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Engineering With Nature®

Embracing Biodiversity on Engineered Coastal Infrastructure through Structured Decision-Making and Engineering With Nature®

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Engineer Research and Development Center

Cover photo credit: Emily Dolatowski; Living Shoreline at Burton 4-H Center in Tybee Island, Georgia.

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Abstract

Extreme weather variation, natural disasters, and anthropogenic actions negatively impact coastal communities through flooding and erosion. To safeguard coastal settlements, shorelines are frequently reinforced with seawalls and bulkheads. Hardened shorelines, however, result in biodiversity loss and environmental deterioration. The creation of sustainable solutions that engineer with nature is required to lessen natural and anthropogenic pressures. Nature-based solutions (NbS) are a means to enhance biodiversity and improve the environment while meeting engineering goals. To address this urgent need, the US Army Corps of Engineers (USACE) Engineering With Nature® (EWN) program balances economic, environmental, and social benefits through collaboration.

This report presents how design and engineering practice can be enhanced through organized decision-making and landscape architectural renderings that integrate engineering, science, and NbS to increase biodiversity in coastal marine habitats. When developing new infrastructure or updating or repairing existing infrastructure, such integration can be greatly beneficial. Further, drawings and renderings exhibiting EWN concepts can assist in decision-making by aiding in the communication of NbS designs. Our practical experiences with the application of EWN have shown that involving landscape architects can play a critical role in effective collaboration and result in solutions that safeguard coastal communities while maintaining or enhancing biodiversity.

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Preface

This research was conducted for the US Army Engineer Research and Development Center (ERDC) as part of the Network for Engineering With Nature (N-EWN, https://n-ewn.org). This work was supported by the US Army Corps of Engineers's Engineering With Nature® Program through Cooperative Ecosystem Studies Unit Agreement W912HZ-20-2-0031.

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COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

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1 Introduction

1.1 Purpose

Global environmental hazards that pose a threat to human communities are ranked highest in the annual Global Risks Report and include extreme weather, ineffective climate action, natural disasters, and environmental degradation caused by human interventions (Schwab and Zahidi 2021). Coastal areas frequently bear the brunt of these dangers because of storm storms, storm surge, and increasing sea levels. Due to rising competition and conflicts brought on by population growth and climate change, the effects of these threats are likewise expanding in size, scope, and complexity (e.g., Hurricanes Harvey and Ian in 2017 and 2022, respectively). In this report, we argue that these pressures demand creative solutions that adjust to shifting environmental and societal needs through improved landscape design to enhance biodiversity goals.

1.2 Background

Many coastal areas are currently fortified with hardened (gray) infrastructure, such as levees, seawalls, floodwalls, breakwaters, dykes, groynes, tidal gates, and storm-surge barriers, that are intended to defend against coastal flooding. However, the widespread global technique of coastal hardening or armoring can hasten beach erosion and tidal wetland loss (Gittman et al. 2016). Hardened shorelines also contribute to the loss of biodiversity, a worldwide environmental problem (Gittman et al. 2016). Biodiversity refers to all living things in a particular area or habitat. In the context of this report, biodiversity refers to all living things on a coastal infrastructure feature such as a breakwater. When comparing riprap and breakwater structures, for instance, sea barriers result in poorer biodiversity than natural shorelines, albeit project type variability may conceal differences (Gittman et al. 2016). Alternatively, a combination of natural and nature-based features (NNBFs) (e.g., salt marshes, mangroves, reefs, and dunes) and hard infrastructure can increase economic and societal value (e.g., recreation), provide flood and storm protection, lower the cost of building coastal structures, improve coastal and community resilience, adapt to climate change, and enhance biodiversity (Firth et al. 2014a; Sutton-Grier et al. 2015; Browne and Chapman 2011; Narayan et al. 2016; Morris et al. 2018; Bouw and van Eekelen 2020; EEA 2021).

A systems-based approach necessitates the identification of a variety of nature-based solutions (NbS) that could leverage existing physical, ecological, and socioeconomic infrastructure. Such NbS can help reduce impacts and life-cycle costs while also providing multiple benefits, buying time for future adaptation, and improving biodiversity. Planners and engineers can protect coastal communities by strengthening sand dunes, constructing salt marshes and barrier islands, and constructing new offshore reefs, among other techniques. The protection also improves public amenities and provides habitat for fish and wildlife, supporting local economies and mitigating the negative effects of hard infrastructure (Nelson et al. 2020; Bridges et al. 2018; Bridges et al. 2021). The US Army Corps of Engineers (USACE) 2011 Civil Works Strategic Plan (USACE 2011) sought to balance economic, environmental, and social objectives while increasing stakeholder engagement and active partnering through innovative and environmentally sustainable solutions to the nation's water resources challenges. Goal #4 proposes restoring, safeguarding, and maintaining aquatic habitats that have degraded, with biodiversity playing a meaningful role. The Engineering With Nature® (EWN®; www.engineeringwithnature.org) initiative was launched by USACE in 2010 with the goal of utilizing NbS to balance social, environmental, and economic benefits through collaboration (King et al. 2020).

The Convention on Biodiversity's (CBD) 2050 Vision for Biodiversity calls for the preservation and restoration of marine and coastal ecosystems to ensure sustainability, the use of NbS in built landscapes and spatial planning to lessen the adverse effects of urban infrastructure on biodiversity, and the provision of resilient ecosystems for adaptation while minimizing negative impacts on biodiversity (CBD 2020). The loss of biodiversity is also mentioned in three Sustainable Development Goals (SDGs) of the UN 2030 Agenda for Sustainable Development (UN General Assembly 2015). SDG #14 encourages protecting and sustainably using the oceans, seas, and marine resources, while SDG #15 urges sustainably managing forests, stopping and reversing land degradation, and halting biodiversity loss. SDG #13 on climate action tackles the drivers of biodiversity loss. Together, the 2050 Vision for Biodiversity and UN SDGs encourage the use of NbS to address biodiversity issues related to climate change and to improve the synergy between climate change adaptation and disaster risk reduction (EEA 2021; Cohen-Shacham et al. 2019).

NbS have improved coastal infrastructure at numerous scales and locations (Chapman and Blockley 2009; Bulleri and Chapman 2010; Coombes et al. 2015; Strain et al. 2018; Suedel et al. 2022b; Perkol-Finkel and Sella 2015). Through the Building with Nature (BwN) initiative in the Netherlands, the EcoShape consortium has created precise design renderings to communicate with practitioners implementing coastal biodiversity benefits using NbS (Bouw and van Eekelen 2020). A four-step strategy to avoid, minimize, restore, and offset is presented by Milner-Gulland et al. (2021) for reducing and compensating the biodiversity impacts of human development. According to Díaz et al. (2020), there are three main ways to use NbS to stop biodiversity loss: set multiple goals to address nature's complexity, create goals that are comprehensive and minimize trade-offs, and integrate the goals with a high level of ambition (set lofty goals). These lofty goals include using NbS to lower climate risk and promote more resilient natural and managed ecosystems (Firth et al. 2014a; Firth et al. 2014b). Firth et al. (2014a) provided easy ways to improve hardened coastal buildings at three project phases: during quarrying and concrete casting, during construction, and retrospectively. They also developed guidelines for boosting biodiversity through the production of targeted habitat types.

Decision-making that helps communicate designs using NbS within a structured decision-making process can be facilitated using drawings and renderings exhibiting EWN concepts (Holmes et al. 2021). Our experiences implementing EWN into practice have shown that integrating landscape architects (LAs) into project planning can be essential in achieving successful collaboration centered on finding and selecting NbS. There are a multitude of project examples of LAs working with engineers and scientists on NbS globally to enhance decision-making. For instance, in the Rebuild By Design (New York and New Jersey, 2013–19) and Resilient By Design Bay Area (California, 2017–18) design competitions, multidisciplinary teams collaborated with a wide spectrum of expert and community voices to propose NbS to solve coastal resilience concerns (Ovink and Boeijenga 2018; Brown-Stevens 2019). In the Netherlands, LAs have significantly contributed to the development, rollout, and scaling up of NbS for water-related infrastructure through BwN (Bouw and van Eekelen 2020). Regarding these cases, multidisciplinary project teams tasked with implementing EWN that include LA capabilities have been helpful in gaining support for suggested NbS. For example, abstract ideas, like a desire to design a specific habitat feature, become linked to effective imagery (King et al. 2021).

1.3 Objectives

In this report, we build upon the USACE Civil Works Strategic Plan (USACE 2011) to demonstrate how creative designs that use EWN concepts might improve biodiversity related to coastal projects. We provide an example of how a structured decision-making process might be used to create coastal infrastructure that has minimal negative effects on biodiversity and maximizes its positive effects. Our emphasis is on design because the construction and administration aspects of coastal projects are covered in other publications (e.g., Bridges et al. 2021). We demonstrate how incorporating structured decision-making can boost engineering practice. This method integrates landscape architecture, engineering, ecological sciences, and NbS into a generally applicable approach for promoting biodiversity through conventional infrastructure during renovation, replacement, or design of new infrastructure projects.

1.4 Approach

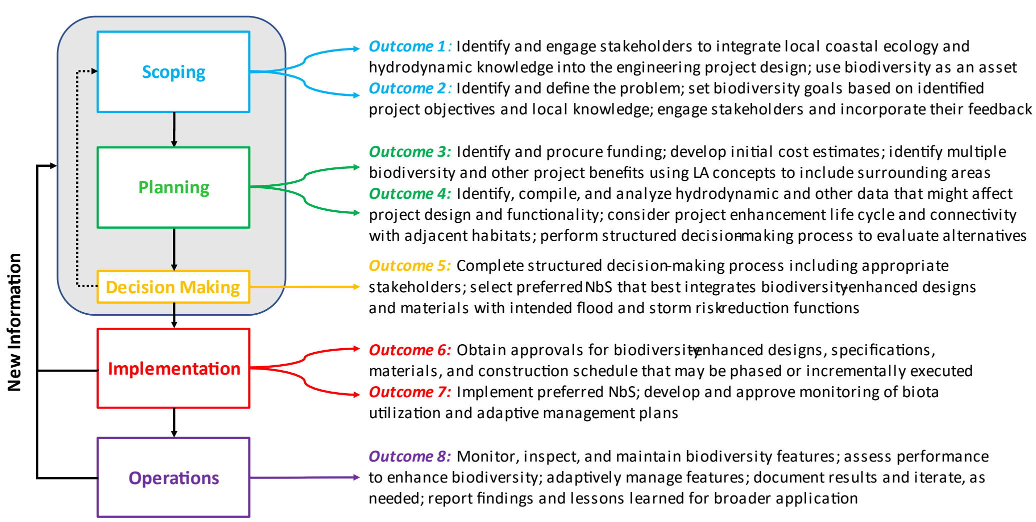
In this report, we build on the approach presented in Suedel et al. (2022a). This is accomplished by providing additional detailed renderings of coastal engineering structures that highlight how NNBF (a subset of NbS that lowers flood risks) can be integrated into the structures' design to enhance biodiversity benefits while maintaining the underlying coastal engineering function.

2 Methods

2.1 Description of the Approach

Projects that utilize NbS are not inherently different from gray infrastructure, so existing frameworks that foster coastal infrastructure planning and engineering projects can incorporate NbS and habitat features into the project design. However, those implementing NbS in coastal strategies require direction on how NNBF fit into the larger project development process. One such strategy that can be adopted generally is the *International Guidelines on Natural and Nature-Based Features for Flood Risk Management* (Bridges et al. 2021), which served as the inspire-ation for the strategy presented in Figure 1. The USACE NNBF framework in pursuit of coastal resilience (Bridges et al. 2015) and the World Bank (2017) framework, which concentrated on the implementation of nature-based flood protection measures, are the two complementary frameworks on which the NNBF guidelines are based (Sayers et al. 2013). Future NbS applications that aim to include components that improve coastal bio-diversity can follow this strategy, or road map. According to Mace et al. (2012), NbS are intrinsically sustainable and enhance ecosystem services (e.g., provision, regulating, habitat, and cultural services) as well as pro-viding other environmental, social, and economic advantages (ECDRI 2021). This strategy views biodiversity as a resource for the development of coastal projects (Figure 1).

Figure 1. Design strategy for coastal infrastructure that prioritizes biodiversity (Image reproduced with permission from Suedel et al. 2022*a*).



Scoping, planning, decision-making, implementation, and operations are the five stages of the strategy. Although they are shown in a sequential order, these phases serve to emphasize a general evolution. The framework is iterative, allowing for the incorporation of new data that is discovered in later phases. Since several actions are connected and may occur simultaneously, the order and sequencing of the phases are meant to be illustrative rather than mandatory. Each stage of the strategy is described in more detail below.

2.2 Scoping

Scoping involves performing an initial assessment of the needs and objectives, as well as identifying, organizing, and meaningfully engaging stakeholders and partners in integrating their knowledge of local coastal ecology and hydrodynamics into the project design. The problem is also identified and defined during scoping. Biodiversity goals, with biodiversity as an asset, are established based on project objectives and local knowledge, such as including microhabitats in the structure (Aguilera et al. 2014; Aguilera et al. 2019). Prioritizing appropriate habitat creation and restoration to enhance biodiversity is one way to increase sustainability; projects that are intentionally linked with other existing projects can improve habitat connectivity.

Opportunities to improve infrastructure can arise at any time during the design life cycle, including during new construction, repair, maintenance, or modification (Suedel et al. 2021). Projects that are likely candidates for enhancement include deteriorating existing structures that require repair, modification, or replacement. Other candidates include new projects with a large construction footprint in areas where biodiversity is impaired or declining. In this case, ecological connections bridge to adjacent, more biodiverse areas. Rather than mitigating short-term ecologically negative impacts, the goal is to incorporate ecological principles beginning with planning and progressing through design and construction. Such designs provide opportunities to use biomimetic technologies that mimic nature's forms and functions to improve structural and ecological performance (Makram 2019).

While scoping infrastructure projects, keep in mind that coastal infrastructure is subject to harsh environmental conditions and must adhere to applicable building codes and standards. This applies to the materials used (e.g., concrete mix), construction methods, and phasing or sequencing (Perkol-Finkel and Sella 2015; Firth et al. 2014a). Enhancing structures for biodiversity can take many forms, serving as a continuum of measures at various scales and structure types in coastal and fluvial environments (Schoonees et al. 2019; Suedel et al. 2021). These design elements are important to contemplate during the project's scoping phase to help identify potential constraints and opportunities.

Funding sources may include the federal, state, and local governments, nongovernmental organizations, and the private sector due to the multiobjective character of many coastal infrastructure projects that contain elements for enhancing biodiversity. Other funding options, such as public-private partnerships, should also be sought. When identifying funding sources for such coastal projects, both the cost and funding strategies for the actual studies, evaluations, and analyses that will be conducted as part of the alternative's design and construction should be examined along with funding life cycle costs associated with project monitoring and maintenance. The funding strategy begins with scoping, which is improved during the planning and decision-making phases and is completed during the implementation phase.

2.3 Planning

Planning provides an opportunity to better understand and characterize the existing system, as well as explore alternatives that meet project biodiversity goals and objectives using a systems approach. Considerations during planning include identifying the objectives of the structure slated for enhancement (e.g., stop or slow the water; high energy versus low energy environment), which native species reside in the system, and feature selection to encourage a diverse assemblage of organisms while achieving the engineering objectives. Any challenges associated with incorporating NbS for biodiversity into the design, including the ability to improve biodiversity beyond conventional approaches, are important considerations (Nelson et al. 2020; Chapman and Underwood 2011). To more fully comprehend the site-specific hydrodynamic circumstances and habitat elements that can be incorporated into the design, these factors must also be weighed during planning (Strain et al. 2018).

Planning involves assessing the system's vulnerability to storms and flooding as well as the related physical, biological, and social processes.

These analyses may include analyzing the available data and information; performing the necessary hazard, vulnerability, and risk assessments; and using modeling to comprehend how water levels, erosional pressures, and sediment transport patterns vary over time. Understanding local conditions may be crucial for developing alternative solutions. This can be done with the help of coastal and riverine models, such as Advanced Circulation (ADCIRC), Adaptive Hydraulics (AdH), and others. The project team can engineer with nature with the aid of modeling tools (see examples in Bridges et al. 2018, 2021). Hybrid options, which combine coastal NbS (e.g., salt marshes) with hard structures (Sutton-Grier et al. 2015), may be compared using socioeconomic analysis to determine their likely economic, social, and ecological costs and benefits. Through modeling, it is possible to argue for the importance of biodiversity and to highlight its potential benefits not only for the environment but also for the economy and society in general. Metrics need to be determined that are suitable for site-specific conditions, meaningfully connect to project goals and objectives, and can be measured or subjectively assessed quickly and affordably. The outcome of planning is a transparent evaluation, including numerical rankings of the alternatives being considered. During the decision-making phase, the results of the alternative analysis highlight high-priority options.

2.4 Decision-Making

The preferred alternative is chosen during decision-making from the list of high-priority alternatives created during planning. This preferred alternative best meets project objectives and manages identified risks of storms and flooding to the system. Designs that provide the desired engineering function, enhanced biodiversity, and coastal resilience may combine NbS, structural, and nonstructural elements. The flood and storm risk reduction function of the structure should be maintained by features incorporated into the design (King et al. 2021; Suedel et al. 2021; Holmes et al. 2021). The chosen preferred alternative is further distinguished from the other alternatives in the decision-making phase. The complexity and scope of the resulting biodiversity, as well as the associated social and economic benefits, become deciding considerations for choosing the favored alternative. Additional elements that could influence the evaluation’s findings include investor contributions; land acquisition requirements; and regulatory, governance, or financial requirements (Milner-Gulland et al. 2021). A structured decision-making process is recommended to help illustrate how to apply design elements in practice, highlight how tradeoffs can happen, and involve stakeholders in the decision-making process (Gregory et al. 2012; Kiker et al. 2005). The value that biodiversity provides can be identified and quantified to make it easier to compare the costs and benefits of implementing improvements to more traditional structural approaches (Suedel et al. 2021).

Successful decision-making must meaningfully interact with stakeholders, members of the community, and the public during the scoping and planning phases (e.g., floodplain managers, city or county planners, coastal planners, and resource agency representatives). One of the essential components of a successful project is effective communication with partners, stakeholders, and the public on the results of decision-making and the expected project benefits. Engineering With Nature landscape architecture (EWN-LA) drawings and renderings can aid to enhance effective communication by demonstrating how alternate designs can be created and chosen to guide the decision-making process. The final alternative design and its inherent benefits can then be seen by stakeholders and decision-makers thanks to renderings acting as communication tools (Holmes et al. 2021; King et al. 2021). One instance is the EWN-LA partnership with the USACE Philadelphia District, where several design renderings were created and assessed for use in the New Jersey Back Bay area. The conclusions are detailed in Holmes et al. (2021), which also offers methods for combining NbS with nonstructural actions to achieve coastal storm risk management (CSRM) and ecological benefits.

2.5 Implementation

After being chosen, the preferred alternative undergoes further revision and finalization during the implementation phase, at which time construction is completed. This stage entails adjusting budget and financing plans, pursuing final designs and permits, creating the construction timeline, and securing regulatory approvals. Once completed, the construction of the project can commence. Those working in the project who have experience with biodiversity should provide oversight to verify that features are built as intended and that any necessary engineering adjustments do not conflict with features intended to improve biodiversity. The system should not be “overengineered,” and project parts do not have to be built all at once. This means that the precise engineering goal is defined because it affects the engineering solutions that are available. Alternatives to enhance the design for biodiversity in phases over time should consider objectives (e.g., stop the water versus slow the water; see Dugan et al. 2018 for example), local conditions (e.g., high energy versus low energy, subtidal versus supratidal, pulsed; see Odum et al. 1995), and species the infrastructure is intended to attract such as fish (Ziegler et al. 2021). Future changes in environmental conditions, like sea-level rise and storm strength, may necessitate the adaptation or modification of some design elements. Given that improved designs that incorporate biodiversity elements may mitigate certain regulatory and compliance concerns by minimizing the project's footprint, environmental compliance issues may become less challenging to navigate.

2.6 Operations

When the project's construction is finished, the operations phase starts. A well-developed monitoring and maintenance plan that implements actions promoting the long-term performance of the project is necessary to enable optimal project performance in the face of the dynamic nature of coastal environments and anticipated future system changes (e.g., natural or built). Plans integrating NbS will assist adaptive management, and the lessons acquired can be used to advise upcoming coastal infrastructure initiatives that incorporate biodiversity goals. A crucial component of operations is reporting on monitoring and maintenance tasks since it keeps communities, stakeholders, and decision-makers interested and informed. Metrics selected during planning and utilized in operations should reflect regional conditions, species, and scales, and meaningfully relate to the aims and objectives of the project. Benefits can be estimated using metrics that compare biodiversity gains and losses.

3 Coastal Infrastructure Renderings

This section identifies 10 common types of coastal infrastructure that can be improved to support a more biodiverse community using NbS deploying the strategy described above. We present ways to improve each structure type, either alone or in combination with other structural features. Finally, we show how these structural types can be rendered using EWN-LA techniques to aid in coastal infrastructure decision-making.

3.1 Thin-Layer Placement

Thin-layer placement (TLP) is a technique for restoring ecological function by placing dredged sediment to simulate natural accretion (Myszewski and Alber 2017). Sediment is placed at various depths to meet project objectives, typically ranging from about 10 cm* to a maximum depth of 36 cm (Figure 2) (Berkowitz et al. 2019). TLP is frequently used to stabilize or nourish marshes, as well as elevate areas in shallow open water. TLP is a more environmentally friendly method of placing dredged sediments in thin layers on wetlands and other natural infrastructure with the goal of preserving established natural processes, supporting existing vegetation, and promoting new vegetative growth and related habitat.

Due to sea-level rise, some coastal marshes, such as those in New England, are losing area and converting from high to low marsh. This type of marsh loss reduces biodiversity and may impact the nesting success of bird species that rely on high marsh habitats. TLP can help prevent or postpone high marsh loss while having no short-term negative effects on native high marsh vegetation (Payne et al. 2021). Furthermore, the use of TLP can aid in the restoration of sediment-starved ecosystems and is consistent with EWN principles of keeping dredged sediments in the system (Parson et al. 2015).

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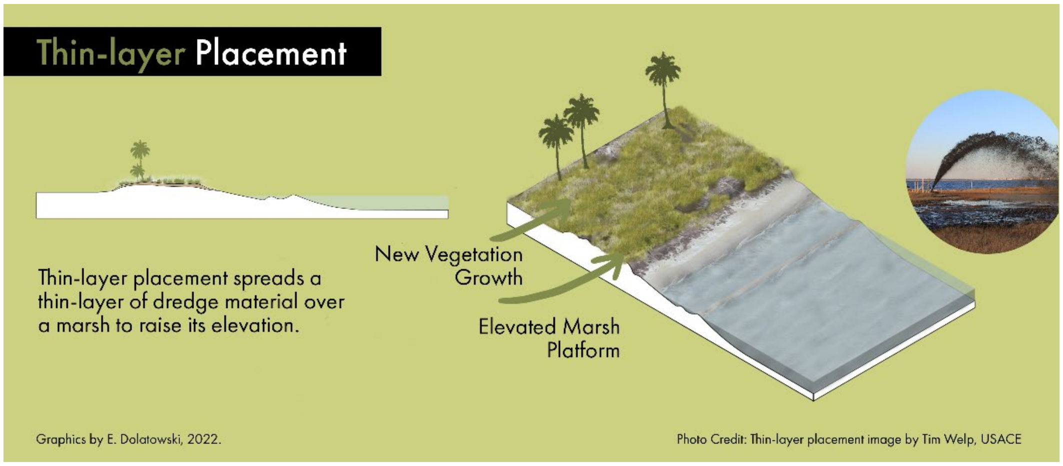
* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

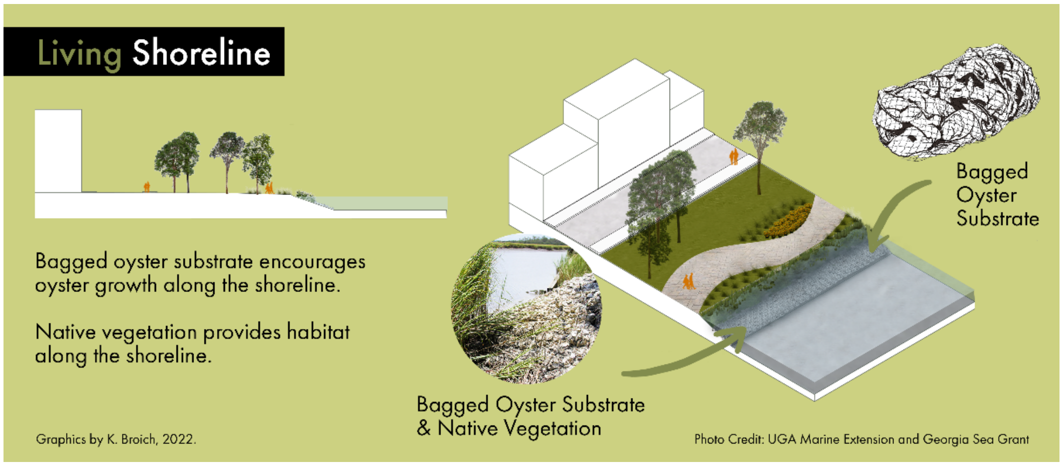
Figure 2. Rendering of thin-layer placement in a coastal environment.



3.2 Living Shoreline

A living shoreline is a sloped, erosion-control technique used to protect an embankment that mimics natural habitat, increases opportunities for species diversity and productivity, and helps improve water quality and ecological integrity of the area (Georgia Department of Natural Resources 2013). Living shorelines can offer a more natural alternative to “hard” shoreline stabilization methods while also improving long-term coastal resilience. Unlike traditional coastal erosion techniques, which use hard infrastructure and materials such as steel, concrete, and large rock, living shoreline projects use natural materials such as oyster shells to promote oyster recruitment and growth (Figure 3). Natural cements produced by organisms as they adhere to each other and the underlying structures can help to stabilize living shoreline features; roots of native vegetation, such as marsh grasses, can be used to stabilize soils and sediments and provide additional habitat (Gittman et al. 2016). Living shorelines can thus improve the ecological integrity of the coastal environment; promote biodiversity; and provide additional water filtration, habitat, recreational, commercial, and coastal resilience benefits (Georgia Department of Natural Resources 2013; Smith et al. 2020).

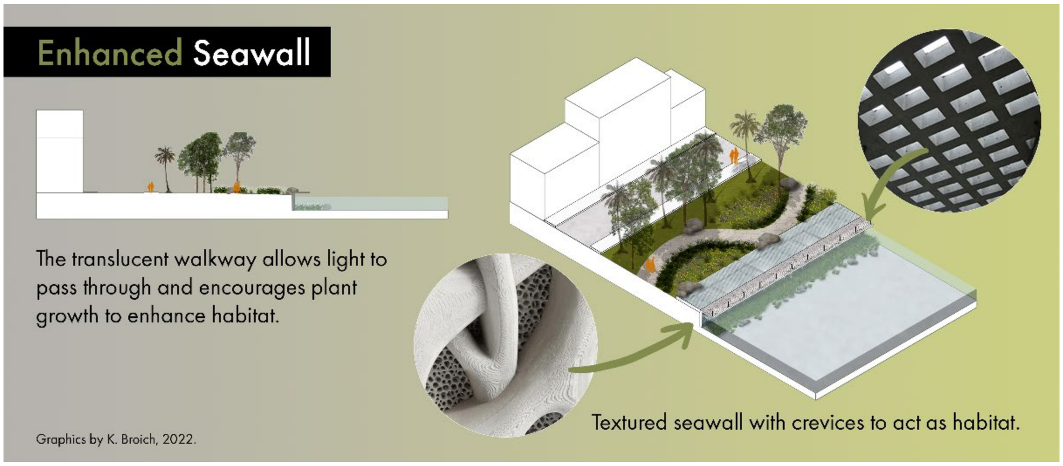
Figure 3. Rendering of a living shoreline in a coastal environment.



3.3 Seawall

USACE has defined *seawalls* as onshore structures built parallel to the shoreline. Their main purpose is to prevent overtopping and subsequent flooding of land and infrastructure caused by storm surges and waves (USACE 1995). Although the terms *seawall* and *bulkhead* are interchangeable, seawalls are generally larger and serve the primary purpose of intercepting waves to protect high-value property. Concrete and stone are common conventional materials used to construct seawalls, and various designs and materials are used to prevent the structure from collapsing. However, seawall design can be altered to increase the habitat value associated with these structures (Figure 4). Seawalls can be designed, modified, or built to increase biodiversity by planting native vegetation both on land and at sea, creating a submerged reef in front of the seawall, using different construction materials, retrofitting habitat features (e.g., vertipools), and adding roughness to the seawall face (Browne and Chapman 2011; Suedel et al. 2021; NSW Government 2009; Cordell et al. 2017; Rasna et al. 2019). An example is the Seattle, Washington, seawall designed to encourage juvenile salmon migration and generally improve habitat (Cordell et al. 2017).

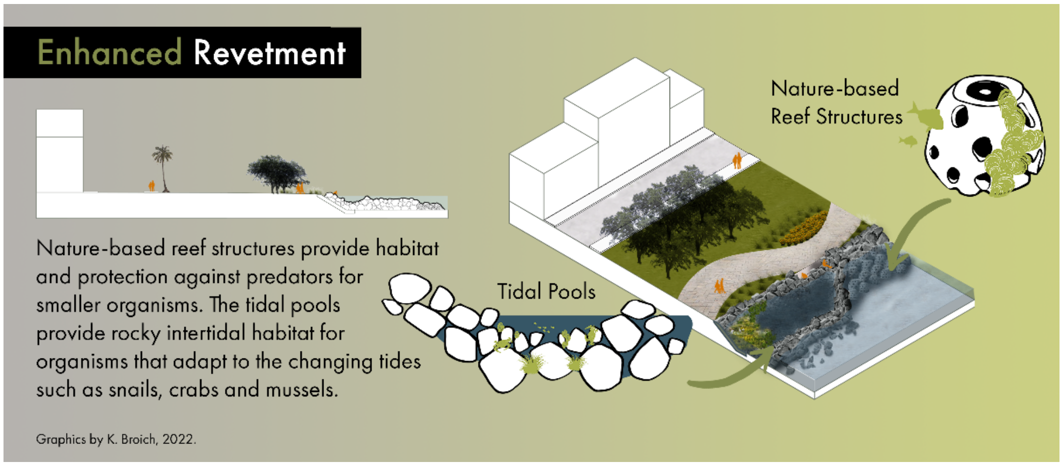
Figure 4. Rendering of an enhanced seawall designed and constructed in a coastal environment.



3.4 Revetment

Revetments are onshore sloped structures that protect the shoreline from erosion by dissipating wave action, storm surge, and currents. Revetments, like other coastal structures, are intended to reduce coastal erosion rather than prevent flooding. They can be exposed or buried and are typically built with rock, concrete, and other building materials (USACE 1995). Rock or other natural and nature-based materials can be placed with enough spacing between them to provide habitat for marine life and vegetation in a revetment to increase biodiversity (Figure 5). To increase habitat value and biodiversity, some habitat features can be designed to be dry, submerged, or both during low tide. Microhabitats can be created by scoring or texturing rocks, and conventional materials such as concrete can be designed and fabricated to include shapes and textures that enhance habitat value (Bouw and van Eekelen 2020; MacArthur et al. 2020).

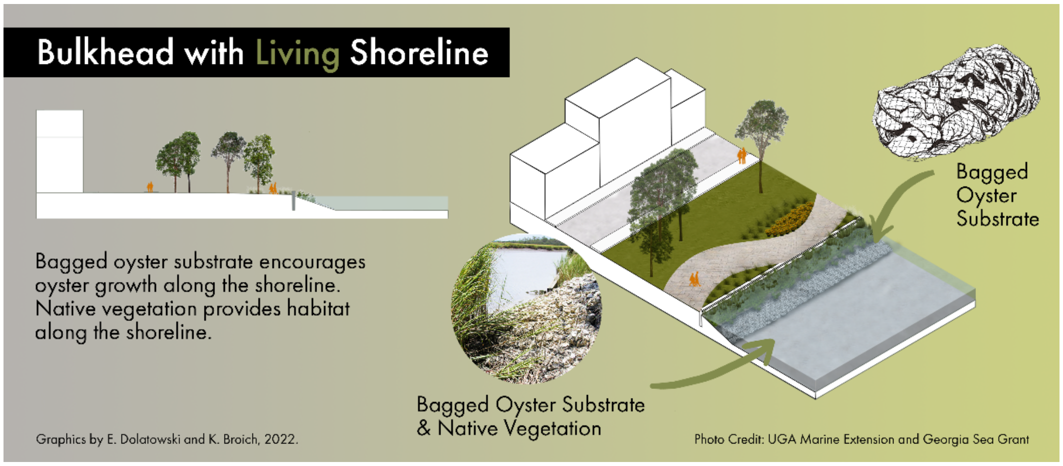
Figure 5. Rendering of an enhanced revetment designed and constructed in a coastal environment.



3.5 Bulkhead

A bulkhead's primary function is to retain or prevent land sliding, with a secondary function of protecting the upland area from wave action (USACE 1995). Bulkheads are typically vertical walls made of concrete, rock, or other hard materials. Bulkheads made of conventional materials have been linked to decreased submerged aquatic vegetation abundance (Patrick et al. 2016) and other negative effects (Currin et al. 2010). However, bulkheads can be combined with other coastal protection features to increase biodiversity while concomitantly protecting the shoreline (Figure 6). Living shorelines, for example, can be placed seaward of the bulkhead to prevent erosion while greatly increasing habitat value (Nordstrom 2019). Other researchers have developed alternative materials and designs (e.g., enhanced concrete designed to mimic mangrove root structures) for bulkhead structures that improve habitat value while meeting underlying engineering objectives (e.g., see Bridges et al. 2021, 128–130).

Figure 6. Rendering of a living shoreline feature combined with a conventional bulkhead to create hybrid infrastructure that enhances biodiversity value in a coastal environment.

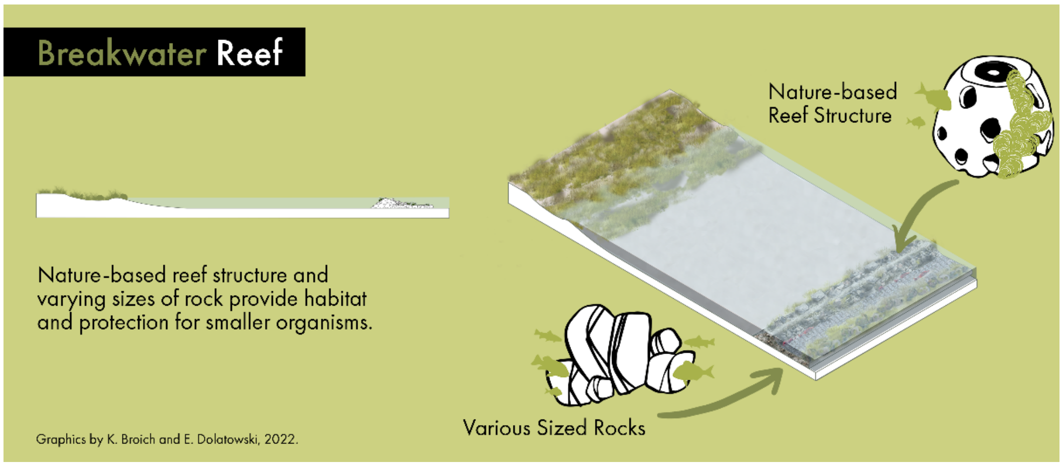


3.6 Detached Breakwaters and Jetties

Detached breakwaters are nearshore structures constructed parallel to the shore in shallow water depths. The primary function is to reduce beach erosion by lowering wave height, which in turn reduces longshore and cross-shore sediment transport (USACE 2002). To create or stabilize coastal wetlands, detached breakwaters can be used. For many years, they have been used in conjunction with sediment dredged from adjacent federal navigation channels (Chasten et al. 1993). To increase biodiversity, detached breakwaters can be designed or modified in a variety of ways (e.g., to attract fish and other species to the rocky structure; Geisthardt et al. 2022). Detached breakwaters can be submerged for aesthetic purposes or segmented to promote water circulation and habitat value. A detached breakwater can be made of a variety of materials, but structures like reef balls can help to stimulate reef habitats (Figure 7) (Harris 2009). Multipurpose breakwaters, which are designed to provide additional environmental or social benefits, or both, in addition to structural benefits, play an important role in harbor and coastal resiliency efforts (Fredette et al. 2016; Manson et al. 2018; Hardaway et al. 2020).

Jetties are perpendicular to shore structures and are placed adjacent to tidal inlets and harbors to control inlet migration and minimize sediment deposition within the inlet. Jetties are like breakwaters in design and materials but differ in function (USACE 1989). Jetties have the potential to disrupt natural sediment regimes and cause erosion along the coast. Jetties can be made more biodiverse by using natural building materials and materials that can promote habitat enhancement (see King et al. 2021) for an example jetty rendering).

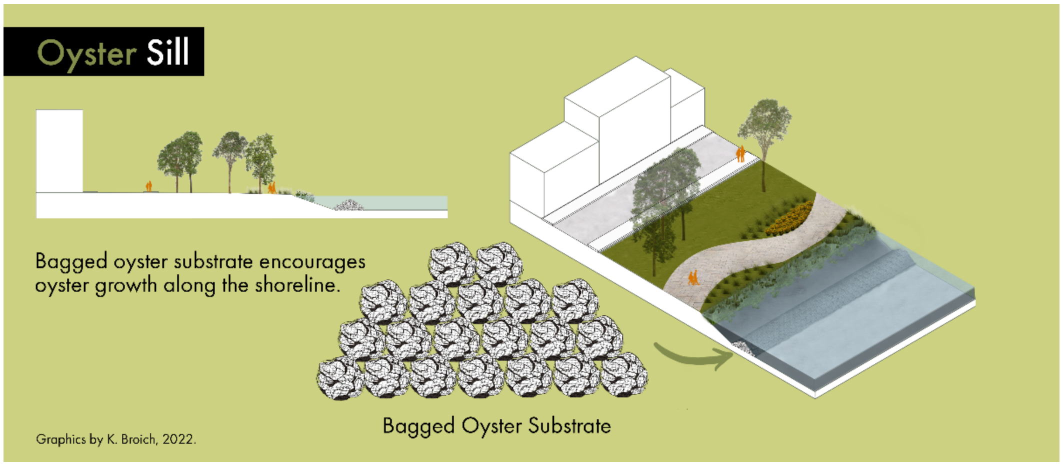
Figure 7. Rendering of a detached breakwater reef seaside of a coastal shore. Placement of the reef balls in this rendering has promoted the growth and expansion of seagrasses landward of this natural infrastructure.



3.7 Sill

A sill is a rock structure that is placed parallel to the shore to absorb wave energy. Sills are like breakwaters, but they are usually smaller and placed closer to the shore (Hardaway and Byrne 1999). Fill is frequently required to supplement the backshore to help establish a marsh fringe in the lee of the sill. Sills can be used to establish intertidal marsh grasses in higher wave energy environments; and as features in living shorelines, sills provide opportunities to improve biodiversity through design elements and backshore fill material selection (Figure 8). Sills help to stabilize the shoreline while also encouraging the development of a marsh fringe landward of the sill to promote biodiversity (Bilkovic and Mitchell 2017; Bilkovic et al. 2021).

Figure 8. Rendering of an enhanced oyster sill feature in a coastal environment.

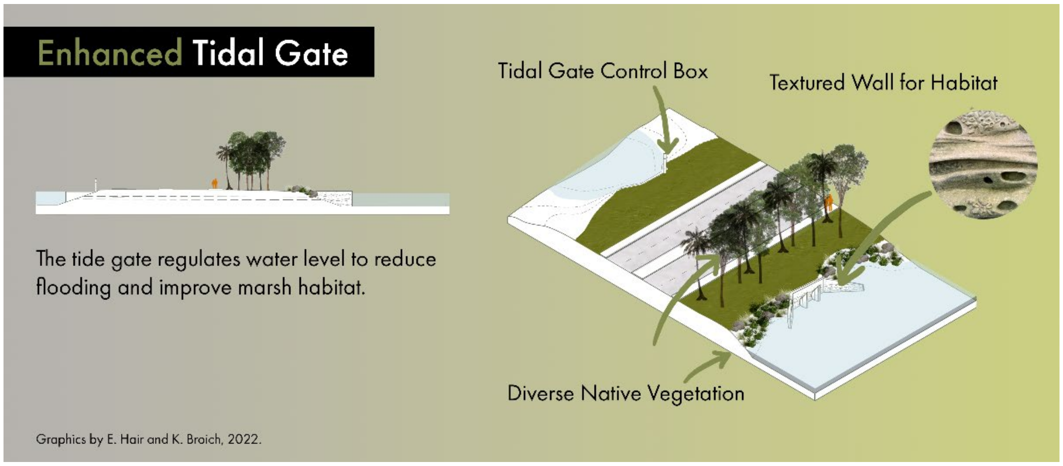


3.8 Tidal Control Structure

Tidal control structures, such as dykes and tide gates, are used to drain wetlands in estuaries and river valleys influenced by tides. Tide control structures are constructed into levees and other structures to restrict incoming tides and thus reduce tidal influx. Structures remain open to allow water to drain into receiving waters. Unfortunately, the way these structures have been designed, built, and operated has had a negative impact on ecosystems (Giannico and Souder 2005). Adverse effects include severing connectivity within tidal floodplains, which has an impact on water quality, fish passage, and biodiversity (Scott et al. 2016); this highlights the difficulties in balancing flood protection and floodplain connectivity. Recently, tidal and flood control structures have been designed and operated to be more friendly to native fish and coastal marsh habitats (Figure 9) (Bridges et al. 2021).

In the Tomago Wetlands of New South Wales, Australia, for example, novel tidal control gates were designed and built to restore 450 ha of coastal marsh habitat, including avifauna migration. In another case, the Southern Flow Corridor project in Tillamook Bay, Oregon, used an existing tide gate in conjunction with other measures, such as levee removal and the addition of setback levees, to restore nearly 180 ha of land and over 21 km of tidal channels for migratory salmonids (Bridges et al. 2021). In both cases, how the tide gates were operated played a key role in improving habitat because the gates were operated while considering both flooding and habitat objectives.

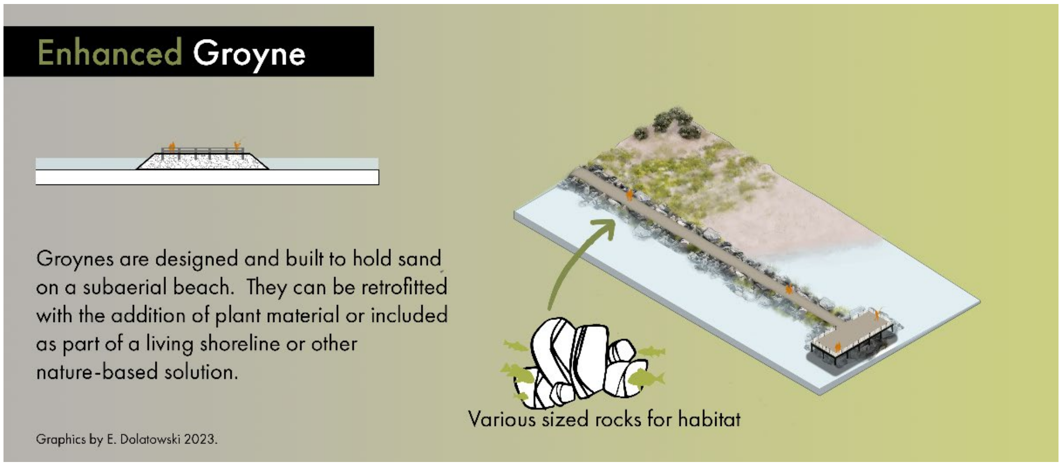
Figure 9. Rendering of an enhanced tidal gate structure. In some cases, such gates can be designed, built, and operated to achieve both engineering and environmental objectives.



3.9 Groyne

Groynes are designed and built to hold sand on a subaerial beach (Basco and Pope 2004; USACE 2002). Groynes, typically constructed using large rock or stone, can cause beach material to accumulate on the updrift side and material to erode on the downdrift side. Typically, erosion extends from the structure down the coast, prompting the construction of additional groynes and causing a ripple effect (USACE 2013). A groyne, like jetties, can be retrofitted with the addition of plant material or included as part of a living shoreline or other nature-based solution (van der Spek et al. 2020; The Nature Conservancy 2021). The rendering in Figure 10 shows how native coastal plant species can be incorporated into the design of a groyne structure. Such plant species can be placed directly on the structure itself and in surrounding areas. The top of the structure could incorporate a flattened pervious surface of smaller rock or stone to allow for public access, improving the recreational benefits.

Figure 10. Renderings of an enhanced groyne. Enhancements can include features directly on the structure itself and may include enhancements to the surrounding infrastructure. Enhancements (as rendered) may also include a flat level surface to allow for public access. This figure focuses on vegetation enhancement and does not emphasize littoral processes.



4 Discussion

The structured decision-making approach described herein can be used to design and develop a variety of structural enhancement features for alternatives that can be implemented within each of these coastal infrastructure types. Aspects of EWN-LA that promote biodiversity on coastal infrastructure can be applied to each of the five phases of the overall strategic approach.

Using a failing bulkhead as an example of conventional infrastructure that can be enhanced through repair of the existing structure, we show how EWN-LA can play a meaningful role in each phase. Scoping should identify and include EWN-LA expertise on the project team to help define the nature and scope of the bulkhead repair and the prospects for including EWN concepts into the alternatives being considered. LAs create drawings and renderings of various bulkhead designs in the planning phase to aid in the transparent evaluation of alternatives and to inform the analysis and identification of those with the highest priority. EWN-LA drawings and renderings can serve as communication tools in decision-making, allowing stakeholders and decision-makers to visualize the final alternative bulkhead design and its inherent benefits, as shown in Figure 6. During implementation, LAs would develop bulkhead design alternatives that promote biodiversity while taking other project objectives, local hydrodynamic conditions, and the species the enhanced bulkhead is designed to support into account. EWN-LA can also communicate design features that are convertible or modifiable based on lessons learned or in response to changing environmental conditions. Finally, in operations, lessons learned could be documented with EWN-LA renderings and presented during webinars or workshops reporting on the findings of the preferred repair alternative.

As with any coastal infrastructure project, opportunities for success require consideration of the risks and uncertainties associated with incorporating NbS that promote biodiversity. Such risks and uncertainties include obtaining project approval (in terms of costs, etc.), impeding future maintenance, jeopardizing structural integrity, and selecting project materials, along with the timing, location, ecological connectivity, project scale, and aspects of a changing community and climate. Several actions, however, can be taken to increase the likelihood of project success. As outlined by Suedel et al. (2021), actions to advance infrastructure enhancement practice include (1) early and often stakeholder communications, (2) meaningful community engagement, (3) partnering and collaborating with stakeholders to monitor project success, (4) developing designs with the intent to achieve multiple benefits (engineering as well as economic, social, and environmental) simultaneously, and (5) developing a monitoring program that identifies and quantifies the costs and multiple short- and long-term benefits of the project.

The value that NbS provides should be identified and quantified so that the full range of project benefits and costs can be calculated. Biodiversity enhancements are framed in terms of both short- and long-term benefits to current risks and uncertainties; the enhancements should not reduce the structure's engineering objective or limit access for maintenance or repairs. Sea-level rise and increased storm intensity, which may have an impact on NbS implementation, should be considered during planning. NbS features can serve as lines of defense alone or in tandem with conventional infrastructure when managing coastal flood risk. When considering a "hold-the-line" goal against sea-level rise, structural measures can be designed to provide future accommodation space for intertidal species, thereby reducing the risks associated with coastal squeeze (Perkol-Finkel and Sella 2015; Perkol-Finkel et al. 2018; Naylor et al. 2017).

Coordination and education activities can help reduce NbS risks and uncertainties. Education is vital because NbS may be a new concept for some stakeholders and project managers. The introduction of the concept may cause a shift in how a risk manager perceives a proposed project. While the primary goal of the project may be to reduce coastal flood risk, NbS consider what can be accomplished beyond the engineering objective to enhance biodiversity on coastal infrastructure. Education, training, and technology transfer can also include case study documentation, webinar or workshop development, and site visits to successful coastal NbS projects. This approach has proven successful in the United Kingdom, where these activities have helped raise awareness and boost the confidence of practitioners who are eager to help promote NbS (Naylor et al. 2017).

Effective communication is required both internally within the project team and externally with stakeholders for the approach to be successfully applied elsewhere. Monitoring should include data collection to improve understanding of the future value that such an approach can achieve in practice and how effectively the NbS can integrate into larger coastal risk reduction measures. Maintenance activities appropriate for improved structures may include slightly modified engineering inspections, such as scraping off nonnative biota (Perkol-Finkel and Sella 2015) or using unmanned technologies in situations where access is restricted due to safety concerns. Projects meeting success criteria that relay lessons learned are more informative and useful for applying these concepts in other contexts.

5 Conclusion

In this report, we outline a strategy for enhancing biodiversity in coastal infrastructure at different geographical and temporal scales using NbS. When working with partners and stakeholders, decision-making is structured into the following phases: scoping, planning, decision-making, implementation, and operations. Landscape architecture renderings that incorporate ecological sciences and NbS into an integrated approach for promoting biodiversity in coastal marine areas can promote engineering practice through this structured strategy.

The likelihood of success when reconstructing reinforced shorelines should be evaluated for the challenges and uncertainties of using NbS. Gaining project approval (for costs, etc.), estimating future maintenance needs, protecting structural integrity, and selecting project materials are keys to success, along with considering the timing, location, ecological connectivity, and scale of the project in a changing climate.

The identification and quantification of the short- and long-term value of NbS, coordination and education efforts, and efficient internal and external project team interactions are all part of promoting best NbS practices. In addition, LA visualizations when used as a communications tool can positively impact coastal biodiversity projects. Finally, guidance manuals like USACE Engineering Manuals and Coastal Engineering Manuals can be updated as new information is learned from the design, construction, and use of such improved structures, helping to advance NbS as a best practice and thereby enhancing value to the nation.

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Abbreviations

ADCIRC	Advanced Circulation
AdH	Adaptive Hydraulics
BwN	Building with Nature
CBD	Convention on Biodiversity
CSRM	Coastal storm risk management
ECDRI	European Commission, Directorate-General for Research and Innovation
EEA	European Environment Agency
EWN	Engineering With Nature
EWN-LA	Engineering With Nature landscape architecture
LA	Landscape architect
NbS	Nature-based solutions
NNBF	Natural and nature-based feature
NSW	New South Wales
SDG	Sustainable Development Goals
TLP	Thin-layer placement
UN	United Nations
USACE	US Army Corps of Engineers

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14. ABSTRACT

Extreme weather variation, natural disasters, and anthropogenic actions negatively impact coastal communities through flooding and erosion. To safeguard coastal settlements, shorelines are frequently reinforced with seawalls and bulkheads. Hardened shorelines, however, result in biodiversity loss and environmental deterioration. The creation of sustainable solutions that engineer with nature is required to lessen natural and anthropogenic pressures. Nature-based solutions (NbS) are a means to enhance biodiversity and improve the environment while meeting engineering goals. To address this urgent need, the US Army Corps of Engineers (USACE) Engineering With Nature (EWN) program balances economic, environmental, and social benefits through collaboration.

This report presents how design and engineering practice can be enhanced through organized decision-making and landscape architectural renderings that integrate engineering, science, and NbS to increase biodiversity in coastal marine habitats. When developing new infrastructure or updating or repairing existing infrastructure, such integration can be greatly beneficial. Further, drawings and renderings exhibiting EWN concepts can assist in decision-making by aiding in the communication of NbS designs. Our practical experiences with the application of EWN have shown that involving landscape architects can play a critical role in effective collaboration and result in solutions that safeguard coastal communities while maintaining or enhancing biodiversity.

15. SUBJECT TERMS

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