The Science Behind Virginia's Living Shoreline Standards: Resource for Coastal Decision-Making

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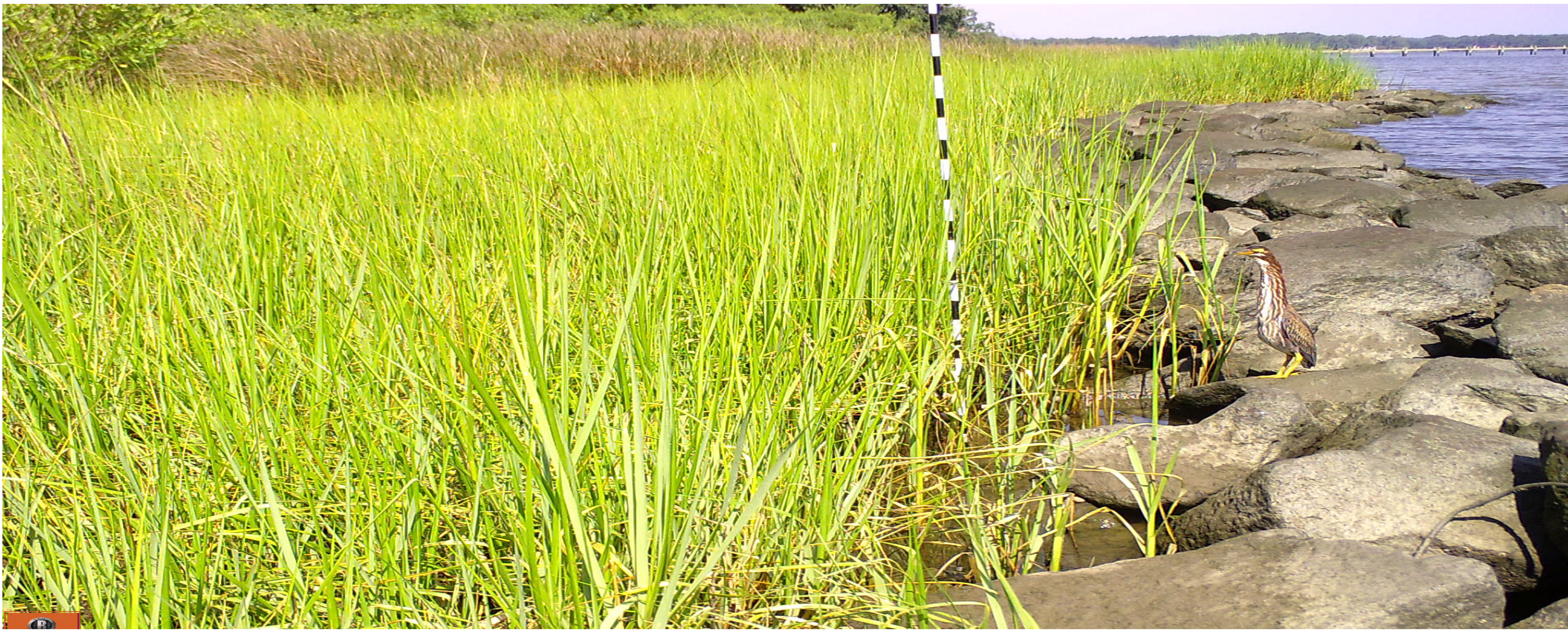
OVERVIEW

Virginia's living shoreline standard promotes nature-based approaches that provide erosion control and water quality benefits, protect, restore or enhance natural shoreline habitat, maintain land–water connections and coastal processes, and, where possible, enhance coastal resilience. Under Code of Virginia § 28.2-104.1, a living shoreline is defined not by materials alone, but by its ability to deliver these functions.

The central premise of this paper is that living shorelines should be defined by function rather than materials. To qualify, a project must use natural shoreline habitat as the basis for erosion control, provide water quality benefits, maintain land–water connectivity, and support the physical, chemical, and biological processes that sustain coastal systems over time. No single feature or material is sufficient on its own.

When properly designed, living shorelines reduce erosion, improve water quality, support habitat, and enhance resilience to storms and sea-level rise, with benefits often increasing as biological communities establish and mature. In contrast, projects that add vegetation or habitat features to armored shorelines should not be classified as living shorelines if they fail to maintain connectivity and core coastal processes. This paper presents a science-based, process-oriented framework for evaluating whether a shoreline project functions as a living shoreline in practice.



HOW TO USE THIS PAPER

Who this paper is for

This paper is intended for shoreline designers, engineers, regulators, resource managers, conservation practitioners, and funding decision-makers working in Virginia’s tidal coastal environments. It is designed primarily to support managers and practitioners applying Virginia’s living shoreline definition in practice.

What this paper does

This paper explains the scientific basis for each required element of Virginia’s living shoreline definition under **Code of Virginia §28.2-104.1**.

It is designed to support:

- Consistent interpretation of Virginia’s living shoreline definition
- Evaluation of shoreline designs and permit applications
- Alignment in decision-making across agencies and practitioners

Rather than focusing solely on materials or design configurations, this paper emphasizes the coastal processes that define a functioning living shoreline.

What this paper does NOT do

This document:

- Is **not** a prescriptive design manual
- Does **not** specify minimum dimensions, slopes, or construction materials
- Does **not** replace existing design guidance or permitting requirements

How to read this paper

Each section corresponds to one element of Virginia’s living shoreline definition. Together, these elements form a **process-based framework**. All elements are required; no single element is sufficient on its own. A project must satisfy the full definition to function as a living shoreline.

Because this paper is comprehensive, readers may:

- Navigate directly to the section corresponding to a specific element of the living shoreline definition
- Use boxed summaries within each section for quick reference
- Apply the evaluation questions below as a screening tool

Readers are encouraged to focus not only on the materials used in shoreline projects, but on whether designs **maintain physical, chemical, and biological coastal processes over time**.

Evaluating a project: is it functioning as a living shoreline?

Living shorelines are defined by function, not just materials. The following questions can guide evaluation.

1. Erosion control and water quality
   - Does the project use natural habitats as the primary erosion control mechanism?
   - Are groundwater and tidal pathways maintained for nutrient processing?

2. Natural shoreline habitat
   - Do natural elements dominate over structural components?
   - Do habitat type and elevation match local reference conditions?

3. Coastal processes
   - Is tidal exchange allowed across the shore?
   - Are longshore and cross-shore sediment transport processes maintained?
   - Does the design avoid scouring or downdrift erosion?

4. Resilience and adaptation
   - Is the project designed to adjust to storms and sea level rise?
   - Where feasible, does it allow for landward migration?

5. Potential causes for concern
   - Continuous hard structures with no tidal openings
   - Vegetation added to a mostly armored shoreline
   - Project labeled “living shoreline” based on materials alone

DEFINING LIVING SHORELINES

Nature-based approaches to coastal protection make use of native ecosystems, like saltmarshes, seagrasses, coral and shellfish reefs, mangroves, sand and cobble beaches, and dunes, which attenuate waves, are resilient to storms, and can adapt to changing systems [1–3]. Globally, there are different regional terms used to represent these coastal protection approaches; however, the term *living shoreline* has begun to be adopted into governance structures in the United States [4]. Living shoreline techniques include those that restore the habitat alone or are used in combination with hard engineered structures (e.g., breakwaters, rock sills, artificial reef materials) to support habitat establishment (also called “hybrid” approaches) [5,6]. The intended overall goal of a living shoreline is to balance ecological and engineering goals to achieve coastal protection and ecosystem sustainability [2,4]. The Commonwealth of Virginia requires the use of a *living shoreline* where suitable and has codified the definition of a *living shoreline* (Code of Virginia § 28.2-104.1). There are varied materials and designs that are being applied as living shorelines, with an increasing number of proprietary materials being used.

To support decision making on the implementation of living shoreline techniques, this paper outlines the science that underpins the constituent elements of a living shoreline as defined by the Commonwealth of Virginia.

Living shorelines as defined by the Commonwealth of Virginia

The Virginia living shoreline definition is built with constituent elements that are equally critical and are explored from a scientific perspective in the following sections.

Virginia defines living shorelines in Code (Code of Virginia § 28.2-104.1) as

(1) *a shoreline management practice that provides* erosion *control and water quality benefits;*
(2) *protects, restores or enhances natural shoreline habitat; and*
(3) *maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural and organic materials.*
(4) *When practicable, a living shoreline may enhance coastal resilience and attenuation of wave energy and storm surge*.

"Other structural and organic materials" means materials or features that provide added protection or stability for the natural shoreline habitat components of a living shoreline that attenuate wave energy and do not interfere with natural coastal processes or the natural continuity of the land-water interface. "Other structural and organic materials" may be composed of a variety of natural or man-made materials, including rock, concrete, wood fiber, oyster shells, and geotextiles; however, structural features shall be free from contaminants and shall be adequately secured to prevent full or partial dislodging or detachment due to wave action or other natural forces.

1. A shoreline management practice that provides erosion control and water quality benefits

> *Living shorelines are a nature-based strategy to reduce shoreline erosion while also improving water quality. By using natural features like wetlands, beaches, and oyster reefs, they slow waves, absorb storm energy, and stabilize sediments, protecting both coastal property and habitats. At the same time, these systems filter pollutants and excess nutrients from the water, supporting healthier coastal ecosystems and meeting water quality goals. As a result, living shorelines offer a practical approach that balances shoreline protection with long-term environmental benefits.*

Shoreline erosion is a natural process that is essential to maintain healthy coastal habitats, including beaches, spits, and wetlands. When active erosion becomes detrimental to human infrastructure and coastal habitats, erosion control measures may be considered. Virginia allows for the alteration of shorelines to "protect property from significant damage or loss due to erosion…", "provided that marine fisheries, valuable fish habitat, wetlands and wildlife resources, flood protection, and water quality are not detrimentally affected, and the proposed use does not contribute to the cumulative net losses of tidal wetlands" (VMRC 2021, https://mrc.virginia.gov/Regulations/Final-Wetlands-Guidelines-Update_05-26-2021.pdf).

Living shorelines use natural shoreline habitat, such as tidal wetlands, beaches, and dunes, as the primary erosion control feature. Laboratory and field studies have demonstrated that structural coastal habitats, such as salt marsh vegetation, are highly effective at reducing current flow velocities and attenuating storm surge and wind waves [7–13]. Tidal wetland vegetation enhances coastal resilience by anchoring sediments, elevating intertidal zones, and dissipating wave energy[1]. Collectively, these processes diminish the intensity, height, and duration of wave forces before they reach inland areas, thereby mitigating erosion. This natural buffering capacity also contributes to storm surge attenuation through greater water retention and absorption compared to unvegetated tidal flats, resulting in enhanced flood mitigation and erosion control even during major storm events. Nearshore oyster reefs can further dampen wave energy and protect adjacent shoreline habitats (e.g., salt marshes) while increasing sediment accretion rates [14–18]. While wave attenuation decreases when the habitats are submerged (e.g., subtidal oyster reefs or marsh vegetation during storm events), these structurally complex systems still dampen wave energy under such conditions [19]. When multiple ecosystems are arranged sequentially from offshore to the intertidal zone (e.g., oyster reefs, seagrasses, tidal wetlands), they can provide additive layers of coastal defense [20]. **The ability of these habitats to provide erosion control forms the foundation of a living shoreline.**

Habitat as erosion control

The ability of native shoreline habitats to provide erosion control forms the foundation of a living shoreline

At the same time, these natural shoreline habitats deliver important water quality co-benefits. For example, tidal wetlands intercept nutrients from upland groundwater discharge and capture nutrients from tidal waters [21–24]. As freshwater inputs from upland sources flow through tidal wetlands, the flow is naturally slowed by the upright structure of the vegetation. This reduction in velocity facilitates the settling of suspended sediments and enhances the uptake of nutrients by wetland vegetation, effectively filtering and retaining pollutants before they reach open waters[25].The ability of vegetated coastal habitats (i.e., wetlands, beaches, and dunes) to filter water from surface, subsurface, and tidal sources not only benefits human health and infrastructure but also supports the ecological health of adjacent habitats—such as seagrass beds—that are sensitive to nutrient enrichment and turbidity. In this way, living shorelines that incorporate constructed wetlands contribute to achieving water quality goals under programs such as the Chesapeake Bay Total Maximum Daily Load (TMDL) ([26]). For managers, this means that living shorelines simultaneously address multiple regulatory and ecological goals—reducing erosion, improving water quality, and enhancing resilience—without sacrificing natural processes. In many cases, these approaches meet conditions for the desired erosion protection and requirements for pollution reduction credits.

2. A shoreline management practice that protects, restores or enhances natural shoreline habitat

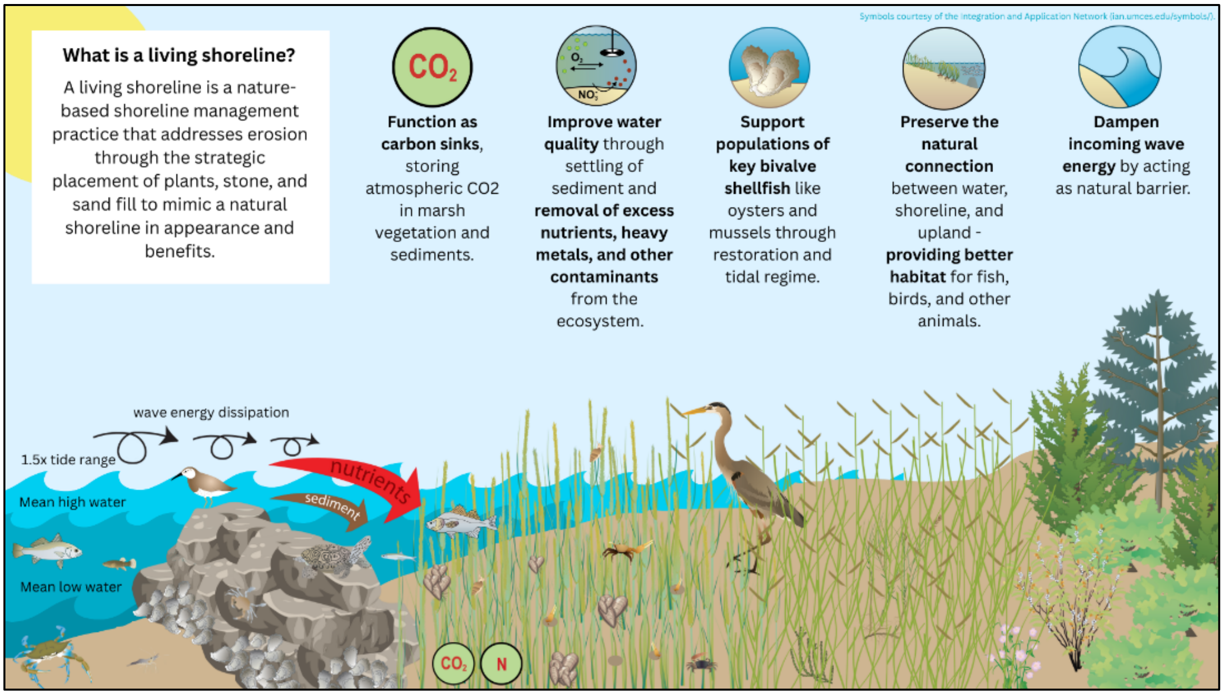
> *Living shorelines are designed to protect, enhance, or restore natural shoreline habitats such as wetlands, beaches, and dunes. They can stabilize existing habitats, support habitat expansion, or rebuild habitats through plantings and other natural features. While some structural elements may be used, natural materials and processes remain the focus to ensure these shorelines continue to function as healthy ecosystems. Overall, living shorelines increase shoreline stability and resilience while preserving the natural character and ecological benefits of coastal habitats.*

“Natural shoreline habitat” is not further defined or specified in the Virginia Living Shoreline definition. Because tidal wetlands, coastal primary sand dunes and beaches are preserved and protected in state law (§ 28.2-1301 and § 28.2-1401) and are the primary habitat features used in living shorelines in Virginia, for this paper, these features are considered “natural shoreline habitat”.

A living shoreline has a net resilience benefit to these natural shoreline habitats. In practice, living shoreline techniques can:

- **i)** *Protect* an existing natural shoreline habitat by incorporating stabilizing features (e.g., bagged oyster shell) along the water’s edge,
- **ii)** *Enhance* natural shoreline habitat by promoting sediment capture and habitat expansion, such as through the use of temporary (e.g., coir logs) or permanent (e.g., rock sills) stabilizing features placed waterward of the habitat, or
- **iii)** *Restore* natural shoreline habitat through the direct construction of habitat (e.g., tidal wetland vegetation plantings), incorporating, when necessary, temporary stabilization features or permanent hard engineered structures to support the establishment and persistence of the restored habitat.

However, to maintain the character and ecosystem services of the natural shoreline habitat, natural elements should predominate over artificial elements (**Figures 1 and 2**). Emerging research further emphasizes that material selection in coastal restoration carries broader environmental implications, reinforcing the importance of prioritizing natural or reduced-impact materials where feasible [27]. Moreover, Virginia state law mandates "If the best available science shows that a living shoreline approach is not suitable, the Commission shall require the applicant to incorporate, to the maximum extent possible, elements of living shoreline approaches into permitted projects." VMRC Tidal Wetlands Guidelines (May 2021 Update) provides additional details to aid in the interpretation of state law for wetland permits.



Symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols/).

What is a living shoreline?

A living shoreline is a nature-based shoreline management practice that addresses erosion through the strategic placement of plants, stone, and sand fill to mimic a natural shoreline in appearance and benefits.

Function as carbon sinks, storing atmospheric CO2 in marsh vegetation and sediments.

Improve water quality through settling of sediment and **removal of excess nutrients, heavy metals, and other contaminants** from the ecosystem.

Support populations of key bivalve shellfish like oysters and mussels through restoration and tidal regime.

Preserve the natural connection between water, shoreline, and upland - **providing better habitat** for fish, birds, and other animals.

Dampen incoming wave energy by acting as natural barrier.

Figure 1. Example of a 'hybrid' living shoreline showing how natural habitats (tidal wetland) and hard engineered structural features (rock sill) are placed so that they work together to protect shorelines and support ecosystem services

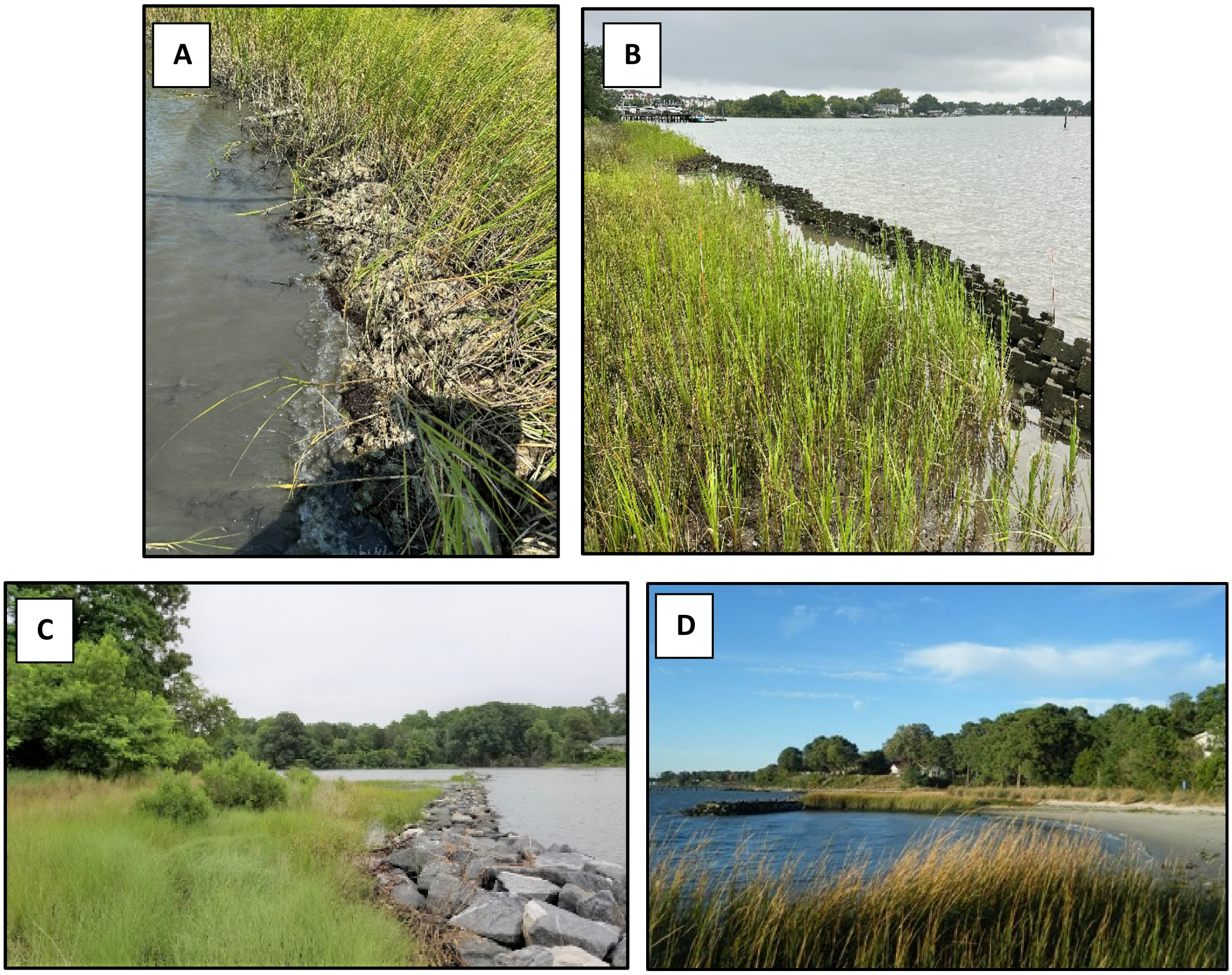


Figure 2. Example living shoreline techniques in Virginia (**A**) bagged oyster shell protecting an eroding marsh edge, (**B**) planted marsh with oyster reef structures placed waterward to stabilize the edge, (**C**) planted marsh with rock sill, (**D**) vegetated pocket beaches with rock breakwater.

3. A shoreline management practice that maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural and organic materials

> *Living shorelines are designed to manage erosion while maintaining the natural physical, chemical, and biological processes that shape coastal environments. By strategically placing native vegetation, sediment, and low-profile structural elements, they allow sediment movement, water exchange, and habitat connectivity to continue, supporting long-term resilience to storms and sea-level rise. These designs promote wave attenuation, sediment retention, nutrient and carbon cycling, and the recovery of native plant and animal communities. Compared to hard shoreline armoring, living shorelines better sustain ecosystem functions, water quality, and biodiversity while providing durable shoreline protection.*

Coastal processes

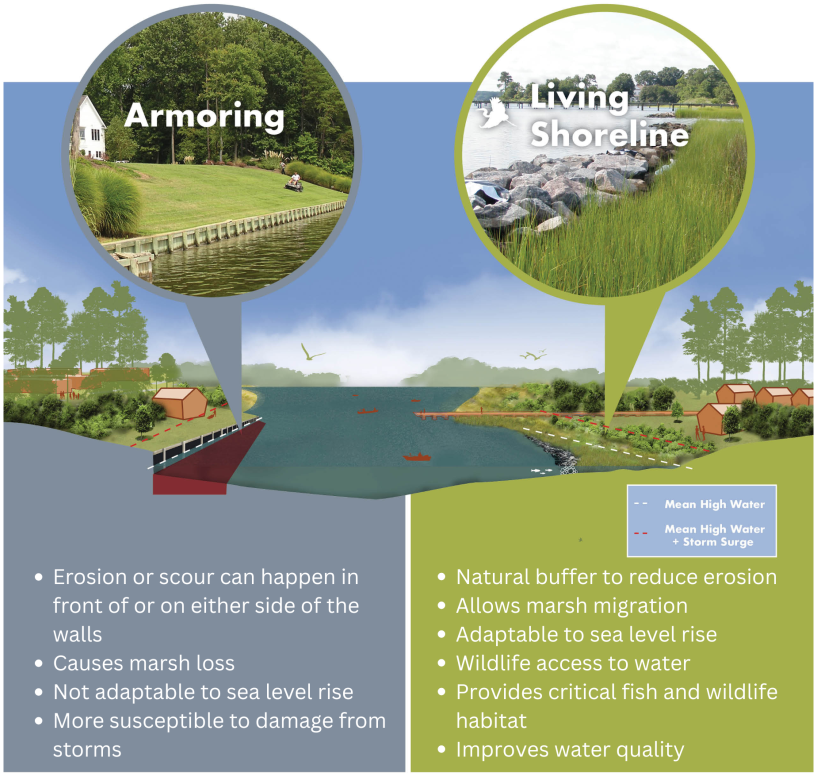
Coastal processes are the physical, chemical, and biological forces that shape shorelines and influence the distribution of coastal habitats and species (Penn State Earth 107 https://courses.ems.psu.edu/earth107/node/2) [28]. A living shoreline uses natural and engineered features to work with, rather than against, these processes.

The design of a living shoreline modifies natural processes to varying degrees, depending on site conditions and materials. Living shorelines are intended, by design, to interrupt the otherwise natural process of shoreline erosion. However, by leveraging natural shoreline habitats to curb erosion, such as tidal wetlands, beaches, and dunes, as opposed to conventional hard armoring (i.e., riprap revetment and bulkheads), other natural coastal processes can be maintained to attain habitat and water quality benefits (**Figure 3**).

Indicators of success include the continuity of sediment transport pathways, the exchange of water, carbon, nutrients, and organisms between ecosystems, and the natural recruitment and succession of plants and animals over time. Living shorelines should be dynamically and thoughtfully designed to allow for shifts in sand and plants over time in response to changing conditions. These shifts are necessary for supporting long-term resilience by enabling adaptive responses to dynamic forces like sea level rise, storm events, and sediment supply variability [3,12]. In this way, living shorelines can provide both protective and regenerative benefits while maintaining the integrity of coastal processes.

Disruption of coastal processes can be minimized by:

- **limiting the use of engineered and artificial materials**
- **using native and locally sourced materials**, such as wetland and riparian plants
- **maintaining land-water connectivity** between upland, proposed project natural shoreline habitats, and nearshore environments, as well as the exchanges between sediments and the overlying water column (benthic–pelagic coupling)
- **designing within the geomorphic and ecological context of the site.** For example, selecting plant species based on nearby native habitats; placing oyster reef structures in suitable oyster habitat with nearby larval sources for recruitment; placing a sill at an elevation compatible with the site's natural tidal range so that tidal exchange, sediment delivery, and vegetation growth occur in patterns similar to surrounding habitats
- **allowing for the dynamic movement of biological and physical components,** such as plants and sediment



- Erosion or scour can happen in front of or on either side of the walls
- Causes marsh loss
- Not adaptable to sea level rise
- More susceptible to damage from storms

- Natural buffer to reduce erosion
- Allows marsh migration
- Adaptable to sea level rise
- Wildlife access to water
- Provides critical fish and wildlife habitat
- Improves water quality

Developed by the Virginia Institute of Marine Science (VIMS) at William and Mary for the National Science Foundation (NSF) Coastal Science, Engineering, and Education for Sustainability (SEES) Initiative.Image designed by Kelsey Broich, Network for Engineering with Nature, University of Georgia. (2021). Bulkhead (left) and living shoreline (right) images by VIMS Center for Coastal Resource Management.

Figure 3. Living shorelines work with natural processes to attain ecosystem benefits and enhance resilience. Armoring disrupts coastal processes, reduces ecosystem benefits, and is not adaptable to changing conditions

Physical processes

To maintain physical coastal processes, a living shoreline management practice, while providing erosion control, should allow to the maximum extent possible:

> **Naturally unimpeded movement of sediment, water, water-borne materials, and aquatic and terrestrial fauna at local and larger scales, both along and across the shore.**

Designing for long-term erosion control

To achieve erosion control goals without disrupting these coastal processes, a well-designed living shoreline promotes the establishment or enhancement of native shoreline habitats that are self-sustaining – requiring no routine replenishment of sand or vegetation – and causes little to no adverse impact on surrounding shores and habitats. In Virginia, these habitats typically include salt marshes, beaches, dunes, and oyster (*Crassostrea virginica)* reefs.

Sediment movement

Unlike practices such as routine beach nourishment, living shorelines typically rely on a single sediment addition that functions within natural sediment dynamics, including alongshore (downdrift) transport, to retain sediments and support long-term habitat persistence. Sediment movement is driven by waves, tides, storms, and upland runoff. **Longshore sediment transport** refers to the movement of sand, silt, and other unconsolidated materials parallel to the shoreline, generated by waves that approach the coast at an angle and produce longshore currents. This process redistributes sediment laterally along the coast and plays a major role in shaping shoreline morphology. Although longshore transport typically follows the dominant downstream direction, seasonal prevailing wind-driven changes and storm events can reverse transport and move sediment upstream. **Cross-shore sediment transport** refers to the landward and seaward movement of sediments between nearshore waters and coastal landforms, including beaches, dunes, and marsh edges, driven by wave breaking, storm surge, and tidal water-level fluctuations, with aeolian processes and vegetation-mediated trapping playing key roles in sediment delivery and retention within dunes and marsh interiors. Together, longshore and cross-shore transport govern beach and wetland stability, shape system recovery after storms, and affect the performance of living shorelines. By intercepting and retaining sediment from offshore, adjacent shorelines, and upland sources, living shorelines help mitigate erosion and contribute to habitat persistence [29,30].

A healthy shoreline needs movement of water, sand, and living things

Living shorelines are designed to reduce erosion without shutting down these natural flows. When plants, marshes, dunes, and oyster reefs are allowed to shift and grow, they trap sediment, slow waves, and build elevation over time. This natural “self-maintenance” makes living shorelines more resilient than hard structures, better for wildlife, and better able to keep up with storms and sea-level rise.

Wave attenuation and vertical accretion

Vegetated wetlands, beaches, and dunes attenuate waves by increasing surface roughness through aboveground vegetation, which slows water movement, dissipates energy, and promotes sediment deposition while reducing resuspension [10,11,31–38]. There is a positive relationship between vegetated marsh width and wave energy reduction - generally, marshes are able to attenuate up to ~ 40 % of wave energy within the first meter, with a linear increase to 100 % by 25 m (80 ft) [7,39–41]. A meta-analysis concluded that marshes less than 10 m (30 ft) in width can reduce wave heights by 50–80% [11].

Salt marsh absorbing waves

Under storm surge, salt marsh vegetation was observed to contribute up to 60% of observed wave reduction, and even when waves were large enough to flatten or break stems, the marsh substrate was resistant to erosion [42]. In North Carolina, both marshes—with and without oyster-shell or rock sills—exhibited greater resilience to hurricane impacts than bulkheads, and while marsh vegetation densities temporarily declined, recovery to pre-storm levels occurred within one year [43]. These findings highlight the importance of the biotic components of a living shoreline (i.e., the vegetation) as being durable and resilient to storms. The capacity of beaches and dunes to reduce wave energy and storm surge impacts is also well documented. Vegetation is a critical stabilizing component for beaches and dunes, enhancing sediment retention, increasing erosion resistance, and improving wave attenuation performance [44–47].

Large, dense clumps of marsh vegetation (*Spartina* spp.) tend to provide the greatest attenuation and sediment stability [48], with some studies suggesting that clustered planting, rather than evenly spaced individuals, improves survival, aboveground growth, and stem density of marsh grasses [48,49]. Belowground biomass (i.e., roots and rhizomes of tidal vegetation) further binds sediments and enhances resistance to erosion[38,50]. These mechanisms collectively facilitate the accumulation of mineral and organic sediments, increasing substrate stability, supporting vertical accretion, and helping habitats maintain their elevation relative to sea level [3].

Marsh vegetation is particularly effective at capturing both mineral and biogenic sediments, a key process underlying vertical accretion [51]. However, in the Chesapeake Bay, where relative sea-level rise is high, natural accretion rates may be insufficient for marshes to keep pace [52,53]. Living shoreline designs that combine restored marshes with a stabilizing sill may enhance sediment capture beyond that of natural marshes. In North Carolina, restored marshes planted landward of rock sills accumulated sediment at rates 1.5–2 times higher than natural marshes, suggesting that these structure-associated habitats may exhibit increased resilience to sea-level rise [54].

Designing stabilizing structures to maintain coastal processes

In higher-energy environments, where wave energy exceeds thresholds acceptable for plant establishment and sediment retention, an addition of an engineered wave-break structure (e.g., rock sills, breakwaters, reefs) may be necessary [55-57]. Low-profile sills used in combination with planted marshes have been shown to significantly decrease rates of shoreline erosion and protect fringing marsh [58,59]. This protection was demonstrated even in the context of extreme events such as storms [59]. Protective structures such as breakwaters may also be used to stabilize vegetated beaches and dunes. A trade-off exists between protection of the shore from wave climate and maintaining tidal exchange to the habitat via tidal gaps, which may allow pockets of shoreline erosion. Certain design elements, such as lower-profile sills with tidal gaps, vents, or lowered sections of stone, allow greater access to the habitat by aquatic organisms and encourage faunal colonization. Insufficient tidal gaps will restrict flushing, possibly causing elevated temperatures and reduced access by mobile aquatic species [60–64]. Regrettably, there is an absence of information on the efficacy of varying distances and configurations of tidal gaps to allow optimal habitat inundation and access for marine fauna. However, researchers have observed that in addition to tidal gaps, marsh access for fish was maintained through macropores in the sill stone and by overtopping of the sill by tidal waters [65]. Likewise, a recent study found that rock sills with gaps had reduced marsh edge erosion, enhanced tidal flushing, and sediment deposition compared to continuous sills [29]. Innovative vent designs (e.g., staggered system), sill porosity, and overtopping by tidal waters are potential balancing mechanisms [60]. While projects with gaps, or tidal openings, between structures can provide ecological and hydrological benefits, they also allow for additional wave energy transmission. To account for this, gaps may be staggered or the structures angled away from the shore at the gap[65,66]. Additionally, structures should be oriented perpendicular to the dominant wave direction, or, if waves come from multiple directions, built in a chevron[66,65].

While structures, such as a stabilizing stone sill or breakwater, may enhance recruitment of species that are limited by the availability of hard substrate, including native and introduced species [67], they may also alter the hydrodynamic and physical conditions around them, likely affecting the distribution of planktonic larvae that rely on currents to transport them to suitable substrate for settlement, such as ribbed mussels (*Geukensia demissa*) seeking suitable salt marsh substrates [68]. Species recruitment to structures is expected to be highly variable because it is regulated by many factors such as species distribution, life history, distance from source populations, relative dominance of pioneer species, estuarine circulation patterns, physical conditions, and wave energy [69–71], as well as the material and design of the structures. Structures with greater interstitial space, niches, and submergence periods (e.g., bagged oyster shell, concrete reef structures, and sills with smaller interior core stone) tend to support greater species diversity and abundance compared to high profile breakwaters made of larger quarry stone [62] (**Figure 4**). In addition, the placement of a structure requires the conversion of existing shallow subtidal bottom, which often supports high macrobenthic diversity [67]. Because of the loss of shallow bottom under the sill footprint and the filling to create new intertidal habitat, infaunal diversity may be reduced for several years following construction [67].

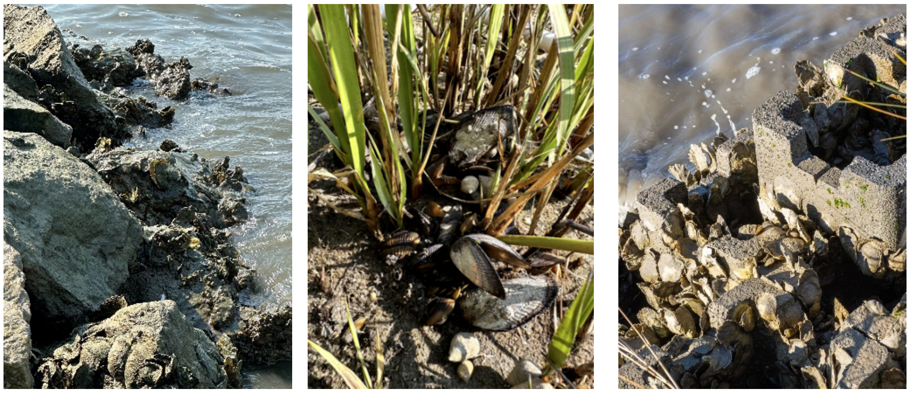


Figure 4. Images show native species recruitment on different substrates from left to right: stone sill/breakwater in the low tide zone, mussels to the salt marsh substrate, and oyster castle reef structure.

To minimize disruption of coastal processes, hard structures used in a living shoreline should:

- **be low profile** to allow tidal overtopping
- **be sufficiently porous** to provide interstitial habitat for fish and invertebrates and to permit water flow through the structure, reducing wave reflection and limiting scour at the base
- **incorporate tidal openings** (gaps) which facilitate increased circulation and faunal movement
- **have a minimized footprint** to limit direct loss or displacement of subtidal and intertidal habitat and reduce the chance of causing downstream erosion

Indications that a shoreline management practice may be significantly disrupting natural physical processes at local and larger shoreline reach scales include:

- interference with downdrift sediment transport that results in erosion on surrounding shores
- increased turbidity in the nearshore subtidal, which may result in adverse effects on water quality and clarity and/or submerged aquatic vegetation
- reduction in sediment capture on marsh surface, limiting vertical accretion and therefore resilience
- scouring or deepening of the nearshore zone adjacent to hard structures
- channelization or redirection of surface runoff leading to erosion hotspots
- blockage or redirection of longshore and cross-shore water movement, which can fragment habitat and impair tidal flushing
- faunal movement, settlement, or recruitment is impeded

Long-term sustainability

For a living shoreline to remain self-sustaining, designs must support the dynamic movement of habitat features (e.g., vegetation and sediments) in response to storms and evolving coastal conditions [3,72]. Long-term sustainability increasingly depends on sufficient local sediment supply and the opportunity for upland retreat. Living shoreline capacity to self-adapt to rising sea levels is derived from living components that generate organic matter and retain sediment, enabling elevation gain through plant productivity and sediment capture [3]. Compared to conventional hard armoring, living shorelines are more resilient due to their ability to intercept, accumulate, and retain sediments, strengthening substrate stability and building elevation [73]. Sediment deposition is further enhanced by wave-energy reduction, which is governed by marsh width, vegetation height and density, and the configuration of any stabilizing structure when present [10,43,54,74].

Where sea-level rise is accelerating and sediment delivery is inadequate, tidal wetland migration into adjacent uplands becomes a key determinant of habitat persistence. Under these conditions, living shorelines are more durable long-term solutions when designed to enable landward migration rather than relying solely on vertical marsh accretion [3,72].

Because static stabilization elements lose effectiveness as water levels rise, rock sills and breakwaters will decline in their ability to dissipate waves and retain sediment. Conversely, biologically active reef structures can maintain or increase protective performance post-installation. As oysters grow and expand on modules such as oyster castles, the added surface roughness increases wave dissipation, supports continued sediment capture, and promotes natural recruitment [75,76]. Additionally, some studies showed promising results on the ability of oysters (*C. virginica*, Eastern oyster, in the United States and *C. gigas,* Pacific oyster, in the Netherlands) to keep pace with rising waters in high-salinity intertidal areas[16,77,78].

Overall, living shorelines achieve the greatest long-term success when sediment connectivity is preserved, engineered footprints are minimized, and designs facilitate habitat migration into adjacent uplands as sea level rises, enhancing ecological function and coastal resilience [3,62,72].

Chemical processes

To maintain chemical processes, a living shoreline management practice should allow to the maximum extent possible:

> **Naturally functioning nutrient and carbon cycling, strong benthic–pelagic coupling, and two-way exchange of water, dissolved and particulate carbon and nutrients, and organisms between living shoreline habitats and adjacent ecosystems.**

Designing for water quality

Maintaining chemical processes facilitates carbon sequestration, removal of excess nitrogen and phosphorus, and filtration of contaminants such as heavy metals. By replicating natural ecosystems, well-designed living shorelines may facilitate and perform many of the chemical processes necessary to achieve water and habitat quality goals, including those established under the Chesapeake Bay Total Maximum Daily Load.

Carbon storage

Living shorelines can function as carbon sinks by capturing and storing atmospheric carbon dioxide within the vegetation and soils [79-81]. Incorporating vegetation, whether marsh, beach, or dune plants, enhances carbon sequestration potential. The aboveground biomass of living shoreline marsh plants generally takes less than 5 years to match those of natural marshes [54,82,83] and the leaf tissues of *S. alterniflora* and *S. patens* have similar concentrations of carbon, nitrogen and phosphorus, averaged across living shoreline and natural fringing marshes [79]. However, carbon storage in the soils can take longer to achieve equivalence depending on construction practices [84]. For living shoreline marshes constructed with clean sand fill and plantings, carbon storage within the soils tends to initially be lower than natural marsh soils because of the relative absence of organic matter that—when present—decreases bulk density and stores carbon and nitrogen [79]. Over time, as vegetation develops and organic matter accumulates, soil carbon stocks converge with those of natural marshes, typically within ~24 years [79].

Living shorelines act like natural water filters

Plants, soils, and healthy sediment–water exchange allows living shorelines to trap pollutants, pull nitrogen and phosphorus out of the water, and store carbon in vegetation and marsh soils. As the habitat matures, its ability to clean and improve water quality becomes comparable to natural marshes helping meet Chesapeake Bay goals while providing cleaner water for people and wildlife.

Nutrient cycling

Living shorelines can function as nutrient sinks by capturing, storing, and transforming nitrogen and phosphorus within the vegetation and soils [79]. Nutrients are stored temporarily in plant tissue and long-term in soils. Leaf tissues of *S. alterniflora* and *S. patens* compared between natural marshes and living shorelines have similar concentrations of nitrogen and phosphorus [79]. In the Chesapeake Bay, as living shoreline marshes mature, nitrogen and phosphorus storage within the soils tends to converge with natural marsh soil levels within approximately 6 and 13 years, respectively [79].

Wetlands remove nitrogen from both upland inputs, surface and groundwater and recirculating tidal surface waters. A substantial portion of groundwater nitrate loads are intercepted near marsh–upland transitions, where one study showed up to 90% of groundwater nitrate loads were intercepted within the first 50 cm of marsh soils along the upland border [85], and another showing ~80% removal within 5 m of the marsh edge on shorelines adjacent to managed lands [61]. Living shorelines incorporating marshes have the capacity to remove a major fraction of nitrogenous nutrient species from both groundwater and surface waters at levels comparable to natural marshes in the Chesapeake Bay region[24].

Tidal wetlands serve as biogeochemical hotspots, supporting high rates of microbial nitrogen removal through denitrification pathways that transform nitrates to inert nitrogen gas (N_2) [86–89](**Figure 5**). In contrast to these living systems, conventional hard armoring (e.g., bulkheads) can steepen the tidal ecotone, eliminate intertidal habitat, and disrupt key microbial and biological interactions required for nitrogen removal. Unlike hard armoring, living marsh-based shorelines enhance nitrogen removal via denitrification while avoiding excess production of nitrogen-based greenhouse gases [88]. Nitrogen transformations are further influenced by biological interactions that enhance sediment–water exchanges. Burrowing infauna increase bioirrigation and diffusion of oxygen and nutrients into sediments [90–92, 135], promoting conditions that favor microbial nitrogen removal. Coupled vegetation–faunal interactions amplify these functions, including the enhancement of denitrification by ribbed mussels in association with marsh cordgrass, *S. alterniflora*, which significantly increases denitrification rates relative to vegetation alone [93].

To support these nutrient-removal processes, living shoreline construction should minimize engineered, impervious, or artificial materials that may disrupt benthic–pelagic coupling, for example, by covering intertidal soils. Certain synthetic materials—especially plastics—can alter sediment characteristics, shift microbial communities, and interfere with biogeochemical pathways such as nitrogen cycling [94]. Impervious structures may also sever water connections to marsh sediments and limit burrowing fauna, thus weakening benthic–pelagic coupling and limiting denitrification and organic matter processing. Minimizing such materials helps preserve the sediment–water interactions required for effective nutrient processing and ecosystem functioning (**Figure 5**). While structures such as riprap revetments and sills can increase settlement and local densities of epifaunal suspension feeders (e.g., oysters and mussels) by providing additional attachment surfaces [67], their net contribution to nutrient cycling remains uncertain and needs further study.

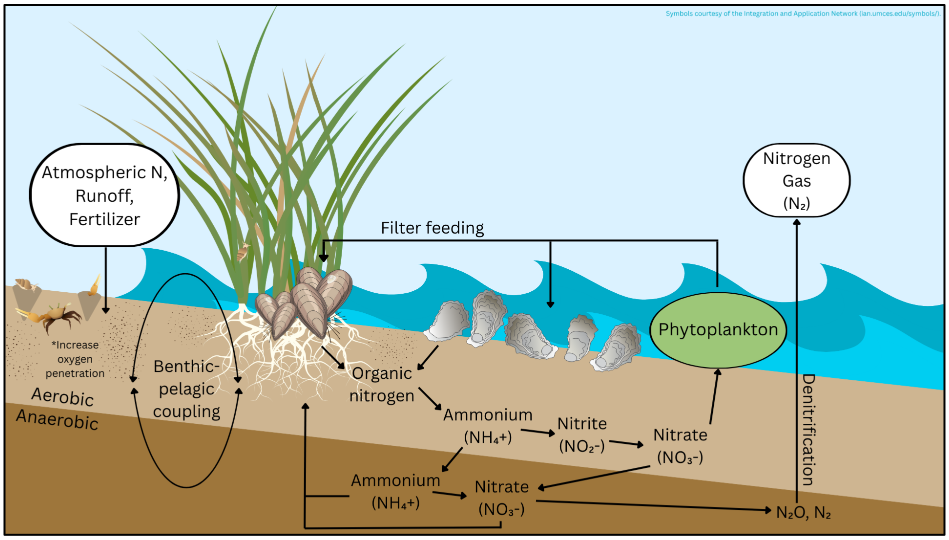

Symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols/).
Atmospheric N,
Runoff,
Fertilizer
Filter feeding
Nitrogen
Gas
(N_2)
Phytoplankton
*Increase
oxygen
penetration
Aerobic
Anaerobic
Benthic-
pelagic
coupling
Organic
nitrogen
Ammonium
(NH_4+)
Nitrite
(NO_2-)
Nitrate
(NO_3-)
Denitrification
Ammonium
(NH_4+)
Nitrate
(NO_3-)
N_2O, N_2

Figure 5. Microbially mediated processes and biodeposits of organic carbon and nitrogen support benthic-pelagic coupling and nitrogen removal within the marsh community. Fiddler crab burrows enhance aeration and bioturbation, promoting sediment oxygen exchange and nutrient cycling.

Contaminant filtration

Natural marshes filter polluted runoff, trapping contaminants that would otherwise enter the estuary [95]. Living shorelines provide comparable levels of contaminant filtration [96] and similarly to natural marshes can trap excess nutrients delivered from uplands [24]. Incorporating vegetated components, such as planted marshes, enhances this water-quality service. Increasing structural porosity or adding gaps can further improve water circulation, supporting oxygenation and maintaining water quality [65].

Biological processes

To maintain biological processes, a living shoreline management practice, should to the maximum extent possible:

> **Protect, restore, and enhance natural shoreline habitat and support primary and secondary production of native flora and fauna.**

Designing for biodiversity – restoring a native ecosystem

Living shorelines involve the restoration of native ecosystems to stabilize shorelines. Essential components of restored ecosystems include foundation or habitat-forming species, such as marsh vegetation and oysters [97]. These foundation species create habitats that support a variety of other species, including economically important fish and shellfish [98]. Living shoreline techniques frequently use nearby coastal habitats as a "reference" to identify suitable vegetation and their preferred elevations [66]. Marsh plant communities are structured by tidal range, as species exhibit varying sensitivity to salinity and inundation [66]. Plant growth is also dependent on site-specific factors such as substrate type, sunlight availability (which may be limited if there are overhanging trees), and planting season, with spring plantings typically more successful than summer [63,65-66,99]. After planting, it may take up to 3-5 years for the aboveground biomass (plant density and height) to reach ecological equivalence with natural marshes [82,84,100,101], with belowground biomass typically developing more slowly [83].

Living shorelines restore the natural food web from the bottom up

Living shorelines rebuild native habitats such as marsh plants, oysters, mussels, and healthy sediments that in turn support crabs, small fish, juvenile sportfish, shorebirds, and even terrapins. Because they keep land and water connected, living shorelines allow animals to move, feed, and grow just as they do in natural marshes. Over time, these restored habitats become biologically rich, self-sustaining communities like natural shorelines and far exceed the ecological value of hard-armored coasts.

Across a range of biological metrics, established living shorelines (i.e., restored salt marsh with gapped rock sills) in the Chesapeake Bay have been shown to support ecological communities like those of natural shorelines [82]. To achieve ecological performance goals, living shorelines should allow for faunal movement, trophic interactions, benthic-pelagic coupling, and nutrient cycling [102,103]. Designs that use low-profile structures or incorporate gaps between structures, particularly for larger projects, allow for tidal exchange and accommodate faunal use of the marsh[5,65]. Alternatively, conventional hard armoring (e.g., riprap revetment, bulkhead) eliminates coastal habitat and disrupts land-water connectivity. Disruption of connectivity due to hard shoreline armoring has been associated with increased erosion due to reduced sediment supply from the upland [104,105], reduced adjacent submerged aquatic vegetation (SAV) presence [106], reduced fish habitat quality [107,108], and low taxa diversity [109]. Living shorelines that preserve upland-water connectivity are associated with productive benthic communities [67,110] and sustained SAV coverage [30,111]. Moreover, the preserved upland-water connection of a living shoreline increases the potential for marshes to migrate landward in response to sea level rise [3]. To preserve and restore ecological function, living shorelines should be designed such that they restore or enhance connectivity from the upland to the nearshore subaqueous waters.

Benthic communities

In addition to promoting cross-shore connectivity between the upland and subtidal, the permeable nature of living shorelines facilitates coupling between benthic and pelagic environments. This coupling allows for the recruitment and survival of key species groups that contribute to ecosystem function and the provisioning of services. In salt marsh habitats, this includes fiddler crabs (*Minuca* & *Leptuca* spp.), marsh periwinkle snails (*Littoraria irrorate*), and ribbed mussels. Fiddler crabs play important roles in many marsh processes, serving as links in the food web, transferring energy from the marsh to the greater estuary. They consume algae, bacteria, and decaying plants (primary production) and, in turn, they are important food items of large predators such as blue crabs, finfish, rails, egrets, and herons. Their burrows help aerate the sediments, promoting marsh plant growth, and are used by other small invertebrates, such as the marsh periwinkle snails (**Figure 5**). Marsh periwinkle snails enhance organic matter processing by feeding on microalgae, detritus, and fungus from the marsh surface and on the leaves of *S. alterniflora* and are important prey for blue crabs, mud crabs, and diamondback terrapin[62]. Furthermore, living shorelines have been associated with increased density of important infauna (animals that live within the sediments of aquatic environments), such as clams, which are important food sources for larger predators [110], and polychaeate worms that bioturbate sediments and facilitate nutrient cycling processes through their burrowing activities [90,91]. Additionally, ribbed mussels are semi-infaunal marsh residents that enhance ecosystem functionality through direct and indirect mechanisms, such as biodeposition, stabilization, and facilitation of bioturbators such as marsh and mud crabs that increase water infiltration and decomposition [112]. The mutualistic relationship between ribbed mussels and *S. alterniflora* boosts primary productivity, increases ecosystem resilience [112], and enhances nitrogen cycling and removal [93]. In contrast, hard armored shorelines are associated with reduced infauna density [113,114] and lower abundances of blue crabs and other predators [107,114]. Shoreline stabilization designs that cover benthic habitat with hard engineered materials disrupt infaunal habitat, sever benthic-pelagic connectivity, and generally cannot support thriving benthic communities performing ecological functions at optimal levels.

Healthy living shorelines depend on life below the surface

Infaunal species like clams, worms, fiddler crabs, and ribbed mussels keep marshes functioning by aerating soils, cycling nutrients, supporting plant growth, and fueling the food web. Living shorelines sustain these hidden communities, while hard structures bury or block them, disrupting coastal biological processes and reducing water quality, habitat value, and resilience.

Periwinkle snails, fiddler crabs and their burrows

Bivalves - Oysters and mussels

Other important biological components of living shorelines include reef and aggregation-forming bivalves, such as oysters and mussels [62,82,115]. Restoration of tidal regime, planting of marsh vegetation, and use of natural substrates, like shell bags or rocks, provide habitat for mussels and oysters. In turn, these aggregation-forming bivalves provide habitat for other marsh fauna and may enhance the wave attenuation, shoreline stabilization, and accretion functions of living shorelines [62,82,116–118]. Once bivalve populations are established at living shorelines, they may become a self-sustaining recruitment hotspot and serve as a local larval source to nearby marshes and reefs. As reefs mature and expand with oyster growth, wave attenuation and habitat provision of the structure may increase [119,120]. If habitat is appropriate and site conditions suitable for oysters, shell bags or oyster reef structures may be incorporated into living shoreline designs. Oyster suitability may be predicted using habitat suitability models which incorporate parameters such as salinity, fetch, and residence time, though predicted ideal conditions may vary spatially [121,122]. When designing a living shoreline, there is a trade-off between shore protection and oyster restoration. Shoreline reef structures with taller crests attenuate more wave energy, but reef structures should be submerged at least 50% of the time to support optimal oyster growth and establishment [118]. Low-crested structures placed in a wider footprint more closely mimic natural reef morphology than high-crested, pyramid, or trapezoidal-shaped structures placed in a narrow footprint along the shore [118,123,124]. Site-specific limitations (e.g., nearshore space, slope, depth) will dictate structure materials and placement, but designs should strive to meet both ecological and protection goals. Ribbed mussels also settle on rock sills commonly deployed with marsh plantings [82]. However, rock sills may disrupt mussel larval settlement on the marsh surface, which are naturally found in marsh soils (Rose et al. in review). Ribbed mussels occurring on the rock sill still provide valuable water filtration services but are decoupled from their mutualistic partner, *S. alterniflora,* and the marsh soils, where denitrification occurs [93]. Further research is needed to determine ways to enhance ribbed mussel settlement and recruitment to living shorelines.

Ribbed Mussels

Oysters and mussels

Fish and crustaceans

Living shorelines function as vital nursery habitats for many of the Bay's fish and crustacean species. The structural complexity provided by marsh vegetation and other living shoreline features provide forage (small-bodied) and juvenile fish with foraging opportunities and refuge from predation [98,125]. While fish may quickly begin utilizing restored marsh habitats after construction[126], studies show that within 2-3 years after project completion, living shorelines support equal or greater abundance, biomass, and richness than their natural marsh counterpart [98]. In contrast, hard shoreline armoring, such as bulkheads, support less numerous and less diverse fish communities [107,125]. Living shorelines provide habitat comparable to natural marshes for both forage and juvenile species, including several economically important species, such as blue crab, red drum, spotted seatrout, and summer flounder [15,98,127,128]. Marsh vegetation is central to habitat provision; therefore, plantings must be suited to site-specific conditions, such as tidal range, salinity and substrate type. Incorporating vegetation in living shoreline designs increases structural complexity relative to hard armored designs, thereby creating suitable nursery and foraging habitat for economically important fish and crustacean species.

Juvenile spotted seatrout

Summer flounder

Blue crab

Birds and wildlife

Living shorelines support diverse wildlife, including birds and terrapins [82,129] (**Figure 6**). For many shorebirds and herons, living shorelines serve as important resting, preening, and foraging habitat [82,130]. Some short-legged shorebirds, such as the Spotted Sandpiper, benefit from intertidal structures as additional habitat available during high tide [130]. Diamondback terrapins, a species classified as a special concern in Virginia, utilize the marsh habitats for foraging and have been observed to use intertidal structures as basking sites [82]. Mammals have been observed utilizing living shoreline habitats, including river otters, and American mink. Within a well-designed and implemented living shoreline, the established ecological community should support and include a variety of taxa. Moreover, living shorelines may serve to "connect" other estuarine habitats and habitat complexes [84,131,132].

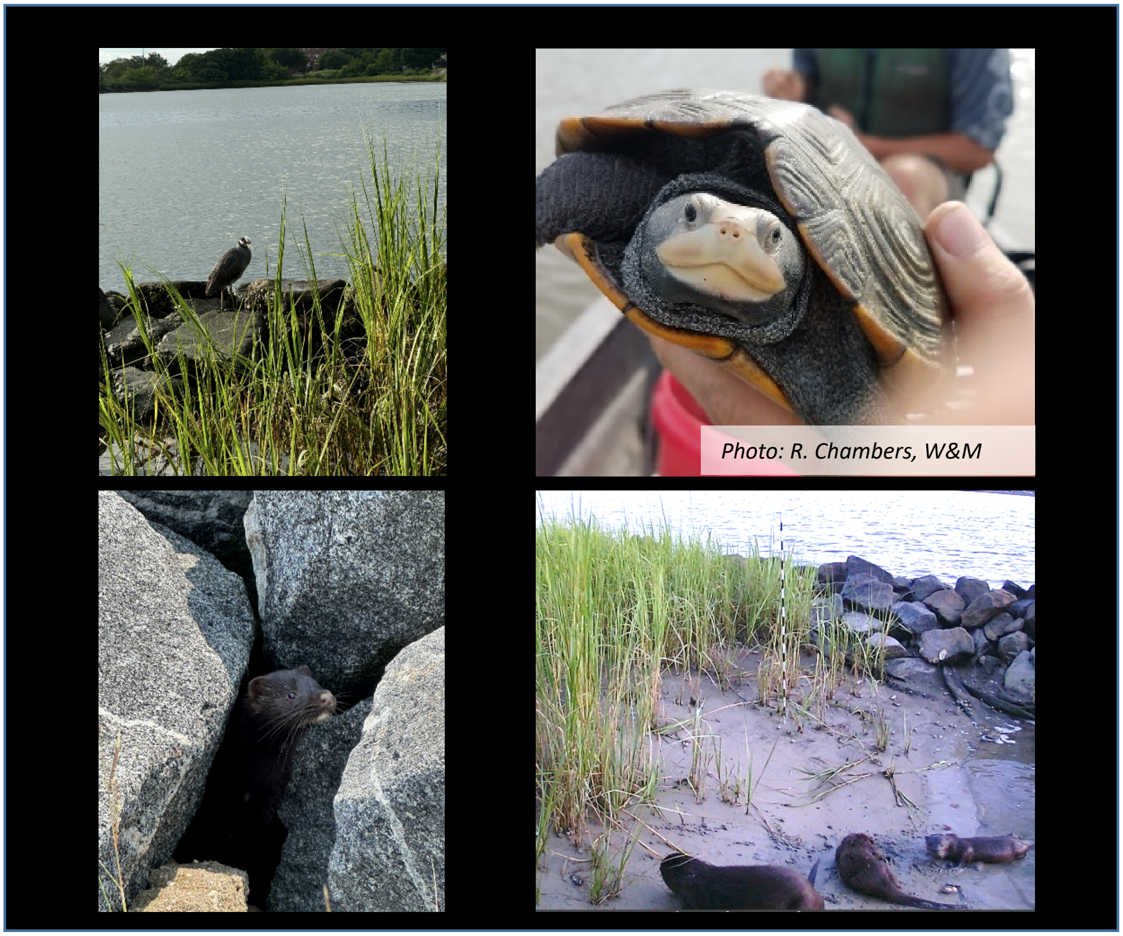


Photo: R. Chambers, W&M

Figure 6. Wildlife observed at living shorelines (clockwise from upper left: Yellow-crowned night heron, diamondback terrapin, American Mink, River otter)

Table 1. Pathways by which living shorelines maintain coastal processes to attain habitat and water quality benefits.

Process Category	Significant Processes	Pathways by which living shoreline practices preserve coastal processes while enhancing ecosystem functions and services
Physical Processes	**Wave attenuation**	- Vegetated wetlands, beaches, and dunes attenuate waves by increasing surface roughness through aboveground vegetation, which slows water movement, dissipates energy, and promotes sediment deposition while reducing resuspension [8–12,31–34,36–38,42–47,58,59] - Large dense clumps of *Spartina* tend to provide the greatest wave attenuation and sediment stability [48,133] - There is a positive relationship between marsh width and wave energy reduction [7,11,39–41] - A trade-off exists between protection of the shore from wave climate and maintaining tidal exchange to the habitat. Tall, wide, low-porosity structures dissipate more wave energy, while more porous structures support faunal movement and initial recruitment. Over time, living reef structures will decrease in porosity and increase in wave dissipation capacity. Designs should strive to meet both ecological and protection goals [118–120,123,124,134] - Tidal openings and staggered or chevron layouts of structures allow controlled exchange of water and sediment and promote sediment deposition on the marsh platform [29,61]
	Sediment movement & capture	- Tidal wetland, beach, and dune vegetation capture sediment facilitating vertical accretion and increased resilience to sea level rise [30,51,54,64,111] - Belowground biomass (i.e., roots and rhizomes of tidal vegetation) further binds sediments and enhances resistance to erosion [38,50] - Structures configured to maintain longshore & cross-shore sediment transport allow for sediment deposition onto the marsh and minimize adverse effects to downdrift shorelines and habitats [29,60,65]
	Continuity of land–water interface	- Preserve shorescape connectivity (upland buffer to subtidal nearshore habitats) [5,106] - Support biotic exchange and tidal flushing [60–64] - For a living shoreline to remain self-sustaining, designs must support the dynamic movement of habitat features (e.g., vegetation and sediments) in response to storms and evolving coastal conditions [3,72]
Chemical Processes	**Nutrient cycling**	- Promote nitrogen and phosphorus removal via microbial communities in the soils, vegetation, & burrowing fauna [62.86–92] - Sustain benthic–pelagic coupling by restricting the use of artificial materials that cover, bury, alter, or sever natural sediment–water interactions in intertidal and subtidal zones [94]
	Carbon storage	- Store CO_2 in plant biomass & sediments [80,81] - Constructed marshes in Virginia reach natural-marsh soil carbon storage levels in ~24 years [79]
	Contaminant filtration	- Tidal wetland plants and soils trap sediments, nutrients, heavy metals, and microplastics[24,25,95,96]

Process Category	Significant Processes	Pathways by which living shoreline practices preserve coastal processes while enhancing ecosystem functions and services
Biological Processes	**Tidal wetland vegetation stabilization & succession**	- Aboveground biomass of tidal wetland and beach vegetation tends to evolve to resemble natural habitats within a few years, while dune vegetative communities may take longer to fully mature[46,54,82,84,100,101,136]
	Bivalve support	- Support populations of key bivalves like oysters and mussels through restoration of habitat and tidal regime [62,72,82,115] - Structures including rock sills and reef substrates may support oyster and mussel recruitment, leading to enhanced biomass and filtration capacity. Shoreline reef structures should be submerged at least 50% of the time to support optimal oyster growth and establishment [67,116,117,118,119,121,123,137]
	Fish & crustacean habitat provision	- Provide nursery habitat, refuge, and foraging for finfish & crustaceans, including economically important species such as blue crab and spotted seatrout[15,126,127,129] - Abundance, biomass, & richness equal or exceed natural marshes within 2–3 years. In contrast, hard armored shorelines reduce fish abundance and diversity [98,125,128]
	Tidal wetland fauna diversity	- Support a diversity of birds, terrapins, and invertebrates (e.g., fiddler crabs) comparable to natural marshes[5,62,67,82,113,129,130] - Promotes trophic interactions and nutrient cycling [82,130]

Materials

The definition further lists the elements that can be included as components of a living shoreline as "plants, stone, sand fill, and other structural and organic materials". Plants, stone and sand fill are not further defined or specified in the Code. Other structural and organic materials are specified for use as added protection for the natural components of the living shoreline that do not interfere with coastal processes or continuity of the land-water interface. A list of natural or man-made materials that may be an "other structural or organic material" is provided.

Using elements listed as possible materials does not lead to categorization of any project as a living shoreline. It is the placement of those materials within the overall landscape and project design, and the resultant impacts, or not, on water quality, habitat and coastal processes, that define a project as a living shoreline. To that point, stone is listed before other materials. When that stone is placed in shallow water to protect an existing or newly constructed marsh, if it allows for tidal water exchange, cross and longshore movement of aquatic fauna (over, around and/or through the structure to access the marsh), then the stone can be considered part of a living shoreline. However, if the stone is placed upon an existing, or newly graded upland slope and does not support the persistence of a marsh or beach, it is commonly called a revetment and is not categorized as a living shoreline.

Placement is key!

Using elements listed as possible materials does not lead to categorization of any project as a living shoreline. It is the placement of those materials, and the resultant impacts, or not, on water quality, habitat and coastal processes, that define a project as a living shoreline.

Living shoreline implementation may necessitate the structural support provided by use of non-native natural (stone, coconut fiber) or other manufactured materials (geotextiles, concrete) for the existing or created natural shoreline habitat. Use of a hard structure waterward of the habitat is common for higher energy shorelines to provide the additional wave energy dissipation necessary for the establishment and persistence of the natural feature. Structures are also included to enable landward placement of nourishment material for establishment of appropriate elevations. These features are not native to the coastal Virginia, and their use results in the conversion of natural wetlands, beaches, or shallow water habitat to non-native or artificial structural habitat. In addition, where this conversion happens below mean low water, it results in impacts to state-owned subaqueous lands that may shift from subtidal to subaerial lands. Since the early use of living shorelines, Virginia has moved from reluctance to allow these encroachments on subaqueous lands to acceptance of the trade-offs based on the intended ecological net-gain for public trust resources. When living shorelines effectively mimic natural habitats such as marsh, the state benefit includes water quality, terrestrial and aquatic fauna habitat and more. Project proponents may include consideration for enhancing aquatic fauna habitat, especially oysters, to offset some of the adverse impacts of placement of structures and fill on wetlands and shallow water bottom. Generally, for living shoreline techniques that incorporate hard engineered structures, project designs should aim to minimize primary (direct), secondary (indirect), and cumulative impacts while maximizing ecological enhancement to deliver an overall ecological net gain.

4. A shoreline management practice that… When practicable, a living shoreline may enhance coastal resilience and attenuation of wave energy and storm surge

> *Living shorelines are recognized in Virginia as climate adaptation strategies that can enhance coastal resilience by reducing wave energy and storm surge, retaining sediment, and maintaining land–water connectivity. State law and guidance emphasize the use of living shorelines where practicable to protect shorelines and sensitive habitats while accounting for sea-level rise and coastal hazards. Effective design requires balancing engineered stabilization with preservation of native vegetation and coastal processes to sustain multiple ecosystem services across the shoreline. Although their benefits develop over time, living shorelines become increasingly resilient and functional as habitats mature, ultimately providing durable protection and long-term ecological value compared to static hard armoring.*

Coastal resilience is the capacity of coastal systems, including ecosystems, infrastructure, and communities, to absorb, adapt to, and recover from disturbance while retaining critical functions and structure. In the context of Virginia's Coastal Resilience Master Plan, resilience is achieved by identifying and implementing strategies that reduce flood risk, support natural infrastructure, protect vulnerable populations, and enhance long-term adaptive capacity (Commonwealth of Virginia 2021, *Virginia Coastal Resilience Master Plan – Phase I*. Department of Conservation and Recreation. https://www.dcr.virginia.gov/crmp/plan). **Living shorelines are climate adaptation strategies with the potential to enhance coastal resilience through attenuation of wave energy and storm surge, sediment retention, and maintenance of land–water connectivity, all of which contribute to shoreline stability and reduced storm impacts.**

Virginia Wetlands Act amendments (2020) not only mandated the use of living shorelines where suitable, but also required an update to standards and guidelines to ensure the "protection of shorelines and sensitive coastal habitats from sea level rise and coastal hazards (Code of VA § 28.2-104.1). The Virginia Wetlands Act Guidelines stipulate that all shoreline alterations should both mitigate coastal hazards and be functionally resilient and structurally designed to endure the impacts of sea level rise. To inform how to design resilient living shorelines in Virginia, a working group, led by Wetlands Watch, recently developed a resource that provides technical design guidance and examples of adaptive living shorelines that may enhance coastal resilience (https://www.wetlandswatch.org/designing-living-shorelines-for-sea-level-rise).

From an ecosystem services perspective, living shorelines can provide a bundle of ecosystem services including shoreline protection, aquatic and terrestrial habitat, and improved water quality, and more, in the cross-shore environment. This means weighing the risks and benefits of impacts to all the shoreline resources from the upland buffer to the nearshore shallow waters, as well as to surrounding shores and habitats. This process requires consideration of the trade-offs in impacts to all the ecosystem services in order to select the least adverse or most beneficial approach which includes balancing engineered stabilization with preservation of native vegetation and coastal processes (e.g., tidal exchange and sediment, carbon, and nutrients flow between ecosystems). Because these decisions affect multiple interconnected habitats, project designs must also account for how natural systems respond to physical forces, seasonal changes, and long-term environmental trends. By planning for shifting conditions and ecological responses, practitioners can create shoreline designs that remain resilient over time. The “big picture” perspective also builds in the ability to consider the sustainability of tidal wetlands as sea level rises and wetlands are converted to open water.

Proprietary ownership of state subaqueous lands imbues the state with the responsibility to manage these lands for the benefit of the citizens of the Commonwealth. The proper management of tidal wetlands is similarly derived from the protection and provision of public trust benefits to the citizens. The allowance by the Commonwealth of impacts to subaqueous lands as part of a project protecting the uplands is considered an acceptable trade-off wherein there are ecosystem benefits resulting from the project.

The ecological and resilience benefits of a living shoreline unfold gradually rather than immediately after construction. As they mature, living shorelines can offer ecosystem co-benefits comparable to those of natural habitats. Evidence from Virginia shows that certain services—such as fish, crustacean, and shorebird use and marsh plant production—develop within the first few years [98,127,129,130], whereas others, like nutrient and carbon storage, are slower to manifest [79,82]. Unlike hard armored structures, which remain static, living shorelines continue to evolve, increasing their ecological function and protective capacity as biological communities become more established, and natural materials build within the system. Allowing these constructed habitats the time needed to establish and mature is therefore key to achieving their full ecological and resilience benefits.

Adaptive and Resilient

Living shorelines are climate adaptation strategies with the potential to enhance coastal resilience through attenuation of wave energy and storm surge, sediment retention, and maintenance of land–water connectivity, all of which contribute to shoreline stability and reduced storm impacts.

Enhancement of Hard Armor

There has been a rise in conservation strategies intended to enhance biodiversity of hard infrastructure. These strategies are diverse and have been called a variety of terms, including integrated green grey Infrastructure (IGGI), green riprap, ecoengineering technique, retrofits, and enhanced shorelines. Virginia state law encourages these features to be incorporated into hard armored shoreline projects where possible. To avoid misuse of shoreline enhancement techniques, it is crucial to clearly distinguish living shorelines from enhancement of hard armor to minimize the risk of greenwashing and unintended consequences [138](**Figure 7**). These are not substitutes for, or a type of living shoreline. Rather, these techniques are an enhancement of a hard armored shoreline solution (e.g., revetments, bulkheads, seawalls) and should be limited to areas that are already armored or where living shorelines are not practicable[138, 139]. These approaches integrate natural elements into a hard armored shoreline, such as adding plants or settlement features for epifauna. Examples include floating wetland islands attached to seawalls for fish habitat, marsh vegetation placed within a revetment or articulated concrete block mats, or structural complexity added to or near bulkheads or revetments to attract oysters.

Shoreline enhancement techniques are NOT living shorelines because they do not maintain the land-water connection and significantly disrupt other coastal processes such as benthic-pelagic coupling, sediment movement within and around the wetland, carbon storage in soils, natural recruitment of diverse tidal wetland flora and fauna, and nutrient cycling. For example, placement of hard structures on the surface of the marsh soil restricts marsh plant density, diversity, and rhizomatic growth. This in turn reduces the capacity for marsh soil and vegetation to support food webs, improve water quality, and reduce wave energy. Reduced stem counts and less diverse plant species affect the potential for wave attenuation, sediment trapping, and underground biomass development for nutrient cycling and carbon storage. Likewise, faunal diversity is restricted, such as for burrowing animals which contribute to the food web and nutrient/carbon cycling process. Within Virginia, at times living shorelines are publicly funded or are assigned ‘value’ as natural capital towards a management or regulatory goal. For example, living shorelines can be credited towards a water quality regulatory mandate (Total Maximum Daily Load, https://www.epa.gov/chesapeake-bay-tmdl) under the assumption that the created or restored wetland habitats are performing similar water quality functions as natural wetlands in the region. If approaches are misclassified and assigned a credit towards achieving a water quality goal, this diverts limited resources, compromises management goals, and may undermine public confidence in restoration efforts.

Distinguishing Living Shorelines from Enhancement of Hard Armor

Shoreline enhancement techniques integrate natural elements into hard armored shorelines to increase local biodiversity as an offset for the understood adverse impacts of conventional hardening. While these approaches may provide ecological benefits relative to unmodified armoring, they do not maintain land-water connectivity or coastal processes and therefore do not meet Virginia’s definition of a living shoreline.

Enhancement techniques should be limited to areas where living shorelines are not practicable or where shorelines are already hardened. Misclassifying hard armor enhancements as living shorelines results in missed opportunities to implement true living shoreline projects that provide long-term water quality, habitat, and resilience benefits.

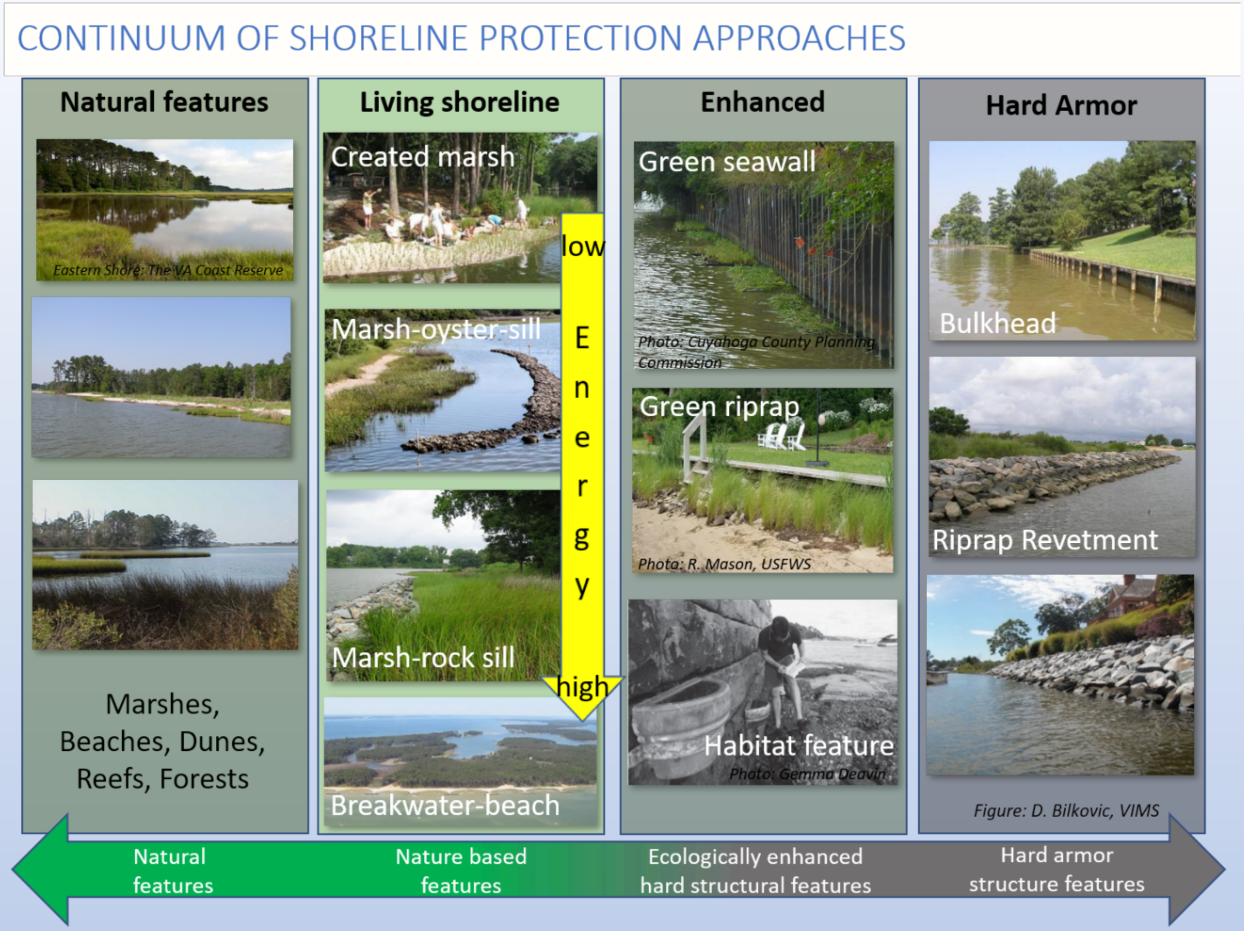

CONTINUUM OF SHORELINE PROTECTION APPROACHES
Natural features
Eastern Shore: The VA Coast Reserve
Marshes, Beaches, Dunes, Reefs, Forests
Living shoreline
Created marsh
Marsh-oyster-sill
Marsh-rock sill
Breakwater-beach
low
Energy
high
Enhanced
Green seawall
Photo: Cuyahoga County Planning Commission
Green riprap
Photo: R. Mason, USFWS
Habitat feature
Photo: Gemma Deavin
Hard Armor
Bulkhead
Riprap Revetment
Figure: D. Bilkovic, VIMS
Natural features
Nature based features
Ecologically enhanced hard structural features
Hard armor structure features

Figure 7. There is a continuum of shoreline erosion control approaches that may be implemented depending on the condition of the shoreline, depth of the nearshore waters, and energy setting. These options range from conserving natural features of marshes to hard armoring shorelines, and in between are hybrid approaches that combine natural and engineered features.

Living shoreline techniques vary depending on shoreline energy, but generally follow 4 principles: ***1***) predominantly consist of organic techniques and materials that are characteristic of the local system, such as wetland, riparian, and dune plantings; beach nourishment; and shellfish reefs, ***2***) maintain the connection between aquatic and terrestrial habitats, ***3***) maintain natural coastal processes in support of a sustainable ecosystem, and ***4***) allow the dynamic movement of habitat features (e.g., plants and sediment) in response to storm events and changing conditions to enhance resilience. In higher-energy sites that require engineered structures to provide the requisite wave attenuation to sustain planted vegetation and habitats, structures should be minimized to not overwhelm the living habitat features they are supporting.

Enhanced shoreline techniques integrate natural elements into a hard armored shoreline to enhance biodiversity, such as adding plants or settlement features for epifauna. Examples from Chesapeake Bay include vegetation planted within revetments or articulated concrete block mats placed in the intertidal, and structural complexity added to or near bulkheads or revetments to attract oysters. These techniques do not maintain land-water connectivity or natural coastal processes and therefore do not meet Virginia’s definition of a living shoreline.

Summary

Virginia's legal definition of a living shoreline incorporates language that supports its interpretation as a nature-based approach to erosion control that is self-sustaining, improves water quality and habitat conditions, maintains coastal processes, and enhances coastal resilience. The definition also addresses the materials used in a living shoreline and how they are placed, requiring that they support natural shoreline habitat features that reduce wave energy without disrupting natural coastal processes or the continuity of the land–water interface. Examination of each element of the definition from a scientific and policy perspective, including the terms and phrases, enables an improved understanding of the intended public policy outcomes for the Virginia stated requirements for the use of living shorelines for tidal shoreline erosion management.

Photo: Karen Duhring, CCRM

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