocket beaches. An enclosed beach is typically bordered by headlands or other natural barriers that limit the movement of sand beyond the beach itself. One of the key processes observed in these environments is beach rotation, where the shape of the beach changes with the seasons. During one season, one end of the beach becomes relatively wide, while the other narrows. In the next season, this pattern reverses. While this alternating movement may give the appearance of shoreline retreat, it is actually a temporary redistribution of sand, with no net loss of sand volume. Instead, the sand is simply stored at the opposite end of the beach, highlighting the dynamic yet balanced nature of sediment movement in these enclosed beach systems.

2.5

HOW COASTAL AND MARINE HABITATS HELP STABILIZE BEACHES

Beaches are not just exposed sandy shores but are often adjacent or bordered by diverse coastal habitats, such as mangrove forests, salt marshes, coral reefs, shellfish reefs, and seagrass meadows. Each habitat plays a vital role in maintaining beach stability and providing multiple protective functions. A high-level overview of these functions is given in table 2.1, while section 4.2 provides further details on NBS that utilize these habitats for beach stabilization.

TABLE 2.1 PROCESSES BY WHICH KEY COASTAL AND MARINE HABITATS CAN SUPPORT BEACH STABILIZATION

HABITAT TYPE	BEACH PROTECTION FUNCTION
MANGROVE FORESTS	Mangrove forests are characterized by salt-tolerant trees and shrubs that thrive in intertidal zones, where they are periodically flooded by seawater. They are formed through the dispersion of buoyant seeds by currents, and settle in shallow and sheltered (low wave energy) areas. As the mangroves grow, they create complex root systems that can trap sediment, providing shoreline stability. Their trunks and branches form a barrier to large waves and wind when these occur.
SALT MARSHES	Salt marshes form through a combination of sediment accumulation and vegetation growth in intertidal zones. Sediment is deposited by tidal currents settling in low-lying coastal areas. Pioneer plants establish themselves, trapping more sediment with their roots. Overtime the accumulation of sediment and organic matter raises the elevation of the marsh, promoting shoreline stability. Salt marsh also attenuates wave energy and storm surge, protecting the hinterland.

HABITAT TYPE	BEACH PROTECTION FUNCTION
CORAL REEFS	Coral reefs are vital for coastal protection as they dissipate wave energy before it reaches the shore, reducing the impact of storms and preventing erosion. Coral reefs also promote sediment accumulation by providing habitat for marine organisms that produce and trap sand, thereby supporting the growth and stability of adjacent sandy beaches.
SHELLFISH REEFS	Similar to coral reefs, shellfish reefs, such as oyster reefs attenuate wave energy and can trap sediments, which helps to stabilize shorelines.
SEAGRASS	Seagrass meadows, found in shallow coastal waters, are highly effective at stabilizing sediments with their dense root systems. They can reduce wave energy, promote sediment deposition, and protect shorelines from erosion.

Source: Authors' elaboration.

2.6

THE INFLUENCE OF CLIMATE CHANGE ON BEACH EROSION

Climate change poses significant threats to coastal areas, including sandy beaches (figure 2.5). One of the most direct impacts is sea level rise, which is projected to cause most beaches to recede inland, leading to shoreline retreat. According to the Intergovernmental Panel on Climate Change (IPCC), global mean sea levels could rise by 0.43 meters under a low-emission trajectory to 0.84 meters under a high-emission trajectory by 2100 (IPCC 2019). This rise is mostly due to a combination of melt water from glaciers and ice sheets and thermal expansion of seawater as it warms.

Besides global thermal expansion, spatial variations in sea level rise can occur, influenced by ocean surface temperature oscillations, such as El Niño-Southern Oscillation, which can temporarily elevate or depress sea levels in specific regions (Cai et al. 2014). Other factors contributing to regional differences include gravitational changes caused by ice melt and shifts in ocean currents. These variations mean that even if the limited number of observational records currently available prevent the drawing of definitive conclusions, some areas may

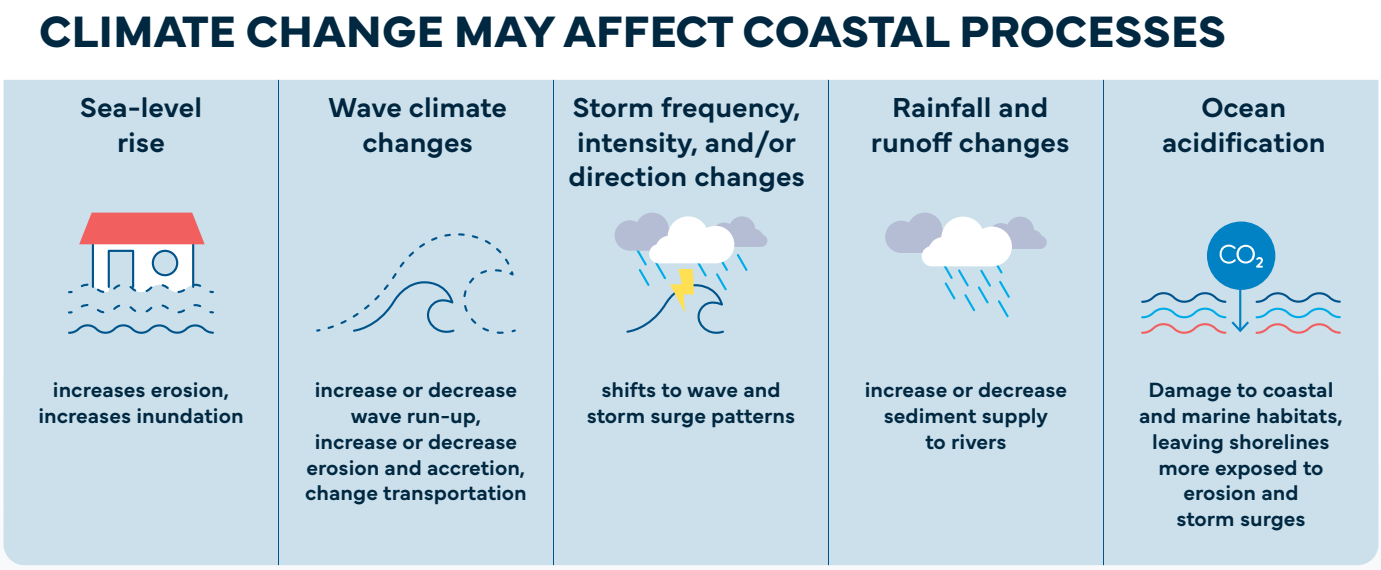
experience sea level rise well above the global average, placing low-lying coastal communities and islands at even greater risk (Lee and McPhaden 2010; Domingues et al. 2018).

In addition, changing weather patterns, including the frequency and intensity of storm events, will alter wave climates and shoreline dynamics. Studies suggest that increased storm intensity and shifting storm tracks will lead to more severe coastal erosion in certain regions, while other areas may experience reduced wave energy and less erosion (Vousdoukas et al. 2018). These changes are highly dependent on geographical location, with tropical areas and SIDS being particularly vulnerable.

Another indirect impact of climate change is the alteration of river sand supplies due to changes in rainfall and runoff patterns. Reduced river flow caused by altered precipitation patterns could significantly impact the sand supply to beaches, exacerbating erosion issues in the long term (Syvitski et al. 2009).

Finally, global warming and ocean acidification threaten coastal and marine habitats, such as coral reefs and mangroves, which naturally protect shorelines from erosion (IPCC 2014). The degradation of these ecosystems leaves coastal areas more exposed to erosion and storm surges, further threatening beaches, tourism assets, and other coastal infrastructure.

FIGURE 2.5 HOW CLIMATE CHANGE MAY AFFECT COASTAL PROCESSES



Source: Adapted from CoastAdapt 2017.

3

MAINSTREAMING NBS IN THE TOURISM INDUSTRY

Photo by Natalia Blauth on Unsplash

In the current context, investing in NBS for beach stabilization is not only an environmentally responsible choice but also a potential strategic move for the tourism sector. The convergence of improved scientific understanding, heightened regulatory focus on sustainable practices, and evolving market preferences towards eco-friendly tourism creates an ideal moment to implement these strategies for protecting economically valuable beaches and other ecosystems.

3.1

RETHINKING TRADITIONAL ENGINEERING APPROACHES

For many years, the tourism sector's approach to coastal and beach management has relied heavily on traditional engineering solutions to protect valuable assets and infrastructure (appendix A). This strategy, often referred to as gray infrastructure, involves constructing hard barriers like seawalls, groins, and rock armoring to prevent coastal erosion and flooding. While these structures are designed to fix and harden the shoreline, they interfere with the natural dynamics of beach environments, where sand and sediment naturally shift in response to waves, tides, and seasonal weather events.

Beaches are inherently dynamic, constantly moving and evolving with the forces of nature. When gray infrastructure is installed, it prevents this natural migration, lead to unintended consequences, such as increased erosion in neighboring areas or the loss of natural beach profiles, as well as high ecological and economic costs.

Furthermore, gray infrastructure is not adaptive. It cannot adjust to changing climate conditions, such as sea-level rise, and it may eventually fail without constant and costly maintenance. Additionally, the construction of such structures can harm marine and terrestrial life, degrade water quality, and diminish the aesthetic and recreational value of natural shorelines, which are essential attractions for tourists.

Given these limitations, the tourism sector should begin to shift towards more sustainable approaches by integrating NBS into coastal management strategies. Hybrid approaches offer a balanced solution in many contexts. For instance, reinforced dunes combined with fencing or other soft measures (see case studies 3 and 4) or submerged breakwaters that mimic natural reefs dissipating the wave energy while serving as substrates for the colonization of marine life (see case study 2) are some interesting alternatives to be better explored. These hybrid interventions can leverage the strengths of both methods, providing long-term, adaptive coastal protection while preserving the natural beauty and biodiversity of beach environments.

3.2
WINDOW OF OPPORTUNITY

Our understanding of ecosystem services has increased substantially over the past decade. Improved understanding and experience of the role of beach and dune systems on controlling erosion indicate that beach and dune restoration are effective techniques for shoreline protection and adaptation (Nordstrom and Jackson 2013), while also providing various other benefits, such as recreational opportunities and biodiversity enhancement. This enhanced understanding and proven success from coastal engineers, governments, and research organizations bolster the case for broader adoption of these methods in coastal areas.

On the regulatory front, governments and international bodies are progressively mandating more rigorous environmental standards. The European Union's (EU) ICZM (European Commission 2000) and the US Coastal Zone Management Act (US Government 1972) are examples of policies encouraging the use of NBS to combat coastal erosion and protect marine ecosystems. This trend is not only being seen in higher-income countries. Some lower-income countries with economies heavily dependent on tourism, such as Belize and Seychelles, have also adopted management strategies to help maintain and protect their coastal zones, reducing coastal risk and supporting healthy ecosystems (CZMAI 2016; World Bank et al. 2019). By starting to adopt these solutions, the tourism sector can stay ahead of regulatory requirements, ensuring compliance and reducing potential future liabilities.

The landscape of the tourism sector is also changing, with market trends increasingly leaning towards sustainability (Wang et al. 2018; Trang et al. 2019). While mass tourism has dominated the sector, tourists increasingly tend to prefer pristine and well-cared-for environments. Beach user satisfaction depends highly on the type of beach and the user profile, such as age and education level. However, studies demonstrate that tourists place high value on the natural and aesthetic resources a beach provides, and there is a willingness to pay to experience them (Enriquez-Acevedo et al. 2018). There is also a growing demand for ecotourism and demonstrative actions towards improved sustainability. Implementing NBS for beach stabilization aligns perfectly with this market trend, positioning destinations as leaders in sustainable tourism.

Looking beyond the private benefits, NBS also hold strong potential to drive inclusive and sustainable employment, particularly in coastal regions where livelihoods are tightly interwoven with natural ecosystems. In developing coastal areas, where tourism often accounts for a substantial share of GDP, restoring and protecting ecosystems such as mangroves, dunes, and coral reefs can generate both direct and indirect employment across sectors like ecotourism, hospitality, guiding, conservation, and artisanal fisheries. NBS are inherently labor-intensive, especially during their design, implementation, and monitoring phases, and often rely on local, nonspecialized labor (Lieuw-Kie-Song and Pérez-Cirera 2020). This makes them particularly well-suited to supporting job generation in vulnerable coastal communities while enhancing natural capital for long-term economic gains.

A study found that coastal habitat restoration projects generate between 15 and 33 jobs per US$1 million invested, significantly more than traditional industries such as coal, gas, or nuclear energy (Edward et al. 2013).

In the United States, it has been estimated that each dollar spent on ecosystem restoration yields up to US$9 in economic returns and creates 10 times more jobs than fossil fuel–based investments (Nature4Climate 2020). When applied to developing coastal economies, these multipliers highlight the high-impact potential of NBS for future-proof, inclusive employment.

Compelling field examples reinforce this. In Indonesia, the World Bank's Mangroves for Coastal Resilience Project has combined ecosystem restoration with livelihood development, employing local communities, especially women, in mangrove planting through a cash-for-work program, while also boosting incomes by strengthening small businesses in tourism, fishing, or aquaculture (World Bank 2023b). Similarly, a beach restoration and coastal protection project in Saly, Senegal, supported by the World Bank, helped safeguard over 15,000 jobs in the tourism and fishing sectors, demonstrating how strategic investment in NBS can directly sustain local economies (World Bank 2023a).

The tourism sector, as one of the primary beneficiaries of healthy coastal ecosystems, has an important role to play in scaling up NBS. Its long-term financial planning horizons, established networks of suppliers, and deep integration with local communities give it the unique ability to foster multistakeholder partnerships, finance restoration efforts, and advocate for supportive policy and legislation (Blanco-Pimentel et al. 2022; Padma et al. 2022). Moreover, tourism operations that engage in NBS for shoreline protection and ecosystem health also help secure their own future viability while supporting the well-being of coastal communities, many of whom form the industry's workforce.

3.3

KEY CHALLENGES TO OVERCOME

Although global interest in implementing NBS to promote beach stabilization is gradually increasing, there are key challenges that may prevent further uptake from the private sector, such as:

Photo by Eggy Febryano on Unsplash

1. UNCERTAINTY ABOUT THE EFFECTIVENESS LEVEL:

It is important to recognize that NBS may not be suitable for every scenario, particularly in extreme contexts where erosion pressures are severe or highly dynamic, and available land is limited. Additionally, many NBS approaches are still relatively novel or have been applied only on a small scale or in specific contexts. As a result, much of the existing data on nature-based projects rely heavily on anecdotal evidence, and confidence levels regarding the ability of NBS to stabilize beaches remain variable. Furthermore, uncertainties linked to climate change and future development risks can heighten risk aversion. To attract large-scale private investment, there is a pressing need for objectively verifiable indicators to demonstrate the long-term impacts of these projects, helping to build a stronger evidence base and track record.

2. UNCERTAINTY ABOUT THE RETURN ON INVESTMENT:

Many tourism operators may be hesitant to face upfront NBS costs due to uncertainty regarding the return on investment, particularly when benefits are not immediate or easily quantifiable. Besides the beach stabilization service, other benefits generated, such as the improved client experience or brand reputation, are a critical part of the value proposition of these NBS and should be considered in their economic assessment. Failure to incorporate these broader benefits into the NBS investment case can cause a significant underestimation. A better estimation of the full range of impacts of NBS for beach stabilization can help business owners better understand the multiple benefits provided and better support the funding and implementation of these sustainable interventions.

3. LACK OF TECHNICAL AND ECOLOGICAL EXPERTISE:

The complex nature of coastal dynamics, ecosystems, and NBS design requires specialized technical expertise in coastal ecology, engineering, and management. However, tourism operators in developing countries may lack access to such expertise, hindering their ability to fully understand coastal processes and design, implement, and maintain nature-based interventions effectively. Additionally, there are often limited local information and data on climate change, native species, environmental degradation, and ecosystem services (including shoreline protection). The public sector, with support from international development organizations, should facilitate access to technical assistance and guidance from experts providing beach tourism operators with the necessary support throughout the whole project cycle to implement appropriate NBS.

4. REGULATORY AND PERMITTING PROCESSES:

Weak or outdated policy and regulatory frameworks related to coastal management and tourism development can pose significant barriers to the adoption of NBS in coastal areas. Ambiguous permitting processes, lengthy approval timelines, conflicting land use regulations, and inadequate enforcement mechanisms can create uncertainties, unexpected costs, and delays in project implementation, deterring tourism operators from pursuing such projects. Conversely, NBS can also be favored by regulators in many parts of the world due to their potential environmental and social benefits and alignment with the United Nations Sustainable Development Goals (SDGs). Engaging with regulatory agencies early in the project planning process and seeking technical assistance from experts can help streamline permitting procedures and ensure compliance with applicable regulations.

5. HIGH OPPORTUNITY COSTS FROM COMPETING ACTIVITIES:

Opportunity costs, which determine the value to the economy in its next best alternative use, are important considerations for tourism business owners. There may be a perception, sometimes justified, that NBS may restrict tourism activities, limiting their expansion, disrupting their operations, or potentially affecting access to certain amenities. However, studies have shown that NBS, by enhancing the aesthetic appeal of beaches, have the potential to attract more visitors and contribute to sustainable coastal and marine tourism development. NBS for beach stabilization can be designed and implemented in a way that balances environmental conservation with tourism objectives, outweighing the economic impact of other competing development alternatives in the long term.

6. SOCIETAL ACCEPTANCE:

A lack of public support for NBS can prevent actions being implemented. To successfully develop NBS projects, it is important to consider who will be impacted, both positively and negatively, by the project outcomes. Projects are more likely to gain political and public support when all stakeholder interests are considered for incorporation into the planning process. There is an opportunity for tourism operators to implement successful NBS by ensuring a robust engagement strategy with stakeholders and the public. Active social inclusion is recommended in all project stages, including planning, implementation, and long-term management and maintenance.

3.4

THE BUSINESS CASE FOR THE TOURISM INDUSTRY

Coastal erosion can negatively impact the income statement of tourism businesses by reducing the attractiveness of beachfront properties, increasing infrastructure maintenance costs and compromising recreational amenities. Traditional engineering solutions designed for a single protection purpose usually involve high upfront costs and the construction of artificial structures, which may not align with the business interests of tourism establishments. However, NBS offer an attractive value proposition for the industry, delivering multiple co-benefits beyond erosion control. Some of these other benefits create cost reduction and revenue generation opportunities in the short term and support a better management of business risks in the long term, enhancing the overall economic value of these investments (figure 3.1).

FIGURE 3.1 RECAP OF BENEFITS PROVIDED BY NBS FOR BEACH STABILIZATION AND POTENTIAL IMPACTS FOR TOURISM SECTOR BUSINESSES

BENEFITS OF NBS FOR BEACH STABILIZATION	TYPES OF BUSINESS IMPACTS		
	REDUCING COSTS	INCREASING REVENUE	IMPROVED RISK MANAGEMENT
Cost-effectiveness in the long term	✓		✓
Costs distribution over time	✓		✓
Enhancement of tourism experience		✓	
Regulatory compliance			✓
Brand reputation and credibility		✓	✓
Financing opportunities	✓		

Source: Authors' elaboration.

COST-EFFECTIVENESS IN THE LONG-TERM

Depending on the local circumstances, NBS can be more cost-effective than traditional hard infrastructure, especially when looking at longer time periods. These approaches mimic natural coastal processes and promote sediment deposition, leading to more sustainable erosion control over the long term (Cunniff and Schwartz 2015).

The longer-term effectiveness of NBS can increase the cost-benefit ratio of these investments in comparison to other beach stabilization interventions. Additionally, by reducing the risk of damage from coastal hazards such as storms and flooding (Silva et al. 2016), nature-based approaches can make coastal communities more insurable and less susceptible to financial losses. NBS that enhance coastal resilience can lead to lower insurance premiums for coastal properties (Swiss Re Group 2024), including hotels and other coastal businesses. Insurance companies are increasingly recognizing the value of NBS in reducing risk and offering incentives such as premium discounts for properties located in areas with natural coastal buffers (Lloyd's 2018; Swiss Re Group 2022). See box 3.1.

BOX 3.1 INSURANCE INNOVATION FOR NATURE-BASED TOURISM INFRASTRUCTURE

In recent years, leading insurers and reinsurers have begun to recognize the strategic value of NBS in addressing the growing risks associated with biodiversity loss and climate change. For coastal tourism economies, where natural ecosystems are both economic assets and buffers against storms, insurance can be a powerful enabler of cost-effective NBS investment. Innovative insurance solutions can reduce the perceived risk of NBS, attract blended finance, and provide rapid postdisaster payouts to restore ecosystem services essential to the tourism sector.

A landmark case is the Quintana Roo Coral Reef insurance scheme in Mexico. This was the world's first parametric insurance policy designed specifically for an ecosystem. It covers 400 km of the Mesoamerican Reef along the Yucatán Peninsula and is triggered by wind speeds exceeding 96 knots within 60 km of the reef. When Hurricane Delta struck in 2020, the policy paid out US$760,000 within days, enabling a trained brigade to rapidly restore over 9,000 coral fragments and stabilize reef structures. This helped reduce further ecological and economic losses to the tourism sector, which supports 148,000 jobs and generates US$10 billion annually in the region.

The model operates through a coastal zone management trust, funded by tourism-related fees and complemented by public and philanthropic contributions. This public-private structure ensures that the tourism sector, both a beneficiary and a risk bearer, actively supports reef protection. It also provides an example of how financial instruments, such as parametric insurance, can unlock resources for NBS while aligning the interests of insurers, governments, and local tourism operators.

Building on the success of the Quintana Roo reef insurance model, similar approaches are now being expanded across the Mesoamerican Reef and adapted to new ecosystems and climate risks in other parts of the world.

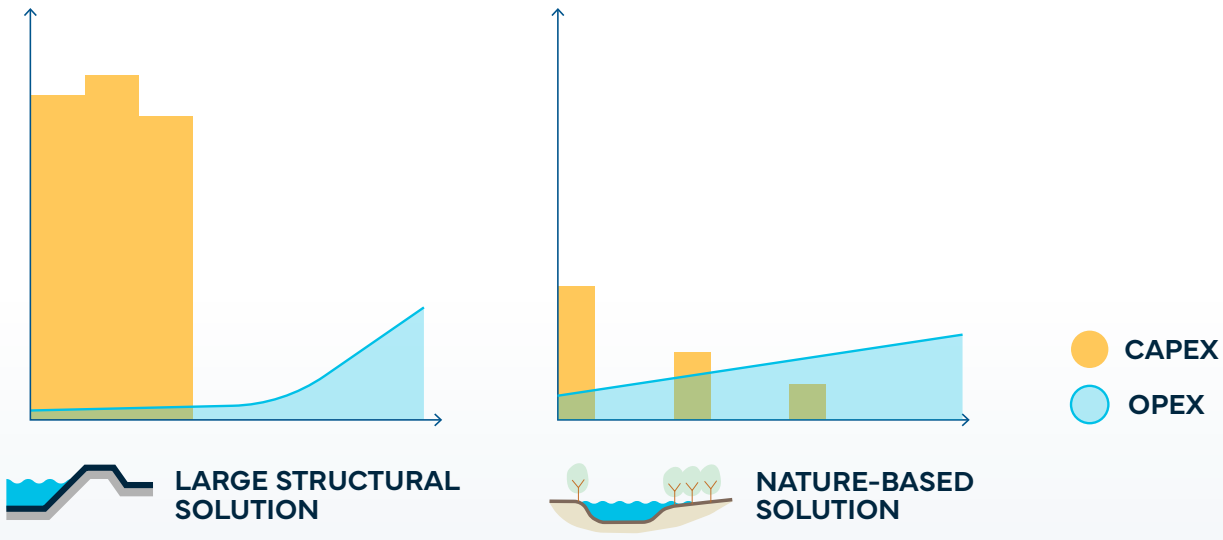
Source: TNC 2021

COST DISTRIBUTION OVER TIME

The costs of NBS investments differ from costs associated with traditional gray infrastructure in the distribution of capital and operating expenses over time (figure 3.2). NBS often have lower initial costs compared to traditional engineering structures such as seawalls and groins. While the construction of gray structures requires significant investment in materials, labor, and machinery, NBS like dune restoration or mangrove planting rely on natural processes and native vegetation, which can reduce upfront expenses when done in favorable environments (see case studies 3 and 4). On the other side, gray infrastructure could have reduced operating expenses in the first years of operation, but NBS may require sustained operational expenditures to manage restoration efforts over time and protect areas from encroachment.

While a case-by-case cost-benefit analysis is always necessary, NBS frequently offer a financial advantage due to their gradual investment structure. This phased approach can help avoid large upfront costs early in the project life cycle, precisely when uncertainties around effectiveness and climate conditions are highest. For instance, constructing a breakwater typically requires significant initial capital and may incur high additional costs if future developments necessitate its removal or redesign. In contrast, NBS are generally more flexible and adaptive to changing circumstances, making them a financially attractive option for managing long-term risks and avoiding costly infrastructure lock-ins.

FIGURE 3.2 DISTRIBUTION OF CAPITAL AND OPERATING EXPENSES OVER TIME FOR TYPICAL GRAY INFRASTRUCTURE (LEFT) AND NBS (RIGHT)



Source: van Zanten 2023.

Note: CAPEX = capital expenditure; OPEX = operating expenditure.

IMPROVED TOURIST EXPERIENCE

Hard infrastructure, typically rock and concrete engineering, can restrict public access to beaches and alter the natural aesthetic of coastal landscapes. The aesthetic appeal of natural coastal landscapes plays a crucial role in attracting tourists to beach destinations. NBS help to enhance or retain the scenic beauty of beaches, having the potential to attract more visitors and generate revenue for coastal businesses, including hotels, restaurants, and tour operators. Studies have shown that tourists are willing to pay a premium for destinations with well-preserved natural environments (Balmford et al. 2009), indicating the economic value of NBS for tourism experiences.

Coastal NBS can also create opportunities for diversifying revenue streams within the tourism sector. Ecotourism activities such as birdwatching, nature trails, and diving tours appeal to environmentally conscious travelers seeking authentic and eco-friendly experiences (Booking.com 2019). By integrating these offerings into their business models, coastal businesses can create new or increase existing revenue lines, and at the same time, capture an expanding niche market segment. See box 3.2.

BOX 3.2 ENHANCING GUEST EXPERIENCE THROUGH COASTAL ECOSYSTEMS RESTORATION

Six Senses Laamu Atoll, a pioneering resort in the Maldives, has made a significant commitment to the protection and restoration of seagrass beds, which are essential ecosystems that support beach protection, fisheries, biodiversity, livelihoods, and carbon storage. Since the project's inception, the resort has observed a remarkable flourishing of these ecosystems.

To engage guests, Six Senses Laamu offers weekly snorkel tours, allowing visitors to observe seahorses and green sea turtles in their natural habitat. This interactive approach not only educates guests on the importance of seagrass beds but also enhances their overall experience, fostering a deeper connection with the environment.

The resort's commitment extends to the local community as well. It collaborates with all 16 communities across Laamu Atoll, inviting guests to participate in local initiatives and supporting mangrove protection efforts. This approach offers a valuable experience outside of the traditionally closed-off resort environment.

By integrating customer engagement with community collaboration, Six Senses Laamu Atoll effectively enhances its coastal ecosystem restoration efforts. This approach not only protects their beach but also attracts eco-conscious travelers, demonstrating the business value of sustainability.

Source: King and Burns 2022.

REGULATORY COMPLIANCE AND PUBLIC SUPPORT

The tourism industry, representing between 8 percent and 10 percent of global GHG emissions (Lenzen et al. 2018), must prioritize quick and effective climate action in support of global climate compacts. According to the World Economic Forum's Global Risks Report (World Economic Forum 2024), extreme weather events, failure of climate change mitigation and adaptation measures, and disasters are among the top global risks in terms of likelihood and impact. The recent 2023 United Nations Climate Change Conference of the Parties (COP 28) clearly emphasized the necessity for a paradigm shift in tourism management, recognizing climate resilience as crucial for the sector's long-term sustainability and competitiveness (TPCC 2023).

In response to these challenges, many countries are implementing stricter regulations regarding carbon emissions, coastal development, and environmental protection. Others are introducing policies and incentives to encourage sustainable tourism investments (see box 3.3). By investing in NBS as a way of decarbonizing operations and advancing towards other SDGs, beach tourism operators can not only stay ahead of regulatory requirements but also position themselves to benefit from emerging public initiatives and financial incentives that support sustainable coastal management.

BOX 3.3 COLOMBIA'S APPROACH TO RESILIENT AND SUSTAINABLE TOURISM

The Republic of Colombia has embraced nature-based solutions (NBS) as a core component of its strategy to build resilience in the tourism sector. As part of the Tourism Sectoral Plan 2022–2026, "Tourism in Harmony with Life," the government has integrated disaster risk management and climate adaptation into its tourism policies, recognizing that sustainable tourism depends on the health of natural ecosystems.

Tourism plays a crucial role in Colombia's economy, contributing 1.6 percent of gross domestic product and employing over 2.6 million people. However, the sector faces increasing threats from climate-related hazards. Past events, such as the 2010–2011 La Niña phenomenon and Hurricane Iota, caused severe economic losses, highlighting the urgent need for proactive climate risk management. The government's response includes promoting NBS and environmental best practices to protect key tourism destinations from erosion, flooding, and other climate-related hazards.

Supported under the World Bank's Catastrophe Deferred Drawdown Option (Cat DDO), a financing instrument designed to provide immediate liquidity in response to disasters, this policy reform encourages tourism businesses to implement sustainable conservation and restoration projects, including mangrove and wetland restoration and green infrastructure. The government has also launched new financial instruments and technical assistance programs to incentivize private investment in sustainable tourism. These measures aim to strengthen the sector's climate resilience while preserving Colombia's leadership in nature-positive tourism development.

Source: World Bank 2025.

BRAND REPUTATION AND CREDIBILITY

Consumers are becoming more environmentally conscious and are increasingly choosing businesses that demonstrate a commitment to sustainability. According to a Nielsen study, 73 percent of consumers are willing to change their consumption habits to reduce their impact on the environment (Nielsen 2018). The tourism sector is particularly sensitive to this market change, and adopting NBS can open opportunities to differentiate tourism brands in a very competitive market. Several surveys by industry benchmarks such as Booking.com (2018) reveal that "awareness of eco-friendly accommodation options keep growing, with global travelers seeking to book more of these greener stays than ever, while showing a willingness to absorb extra costs to ensure they are traveling more sustainably." By positioning themselves as environmentally responsible establishments committed to preserving coastal ecosystems, brands can attract a loyal customer base that values sustainability and conservation efforts. See box 3.4.

Additionally, various studies and surveys also suggest that investing in environmental sustainability enhances a company's ability to attract and retain talent by aligning with the values of environmentally conscious employees, particularly younger generations (Deloitte 2024; Cone Communications 2016).

BOX 3.4 IBEROSTAR'S SUCCESSFUL COASTAL RESTORATION INITIATIVE

Iberostar hotel chain has launched an innovative coastal restoration program as part of its "Wave of Change" strategy, initiated in 2023. This program targets the restoration of vital coastal ecosystems, including reefs, seagrasses, mangroves, and sand dunes, across 12 resorts in the Dominican Republic, Mexico, and Jamaica. By enhancing these ecosystems, Iberostar aims to mitigate coastal risks such as erosion and flooding while improving the overall beachfront experience.

Financed through Iberostar's corporate sustainability budget, the program's long-term vision is to integrate restoration costs into each resort's budget and profit-and-loss statements. This commitment underscores the hotel's dedication to sustainable practices and ecological health. Furthermore, Iberostar collaborates with local governments, academia, other hotel operators, and development agencies to expand its restoration efforts, ensuring a collective approach to coastal conservation.

Iberostar's initiative not only helps to protect and restore crucial marine environments but also boosts the hotel's brand reputation. The success of this program highlights the potential for tourism operators to play a pivotal role in environmental stewardship, demonstrating that sustainable practices can align with and enhance business objectives.

Source: World Bank 2024.

FINANCING OPPORTUNITIES

Investing in NBS presents a growing opportunity for both public and private financing, particularly as governments, development institutions, and the private sector increasingly prioritize sustainable and climate-resilient strategies (World Bank 2023c). For the coastal tourism sector, which is deeply dependent on healthy ecosystems and climate stability, financing NBS is not only a matter of environmental stewardship but also of long-term business viability and competitiveness.

From the public sector perspective, development banks, international climate funds, and national governments are scaling up efforts to support nature-positive investments. Public financing remains the dominant source of funding for NBS, especially in areas like coastal protection, which are often considered public goods with benefits that are difficult to monetize directly. However, tourism operators that align their business strategies with sustainability goals may access cheaper financing by becoming eligible for grants, subsidies, and concessional finance instruments offered by institutions (for example, The Coalition for Private Investment in Conservation, Global Fund for Coral Reefs, and the Global Center on Adaptation).

Private financing is also beginning to flow toward NBS, albeit still at a limited scale. Impact investors, philanthropic donors, and NGOs are supporting projects that deliver environmental and social returns alongside financial outcomes (van Raalte and Ranger 2023). In particular, tourism businesses can benefit from partnering with NGOs experienced in conservation finance, helping to strengthen project design, monitoring, and access to blended finance opportunities. Mechanisms such as blue bonds and biodiversity offset are also emerging as innovative financing tools that can complement more traditional forms of capital (World Economic Forum 2022).

However, to mobilize private investment at scale, NBS projects must become bankable. This means demonstrating clear, quantifiable value and a credible pathway to financial sustainability. For many NBS, the value lies in avoided losses, such as reduced flood or erosion damage, or co-benefits such as enhanced guest experiences, improved brand reputation, or increased occupancy rates. Structuring projects to capture and monetize these benefits is key to attracting investors. Carbon credit markets, particularly for blue carbon ecosystems such as mangroves and seagrasses, offer one pathway to generate revenue streams from restoration activities. Voluntary carbon markets are growing in relevance and can provide an additional incentive for private sector engagement in NBS.

Another innovative model gaining attention is ecosystem service insurance. For example, coral reef insurance pilots in Mexico and elsewhere provide rapid poststorm payouts to fund restoration of reef systems that protect tourism infrastructure and support livelihoods (see box 3.1). Such models showcase the potential for the tourism sector to coinvest in natural infrastructure that directly supports its long-term profitability.

Despite this positive momentum, financing for early-stage NBS projects remains a challenge. Many potential interventions, especially those led by small tourism enterprises in developing regions, face barriers such as lack of technical capacity, insufficient baseline data, and limited access to financial instruments. Addressing these challenges will require stronger collaboration between public and private stakeholders, clearer policy incentives, and the development of tools that improve the financial viability and risk-return profiles of NBS investments.

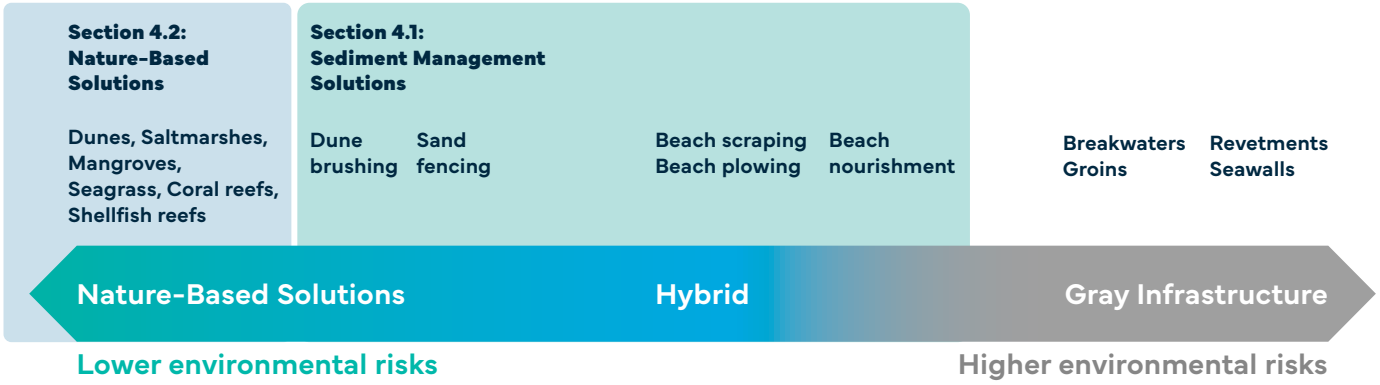
4

BEACH INTERVENTIONS TO MITIGATE EROSION

Photo by Frank van Hulst on Unsplash

Chapter 4 showcase strategies to address beach erosion, presenting two main categories of structural interventions aimed at stabilizing sandy beaches. Section 4.1 introduces a portfolio of sediment management or soft engineering solutions that prioritize less intrusive interventions to coastal processes and the use of natural materials rather than traditional hard engineering approaches. Section 4.2 delves into a catalogue of nature-based solutions for beach stabilization, showcasing approaches that have proven effective in diverse contexts (Figure 4.1).

FIGURE 4.1 BEACH STABILIZATION METHODS INCLUDED IN THIS CHAPTER POSITIONED ON THE GREEN-HYBRID-GRAY SPECTRUM



Source: Authors' elaboration.

Note: This report focuses on structural and restoration methods when conservation or protection approaches are previously discarded, and active beach restoration strategies become most suitable options.

While the presented interventions can offer effective and sustainable methods to mitigate erosion, it is critical to approach their implementation with careful planning and a comprehensive understanding of the coastal system. Beaches and dunes are dynamic environments, part of interconnected biophysical systems where changes in one area inevitably influence others. Effective interventions must acknowledge these interdependencies and prioritize the conservation of existing ecosystems to minimize unintended consequences.

Additionally, human activities and aspirations must be considered in rehabilitation projects, ensuring that interventions align with societal needs while addressing the root causes of degradation.

Rehabilitation efforts must also align with broader strategic objectives at national, regional, and local levels, ensuring that projects are thoughtfully planned and integrated into existing frameworks. By recognizing the interconnectedness and dynamic nature of coastal systems, these interventions can protect tourism assets, enhance biodiversity, and support long-term coastal resilience.

4.1.

SEDIMENT MANAGEMENT SOLUTIONS

Soft engineering measures provide sustainable solutions to stabilize sandy beaches. These approaches do not involve building rock or concrete structures, but instead use natural materials like sand, vegetation, and wood to protect coastal areas from erosion and flooding. Each strategy offers unique advantages and disadvantages, requiring careful consideration to ensure effective implementation.

For example, sand fencing helps trap wind-blown sand, promoting dune formation, while dune brushing and beach plowing encourage vegetation growth, stabilizing the sand. Beach scraping and nourishment replenish eroded beaches, maintaining their recreational value for tourists. These are more aggressive sediment management solutions that use machinery to accelerate natural processes, typically applied when urgent recovery or protection is needed. However, these methods also come with risks and challenges, such as the need for ongoing maintenance and potential environmental impacts if not properly managed.

Beach stabilization efforts aim to create and maintain large accumulations of sand at the upper part of the beach. This sand acts as a physical barrier against storm-induced waves and water levels and serves as a sand reservoir during severe erosion events. While ecosystem restoration often takes time, immediate interventions are sometimes necessary to stabilize the upper beach or dune. Combining stabilization interventions with restoration efforts, such as revegetation, ensures long-term success. These interventions range from simple, low-cost methods that volunteers can perform, like dune brushing, to more complex, costly techniques requiring dedicated machinery.

Photo by Aleksei Agafonov on Unsplash

DUNE BRUSHING

Dune brushing concerns the strategic placement of native tree branches and shrubs to stabilize or rehabilitate degraded or unstable dunes.

SUITABLE FOR

most dunes or coastal banks where sand and sediments are exposed to wind and waves. However, establishing vegetation in areas regularly inundated or overwashed by tides can be challenging, potentially limiting the project's longevity and effectiveness.

BENEFITS FOR THE TOURISM SECTOR

The main benefit is the preservation of the natural character of the beach, which is an attribute highly valued by tourists. Vegetation can also provide wildlife habitat, benefiting activities like bird and wildlife watching.

The practice of dune brushing can also offer opportunities to engage with the local community in a positive manner and to provide a low-key yet meaningful opportunity for tourists to be part of a dune restoration and rehabilitation effort. (See also: **Benefits of dunes**)

CAPEX

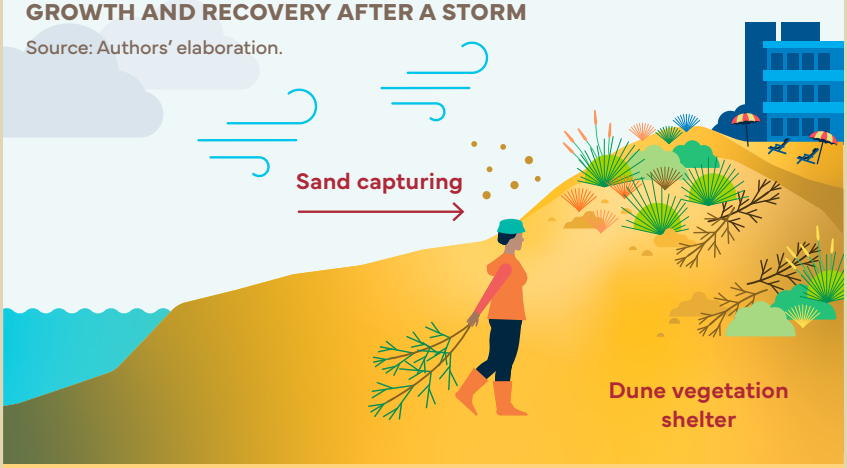
Dune brushing includes the sourcing and placement of brushwood obtained from nearby areas. Generally, the only significant costs to be expected are labor costs, which are highly dependent on the project scale and local wages. Dune brushing is sometimes done volunteer-based, resulting in very low capital costs.

PHOTO 4.4.1. VOLUNTEERS PLACING BRANCHES FROM LOCAL SHRUBS IN FREMANTLE, AUSTRALIA

Source: © Perth NRM. Used with permission. Further permission required for reuse.

FIGURE 4.1.1. DUNE BRUSHING CAN HELP ACCELERATE DUNE GROWTH AND RECOVERY AFTER A STORM

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

Dune brushing helps capture wind-blown sand, which directly promotes dune growth (Itzkin et al. 2020). It creates a microclimate that protects and shades the sand surface, increases water infiltration, reduces erosion and wind speed, deters traffic, and traps sand. This process helps stabilize dunes and creates favorable conditions for even more vegetation growth.

OPEX

Operational costs may include labor costs associated with removal or adding brushwood in the years following the initial placement and would generally be relatively low (if volunteer-based).

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

A variety of factors that should be considered to minimize adverse impacts and ensure successful implementation and maintenance of vegetation projects. To protect young plants before their root systems are established, several techniques can be employed. Installing natural fiber blankets on the ground surface helps hold soils in place while roots develop. Temporary baffles made from natural-fiber material can shelter plants from wind, and sand fencing can slow wind, trap sand, and reduce erosion. Combining these techniques increases overall effectiveness. Additionally, ensuring water availability is crucial, as new plants with small root systems need consistent supplementary water sources to develop.

One common challenge in dune brushing projects is sourcing quality brushwood, ideally from nearby, although transport may be necessary (NACC, 2018). The work can be labor-intensive, particularly on steep dunes, but sufficient personnel or volunteers can form a working chain to address this issue. Brushing should use native species with tight stem arrangements and be free of weeds and disease (NSW Department of Land and Water Conservation, 2001). The required volume of compact brushwood estimated to be about 20 times smaller than the site area in square meters (Darvill, 2017). While machinery can be beneficial, it is not always feasible or necessary.

Restricting pedestrian access to designated paths is essential to protect dune and bank vegetation. Limiting the number of access points further minimizes impacts.

SAND FENCING

Sand fencing is the placement of fences along the upper beach or in the dunes to increase the capture of wind-blown sand. It is primarily used to promote the growth of dune volume, but can also be used to provide shelter to juvenile dune plants (that may have been planted as part of a rehabilitation effort) or to prevent sand from being blown farther inland. See case studies 1, 3, and 4.

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most sites, provided it does not interfere with protected shorebird and turtle species or native vegetation and is not reached by daily high tides or minor storm waves. It can be used to build up existing dunes, create dunes at the base of banks, or form dunes in low-lying areas with blowing sand.

BENEFITS FOR THE TOURISM SECTOR

Sand fencing offers a low-cost, nonintrusive method for stabilizing sandy beaches, making it a good solution for both environmental preservation and tourism enhancement. Unlike hard structures, sand fencing helps maintain the natural aesthetic of dune environments, particularly when organic materials like wood are used.

Strategically placed sand fencing can direct pedestrian traffic to designated access points, minimizing the impact on dunes and other protected areas. This not only preserves the natural landscape but also enhances the visitor experience by providing clear paths and reducing habitat disturbance.

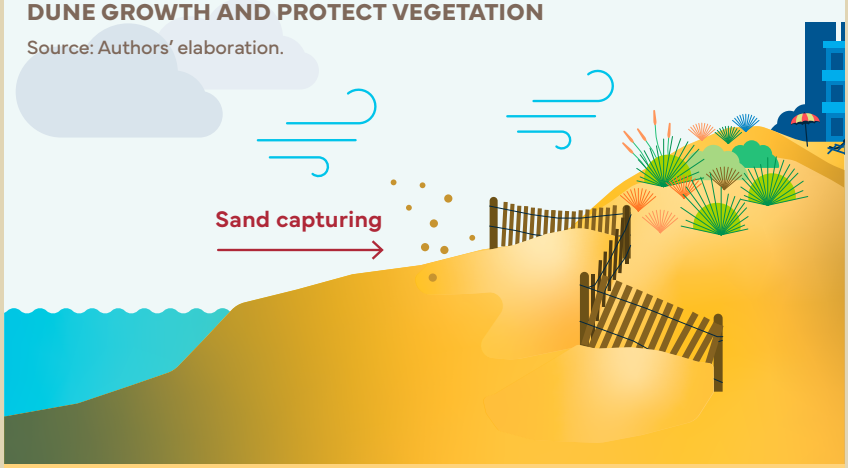
(See also: **Benefits of dunes**)

CAPEX

Overall, the main costs in dune restoration are typically associated with dune renourishment (if required) and revegetation or planting, while fencing itself is generally relatively low-cost (RISC-KIT 2017a; 2017b). Costs will vary significantly depending on location, project scale, fencing material, and whether professional labor is required, but sand fencing projects typically have relatively low design and permitting costs and low construction costs (CZM n.d.).

FIGURE 4.2.1. SAND FENCING CAN HELP ACCELERATE DUNE GROWTH AND PROTECT VEGETATION

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

Sand fencing promotes beach stabilization and reduces erosion risks by trapping and accumulating sand. This technique involves installing wooden (or synthetic fences) perpendicular to the prevailing wind direction, which reduces wind velocity and encourages sand deposition on the leeward side of the fence (Itzkin et al. 2020). As the wind-blown sand particles hit the fence, they lose momentum and settle, gradually building up the dune system. This accumulation of sand forms a physical barrier that protects inland areas from storm surges and high waves, thereby enhancing beach resilience. Sand fencing is particularly effective in promoting the growth of dune vegetation, which further stabilizes the accumulated sand through root systems, reducing the likelihood of erosion during severe weather events. This method has been widely studied and validated in coastal management literature as an efficient, cost-effective strategy for maintaining beach stability (Nordstrom 2021).

OPEX

Maintenance costs are expected to be low but may include repair or replacement after storm or human-induced damage. The lifespan of fences is proportional to its height relative to the speed of sand capture. Fences will gradually lose their trapping function once sand accumulates to about 80 percent of their height (Morris et al. 2021). Generally, new fences may need to be placed after three to five years (CZM n.d.).

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

Understanding prevailing wind speeds and directions is essential for optimizing design and minimizing costs. Sand fences should be placed well above the high-water mark to avoid damage and to capture dry sand (Tasmanian Government 2001). Materials such as chestnut palings, brushwood, or synthetic fabrics can be used, with a solid ratio of 30–50 percent (Morris et al. 2021) and an optimal height around 0.5 meters (Lima et al. 2017). Material choice depends on lifespan, maintenance commitment, and vandalism potential (RISK-KIT 2017). However, certain designs and materials, such as sturdy drift fencing and plastic fencing, can have additional impacts that need consideration. Another concern is ensuring the fencing is not placed too close to sensitive habitats, such as nesting areas for protected shorebird or turtle species.

PHOTO 4.2.1. SAND FENCING WITH GEOTEXTILE GRID AIMS TO CAPTURE WIND-BLOWN SAND TO PROMOTE DUNE GROWTH

Source: Authors' elaboration (AI-generated image).

BEACH SCRAPING

Beach scraping, sometimes referred to as nature-assisted beach enhancement, involves the mechanical transport of sand from the lower beach to the upper beach or dunes. As such, it mimics the natural recovery of the beach profile after storm erosion. In addition, it is meant to accelerate onshore sand transport by lowering the lower beach.

SUITABLE FOR

sandy beaches that have little to no natural vegetation, such as dune or beach plants, seaweed, or seagrass, provided it does not interfere with local wildlife such as shorebirds or turtles. Beach scraping should only be considered when urgent recovery or protection is needed.

BENEFITS FOR THE TOURISM SECTOR

Compared to many other measures, beach scraping is a low-cost method that will directly strengthen the upper beach and dune. It also allows the modification of the beach morphology, keeping the tourism function in mind—for example, by creating relatively flat areas that are more suitable for sunbathing, beach sports, or walking.

(See also: **Benefits of dunes**)

CAPEX

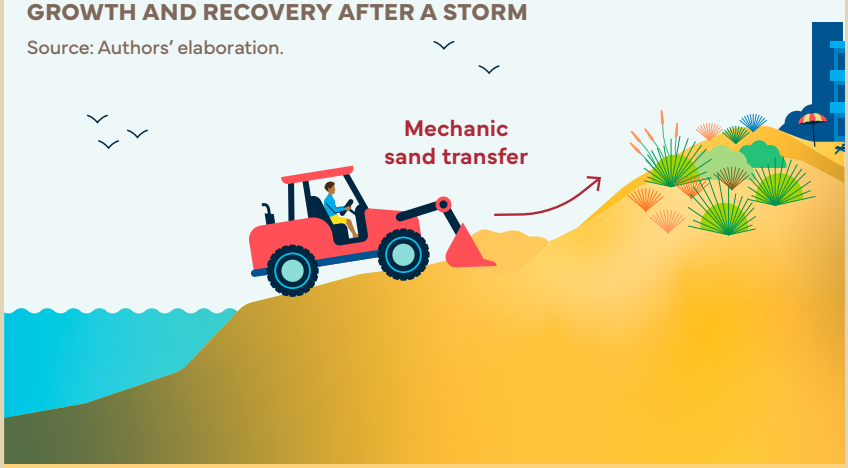
Reported costs for beach scraping in Australia are US$3–7 per cubic meter or ~US$85–170 per meter of shoreline (Gordon 2015) and generally consider the use of a bulldozer or front-end loader and labor. Based on reported costs for beach nourishment across a range of higher and lower income countries (World Bank 2021a), beach scraping costs are expected to fall within this range around the world although it can be more economical in lower-income countries due to reduced labor costs.

OPEX

Beach scraping is generally done as part of ongoing maintenance or in response to event-driven erosion (Carley et al. 2010). As such, a differentiation between CAPEX and OPEX does not apply.

FIGURE 4.3.1. BEACH SCRAPING CAN HELP ACCELERATE DUNE GROWTH AND RECOVERY AFTER A STORM

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

Beach scraping directly accelerates dune recovery after severe storms by transporting sand from the lower beach, which would normally occur over much longer timescales under influence of tide, waves and wind (Gordon 2015).

PHOTO 4.3.1. MECHANICAL BEACH SCRAPING IN PERTH, AUSTRALIA

Source: © Arnold van Rooijen. Used with permission. Further permission required for reuse.

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

It is essential to consider the seasonal dynamics of the beach and consider letting it recover naturally, if possible. If accelerated recovery is needed, it is important not to overdo beach scraping as it can lead to oversteepening of the beach, which could lead to higher rates of erosion (Carley et al. 2010).

The ecological impacts of incidental beach scraping are considered relatively small. The lower beach is a very dynamic area where organisms are frequently disturbed and generally capable of recovering quickly. The (accidental) removal of vegetation should be avoided as that may reduce the capacity to trap sand and bind the soil. Along beaches with turtle populations, it is essential to time these activities outside periods of the nesting period (Carley et al. 2010).

It is also important to consider the potential impact on recreational activities and tourism as the presence of machinery on the beach could pose considerable disturbances and safety risks.

BEACH PLOWING

Beach plowing is the mechanical creation of beach height variations between the low- and high-water mark. Beach plowing involves a tractor with a plow creating alongshore ridges on the beach. It has been shown to promote onshore transport of sand and can accelerate beach recovery after a storm event when performed repeatedly on several days.

SUITABLE FOR

sandy beaches that are highly urbanized or that can be accessed by machinery without damage, provided it does not interfere with local vegetation and wildlife such as shorebirds or turtles. Beach plowing should only be considered when urgent recovery or protection is needed.

BENEFITS FOR THE TOURISM SECTOR

Beach plowing aims to accelerate beach recovery in spring, creating the opportunity for a wide, sandy beach during peak tourism season—enhancing conditions for activities such as beach sports and sunbathing.

CAPEX

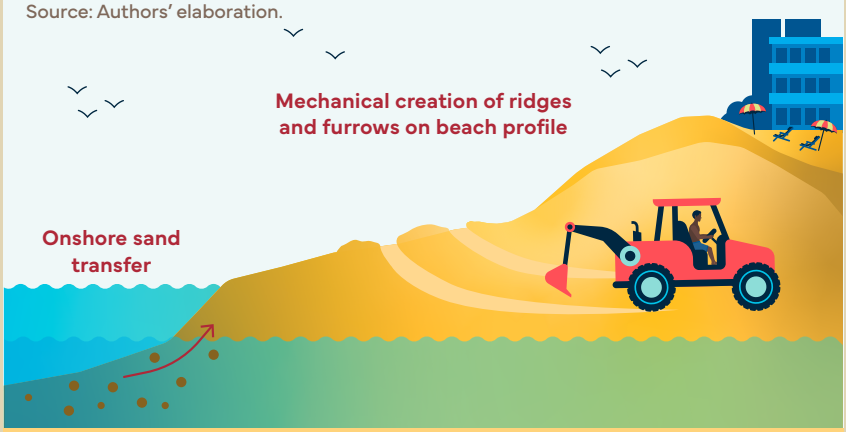
Costs for beach plowing have not been reported but are assumed to be similar to beach scraping (US$~85–170 per meter of shoreline) and may depend on geographical location due to local labor costs.

OPEX

Beach plowing is generally done as part of ongoing maintenance, or in response to event-driven erosion. As such, a differentiation between CAPEX and OPEX does not apply.

FIGURE 4.4.1. EXAMPLES OF LOWER- TO MID-BEACH STABILIZATION METHODS INCLUDE BEACH PLOWING

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

The process of beach plowing creates ridges and furrows along the beach (Gainza et al., 2019). It stimulates wave energy dissipation under low-energy conditions and promotes sand being transported in onshore direction. This will gradually widen the beach, and accelerate recovery after a storm event.

PHOTO 4.4.1. MECHANICAL PLOWING BEING PERFORMED AT LAIDA BEACH (SPAIN)

Source: Pellón et al. 2023.

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

It is essential to consider the seasonal dynamics of the beach and consider letting it recover naturally, if possible. The beach generally smoothens out relatively quickly (for example in a few hours), so the process may have to be repeated for several tidal cycles to get the outcome desired.

The ecological impacts of incidental beach plowing are considered relatively small. The lower beach is a very dynamic area where organisms are frequently disturbed and generally capable of recover quickly. The (accidental) removal of vegetation should be avoided as that may reduce the capacity to trap sand and bind the soil. Along beaches with turtle populations, it is essential to time these activities outside periods of the nesting period (Carley et al. 2010).

Engaging with local communities and other stakeholders is crucial to gain support, gather local knowledge, and address concerns about potential project impacts and benefits. It is also important to consider the potential impact on recreational activities and tourism as the presence of machinery on the beach could pose considerable safety risks.

SAND NOURISHMENT

Sand nourishment is a sediment management solution that has been widely applied around the world. It is the act of adding relatively large volumes from a remote source to the beach or the nearshore ocean (shoreface). See case studies 1 and 5.

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sandy beaches that are highly urbanized or that can be accessed by machinery without major damage, provided it does not interfere with plant, trees, seaweed, seagrass, or wildlife such as shorebirds or turtles. Sand nourishment should only be considered when urgent recovery or protection is needed and when there is access to a sustainable source of sand.

BENEFITS FOR THE TOURISM SECTOR

Sand nourishment directly leads to a wider beach that provides direct protection against flooding, landward erosion, and damage to coastal infrastructure (Hanley et al. 2014).

A wide sandy beach offers a great appeal to coastal tourists and provides increased opportunities for recreational activities such as walking, sunbathing, and beach sports (Orams 2003).

CAPEX

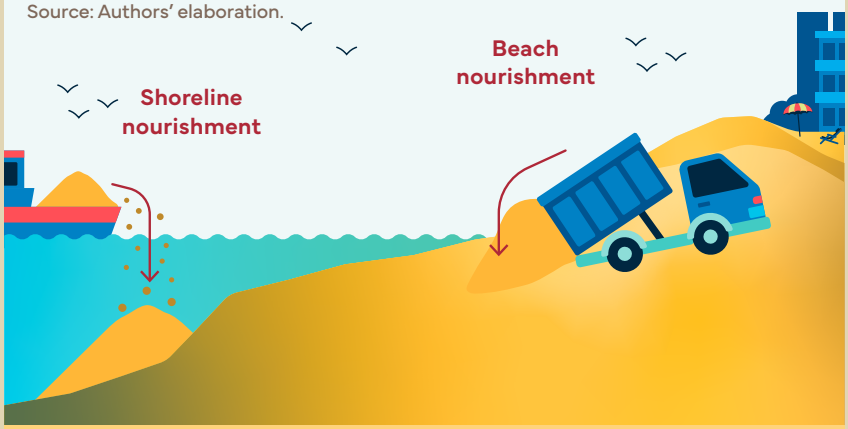
Costs vary based on geographical location, project scale, stabilization technique, and sand availability (World Bank 2021). Reported costs for beach nourishment are between US$5 and US$20 per cubic meter.

OPEX

Maintenance and monitoring costs vary widely across project scale, location, and the occurrence of extreme weather events, but would be similar per unit sand volume to capital costs.

FIGURE 4.5.1. BEACH AND SHOREFACE SAND NOURISHMENT

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

The sand for nourishment is usually obtained from deeper water through dredging or from a terrestrial site. The nourishment is placed on the beach, usually using dump trucks or pipelines, or in the nearshore (shoreface nourishment) using a dredge vessel or barge. The sand is then gradually transported along the shoreline under influence of wind, waves, and tides. Sometimes, a relatively large volume of sand (mega nourishment or sand motor) is placed along the coast with the aim to feed the adjacent stretches of shoreline over longer periods of time.

PHOTO 4.5.1. SAND NOURISHMENT IN PERTH (AUSTRALIA)

Source: © Arnold van Rooijen. Used with permission. Further permission required for reuse.

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

Sand nourishment can cause considerable disturbance to the environment, especially in the short term and in the direct vicinity of extraction and placement areas. The following drawbacks may occur (de Schipper et al. 2021):

- During both sand extraction and placement, sediment plumes can appear that can impact marine and terrestrial ecosystems such as dunes, coral reefs, and seagrass meadows.
- Recovery of the benthic ecosystems at the extraction and placement sites could take several months to years (Greene 2002).
- The potential impact on nearby marine ecosystems can have a negative effect on biodiversity and tourist activities such as snorkeling and diving. It can also affect the well-being and livelihood of local communities when fishing and harvesting practices are impacted.

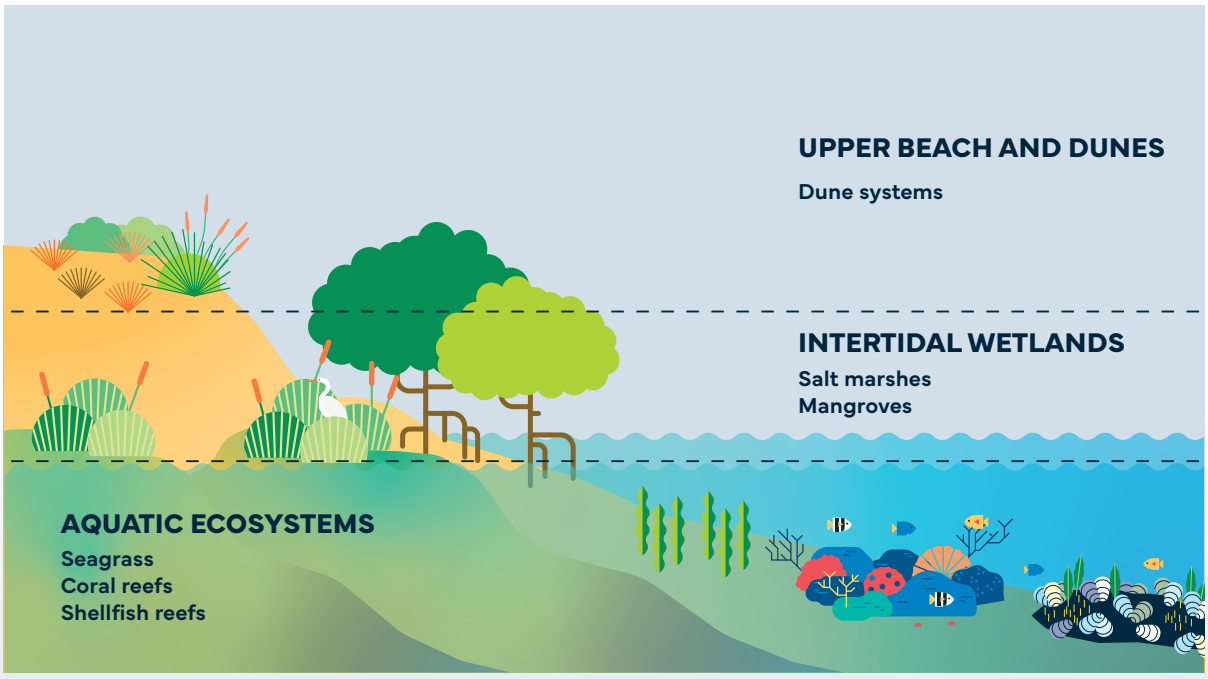
Mega nourishments aim to reduce long-term environmental impact by allowing for lower nourishment frequencies, offering longer periods without ecosystem disturbance. However, careful design is critical as the sand volume for a single nourishment is much larger, as is the potential impact on nearby ecosystems. Implementing larger scale sand nourishment projects requires careful planning and accounting of various factors to ensure success and effectiveness, such as local wave climate, sediment transport and erosion patterns, and native sediment properties.

4.2.
NATURE-BASED SOLUTIONS

Protecting or restoring coastal ecosystems can also be an effective solution to support the stabilization of sandy beaches, providing significant benefits to the tourism sector. Ecosystems such as dunes, mangrove forests, and salt marsh meadows are highly biodiverse and productive, forming a crucial interface between land and water. These ecosystems offer invaluable services, including protecting beaches and tourism assets from flooding and erosion. Additionally, reefs and seagrass meadows help stabilize lower-beach sediments, such as sand and stones, while also dissipating wave energy.

This section presents a catalogue of NBS for beach stabilization that have been proven effective in various contexts. The different measures are grouped into three typologies: beach and dunes ecosystems, intertidal wetlands, and aquatic submerged vegetation and reefs habitats (see figure 4.2). Each type can play a unique role in maintaining beach stability, whether by stabilizing sand directly or helping regulate erosion through other mechanisms.

FIGURE 4.2 NBS TYPOLOGIES DESCRIBED IN THIS REPORT LOCATED AT DIFFERENT SECTIONS OF A REPRESENTATIVE SANDY BEACH



Source: Authors' elaboration.

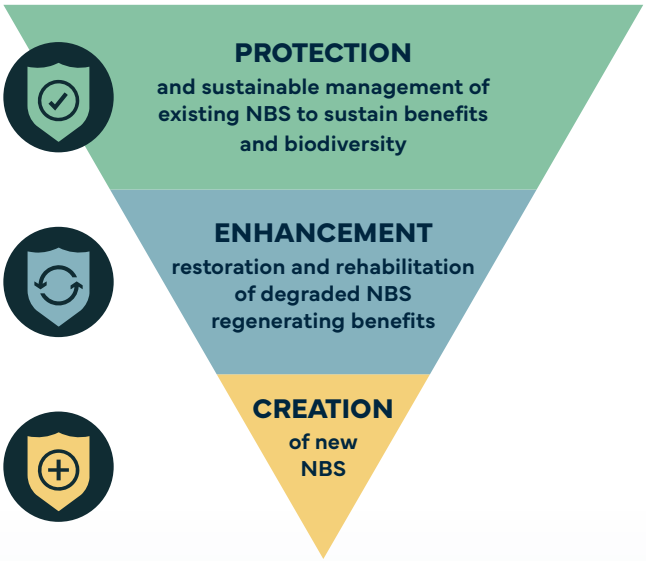
Note: In open, sandy beach environments, intertidal wetlands are typically not found directly on the beach but sometimes in nearby areas. Their presence, extent, and ecological characteristics can influence erosion patterns in adjacent sandy beaches.

INTEGRATING NBS FOR RESILIENCE AND BIODIVERSITY OUTCOMES

NBS encompass a variety of ecosystem-based approaches, including protection, sustainable management, restoration, and the creation of green infrastructure. These methods follow a hierarchical approach, prioritizing the protection of existing ecosystems as the first step, followed by enhanced management and rehabilitation of degraded areas, and, as a last resort, the creation of new interventions (figure 4.3). Protecting intact habitats is particularly crucial, as these areas already provide essential ecosystem services that are difficult to replace.

Achieving both resilience and biodiversity outcomes requires an integrated approach where NBS are purposefully planned, designed, monitored, and maintained to maximize environmental benefits. These interventions should not only provide shoreline stabilization but also restore ecosystem services that support coastal livelihoods. Restoration efforts, when needed, should prioritize native species and locally adapted ecosystems to help maintain ecological integrity, prevent invasive species risks, and enhance ecosystem resilience.

FIGURE 4.3 A HIERARCHY OF APPROACHES UNDER THE NBS UMBRELLA.

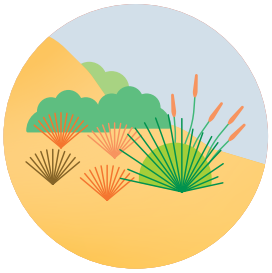


Source: Adapted from World Bank 2021a.

More intensive stabilization interventions may become necessary in cases where protection or natural recovery of the shoreline is not feasible due to significant human activity or environmental degradation. However, it is essential to recognize that no beach stabilization method can permanently eliminate erosion. These interventions should be implemented following thorough evaluation and in conjunction with comprehensive management practices to strike a balance between effectiveness, environmental stewardship, and economic feasibility. The level of protection will depend on site-specific conditions, project design, and the method used.

Additionally, regular maintenance is necessary to ensure long-term functionality and minimize any unintended consequences on adjacent ecosystems.

While NBS approaches are discussed individually in this report, they should not be seen as isolated interventions in the majority of the cases. To effectively address the complex and dynamic phenomenon of coastal erosion, it is often necessary to combine various measures at different spatial and time scales and simultaneously understand and address other external root causes.



UPPER BEACH AND DUNE ECOSYSTEMS

Beaches and dunes are key components of coastal systems, offering both coastal protection and opportunities for tourism. Dunes form when sand from the beach is carried inland by the wind and accumulates in the hinterland, where specialized vegetation can establish. These dunes, with their deep root systems, stabilize the shoreline by trapping sand and reducing the impact of wind and storm surges, which helps mitigate erosion.

Photo by Annie Spratt on Unsplash

UPPER BEACH AND DUNES

Dune rehabilitation or restoration involves the reestablishment and strengthening of sand dunes. Along many urban shorelines, dunes have lost considerable volume due to coastal developments. Sometimes, this is due to erosion caused by severe storms. An essential part of dune restoration and rehabilitation is the planting of native vegetation that can help capture wind-blown sand and strengthen the soil against erosive winds and waves. Planting can be done manually or automatically. See case study 3.

SUITABLE FOR

sites with sufficient space and not reached by daily high tides or minor storm waves. It is also important to try not to interfere with local wildlife. It can be used to build up existing dunes, create dunes at the base of banks, or form dunes in low-lying areas with blowing sand.

BENEFITS FOR THE TOURISM SECTOR

Dunes form a physical barrier against storm waves and surge, providing protection against flooding for the hinterland (Sigren et al. 2014). This function protects the infrastructure present in the hinterland, including hotels, restaurants, access roads, and other tourism-focused infrastructure.

A healthy and thriving dune system also offers opportunities for tourist activities, such as nature trails, bird and wildlife watching (Burger 1995), and sand boarding, provided these activities are organized in a sustainable manner. Overall, a well-maintained dune system can significantly enhance the beauty of the beach and the tourist experience (Pafi et al. 2020).

CAPEX

Reported costs for dune revegetation projects in higher income countries were in the range of US$10,000 per hectare (ha), which includes labor, vegetation, and sand (Aerts 2018). In Europe, planting vegetation on dunes was estimated to cost around US$15,000 per ha (Verburg et al. 2017).

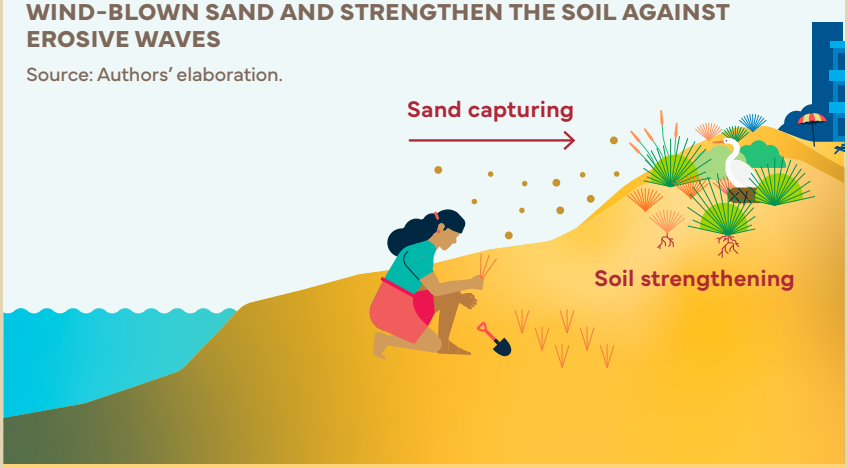
In many countries, the planting and weeding of the dune vegetation is done by volunteers, reducing the costs significantly.

OPEX

Maintenance and monitoring costs vary widely, depending on project scale, survival, and methods used, and can also be reduced considerably when using volunteer-based planting.

FIGURE 4.6.1. PLANTING DUNE VEGETATION CAN HELP CAPTURE WIND-BLOWN SAND AND STRENGTHEN THE SOIL AGAINST EROSIVE WAVES

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

Thriving dune systems have an essential function in beach stabilization by providing sand storage for the beach. During severe storms, erosive waves transport sand from the upper beach and dune into the nearshore ocean. This forms sandbars that cause the waves to break farther offshore (Ruessink et al. 2016).

A healthy cover of dune vegetation stimulates the post-storm dune growth by capturing wind-blown sand (Hesp 2004). It also slows down landward erosion by attenuating wave energy and strengthening the soil (Sigren et al. 2014).

PHOTO 4.6.1. COMMUNITY PLANTING OF NATIVE DUNE VEGETATION IN PHAN THIẾT, VIET NAM

Source: © Tuong Chopper from Pexels. Used with permission.

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

Implementing dune restoration projects, particularly along high-influx coastlines, requires careful consideration of several factors to ensure their success and effectiveness (Nordstrom 2021). First, understanding local coastal dynamics, such as wave energy, sediment transport patterns, and erosion rates, is essential for identifying suitable restoration sites and designs. Selecting appropriate native species, often a diverse range, is also crucial (Jamieson 2010).

Engaging with local communities and stakeholders is vital to gain support, gather local knowledge, and address concerns about project impacts, such as reduced access for people and vehicles (Nordstrom 2021). Additionally, considering the potential for recreational activities and tourism is important for integrating dune restoration with existing land uses and infrastructure while enhancing visitor experiences.

Incorporating climate change projections and sea-level rise scenarios into restoration planning ensures the resilience and long-term viability of restored dune systems against future coastal hazards. Reported dune restoration failures have generally been due to storm impacts or human activities, such as trampling (Muñoz-Vallés and Cambrollé 2014).

Photo by Immo Wegmann on Unsplash

INTERTIDAL WETLANDS

Intertidal wetlands, such as mangroves and salt marshes, play a crucial role in stabilizing adjacent sandy beach areas by acting as natural buffers. These ecosystems, though often not part of the beach itself, are typically located in nearby intertidal zones and provide indirect protection to sandy shorelines. Mangroves and salt marshes help reduce the impacts of coastal flooding and erosion by stabilizing sediments and dissipating wave energy before it reaches the beach. By creating this protective buffer, they mitigate erosion upstream and allow sandy beaches to maintain their natural form and function.

Beyond stabilizing sediments, mangroves and salt marshes offer a wide range of environmental benefits. These ecosystems act as natural sponges, absorbing excess water during floods and droughts, and sequestering significant amounts of carbon, making them vital tools in combating climate change. In many cultures, they also provide valuable resources, such as plants used for building materials and food. Moreover, their diverse habitats support a variety of species, including fish, birds, and other threatened wildlife, further enhancing biodiversity.

Many coastal regions, particularly those reliant on tourism, have recognized the value of these ecosystems and initiated efforts to restore and protect them. By maintaining healthy mangroves and salt marshes, coastal communities not only enhance their resilience to climate impacts but also safeguard the scenic and recreational assets that attract tourists.

Photo by Juan Manuel Núñez Méndez on Unsplash

SALT MARSHES

Salt marsh restoration or rehabilitation involves rebuilding and strengthening of salt marsh ecosystems that are damaged. Common causes for salt marsh degradation are changes to the hydrology and/or tidal dynamics, pollution, coastal developments, and introduction of nonnative or invasive species. Often, removing or adjusting man-made obstructions to freshwater and tidal flow is applied to allow flushing of excess nutrients and pollutants. Other methods include managed realignment (for example, converting farmland to salt marsh), control of invasive species, and revegetation using native species.

SUITABLE FOR

areas where salt marshes naturally exist, which are areas with brackish or salt water situated between the low-water and high-water marks with relatively low energy wave exposure and a temperate climate. While salt marshes themselves are normally not part of sandy beaches, they can play an indirect role in stabilizing coastal systems and creating healthier sediment systems for nearby beaches.

BENEFITS FOR THE TOURISM SECTOR

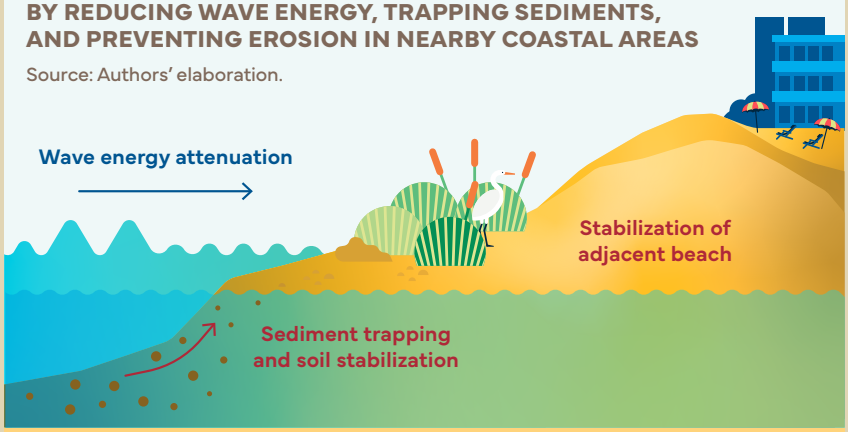
The natural flood protection and erosion control functions of salt marshes protect coastal infrastructure, such as hotels, restaurants, and recreational facilities, from storm damage and flooding. This protection reduces maintenance costs (Narayan et al. 2016) and minimizes disruption to the tourism industry.

Salt marshes enhance the aesthetic appeal of coastal areas, providing scenic landscapes that attract tourists interested in nature-based activities, such as bird watching, kayaking, and photography (Friess et al. 2020). These activities can boost local economies by increasing demand for guided tours, equipment rentals, and hospitality services.

Salt marshes also contribute to cleaner and safer beaches by filtering pollutants and trapping sediments, resulting in improved water quality (Vernberg 1993) and a more enjoyable recreational experience for beachgoers.

FIGURE 4.7.1. SALT MARSHES HELP STABILIZE SANDY BEACHES BY REDUCING WAVE ENERGY, TRAPPING SEDIMENTS, AND PREVENTING EROSION IN NEARBY COASTAL AREAS

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

The dense vegetation in salt marshes acts as a natural buffer against storms. It reduces the energy of incoming waves (Möller et al. 2014) and can reduce storm surge levels at the shoreline (Krauss et al. 2009).

The root systems of marsh plants stabilize the soil and sediments, reducing erosion and preventing the loss of coastal land (McKinley et al. 2018). The physical presence of the plants and accumulated organic matter helps bind the soil together, making it more resistant to erosive forces from waves and currents and having a positive effect on shoreline stabilization as measured by accretion, reduction in lateral erosion, and change in marsh surface elevation (Shepard et al. 2011).

Salt marshes trap and hold sediments transported by tidal waters. The sediment accumulation process contributes to the vertical growth of the marsh, allowing it to keep pace with sea-level rise (Kirwan et al. 2010).

CAPEX

The costs reported for completed salt marsh restoration projects varies significantly, with a median of US$67.00 per hectare (ha) and a standard deviation of US$1.8 million per ha (Bayraktarov et al. 2016). These numbers are based on 73 relatively small scale (< 1 ha) projects in higher-income countries, and costs per unit area are expected to be lower for larger-scale projects and in lower-income countries (Bayraktarov et al. 2016).

OPEX

Monitoring costs of salt marshes can be considerable. For example, on average, postconstruction monitoring accounted for 15 percent of the total project costs across 11 salt marsh restoration projects in New England (Louis Berger and Associates 1997). If the salt marsh is functioning well, maintenance costs are expected to be low.

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

Understanding local hydrology and tidal patterns is crucial for establishing and growing salt-tolerant vegetation. Salt marshes typically thrive in areas with salinity between 18 and 35 ppt (Odum 1988) and require current velocities below 1.2 meters per second to prevent edge erosion (van Loon-Steensma et al. 2012). Wave exposure should be minimal, as these habitats flourish in relatively sheltered areas. Strategically placing permeable structures, often made from brushwood, can temporarily shelter juvenile plants from waves and promote sedimentation (Hudson et al. 2021).

Selecting appropriate plant species and timing the planting to align with optimal growing conditions is essential. Restoration projects must also address potential pollution sources and manage runoff to maintain water quality. Navigating land ownership challenges, regulatory requirements, and obtaining necessary permits is often necessary, involving coordination with multiple stakeholders and government agencies.

Continuous monitoring and adaptive management are crucial to address unforeseen issues, such as invasive species or extreme weather events, ensuring the long-term success and sustainability of the restored salt marsh.

The success rate of salt marsh restoration is around 65 percent (Bayaktarov et al. 2016). Failures are often due to inadequate species selection, such as using nonnative species, high salinity or sedimentation, algal smothering, and animal activities like grazing.

PHOTO 4.7.1. SALT MARSH ADJACENT TO A SANDY BEACH

Source: © Emphyrio from Pixabay. Used with permission.

MANGROVES

Mangrove restoration and rehabilitation involves the regeneration of mangrove forests that have been damaged or destroyed for various reasons, including human developments, pollution, and tropical cyclones. The restoration process may include growing seedlings in greenhouses and transplantation to mudflats, or sometimes through direct seeding of the area.

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areas where mangroves naturally exist, which generally are tidal areas with brackish or salt water situated between the low-water and high-water marks with relatively low energy wave exposure and a (sub)tropical climate. While often not part of sandy beaches, mangroves can be located in nearby intertidal zones, offering protection to beaches by reducing wave energy and preventing erosion upstream.

BENEFITS FOR THE TOURISM SECTOR

The natural function of mangroves includes providing protection to coastal infrastructure, such as hotels, restaurants, and recreational facilities, from storm damage and flooding. A thriving mangrove forest leads to reduced maintenance and poststorm recovery costs. For example, based on an economic analysis of the damage caused by the 1999 Odesha Cyclone in India, the annual protection value per hectare (ha) mangrove was estimated to be more than twice the market price of the cleared mangrove forest land and nearly 20 times higher than the annual return from land (Das 2022). Another study estimated that if mangroves were lost, each year, 15 million people would be flooded (particularly in Viet Nam and India) and property damage would be US$65 billion globally (Menendez et al. 2020).

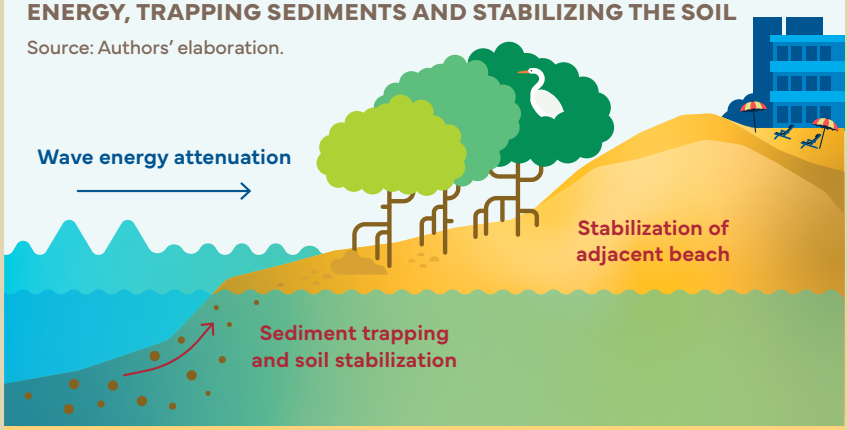
Mangroves provide many other co-benefits, including opportunities for tourist activities, such as nature exploring, hiking, canoeing or kayaking, stand-up paddling, and bird and wildlife viewing (Dushani Salpage, Aanesen, and Vondolia 2021). These activities increase demand for guided tours, equipment rentals, and hospitality services, thereby boosting local economies.

Mangroves can also improve water quality by filtering pollutants and absorbing nutrients from runoff that may otherwise cause algal blooms in the nearshore ocean (MacDonnell et al. 2017).

The increase in biodiversity can have a positive influence on the local fishing industry that provides fresh seafood to restaurants, which promotes culinary tourism (Horng and Tsai 2012).

FIGURE 4.2.6. MANGROVES CAN HELP ATTENUATING WAVE ENERGY, TRAPPING SEDIMENTS AND STABILIZING THE SOIL

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

As mangrove trees grow, they create complex root systems that can trap sediment and stabilize the soil, decreasing the potential for erosion (Karimi et al. 2022).

The mangrove root-trunk-canopy structure forms a resilient barrier to waves and currents, and the reduction of wave energy may be well over 50 percent depending on species, tree dimensions, forest density, and forest width (Hashim and Catherine 2013). The canopy of the trees also form an important barrier against storm winds. Apart from this cross-shore effect, in some locations, wetlands have the ability to influence alongshore sand transport, thereby acting as barriers stabilizing adjacent beaches (Broome et al. 1981).

Mangroves are considered to have broad capacity to adapt to relative sea level changes due to their ability to capture inorganic sediment as well as organic matter effectively, even in areas with land subsidence (Woodroffe et al. 2016).

CAPEX

Compared to other habitats, mangrove restoration projects have been relatively large-scale and low-cost. Out of 109 projects a median cost of 9,000 US$/ha and standard deviation of 63,000 US$/ha was reported (Bayraktarov et al., 2016). Out of those projects, 50 were in lower income countries with a median cost of 1,200 US$/ha and a standard deviation of 8,200 US$/ha.

OPEX

Maintenance cost can vary considerably, depending on restoration method, location and weather events. Overall, reported maintenance costs are relatively low such as 7.1 US$/ha in Vietnam (Marchand, 2008) and 143 US$/ha in Kenya (Kairo et al., 2009). In Indonesia, the total cost of replanting in the four years after construction is estimated to be around 10 percent of the cost for initial plantation (Hakim, 2016).

PHOTO 4.8.1. EXAMPLE OF A MANGROVE FOREST THAT MAY HAVE THE ABILITY TO STABILIZE THE ADJACENT BEACH BY REDUCING LONGSHORE SAND TRANSPORT (UNITED ARAB EMIRATES)

Source: Fletcher 2020. ©Emirates News Agency. Used with permission.

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

For successful mangrove restoration, understanding local hydrology and tidal dynamics is critical. Mangrove seedlings, less salt-resistant than mature trees, grow best in areas with salinity between 3 and 27 ppt (Krauss et al., 2008). They typically require daily tidal flooding for 7 to 13 hours (van Loon et al., 2007). Additionally, exposure to waves and strong currents should be minimized as these habitats thrive in relatively sheltered areas. Restoration projects often use permeable structures made from bamboo, brushwood, or other natural materials to provide temporary shelter, allowing seedlings to mature and promote sedimentation (Winterwerp et al., 2020).

Selecting appropriate species and timing the project to coincide with optimal growing conditions is essential. Restoration projects must also address potential pollution sources and manage runoff to maintain water quality. Land ownership challenges and regulatory compliance, including obtaining necessary permits and coordinating with multiple stakeholders and government agencies, must be managed. Continuous monitoring and adaptive management are crucial to address unforeseen issues such as invasive species or extreme weather events, ensuring the long-term success and sustainability of the restored mangrove forest.

The success rate of mangrove restoration is around 50 percent (Bayaktarov et al., 2016). Reported failures were due to inadequate site selection, such as areas lacking natural recruitment, damage by barnacles, filamentous algae, and sedimentation, and lack of community involvement resulting in damage by trampling.

AQUATIC SUBMERGED VEGETATION AND REEFS HABITATS

The restoration or rehabilitation of aquatic ecosystems, such as coral reefs, seagrass meadows, and shellfish reefs, offers support for stabilizing sandy beaches and providing significant benefits to the tourism sector. These ecosystems are critically important for shoreline stabilization and ecological balance, yet they face alarming rates of habitat loss. The global annual rate of habitat loss is estimated at 4–9 percent for coral reefs and 2–5 percent for seagrass meadows (Duarte et al. 2009). The complex services these ecosystems provide are irreplaceable, and constructing artificial alternatives is both costly and less effective.

These ecosystems contribute immensely to local economies, particularly in developing countries, by supporting small-scale commercial and informal economic activities. These activities, such as fishing are vital for the livelihoods of local populations. Additionally, aquatic ecosystems offer recreational opportunities and tourism attractions, which are crucial for economic development and community well-being.

Photo by The Tampa Bay Estuary Program on Unsplash

SEAGRASS

Seagrass restoration or rehabilitation aims to reestablish degraded seagrass meadows that have been damaged or destroyed due to a range of reasons, including pollution, dredging and overfishing. Restoration techniques include transplantation of seagrass seedlings, sprigs, shoots, or rhizomes, transplantation of aquaculture-grown seagrass, deployment of hessian jute bags filled with seeds, and transplanting seagrass cores or plugs.

SUITABLE FOR

sites where seagrasses occur naturally, such as shallow-water open ocean environments with species-dependent climate and environmental conditions.

BENEFITS FOR THE TOURISM SECTOR

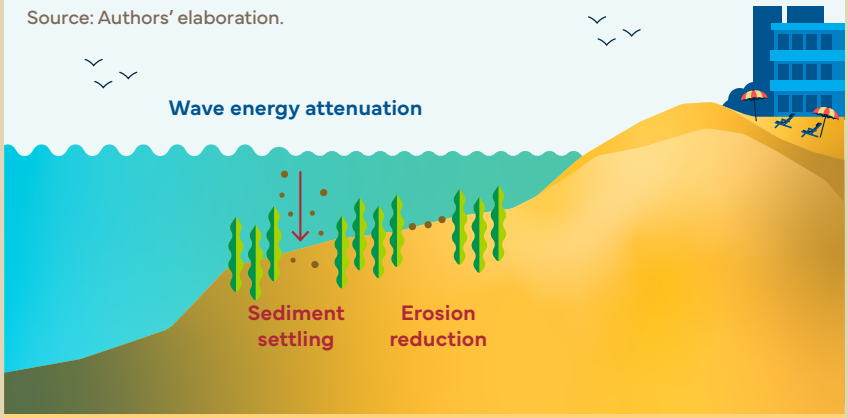
Depending on species, location, and environmental conditions, seagrass can significantly attenuate wave energy. Field observations show wave height reductions of up to 50 percent over approximately 1 km of seagrass meadow for both Posidonia oceanica (Infantes et al. 2012) and Zostera marina (Reidenbach and Thomas 2018).

While the coastal protection benefits of seagrass are not fully quantified, seagrass meadows span 160,000 to 267,000 km² across 136 countries (McKenzie et al. 2020). The reduction in beach erosion risk is significant in areas with large-scale meadows that diminish wave energy (Ondiviela et al. 2014). Seagrass species are found on every continent except Antarctica (Short et al. 2007), particularly in coastal ocean environments popular with tourists, such as sandy shorelines. Therefore, it is reasonable to conclude that seagrass meadows contribute to the stability of many tourist beaches.

Seagrass meadows also play a vital role in carbon storage and ocean water purification, and serve as nurseries for various species, including fish, crabs, lobsters, and squid (Mtwana Nordlund et al. 2016). They enhance biodiversity and support ocean-based tourist activities such as snorkeling, diving, and fishing (Zunino et al. 2020). Additionally, healthy seagrass ecosystems support local fisheries (Potouroglou et al. 2020), contributing to a more authentic tourist experience (Voyer et al. 2017).

FIGURE 4.8.1. SEAGRASS CAN ENHANCE BEACH STABILITY BY PROMOTING SAND CAPTURE AND REDUCING EROSION

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

Although seagrass is flexible and moves with ocean currents and waves, it plays an essential role in beach stabilization worldwide (Ondiviela et al. 2014). Seagrass stabilizes the seabed, which indirectly helps stabilize beaches (Christianen et al. 2013). By reducing ocean currents and wave-driven flows near the bottom, seagrass increases sedimentation and decreases the potential for erosion (Madsen et al. 2001). Additionally, the roots of seagrasses provide further stability to the soil, enhancing overall beach stability (Barbier et al. 2011).

CAPEX

The median cost based on 64 relatively small-scale (< 10 hectares [ha]) seagrass restoration projects in higher income countries was US$107,000 per ha (Bayraktarov et al. 2016). The restoration method used plays an important role, with examples of manual transplantation of seagrass cores or plugs costing US$30,000 per ha and mechanical transplantation costing US$120,000 per ha. Costs may be considerably less in lower-income countries (Bayraktarov et al. 2016), when the project scale is relatively large, and when planting is predominantly done by volunteers (Rogers et al. 2019).

OPEX

Monitoring and maintenance costs depend highly on the project scale, restoration method, location, and survival rate, and can be considerable. An evaluation of total costs reported for 22 restoration projects in higher-income countries suggests that total maintenance and monitoring costs may well exceed the initial restoration costs (Bayraktarov et al. 2016).

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

The effectiveness of seagrass in providing beach stability depends on local environmental conditions, the size and density of the meadow, and the species (Ondiviela et al. 2014). Seagrass is most effective in shallow water and low wave energy environments. Large, long-living, and slowly growing seagrass species have the greatest potential for stabilizing beaches.

Successful seagrass restoration requires understanding local environmental conditions and the causes of degradation (van Katwijk et al. 2009).

The restoration site should be carefully selected, preferably in areas with a history of seagrass presence. Donor populations must be chosen based on plant properties suited to surviving and thriving at the site in both the short and long terms. It is important to mitigate risks of loss due to storms and fluctuations in temperature or salinity (van Katwijk et al., 2009). Stabilizing methods, such as using mesh, wires, or staples (van Keulen 2003), or constructing shellfish reefs to provide shelter from currents or waves (Bos and van Katwijk 2007), can help establish seagrass.

Partnerships with local stakeholders, including indigenous communities (Tan et al. 2020), are essential. Compliance with regulatory requirements and obtaining relevant permits are necessary. Ongoing monitoring and management are crucial to maximize the project's success.

The success rate of seagrass restoration projects is around 38 percent (Bayaktarov et al. 2016). Common causes of failure include inadequate site selection, such as locations with high wave energy or sedimentation, stochastic events like severe storms, illegal trawling activity, and marine contamination or poor water quality.

PHOTO 4.8.1. MEMBERS OF THE FLORIDA OCEANOGRAPHIC SOCIETY PLANTING SEAGRASS IN FLORIDA

Source: © Kim Shiflett / NASA from Flickr.

CORAL REEFS

Coral reef rehabilitation or restoration involves the process of rehabilitating and rebuilding coral reefs that have been damaged or destroyed due to various reasons, such as marine heatwaves, pollution, overfishing or destructive fishing practices. It has been widely used globally, employing a range of techniques, including direct transplantation, larval enhancement, and coral gardening. Construction or stabilization of a substrate is sometimes required to promote coral settlement. See case study 2.

SUITABLE FOR

areas where coral reefs naturally occur, such as tropical, nutrient-limited coastal ocean areas with clear water.

BENEFITS FOR THE TOURISM SECTOR

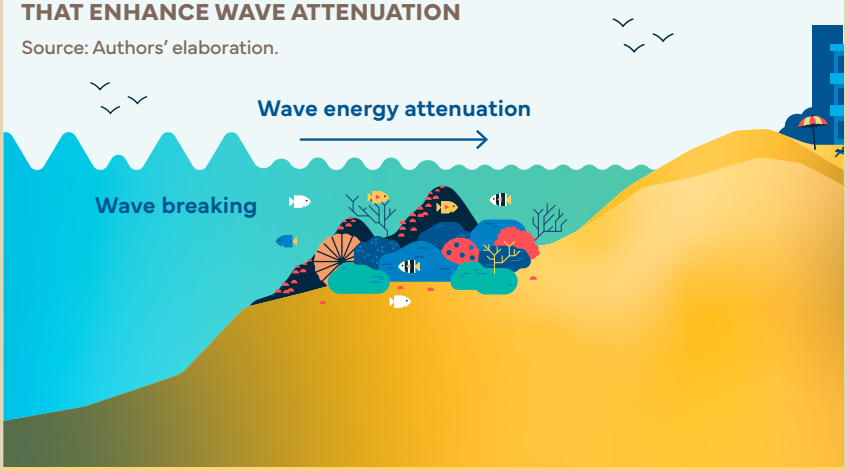
It is estimated that 30 percent of the world's coral reefs are of value to the tourism sector (a total of US$36 billion), equivalent to 9 percent of all coastal tourism value within coral reef countries (Spalding et al. 2017). Coral reefs are estimated to reduce annual expected damages from storms by over US$4 billion (Beck et al. 2018), which includes considerable coastal tourism infrastructure and key attractions, such as sandy beaches.

Along many coral reef coast tourist destinations, revenues from on-reef activities such as snorkeling, diving, and fishing are significant, but generally, indirect reef-adjacent tourism value is found to be much higher (Spalding et al. 2017). This includes indirect benefits of the presence of coral reefs at tourism destinations to nearby restaurants, shops, and accommodation.

Corals can also improve water quality and provide habitat for resident and transient species (Cesar 2002), which can further boost biodiversity and on-reef tourist activities, local fisheries, culinary tourism, and aquatic tourism (Horng and Tsai 2012).

FIGURE 4.9.1. CORALS CAN FORM CONSIDERABLE ROUGHNESS THAT ENHANCE WAVE ATTENUATION

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

Coral communities form rough structures that effectively dissipates wave energy, thereby protecting coastlines from flooding and erosion (Beck et al. 2018). The intricate formations of coral branches, ridges, and crevices break up and slow down incoming waves, reducing their height and force before they reach the shore, thereby reducing the potential for beach erosion. Over longer time periods, corals can form massive reef structures that grow vertically, thereby reducing the water depth and causing waves to break farther away from shore. Coral reefs are also important for sediment production, providing a primary sand source for many of the world's beaches (Perry and Alvarez-Filip 2018). Their effectiveness depends largely on the overall ecosystem health as well as physical properties of individual organisms (Harris et al. 2018). As such, degraded ecosystems tend to lose much of their coastal protection capacity (Reguero et al. 2018) and restoration efforts are now increasingly motivated by beach erosion issues (Brathwaite et al. 2022).

CAPEX

The costs for coral reef restoration show a large variation depending on the technique used (Bayaktarov et al. 2019). They tend to increase considerably if construction or stabilization of substrate (for example, using an artificial reef) is required (Ammar 2009). The median cost reported across 42 coral reef restoration projects is US$166,000 per hectare (ha) with a median of US$89,000 per ha for 24 projects in lower-income countries (Bayraktarov et al. 2016). The median cost for coral restoration using the coral gardening approach was US$28,000 per ha, while projects that required a substrate or artificial reef had a median cost of US$4 million per ha (Bayaktarov et al. 2019).

OPEX

Monitoring and maintenance costs highly depend on the project scale, restoration method, location, and survival rate, and are usually not reported. For a three-year maintenance and monitoring period, operational costs have been assumed to be about 15 percent of the total project costs (Edwards 2010).

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

Successful coral reef restoration begins with understanding the causes of reef degradation. Addressing these causes may sometimes be sufficient for natural recovery (Escovar-Fadul et al. 2022). However, if these issues are not resolved, restoration efforts are likely to fail. When the causes of degradation are managed, and natural recovery is unlikely, restoration becomes feasible. It is crucial to understand local environmental conditions, including ocean currents, wave patterns, salinity, and temperature, to select appropriate coral species and restoration methods (Shaver et al. 2020). In some cases, substrates may need stabilization or construction, such as using artificial reefs, to facilitate coral recruitment or planting (Hein et al. 2020).

The project may face challenges related to land ownership, involving both public and private lands. It must engage various stakeholders and government agencies, comply with regulatory requirements, and obtain necessary permits. Ongoing monitoring and management are essential to ensure project success.

The success rate of coral reef restoration projects is around 65 percent (Bayaktarov et al. 2016). Common causes of failure include inadequate site selection, such as areas with high sedimentation or strong currents, unsuitable substrates, and stochastic events, like extreme temperature fluctuations.

PHOTO 4.9.1. RESTORATION OF CORAL REEFS IN BELIZE AS PART OF THE MARINE CONSERVATION AND CLIMATE ADAPTATION PROJECT

Source: World Bank 2020.

SHELLFISH REEFS

Shellfish reef restoration or rehabilitation includes rebuilding damaged and lost oyster and mussel reefs. Common causes for degradation of these ecosystems are pollution and overharvesting. Restoration projects typically use juvenile shellfish from hatcheries or pond systems, or transport wild spat from high-recruitment areas to the restoration site. Construction or stabilization of a substrate is sometimes required to promote shellfish settlement. This is generally done using rocks or recycled shells.

SUITABLE FOR

areas where shellfish reefs naturally occur, generally areas with temperate climates and brackish to saltwater conditions and availability or opportunity for hard substrate for shells to settle on.

BENEFITS FOR THE TOURISM SECTOR

In addition to potential for beach stabilization, oyster and mussel reefs provide habitat for fish and other species and improve water quality through filtration. This leads to increased opportunities for recreational fishing and overall, more desirable environments for tourists to visit (Lipton 2004). Indirect benefits may include increased tourist spendings in local shops, accommodations, and restaurants (Schug et al. 2009). Thriving shellfish reef ecosystems can also support local fisheries opening opportunities for culinary tourism, while novel restoration projects may have potential for educational tourism opportunities (Rogers et al. 2018).

CAPEX

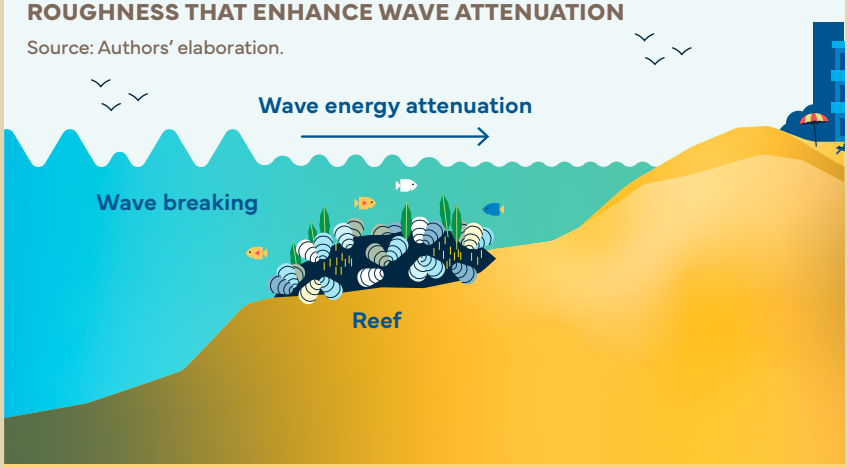
The median cost based on 23 relatively small-scale (< 1 hectare [ha]) oyster reef restoration projects in higher-income countries was US$67,000 per ha (Bayraktarov et al. 2016). Costs vary considerably based on restoration method, material used for substrate, and potential permitting and survey costs (Schug et al. 2009).

OPEX

Monitoring and maintenance costs highly depend on the project scale, restoration method, location, and survival rate. As an example, for a recent large-scale oyster restoration project in Australia, the annual monitoring and maintenance costs were estimated to be about 1 percent of the initial construction costs in the first two years, and less than half of that in the next eight years (Rogers et al. 2018).

FIGURE 4.10.1. SHELLFISH REEFS CAN FORM CONSIDERABLE ROUGHNESS THAT ENHANCE WAVE ATTENUATION

Source: Authors' elaboration.



BEACH STABILIZATION FUNCTION

Oysters and mussels tend to form rough structures that effectively dissipates wave energy, thereby protecting coastlines from flooding and erosion (Spalding et al. 2017). They can also build reefs that act as a natural breakwater causing high-energy waves to break farther from the shore. As considerable wave energy is dissipated offshore, there is less capacity for waves to stir up nearshore sediments, reducing the potential for beach erosion. The higher, wider, and more complex the reef, the more effective it is in reducing wave energy. Unfortunately, these ecosystems are under severe threat worldwide (Beck et al. 2011), and with that, their ability to provide beach stability.

PHOTO 4.10.1. VOLUNTEERS CARRYING OYSTER CAGES AS PART OF AN OYSTER REEF RESTORATION PROJECT

Source: © Agata Poniatowski.

IMPLEMENTATION CONSIDERATIONS AND CHALLENGES

Successful shellfish restoration requires understanding the local environment and determining whether the site is recruitment-limited (insufficient mature reproducing shellfish), substrate-limited (lack of suitable reef structure), or both (Westby et al. 2019). If the area is recruitment-limited, shellfish, often juveniles, may need to be sourced from hatcheries. It is crucial to use native species and appropriate substrate material (Westby et al. 2019).

Collaboration with local stakeholders is important, along with compliance with regulatory requirements and obtaining necessary permits. Ongoing monitoring and management are essential to maximize the project's success (Fitzsimons et al. 2020).

The success rate of oyster reef restoration projects is around 56 percent (Bayaktarov et al. 2016). Common causes of failure include inadequate site selection, such as sandy bottoms leading to burial of shells, and overgrowth or smothering by other species like tunicates, barnacles, or small mussels.

Photo by The Tampa Bay Estuary Program on Unsplash

5

PRACTICAL GUIDE TO BEACH MAINTENANCE WITH TOURISM SECTOR ENGAGEMENT

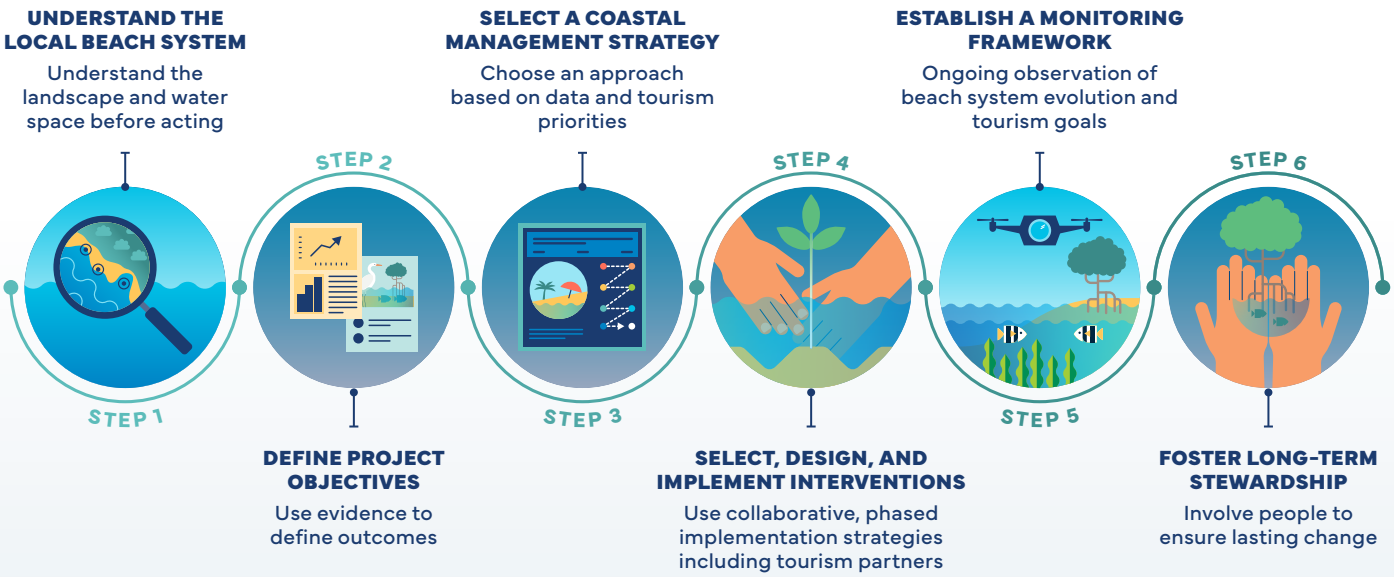
Photo by Jordan Beltran on Unsplash.

Coastal management encompasses a range of policy, governance, and engineering approaches aimed at regulating human activity along shorelines. The scale of intervention can vary, from large transboundary deltas to small, privately managed pocket beaches. In all cases, decision-makers are tasked with shaping what can or cannot occur in these spaces across different timescales, from immediate development needs to long-term planning for flooding, erosion, and climate adaptation. These decisions are often influenced by local governments, civil society leaders, private landowners, and community voices, including those of tourism businesses.

The tourism sector, comprising both large operators and small businesses, holds a legitimate and strategic role in shaping how coastal areas are used and protected. Their perceptions and priorities are essential to achieving sustainable, forward-looking beach management.

This chapter offers a quick, step-by-step framework for designing and implementing sustainable beach maintenance projects in tourism contexts (figure 5.1). Drawing on international best practices and coastal planning principles (see additional readings section at the end of this document), it emphasizes participatory processes, long-term resilience, and environmental stewardship, highlighting the critical role tourism operators can play in protecting the very ecosystems that sustain their livelihoods.

FIGURE 5.1 SIX STEPS FOR IMPLEMENTING BEACH MAINTENANCE PROJECTS WITH TOURISM SECTOR ENGAGEMENT



Source: Authors' elaboration.

STEP 1

UNDERSTAND THE LOCAL BEACH SYSTEM

The foundation of any beach maintenance project lies in understanding how the beach system functions and how it has changed over time. Developing a sound understanding of the local beach system is a critical first step to identifying and implementing appropriate NBS. This requires an integrated assessment of three main dimensions:

- **Drivers and coastal dynamics:** Analyze hydrodynamic and geomorphological processes, including wave and wind patterns, tidal regimes, currents, sediment transport, erosion trends and seasonality, bathymetry, and the history of extreme events, such as storms or flooding.
- **Habitats and ecosystems:** Conduct ecological assessments of coastal and marine habitats. Identify biodiversity features, habitat conditions, and potential sources of degradation, including pollution or water quality issues.
- **People and infrastructure:** Map existing infrastructure, land uses, and tourism activities that exert pressure on the beach system. Assess how human activity affects coastal dynamics and ecological health.

1.1 REVIEW EXISTING DATA AND HISTORICAL TRENDS

Before launching new studies, assess what data already exist. Historical trends offer crucial insights into how the coastline behaves and how it has responded to past pressures or interventions. A good start can be undertaken by reviewing existing data and information such as:

- Historical aerial photographs and satellite imagery (for example, from Landsat or Sentinel)
- Beach profiles and shoreline change data (if available)
- Tide gauge and wave buoy records and storm event reports
- Local reports from environmental agencies, universities, NGOs, or private tourism operators.

1.2 USE REMOTE SENSING AND GIS TOOLS

Utilizing satellite imagery and geographic information systems (GIS) help to track large-scale changes in coastal morphology and vegetation cover. Modern satellite and geospatial technologies provide efficient, low-cost methods for assessing beach conditions. These tools support tourism managers and local authorities in identifying where intervention or protection is needed.

Key methods include:

- Satellite imagery to track vegetation loss or changes in beach width
- Digital elevation models and photogrammetry to monitor beach topography and dune formation
- Drone surveys to create more detailed beach maps, highlighting areas prone to erosion or accretion
- GIS software to layer tourism infrastructure, habitat zones, and erosion risks.

1.3 IDENTIFY KEY ISSUES AND TRENDS

To clarify the complexity of the natural world, a series of analysis and studies are typically undertaken. An understanding of the environment may be developed by experts, such as marine scientists (oceanographers, meteorologists, ecologists, and botanists) and engineers(coastal, civil, and structural), as well as landscape architects and social economics specialists to develop appropriate community-based projects.

Typically, data visualizations and graphics are presented with the interpretation of those data and situational information in technical reports to:

- Pinpoint erosion and accretion hotspots;
- Identify vegetation loss or sensitive habitats and connectivity in ecosystems;
- Recognize tourism infrastructure and assets vulnerable to erosion and storm damage; and
- Highlight nature tourism opportunities.

1.4 CAPTURING THE DIVERSITY OF TOURISM INTERESTS EARLY ON

The coastal tourism sector encompasses a wide range of actors, from multinational resort chains to small, family-run hotels and local tour operators, each with distinct interests, capacities, and levels of influence. Understanding this diversity and engaging each group appropriately from the outset are essential to building lasting partnerships and designing interventions that are both technically sound and socially accepted.

Larger tourism groups may cofinance projects, pilot NBS, or help shape concession agreements that include sustainability clauses. Smaller operators may have more limited resources but can contribute effectively by participating in citizen science, sharing site-specific knowledge, or joining collective advocacy efforts.

Tourism associations can serve as valuable intermediaries between individual operators and public authorities and project managers. They are well placed to coordinate multiproperty actions, support strategic planning, promote cohesive messaging across the sector, and pool resources to fund larger-scale interventions. Under the leadership of these associations, public and private stakeholders can also collaborate through special purpose vehicles to finance and implement erosion control projects (CARICHAM 2024). This collective approach enables cost sharing and improves coordination across properties and jurisdictions.

Early and tailored engagement with tourism stakeholders can also help identify operational or legal constraints that might otherwise derail or delay projects. For instance, exclusive beach use rights held

by hotels may hinder access for public restoration efforts, while smaller operators might face difficulties navigating permitting or insurance requirements. Addressing these concerns at an early stage can reduce the risk of resistance and foster trust among stakeholders.

Moreover, tourism businesses are often long-term users of the coastal space and possess detailed, place-based knowledge of beach dynamics. Many operators have observed seasonal changes, erosion trends, or wildlife behavior for years, offering valuable insights that can enrich technical assessments. In some cases, hotels have contributed to scientific baselines or hosted mapping sessions with conservation NGOs (see box 3.4). However, this information should be interpreted with care, especially when business interests are closely tied to specific beach features.

BOX 5.1 UNDERSTANDING THE ECOLOGICAL CONTEXT AND MONITORING BIODIVERSITY

To maximize the effectiveness of nature-based solutions (NBS), it is essential to first understand the ecological context of the project area. Conducting an initial environmental screening helps identify key challenges, such as erosion, flooding, or water quality issues, while also assessing local biodiversity, stakeholder involvement, and regulatory frameworks. A strong biodiversity baseline study is crucial for selecting appropriate NBS interventions that provide both ecological and socioeconomic benefits. Innovations such as environmental DNA analysis are offering new, efficient methods for establishing biodiversity baselines.

There are also several free tools and databases available to help project developers assess the ecological context of their sites. The Global Biodiversity Information Facility and Map of Life provide access to global biodiversity data, while the Global Safety Net offers insights into ecological connectivity and carbon sink areas. The Integrated Biodiversity Assessment Tool compiles key datasets such as the International Union for Conservation of Nature Red List and World Database of Protected Areas to guide conservation planning.

Beyond initial assessments, biodiversity monitoring is critical for tracking the long-term impact of NBS interventions. Key indicators may include species richness, habitat restoration area, ecological connectivity, and ecosystem service improvements. Ensuring that NBS projects include clear biodiversity objectives, long-term management plans, and adaptive monitoring strategies will help sustain their climate resilience and ecological benefits well beyond the project's duration. Engaging local communities in monitoring efforts and leveraging new technologies can further enhance conservation outcomes while fostering long-term stewardship of natural assets.

Source: Jongman et al. 2022

STEP 2

DEFINE PROJECT OBJECTIVES

With baseline information in place, the next step is to analyze data and site assessments to define quantitative project objectives and the main reason of your initiatives. This stage supports the creation of adaptation pathways and identifies the priority zones for action. The emphasis here is on translating insights into realistic, measurable project goals.

2.1 USE DECISION-SUPPORT TOOLS

The interpretation of the analysis, modeling, and studies is a critical step in developing a successful concept for management and intervention design. Consulting firms specializing in beach management and coastal engineering are better placed to develop a holistic and integrated project efficiently. This involves bringing together the learnings from each discipline and supporting the decision-maker in choosing an appropriate conceptual path for planning over time. Whether leaning on management approaches, traditional engineering, or NBS, bringing all the results together and developing a plan for a coastal space can be overwhelming without experienced and capable support.

One option is to collate information and data under frameworks such as the Coastal Vulnerability Assessment (see box 5.2) or the relatively novel Natural Capital Assessment, which strives to value all natural features and their benefits to mankind annually as economic assets (Natural Capital Committee 2019; Vionnet and Blower 2021).

2.2 DEFINE TOURISM-ALIGNED OBJECTIVES

Engaging tourism businesses in setting project objectives is essential, particularly where beach conditions directly affect their operations. For instance, surf schools may oppose changes that disrupt wave patterns, while resorts may prioritize aesthetics or beach access. A participatory process ensures that diverse needs are reflected, increasing local support and project relevance. Objectives should align with regional tourism and climate adaptation plans, and reporting should connect clearly to local policy frameworks while incorporating input from both tourism stakeholders and the wider community.

BOX 5.2 COASTAL VULNERABILITY ASSESSMENT

A Coastal Vulnerability Assessment (CVA) is a systematic evaluation of the susceptibility of coastal areas to hazards such as erosion, flooding, sea-level rise, and storm impacts. This assessment involves analyzing physical, environmental, and socioeconomic factors to determine the potential risks and impacts on coastal regions. The purpose of a CVA is to inform coastal management and policy decisions, helping to prioritize areas for intervention and adaptation measures (Thieler and Hammer-Klose 2000).

Using CVA in combination with nature-based solutions is a strategic approach to enhancing coastal protection and resilience. This integrated approach ensures that interventions are data-driven, targeted, and capable of providing lasting benefits to both natural ecosystems and human communities. By addressing current vulnerabilities and building resilience against future risks, this combination supports sustainable coastal management in the face of growing environmental challenges.

The Coastal Vulnerability Index (CVI) is one of the simplest and most widely used methods to assess coastal vulnerability to sea-level rise, particularly caused by erosion and/or inundation (Gornitz et al. 1991). More information on how to use CVI can be found in the technical report produced by Ramieri et al. 2011.

Photo by Matthew Jungling on Unsplash

STEP 3

SELECT A COASTAL MANAGEMENT STRATEGY

This section guides teams in selecting a coastal management strategy that fits local environmental conditions, resource availability, and tourism development goals. It outlines key adaptation options and encourages the use of zoning tools to help balance tourism, conservation, and infrastructure needs across coastal and marine areas.

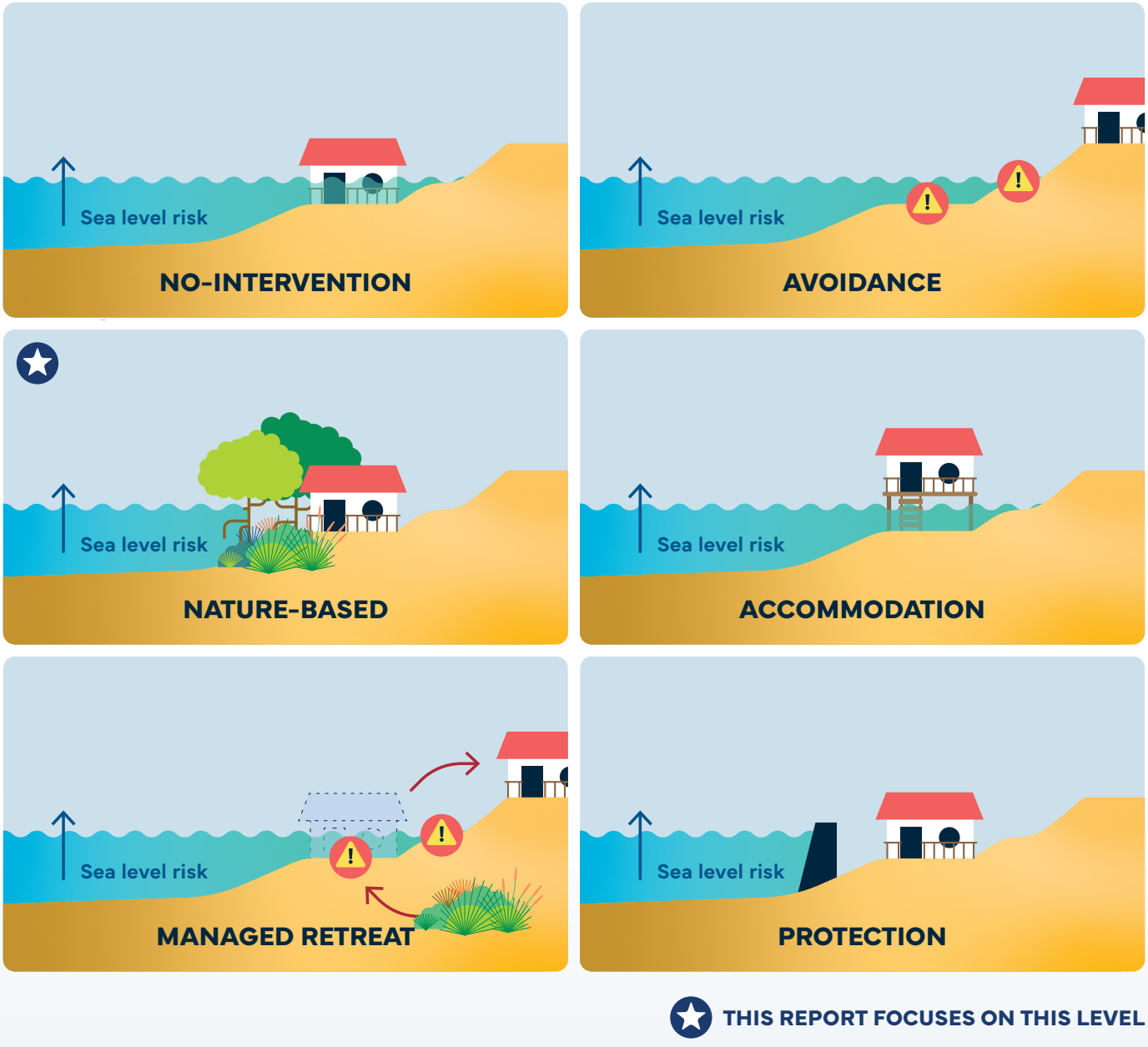
3.1 ADAPTATION OPTIONS

As climate change exacerbates the vulnerability of coastal areas, it is essential to adopt effective approaches to protect assets, communities, and natural habitats. There are six main approaches to managing coastal risk, often used in combination (figure 5.1):

- **No intervention:** This strategy involves allowing the beach to erode and the shoreline to reach a new equilibrium. It is suitable for areas with minimal coastal infrastructure, typically along regional or nonurban shorelines. This approach may be chosen when intervention would be environmentally damaging or economically unfeasible.
- **Avoidance:** This approach focuses on preventing development in high-risk areas. It includes selecting land uses and designing developments to enhance resilience against climate risks. Avoidance may involve altering development plans to ensure they are safe and sustainable over the long term.
- **Nature-based methods:** As discussed throughout this document, this approach enhances or restores natural features to reduce coastal hazard risks. These methods can help stabilize shorelines while also restoring biodiversity and improving the resilience of coastal environments.
- **Accommodation:** Accommodation strategies involve building infrastructure that can be easily dismantled or relocated, thereby managing risks without permanent structures. This approach can buy time and flexibility, allowing for adaptive responses as conditions change.
- **Retreat:** This strategy entails decommissioning existing assets and relocating them to safer areas. It includes implementing setback policies and establishing no-building zones to enable natural ecosystems, such as dunes and salt marshes, to migrate landward in response to sea level rise.
- **Protection:** This strategy involves building or reinforcing physical barriers to mitigate coastal hazards like sea-level rise and storm surges. Protection measures can be categorized as hard engineering, which includes rigid structures like seawalls or groins, or soft engineering, which relies on more adaptive and natural approaches.

Despite the challenges associated with each approach, there will inevitably come a time in many areas where either retreat or protection strategies become the most viable or effective options. The appropriate timing for implementing these measures will vary depending on the unique characteristics and conditions of each coastal zone.

FIGURE 5.1 MANAGEMENT STRATEGIES AS RESPONSES TO SEA-LEVEL RISE



Source: Authors' elaboration.

3.2 USE SPATIAL ZONING

Management strategies can be considered as either a first stop and single approach to protecting a coastline, or when a stabilization solution is required, then management strategies should be implemented in combination.

- **Integrated Coastal Zone Management (ICZM)** is an approach that aims to balance the sustainable use and conservation of coastal resources by considering social, economic, and environmental factors in decision-making processes along coastal areas (UNEP 1995; UNEP, MAP, and PAP 2015; EU Commission 2012).
- **Marine Spatial Planning** is a strategic approach to managing human activities in marine environments while preserving ecosystem health and integrity. By identifying areas suitable for specific uses, such as recreational tourist activities, it helps to balance economic development with environmental conservation, reducing the risk of ecosystem degradation and potential beach erosion[2] (Ehler and Douvere 2009).

These strategies lean on the concept of splitting marine and coastal space into "zones" or areas where people or activities may occur or are restricted, a critical component especially relevant for the tourism sector. A management zone can be designated for specific activities and amenity benefits, such as beach sports, sunbathing, swimming and snorkeling, and alternatively, shipping or fishing activities. Other zones might preclude, control, or ban activities detrimental to wider interests; for example, national parks, no-take zones, sanctuaries, and marine protected areas. This approach helps to manage and protect coastal resources by allocating spaces for specific uses, thereby minimizing conflicts and environmental impacts.

An essential aspect of zones is restricting access to sensitive areas, such as dunes or coral reefs, to prevent damage to the flora and fauna that work to stabilize these features. Avoiding crowding, overuse, and damage to sensitive habitats is the main goal. Implementing no-go, no-vehicle, and no-access zones can help maintain dune stability and reduce erosion. Keeping water users aways from sensitive reefs and seagrass helps prevent accidental damage through incidental and thoughtless actions, including dropping anchors, trampling, or kicking. These are typically combined with designated walkways and paths for access. The creation of coastal adaptation zones may provide space for natural processes to occur, concepts such as making space for water, sand, or nature to thrive away from detrimental impact of human interaction.

2 See https://maritime-spatial-planning.ec.europa.eu/.

STEP 4

SELECT, DESIGN AND IMPLEMENT INTERVENTIONS

This step outlines options ranging from low-cost, tourism-friendly measures to larger, hybrid infrastructure projects. It encourages a codesign approach, particularly with tourism stakeholders, and alignment with seasonal operations, ensuring that beach maintenance actions are both ecologically sound and compatible with guest experiences. Effective implementation requires careful planning that considers performance, costs, stakeholder roles, timelines, and long-term viability.

4.1 IDENTIFY FEASIBLE AND DESIRABLE OPTIONS

The selection process must account for technical feasibility, economic viability, and stakeholder preferences. Begin by reviewing existing development plans, coastal management frameworks, and regional policies. Understanding the local governance context helps determine whether state-led initiatives, community-driven projects, or public-private partnerships are most suitable.

Next, explore green or hybrid options with similar performance as conventional options that could address erosion and how they align with tourism preferences (for example, beach aesthetics, safety, access, and biodiversity). Use insights from earlier risk and ecosystem assessments to develop a shortlist of technically sound solutions. Where possible, draw from existing projects to estimate costs, understand ecosystem stability, and identify potential implementation constraints.

Engage tourism stakeholders in structured consultations to assess potential interventions. This process, facilitated by chambers of commerce, tourism boards, or local councils, can help align goals and reduce conflicts, ultimately leading to more inclusive and realistic project designs.

4.2 EVALUATE ALTERNATIVES USING COST-BENEFIT ANALYSIS

Once options are identified, assess their effectiveness and cost-efficiency. Compare construction and maintenance costs with the full range of projected benefits (avoided damages, increased tourism revenue, biodiversity gains, and other ecosystem services). Where possible, quantify benefits economically; for nonmonetizable benefits, provide clear qualitative justifications. Evaluate trade-offs and document any negative externalities.

NBS often deliver multiple co-benefits beyond erosion control, including job creation, biodiversity conservation, recreation, and improved public health. These should be factored into decision-making, alongside tourism-specific considerations.

Tourism actors can provide valuable data for estimating the benefits generated by each alternative, such as occupancy rates, damage costs from past storms, or beach user satisfaction surveys. This can help quantify benefits in economic terms and strengthen cost-benefit analysis.

4.3 DEVELOP AN INVESTMENT PLAN

Prepare a comprehensive implementation and investment plan. Assign roles and responsibilities across relevant stakeholders, including local governments, private sector, and civil society groups. Set realistic timelines and confirm alignment with tourism operational cycles.

Develop a draft engineering design and feasibility study covering materials, labor, and site conditions. Include a clear maintenance plan to ensure long-term effectiveness, especially for living systems like dunes or vegetated buffers. Coordinate ongoing maintenance and monitoring with local tourism operations where possible, recognizing their vested interest in the beach's long-term resilience.

Early-stage baseline monitoring and a defined evaluation framework are critical to track success and allow adaptive management.

4.4 IMPLEMENT THE PROJECT:

Implementation should be carried out in close coordination with all stakeholders, ensuring compliance with environmental and social standards while minimizing disruptions to tourism operations. Adopting a phased implementation approach can offer significant advantages, particularly in terms of financing, allowing for piloting of interventions, and reducing interruptions caused by construction activities. This approach is especially valuable when dealing with solutions that carry a high degree of uncertainty, whether related to performance, environmental interactions, or unforeseen impacts. A strong focus on transparency, continuous communication, and adaptive learning throughout each phase will enhance project ownership, support effective delivery, and lay the groundwork for successful scaling and long-term sustainability.

BOX 5.3 SIMPLE STEPS FOR IMPROVED BEACH MANAGEMENT: WHAT CAN THE TOURISM SECTOR DO?

Tourism businesses, especially those along coastlines, are well-positioned to support sustainable coastal management without the need for costly or large-scale protection interventions (see chapter 4 and case studies for beach interventions to mitigate erosion). By integrating small, low-cost measures into daily operations, businesses can contribute to the protection and restoration of vital coastal ecosystems, while enhancing the quality of their guest experience.

These small but impactful actions include:

- **Construct walkways and bridges:** Create paths, walkways, or small bridges to protect sensitive dunes, stream banks, or newly restored areas from trampling, while still allowing beach access.
- **Revegetate key areas:** Plant native vegetation on dunes or along ridges to strengthen their capacity to hold sand in place and reduce erosion. Removing invasive species that compete with native plants can also boost dune health.
- **Install shelters for wildlife:** Provide insect hotels or small shelters to protect beach-dwelling critters and support the local ecosystem's biodiversity.
- **Protect nesting areas** for characteristic birds, potentially enabling bird-watching activities.
- **Pollution reduction:** Install well-marked trash cans, recycling bins, and waste disposal stations with good signage to reduce littering on the beach and nearby areas. Improve wastewater storage, filtration, and treatment thereby reducing the impact of suspended solids and debris on habitats.
- **Permeable paths:** Reduces runoff and improves infiltration to replenish groundwater or aquifers as natural water storage.
- **Eco-sensitive lighting:** Minimizes impact on sea turtles and nocturnal species.

Photo by Matthew Jungling on Unsplash

STEP 5

ESTABLISH A MONITORING FRAMEWORK

Monitoring is crucial to track beach conditions, measure the impacts of interventions, and support adaptive management. Practitioners should aim at creating low-cost, locally appropriate monitoring programs, often leveraging partnerships with tourism staff and citizen science. The framework should be simple, scalable, and integrated with both management cycles and tourism operations.

5.1 DEFINE MONITORING OBJECTIVES

First, it is essential to establish clear monitoring objectives that should be tailored to the tourism sector and wider coastal community priorities, such as:

- Maintain usable beach width during peak tourist seasons
- Improve biodiversity indicators near resorts
- Track dune stability to protect tourism infrastructure from flood risk
- Preserve or improve ease of access to beach and/or viewing platforms
- Lessen erosion or accretion issues and impacts.

These can be derived from discussions with stakeholders and the community during the early scoping phase of the project investigation (steps 1 and 2).

5.2 CHOOSE MONITORING METHODS

Next, given your budget, human resource and time availability, select the approaches to monitoring that are best suited to your project. The capacity of staff and the wider community should be considered alongside paid experts and/or researchers. Relatively inexpensive approaches might include:

- Time-lapse photography from resort viewpoints
- Community-based beach surveys
- Periodic drone flyovers
- Water quality testing for recreational safety
- Citizen science apps (for example, Coast Snap Citizen Science Application).

Focused coastal monitoring efforts will provide in-depth information to studies and models in order to understand system function and behavior under certain stresses; however, these are more involved and

will likely require paid consultants. The following list is provided as an example of the data and information that could be collected by a more involved study and likely required to inform projects with heavier construction initiatives:

- **Hydrodynamic processes:** Assess changes in wave patterns, tidal or wave induced flows, and sediment transport to understand how the NBS influences coastal dynamics.
- **Ecological systems and habitat health:** Track the health and growth of the restored ecosystems, such as vegetative cover, species diversity, and habitat quality.
- **Geomorphological change and development:** Observe changes in coastline shape and sediment deposition to evaluate the physical stability provided by the NBS.
- **Water quality and pollution issues:** Monitor parameters such as salinity, turbidity, and nutrient levels to ensure the aquatic environment remains healthy.
- **Community opinion and perception:** Involve local communities through consultations and community engagement exercise in monitoring efforts to foster stewardship and gather valuable local knowledge.

5.3 ENGAGE THE TOURISM SECTOR

Tourism businesses can play an instrumental role in supporting long-term beach monitoring efforts, helping to generate the data and engagement needed for effective coastal risk reduction.

- **Support citizen science:** Encourage guests and staff to use mobile apps that track shoreline changes or log wildlife sightings. These initiatives raise awareness while supplying valuable data for public agencies and researchers.
- **Collaborate with researchers:** Partner with universities or environmental organizations to host monitoring stations or share beach access for studies on sediment movement, dune health, or wave dynamics.
- **Appoint coastal champions:** Designate staff or local volunteers to lead sustainability actions, from beach clean-ups to community education, boosting a sense of ownership and visibility for conservation efforts.
- **Foster community participation:** Work with local residents to support small-scale monitoring and restoration activities. Involving the broader community builds trust and reinforces the social foundation for long-term stewardship.
- **Provide access or funding for monitoring tools:** Businesses can offer basic infrastructure or contribute to scientific baselines through cofinancing, especially in data-poor areas.

You should develop a monitoring strategy and schedule that aligns with both tourism operations and natural cycles, such as conducting preseason and postseason checks, post-storm surveys, and updates during peak visitor periods. Coordinating these efforts with tourism activity not only enhances operational feasibility but also increases the likelihood of active participation.

5.4 REVIEW, EVALUATE, AND ACT

Regularly reviewing and evaluating beach erosion interventions allows project teams to understand what is working, what is not, and why. This process should focus not only on technical performance, such as risk reduction effectiveness, but also on broader community and environmental impacts. Monitoring results must inform timely maintenance actions and, when necessary, adjustments in project design or implementation, ensuring that interventions remain functional and aligned with long-term resilience goals.

Photo by Molly the Cat on Unsplash

STEP 6

FOSTER LONG-TERM STEWARDSHIP

Sustainable beach management does not end with the implementation of erosion control measures. It demands ongoing care, monitoring, and adaptive management. As environmental conditions evolve, interventions must be maintained, adjusted, and reevaluated over time. Long-term stewardship is essential to ensure that NBS remain effective and that the benefits for both ecosystems and tourism endure.

Just as a well-maintained garden requires regular pruning, planting, and weeding, beach ecosystems need consistent attention, from monthly maintenance activities to seasonal tasks and annual reviews. Encouraging others to participate in this stewardship journey, whether hotel guests and staff, local communities, or other businesses, can help sustain momentum and generate new resources through volunteerism, advocacy, and fundraising.

6.1 BUILD OWNERSHIP AND VISIBILITY

Many tourism operators are natural communicators and are uniquely positioned to champion coastal stewardship. Resorts and tour companies can transform their properties into demonstration sites, inspiring guests and setting benchmarks for the industry. By educating visitors about local ecosystems through signage, events, or interactive exhibits, they can deepen guests' connection to the destination and foster more sustainable behavior. Public-facing commitments to sustainability, eco-certifications, and participation in green tourism awards further enhance reputation while reinforcing environmental values (see boxes 3.2 and 3.4).

6.2 MAINTAIN FEEDBACK AND FUNDING CHANNELS

Effective stewardship requires continuous monitoring and a structured feedback system to track progress, share results, and guide adaptive management. Tourism businesses can contribute to and benefit from this process in several ways:

- Share progress and lessons learned through newsletters, physical signs, social media updates, and/or technical reports. These communication tools help maintain transparency, engage guests, and encourage community participation.
- Use performance data to secure new funding. Documenting both successes and setbacks is essential to attract continued support from donors, governments, and private investors. Demonstrating adaptive learning, where challenges are addressed and improvements made, builds confidence in the intervention.

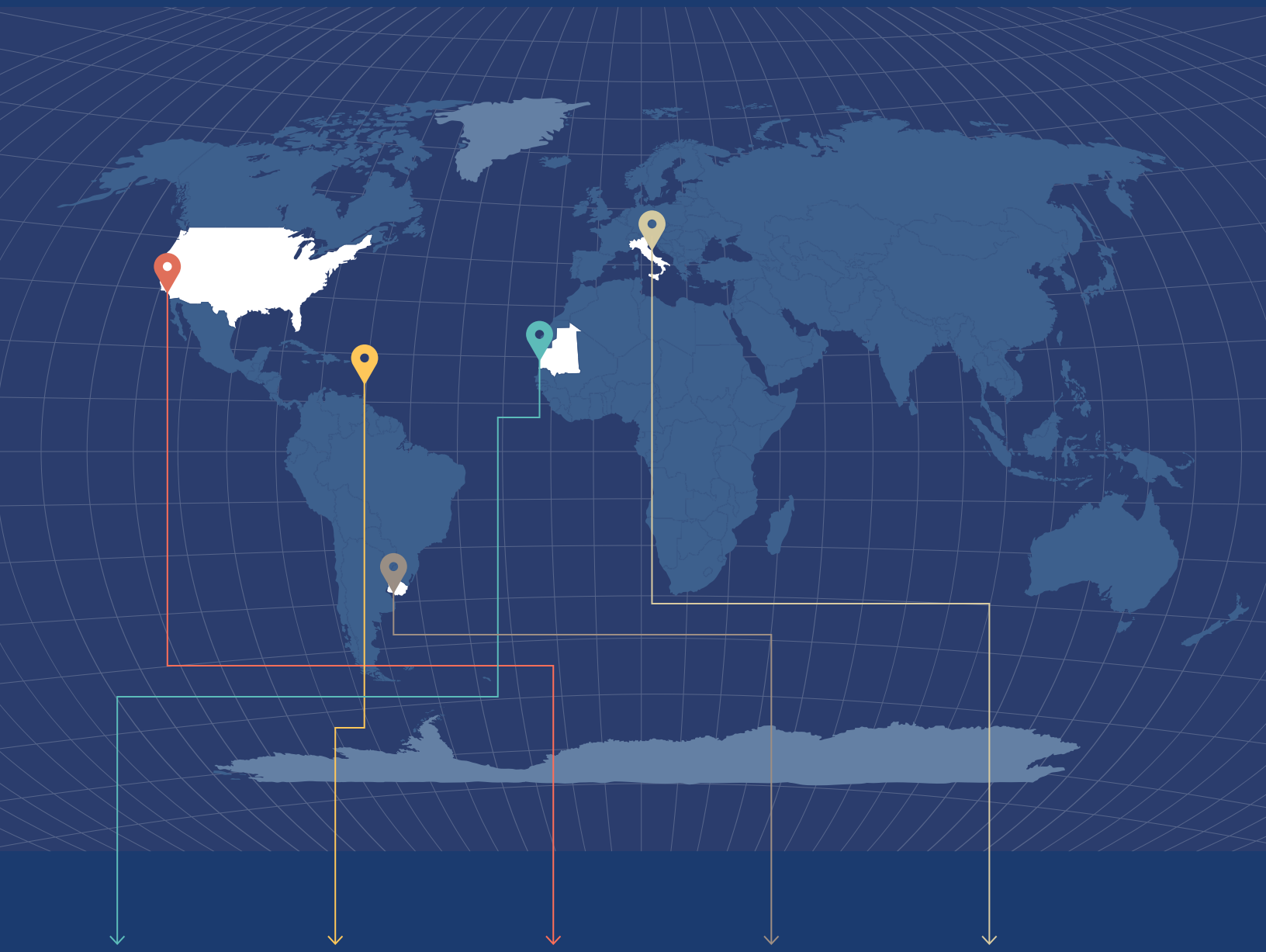
- Foster peer-to-peer exchange by connecting with other tourism operators, NGOs, and coastal managers working on similar projects. Regional or international networks can provide valuable insights and technical advice, especially during moments of uncertainty or change.
- Participating in national or local tourism awards or certification programs can elevate visibility, celebrate achievements, and motivate ongoing commitment among staff, partners, and stakeholders.

Photo by Juliana Castaño-Isaza

6

CASE STUDIES

Photo by Sonny Mauricio on Unsplash



CASE STUDY
1

STABILIZING NOUAKCHOTT'S DUNE BELT AND STRENGTHEN ITS DEFENSIVE ROLE

Nouakchott, Mauritania

CASE STUDY
2

PILOTING AN ARTIFICIAL CORAL REEF IN GRENADA

Grenville Bay, Grenada

CASE STUDY
3

PASSIVE DUNE RESTORATION IN AN URBAN BEACH

Santa Monica Beach, California, USA

CASE STUDY
4

REGENERATION OF SAND DUNES AND CAPACITY BUILDING STRATEGY ON THE URUGUAYAN COAST

Kiyú, Uruguay (Uruguayan coast of the Rio de la Plata River estuary)

CASE STUDY
5

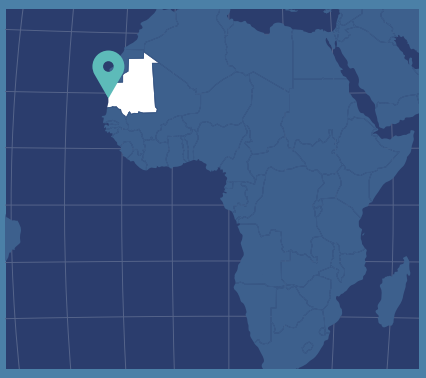
INTEGRATED COASTAL ZONE MANAGEMENT IN THE MARCHE REGION

Marche region, Italy

CASE STUDY

1

STABILIZING NOUAKCHOTT'S DUNE BELT AND STRENGTHEN ITS DEFENSIVE ROLE



LOCATION

Nouakchott, Mauritania

DATES AND STATUS

2018–present

MAIN IMPLEMENTING ORGANIZATION

Ministry of Environment and Sustainable Development through a dedicated project unit. The project will boost regional cooperation by also working with the West African Economic and Monetary Union, the Abidjan Convention, the Dakar-based Center for Ecological Monitoring, and the International Union for Conservation of Nature.

FUNDING SOURCE

Public national budget and West Africa Coastal Areas Program (WACA) of the World Bank.

PROBLEM:

Nouakchott, the capital of Mauritania, is largely below sea level and protected from the Atlantic Ocean by a fragile belt of coastal dunes. These natural defenses are increasingly threatened by erosion, sand mining, unregulated grazing, and recreational misuse, such as dune racing. As environmental degradation accelerates, the shifting dunes pose serious risks to homes, infrastructure, and livelihoods. With rising groundwater levels, seawater intrusion, and flooding intensifying the city's vulnerability, protecting and stabilizing the dune belt has become a national priority.

INTERVENTION:

With support from the World Bank's WACA Resilience Investment Project, Mauritania launched a comprehensive initiative to stabilize Nouakchott's vulnerable coastal dunes using NBS. The project combines mechanical and biological dune restoration using vegetation planting and sand stabilization techniques. These efforts aim to restore the dunes' natural protective function, enhance biodiversity, and reduce risks from erosion and flooding. Complementary measures include wetland and

mangrove restoration, beach replenishment, and the construction of seawalls and dikes where needed. The project also promotes ecotourism, biodiversity awareness, and climate education within local communities, ensuring long-term protection of Nouakchott's coastal assets and livelihoods.

PHOTO 6.1. EXPERTS EXCHANGE KNOWLEDGE ON HOW TYPHA WOOD CAN BE USED TO STABILIZE DUNES IN NOUAKCHOTT'S BEACH RESTORATION PROJECTS

Source: World Bank 2023.

OUTCOMES AND SUCCESSES:

- → The project successfully implemented a range of protective measures, including the development of controlled access paths to reduce trampling, the preservation of stabilizing dune vegetation, and the prohibition of sand extraction and new construction activities.
- → Local land-use plans are being developed to coordinate sectoral strategies and preserve space for future nature-based interventions.
- → A coastal connectivity plan was developed to link sensitive ecosystems and enhance ecological resilience.
- → There is a partnership with the Diawling National Park to restore degraded ecosystems and combat invasive species like Typha.
- → The dune ridge stabilization is not only strengthening natural defenses but also enhancing local biodiversity and contributing to its potential as a sustainable tourism asset.
- → 51.5 km of coastline have been reinforced against erosion reducing risks for 4,879 households.
- → More than 12,590 ha of coastal land have been targeted with flood mitigation measures, protecting 41,581 households from inundation.
- → An interministerial coastal committee was established and is fully operational, facilitating cross-sectoral collaboration and long-term governance of coastal resilience efforts.
- → A national early warning system was launched and is now operational, enhancing the country's preparedness for coastal hazards.

LIMITING FACTORS AND CHALLENGES:

- → Infrastructure development near the Port of Nouakchott has altered erosion patterns, compromising the stability of surrounding coastal areas and increasing the risk of marine intrusion during storm surges.
- → Preliminary plans for the potential relocation of residents from high-risk flood zones present significant social and logistical challenges, with high costs and likely resistance from affected communities.
- → Past unsustainable sand extraction at multiple locations has weakened the natural sediment balance of the coastal system.
- → Planned construction activities and urban expansion on or near the dune belt, including by some tourism-related developments, could led to vegetation loss and dune degradation, highlighting the need for stronger enforcement of land-use regulations and environmentally sensitive planning.

KEY LESSONS LEARNED:

- → A coordinated, triple approach, addressing social, technical, and policy dimensions simultaneously, is enabling a more strategic and adaptive response to complex coastal challenges.
- → Establishing a regulatory framework was fundamental. The project built on two foundational documents: the 2005 Mauritania Coastal Master Plan and the 2007 coastal protection decree, both updated and expanded through the 2018–2022 Coastal Master Plan. These tools offered a spatially explicit vision for climate adaptation, risk reduction, and sustainable development across sectors.
- → Project design was strengthened by its focus on maximizing co-benefits, balancing coastal risk reduction with economic development. By recognizing the tourism potential of Mauritania's vast, underutilized beaches and rich marine biodiversity, the intervention is supporting efforts to attract investment in sustainable recreation and local business opportunities.

CASE STUDY REFERENCES AND RESOURCES:

Japan International Cooperation Agency (JICA). 2010. *Information disclosure under JICA guidelines for environmental and social considerations (April 2010) and the guidelines revised thereafter.* https://www.jica.go.jp/english/about/policy/environment/id/africa/a_b_fi/mauritania/c8h0vm00009ulj9f.html

Ministry of Environment and Sustainable Development, Islamic Republic of Mauritania. 2022. *Mauritania: Coastal Master Plan – Detailed Master Plan.* West Africa Coastal Areas Management Program, Washington, DC. https://www.wacaprogram.org/sites/waca/files/knowdoc/MAURITANIA-EN.pdf

Urban Nature Atlas. 2024. "Reviving Nouakchott's Coastal Dunes." Nature-Based Solutions, June 2024. https://una.city/nbs/nouakchott/reviving-nouakchotts-coastal-dunes.

World Bank. 2018. "World Bank Board Approves West Africa Coastal Areas (WACA) Resilience Investment Project." Press Release, April 9, 2018. https://www.worldbank.org/en/news/press-release/2018/04/09/world-bank-board-approves-west-africa-coastal-areas-waca-resilience-investment-project.

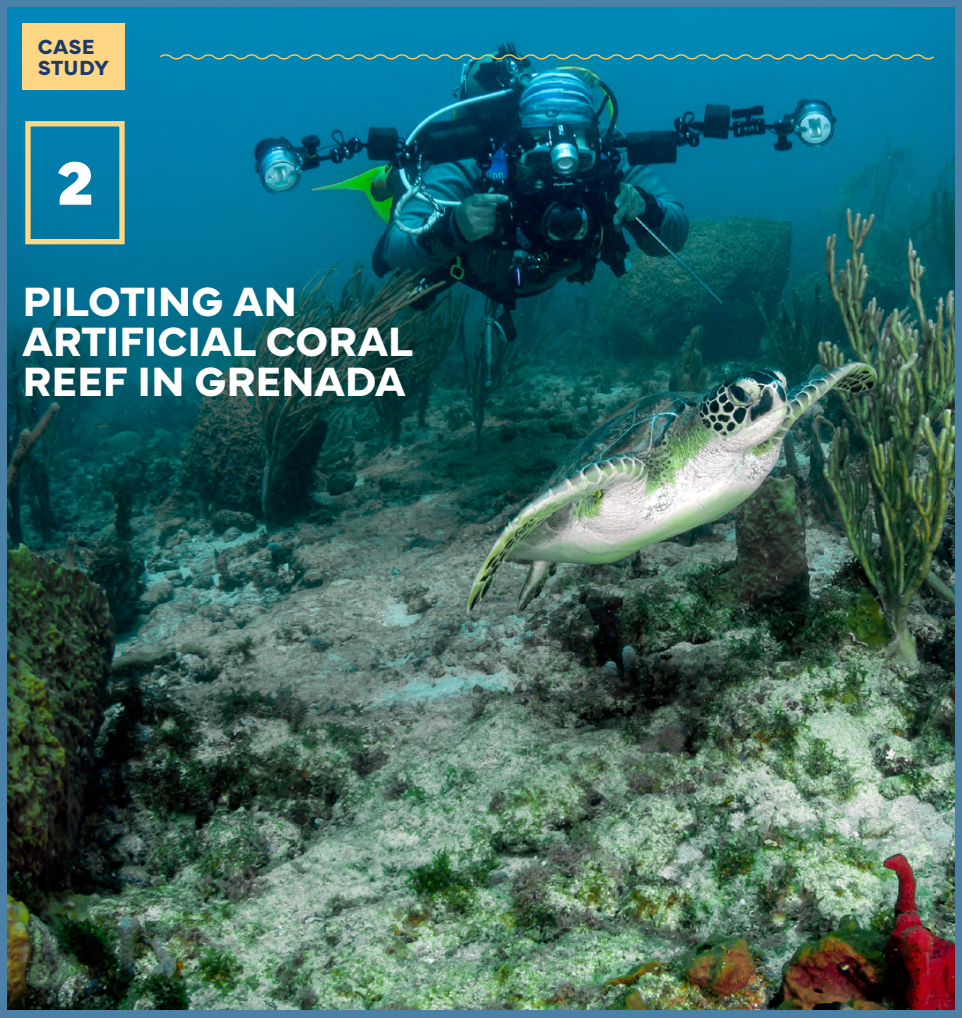
World Bank. 2021. *Resilient Coastlines, Resilient Communities: West Africa Coastal Areas Management Program – Annual Report 2020.* World Bank, Washington, DC. https://documents1.worldbank.org/curated/en/462991621974738944/pdf/Resilient-Coastlines-Resilient-Communities.pdf.

World Bank. 2023. "WACA Impact Stories: Coastal Protection." West Africa Coastal Areas Management Program, World Bank, Washington, DC. https://www.wacaprogram.org/knowledge/impact-stories-coastal-protection.

CASE STUDY

2

PILOTING AN ARTIFICIAL CORAL REEF IN GRENADA



LOCATION

Grenville Bay, Grenada

DATES AND STATUS

Pilot reef installation in 2015; project ongoing with subsequent measures under development

MAIN IMPLEMENTING ORGANIZATION

The Nature Conservancy (NGO) and Government of Grenada

FUNDING SOURCE

The Nature Conservancy's At the Water's Edge program, support from German Federal Foreign Office, Carnival Cruise Lines, Angell Foundation, the Grenada Fund for Conservation, Grenada Red Cross Society, and the Government of Grenada. Funding to finish the project has been earmarked by the Nature Conservancy for At the Water's Edge Phase II for continued reef restoration and shoreline stabilization.

PROBLEM:

Sea-level rise has led to coastal erosion, flooding, and greater storm surges. Erosion and sedimentation in Grenville Bay's harbor required dredging and caused economic loss and ecological hazards. Wave energy modeling showed that reef degradation likely was the biggest contributor to coastal erosion. Grenada is heavily dependent on limited natural resources and coastal ecosystems to support three of their primary sectors: tourism, agriculture, and fishing.

INTERVENTION:

This project aimed to enhance the coral reef in Grenville Bay by strengthening the existing reefs and improving coastal resilience. The intervention involved constructing a submerged breakwater and installing artificial reef-like structures to provide a stable substrate for coral colonization and restore habitats for fish and other marine species. In addition to reef enhancement, the project incorporated

community-led mangrove restoration to strengthen the natural shoreline barrier. Local community members were actively involved in planting mangroves and participating in resilience planning. This combined effort of ecological restoration and community resilience-building is aiming to create a stronger, more adaptive coastal system for Grenville Bay.

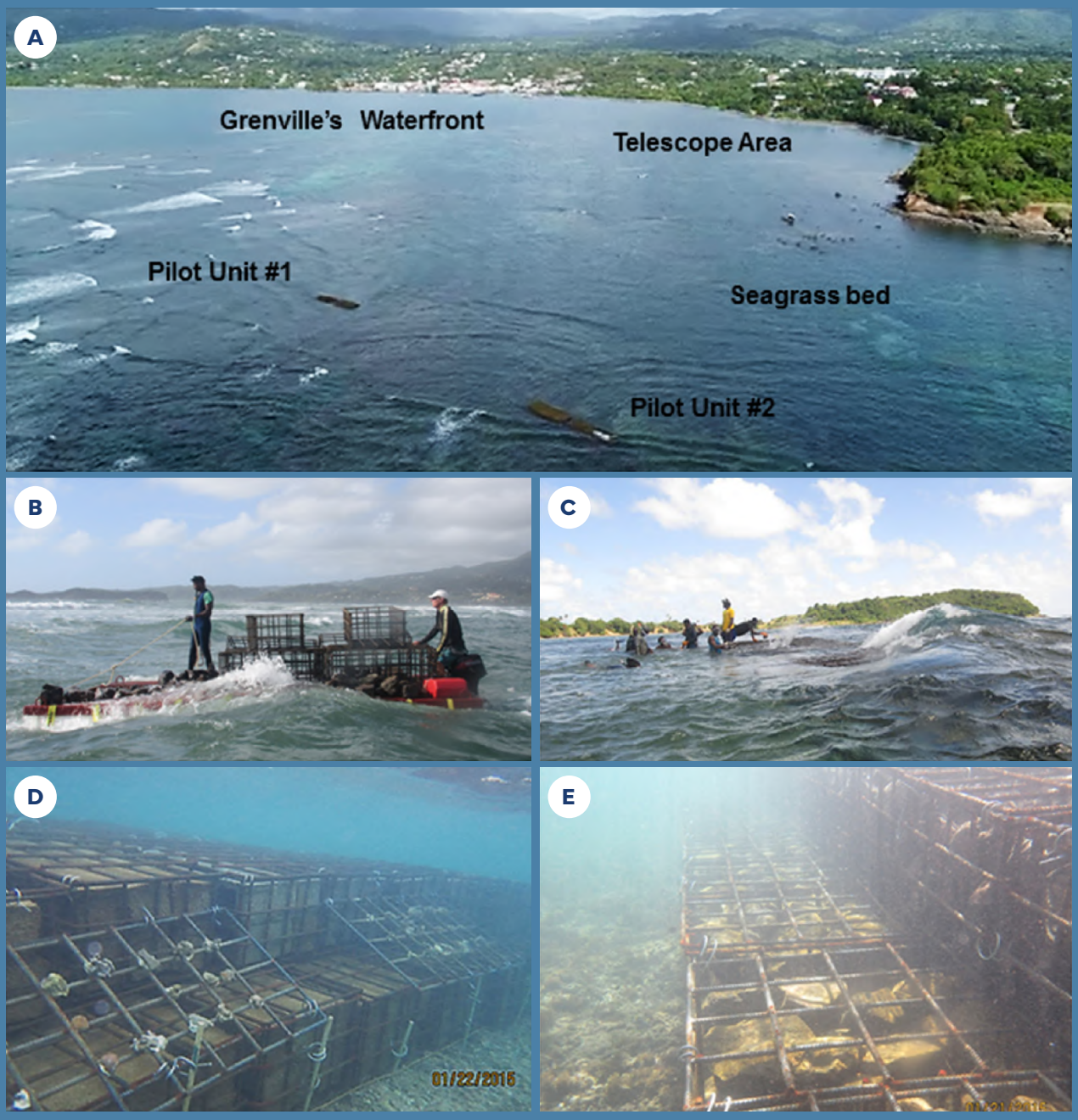


PHOTO 6.2. THE PILOT REEF ENHANCEMENT PROJECT IN GRENVILLE BAY, GRENADA

Source: Reguero et al. 2018.

Note: (a) General overview of pilot sites 1 and 2 with respect to the coastline; (b) custom-made barge loaded with baskets and rocks for constructing the breakwater; (c) building the reef breakwater one stone at a time and packing the second layer of baskets at low tide with waves now breaking directly on the breakwater; (d) and (e) submerged view of the pilot units on top coral reef rubble right after installation with coral transplants evident in (d).

OUTCOMES AND SUCCESSES:

- → The pilot reef enhancement project involved constructing a 30-meter submerged breakwater and installing artificial reef-like structures. The design of the reef enhancement project was informed by wave energy modeling, in-depth measurements of the seabed, and continuous engagements with community members of Grenville. The modular, porous units are easy to assemble and facilitate habitat creation for marine species.
- → Informed decision-making and climate change impact visualization were supported by integrated vulnerability assessments, using a shared database of spatial information on ecological, social, and economic systems, along with participatory 3D modeling.
- → Residents have reported that reef enhancement had succeeded in breaking wave energy as designed, likely contributing to potential reductions in coastal erosion and flooding.
- → The pilot structures have withstood winter swells and are crusting over with crustose coralline algae, recruiting coral, dissipating wave energy, and serving as a nursery and habitat for fish.
- → Within 12 months of installation, significant levels of coral recruitment were observed on various parts of the structure, with anecdotal evidence indicating increased species richness, including the presence of fish, octopus, and lobster.
- → Local community involvement in mangrove restoration not only fostered project ownership but also provided insights into the potential of these intertidal habitats to recover and strengthen the shoreline's biological barrier.
- → Yearly monitoring assesses the effectiveness of both the reef design and its implementation, including tracking coastal erosion in the surrounding area.
- → The project created income opportunities for locals through the construction and installation of reef structures, utilizing local materials.
- → The Nature Conservancy provided training to community leaders, helping to develop a community action plan for maintaining coastal ecosystem health, while also fostering social cohesion as community members worked together to protect their homes and livelihoods.
- → Future funding has been earmarked for At the Water's Edge Phase II, which will focus on shoreline stabilization using a living shoreline approach and further reef restoration through enhanced engineered structures.

LIMITING FACTORS AND CHALLENGES:

- → Artificial reefs in the Caribbean tend to develop biotic communities that differ from natural reefs, necessitating active fisheries management to maintain ecological balance.
- → Algal overgrowth became a challenge on the artificial reef structures, exacerbated by human impacts such as overfishing and eutrophication, which requires ongoing management.
- → The Phase II project strategy is considering armoring the shoreline and constructing groins, indicating a need to incorporate harder gray infrastructure to enhance coastal protection efforts.
- → Mangrove restoration, carried out mainly for community involvement purposes, was unsuccessful along the coastline section due to unsuitable geophysical conditions.

KEY LESSONS LEARNED:

- → Partnering with diverse groups, including engineers, land use planners, and local NGOs facilitated the integration of a wide range of expertise, enhancing informed decision-making throughout the project.
- → Applying a participatory process successfully empowered community involvement, ensuring local stakeholders played an active role in the project and was essential for effective information sharing and collaboration across agencies.
- → Building capacity and working at pilot sites engaging closely with communities required a significant investment of time and resources, emphasizing the importance of long-term commitment.
- → Participatory 3D mapping proved to be a powerful tool for collecting community knowledge and fostering discussions, though it required skilled facilitators and substantial community mobilization to be implemented effectively.
- → Engaging a local commercial dive operator and divers was critical during installation, as their expertise and local knowledge proved invaluable to the project's success.

CASE STUDY REFERENCES AND RESOURCES:

Blue Solutions Initiative. 2015. "Blue Solutions from Latin America and the Wider Caribbean." Regional Forum on Solutions for Oceans, Coasts and Human Well-Being in Latin America and the Wider Caribbean. https://portals.iucn.org/library/sites/library/files/documents/2015-042-2nd%20ed.pdf.

Nature-Based Solutions Initiative. 2024. "Reef Enhancement and Vegetation Restoration to Enhance Coastal Resilience in Grenville Bay." Case study platform, University of Oxford, Oxford. https://casestudies.naturebasedsolutionsinitiative.org/casestudy/reef-enhancement-and-vegetation-restoration-to-enhance-coastal-resilience/.

Frederick, Nealla. 2024. "At the Water's Edge: Enhancing Coastal Resilience in Grenada." PANORAMA, The Nature Conservancy Caribbean Programme, Miami. https://panorama.solutions/en/solution/waters-edge-enhancing-coastal-resilience-grenada.

Reguero, Borja G., Michael W. Beck, Vera N. Agostini, Philip Kramer, and Boze Hancock. 2018. "Coral Reefs for Coastal Protection: A New Methodological Approach and Engineering Case Study in Grenada." *Journal of Environmental Management 210: 146–161.*

The Nature Conservancy. 2015. "Grenville Pilot Reef Breakwater, Innovative Reef Engineering for Small Island States." https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/Caribbean/science/adaptation/Documents/Grenville%20Reef%20and%20AWE%20Project%20Update%20-%20Final.pdf.

The Nature Conservancy. 2021. "A Post-Storm Response and Reef Insurance Primer: Building the Response Capacity to Repair Reefs Damaged by Hurricanes." https://www.nature.org/content/dam/tnc/nature/en/documents/A_POST_STORM_RESPONSE_REEF_INSURANCE_PRIMER_2021_final.pdf.

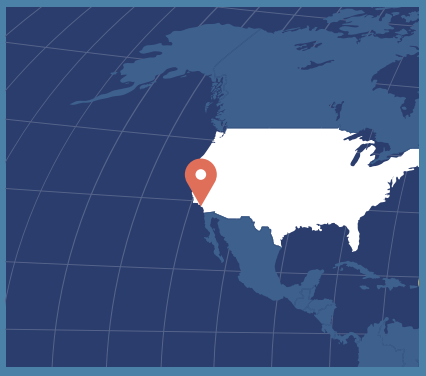
The Nature Conservancy. 2021. "At the Water's Edge, Coastal Resilience Network." https://coastalresilience.org/project/grenada-at-the-waters-edge/.

CASE STUDY

3

PASSIVE DUNE RESTORATION IN AN URBAN BEACH

Photo by Steve Wrzeszczynski on Unsplash



LOCATION

Santa Monica Beach, California, USA

DATES AND STATUS

Intervention in 2016 and monitoring ongoing

MAIN IMPLEMENTING ORGANIZATION

The Bay Foundation, City of Santa Monica, California Department of Parks and Recreation, and the University of California, Santa Barbara

FUNDING SOURCE

The U.S. Environmental Protection Agency and the Metabolic Studio funded the initial implementation of the pilot restoration project. Research funding came from the University of Southern California, California Sea Grant Program, University of California Office of the President Climate Action Seed Fund, California Ocean Protection Council, and the National Science Foundation.

PROBLEM:

Santa Monica Beach, a globally recognized urban tourist destination, faces challenges from long-term erosion and sediment loss, worsened by sea-level rise and intensive human activities. The beach has a long history of beach nourishment. It had also been mechanically groomed for decades to enhance its appeal for recreation, leading to the removal of natural dune formations and weakening its natural defense against storm surges. To address these issues, a dune restoration pilot project was initiated to restore the beach's resilience while enhancing its value for tourism and wildlife.

INTERVENTION:

The project restored 1.2 ha of degraded beach by promoting natural dune formation through passive interventions (no sediment addition or use of heavy equipment). Key actions included the installation of sand fencing to trap sediment, halting mechanical grooming, and planting native dune vegetation. These actions helped restore the natural sand accumulation, while also making the beach more attractive to visitors.

The project was informed by scientific assessments of wave and sediment dynamics and engaged local tourism businesses and the community in awareness campaigns.

PHOTO 6.3. OBLIQUE AERIAL PHOTOGRAPH OF THE RESTORATION PROJECT SITE FROM THE NOVEMBER 20, 2022 UAS FLIGHT

Source: Johnston et al. 2023.

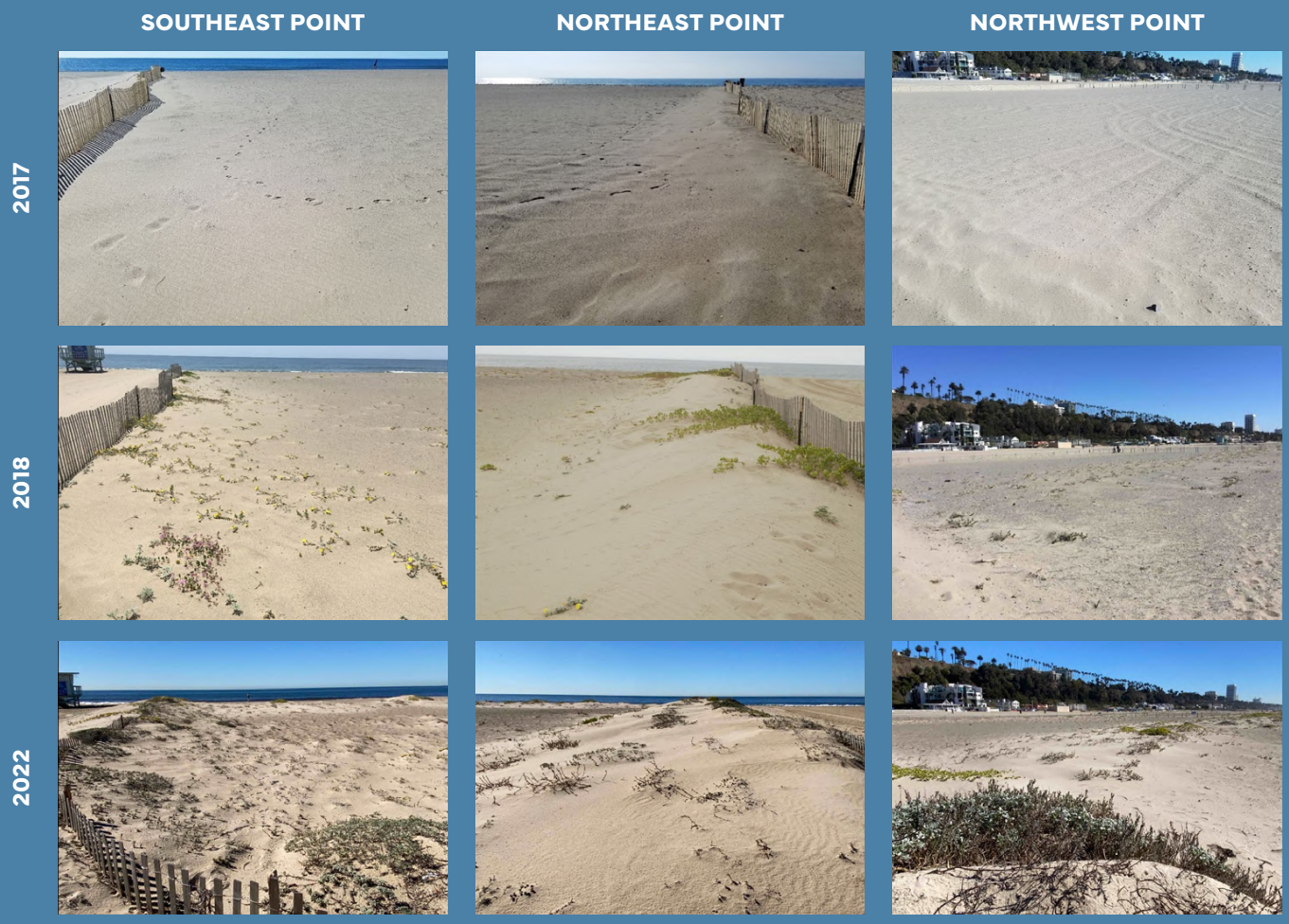
Note: Key elements have been labeled, including the project boundary, perimeter fence, various habitat types, adjacent groomed beach (control site), and the incipient foredune ridge. Alongshore distance of the site was ~150 m, with a dune cross-shore length of ~60 m.

OUTCOMES AND SUCCESSES:

- → **The restoration used 1-meter wood slat sand fences,** a central path through the restoration area, seeding of California native perennial dune plant species, two interpretive signs installed along pathways, and an unenclosed perimeter on the seaward edge.
- → **No irrigation was used,** and maintenance consisted of occasional removal of a nonnative plant.
- → **Sand accumulation and incipient foredune crest height:** The project resulted in the accumulation of 1,777 m^3 of sand, forming a 0.9-meter-high foredune, stabilizing the beach, and mitigating erosion (see figure 6.1).
- → **Vegetation cover:** Native plant cover reached 7 percent, with species like Abronia maritima and Ambrosia chamissonis contributing to sand stabilization.

- → **Biodiversity benefits:** The restoration supported the return of shorebird nesting in the studied site.
- → **Following an extreme wave surge** event in December 2023, the performance of the pilot dune restoration section was compared to an adjacent mechanically groomed control site. Using total water level (wave setup, tide, wave runup) as a proxy for flooding potential, the average wave runup incursion distance was found to extend 13.6 meters farther inland on the groomed control site compared to the restored dune, demonstrating the dune's effectiveness in reducing flood risk (see figure 6.2).
- → **Increased tourism appeal:** Restored dune features and native vegetation provided a more natural beach aesthetic, enhancing the experience for visitors.
- → **Community engagement:** Local businesses, especially those in tourism, supported the project, recognizing the long-term benefits of preserving beach assets for both visitors and residents. Awareness-raising campaigns helped promote the project as an eco-friendly initiative.

FIGURE 6.1. COMBINATION PANEL OF GEOREFERENCED PHOTOGRAPHS OF THE RESTORATION SITE OVER TIME



Source: Johnston et al. 2023.

Note: Top photographs were taken in January 2017, middle in May 2018, and bottom in November 2022. Left series is the southeastern portion of the restoration area and fence line, middle is the northeastern point and fence line, and right is the northwest point facing south across the incipient foredune ridge.

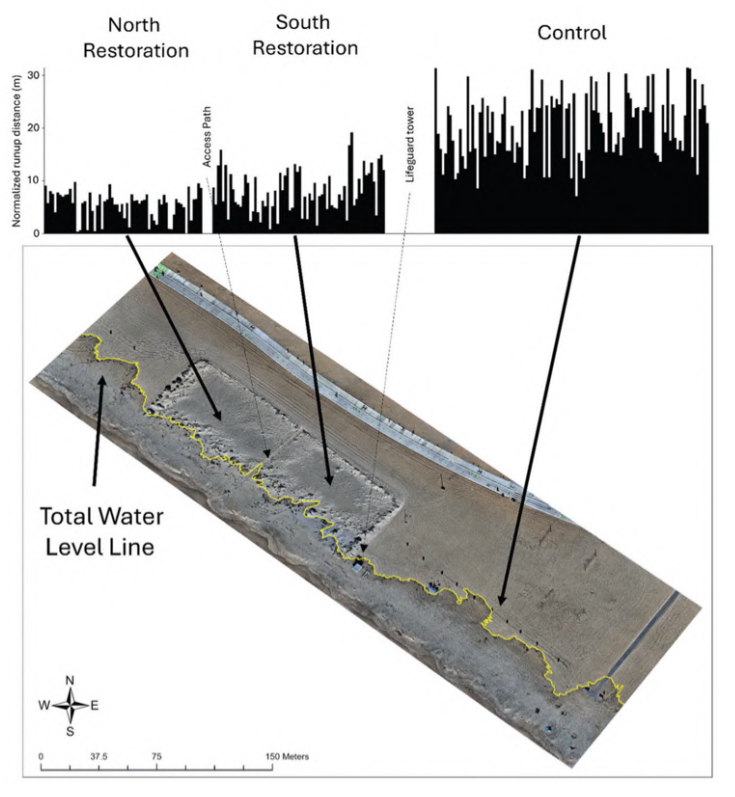


FIGURE 6.2. AN ORTHOMOSAIC OF THE PILOT PROJECT DUNE RESTORATION SITE

Source: Emery et al., 2024.

Note: Orthomosaic with an inset of normalized wave runup incursion distance showing the greater inland distance of the total water level line on the beach in the control site outside of the dune restoration site. Excluded regions (access path and lifeguard tower) are indicated with dashed lines.

LIMITING FACTORS AND CHALLENGES:

→ **Limited scale:** The restoration site covered only a small portion of the larger Santa Monica Beach, meaning further expansion is necessary to ensure broader ecological recovery, protection of tourism infrastructure, and fully assess the potential to enhance coastal resilience.

→ **Human disturbance:** Continued grooming and beach driving outside the restoration area may limit the full recovery of the ecosystem and reduce the long-term benefits for coastal protection.

KEY LESSONS LEARNED:

→ The project demonstrates the potential use of dune restoration with minimal human intervention, cost, and maintenance as an adaptation approach that not only restores coastal habitat and function but also improves resilience to sea level rise and coastal erosion without heavy engineering or disrupting the beach's recreational use.

→ The applicability of dune restoration in urban areas requires careful consideration of opportunities and constraints, such as balancing with other beach uses.

→ The results of this restoration project over six years suggests that replication of a dune nature-based adaptation strategy could be a successful approach to improving coastal resilience in appropriate geomorphic conditions around the globe; for example, wide beaches with sufficient aeolian sand transport and fetch distance.

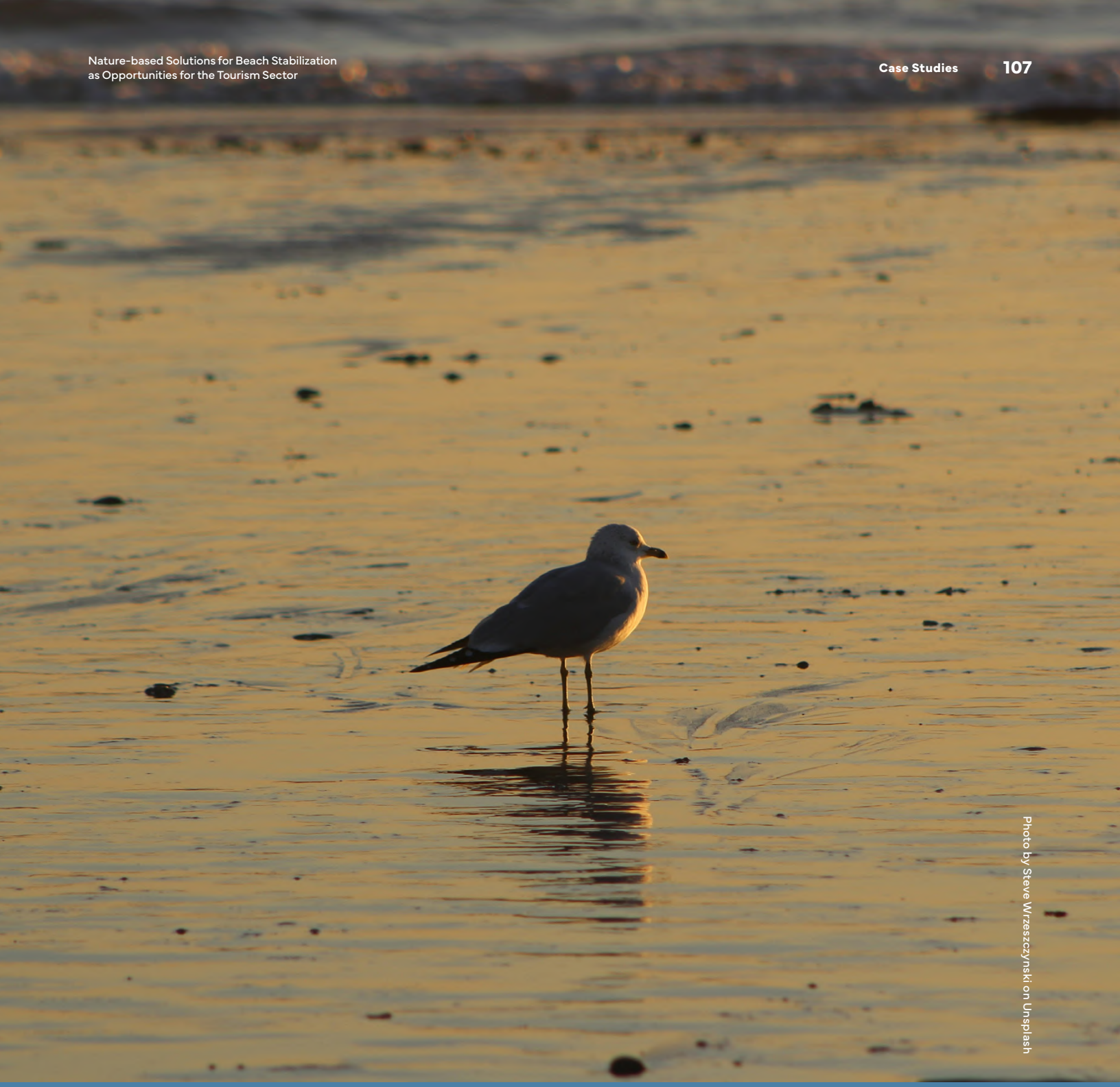


Photo by Steve Wrzeszczynski on Unsplash

CASE STUDY REFERENCES AND RESOURCES:

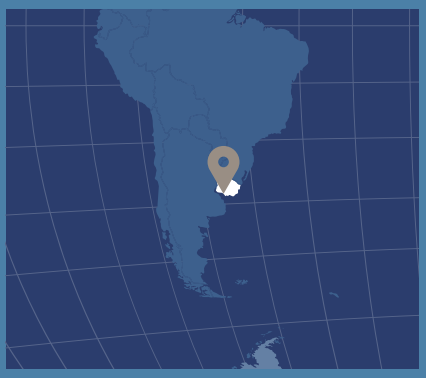
Emery, K. A., Baxter, T. I., Callahan, M. C., Cavanaugh, K. C., Dugan, J. E., Engeman, L. E., Hubbard, D. M., Johnston, K. K., Walker, I. J., & Wisniewski, J. 2024. "Evaluating the response of a pilot dune restoration project on an urban beach to an extreme wave surge event." *Shore & Beach*, 92(4), 28–33. https://doi.org/10.34237/1009243

Johnston, Karina K., Jenifer E. Dugan, David M. Hubbard, Kyle A. Emery, and Melodie W. Grubbs. 2023. "Using Dune Restoration on an Urban Beach as a Coastal Resilience Approach." *Frontiers in Marine Science 10.* https://doi.org/10.3389/fmars.2023.1187488

CASE STUDY

4

REGENERATION OF SAND DUNES AND CAPACITY BUILDING STRATEGY ON THE URUGUAYAN COAST



LOCATION

Kiyú, Uruguay (Uruguayan coast of the Rio de la Plata River estuary)

DATES AND STATUS

2012–2013 (completed)

MAIN IMPLEMENTING ORGANIZATION

Departmental Office of Climate Change (Government of Uruguay)

FUNDING SOURCE

Funded by a combination of local and subnational government entities with support from the federal government, United Nations Development Program, and Global Environment Facilities (GEF, 2024)

PROBLEM:

In 2012, extreme windstorm surges impacted Kiyú, located at the Rio de la Plata's tidal river estuary, resulting in direct losses totaling US$1 million. The region's vulnerability is exacerbated by extreme weather events, sea-level rise, storm surges, and strong winds, which have caused significant sand dune erosion. These factors pose ongoing threats to both the local tourism industry and the agricultural sector that depend on the stability of the coastline.

INTERVENTION:

This project involved regenerating sand dunes through the installation of natural material fencing and the revegetation of dunes with native plants (photos 6.4 and 6.5). Decision-making for the project was a participatory process, engaging both institutional stakeholders and the local community in selecting coastal adaptation measures. The goal was to reduce erosion of the sandy beach, dunes, and bluffs caused by wind, storm surges, sea-level rise, rainfall, and poor management practices. NBS were prioritized for ecosystem recovery, including fencing with natural materials, dune revegetation using native species, sustainable drainage systems, and reducing human pressure by creating appropriate access points and zoning for better management.

PHOTO 6.4.DUNE RESTORATION USING CUTS OF NATIVE PLANTS TO FORM A FENCE TO CONTAIN SAND AND PREVENT EROSION

Source: Ministerio de Ambiente Uruguay 2019.

Note: The work was done with the help of volunteers in Kiyú, Uruguay.

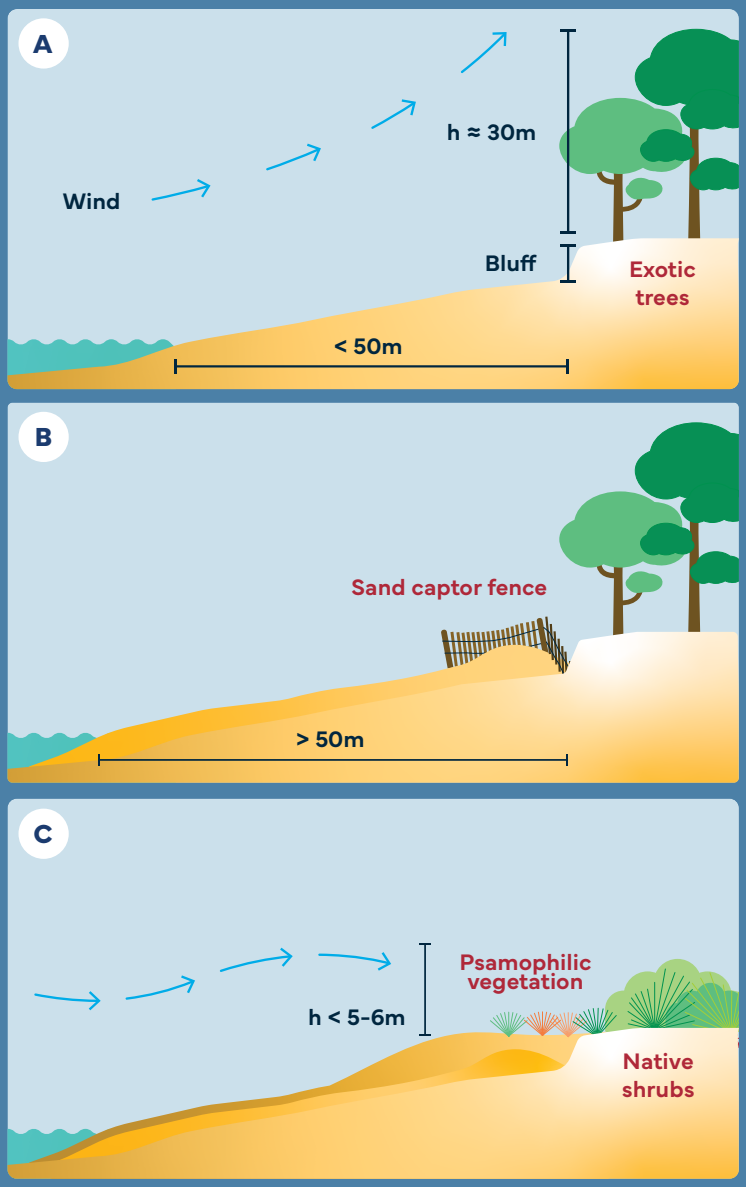
PHOTO 6.5. FENCING CONSTRUCTED WITH NATURAL MATERIALS

Source: AFP Español 2013.

OUTCOMES AND SUCCESSES:

- → A low-cost, low-tech sand capture fence made from tree branches (1,200 linear meters) was installed to protect the bluff and support the recovery of the dune system.
- → Regeneration of sand dunes and native plant revegetation helped reduce erosion and improve natural drainage, increasing resilience to storm-induced flooding.
- → Rapid recovery of the beach and dunes was observed. A proto-dune of 1 m high and 6 m wide at its base was created after three months, increasing the slope of the beach through accumulating 6 m^3 per meter per captor fence during 2013. The estimated total volume of rebuilt dunes was up to 10,000 m^3.
- → A native plant nursery was established to ensure sustainable revegetation of the dune system.
- → Large eucalyptus trees that hindered the growth of native grasses and shrubs more suited for retaining sand were cut down—a strategy shown to be beneficial for maintaining sand bluffs.
- → Extreme events, including the highly erosive rainfalls in early 2014 (the highest ever recorded over a 15-day period) and in September 2016 (with average winds of 61 km per hour and gusts exceeding 100 km per hour) with storm surge in the same period (2.43 m, with a 0.1 percent occurrence), did not erode the sandy beach, dunes, bluffs (cliffs), or shrubby forest.
- → It was a participatory process with community and capacity building, including facilitating knowledge exchange and strengthening socio-institutional behavior, structure, and sustainability.
- → Vulnerability reduction assessment workshops revealed participants perceived themselves to have lower vulnerability and higher adaptive capacity after the implementation of the program.

FIGURE 6.3. SCHEMATIC REPRESENTATION OF THE BEACH PROFILE BEFORE AND AFTER THE SOFT INTERVENTION IN 2013



Source: Adapted from Carro et al. 2018.

Note: Beach profile (a) before and (b) after the intervention. Panel c shows the desired outcome after rebuilding the beach profile and dunes.

LIMITING FACTORS AND CHALLENGES:

- → Infrastructure realignment is needed to achieve further success.
- → Although a beach monitoring and early warning strategy was put in place after implementation, its accuracy and the time period were insufficient.
- → If coastal hazards continue to harm the local economy and infrastructure despite interventions, the motivation for ongoing management could decline. Kiyú may eventually reach a tipping point in the future where adaptation costs outweigh the benefits.

KEY LESSONS LEARNED:

- → A newly established socio-institutional structure and adaptive governance framework successfully harmonized Integrated Coastal Management steps with NBS.
- → This framework facilitated the implementation of effective NBS, which preserved coastal systems and managed extreme events, while also generating key tools for regional management, such as vulnerability risk assessments and nurseries.
- → Active stakeholder participation enhanced social legitimacy and built trust.
- → The NBS measures tested in this project offer potential for replication along other parts of the country's coastline.

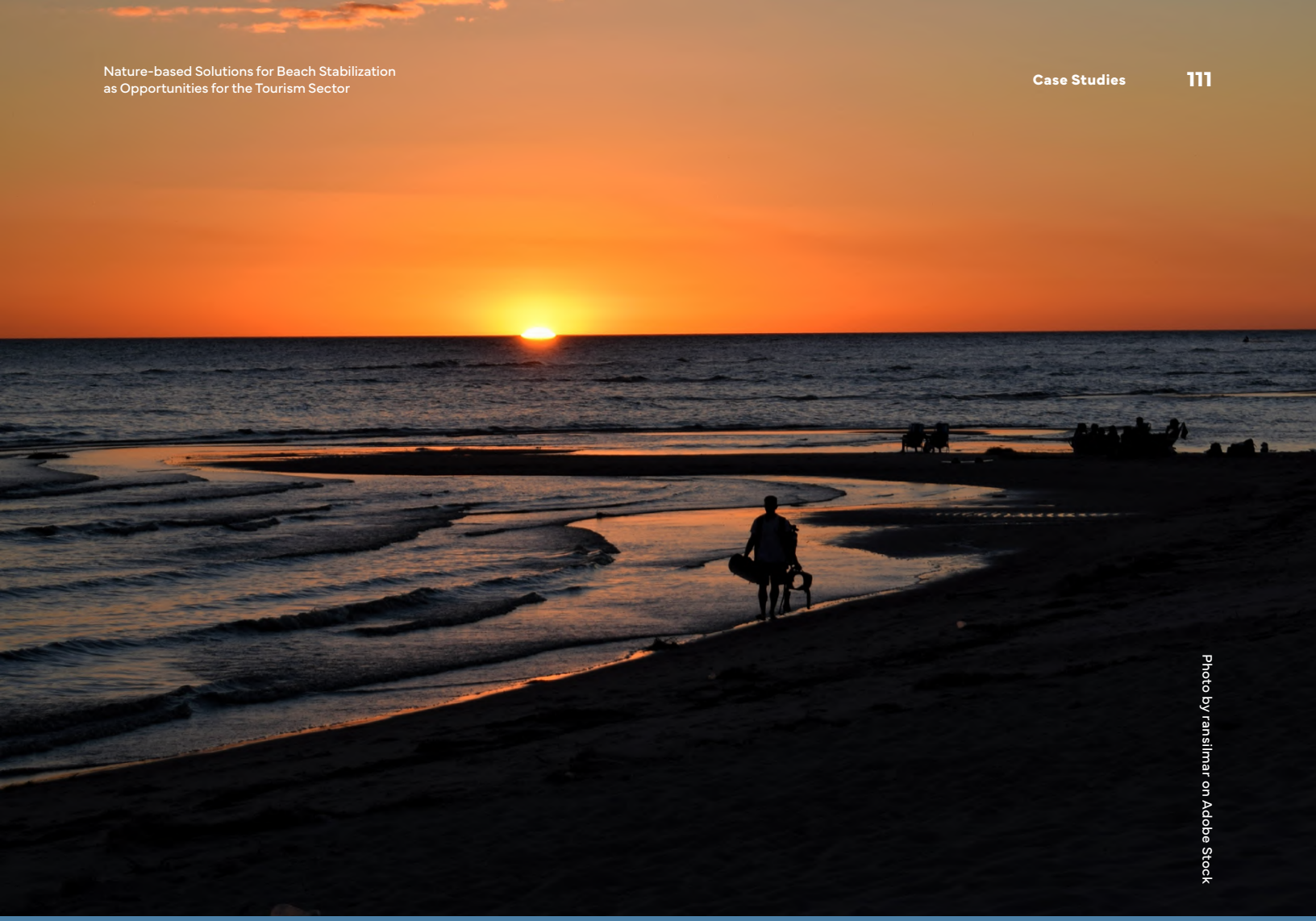


Photo by ransilmar on Adobe Stock

CASE STUDY REFERENCES AND RESOURCES:

AFP Español. 2013. Uruguay busca salvar las dunas de Kiyú. YouTube. https://www.youtube.com/watch?v=ceO68YlUhG0.

Carro, Inti, Leonardo Seijo, Gustavo J. Nagy, Ximena Lagos, and Ofelia Gutiérrez. 2018. "Building Capacity on Ecosystem-Based Adaptation Strategy to Cope with Extreme Events and Sea-Level Rise on the Uruguayan Coast." *International Journal of Climate Change Strategies and Management 10* (4): 504–522. https://doi.org/10.1108/IJCCSM-07-2017-0149.

Fitton, James M., Kwasi Appeaning Addo, Philip Neri Jayson-Quashigah, Gustavo J. Nagy, Ofelia Gutiérrez, Daniel Panario, Inti Carro, Leo Seijo, Carolina Segura, José E. Verocai, Samrit Luoma, Johannes Klein, Ting Ting Zhang, Jeff Birchall, and Peter Stempel. 2021. "Challenges to Climate Change Adaptation in Coastal Small Towns: *Examples from Ghana, Uruguay, Finland, Denmark, and Alaska." Ocean & Coastal Management* 212: 105787.

GEF (Global Environment Facility). 2024. *Implementing Pilot Climate Change Adaptation Measures in Coastal Areas of Uruguay.* Status report, GEF, Washington, DC.

Ministerio de Ambiente Uruguay. 2019. "Regeneración de dunas en Kiyú." News page, June 3, 2019. https://www.gub.uy/ministerio-ambiente/comunicacion/noticias/regeneracion-dunas-kiyu.

Nature-Based Solutions Initiative. 2024. "Ecosystem-Based Adaptation to Cope with Sea-Level Rise and Extreme Climatic Events." Case study platform, University of Oxford, Oxford. https://casestudies.naturebasedsolutionsinitiative.org/casestudy/ecosystem-based-adaptation-to-cope-with-sea-level-rise-and-extreme-climatic-events-on-the-uruguayan-coast/.

CASE STUDY

5

INTEGRATED COASTAL ZONE MANAGEMENT IN THE MARCHE REGION

LOCATION

Marche region, Italy

DATES AND STATUS

2009–2019, ICZM Plan and update complete, project implementation ongoing

MAIN IMPLEMENTING ORGANIZATION

Marche Regional Administration (Department of Infrastructure and Territory, Environment and Water Resource Department)

FUNDING SOURCE

Marche Regional Administration

PROBLEM:

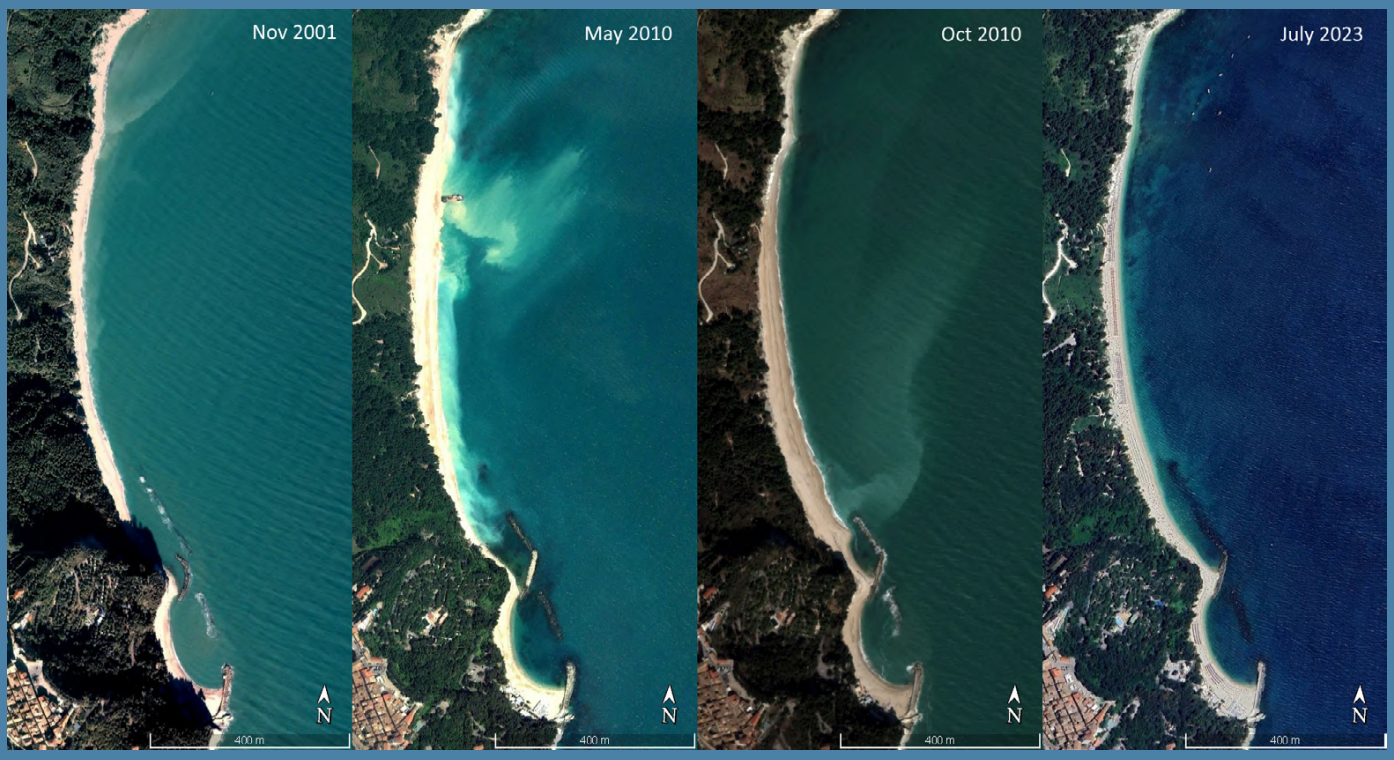
The coastline of the Marche region of Italy has a landscape of beaches and cliff faces heavily impacted by erosion. Climate change and sea-level rise are expected to lead to an increased risk of storm surge–induced flooding and erosion events and landslides along coastal cliffs. The 176 km long coastline is heavily urbanized, and river modification activities inland have reduced transport of sediment to the shoreline. In addition, certain coastal defenses built in previous years are now thought to exacerbate local issues. Examples of prior maladaptation includes defensive blocks deployed at the base of the sea cliff of Mount Conero, which has since appeared to accentuate wave energy. Shoreline retreat in the municipalities of Sirolo and Numana puts properties and coastal infrastructure at risk.

INTERVENTION:

The ICZM Plan for the Marche Region, initially approved in 2005 and updated in 2019, is a long-term strategy aimed at addressing coastal erosion and building climate resilience along the region's coastline. The plan focuses on soft engineering techniques to manage coastal retreat by restoring the balance between sediment erosion and accretion and reducing the environmental impacts of traditional coastal defenses. These measures are designed to protect local settlements and the tourism-dependent economy of the coastal area.

In line with national guidelines on climate change and coastal erosion, the plan also integrates data collection and flood risk scenario modeling to identify high-risk zones where adaptive measures should be prioritized. The ICZM strategy supports the diversification of tourism opportunities by coupling traditional seaside tourism with trekking and environmental tourism in the Conero Regional Natural Park. Between 2005 and 2016, 277 protection measures were implemented along the coastline, demonstrating the region's commitment to sustainable coastal management and enhancing the resilience of both the natural environment and the tourism sector.

FIGURE 6.4. COASTAL EVOLUTION OF SAN MICHELE BEACH, 2001–2023



Source: Google Earth 2024. [3]

Note: The bay's wider southern sandy section reflects the impact of major nourishment events in 2005 and 2019, along with periodic top-up efforts.

3 Satellite imagery of Spiaggia di San Michele, La Marche beach nourishment and evolution snapshots 2001-2023. Retrieved from https://earth.google.com/web/ on January 8, 2025.

OUTCOMES AND SUCCESSES:

→ The beach nourishment aimed to preserve the natural environment, restore coastal dune habitats, and maintain beach accessibility for both locals and tourists. Strict legislative requirements ensured that the sand and gravel used for nourishment matched local materials, minimizing environmental impact.

- Approximately 156,000 m³ of sand and gravel were used for beach nourishment along 1,200 m of shoreline in San Michele Bay.
- Nourishment activities also included cliff stabilization efforts at Mount Conero.
- Periodic beach nourishment is planned to sustain long-term coastal resilience.

→ Additional adaptation measures implemented at Sirolo and Numana included:

- Maintenance of existing hard defense structures to ensure their continued effectiveness.
- The removal of a breakwater in Numana, with around 172,000 m³ of sand and gravel deposited along 1,500 m of beachfront. Two new groins were constructed, and an existing one was restored.

→ Stakeholder consensus-building was a key element of the plan, encouraging public acceptance and participation in proposed coastal measures.

→ Strong collaboration between local authorities and tourism operators was maintained throughout the design and implementation phases, ensuring alignment with tourism needs.

→ Satellite monitoring revealed a shoreline advancement of 2,445 m between 1999 and 2012 following implementation of the planned interventions (figure 6.4).

PHOTO 6.6. SAN MICHELE BEACH (LA MARCHE REGION) DURING PEAK TOURISM SEASON FOLLOWING SAND NOURISHMENT

Source: Marche Regional Administration from AdapteCCa. n.d.

LIMITING FACTORS AND CHALLENGES:

- → The success of the 2019 ICZM Plan update remains under evaluation, with full outcomes yet to be reported.
- → Budget uncertainties at both the national and regional levels pose a risk to the timely maintenance of existing coastal measures and the implementation of new initiatives.
- → Beach nourishment activities will require ongoing repetition due to persistent erosion. Ensuring a steady supply of materials that meet strict legislative and environmental requirements may present a significant challenge to future maintenance efforts.

KEY LESSONS LEARNED:

- → A collaborative approach among stakeholders, including regional councilors, municipal administrators, the private sector, environmental organizations, technicians, and citizens, fostered strong community engagement and resulted in a high level of acceptance for the proposed measures.
- → Collaboration between municipalities was essential to balance the demand and supply of beach nourishment materials, optimizing the use of available resources and minimizing the need to dispose of dredged materials in landfills or at sea.
- → The EU-funded Shaping a Holistic Approach to Protect the Adriatic Environment between Coast and Sea showed that tourism revenue co-benefits could incentivize local tourism businesses, which benefit from coastal defense measures, to contribute directly to the resources needed for implementing such adaptation strategies.

ACKNOWLEDGMENT:

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CASE STUDY REFERENCES AND RESOURCES:

AdapteCCa. n.d. "Addressing Coastal Erosion in Marche Region, Italy." Retrieved September 12, 2024. https://adaptecca.es/en/addressing-coastal-erosion-marche-region-italy

Cantasano, Nicola, Gaetano Pellicone, and Fabio Ietto. 2017. "Integrated Coastal Zone Management in Italy: A Gap between Science and Policy." *Journal of Coast Conservation* 21: 317–325. https://doi.org/10.1007/s11852-016-0479-z

Legislative Assembly of Marche. 2013. *Economic Analysis Applied at a Maritime State Property Territorial Unit, Action 4.4 MSP Pilot Project*. Marche Region Final Report, Marche. https://www.regione.marche.it/Portals/0/Paesaggio_Territorio_Urbanistica/Difesa_Costa/shape_RM_report.pdf.

Legislative Assembly of Marche. 2005. *Integrated Management Plan for Coastal Areas, Regional Law*, 14 July 2004, No. 15. https://www.consiglio.marche.it/banche_dati_e_documentazione/iter_degli_atti/paa/pdf/d_am156.pdf.

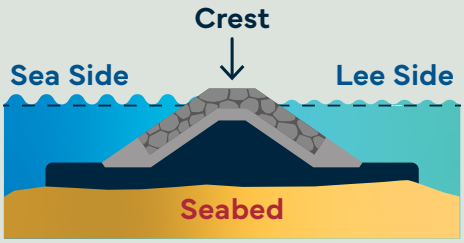
APPENDIX A

TRADITIONAL GRAY ENGINEERING: COASTAL EROSION RISK MITIGATION SOLUTIONS

TABLE A.1 AN OVERVIEW OF GRAY COASTAL ENGINEERING SOLUTIONS

NAME	DESCRIPTION	LIMITATIONS	IMAGE
Seawalls	Vertical or relatively steep sloping barriers parallel to the shoreline to absorb wave energy and prevent landward erosion	Seawalls and revetments can be effective for coastal protection but generally come with significant drawbacks. They entail high construction and maintenance costs, including ongoing monitoring and repairs. Additionally, they can have adverse ecological and aesthetic impacts, disrupting natural habitats and coastal landscapes. Furthermore, they can exacerbate erosion and lead to the loss of beach habitat due to wave reflection and scouring.	**PHOTO A.1.1. SEAWALL AT HORNSEA BEACH** Source: © J. Thomas/ Wikimedia Commons.
Revetments	Rock piled on shoreline		**PHOTO A.1.2. ROCK REVETMENTS AT KINMEL BAY, WALES** Source: © Eirian Evans / Wikimedia Commons.

NAME	DESCRIPTION	LIMITATIONS	IMAGE
Groins	Perpendicular structures that extend into the ocean and aim to stabilize beaches by interrupting longshore sediment transport	Groins and breakwaters disrupt natural sediment transport, causing erosion on the lee side, resulting in beach narrowing and habitat loss. They can also impact navigational and recreational activities; for example, by generating relatively strong currents. They generally have high construction and maintenance costs.	**PHOTO A.1.3. ROCK GROINS AT KANAHA BEACH, HAWAII** Source: © Forest and Kim Starr / Wikimedia Commons.
Breakwaters	Shore-connected or detached shoreline-parallel structures that reduce wave energy and thereby provide shelter from waves as well as manipulate alongshore sand transport		**PHOTO A.1.4. SHORE-CONNECTED BREAKWATER AT YORK RIVER, VIRGINIA** Source: © K. During / Center for Coastal Resources Management, Virginia Institute of Marine Science. **PHOTO A.1.5. DETACHED OFFSHORE BREAKWATER AT BORTH, WALES** Source: © J. Bolwell / Wikimedia Commons.

NAME	DESCRIPTION	LIMITATIONS	IMAGE
Low-crested breakwaters	Structures typically built parallel to the shore and designed to absorb and dissipate wave energy. Unlike traditional breakwaters, they are partially submerged or sit just above water level, allowing waves to pass over them while reducing their intensity.	Their effectiveness is limited against extreme events and highly dependent on wave height and local sea conditions. Low-crested breakwaters may also cause sediment accumulation in some areas, leading to unintended erosion elsewhere along the coast. They also carry a risk of damage by high-energy waves or storms, necessitating repairs to prevent structural failures.	**FIGURE A.1.1. ILLUSTRATION OF SUBMERGED BREAKWATER DESIGN**  Source: Authors' elaboration.

ADDITIONAL READINGS

THEME	TITLE	MAIN ORGANIZATION	YEAR	ACCESS LINK
Coastal NBS	Catalogue of Nature-Based Solutions for Coastal Resilience	World Bank	2025	To be published soon at: https://naturebasedsolutions.org/
	The Australian Guide to Nature-Based Methods for Reducing Risk from Coastal Hazards	Earth Systems and Climate Change Hub	2021	https://nespclimate.com.au/wp-content/uploads/2021/05/Nature-Based-Methods_Final_05052021.pdf
	Use of natural and nature-based features for coastal resilience	U.S. Army Engineer Research and Development Center	2015	http://hdl.handle.net/11681/4769
	Catalogue of adaptation measures to the effects of climate change in the coastline	IH Cantabria	2023	https://lifeadaptablues.eu/wp-content/uploads/2023/04/Catalogue_EN.pdf
	The Blue Guide to Coastal Resilience: Protecting Coastal Communities through NBS	The Nature Conservancy	2021	https://www.natureprotects.org/
Beach Management	Compendium: Coastal Management Practices in West Africa	World Bank	2022	https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099756404272220828/idu0ef51204303cd20453e0a032077ea722ac4d1
	Advice on Options for Sand Dune Management for Flood and Coastal Defence	Natural Resources Wales	2017	https://naturalresources.wales/media/685949/eng-report-207-advice-options-for-sand-dune-management-for-flood-and-coastal-defence.pdf

THEME	TITLE	MAIN ORGANIZATION	YEAR	ACCESS LINK
General NBS	Implementing Nature-Based Flood Protection: Principles and Implementation Guidance	World Bank	2017	https://documents1.worldbank.org/curated/en/739421509427698706/pdf/Implementing-nature-based-flood-protection-principles-and-implementation-guidance.pdf
	Building with Nature – Creating, Implementing, and Upscaling Nature-Based Solutions	Ecoshape	2020	https://www.ecoshape.org/en/book-building-with-nature-creating-implementing-and-upscaling-nature-based-solutions/
	International Guidelines on Natural and Nature-Based Features for Flood Risk Management	U.S. Army Engineer Research and Development Center	2021	http://dx.doi.org/10.21079/11681/41946
	Catalogue of Nature-Based Solutions for Urban Resilience	World Bank	2021	https://www.gfdrr.org/en/publication/catalogue-nature-based-solutions-urban-resilience
Nature-Based Tourism	Tools and Resources for Nature-Based Tourism	World Bank	2023	https://openknowledge.worldbank.org/entities/publication/e51e4a32-2749-5918-8da6-c7b44b67a31f
NBS Economics and Finance	Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers	World Bank	2023	https://openknowledge.worldbank.org/entities/publication/9ed5cb4b-78dc-42a4-b914-23d71cef24a2
	Blue Infrastructure Finance: A new approach Integrating Nature-based Solutions for Coastal Resilience	International Union for the Conservation of Nature	2020	https://www.conservation.org/docs/default-source/publication-pdfs/blue-infrastructure-finance.pdf?Status=Master&sfvrsn=6ed0bda1_2

REFERENCE LIST

Aerts, Jeroen C.J.H. 2018. "A review of Cost Estimates for Flood Adaptation." Water 10 (11): 1646.

Alexandrakis, George, Constantine Manasakis, and Nikoloas Kampanis. 2015. "Valuating the Effects of Beach erosion to Tourism Revenue: A Management Perspective." *Ocean & Coastal Management* 111: 1–11. https://doi.org/10.1016/j.ocecoaman.2015.04.001.

Ammar, M. S. A. 2009. "Coral Reef Restoration and Artificial Reef Management, Future and Economic." *The Open Environmental Engineering Journal* 2 (1): 37–49.

Balmford, Andrew, James Beresford, Jonathan Green, Robin Naidoo, Matt Walpole, and Andrea Manica. 2009. "A Global Perspective on Trends in Nature-Based Tourism." *PLOS Biology* 7 (6): e1000144.

Barbier, Edward B., Sally D. Hacker, Chris Kennedy, Evamaria W. Koch, Adrian C. Stier, and Brian R. Silliman. 2011. "The Value of Estuarine and Coastal Ecosystem Services." *Ecological Monographs: Ecological Society of America* 81 (2): 169–193. https://doi.org/10.1890/10-1510.1.

Bayraktarov, Elisa, Megan I. Saunders, Sabah Abdullah, Morena Mills, Jutta Beher, Hugh P. Possingham, Peter J. Mumby, and Catherine E. Lovelock. 2016. "The Cost and Feasibility of Marine Coastal Restoration." *Ecological Applications: Ecological Society of America* 26 (4): 1055–1074.

Bayraktarov, Elisa, Phoebe J. Stewart-Sinclair, Shantala Brisbane, Lisa Boström-Einarsson, Megan I. Saunders, Catherine E. Lovelock, Hugh P. Possingham, Peter J. Mumby, and Kerrie A. Wilson. 2019. "Motivations, Success, and Cost of Coral Reef Restoration." *Restoration Ecology* 27 (5): 981–991.

Beck, Michael W., Robert D. Brumbaugh, Laura Airoldi, Alvar Carranza, Loren D. Coen, Christine Crawford, Omar Defeo, Graham J. Edgar, Boze Hancock, Matthew C. Kay, Hunter S. Lenihan, Mark Luckenbach, Caitlyn L. Toropova, Guofan Zhang, and Ximing Guo. 2011. "Oyster Reefs At Risk and Recommendations for Conservation, Restoration, and Management." *Bioscience* 61 (2): 107–116.

Bird, Eric C.F. 2000. *Coastal Geomorphology: An Introduction.* Chichester: Wiley and Sons.

Blanco-Pimentel, Macarena, Nicolas R. Evensen, Camilo Cortés-Useche, Johanna Calle-Triviño, Daniel J. Barshis, Victor Galván, Erika Harms, and Megan K. Morikawa. 2022. "All-Inclusive Coral Reef Restoration: How the Tourism Sector Can Boost Restoration Efforts in the Caribbean." *Frontiers in Marine Science* 9.

Booking.com. 2018. "Where Sustainable Travel is Headed in 2018." Booking.com News, April 17, 2018. https://news.booking.com/en/where-sustainable-travel-is-headed-in-2018/.

Booking.com. 2019. "Booking.com Reveals Key Findings from its 2019 Sustainable Travel Report." Booking.com News, April 17, 2019. https://news.booking.com/bookingcom-reveals-key-findings-from-its-2019-sustainable-travel-report.

Bos, Arthur R., and Marieke M. van Katwijk. 2007. "Planting Density, Hydrodynamic Exposure and Mussel Beds Affect Survival of Transplanted Intertidal Eelgrass." *Marine Ecology Progress Series* 336: 121–129.

Bosboom, Judith, and Marcel J.F. Stive. 2021. *Coastal Dynamics*. Delft: TU Delft Open Publishing.

Boto-García, David, and Veronica Leoni. 2023. "The Economic Value of Coastal Amenities: Evidence from Beach Capitalization Effects in Peer-to-Peer Markets." *Environmental Resource Economics* 84: 529–557. https://doi.org/10.1007/s10640-022-00735-5.

Bozzeda, Fabio, Leonardo Ortega, Leonardo Lopes Costa, Lucia Fanini, Carlos A.M. Barboza, Anton McLachlan, and Omar Defeo. 2023. "Global Patterns in Sandy Beach Erosion: Unraveling the Roles of Anthropogenic, Climatic and Morphodynamic Factors." *Frontiers in Marine Science* 10: 1270490.

Brathwaite, Angelique, Eric Clua, Ramon Roach, and Nicolas Pascal. 2022. "Coral Reef Restoration for Coastal Protection: Crafting Technical and Financial Solutions." *Journal of Environmental Management* 310: 114718.

Brew, David, Gregor Guthrie, Jenny McArthur, Alun Williams, and Bronwen Gibberd. 2005. *Coastal Processes and Geomorphology Training Course Manual.* Environment Agency, Peterborough.

Broome, S.W., Seneca, E.D., and Woodhouse, W.W. 1981. "Planting Marsh Grasses for Erosion Control." Sea Grant Publication. North Carolina University Sea Grant Program.

Burger, Joanna. 1995. "Beach Recreation and Nesting Birds." In *Wildlife and Recreationists: Coexistence Through Management and Research*, edited by Richard L. Knight and Kevin Gutzwiller, 281–295. Washington, DC: Island Press.

Cai, Wenju, Simon Borlace, Matthieu Lengaigne, Peter van Rensch, Mat Collins, Gabriel Vecchi, Axel Timmermann, Agus Santoso, Michael J. McPhaden, Lixin Wu, Matthew H. England, Guojian Wang, Eric Guilyardi, and Fei-Fei Jin. 2014. "Increasing Frequency of Extreme El Niño Events Due to Greenhouse Warming." *Nature Climate Change* 4 (2): 111–116. https://doi.org/10.1038/nclimate2100.

Carley, J.T., T.D. Shand, I.R. Coghlan, M.J. Blacka, R.J. Cox, A. Littman, B. Fitzgibbon, G. McLean, and P. Watson. 2010. "Beach Scraping as a Coastal Management Option." In Proceedings of the 19th NSW Coastal Conference, vol. 890.

Cesar, Herman S. J. 2002. *Coral Reefs: Their Functions, Threats and Economic Value.* AquaDocs Technical Report. https://aquadocs.org/handle/1834/557?show=full.

Christianen, Marjolijn. J., Jim van Belzen, Peter M.J. Herman, Merieke M. van Katwijk, Leon P.M. Lamers, Peter J.M. van Leent, and Tjeerd J. Bouma. 2013. "Low-Canopy Seagrass Beds Still Provide Important Coastal Protection Services." *PLOS One* 8 (5): e62413.

CoastAdapt. 2017. "What Shapes Our Coastlines?" https://coastadapt.com.au/sites/default/files/infographics/What_shapes_our_coastlines.pdf

Cone Communications. 2016. "Millennial Employee Engagement Study." Cone Communications, November 2, 2016. www.conecomm.com.

Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton, and Marjan van den Belt. 1997. "The Value of the World's Ecosystem Services and Natural Capital." *Nature* 387: 253–260. https://doi.org/10.1038/387253a0.

Cunniff, Shannon, and Aaron Schwartz. 2015. *Performance of Natural Infrastructure and Nature-Based Measures as Coastal Risk Reduction Features*. Technical report, Environmental Defense Fund, New York.

CZM (Massachusetts Office of Coastal Zone Management). n.d. "StormSmart Properties Fact Sheet 6: Sand Fencing. Commonwealth of Massachusetts." CZM, Boston. https://www.mass.gov/info-details/stormsmart-properties-fact-sheet-6-sand-fencing.

CZMAI (Coastal Zone Management Authority and Institute). 2016. *Belize Integrated Coastal Zone Management Plan*. Belize City: CZMAI.

Darvill, Blair. 2017. "CoastSWaP Coastal Management Case Studies (2/10), Brushing to Stabilise Exposed Sand Dunes and Blow-Outs." South West and Peel Coast Management Group Inc., WA. http://coastswap.org.au/PDF/CoastSWaP_Case_Study_2_Brushing.pdf.

Das, Saudamini. 2022. "Valuing the Role of Mangroves in Storm Damage Reduction in Coastal Areas of Odisha." In *Climate Change and Community Resilience: Insights from South Asia,* edited by A.K. Enamul Haque, Pranab Mukhopadhyay, Mani Nepal, and Md Rumi Shammin, 257–273. Singapore: Springer.

Deloitte. 2024. 2024 *Gen Z and Millennial Survey: Living and Working with Purpose in a Transforming World.* Deloitte, London. https://www.deloitte.com/global/en/issues/work/content/genz-millennialsurvey.html.

Defeo, Omar, Anton McLachlan, Derek Armitage, Michael Elliott, and Jeremy Pittman. 2021. "Sandy Beach Social-Ecological Systems at Risk: Regime Shifts, Collapses, and Governance Challenges." *Frontiers in Ecology and the Environment* 19 (10): 564–573.

de Groot Alma Vimala, Gerard M. Janssen, Maike Isermann, Martin Stock, Maria Glahn, Sebastiaan Martinus Arens, Kelly Elschot, Ulrich Hellwig, Jörg Petersen, Peter Esselink, Willem van Duin, Peter Körber, Kai Jensen, and Norbert Hecker. 2017. "Beaches and Dunes." In *Wadden Sea Quality Status* Report, edited by S. Kloepper, M.J. Baptist, A. Bostelmann, J.A. Busch, C. Buschbaum. L. Gutow, G. Janssen, K. Jensen, H.P. Jørgensen, F. de Jong, G. Lüerßen, K. Schwarzer, R. Strempel, and D. Thieltges. Wadden Sea World Heritage, Wilhelmshaven. https://qsr.waddensea-worldheritage.org/reports/beaches-and-dunes

de Schipper, Matthieu A., Bonnie C. Ludka, Britt Raubenheimer, Arjen P. Luijendijk, and Thomas. A. Schlacher. 2021. "Beach Nourishment Has Complex Implications for the Future of Sandy Shores." *Nature Reviews Earth & Environment* 2: 70–84. https://doi.org/10.1038/s43017-020-00109-9.

DiVenere, Vic. 2017. "Columbia University Summer Session 2017, Earth and Environmental Sciences, Introduction to Earth Sciences I, Coastal Processes." https://www.columbia.edu/~vjd1/coastal_basic.htm.

Dodds, Rachel, and Mark Robert Holmes. 2019. "Beach Tourists; What Factors Satisfy Them and Drive Them to Return." *Ocean & Coastal Management* 168: 158–166.

Domingues, Ricardo, Gustavo Goni, Molly Baringer, and Denis Volkov. 2018. "What Caused the Accelerated Sea Level Changes Along the U.S. East Coast During 2010–2015?" *Geophysical Research Letters* 45 (24): 13367–13376. https://doi.org/10.1029/2018GL081183.

Duarte, Carlos M., ed. 2009. *Global Loss of Coastal Habitats: Rates, Causes and Consequences*. Madrid: Fundación BBVA.

Dushani Salpage, Nesha, Margrethe Aanesen, and Godwin Kofi Vondolia. 2021. "Balancing Conservation Goals and Ecotourism Development in Coastal Wetland Management in Sri Lanka: A Choice Experiment." *Ocean & Coastal Management* 210: 105659.

Edwards, Alasdair J., ed. 2010. *Reef Rehabilitation Manual*, Coral Reef Targeted Research & Capacity Building for Management Program, St. Lucia.

Edwards, Peter E.T., Ariana E. Sutton-Grier, and Coyle, G.E. 2013. "Investing in Nature: Restoring Coastal Habitat Blue Infrastructure and Green Job Creation." *Marine Policy* 38: 65–71. https://doi.org/10.1016/j.marpol.2012.05.020.

Ehler, Charles, and Fanny Douvere. 2009. *Marine Spatial Planning: A Step-by-step Approach Toward Ecosystem-Based Management*. UNESCO, London. https://unesdoc.unesco.org/ark:/48223/pf0000186559.

Emirates News Agency. 2020. "Mangrove Beach in Umm Al Quwain Opens to Visitors." Emirates News Agency, December 20, 2020. https://www.wam.ae/en/article/hszrbhir-%E2%80%98mangrove-beach%E2%80%99-umm-qaiwain-opens-visitors.

Enriquez-Acevedo, Tatiana, Camilo M. Botero, Ruben Cantero Rodelo, Ana Milena Pertuz Rodriguez, and Andres Suarez Agudelo. 2018. "Willingness to Pay for Beach Ecosystem Services: The Case Study of Three Colombian Beaches." *Ocean & Coastal Management* 161: 96–104.

Escovar-Fadul, Ximena, Margaux Hein, K. Garrison, Elizabeth McLeod, M. Eggers, and F. Comito. 2022. *A Guide to Coral Reef Restoration for the Tourism Sector: Partnering with Caribbean Tourism Leaders to Accelerate Coral Restoration. The Nature Conservancy, Arlington.*

European Commission, Directorate-General for Environment, Tanya Huizer, Maria Ferreira, Patrycja Czerniak, Remment ter Hofstede, Annemie Volckaert, Erik Devilee, Rob Steijn. 2012. *Integrated Coastal Zone Management: OURCOAST, Outcomes and Lessons Learned.* European Union Publications Office. https://data.europa.eu/doi/10.2779/9345.

European Commission. 2000. "Communication from the Commission to the Council and the European Parliament on Integrated Coastal Zone Management: A Strategy for Europe." European Union, Brussels.

FitzGerald, Duncan M., Michael S. Fenster, Britt A. Argow, and Ilya V. Buynevich. 2008. "Coastal Impacts Due to Sea-Level Rise." *Annual Review of Earth and Planetary Sciences* 36: 601–647. https://doi.org/10.1146/annurev.earth.35.031306.140139.

Fitzsimons, James A., Simon Branigan, Chris L. Gillies, Robert D. Brumbaugh, Jun Cheng, Bryan M. DeAngelis, Laura Geselbracht, Boze Hancock, Andrew Jeffs, Tein McDonald, Ian M. McLeod, Bernadette Pogoda, Seth J. Theuerkauf, Marine Thomas, Stephanie Westby, and Philine S.E. zu Ermgassen. 2020. "Restoring Shellfish Reefs: Global Guidelines for Practitioners and Scientists." *Conservation Science and Practice* 2 (6): 198.

Fletcher, Lauren. 2020. "A Stunning New 'Mangrove Beach' is Now Open in the UAE." What's On, December 21, 2020. https://whatson.ae/2020/12/a-stunning-new-mangrove-beach-is-now-open-in-the-uae/.

Fox-Kemper, Baylor, Helene T. Hewitt, Cunde Xiao, Guðfinna Aðalgeirsdóttir, Sybren Drijfhout, Tamsin L. Edwards, Nicholas R. Golledge, Mark Hemer, Robert E. Kopp, Gerhard Krinner, Alan C. Mix, Dirk Notz, Sophie Nowicki, Intan Suci Nurhati, Lucas Ruiz, Jean-Baptiste Sallee, Aimee B.A. Slangen, and Yongqiang Yu. 2021. "Ocean, Cryosphere and Sea Level Change." In *Climate Change 2021: The Physical Science Basis,* edited by Valérie Masson-Delmotte, Panmao Zhai, Anna Pirani, Sarah L. Connors, Clotilde Péan, Yang Chen, Leah Goldfarb, Melissa I. Gomis, J.B. Robin Matthews, Sophie Berger, Mengtian Huang, Ozge N. Yelekçi, Rong Yu, Baiquan Zhou, Elisabeth Lonnoy, Thomas K. Maycock, Tim Waterfield, Katherine Leitzell, and Nada Caud, 1211–1362. Cambridge University Press: Cambridge.

Franzen, Monique O., Elisa H.L. Fernandes, and Eduardo Siegle. 2021. "Impacts of Coastal Structures on Hydro-Morphodynamic Patterns and Guidelines Towards Sustainable Coastal Development: A Case Studies Review." *Regional Studies in Marine Science* 44: 101800. https://doi.org/10.1016/j.rsma.2021.101800.

Friess, Daniel A., Erik S. Yando, Jahson B. Alemu, Lynn-Wei Wong, Sasha D. Soto, and Natasha Bhatia. 2020. "Ecosystem Services and Disservices of Mangrove Forests and Salt Marshes." In *Oceanography and Marine Biology, An Annual Review,* edited by S.J. Hawkins, A.L. Allcock, A.E. Bates, A.J. Evans, L.B. Firth, C.D. McQuaid, B.D. Russell, I.P. Smith, S.E. Swearer, and P.A. Todd. Boca Raton: CRC Press.

Gainza, June, Roland Garnier, Paula Nuñez, Camilo Jaramillo, Ernesto Mauricio González, Raúl Medina, Pedro Liria, Irati Epelde, Adolfo Uriarte, Manu Monge-Ganuzas. 2019. "Accelerating Beach Recovery by Plowing the Intertidal Bar: A Field Experiment along the Northern Spanish Coast." *Journal of Coastal Research* 35 (5): 973–984.

Georgopoulou, Elena, Sebastian Mirasgedis, Y. Sarafidis, V. Hontou, N. Gakis, and D.P. Lalas. 2019. "Climatic Preferences for Beach Tourism: An Empirical Study on Greek Islands." *Theoretical Applied Climatology* 137: 667–691. https://doi.org/10.1007/s00704-018-2612-4.

Gittman, Rachel K., Steven B. Scyphers, Carter S. Smith, Isabelle P. Neylan, and Jonathan H. Grabowski. 2016. "Ecological Consequences of Shoreline Hardening: A Meta-Analysis." *BioScience* 66 (9): 763–773. https://doi.org/10.1093/biosci/biw091.

Gordon, Angus D. 2015. "When Did You Last NABE a Beach? Beach Scraping Demystified for Fun and Profit." Proceedings of the 24th New South Wales Coastal Conference, "Great Expectations – Pathways for Learning and Delivery," Forster, November 11–13, 2015.

Gornitz, Vivien, Tammy W. White, and Robert M. Cushman. 1991. "Vulnerability of the US to Future Sea Level Rise." Proceedings of the Symposium on Coastal and Ocean Management, Long Beach, July 8-12, 1991.

Gracia, Adriana, Nelson Rangel-Buitrago, Judith A. Oakley, and Allan T. William. 2018. "Use of Ecosystems in Coastal Erosion Management." *Ocean & Coastal Management* 156: 277–289. https://doi.org/10.1016/j.ocecoaman.2017.07.009.

Greene, Karen. 2002. *Beach Nourishment: A Review of the Biological and Physical Impacts.* ASMFC Habitat Management Series #7, Atlantic States Marine Fisheries Commission, Washington, DC.

Hakim, Lugas Lukmanul. 2017. "Cost and Benefit Analysis for Coastal Management: A Case Study of Improving Aquaculture and Mangrove Restoration Management in Tambakbulusan Village Demak Indonesia." MSc thesis, Wageningen University.

Hampton, Mark P., and Julia Jeyacheya. 2020. "Tourism-Dependent Small Islands, Inclusive Growth, and the Blue Economy." *One Earth* 2 (1): 8–10. https://doi.org/10.1016/j.oneear.2019.12.017.

Hanley, Mick E., Simon P.G. Hoggart, David John Simmonds, A. Bichot, Marina A. Colangelo, Fabio Bozzeda, Hugues Heurtefeux, Barbara Ondiviela, Rafal Ostrowski, Maria Recio, R. Trude, Elżbieta Zawadzka, and R.C. Thompson. 2014. "Shifting Sands? Coastal Protection by Sand Banks, Beaches and Dunes." *Coastal Engineering* 87: 136–146.

Harris, Danier L., Alessio Rovere, Elisa Casella, Hannah Power, Remy Canavesio, Antoine Collin, Andrew Pomeroy, Jody M. Webster, and Valeriano Parravicini. 2018. "Coral Reef Structural Complexity Provides Important Coastal Protection from Waves Under Rising Sea Levels." *Science Advances* 4 (2): eaao4350. https://www.science.org/doi/10.1126/sciadv.aao4350.

Harris, Linda R., and Omar Defeo. 2022. "Sandy Shore Ecosystem Services, Ecological Infrastructure, and Bundles: New Insights and Ierspectives." *Ecosystem Services* 57: 101477. https://doi.org/10.1016/j.ecoser.2022.101477.

Hashim, Ahmad Mustafa, Sim Mong Pheng Catherine, and Husna Takaijudin. 2013. "Effectiveness of Mangrove Forests in Surface Wave Attenuation: A Review." *Research Journal of Applied Sciences, Engineering and Technology* 5 (18): 4483–4488.

Heger, Martin Philipp, and Lukas Vashold. 2021. Disappearing Coasts in the Maghreb: Coastal Erosion and Its Costs. World Bank, Washington, DC. https://thedocs.worldbank.org/en/doc/8320c30ab5eee11e7ec39f7f9496b936-0280012021/original/Note-Cost-of-Coastal-Erosion-En.pdf

Hein, Margaux Y., Ian Michael McLeod, Elizabeth C. Shaver, Tali Vardi, Sylvain Pioch, Lisa Boström-Einarsson, Ahmed Mohamed, and Gabriel Grimsditch. 2020. *Coral Reef Restoration as a Strategy to Improve Ecosystem Services – A Guide to Coral Restoration Methods.* United Nations Environment Program, Nairobi.

Hesp, Patrick A. 2004. "Coastal Dunes In the Tropics and Temperate Regions: Location, Formation, Morphology and Vegetation Processes." In *Coastal Dunes: Ecology and Conservation*, edited by M. Luisa Martinez and Norbert P. Psuty, 29–49. Berlin: Springer.

Horng, Jeou-Shyan, and Chen-Tsang Tsai. 2012. "Culinary Tourism Strategic Development: An Asia-Pacific Perspective." *International Journal of Tourism Research* 14 (1): 40–55.

Houston, James R. 2008. "The Economic Value of Beaches: A 2008 Update." Shore & Beach, 76 (3): 22–26.

Houston, James R. 2018. "The Economic Value of America's Beaches: A 2018 Update." *Shore & Beach* 86 (2): 3–13. https://asbpa.org/wp-content/uploads/2018/05/Houston_Spring-2018_86_2_color.pdf.

Hudson, Rachel, Joe Kenworthy, and Mike Best, eds. 2021. *Saltmarsh Restoration Handbook: UK and Ireland.* Bristol: Environment Agency.

Hülsen, Sarah, Robert I. McDonald, Rebecca Chaplin-Kramer, David N. Bresch, Richard Sharp, Thomas Worthington, and Chahan M. Kropf. 2023. "Global Coastal Protection Benefits of Ecosystems – Past, Present, and Under Climate Change." *Environmental Research Letters,* 18 (12).

Infantes, Eduardo, Alejandro Orfila, Gonzalo Simarro, Jorge Terrados, Mitul Luhar, and Heidi Nepf. 2012. "Effect of a Seagrass (Posidonia oceanica) Meadow on Wave Propagation." *Marine Ecology Progress Series* 456: 63–72.

IPCC (Intergovernmental Panel on Climate Change). 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Synthesis report, IPCC, Geneva. https://www.ipcc.ch/report/ar5/syr/.

IPCC (Intergovernmental Panel on Climate Change). 2019. *Special Report on the Ocean and Cryosphere in a Changing Climate*. IPCC, Geneva. https://www.ipcc.ch/srocc/.

Itzkin, Michael, Laura J. Moore, Peter Ruggiero, and Sally D. Hacker. 2020. "The Effect of Sand Fencing on the Morphology of Natural Dune Systems." *Geomorphology* 352: 106995.

Jamieson, Samantha Lee. 2010. "Sand Dune Restoration in New Zealand: Methods, Motives, and Monitoring." Doctoral dissertation, Te Herenga Waka-Victoria University of Wellington.

Jongman, Brenden, Ruth Tiffer Sotomayor, and Xueman Wang. 2022. "Nature-Based Solutions for Resilient Cities and Restoring Local Biodiversity." World Bank Blogs, May 19, 2022. https://blogs.worldbank.org/en/sustainablecities/nature-based-solutions-resilient-cities-and-restoring-local-biodiversity.

Kairo, J.G., J. Bosire, Kipkorir Sigi Lang'at, Bernard Kirui, and Nico Koedam. 2009. "Allometry and Biomass Distribution in Replanted Mangrove Plantations at Gazi Bay, Kenya." *Aquatic Conservation: Marine and Freshwater Ecosystems* 19 (S1): S63–S69.

Karimi, Zahra, Ehsan Abdi, Azade Deljouei, Alessio Cislaghi, Anoushirvan Shirvany, Massimiliano Schwarz, and T.C. Hales. 2022. "Vegetation-Induced Soil Stabilization in Coastal Area: An Example from a Natural Mangrove Forest." *Catena* 216: 106410.

Kirwan, Matthew L., Glenn R. Guntenspergen, Andre d'Alpaos, James T. Morris, Simon M. Mudd, and Stijn Temmerman. 2010. "Limits on the Adaptability of Coastal Marshes to Rising Sea Level." *Geophysical Research Letters* 37 (23).

Krauss, Ken. W., Catherine E. Lovelock, Karen L. McKee, Laura López-Hoffman, Sharon M.L. Ewe, and Wayne P. Sousa. 2008. "Environmental Drivers in Mangrove Establishment and Early Development: A Review." *Aquatic Botany* 89 (2): 105–127.

Krauss, Ken W., Thomas W. Doyle, Terry J. Doyle, Christopher Swarzenski, Andrew S. From, Richard H. Day, and William H. Conner. 2009. "Water Level Observations in Mangrove Swamps During Two Hurricanes in Florida." *Wetlands* 29: 142–149.

Landry, Craig E., Andrew G. Keeler, and Warren Kriesel. 2003. "An Economic Evaluation of Beach Erosion Management Alternatives." *Marine Resource Economics* 18 (2): 105–127. https://doi.org/10.1086/mre.18.2.42629388.

Lansu, Eva M., Valerie C. Reijers, Solveig Höfer, Arjen Luijendijk, Max Rietkerk, Martin J. Wassen, Evert Jan Lammerts, and Tjisse van der Heide. 2024. "A Global Analysis of How Human Infrastructure Squeezes Sandy Coasts." Nature Communications 15: 432. https://doi.org/10.1038/s41467-023-44659-0.

Lee, Tong, and Michael J. McPhaden. 2010. "Increasing Intensity of El Niño in the Central Equatorial Pacific." *Geophysical Research* Letters 37 (14). https://doi.org/10.1029/2010GL044007.

Lenzen, Manfred, Ya-Yen Sun, Futu Faturay, Yuan-Peng Ting, Arne Geschke, and Arunima Malik. 2018. "The Carbon Footprint of Global Tourism." *Nature Climate Change* 8 (6): 522–528.

Lieuw-Kie-Song, Maikel, and Vanessa Pérez-Cirera. 2020. *Nature Hires: How Nature-Based Solutions Can Power a Green Jobs Recovery*. Gland and Geneva: World Wide Fund for Nature and International Labour Organization.

Lima, Izael, Ascânio D. Araújo, Eric J.R. Parteli, José S. Andrade, and Hans J. Herrmann. "Optimal Array of Sand Fences." *Scientific Reports* 7: 45148. https://doi.org/10.1038/srep45148.

Lins-de-Barros, Flavia, and Leticia Parente-Ribeiro. 2018. "How Much Is a Beach Worth: Economic Use and Vulnerability to Coastal Erosion: The Case of Ipanema and Arpoador Beaches, Rio de Janeiro (Brazil)." In *Climate Change Adaptation in Latin America: Managing Vulnerability, Fostering Resilience,* edited by Walter Leal Filho and Leonardo Esteves de Freitas, 207–222. Berlin: Springer.

Lipton Douglas. 2004. "The Value of Improved Water Quality to Chesapeake Bay Boaters." *Marine Resource Economics* 19: 265–270.

Lloyd's of London. 2018. *Innovative Finance for Resilient Infrastructure.* Innovation report, London.

Lodder, Quirijn J., Claire Jeuken, Richard Reinen-Hamill, Oli Burns, Robert Ramsdell, Jurre de Vries, Brian McFall, Stéphanie IJff, Corragio Maglio, and Rinse Wilmink. 2021. Beaches and Dunes. In *Natural and Nature-Based Features Guidelines,* edited by Todd S. Bridges, Jeffrey K. King, Jonathan D. Simm, Michael W. Beck, Georganna Collins, Quirijn J. Lodder, and Ram K. Mohan, 329–412. U.S. Army Engineer Research and Development Center, Vicksburg. https://ewn.erdc.dren.mil/nnbf-guidelines/09-beaches-and-dunes/.

Louis Berger and Associates. 1997. Costs for *Wetland Creation and Restoration Projects in the Glaciated Northeast.* U.S. Environmental Protection Agency, Boston.

Luijendijk, Arjen, Gerben Hagenaars, Roshanka Ranasinghe, Fedor Baart, Gennadii Donchyts, and Stefan Aarninkhof. 2018. "The State of the World's Beaches." *Scientific Reports* 8 (1): 1–11.

MacDonnell, Conor P., Li Zhang, Lauren N. Griffiths, and William J. Mitsch. 2017. "Nutrient Concentrations in Tidal Creeks as Indicators of the Water Quality Role of Mangrove Wetlands in Southwest Florida." *Ecological Indicators* 80: 316–326.

Madsen, John D., Patricia A. Chambers, William F. James, Evamaria W. Koch, and D.F. Westlake. 2001. "The Interaction Between Water Movement, Sediment Dynamics And Submersed Macrophytes." *Hydrobiologia* 444: 71–84.

Maldives Financial Review. 2022. "Coastal Erosion and Government Ignorance." Maldives Financial Review, December 14, 2022. https://mfr.mv/climate-change-and-environment/coastal-erosion-and-government-ignorance.

Marchand, Marcel. 2008. *Mangrove Restoration in Vietnam: Key Considerations and a Practical Guide.* WRU/TUD, Ho Chi Minh City.

Masselink, Gerd, and Eli D. Lazarus. 2020. Erratum: "Defining Coastal Resilience." *Water* 12 (5): 1368.

McKenzie, Len J., Lina Mtwana Nordlund, Benjamin L.H. Jones, Leanne C. Cullen-Unsworth, Chris Roelfsema, and Richard K.F. Unsworth. 2020. "The Global Distribution of Seagrass Meadows." *Environmental Research Letters* 15 (7): 074041.

McKinley, Emma, Rhoda Catherine Ballinger, and Nicola Beaumont. 2018. "Saltmarshes, Ecosystem Services, and an Evolving Policy Landscape: A Case Study of Wales, UK." *Marine Policy* 91: 1–10.

Menéndez, Pelayo, Iñigo J. Losada, Saul Torres-Ortega, Siddharth Narayan, and Michael W. Beck. 2020. "The Global Flood Protection Benefits of Mangroves." *Scientific Reports* 10 (1): 1–11.

Möller, Iris, Matthias Kudella, Franziska Rupprecht, Tom Spencer, Maike Paul, Bregje K. Van Wesenbeeck, Guido Wolters, Kai Jensen, Tjeerd J. Bouma, Martin Miranda-Lange, and Stefan Schimmels. 2014. "Wave Attenuation over Coastal Salt Marshes under Storm Surge Conditions." *Nature Geoscience* 7 (10): 727–731.

Morris Rebecca L., Melanie J. Bishop, Paul Boon, Nicola K. Browne, James T. Carley, Benedikt J. Fest, Michael W. Fraser, Marco Ghisalberti, Gary A. Kendrick, Teresa M. Konlechner, Catherine E. Lovelock, Ryan J. Lowe, Abbie A. Rogers, Viveka Simpson, Elisabeth M.A. Strain, Arnold A. Van Rooijen, Elissa Waters, and Stephen E. Swearer. 2021. *The Australian Guide to Nature-Based Methods for Reducing Risk from Coastal Hazards.* Earth Systems and Climate Change Hub Report No. 26., NESP Earth Systems and Climate Change Hub, Canberra.

Mtwana Nordlund, Lina, Evamaria W. Koch, Edward B. Barbier, and Joel C. Creed. 2016. "Seagrass Ecosystem Services and Their Variability Across Genera and Geographical Regions." *PLOS One* 11 (10): e0163091.

Muñoz-Vallés, Sara, and Jesús Cambrollé. 2014. "Successes and Failures in the Management of Coastal Dunes of SW Spain: Status Analysis Nine Years After Management Decisions." *Ecological Engineering* 71: 415–425.

NACC (Northern Agricultural Catchments Council). 2018. "Giving Blowouts the Brush-Off." News page, January 25, 2018. https://www.nacc.com.au/giving-blowouts-brush-off.

Narayan, Siddharth Michael W. Beck, Borja G. Reguero, Iñigo J. Losada, Bregje van Wesenbeeck, Nigel Pontee, James N. Sanchirico, Jane Carter Ingram, Glenn-Marie Lange, and Kelly A. Burks-Copes. 2016. "The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences." *PloS One*, 11 (5): e0154735.

Natural Capital Committee. 2019. "Natural Capital Terminology." Department for Environment, Food and Rural Affairs paper, London. https://assets.publishing.service.gov.uk/media/5f352ebbe90e0732e2d7ca58/ncc-terminology.pdf.

Nature4Climate. 2020. "Nature-Positive Recovery: For People, Economy and Climate." Nature Metrics, Arlington. https://nature4climate.org/news/nature-positive-recovery-for-people-economy-climate/.

CARICHAM (Network of Caribbean Chambers of Commerce). 2024. "Business Resilience Toolkit." CARICHAM, St. George's. https://www.caribbeanchambers.net/caricham-bcp.

Nicholls, Robert J., Poh Poh Wong, Virginia Burkett, Jorge Codignotto, John Hay, Roger McLean, Sachooda Ragoonaden, and Colin D. Woodroffe. "Climate Change 2007: Impacts, Adaptation and Vulnerability." In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by Martin L. Parry, Osvaldo F. Canziani, Jean P. Palutikof, Paul J. van der Linden, and Clair E. Hanson, 315–356. Cambridge, Cambridge University Press.

Nielsen. 2018. The Database: "What Sustainability Means Today." Insights. October 2018. https://www.nielsen.com/insights/2018/what-sustainability-means-today/.

Nordstrom, Karl F. 2021. *Beach and Dune Restoration.* Cambridge: Cambridge University Press.

Nordstrom, Karl F., and Nancy L. Jackson. 2013. "Restoring and Enhancing the Resilience of Beach and Dune Systems." *Journal of Coastal Research* 29 (6A): 161–168.

Nordstrom, Karl F., Nancy L. Jackson, and Kana, T. W. 2021. Beaches and dunes. In *International Guidelines on Natural and Nature-Based Features for Flood Risk Management,* edited by Jeffrey K. King, Jonathan D. Simm, Michael W. Beck, Georganna Collins, Quirijn J. Lodder, and Ram K. Mohan, 9-1–9-52. U.S. Army Engineer Research and Development Center, Vicksburg. https://ewn.erdc.dren.mil/international-guidelines-on-natural-and-nature-based-features-for-flood-risk-management/.

Northrop, Eliza, Peter Schuhmann, Lauretta Burke, Alan Fyall, Sergio Alvarez, Anna Spenceley, Susanne Becken, Kumi Kato, Joyashree Roy, Shreya Some, Joeli Veitayaki, Anil Markandya, Ibon Galarraga, Patxi Greño, Itziar Ruiz-Gauna, Matt Curnock, Megan Epler Wood, Melody Yue Yin, Sibylle Riedmiller, Eleanor Carter, Rizky Haryanto, Elizabeth Holloway, Robertico Croes, Jorge Ridderstaat, and Maksim Godovykh. 2022. *Opportunities for Transforming the Coastal and Marine Tourism: Towards Sustainability, Regeneration and Resilience.* The Ocean Panel. https://oceanpanel.org/opportunity/sustainable-coastal-marine-tourism/.

NSW Department of Land and Water Conservation. 2001. *Coastal Dune Management: A Manual of Coastal Dune Management and Rehabilitation Techniques.* DLWC Coastal Unit, New South Wales. https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Water/Coasts/coastal-dune-management-manual.pdf.

Odum, William E. 1988. "Comparative Ecology of Tidal Freshwater and Salt Marshes." *Annual Review of Ecology and Systematics* 19 (1): 147–176.

OECD (Organisation for Economic Co-operation and Development). 2016. *Development Co-operation Report 2016: The Sustainable Development Goals as Business Opportunities."* OECD Publishing, Paris. https://doi.org/10.1787/dcr-2016-en.

Ondiviela, Barbara, Losada, Iñigo J. Losada, Javier L. Lara, Maria Maza, Cristina Galván, Tjeerd J. Bouma, and Jim van Belzen. 2014. "The Role of Seagrasses in Coastal Protection in a Changing Climate." *Coastal Engineering* 87: 158–168.

Orams, Mark B. 2003. "Sandy Beaches as a Tourism Attraction: A Management Challenge for the 21st Century." *Journal of Coastal Research* 74–84.

OzFish 2019, Seeds For Snapper, Seagrass Restoration 2019, Cockburn Sound, WA. https://ozfish.org.au/projects/seagrass-restoration-2019/

Padma, Panchapakesan, Sundari Ramakrishna, and S. Mostafa Rasoolimanesh. 2022. "Nature-Based Solutions in Tourism: A Review of the Literature and Conceptualization." *Journal of Hospitality & Tourism Research* 46 (3): 442–466.

Pafi, Maria, Wesley Flannery, and Brendan Murtagh. 2020. "Coastal Tourism, Market Segmentation and Contested Landscapes." *Marine Policy* 121: 104189.

Patrick, Christopher J., L. Yeager, Anna R. Armitage, Fernando Carvallo, Victoria M. Congdon, Kenneth H. Dunton, Mark R. Fisher, Amber Hardison, J.D. Hogan. Jacob D. Hosen, X. Hu, Brandi Kiel Reese, Sean Kinard, John S. Kominoski, Xianbiao Lin, Zhanfei Liu, Paul A. Montagna, S.C. Pennings, Lily Walker, C.A. Weaver, and Michael Wetz. 2020. "A System Level Analysis of Coastal Ecosystem Responses to Hurricane Impacts." *Estuaries and Coasts* 43: 943–959. https://doi.org/10.1007/s12237-019-00690-3.

Pellón, Erica, Íñigo Aniel-Quiroga, Mauricio González, Raúl Medina, and Cesar Vidal. 2023. "Working with Nature to Enhance Beach Accretion: Laboratory Experiments of Beach Ploughing." *Coastal Engineering* 180: 104267. https://doi.org/10.1016/j.coastaleng.2022.104267.

Perricone, Valentina, Mirko Mutalipassi, Antonio Mele, Mario Buono, Diego Vicinanza, and Pasquale Contestabile. 2023. "Nature-Based and Bioinspired Solutions for Coastal Protection: An Overview among Key Ecosystems and a Promising Pathway for New Functional and Sustainable Designs." *ICES Journal of Marine Science* 80 (5): 1218–1239. https://doi.org/10.1093/icesjms/fsad080.

Perry, Chris T., and Lorenzo Alvarez-Filip. 2019. "Changing Geo-Ecological Functions of Coral Reefs in the Anthropocene." *Functional Ecology* 33 (6): 976–988.

Potouroglou, Maria, Abbi Scott, Anchana Prathep, Ariane Arias-Ortiz, Benjamin Jones, Catherine Collier, Genki Terauchi, Fanny Kerninon, Hilary Kennedy, Inés Mazarrasa, Janmanee Panyawai, Jennifer O'Leary, Joel Creed, Laura Griffiths, Len McKenzie, Lina Mtwana Nordlund, Milica Stankovic, Patricia Arenas González, Peter Macreadie, Rohani Ambo-Rappe, Salomão Bandeira, Tantely Tianarisoa, Tatsuyuki Sagawa, Teruhisa Komatsu, and Wawan Kiswara. 2020. *Out of the Blue: The Value of Seagrasses to the Environment and to People.* United Nations Environment Programme, Nairobi.

Ramieri, Emiliano, Andrew Hartley, Andrea Barbanti, Filipe Duarte Santos, Ana Gomes, Mikael Hilden, Pasi Laihonen, Natasha Marinova, and Monia Santini. 2011. "Methods for Assessing Coastal Vulnerability to Climate Change." ETC/CCA Technical Paper 1/2011, European Environment Agency, Bologna.

Rego, João Lima, Jorge de Brito, and Joana Mira Veiga. 2023. *Roteiro de base para minimização da extracção de areias costeiras em São Tomé e Príncipe.* World Bank, Washington, DC. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099841506192425069/idu1cf0850b7150cd14e4f1b53e166095fddee3d.

Reguero, Borja G., Michael W. Beck, David N. Bresch, Juliano Calil, and Imen Meliane. 2018. "Comparing the Cost Effectiveness of Nature-Based and Coastal Adaptation: A Case Study from the Gulf Coast of the United States." PLOS One, 13 (4): e0192132. https://doi.org/10.1371/journal.pone.0192132.

Reidenbach, Matthew A., and Emily L. Thomas. 2018. "Influence of the Seagrass, Zostera marina, on Wave Attenuation and Bed Shear Stress within a Shallow Coastal Bay." *Frontiers in Marine Science* 5: 397.

RISC-KIT (Resilience-Increasing Strategies for Coasts – toolkit). 2017a. "Dune Fencing." European Union. https://coastal-management.eu/dune-fencing.html.

RISC-KIT (Resilience-Increasing Strategies for Coasts – toolkit). 2017b. "Example: Cost-Effectiveness Analysis of a Wooden Path over the Dune (Praia de Faro, PT)." European Union. https://www.coastal-management.eu/measure/example-cost-effectiveness-analysis-wooden-path-over-dune-praia-de-faro-pt.

Rogers, Abbie A., Michael P. Burton, John Statton, Matthew W. Fraser, Gary Kendrick, Elizabeth Sinclair, Daniel Gorman, Mat Vanderklift, Jennifer Verduin, and Ian M. McLeod. 2019. *Benefits and Costs of Alternate Seagrass Restoration Approaches.* Report to the National Environmental Science Programme, Marine Biodiversity Hub, University of Western Australia.

Rogers, Abbie A., Anita Nedosyko, Ian M. McLeod, Chris Gillies, and Michael P. Burton. 2018. *Benefit-Cost Analysis of the Windara Shellfish Reef Restoration Project.* Report to the National Environmental Science Program, Marine Biodiversity Hub, University of Western Australia.

Ruessink, Gerben, Chris Blenkinsopp, Joost Brinkkemper, Bruno Castelle, Benjamin Dubarbier, Florent Grasso, J.A. Puleo, and Thijs Lanckriet. 2016. "Sandbar and Beach-Face Evolution on a Prototype Coarse Sandy Barrier." *Coastal Engineering* 113: 19–32.

Ryzhakov, Pavel B., Pedro Hermosilla, Pere-Andreu Ubach, and Eugenio Oñate. 2022. "Adaptive Breakwaters with Inflatable Elements for Coastal Protection: Preliminary Numerical Estimation of Their Performance." *Ocean Engineering* 251: 110818. https://doi.org/10.1016/j.oceaneng.2022.110818.

Shaver, Elizabeth C., Catherine A. Courtney, Jordan M. West, Jeffrey Maynard, Margaux Hein, Cherie Wagner, Jason Philibotte, Petra MacGowan, Ian McLeod, Lisa Boström-Einarsson, Kristine Bucchianeri, Lyza Johnston, and Jennifer Koss. 2020. *A Manager's Guide to Coral Reef Restoration Planning and Design.* NOAA Coral Reef Conservation Program, NOAA Technical Memorandum CRCP 36, Silver Spring.

Schlacher, Thomas A., Dave S. Schoeman, Jenifer Dugan, Mariano Lastra, Alan Jones, Felicitia Scapini, and Anton McLachlan. 2008. "Sandy Beach Ecosystems: Key Features, Sampling Issues, Management Challenges, and Climate Change Impacts." *Marine Ecology* 29 (Suppl. 1):70–90.

Schug, Donald M., Kelly Baxter, and Katharine Wellman. 2009. *Valuation of Ecosystem Services from Shellfish Restoration, Enhancement and Management: A Review of the Literature.* Northern Economics Inc. Report, Pacific Shellfish Institute, Anchorage.

Schuhmann, Peter W., Brittany E. Bass, James F. Casey, and David A. Gill. 2016. "Visitor Preferences and Willingness to Pay for Coastal Attributes in Barbados." *Ocean & Coastal Management* 134: 240–250. https://doi.org/10.1016/j.ocecoaman.2016.09.020.

Secaira Fajardo, Fernando, Borja G. Reguero, and Cesar Acevedo Ramírez. 2017. *The Importance of Reefs and Dunes in Coastal Protection in the Mexican Caribbean – Document Summary.* Technical Series: The Role of Natural Systems in Coastal Dynamics in the Mexican Caribbean, The Nature Conservancy, Mexico.

Shepard, Christine C., Caitlin M. Crain, and Michael W. Beck. 2011. "The Protective Role of Coastal Marshes: A Systematic Review and Meta-Analysis." *PLOS One*, 6 (11): e27374.

Short, Frederick T., Time J.B. Carruthers, William Dennison, and Michelle Waycott. 2007. "Global Seagrass Distribution and Diversity: A Bioregional Model." *Journal Of Experimental Marine Biology And Ecology* 350 (1–2): 3–20.

Sigren, Jacob M., Jens Figlus, and Anna R. Armitage. 2014. "Coastal Sand Dunes and Dune Vegetation: Restoration, Erosion, and Storm Protection." *Shore & Beach* 82 (4): 5–12.

Silva, Rodolfo, M. Luisa Martinez, Itxaso Odériz, Edgar Mendoza, and Rusty A. Feagin. 2016. "Response of Vegetated Dune–Beach Systems to Storm Conditions." *Coastal Engineering* 109: 53–62.

Spalding, Mark, Lauretta Burke, Spencer A. Wood, Joscelyne Ashpole, James Hutchison, and Philine zu Ermgassen. 2017. "Mapping the Global Value and Distribution of Coral Reef Tourism." *Marine Policy* 82: 104–113.

Sun, Yujie, Jie Li, Kejia Zhang, Jingxuan Wu, and Xin Yuan. 2019. *Tourism in Small Island Developing States.* SSRN, Amsterdam. https://doi.org/10.2139/ssrn.4634270.

Swiss Re Group. 2022. "Designing a New Type of Insurance to Protect the Coral Reefs, Economies and the Planet." Insights, May 17, 2022. https://www.swissre.com/our-business/public-sector-solutions/thought-leadership/new-type-of-insurance-to-protect-coral-reefs-economies.html.

Swiss Re Group. 2024. "Insurance to Protect Natural Assets and Enable Nature-Based Solutions." Public Sector Solutions. https://www.swissre.com/our-business/public-sector-solutions/insurance-to-protect-natural-assets-and-enable-nature-based-solutions.html.

Syvitski, James P.M., Albert J. Kettner, Irina Overeem, Eric W. H. Hutton, Mark T. Hannon, G. Robert Brakenridge, John Day, Charles Vörösmarty, Yoshiki Saito, Liviu Giosan, and Robert J. Nicholls. 2009. "Sinking Deltas Due to Human Activities." *Nature Geoscience* 2 (10): 681–686. https://doi.org/10.1038/ngeo629.

Tan, Yi Mei, Oliver Dalby, Gary A. Kendrick, John Statton, Elizabeth A. Sinclair, Matthew W. Fraser, Peter Macreadie, Chris L. Gillies, Rhys A. Coleman, Michelle Waycott, Kor-jent van Dijk, Adriana Verges, Jeff D. Ross, Marnie L. Campbell, Fleur E. Matheson, Emma L. Jackson, Andrew D. Irving, Laura L. Govers, Rod M. Connolly, Ian M. McLeod, Michael A. Rasheed, Hugh Kirkman, Mogens R. Flindt, Troels Lange, Adam D. Miller, and Craig D. H. Sherman. 2020. "Seagrass Restoration is Possible: Insights and Lessons from Australia and New Zealand." *Frontiers in Marine Science* 7: 617.

Tarui, Nori, Marcus Peng, and Dolan Eversole. 2018. *Economic Impact Analysis of the Potential Erosion of Waikiki Beach.* University of Hawai'i Sea Grant College Program. https://seagrant.soest.hawaii.edu/wp-content/uploads/2018/08/Economic-Impact-Analysis-Waikiki-Beach-1016-web.pdf.

Tasmanian Government. 2001. "Tasmanian Coastal Works Manual, Guidelines for Dune-forming Fences." Hobart.

Tavares, Kammie D., Charles H. Fletcher, and Tiffany R. Anderson. 2020. "Risk of Shoreline Hardening and Associated Beach Loss Peaks Before Mid-Century: O'ahu, Hawai'i." *Scientific Reports* 10: 13633. https://doi.org/10.1038/s41598-020-70577-y.

Thieler, E. Robert, and Erika S. Hammar-Klose. 2000. *National Assessment of Coastal Vulnerability to Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast.* U.S. Geological Survey Open-File Report 99-593. USGS Publications, Reston.

TPCC (Tourism Panel on Climate Change). 2023. *Tourism and Climate Change Stocktake 2023 Report.* TPCC, Brussels.

Trang, Ho Le Thu, Jin-Soo Lee, and Heesup Han. 2018. "How Do Green Attributes Elicit Pro-Environmental Behaviors in Guests? The Case of Green Hotels in Vietnam." *Journal of Travel & Tourism Marketing* 36 (1): 14–28. https://doi.org/10.1080/10548408.2018.1486782

UNEP (United Nations Environment Programme). 1995. *Guidelines for Integrated Management of Coastal and Marine Areas.* General report, Nairobi. https://www.unep.org/resources/report/guidelines-integrated-management-coastal-and-marine-areas.

UNEP (United Nations Environment Programme). 2022. *Resolution Adopted by the United Nations Environment Assembly on 2 March 2022.* UNEP, Nairobi. https://wedocs.unep.org/bitstream/handle/20.500.11822/39864/NATURE-BASED%20SOLUTIONS%20FOR%20SUPPORTING%20SUSTAINABLE%20DEVELOPMENT.%20English.pdf?sequence=1&isAllowed=y%C3%A7.

UNEP (United Nations Environment Programme), Mediterranean Action Plan (MAP), and Priority Actions Programme (PAP). 2015. "Guidelines for the Preparation of the National ICZM Strategies Required by the Integrated Coastal Zone Management (ICZM) Protocol for the Mediterranean." PAP, Split. https://iczmplatform.org/storage/documents/YGpSpCeK6HwzM6O39GlsU5n8C5WGjbFqSPLekXTj.pdf.

UN Tourism (United Nations World Tourism Organization). 2019. "International Tourism Highlights, 2019 ed." UN Tourism, Madrid. https://doi.org/10.18111/9789284421152.

UN Tourism (United Nations World Tourism Organization). 2024. "International Tourism in Small Island Developing States (SIDS)." UN Tourism, Madrid. https://pre-webunwto.s3.eu-west-1.amazonaws.com.mcas.ms/s3fs-public/2024-06/SIDS_data%20insights_May_2024_UNTourism.pdf?McasCtx=4&McasTsid=20892.

U.S. Government. 1972. *Coastal Zone Management Act of 1972, as amended through Pub. L. No. 109-58,* the Energy Policy Act of 2005. Washington, DC.

Valsamidis, Antonios, and Dominic E. Reeve. 2020. "A New Approach to Analytical Modelling of Groyne Fields." *Continental Shelf Research* 211: 104288. https://doi.org/10.1016/j.csr.2020.104288.

Van der Meulen, Frank, Stéphanie IJff, and Rien van Zetten. 2023. "Nature-Based Solutions for Coastal Adaptation Management, Concepts and Scope, an Overview." *Nordic Journal of Botany* 2023 (1): e03290.

Van Katwijk, Marieke M., Arthur R. Bos, Victor N. de Jonge, Lucien S.A.M. Hanssen, D.C.R. Hermus, and D.J. de Jong. 2009. "Guidelines for Seagrass Restoration: Importance of Habitat Selection and Donor Population, Spreading of Risks, and Ecosystem Engineering Effects." *Marine Pollution Bulletin* 58 (2): 179–188.

Van Keulen, Mike, Eric I. Paling, and C.J. Walker. 2003. "Effect of Planting Unit Size and Sediment Stabilization on Seagrass Transplants in Western Australia." *Restoration Ecology* 11 (1): 50–55.

Van Loon, Anne F., Roel Dijksma, and Martinus Van Mensvoort. 2007. "Hydrological Classification in Mangrove Areas: A Case Study in Can Gio, Vietnam." *Aquatic Botany* 87 (1): 80–82.

Van Loon-Steensma, J.M., A.V. de Groot, W.E. van Duin, B.K. van Wesenbeeck, A.J. Smale, H.A.M. Meeuwsen, R.M.A. Wegman. 2012. "Search Map for Salt Marshes and Water Safety in the Wadden Area: An Exploration of Locations in the Wadden Area Where Existing Salt Marshes or Salt Marsh Development Could Potentially Contribute to Water Safety (No. 2391)." Wageningen Environmental Research (Alterra), Wageningen.

van Raalte, Dorian, and Nicola Ranger. 2023. *Financing Nature-Based Solutions for Adaptation at Scale: Learning from Specialised Investment Managers and Nature Funds.* Global Center on Adaptation and Environmental Change Institute: University of Oxford.

van Zanten, Boris, Gonzalo Gutiérrez Goizueta, Luke Brander, Borja Gonzalez Reguero, Robert Griffin, Kavita Kapur Macleod, Alida Alves, Amelia Midgley, Luis Diego Herrera, and Brenden Jongman. 2023. *Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience: A Guideline for Project Developers.* World Bank, Washington, DC.

Verburg, R.W., W.H.G.J. Hennen, L.F. Puister, R. Michels, and K. van Duijvendijk. 2017. "Estimating Costs of Nature Management in the European Union: Exploration Modelling for PBL's Nature Outlook (No. 97)." Wageningen University & Research.

Vernberg, F. John. 1993. "Salt-Marsh Processes: A Review." *Environmental Toxicology and Chemistry* 12 (12): 2167–2195.

Vionnet, Samuel, and Luke Blower. 2021. "Corporate Natural Capital Accounting – From building Blocks to a Path for Standardization Understanding the landscape, Leading Applications, Challenges and Opportunities." Capitals Coalition, The Hague.

Vousdoukas, Michalis I., Lorenzo Mentaschi, Evangelos Voukouvalas, Martin Verlaan, Svetlana Jevrejeva, Luke P. Jackson, and Luc Feyen. 2018. "Global Probabilistic Projections of Extreme Sea Levels Show Intensification of Coastal Flood Hazard." *Nature Communications* 9: 2360. https://doi.org/10.1038/s41467-018-04692-w.

Vousdoukas, Michalis I., Roshanka Ranasinghe, Lorenzo Mentaschi, Theocharis Plomaritis, Panagiotis Athanasiou, Arjen Luijendijk, and Luc Feyen. 2020. "Sandy Coastlines under Threat of Erosion." *Nature Climate Change* 10 (3): 260–263. https://doi.org/10.1038/s41558-020-0697-0.

Voyer, Michelle, Kate Barclay, Alistair McIlgorm, and Nicole Mazur. 2017. "Connections or Conflict? A Social and Economic Analysis of the Interconnections Between the Professional Fishing Industry, Recreational Fishing and Marine Tourism in Coastal Communities in NSW, Australia." *Marine Policy* 76: 114–121.

Wang, Jing, Shanyong Wang, Hanbing Xue, Yu Wang, and Jun Li. 2018. "Green Image and Consumers' Word-of-Mouth Intention in the Green Hotel Industry: The Moderating Effect of Millennials." *Journal of Cleaner Production* 181: 426–436. https://doi.org/10.1016/j.jclepro.2018.01.250.

Westby, Stephanie, Laura Geselbracht, and Bernadette Pogoda. 2019. "Shellfish reef restoration in practice. In Restoration guidelines for shellfish reefs." In *Restoration Guidelines for Shellfish Reefs*, edited by James Fitzsimons, Simon Branigan, Robert D. Brumbaugh, Tein McDonald, and Philine S.E. zu Ermgassen, 36–48. The Nature Conservancy, Arlington.

Winterwerp, Johan C., Thorsten Albers, Edward J. Anthony, Daniel A. Friess, Alejandra Gijón Mancheño, Kene Moseley, Abdul Muhari, Sieuwnath Naipal, Joost Noordermeer, Albert Oost, Cherdvong Saengsupavanich, Silke A.J. Tas, Femke H. Tonneijck, Tom Wilms, Celine Van Bijsterveldt, Pieter Van Eijk, Els Van Lavieren, and Bregje K. Van Wesenbeeck. 2020. "Managing Erosion of Mangrove-Mud Coasts with Permeable Dams – Lessons Learned." *Ecological Engineering* 158: 106078.

Woodroffe, Colin D., K. Rogers, Karen L. McKee, Catherine E. Lovelock, Irving A. Mendelssohn, and Neil Saintilan. 2016. "Mangrove Sedimentation and Response to Relative Sea-Level Rise." *Annual Review of Marine Science* 8: 243–266.

World Bank. 2013. *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case For Resilience*. World Bank, Washington, DC.

World Bank. 2020. "Investing in Nature, Investing in the Future of Belize." Feature Story, May 20, 2020. https://www.worldbank.org/en/news/feature/2020/05/20/investing-in-nature-investing-in-the-future-of-belize.

World Bank. 2021a. *A Catalogue of Nature-Based Solutions for Urban Resilience.* World Bank, Washington, DC. http://hdl.handle.net/10986/36507.

World Bank. 2021b. *Resilient Coastlines, Resilient Communities: West Africa Coastal Areas Management Program – Annual Report 2020.* World Bank, Washington, DC. https://documents1.worldbank.org/curated/en/462991621974738944/pdf/Resilient-Coastlines-Resilient-Communities.pdf.

World Bank. 2023a. "Beach Restoration and Coastal Protection to Revive Tourism and Fishing in Saly." Feature Story, June 1, 2023. https://www.worldbank.org/en/news/feature/2023/06/01/beach-restoration-and-coastal-protection-to-revive-tourism-and-fishing-in-saly.

World Bank. 2023b. "Planting Mangrove Forests is Paying Off in Indonesia." Feature Story, December 1. 2023. https://www.worldbank.org/en/news/feature/2023/11/30/planting-mangrove-forests-is-paying-off-in-indonesia.

World Bank. 2023c. *Tools and Resources for Nature-Based Tourism – Second Ed.* World Bank, Washington, DC. https://doi.org/10.1596/39848.

World Bank. 2024. *Blueprints for Private Investment in Ecosystem Restoration, Lessons from Case Studies.* World Bank, Washington, DC.

World Bank. 2025. *Colombia – Fourth Disaster Risk Management Development Policy Loan with a Catastrophe Deferred Drawdown Option* (P181256). World Bank, Washington, DC. https://documents1.worldbank.org/curated/en/099011525180029297/pdf/BOSIB-97e85b55-ee93-468b-914b-0c73c474076f.pdf.

World Bank and Ministry of Environment, Energy and Climate Change of Seychelles. 2019. *Seychelles Coastal Management Plan: 2019–2024*. Washington, DC and Victoria.

World Economic Forum. 2022. "Biodiversity Credits: Unlocking Financial Markets for Nature-Positive Outcomes." Briefing paper, Cologny. https://www3.weforum.org/docs/WEF_Biodiversity_Credit_Market_2022.pdf.

World Economic Forum. 2024. *The Global Risks Report 2024,* 19th ed. Insight report, Cologny.

Zuckoff, Eve. 2020. "Many Hands in the Sand: Aquinnah Tribe, Volunteers Plant Beach Grass for Climate-Resilient Coast." GBH News, April 22, 2022. https://www.wgbh.org/news/local/2022-04-22/many-hands-in-the-sand-aquinnah-tribe-volunteers-plant-beach-grass-for-climate-resilient-coast.

Zunino, Serena, Donata Melaku Canu, Francesco Marangon, and Stefania Troiano. 2020. "Cultural Ecosystem Services Provided by Coralligenous Assemblages and *Posidonia Oceanica in the Italian Seas." Frontiers in Marine Science* 6: 823.

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