Design Considerations for Living Shorelines in Connecticut

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Contents

1 Why Living Shorelines?

Shorelines have traditionally been protected against the natural process of coastal erosion and storm surge through the construction of seawalls, bulkheads, groins and revetments. While these structures provide varying degrees of protection to upland property, they have been shown to cause unintended consequences such as increased coastal erosion and loss of habitat for shore birds and important commercial and recreational fish species (Douglass and Pickel, 1999; Dugan and Hubbard, 2006;

National Research Council, 2006, 2007; Ray-Culp, 2007; Dugan *et al.*, 2008; Swann, 2008; Duhring, 2008a; Atlantic States Marine Fisheries Commission Staff, 2010; Galveston Bay Foundation Staff, 2014). A few, spatially separated coastal protection structures should have little effect on coastal habitats; however, shorelines are becoming increasingly hardened, resulting in significant habitat degradation (Currin, Chappell, and Deaton, 2010; National Research Council, 2007). In some areas, over 50% of the shoreline is already protected with manmade structures. Hardened coastal protection may lead property owners or even entire communities into a false sense of protection from storm surge and wave action, resulting in devastating consequences in the event of structure failure (Sutton-Grier, Wowk, and Bamford, 2015).

The increasing understanding of the adverse impacts of seawalls, bulkheads and groins has resulted in the development of shoreline stabilization approaches that preserve coastal habitats, or at least minimize the destructive effects of traditional shoreline protection approaches (e.g., Arkema et al., 2013; Augustin, Irish, and Lynett, 2009; Bridges et al., 2015; Duarte et al., 2013; Feagin et al., 2009; Gedan et al., 2011; Guannel et al., 2015;

Pinsky, Guannel, and Arkema, 2013; Scyphers et al., 2011; Shepard, Crain, and Beck, 2011; Subramanian et al., 2008a). In 2012, Connecticut passed legislation to encourage the consideration of "feasible, less environmentally damaging alternatives" of shoreline erosion control. Nonstructural approaches (such as beach nourishment, restored or enhanced seagrass, vegetated, graded bluffs, and creation or restoration of fringing salt marshes) are frequently referred to as "living shorelines."

Although Connecticut has not formally adopted a definition for living shorelines, the state is using the following working definition:

> *"A shoreline erosion control management practice which also restores, enhances, maintains or creates natural coastal or riparian habitat, functions and processes. Coastal and riparian habitats include but are not limited to intertidal flats, tidal marsh, beach/dune systems, and bluffs. Living shorelines may include structural features that are combined with natural components to attenuate wave energy and currents."*

Other terms used to describe this approach to shoreline stabilization include "natural or nature-based features," "soft structure," "green infrastructure," and "ecologically enhanced shore protection alternatives"

1.1 Benefits of living shorelines

In addition to mitigating shoreline erosion, living shorelines provide critical habitat for economically and ecologically important fish, shellfish and marine plants, improve water quality through groundwater filtration, and reduce surface water runoff (Atlantic States Marine Fisheries Commission Staff, 2010; Duhring, 2008b; Hardaway, Milligan, and Duhring, 2010; Ray-Culp, 2007). Living shorelines can also improve shoreline access, increase recreational opportunities, enhance the appearance of the shoreline (Atlantic States Marine Fisheries Commission Staff, 2010; Hardaway, Milligan, and Duhring, 2010; Ray-Culp, 2007).

The following sections will discuss the different types of shoreline found along the Connecticut coast, explain the different approaches to living shorelines and provide design considerations for living shorelines.

2 The Connecticut Coast

The Connecticut shoreline of Long Island Sound is highly variable, consisting of three major geomorphological types: beaches and dune, bluffs and wetlands. The different shoreline types provide nesting and foraging habitat for a wide range of aquatic plants and animals. Maintaining the shoreline's ability to absorb wave energy and reduce coastal flooding while preserving the ecosystem services provided by the natural shoreline is the goal of Living Shorelines. The most appropriate type of Living Shoreline for stabilization will depend on the natural geomorphological conditions.

2.1 Marshes

Coastal marshes are low-lying areas of salt tolerant plants that are subjected to regular or occasional

flooding by tides and storm surges. Marsh plants are highly dependent on salinity resulting in distinct zones of plant species based on elevation and the occurrence of salt water flooding (Bendell and The North Carolina Estuarine Biological and Physical Processes Work Group, 2006).

Marshes in Connecticut can be extensive meadows of salt tolerant plants, such as at Barn Island Wildlife Management Area or Hammonasset Beach State Park, usually dominated by high marsh, or fringe marshes, located along protected coastlines or at the toe of eroding bluffs. Fringe marshes may be bordered by mud flats.

Tidal salt marshes, whether natural or restored, can provide critical protection to coastal communities by reducing wave heights and therefore wave energy, storm surge levels and durations, and mitigating coastal erosion (O'Donnell, submitted). In addition, marshes improve water quality by filtering groundwater, reduce surface water runoff, and decrease sediment transport (Ray-Culp, 2007; Duhring, 2008a; Augustin et al., 2009; Hardaway et al., 2010; Thomas-Blate, 2010).

Marshes occur in sheltered areas with low to moderate wave energy; however, they still may be experience erosion caused by:

WAVES	Salt water marshes generally experience low wave energy, but constant wave action can erode marsh edges. Storm waves can be especially damaging to marsh stability. The elevated water level associated with storm surge enables storm waves to damage vegetation that is normally not subjected to wave action. The larger the fetch (the distance wind blows over water), the larger the waves that will affect the marsh.
BOAT WAKES	Marshes, especially those located near marinas or navigable rivers, are subjected to large wakes from motorboat traffic. In some areas, boat wakes are larger and cause more damage than storm waves.
CURRENTS	Currents, including tidal flows, can erode marsh surfaces and edges.
WRACK	Ewanchuk and Bertness (2003) suggest that wrack disturbance is the most important natural disturbance in New England marshes. Wrack primarily affects high marsh where storm waves and surge deposit large amounts of seaweed and algae, smothering the marsh vegetation and resulting in bare areas vulnerable to erosion.
ICE	Ice can be an extremely destructive force in New England marshes, affecting low marsh due to tidal fluctuations. Ice in the coastal ocean is never stationary; its motion can kill marsh vegetation and also move large portions of vegetation and the underlying peat on ebb tides. It can take over 10 years for a marsh to recover from intense ice damage (Ewanchuk and Bertness, 2003).
PUBLIC ACCESS	Foot traffic through the marsh can damage the vegetation leading to erosion of the marsh surface.
CLIMATE CHANGE	Marshes will be not be adversely affected by sea level rise as long as the rate of sedimentation on the marsh surface is able to keep pace with the rate of sea level rise. If sea level rise exceeds the rate of marsh elevation increase, the marsh will be submerged, potentially killing vegetation and enabling larger waves to reach further into the marsh.

Several options are available for addressing erosion of coastal marshes; the most appropriate method will depend on site specific conditions. There are many parameters to consider before selecting a Living Shoreline approach. Some questions to ask are:

1. **Is there an existing coastal engineering structure (seawall, groin, revetment, etc.) at the site?** The presence of an existing engineering structure may affect the coastal processes at the site and must be considered before an appropriate living shoreline approach can be determined. If the structure is functioning as designed, or easily repaired, the most appropriate approach may be to do nothing or repair the structure, while considering alternatives for future needs. See Section 2.4 Currently Defended Shorelines for more information on coastal engineering structures.

2. **What is the condition of the marsh? Is there presently a vegetated wetland at the edge of the property? Is the vegetation dense or sparse? How wide is the marsh?**

The condition of the existing marsh is an indication of the potential success of a living shoreline approach. A marsh with dense, healthy vegetation is likely to be a suitable site for a non-structural approach. A less dense marsh may be enhanced with vegetation management, trimming or overhanding branches and removal of fallen trees and debris. For more information, see the section on Vegetation.

3. **Is the marsh eroding? If so, what is the rate of erosion and what is causing it?**
   Do nothing or vegetation management may be suitable approaches for a stable marsh with little to no erosion. With higher rates of erosion, it is necessary to determine what is causing the erosion. Mitigating erosion from frequent boat wakes may indicate a different approach than one used to reduce storm flooding and wave damage. While seasonal damage may not be a cause for concern, a marsh may take years to recover from significant ice damage (Ewanchuk and Bertness, 2003). The section on Shoreline Change provides more information on how to determine the long-term rate of shoreline change.

4. **Is there infrastructure at risk?**
   If the existing infrastructure cannot be moved back or up, it may be necessary to select an approach that would provide more protection than a non-structural approach. Evaluation of the site may determine that a living shoreline approach is unsuitable.

5. **What is the wave climate?**
   The wave climate is a critical parameter in determining the most appropriate approach to shoreline protection. Vegetation-only approaches are usually only suitable for site exposed to low wave heights. The wave climate will determine the type of living shoreline, and the height and composition of the protective structure. Fetch, the distance wind blows of water, is frequently used as an estimate of the wave conditions at a site. More information on can be found in the section on Wave Climate and Fetch.

6. **What is the boat traffic?**
   Some sites, particularly those along navigable rivers streams, may experience larger waves due to boat wake than wind waves. The proximity to a powerboat marina or navigational channel, and the frequency and size of vessels are an important design consideration. For more information on boat wakes, see Wave Climate and Fetch.

7. **Is the site affected by tidal, riverine or alongshore currents?**
   Nearshore currents can scour protective structures and transport fill material away from the project site.

8. **What is the shoreline geometry?**
   The Connecticut shoreline of Long Island Sound is highly variable. The shoreline geometry may be straight, curved or irregular. This high variability is one reason why the most suitable approach to shoreline protection is so site-specific. A headland beach (also known as a pocket beach) is generally crescent or crenulate-shaped, bounded by protective headlands so the shoreline is relatively protected and the sediment supply usually remains between the headlands. A straight shoreline is more exposed to large waves and transport of sediment away from the site. For more information, see the section on Shoreline Geomorphology.

9. **What is the intertidal slope/nearshore bathymetry?**
The intertidal slope and nearshore bathymetry determine the size of the waves at the shoreline. A gradually sloping nearshore region will cause larger waves to break further offshore, reducing the wave energy at the marsh. Steep nearshore bathymetry will allow larger waves to break near or at the marsh edge. See the section on Nearshore Bathymetry for more information.

10. **Is the upland bank vegetated?**
Upland vegetation is an indication of the stability of the bank. However, mature vegetation may provide too much shade for marsh plant survivability. See the section on Vegetation for more information.

11. **What is the tidal range?**
The tidal range will impact the height and location of the shoreline protection approach. Most of the existing living shoreline structures have been constructed in areas with low tidal ranges on the order of a couple of feet. Tidal ranges along the Connecticut shoreline vary from about 2.4 ft in Stonington to 7.5 ft in Greenwich. In addition, storm surge heights are typically larger in Connecticut than where living shorelines have been constructed previously. See Tidal Range for more information.

12. **Does the project site flood regularly during normal or spring tides? Storm surge?**
Flooding of coastal marshes is a natural process; however, if the site floods during normal or spring tides, the marsh may not provide sufficient protection from storm waves. Marshes typically do not provide protection from storm surge, so the potential risk from coastal inundation is an important design consideration.

13. **Is the project site affected by ice?**
The Connecticut coast is affected by ice damage, exacerbated by nor-easters and tidal flow. The approach selected must withstand anticipated ice forces at the site. For more information, see the section on Ice.

14. **Does the site have submerged aquatic vegetation or nearshore oyster beds?**
Submerged aquatic vegetation or the presence of nearshore recreational oyster beds may affect the type of living shoreline that can be permitted at the site. See the section on Vegetation.

15. **What is the composition of the nearshore region?**
Some soils may not be able to tolerate the weight of living shoreline approaches such as marsh sills or reef balls. Settling of the structure could render it ineffective. The presence of offshore vegetation or aquatic species may be negatively impacted by the living shoreline. For instance, fill material could bury aquatic plants and animals, or sills and breakwaters could damage nearshore habitats.

16. **What is the condition of the adjacent properties?**
Depending on the width of the project site, the condition of adjacent properties may affect the suitability of living shoreline approaches. For instance, the presence of marsh may indicate the suitability of the site for marsh creation or restoration. Hard coastal structures may limit the effectiveness of a living shoreline.

17. **Is the project site accessible from land or water?**

Access to the project site will affect the cost and constructability of a living shoreline.

18. What are the potential effects of sea level rise on the project site?
Depending on the anticipated lifetime of the living shoreline, the effects of sea level rise on the erosion mitigation approach may be a selection factor.

A printable checklist of design considerations can be found here.

Some of the options for mitigating coastal erosion on marshes are:

For marshes that are not eroding:

- Do nothing
- Vegetation Management

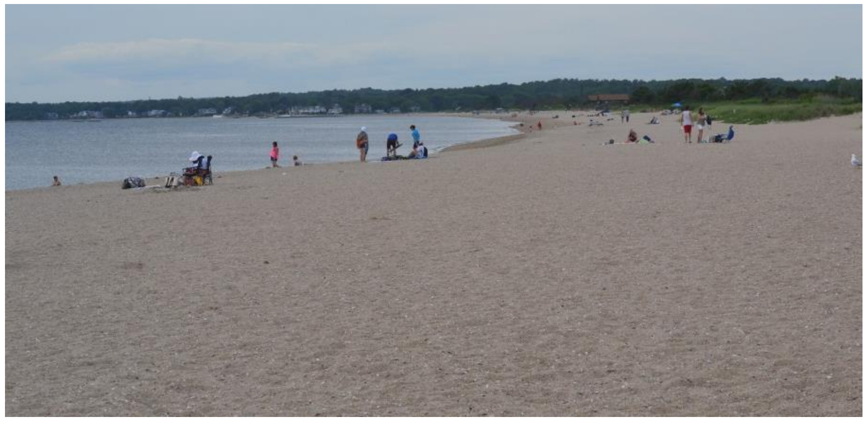
For marshes experiencing erosion, options to consider include:

- Slope or bank grading
- Marsh restoration
- Toe protection with fiber logs
- Marsh Toe Revetment
- Marsh Sills
- Oyster Reefs
- Wave Attenuation Devices
- Breakwaters

2.2 Beaches and Dunes

Connecticut beaches occupy about 14% of the Connecticut shoreline of Long Island Sound, consisting of

sandy barrier beaches backed by low dunes such as at Bluff Point State Park and Long Beach in Stratford,



pocket beaches bounded by headlands,

and cobbled beaches.

Beaches and dunes are natural barriers to the destructive forces of waves and storm surge. By absorbing the impact of storm surge and waves, they prevent or delay erosion, flooding of inland areas and damage to coastal infrastructure. During storms, beaches and dunes provide sacrificial sediment which is transported offshore into a sand bar system to causing waves to break and reducing wave energy reaching the beach.

In addition to storm protection, beaches and dunes provide critical nesting and foraging habitat for shore birds and other aquatic species, and recreation opportunities for property owners and the public.

Beaches and dunes are dynamic features affected by short and long term changes in waves, wind, tides, storm surge, sand availability and sea level rise. These changes may be seasonal, episodic or storm-related, or slow, barely noticeable change over many years. Beach and dune erosion along the Connecticut shoreline of Long Island Sound is generally caused:

SEASONAL CHANGES	Seasonal storms and variations in local wind speed and direction can cause short-term changes in the beach profile. Summer beaches tend to be wider than their corresponding winter beach, with a well-developed berm. Winter beaches are steeper and narrower. These changes are minimized along Connecticut beaches due to the buffering effect of ocean winds and the limited fetch caused by Long Island.
STORMS	Storm impacts occur over a very short period but recovery of the beach may occur with seasonal changes or over a much longer period of time. In the case of severe storms, recovery of the beach may not occur at all.
SAND AVAILABILITY	Sand availability can change when sand is moved offshore during storms and is no longer available for beaches, or when sand transported landward during storms is removed as debris.
MANMADE STRUCTURES	Groins, seawalls and jetties can exacerbate coastal erosion by interrupting the natural transport of sediment.
CURRENTS	Alongshore and cross-shore currents can transport sediment away from beaches, contributing to shoreline erosion.
PUBLIC ACCESS	Foot traffic can damage the dune vegetation reducing dune stability against wave and winds.
CLIMATE CHANGE	The Connecticut shoreline has been affecting for decades by rising sea levels. Sea level rise may adversely affect beaches that are not able to migrate landward over time.

Several options are available for addressing beach and dune erosion; the most appropriate method will depend on site specific conditions. There are many parameters to consider before selecting a Living Shoreline approach. Some questions to ask are:

1. **Is there an existing coastal engineering structure (seawall, groin, revetment, etc.) at the site?**
   The presence of an existing engineering structure may affect the coastal processes at the site and must be considered before an appropriate living shoreline approach can be determined. If the structure is functioning as designed, or easily repaired, the most appropriate approach may be to do

nothing or repair the structure, while considering alternatives for future needs. See Section 2.4 Currently Defended Shorelines for more information on coastal engineering structures.

2. **Is there a sand dune at the seaward edge of the property? If so, is it vegetated? If not, is a dry beach present (sand above normal high tide)? If yes, how wide?**
   An existing dune indicates the suitability and viability of dune restoration at the project site. The presence of vegetation on the dune not only provides an indication of the stability of the dune system, but is important when creating a dune restoration and planting plan.

   If the beach is not currently backed by a dune, there needs to be sufficient dry beach width to create a dune system. In some areas, beach nourishment may be permitting which could extend the width of the beach to allow dune creation. See Beach Nourishment and Dune Creation and Restoration for more information.

3. **Is there evidence that your dune or backshore is regularly overtopped and overwashed by waves, and/or that flooding occurs landward of the dune or beach crest? During normal or spring tides? Storm surges?**
   The frequency of dune or backshore overtopping and flooding is important when determining the necessary elevation of coastal protection to mitigate coastal inundation.

4. **Does the dune and beach naturally gain sand after each winter season?**
   Beach and dune systems change in response to seasonal variations in waves, wind, tides, and storm surge, transforming from a. wider, flatter "summer" beach to a narrower, steeper "winter" profile. Because the Connecticut shoreline is protected from ocean winds by Long Island, the seasonal variation in winds is less pronounced than on more exposed shorelines. It is important to consider seasonal variations in beach profile when selecting and designing a Living Shoreline.

5. **Is the beach eroding? If so, what is the rate of erosion and what is causing it?**
   Do nothing or dune vegetation management may be suitable approaches for a stable beach/dune system with little to no erosion. With higher rates of erosion, it is necessary to determine what is causing the erosion. Mitigating erosion from frequent boat wakes may indicate a different approach than one used to reduce storm flooding and wave damage. The section on Shoreline Change provides more information on how to determine the long-term rate of shoreline change.

6. **Is there infrastructure at risk?**
   If the existing infrastructure cannot be moved back or up, it may be necessary to select an approach that would provide more protection than a non-structural approach. Evaluation of the site may determine that a living shoreline approach is unsuitable.

7. **What is the wave climate?**
   The wave climate is a critical parameter in determining the most appropriate approach to shoreline protection. Vegetation-only approaches are usually only suitable for site exposed to low wave heights. The wave climate will determine the type of living shoreline, and the height and composition of the protective structure. Fetch, the distance wind blows of water, is frequently used as an estimate of the wave conditions at a site. More information on can be found in the section on Wave Climate and Fetch.

8. **What is the boat traffic?**
   Some sites, particularly those along navigable rivers streams, may experience larger waves due to boat wake than wind waves. The proximity to a powerboat marina or navigational channel, and the frequency and size of vessels are an important design consideration. For more information on boat wakes, see Wave Climate and Fetch.

9. **Is the site affected by tidal, riverine or alongshore currents?**
   Nearshore currents can scour protective structures and transport fill material away from the project site.

10. **What is the shoreline geometry?**
    The Connecticut shoreline of Long Island Sound is highly variable. The shoreline geometry may be straight, curved or irregular. This high variability is one reason why the most suitable approach to shoreline protection is so site-specific. A headland beach (also known as a pocket beach) is generally crescent or crenulate-shaped, bounded by protective headlands so the shoreline is relatively protected and the sediment supply usually remains between the headlands. A straight shoreline is more exposed to large waves and transport of sediment away from the site. For more information, see the section on Shoreline Geomorphology.

11. **What is the intertidal slope/nearshore bathymetry?**
    The intertidal slope and nearshore bathymetry determine the size of the waves at the shoreline. A gradually sloping nearshore region will cause larger waves to break further offshore, reducing the wave energy at the beach. Steep nearshore bathymetry will allow larger waves to break on the beach. Larger winter waves or storm waves typically transport available sand offshore, forming protective sand bars. See the section on Nearshore Bathymetry for more information.

12. **What is the tidal range?**
    The tidal range will impact the height and location of the shoreline protection approach. Most of the existing living shoreline structures have been constructed in areas with low tidal ranges on the order of a couple of feet. Tidal ranges along the Connecticut shoreline vary from about 2.4 ft in Stonington to 7.5 ft in Greenwich. In addition, storm surge heights are typically larger in Connecticut than where living shorelines have been constructed previously. See Tidal Range for more information.

13. **Is the project site affected by ice?**
    The Connecticut coast is affected by ice damage, exacerbated by nor-easters and tidal flow. The approach selected must withstand anticipated ice forces at the site. For more information, see the section on Ice.

14. **Does the site have submerged aquatic vegetation or nearshore oyster beds?**
    Submerged aquatic vegetation or the presence of nearshore recreational oyster beds may affect the type of living shoreline that can be permitted at the site. See the section on Vegetation.

15. **What is the composition of the nearshore region?**
    Some soils may not be able to tolerate the weight of living shoreline approaches such as marsh sills or reef balls. Settling of the structure could render it ineffective. The presence of offshore vegetation or aquatic species may be negatively impacted by the living shoreline. For instance, fill

material could bury aquatic plants and animals, or sills and breakwaters could damage nearshore habitats.

16. **How will the shoreline be used?**
    The intended use of the shoreline may affect the suitable types of living shoreline. For instance, swimming and boating require different access to the water than fishing or nature watching. The selected type of living shoreline must be compatible with the intended usage of the shoreline.

17. **What is the condition of the adjacent properties?**
    Depending on the width of the project site, the condition of adjacent properties may affect the suitability of living shoreline approaches. For instance, traditional, hard coastal protection structures may limit the effectiveness of a living shoreline.

18. **Is the project site accessible from land or water?**
    Access to the project site will affect the cost and constructability of a living shoreline.

19. **What are the potential effects of sea level rise on the project site?**
    Depending on the anticipated lifetime of the living shoreline, the effects of sea level rise on the erosion mitigation approach may be a selection factor.

A printable checklist of design considerations can be found here.

Some of the options for mitigating coastal erosion on beach and dune systems are not eroding include:

- Do nothing
- Vegetation Management

For beaches with low waves and limited boat traffic, gradual nearshore and insufficient land to create a dune system:

- Do nothing
- Plant native vegetation
- Beach Nourishment
- Wave Attenuation Devices
- Breakwaters

If there is sufficient dry beach for a dune, the above approaches are suitable as well as

- Dune Creation or Restoration

2.3 Bluffs

The Connecticut shoreline also consists of rocky and erodible bluffs. Connecticut bluffs can be rocky or soft, high or low. Rocky headlands are formed over time by wave action removing the more easily erodible material. Soft bluffs, formed of loose stone, gravel, clary or sand, erode easily. Erosion of soft bluffs provides sediment to nearby beaches and dune systems.

WAVES	Wave action can erode the toe of a bluff, causing the bluff to become unstable and slump, moving the top edge of the bluff landward. The slumped material may become part of the beach, providing toe protection to the bluff (Slovinsky, 2011).
WIND	Windborne transport of unconsolidated bluff material can erode the bluff face.
STORMS	Coastal bluff erosion is frequently caused by major storm events, in particular by storms in which large waves, strong onshore winds, and heavy rainfall coincide with a high tide. Large storm generated waves from hurricanes, nor'easters, or other storms frequently increase coastal bluff erosion processes (DMA, 2000). Storm surge increases the water level allowing storm wave action to erode higher on the bluff, and potentially causing overtopping of the bluff.
RUNOFF	Surface water runoff can cause erosion of the bluff edge and face.
GROUNDWATER SEEPAGE	Groundwater seepage can remove fine sediment contribution to bluff erosion.
ICE	Repeated freeze-thaw cycles can increase the likelihood of slumping (Slovinsky, 2011).
CURRENTS	Currents at the toe of the bluff transport sediment away from the toe causing bluff instability.
PUBLIC ACCESS	Foot traffic can damage vegetation reducing or disturb unconsolidated sediment reducing stability against wave and winds.
CLIMATE CHANGE	The Connecticut shoreline has been affecting for decades by rising sea levels. Sea level rise may allow wave action to erode higher on the bluff, and potentially causing overtopping of the bluff.

Several options are available for addressing bluff erosion; the most appropriate method will depend on site specific conditions. There are many parameters to consider before selecting a Living Shoreline approach. Some questions to ask are:

1. **Is there an existing coastal engineering structure (seawall, groin, revetment, etc.) at the site?**
   The presence of an existing engineering structure may affect the coastal processes at the site and must be considered before an appropriate living shoreline approach can be determined. If the structure is functioning as designed, or easily repaired, the most appropriate approach may be to do nothing or repair the structure, while considering alternatives for future needs. See Section 2.4 Currently Defended Shorelines for more information on coastal engineering structures.

2. **If soft, what is the composition of your bluff? Fine, mixed or coarse (sand or cobble)?**
   The composition of the bluff material will affect the rate of bluff erosion. Finer material is more susceptible to wave damage than coarser sand or cobbles.

3. **Is marsh or a dry beach present (sand above normal high tide) at the toe of your bluff? If yes, how wide?**
   The presence of an established marsh or dry beach will provide protection to the bluff toe from wave action.

4. **If you have a low bluff, is there evidence that your bluff is regularly overtopped and overwashed by waves, and/or that flooding occurs landward of the bluff? During normal or spring tides? Storm surges?**
   The frequency of bluff overtopping and flooding is important when determining the necessary elevation of coastal protection to mitigate coastal inundation and wave damage.

5. **Is the bluff eroding? If so, what is the rate of erosion and what is causing it? Is the base of the bluff eroding?**
   Storms, coastal flooding, waves, and tides contribute to erosion of coastal bluffs and the transport of bluff sediments in the coastal zone; however, coastal bluffs do not recover from destructive forces in the same manner as beach faces do. As the toe of a bluff is eroded by wave action and rising sea level, the bluff becomes unstable and slumps to the shoreline below, causing the top edge of the bluff to move landward. This natural process becomes a hazard when it threatens structures or property at the top of the bluff. The rate of bluff erosion usually varies from year to year. Even a steep bluff may remain unchanged for many years, or slump a large amount of sediment only every few years. Sand, gravel and glacial deposits eroded from the bluff may become part of the beach at the base of the bluff, helping to stabilize the shoreline (Slovinsky, 2011).

   Do nothing or dune vegetation management may be suitable approaches for a stable bluff with little to no erosion. With higher rates of erosion, it is necessary to determine what is causing the erosion. Mitigating erosion from frequent boat wakes may indicate a different approach than one used to reduce storm flooding and wave damage. Surface water runoff and groundwater seepage, as well as freeze/thaw cycles all contribute to soft bluff erosion. The section on Shoreline Change provides more information on how to determine the long-term rate of shoreline change of coastal bluffs.

6. **Is the upland bank vegetated? Has the bluff been planted or graded?**

Upland vegetation is an indication of the stability of the bank and will mitigate bank erosion. For relatively protected sites or those without at-risk structures, bank grading and slope planting may be an appropriate solution to reduce erosion. See the sections on Vegetation Management and Slope of Bank Grading for more information.

7. **Is there evidence of rainfall impacts or surface runoff? Is there evidence of groundwater in the slope (seepage, damp surfaces on slope face, etc.)?**
   Not all erosion of coastal bluffs is caused by wave action. Many slopes are eroded by surface water runoff or groundwater seepage. Mitigating erosion caused by runoff or groundwater necessitates different approaches than for reducing wave impact at the toe of the slope.

8. **What is at the toe of your bluff? Beach? Marsh? Ledge? Do waves or normal tides reach the base of the bluff?**
   The type of shoreline at the toe of the bluff and its width will impact rate of erosion at the toe of the slope and also the type of living shoreline which is suitable. A wider marsh, beach or ledge will provide more protection to the toe of the bluff than a narrower shoreline. The width of the shoreline may also affect the living shoreline approach suitability.

9. **What is the composition of the nearshore region?**
   Some soils may not be able to tolerate the weight of living shoreline approaches such as marsh sills or reef balls. Settling of the structure could render it ineffective. The presence of offshore vegetation or aquatic species may be negatively impacted by the living shoreline. For instance, fill material could bury aquatic plants and animals, or sills and breakwaters could damage nearshore habitats.

10. **What is the intertidal slope/nearshore bathymetry?**
    The intertidal slope and nearshore bathymetry determine the size of the waves at the shoreline. A gradually sloping nearshore region will cause larger waves to break further offshore, reducing the wave energy at the toe of the bluff. Steep nearshore bathymetry will allow larger waves to break near or at the bluff toe. See the section on Nearshore Bathymetry for more information.

11. **What is the tidal range?**
    The tidal range will impact the height and location of the shoreline protection approach. Most of the existing living shoreline structures have been constructed in areas with low tidal ranges on the order of a couple of feet. Tidal ranges along the Connecticut shoreline vary from about 2.4 ft in Stonington to 7.5 ft in Greenwich. In addition, storm surge heights are typically larger in Connecticut than where living shorelines have been constructed previously. See Tidal Range for more information.

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15. Is the site affected by tidal, riverine or alongshore currents?
Nearshore currents can scour protective structures and transport fill material away from the project site.

16. Is the project site affected by ice?
The Connecticut coast is affected by ice damage, exacerbated by nor-easters and tidal flow. The approach selected must withstand anticipated ice forces at the site. Additionally, slope stability may be affected by freeze/thaw cycles. For more information, see the section on Ice.

17. What is the shoreline geometry?
The Connecticut shoreline of Long Island Sound is highly variable. The shoreline geometry may be straight, curved or irregular. This high variability is one reason why the most suitable approach to shoreline protection is so site-specific. A headland beach (also known as a pocket beach) is generally crescent or crenulate-shaped, bounded by protective headlands so the shoreline is relatively protected and the sediment supply usually remains between the headlands. A straight shoreline is more exposed to large waves and transport of sediment away from the site. For more information, see the section on Shoreline Geomorphology.

18. Does the site have submerged aquatic vegetation or nearshore oyster beds?
Submerged aquatic vegetation or the presence of nearshore recreational oyster beds may affect the type of living shoreline that can be permitted at the site. See the section on Vegetation.

19. How will the shoreline be used?
The intended use of the shoreline may affect the suitable types of living shoreline. For instance, swimming and boating require different access to the water than fishing or nature watching. The selected type of living shoreline must be compatible with the intended usage of the shoreline.

20. What is the condition of the adjacent properties?
Depending on the width of the project site, the condition of adjacent properties may affect the suitability of living shoreline approaches. For instance, traditional, hard coastal protection structures may limit the effectiveness of a living shoreline.

21. Is the project site accessible from land or water?
Access to the project site will affect the cost and constructability of a living shoreline.

22. What are the potential effects of sea level rise on the project site?

Depending on the anticipated lifetime of the living shoreline, the effects of sea level rise on the erosion mitigation approach may be a selection factor.

For soft bluffs experiencing little to no erosion, some options are

- Do nothing
- Vegetation Management

For more exposed bluffs experiencing greater rates of erosion or those with critical infrastructure at risk, some options to consider are:

Some of the options for consideration are:

- Slope or bank grading
- Marsh restoration
- Toe protection with fiber logs
- Marsh Toe Revetment
- Marsh Sills
- Oyster Reefs
- Wave Attenuation Devices
- Breakwaters

2.4 Currently Defended Shorelines

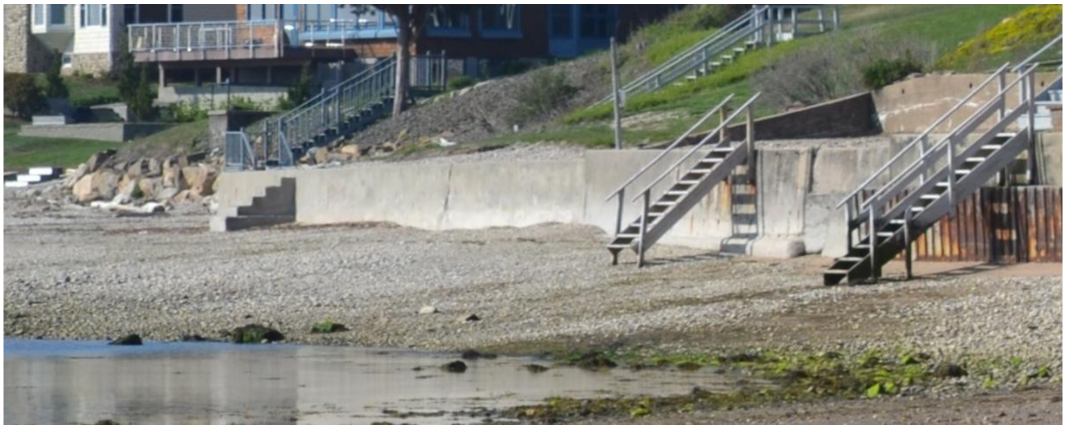
Much of the Connecticut shoreline of Long Island Sound is hardened with manmade coastal protection structures. The types most commonly found along the Connecticut shoreline are:

Groins

Jetties

Breakwaters

[Seawalls](#)



[Bulkheads](#)

[Revetments](#)

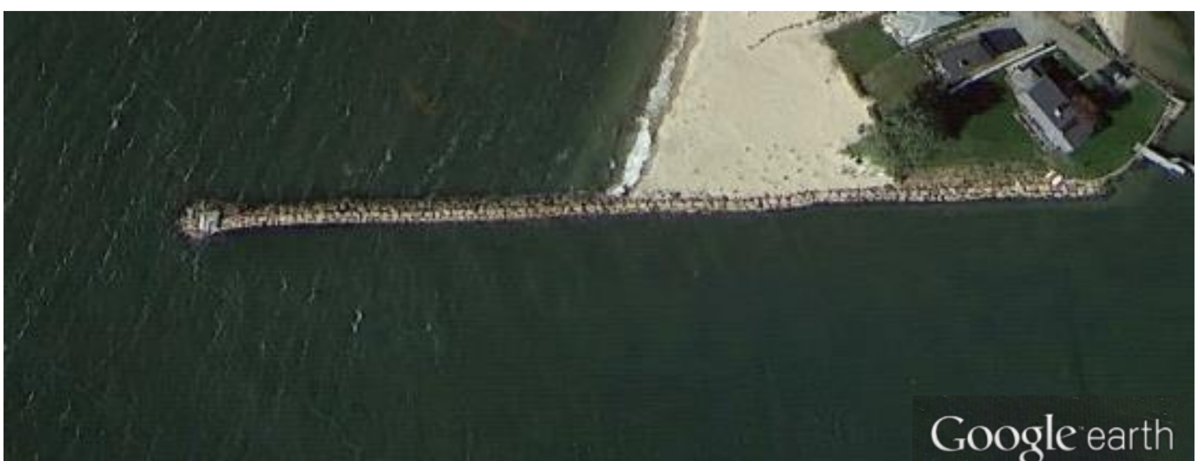
For shorelines currently defended by a functional coastal protection structure, such as a seawall, revetment or groin, the best option may be to do nothing. However, if the structure has failed or is at imminent risk of failure, it may be appropriate to remove it and replace it with a Living Shoreline. Alternatively, the structure could be modified to enhance the coastal habitats at the site.

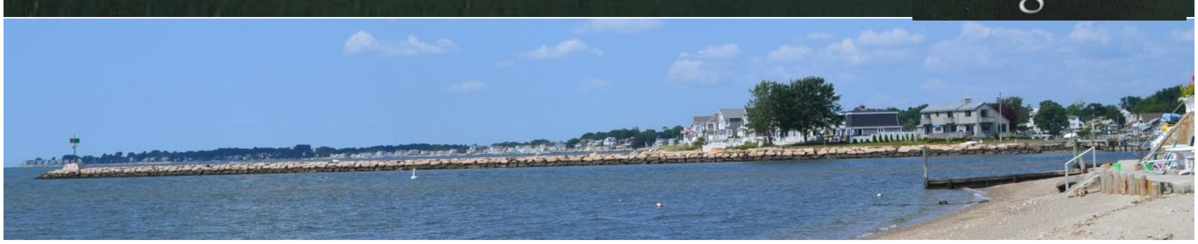
2.4.1 Groins

Groins, frequently incorrectly referred to as jetties, are shore parallel structures designed to prevent the alongshore movement of sand. Constructed of stone, timber, sheet piling or concrete, they increase erosion of downdrift shorelines by preventing natural coastal processes. Groins may be constructed singly or as erosion increases on downdrift beaches, a series of groins are constructed alongshore. Previously, groins were a popular form of coastal protection; however, many groins along the Connecticut shoreline are no longer functional due to lack of available sediment or deterioration of the structure. Newly constructed groins are artificially filled with sand to prevent adverse impacts on neighboring shorelines.

2.4.2 Jetties

Although groins and jetties may be constructed of similar materials and are frequently confused, they perform different functions. Jetties are designed to maintain the position of inlets and prevent sand from filling navigation channels.





2.4.3 Breakwaters

Breakwaters are designed to reduce wave action at the shore. Breakwaters may be

connected to the shoreline

or detached.

Breakwaters are typically not constructed by private property owners.

2.4.4 Seawalls

Seawalls are shore parallel structures, designed to protect upland property from coastal erosion and flooding caused by wave action and storm surge. Seawalls are typically constructed of concrete or steel sheet piling.

2.4.5 Bulkheads

Bulkheads are vertical, shore parallel structures, designed to retain upland sediment. Constructed of concrete, timber or steel sheet piling or vinyl composite, they are typically used in low wave energy environments.

2.4.6 Revetment

A revetment is a sloping, shore parallel structure of rock, or concrete units or slabs, designed built to protect a scarp or bluff against erosion by wave action, storm surge and currents. Revetment may also be used to provide additional protection at the toe of seawalls.

Several options are available for addressing erosion along currently defended shorelines. The most appropriate method will depend on site specific conditions. There are many parameters to consider before selecting a Living Shoreline approach. Some questions to ask are:

1. **What is the existing engineered structure at the site?**
   Coastal engineering structures are designed to perform different functions to provide protection from wave action and storm surge. For instance, groins are designed to interrupt alongshore transport of sand away from the site, creating or maintaining a beach to mitigate wave action. Alternatively, a seawall is a physical barrier to wave action.

2. **Is the existing structure functional or easily repaired? Is the existing structure performing the protective function for which it was designed? Is a different form of protection needed now?**
   If the existing structure is serviceable and performing the protective function which is needed at the site, no action may be the most suitable approach. Even if the existing structure is function, adding a hybrid Living Shoreline could enhance the ecosystem services at the project site.

3. **Is the project site experiencing erosion?**
   Do nothing may be the most suitable approach if the site is experiencing little to no erosion, The engineered structure may no longer be functioning as designed or the site conditions could have changed since completion of the structure.

4. **If you have a seawall or revetment, is there evidence that it is regularly overtopped and overwashed by waves, and/or that flooding occurs landward of the structure's crest?**
   Seawalls, bulkheads and revetments that are regularly overtopped are susceptible to scouring landward of the structure, and to potential failure.

5. **Is the structure damaged on a regular basis? Is it being flanked (erosion around the ends of the structure)?**
   It is critical to address existing and potential damage to the structure before it leads to failure of the structure and potential damage to existing landward buildings and infrastructure. A Living Shoreline may provide sufficient protection to reduce potential damage to the existing coastal structure.

6. **Does the existing coastal structure provide sufficient protection?**
   A Living Shoreline may increase the protection provided by the existing structure.

7. **Is shoreline usage changing?**
   Changes to shoreline usage may warrant a change to the existing protection. For example, a seawall may not be compatible with swimming, sunbathing or small boat access.

8. **Are changes being made to neighboring shoreline protection?**
   Changes made on adjacent or nearby properties may affect the coastal processes at the project site. This needs to be considered when evaluating existing or future coastal protection requirements.

Little information is available in the literature on removing and replacing traditional coastal engineering structures with Living Shoreline approaches, and even less information exists on the best approach to

enhance the ecosystem services of hardened structures. Since a large proportion of the Connecticut shoreline is already armored with traditional coastal protection structures, it is critically important to determine through research and experience the best methods of improving coastal habitats in the presence of hardened structures. This photograph shows a healthy marsh that was planted in front of an existing seawall. The marsh mitigates the wave heights at the wall.

If the existing coastal structure is functional or easily repaired, the best approach is to consider alternatives for the future replacement, or techniques to enhance the shoreline habitat. With the current state of knowledge, some options to consider are:

- Replacing impervious surface landward of your structure, with salt-tolerant plants.
- Roughening the surface of your seawall or adding tidal pools to enhance the shoreline habitat
- Placing rubble mound rock at the base of your seawall to reduce wave energy
- Using environmentally friendly concrete
- Planting dune grass on dry beach to increase sand trapping

3 Types of Living Shorelines

Living shorelines are designed to mitigate coastal erosion while maintaining ecosystem services. Living Shoreline approaches to shoreline stabilization are preferable from environmental or recreational perspective; however, they are not suitable for all coastal sites. At-risk sites exposed to large waves or frequent boat wakes may necessitate the protection afforded by traditional coastal engineering structures such as seawalls, groins and revetment. Other conditions that may preclude the implementation of Living Shoreline approaches including at-risk critical infrastructure or personal structures, insufficient space or inaccessible site for living shoreline construction, high rates of erosion and unacceptable impacts on adjacent shoreline or nearshore habitats (Hardaway, Milligan and Duhring, 2010).

Although there are many different types of living shorelines, they can be characterized into approaches constructed entirely of soft materials with no hard structure and approaches that use hard structures to provide additional protection to the vegetation. These types are frequently referred to as hybrid living shorelines (Smith, 2006; Ray-Culp, 2007; Duhring 2009a).

The table below provides an overview of several types of living shorelines:

	Marsh	Beach	Bluff	Pros	Cons	Approach	Construction Cost	Maintenance Cost
NON-STRUCTURAL								
Bank Grading and planting				• Does not disturb existing habitat • Stabilizes slope • Shoreline access	• Limited to low wave energy sites • May take time for vegetation to become established • Reduction of uplands • Susceptible to surface runoff and groundwater seepage	Very soft	Low	Very low
Marsh Restoration				• Even narrow fringe marsh provides protection from waves • Easy to construct	• Limited to low wave energy sites • May take time for vegetation to become established • Does not protect from storm surge	Very soft	Low	Very low
Beach Nourishment				• Recreational opportunities • Provides habitat for shorebirds and other coastal species • Shore access	• May disturb nearshore habitats • Renourishment may be necessary following storm damage • Requires periodic renourishment	Very soft	Medium	Medium
Dune Creation				• Protection from waves and winds • Provides habitat for shorebirds and other coastal species • Dune planting is easy	• Needs sufficient dry beach to form dunes • Easily damaged by foot traffic • Available sediment necessary for growth	Very soft	Low	Very low
HYBRID								
Fiber Logs		I		• Flexible and can adapt to shoreline • Does not disturb existing habitat • Biodegradable • Shoreline access	• Easily damaged by debris and ice • Limited to low wave energy sites	Very soft	Low	Very Low
Marsh Toe				• Can sustain damage without affecting structural integrity	• Heavy equipment necessary for construction	Hard	Very high	Low

Revetment				• Construction straightforward • Easy to repair • Easy to adapt or modify • Can withstand relatively strong currents and low-moderate waves. • Interstitial spaces provide aquatic habitat	• Scouring and flanking can occur • May cause increased downdrift erosion • Unstable rocks can be a hazard • Limits coastal access			
Marsh Sills				• Shoreline retains many of its natural characteristics. • Interstitial spaces provide aquatic habitat • Creates or enhances marsh habitat • Easily adapted to site conditions • Shoreline access	• Can cause erosion on seaward edge • Scouring and flanking can occur • May cause increased downdrift erosion • Susceptible to damage by ice and/or debris. • Can be navigation hazard. • Typically limited to sites with small-moderate tidal range • Heavy equipment may be necessary for construction	Soft	Very low	Medium
Oyster Reefs				• Provide important habitat functions. • Can improve water quality by filtering out pollutants • Shoreline access	• Susceptible to damage by debris and/or ice. • Extremely sensitive to changes in water quality • Regulatory requirements can be strict.	Soft	Low	Medium
Breakwaters				• Suitable for high wave energy • Remain effective with minor damage • May create aquatic habitat	• Susceptible to settling, scour and flanking. • May pose navigation hazard • Large offshore structural footprint may disturb existing habitat • Heavy equipment necessary for construction	Hard	Very high	Very high
Wave Attenuation				• Suitable for high wave energy • Remain effective with minor damage	• Susceptible to settling • May pose navigation hazard	Hard	High	Medium

Device		• May create aquatic habitat	• Susceptible to damage by debris and/or ice. • Large offshore structural footprint may disturb existing habitat • Heavy equipment necessary for construction	

3.1 Non-structural Approaches

Shoreline stabilization approaches using only vegetation or fill material are most effective at sheltered sites without critical infrastructure.

3.1.1 Vegetation Management

The most minimally disruptive approach to living shoreline protection is vegetation management. Removal of overhanging tree branches reduces shade and thereby increases marsh grass growth (VIMS-CCRM, 2006). Removal of unstable trees reduces the risk of slope destabilization that can occur when upland or slope trees are uprooted.

3.1.2 Slope or Bank Grading

Grading of steep, eroding banks can produce a more stable slope; however, if the bank or bluff is currently vegetated, slope planting is a more appropriate response (Maryland Department of Environment, 2008). Re-graded banks are frequently stabilized by salt tolerant plantings.

(photo credit: New England Environmental)

Upland plantings stabilize bluffs and reduce rainwater runoff. Eroding banks can also be protected from erosion by the creation of a salt marsh. Through bank re-grading or application of fill material, the intertidal zone can be planted with appropriate, salt-tolerant vegetation, thus creating a fringe tidal marsh (Chesapeake Bay Foundation, 2007; Hardaway *et al.*, 2009; VIMS-CCRM, 2006). Steep banks can sometimes be stabilized with “living walls” which are engineered support structures planted with vegetation to reduce erosion. Living wall structures reduce the need for extensive bank re-grading (Duhring, 2008a).Although toe protection can be combined with slope grading, terracing and slope grading are generally not effective shoreline protection for sites exposed to significant wave-induced erosion.

3.1.3 Marsh Restoration or Creation

The creation or restoration of fringing marshes is the most widely used non-structural approach to erosion control. Although it is possible to create a marsh on most shorelines, marsh creation is not recommended for sites where they are not a natural feature along comparable natural shorelines (MD

DOE, 2008). For narrow or eroding marshes, tidal marsh maintenance and enhancement is appropriate. Sparse marsh can be enhanced with plugs of marsh grass (Broome, Rogers, and Seneca, 1992). If necessary, fill material can be deposited to provide a suitably gradual slope for marsh creation or to enable a marsh to maintain its elevation with respect to the water level (VIMS-CCRM, 2006). While shoreline stabilization using only plants may be a viable solution on protected sites, along more exposed shorelines, fringe marsh plantings will likely require temporary or permanent supplemental structures, such as toe protection or sills, to ensure planting establishment. Plugs or live stakes are planted landward of MLW with the expectation that they will fill in within one to two growing seasons, providing the wave attenuation and habitat services of natural marsh vegetation. The success of the restored fringe marsh depends on width of the existing shoreline, the depth and composition of the existing soil, the slope of the shoreline, the shoreline configuration, exposure and orientation, and sun/shade conditions (MD DOE, 2008).

3.1.4 Beach Nourishment

Natural beaches are in a constant state of flux, responding to changes in wave energy and sea level (Lithgow et al., 2013). Post-storm beaches can become too narrow and steep for recreational opportunities or coastal protection. Storms can create steep scarps which could be dangerous for beach goers. With sufficient time, appropriate wave climate and sufficient supply of sand, beaches may restore themselves but few coastal communities can risk the loss of recreational services or erosion control while waiting for natural restoration to occur. Beach nourishment (also referred to as fill or replenishment) “restores” the beach quickly by importing sand from a land or offshore site. While nourishment may recover some of the ecosystem services that are typically lost on a developed and armored beach, nourishment does not “restore” a beach. Beaches nourished for optimum recreation or scenic views are graded too flat and low to provide storm protection. Nourishment can also bury native vegetation which can provide an opportunity for invasive species to colonize. Nourished sediment may also adversely affect nesting and foraging of shorebirds and other coastal animals (Nordstrom, Lampe, and Vandemark, 2000).

It is not unusual for large volumes of fill material to be transported away from the nourished site within the first winter or after the first storm (Dias et al., 2003). Although frequently identified as a “failure” by property owners, this is typically the result of the beach transforming into a more natural profile and had been accounted for during the design process (Committee on Beach Nourishment and Protection, National Research Council, 1995). Therefore, periodic maintenance of nourished beaches should be expected and included in the life-cycle costs of the project.

3.1.5 Dune Creation and Restoration

Dune creation or restoration may be a component of a beach nourishment effort or a stand-alone project. Although it is more effective to maintain existing dunes, coastal development and storm damage can render intervention necessary. The same process is used to create a dune as is found in nature, but at a faster pace. Dune restoration will be most successful if: it is located where the natural dune line should be and if possible, tied into existing dunes; there is sufficient space for the dune to form and move naturally; manmade damage is mitigated or prevented and; nature is assisted not destroyed (Salmon, Henningsen, and McAlpin, 1982).

Even on very small sites with less than ideal conditions, beach grass can be used to create protective dunes. This dune was created by planting beach grass on a 6 m wide property located above a 1 m high seawall, topped by a paved sidewalk. The dune is now over 1 m high and the beach grass is colonizing neighboring properties.

Three approaches are used to create or restore dunes: vegetate, provide additional sediment, or remove manmade structures that constrain dune development (Lithgow *et al.*, 2013; Martinez, Hesp, and Gallego-Fernandez, 2013). Sand fences, planted vegetation, fertilization and water are all used to increase natural dune processes (Salmon, Henningsen, and McAlpin, 1982). In areas where dunes do not form naturally, manmade dunes will not be successful. Dunes that can not be maintained after wave or storm damage will also be successful. In locations where dunes can form, dune creation and restoration should be similar to local naturally formed dunes. For instance, in low wave energy conditions dunes will have lower elevations than dunes in high wave energy conditions. Along the Connecticut shoreline of Long Island Sound coast, the lack of naturally available sediment available for transport and dune growth will limit the ability of dunes to restore naturally from storm damage.

If there is insufficient sediment available for dunes to form naturally, clean sediment of similar composition to that which would occur naturally must be brought to the site to create the dunes. After the dune is formed, fencing and vegetation can be used as barriers to the wind, causing windborne sediment to accumulate around the fence or plantings (O'Connell, 2008). Almost any type of fencing, snow fencing, plastic or fabric fencing, or coniferous (*e.g.*, "Christmas trees") or other brush, can be used to create dunes provided it does not completely block the wind.

3.2 Hybrid Approaches

On more exposed locations with high wave or wake energy environments, marsh plantings and beach nourishment may be unable to withstand wave conditions and reduce shoreline erosion. These environments will require temporary or manmade structures to attenuate wave energy to allow the establishment and maintenance of marshes and beaches. These structures include toe protection, sills or breakwaters constructed of natural materials such as rock, coir logs and matting, oyster reefs or other materialsAlternatively, manmade components such as synthetic matting, geotubes, and concrete wave attenuators can be combined with marsh plantings to reduce shoreline erosion while maintaining ecosystem services (Swann, 2008). This combination of vegetation and/or sediment with hard material is referred to as a "hybrid" living shoreline (Chesapeake Bay Foundation, 2007; VIMS-CCRM, 2015b). Unlike traditional coastal structures, hybrid living shorelines are designed to perform similarly to the natural ecosystem, rather than protect against it (Smith, 2008).

3.2.1 Fiber Logs

Coir logs are used to temporarily protect banks and marsh toe from erosion while planted vegetation develops strong root systems. The coir logs come in a range of sizes and grades, and may be placed in a single or multiple rows. Coir logs must be securely anchored to prevent wave and tidal current induced movement. Coir fiber is biodegradable and typically deteriorates in three to five years in low energy environments, sufficient time for the vegetation to become established (Chesapeake Bay Foundation, 2007; Hardaway *et al.*, 2009; Hardaway, Milligan, and Duhring, 2010; VIMS-CCRM, 2006); they are not recommended for high energy saltwater conditions (Duhring, 2008b; Skrabel, 2013).

(photo credit: V. Hagopian, GEI Consultants, Inc.)

3.2.2 Marsh Toe Revetment

Marsh toe revetment is a specialized riprap revetment designed to protect eroding marsh edges or banks from wave-induced erosion. Unlike traditional revetment protection, marsh toe revetment is low profile, only slightly higher than the existing marsh surface which is usually at or approximately one foot above

MHW. The low profile protects the marsh edge from wave action but allows tidal inundation over and through the structure, thus maintaining the marsh ecosystem. Tidal gaps in long revetments provide the same function by allowing tidal exchange (Barnard, 1999; Duhring, 2008a; Hardaway, Milligan, and Duhring, 2010).

3.2.3 Marsh Sills

Marsh sills are very small, low profile stone breakwaters that are used to protect the seaward edge of a planted marsh (Broome, Rogers, and Seneca,1992). Constructed near mean low water (MLW), they are backfilled with sand to elevate and re-grade the slope, then planted with marsh vegetation to create a protective marsh fringe (Duhring, 2008b; Hardaway, Milligan, and Duhring, 2010). Marsh sills are appropriate for eroding shorelines where site conditions are suitable for marshes although no marsh currently is present (Duhring, 2008b).

Low marsh sills have been used extensively in the Chesapeake Bay and its tributaries; the design has remained fairly consistent (Hardaway et al., 2010). A wider and higher sill would provide more protection from coastal erosion; a too high sill will reduce or eliminate tidal exchange and the marsh behind it will become stagnant and die. If tidal flushing is not enhanced, the area landward of the sill may be unable to support aquatic species that need to migrate with the tidal cycle (Smith, 2006; Chesapeake Bay Foundation, 2007; Duhring, 2008?). Thus, poorly designed sills can do more harm than good to marine animals (Subramanian *et al.*, 2008b). Slopes of 10 H:1 V and sill elevations near MHW have been recommended for the Chesapeake Bay (Duhring, 2008a; Hardaway et al., 2010). Hardaway and Byrne (1999) provide recommendations for marsh widths and sill construction; however, the Chesapeake Bay has a relatively small mean tidal range of 1-3 feet (Xiong and Berger, 2010). Therefore, these design parameters may need to be modified for locations with greater tidal ranges.

Openings or gaps in marsh sills are recommended to allow tidal exchange and to provide marsh access for marine animals. However, the openings expose the marsh to waves which could result in increased erosion. Deposition of sediment in the gaps can also occur which could reduce or eliminate tidal exchange (Hardaway et al., 2007; Smith, 2008). Recommendations for mitigating these concerns include creating dog leg or offset openings, and varying the opening size and orientation of the sills to allow tidal flow exchange and access to the marsh habitat (Bosch et al.; 2006; Hardaway et al., 2007). In addition to sill gaps, access to the marsh takes place through interstitial spaces in the sill and by overtopping. The porosity of the sill may be as important if not more important to tidal exchange and species access than the size or number of gaps in the sill length (Hardaway et al., 2007). Although no scientific study of the effectiveness or design of sill gaps has been performed to date, empirical evidence suggests gaps approximately every 100 ft, although the final design will depend on local marine species, and wave and tidal conditions (Smith, 2008; Hardaway et al., 2010).

3.2.4 Oyster Reefs

Marsh sills are also formed with oyster reefs, constructed of bagged or loose oyster shell, to provide the same erosion control as rock sills, but with additional ecosystem benefits (Atlantic States Marine Fisheries Commission Staff, 2010; Duhring, 2008b; Scyphers *et al.*, 2011; Skrabel, 2013; Swann, 2008). Oyster reefs provide a substrate for oyster recruitment and thus are self-maintaining, building the reef dimensions and therefore, protection and restoration benefits with time (Atlantic States Marine Fisheries Commission Staff, 2010; Gedan *et al.*, 2011; Scyphers *et al.*, 2011) so oyster reefs are sometimes referred to as “living breakwaters” (NOAA National Marine Fisheries Service, 2015). Like rock sills, oyster reefs provide habitat and foraging areas for aquatic species, however, as oysters are filter feeders they also improve water quality and clarity by removing sediment and algae, which improves light transmission and enhances the environment for SAV (Atlantic States Marine Fisheries Commission Staff, 2010).

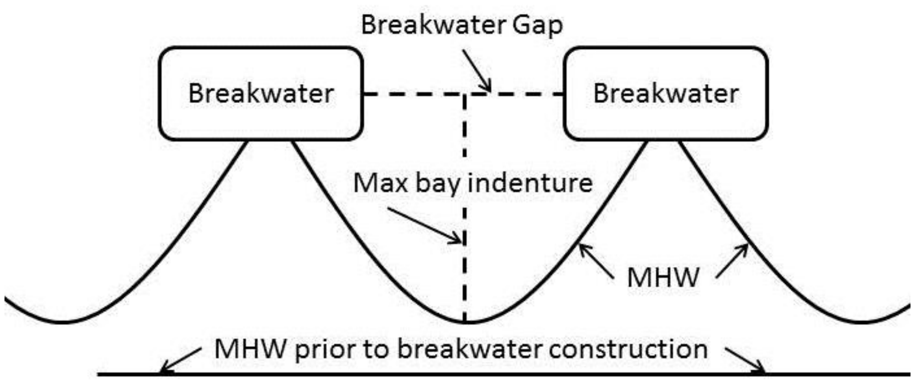
At present, there is limited understanding of the value of oyster reefs for planted marshes (Atlantic States Marine Fisheries Commission Staff, 2010; National Research Council, 2014), and it is not clear if uncontained oyster shell is sufficiently resistant to wave action and tidal currents to provide adequate protection.

(photo credit: B. Branco, Brooklyn College)

The effectiveness for shore protection of low profile marsh sills is limited due to the larger tidal ranges experienced in New England. Large scale oyster reefs are similar to traditional breakwaters but are seeded with oysters to reduce risk to coastal storms while providing ecosystem services enhancement (Rebuild by Design, 2015). The persistence and growth on oyster beds depend on wind, waves, tidal currents and ice. Currently, the Connecticut’s natural beds are only a few oysters deep and since most of the subtidal areas are designated harvest areas, the pyramid shape commonly found in the Chesapeake Bay does not exist in Long Island Sound (Getchis, 2015). In Long Island Sound, commercial oystering limits the feasibility of oyster reefs. Most of the nearshore sites suitable for oyster reef construction are designated town, state or privately held commercial harvesting beds. Additionally, the CT Bureau of Aquaculture has a policy of removing oysters when they reach 5-6 years old to reduce the potential occurrence of MSX (Carey, 2015). Thus, the feasibility of oyster reef sills and breakwaters for living shorelines in Long Island Sound is limited.

3.2.5 Breakwaters

Structural approaches to coastal erosion are not typically considered living shoreline approaches. However, offshore-gapped-headland breakwaters, as a component of a living shoreline, are used to create a pocket or crenulate beach which is the most stable shoreline configuration (Hsu *et al.*, 2010). Hardway *et al.* (1991) examined the effectiveness of the gapped-headland configuration for erosion control for several sites along Chesapeake Bay tributaries and identified design parameters which are currently used by the MD DNR, such as the relationship between the maximum bay indentation (breakwater centerline to MHW) and the breakwater gap. MD DNR uses a relationship of 1:1.65 (Subramania, 2015); however, Berenguer and Fernandez (1988) in their review of Spanish pocket beaches on the Mediterranean Sea found an average ratio of 1:0.75, suggesting the breakwater design parameters are site specific.



In comparison to sills, breakwaters are larger with a higher elevation, designed to protect the shoreline from storm wave conditions. Although breakwaters have been suggested as protection from storm surge, they do not protect against coastal inundation. Breakwaters reduce storm-induced damage by attenuating wave heights, and they provide a protected area landward of the structures so sediment deposition can increase and the beach widened.

3.2.6 Wave Attenuation Devices

Reef balls, WADs, Coastal Havens, BeachSavers and Prefabricated Erosion Prevention (P.E.P.) reefs are marine suitable concrete structures designed to attenuate waves and provide benthic habitat. These wave attenuation devices may be used where appropriate instead of rock sills (Boyd and Pace, 2012; Duhring, 2008b; Gedan *et al.*, 2011; Meyer, Townsend, and Thayer, 1997; Swann; 2008). Of these, Reef Balls are perhaps the best known with over 4000 projects worldwide, albeit not all of the installations were for erosion protection; many were to re-establish coral reefs (Fabian *et al.*, 2013). Wave attenuation devices are deployed as offshore breakwaters, to provide the hard coastal protection of a traditional breakwater with the ecological benefits of habitat creation and marsh restoration (Gedan *et* *al.*, 2011). As the wave attenuation devices become colonized with marine species, they provide recreational benefits such as fishing and snorkeling (USACE, 2005).

(photo credit: A. Dolan, Graduate Student, Department of Biology, Sacred Heart University)

Despite the number of projects using wave attenuation shapes as breakwaters, there is a scarcity of peer-reviewed literature on their effectiveness for shoreline protection (Fabian *et al.*, 2013). Design guidleines suggest that the number of rows of attenuation structures needed is determined by the water depth, wave climate, tidal range and the design attenuation criteria, and is similar to the crest width of a traditional submerged breakwater (Reef Beach Company, 2010). Studies have shown problems with settlement of the devices and the need for extensive restoration after storms which could result in high maintenance costs (Fabian *et al.*, 2013).

3.2.7 Alternative Technologies

Although there are other examples of living shoreline approaches such as live fascines, branch packing, and brush mattresses (*e.g.*, Rella and Miller, 2012), most are unsuited to the wave, surge and ice conditions experienced by New England coasts. Scientists, engineers and even private property owners are continually developing new technologies for responding to coastal erosion, storm surge and sea-level rise. Although property owners remain optimistic, no “silver bullet” has been produced that solves all these problems.

Questions to consider when evaluating any type of shore protection include (Pope , 1997):

(1) Is it heavy enough to withstand storm waves?
(2) Can it be anchored so it will not fall apart?
(3) In case of structural failure, will components become an environmental or safety concern?
(4) Will the structure withstand erosion and toe scour?
(5) Will the material deteriorate?
(6) What are expected storm and longevity design criteria?
(7) Can the structure meet performance criteria?
(8) What are the potential adverse impacts to adjacent properties?
(9) How do construction costs compare with traditional shoreline protection?

(10)What are maintenance and repair costs?
(11)What is its effective life?
(12)What will it cost to remove the system if necessary?

4 Site Considerations

The most appropriate Living Shoreline design is highly dependent on the site conditions. Many parameters must be evaluated to determine the best approach.

- Wave Climate
- Tidal Range
- Ice
- Storm Surge
- Nearshore Bathymetry
- Shoreline Geomorphology
- Site Characteristics
- Vegetation
- Shore Zone
- Existing Coastal Structures
- Shoreline Usage

4.1 Design Parameters

Before an appropriate course of action can be determined, the nature of the problem must be identified, the desired outcome resolved and the characteristics of the site understood. Numerous parameters affect the shoreline; however, the relative importance of each parameter will depend on the site, the problem and the project goal (Hardaway et al., 2010). These parameters include: location, fetch, wave climate, tidal range, storm surge height and frequency, nearshore bathymetry, shoreline exposure, rate of existing shoreline change (erosion/accretion), upland bank characteristics (height, composition, condition, usage, proximity to infrastructure), existing vegetation, width and elevation of beach or marsh, functionality of any existing coastal structures and sea level rise (Duhring, Barnard and Hardaway, 2006; Frizzera, 2009; Hardaway, Milligan and Duhring, 2010;U.S. Department of Agriculture, 1996).

4.1.1 Wave Climate and Fetch

As wave action is the primary mechanism for coastal erosion, determining the wave climate is essential for development of a suitable approach for coastal protection. In locations protected from wind generated waves, proximity to powerboat marinas and navigational channels can cause the shoreline to be adversely impacted by boat wakes (Hardaway et al., 2010). Many researchers consider fetch, the distance that wind can travel over open water, to be one of the most important parameters in determining the feasibility of a living shoreline approach because longer fetches can result in larger wave heights making areas less suitable for living shorelines applications (for example, Chesapeake Bay Foundation, 2007; Hardaway, Milligan and Duhring, 2010; SAGE, 2015).

Hardaway and Byrne (1999) described shoreline wave energy as a function of average fetch. Very low and low energy shorelines have fetches of less than 0.5 miles and 0.5 - 1 miles, respectively and are typically found along tidal creeks and small tributaries. Shorelines along main tributaries with average fetches of 1 - 5 miles are medium energy. High energy shorelines are found at the mouth of tributaries and have fetches ranging from 5 - 15 miles, while very high energy shorelines have fetches greater than 15 miles (Hardaway et al., 2010).

Hardaway et al. (2010) and USACE (1980) recommend calculating an average fetch and a longest fetch to provide design wave conditions. Assuming the wind transfer energy to the water in +/- 45^{o} of the direction of the wind, an effective fetch can be calculated by taking the cosine weighted average of all the rays within a certain sector on either side of the fetch ray (Malhotra and Fonseca, 2007).

Fetch, whether longest, average or effective, can only provide an estimate of the largest potential wave heights. Fetch is used in place of actual wave data because it is a relatively easy to obtain. However, if the wind rarely blows or is very light from that direction, fetch is a misleading indictor of design wave conditions. Rodweder et al. (2012) provide a model which combines the effective fetch with weighted wind directions to estimate the statistical probability of wave heights during average and storm conditions.

4.1.2 Tidal Range

The local tidal range is an important parameter in determining the height of a structure or the width of a marsh or beach necessary to provide protection over the range of water levels at the site (Hardaway et al., 2010). Tidal ranges in the Chesapeake Bay range from 1 – 4 ft. New England tidal ranges are significantly larger; areas in Maine experience tidal ranges of nearly 20 ft. Tidal range is a significant design variation when applying guidelines from other locations.

4.1.3 Ice

Ice can be an extremely destructive force in New England marshes. Ewanchuk and Bertness (2003) suggest that after wrack disturbance, ice is the most important natural disturbance in New England marshes. Wrack primarily affects high marsh, while ice disturbance affects low marsh due to tidal fluctuations. Despite its importance, there is very little in the literature on design guidelines for living shorelines in ice impacted climates; most of what exists is anecdotal (Majka, 2015).

Ice in the coastal ocean is never stationary; its motion creates several different types of forces impacting the shoreline and coastal structures. Wind, tides and currents move ice sheets creating horizontal forces on vertical structures such as seawalls and building foundations. Thermal expansion and contraction creates static forces on structures. Ice sheet adhesion to structures creates uplift and drawdown forces (US Army Corps of Engineers, 1981).

Ewanchuk and Bertness (2003) found that ice disturbances that killed the vegetation, but left the underlying peat intact, recovered quickly, but in marshes where ice damage killed the vegetation and removed the underlying peat, only the most stress-tolerant plants re-colonized. They asume that the recovery process is likely to exceed 10 years for intense ice damage.

Southern and Northern New England are affected somewhat differently from ice forces. In Southern New England, ice damage primarily affects low marsh. Ice adhesion can remove large portions (1 - 3 m^2) and transport the vegetation on the ebb tide (Bertness and Ellison 1987; Brewer et al., 1998; Ewanchuk and Bertness, 2003). Further north, ice damage destroys low marsh vegetation every winter (Bertness, 1999; Ewanchuk and Bertness, 2003). In northern New England, ice disturbances also affect the middle and high marsh when ice sheets melt and deposit sediment that had been transported within the ice sheet from other locations (Ewanchuk and Bertness, 2003). Ice damage also consists of the formation of ice ridges and scouring and gouging of the marsh substrate (Majka, 2015).

The four primary methods of addressing the effects of ice are:

- Do nothing
- Do nothing then restore: this may be the most appropriate and most cost-effective solution if ice damage will be minimal, or no structural or human health risk is anticipated.
- Protect against ice's strength: this is typically accomplished through coastal structures composed of steel, stone or concrete. This approach is rarely used with living shorelines; however, it may be appropriate if structures are at a significant risk to ice damage.
- Attack ice's weakness: although extremely strong in compression, ice is weak in tension. By roughening the surface or installing obstructions, ice can be weakened. Gentle slopes (10 - 20%) allow ice to slide up and down. The addition of ribs to the slope can encourage this mechanism. Plants, particularly emergent vegetation or shrubs, weaken ice, primarily because decaying vegetation produces CO_2 and thermal energy. Ice grows weaker around shrubs because stems flexible obstructions (Majka, 2015).

4.1.4 Storm Surge

The predicted surge for storms of different statistical probability is critical to the design of effective protection against coastal erosion and inland flooding. Surge elevations help identify areas at risk of inundation, volume of floodwaters expected and provide an estimate of the expected level of protection an approach can provide.

4.1.5 Nearshore Bathymetry

The nearshore bathymetry determines the height of the waves approaching the site. A gradual nearshore slope will cause incoming waves to break as they approach the shore, resulting in less erosive wave energy. Steeper nearshore bathymetry will allow larger waves to reach the shoreline. Tidal flats and sand bars can attenuate wave heights reaching the shoreline. Sandy intertidal regions and sand bars indicate sediment available in the systems for natural beach and dune nourishment. Thus, the nearshore bathymetry will determine the size and feasibility of shore protection structures (Hardaway et al., 2010).

4.1.6 Shoreline Geomorphology

Shorelines can be categorized into three major geomorphologic types: beaches and dunes, rocky and soft bluffs, and mudflats and vegetated communities (NRC, 2007). In addition to the types of shorelines, shorelines in New England are highly variable; they can be long and straight, bounded by rocky headlands, or highly irregular. Pocket beaches tend to be crenulated; the waves diffract as they approach the shoreline and sediment transported tends to remain within the pocket beach system. Linear shorelines and headlands are more exposed to erosive wave action, while irregular shorelines are interrupted by headlands, marshes or coastal structures tend to receive reduced wave effects (Hardaway et al., 2010).

The coastal morphology also determines the ability of the substrate to support protective structures. The composition of the substrate is critical to the types of vegetation and its ability to support a structure, such as a sill or oyster reef.

4.1.7 Shoreline Change

"Understanding how a shore reach has evolved is important to assessing how to manage it," (Hardaway et al., 2010). The appearance of erosion does not necessarily indicate an erosion problem. An undercut bank may be stable so a landscaping approach may be sufficient, or it could be a result of recent storm effects and with time, naturally restore itself. Thus, the rate of shoreline change must be assessed to determine the appropriate approach.

4.1.8 Site characteristics

While many parameters for assessing the feasibility of various coastal protections can be evaluated from maps and online sources, it is usually necessary and frequently valuable to visit the site. Although the length of the site may influence the impact of boundary effects, a primary concern is how the site is bounded. Neighboring eroding shorelines may provide sediment while adjacent harden shorelines will limit the amount of sediment available. Headlands and groins may provide wave protection but limit sediment transport into the site.

The upland usage must be considered when evaluating shoreline protection techniques. The importance of coastal development and infrastructure, the cost and feasibility of moving upland structures, and the risk of erosion and flooding all affect the level of protection required.

For a shoreline with no existing shoreline structure or hardening, the condition of the backshore or bank can provide an indication of its stability. Sandy beaches without shoreward dunes may indicate an overwash area that is susceptible to coastal flooding, while a healthy dune system indicates an adequate supply of sediment for repairing storm induced damage. A gradually sloping bank covered with salt tolerant vegetation is a good indicator of bank stability. Steep banks devoid of vegetation frequently exhibit signs of undercutting or slumping. The slumped sediment may act as a buffer to wave action and thus temporarily reducing erosion, but once the slumped sediment is eroded, the toe of the bank is once again exposed to waves and thus susceptible to slumping (Hardaway et al., 2010). The composition of the bank material will affect its erodibility. Rocky bluffs are obviously less susceptible to wave action than unconsolidated sand banks but may be affected by splashover effects.

4.1.9 Vegetation

The presence of marsh plants and nearshore submerged aquatic vegetation (SAV) demonstrates that site conditions are suitable for vegetative protection but also may affect the regulatory acceptability of certain erosion control structures (Hardaway et al., 2010).

4.1.10 Shellfish Beds

Nearshore shellfish beds are a clear indication that the conditions are suitable for shellfish; however, their existence may also preclude the creation of some types of Living Shorelines. The construction and presence of Living Shorelines may negatively impact the shellfish beds. For instance, fill material can bury shellfish; sills and breakwaters can damage shellfish beds.

4.1.11 Shore Zone

The width and elevation of the shoreline, whether sandy beach or intertidal marsh, are indications of its capability to attenuate waves. Typically, a higher, wider shoreface will lead to greater wave attenuation; however, studies have shown that even a narrow marsh region can significantly reduce wave heights (Möller and Spencer, 2002; Gedan et al., 2011).

4.1.12 Existing Coastal Structures

Existing coastal protection structures may indicate an attempt to rectify a pre-existing problem; however, they do not necessarily mean the problem was erosion. Many coastal property owners originally built low seawalls as landscaping assets to maintain grass lawns, not protect against erosion. The condition and functionality of the existing structure should be assessed. If the existing coastal protection is in good condition or easy to repair and the shoreline is stable, the best approach may be to maintain the existing protection. Even deteriorating structures may not need to be replaced if there is no erosion on the site. However, if the structure is flanked or overtopped, the existing protection is inadequate for the conditions (Hardaway et al., 2010)

4.1.13 Shoreline Usage

The level of protection and the anticipated shoreline use must also be considered when selecting shoreline protection approaches. The maximum winds, waves and surge conditions from which protection is desired form the design parameters; however, site conditions, permitting and costs may necessitate a revised design which could result in overtopping, failure of the structure and loss of protection during storm conditions.

Table 1 shows the compatibility of shoreline protection approaches with shoreline usage.

Table 1. Compatibility of shoreline protection approaches with shoreline usages (USACOE, 1981).

Alternative	Walking	Swimming	Fishing	Boating
No Action	Sometimes	Sometimes	Usually	Usually
Slope Grading	Almost always	Almost always	Almost always	Almost always
Marsh Restoration	Almost never	Almost never	Almost always	Rarely
Beach Nourishment	Almost always	Almost always	Usually	Almost always

4.2 Summary

Selection of an appropriate Living Shoreline approach is high dependent on the unique site conditions. Table 2 presents a summary of the conditions for which each Living Shoreline approach may be suitable; however, these guidelines are based on conditions reviewed in the literature and may not be entirely relevant to the Connecticut coast. As Living Shoreline techniques are constructed and monitored in Connecticut, this table will likely be revised.

Table 2. Appropriate conditions for Living Shoreline Approaches (Miller et al., 2015). The parameters in bold are critical parameters for that Living Shoreline approach.

	Slope regrading and planting	Marsh restoration	Beach/Dune Nourishment	Fiber Log	Marsh Toe Revetment	Marsh Sill	Oyster Reef	Breakwater	Wave Attenuation Device
Waves	***Low***	***Low***	***Low-Mod***	***Low***	***Mod-High***	***Low-Mod***	***Low-Mod***	***High***	***Low-Mod***
Tide	Low-Mod	***Low-Mod***	Low-High	Low-Mod	Low-High	***Low-Mod***	***Low-Mod***	Low-High	Low-Mod
Ice	***Low***	***Low***	Low-High	***Low***	***Low-High***	***Low***	***Low***	***Low-Mod***	Low-Mod
Surge	***Low***	Low-High	Low-High	Low-High	***Low-High***	Low-High	Low-High	***Low-High***	Low-High
Nearshore bathymetry	***Mild-Mod***	***Mild-Mod***	***Mild-Steep***	***Mild-Mod***	***Mild-Steep***	***Mild-Mod***	***Mild-Mod***	***Mild-Steep***	Mild-Steep
Shoreline Change	***Low-Mod***	***Low-Mod***	***Low-Mod***	***Low-Mod***	***Mod-High***	***Low-Mod***	***Low-Mod***	***Mod-High***	***Low-Mod***
Upland Slope	***Mild-Steep***	Mild-Steep	***Mild-Steep***	Mild-Steep	***Mild-Steep***	Mild-Steep	Mild-Steep	Mild-Steep	Mild-Steep
Shore Width	***Mod-High***	***Mod-High***	***Mod-High***	***Mod-High***	Low-High	***Mod-High***	***Mod-High***	***Mod-High***	***Mod-High***
Soil Bearing Capacity	Low-High	Low-High	Low-High	Low-High	***Mod-High***	***Mod-High***	Mod-High	***High***	***Mod-High***

5 Permitting Steps

It would be useful here to provide some guidelines or steps for readers interested in constructing a living shoreline in Connecticut. However, if the steps are still in the develop stage or if we decide that it is too technical or confusing for the audience we can modify the content.

6 Resources

6.1 Websites

- DEEP
- CIRCA
- CLEAR
- Maine Coastal Hazards
- Who else on living shorelines?

6.2 Literature Cited

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6.3 Printable Marsh Checklist

1. **Is there an existing Engineered Structure (seawall, groin, revetment, etc.) at the site?**

   ☐ No

   ☐ Yes.

   Is functional or easily repaired?

   ☐ No

   ☐ Yes. Go to Currently Defended Structures.

2. **What is the condition of the marsh? Is there presently a vegetated wetland at the edge of the property? Is the vegetation dense or sparse?**

   ☐ **Healthy** ☐ **Sparse** ☐ **Non-existent**

   How wide is the marsh? ____________

3. **Is the marsh eroding?**

   ☐ No

   ☐ Yes.

   What is causing the erosion?

   ☐ Waves
   ☐ Boat Wakes
   ☐ Currents
   ☐ Wrack
   ☐ Ice
   ☐ Public Access
   ☐ Climate Change

   What level of protection is needed?

   ☐ From on-going erosion (caused by normal wave conditions and boat wakes)

   ☐ From storm-induced erosion (caused by major storm events such as nor'easters and hurricanes)?

   What is the rate of erosion?

   ☐ Highly Erosional (2 feet or more per year)
   ☐ Moderately Erosional (1-2 feet per year)
   ☐ Slightly Erosional (less than 1 foot per year)
   ☐ Stable (no change)
   ☐ Accretional (growing seaward)

   Need more information? See Shoreline Change.

4. **Is there infrastructure at risk?**

   ☐ **No** ☐ **Yes**

5. **What is the wave climate?**

   During normal conditions? __________ feet
   Occasionally? _________________ feet
   Frequently? __________________feet

   During a storm conditions? _________ feet
   Occasionally? _________________ feet
   Frequently? __________________feet

   From boat traffic? _________________ feet
   Occasionally? _________________ feet
   Frequently? __________________feet

   For more information on wave conditions and wakes, see Wave Climate and Fetch.

6. **Is the site affected by tidal, riverine or alongshore currents?**

   ☐ No ☐ Yes

7. **What is the shoreline geometry?**
   - ☐ Pocket
   - ☐ Irregular
   - ☐ Straight
   - ☐ Headland

   Unsure? Check out Shoreline Geomorphology.

8. **Is the marsh backed by**
   High sediment bank (is there a steep slope above the water line, more than 3 feet over 5 yards?)
   ☐ No

   ☐ Yes.
   Go to the Section on Bluffs

   Low sediment bank (is there a gentle slope above the water line, less than 3 feet over 5 yards?)
   ☐ No

   ☐ Yes.
   Is your low bank face
   - ☐ Erosional?
   - ☐ Stable?
   - ☐ Transitional?
   - ☐ Undercut?

9. **Does the bank have**

   Mature upland vegetation?
   ☐ No ☐ Yes

   Fallen or uprooted trees?
   ☐ No ☐ Yes

   Will existing vegetation shade created or restored marsh?
   ☐ No ☐ Yes

10. **What is the intertidal slope/nearshore bathymetry? Is the slope**
   - ☐ Gradual
   - ☐ Moderate
   - ☐ Steep

   For more information see Nearshore Bathymetry.

11. **What is the tidal range?**

   ____________________feet

   Need more information. See Tidal Range.

12. **Does the project site flood regularly during normal tides?**
   ☐ No ☐ Yes

   Spring tides?
   ☐ No ☐ Yes

   Storm surge?
   ☐ No ☐ Yes

13. **Is the project site affected by ice?**
   ☐ No ☐ Yes

   For more information see the section on Ice.

14. **Does the site have submerged aquatic vegetation?**
   ☐ No ☐ Yes

   Nearshore oyster beds?
   ☐ No ☐ Yes

15. **What is the nearshore region?**
   - ☐ Fine
   - ☐ Medium-coarse sediment
   - ☐ Rocky or cobbles
   - ☐ Ledge
   - ☐ Offshore Sand Bars
   - ☐ Tidal Flats

16. **What is the condition of the adjacent properties? Are they experiencing similar rates of erosion?**
   ☐ No ☐ Yes

Do they have existing coastal structures?

☐ No ☐ Yes

How will this project affect the adjacent properties?

____
____
____

17. **Is the project site accessible for construction from land?**

☐ No ☐ Yes

Water?

☐ No ☐ Yes

18. **What is the current rate of sea level rise?**

____________________feet

What is the predicted rate of rise?

____________________feet

What are the potential effects of sea level rise on the project site?

____
____
____

6.4 Printable Beach and Dune Checklist

1. **Is there an existing Engineered Structure (seawall, groin, revetment, etc.) at the site?**
   ☐ No

   ☐ Yes.

   Is functional or easily repaired?
   ☐ No

   ☐ Yes. Go to Currently Defended Structures.

2. **Is there a sand dune at the seaward edge of the property?**
   ☐ No

   ☐ Yes.

   Is it vegetated?
   ☐ Yes

   ☐ No.

   Is a dry beach present (sand above normal high tide)?
   ☐ No

   ☐ Yes.

   What is the width of the dry beach?
   _____25 feet or less
   _____between 25 and 50 feet
   _____between 50 and 75 feet
   _____greater than 75 feet

3. **Is there evidence that your dune or backshore is regularly overtopped and overwashed by waves, and/or that flooding occurs landward of the dune or beach crest?**
   ☐ No ☐ Yes

   During normal or spring tides? Storm surges?
   ☐ No ☐ Yes

4. **Does your dune and beach naturally gain sand after each winter season?**
   ☐ No ☐ Yes

5. **Is the beach or dune eroding?**
   ☐ No

   ☐ Yes.
   What is causing the erosion?

   ☐ Seasonal Changes
   ☐ Storms
   ☐ Sand Availability
   ☐ Manmade structures
   ☐ Currents
   ☐ Public Access
   ☐ Climate Change

   What level of protection is needed?

   ☐ From on-going erosion (caused by normal wave conditions and boat wakes)

   ☐ From storm-induced erosion (caused by major storm events such as nor'easters and hurricanes)?

   What is the rate of erosion?
   ☐ Highly Erosional (2 feet or more per year)
   ☐ Moderately Erosional (1-2 feet per year)
   ☐ Slightly Erosional (less than 1 foot per year)
   ☐ Stable (no change)
   ☐ Accretional (growing seaward)

Need more information? See Shoreline Change.

6. **Is there infrastructure at risk?**
   ☐ No ☐ Yes

7. **What is the wave climate?**
   During normal conditions? __________ feet
   Occasionally? _________________ feet
   Frequently? __________________feet

   During a storm conditions? _________ feet
   Occasionally? _________________ feet
   Frequently? __________________feet

   From boat traffic? _________________ feet
   Occasionally? _________________ feet
   Frequently? __________________feet

   For more information on wave conditions and wakes, see Wave Climate and Fetch.

8. **Is the site affected by tidal, riverine or alongshore currents?**
   ☐ No ☐ Yes

9. **What is the shoreline geometry?**
   ☐ Pocket
   ☐ Irregular
   ☐ Straight
   ☐ Headland

   Unsure? Check out Shoreline Geomorphology.

10. **Is the beach backed by**
    High sediment bank (is there a steep slope above the water line, more than 3 feet over 5 yards?)
    ☐ No

    ☐ Yes.
    Go to the Section on Bluffs

    Low sediment bank (is there a gentle slope above the water line, less than 3 feet over 5 yards?)
    ☐ No

    ☐ Yes.
    Is your low bank face
    ☐ Erosional?
    ☐ Stable?
    ☐ Transitional?
    ☐ Undercut?

11. **Does the bank have**

    Mature upland vegetation?
    ☐ No ☐ Yes

    Fallen or uprooted trees?
    ☐ No ☐ Yes

    Will existing vegetation shade created or restored marsh?
    ☐ No ☐ Yes

12. **What is the intertidal slope/nearshore bathymetry? Is the slope**
    ☐ Gradual
    ☐ Moderate
    ☐ Steep

    For more information see Nearshore Bathymetry.

13. **What is the tidal range?**

    ____________________feet

    Need more information. See Tidal Range.

14. **Does the project site flood regularly during normal tides?**
    ☐ No ☐ Yes

    Spring tides?
    ☐ No ☐ Yes

Storm surge?

☐ No ☐ Yes

15. Is the project site affected by ice?

☐ No ☐ Yes

For more information see the section on Ice.

16. Does the site have submerged aquatic vegetation?

☐ No ☐ Yes

Nearshore oyster beds?

☐ No ☐ Yes

17. What is the nearshore region?

☐ Fine
☐ Medium-coarse sediment
☐ Rocky or cobbles
☐ Ledge
☐ Offshore Sand Bars
☐ Tidal Flats

18. What is the condition of the adjacent properties? Are they experiencing similar rates of erosion?

☐ No ☐ Yes

Do they have existing coastal structures?

☐ No ☐ Yes

How will this project affect the adjacent properties?

____
____
____

19. Is the project site accessible for construction from land?

☐ No ☐ Yes

Water?

☐ No ☐ Yes

20. How will the shoreline be used?

☐ Walking
☐ Swimming
☐ Boating
☐ Fishing
☐ Nature watching
☐ Other

21. What is the current rate of sea level rise?

____________________feet

What is the predicted rate of rise?

____________________feet

What are the potential effects of sea level rise on the project site?

____
____
____

6.5 Printable Bluff Checklist

1. **Is there an existing Engineered Structure (seawall, groin, revetment, etc.) at the site?**
   - ☐ No
   - ☐ Yes.

   Is functional or easily repaired?
   - ☐ No
   - ☐ Yes. Go to Currently Defended Structures.

2. **If soft, what is the composition of your bluff? Fine, mixed or coarse (sand or cobble)?**
   - ☐ Fine
   - ☐ Mixed
   - ☐ Coarse

3. **Is marsh or a dry beach present (sand above normal high tide) at the toe of your bluff? If yes, how wide?**
   ☐ **Marsh** ☐ **Sand**

   How wide? ____________ feet

4. **If you have a low bluff, is there evidence that your bluff is regularly overtopped and overwashed by waves, and/or that flooding occurs landward of the bluff?**
   ☐ No ☐ Yes

   During normal or spring tides? Storm surges?
   ☐ No ☐ Yes

5. **Is the bluff eroding?**
   - ☐ No
   - ☐ Yes.

   What is causing the erosion?
   - ☐ Waves
   - ☐ Wind
   - ☐ Storms
   - ☐ Runoff
   - ☐ Groundwater seepage
   - ☐ Ice
   - ☐ Currents
   - ☐ Public Access
   - ☐ Climate Change

   What level of protection is needed?
   - ☐ From on-going erosion (caused by normal wave conditions and boat wakes)
   - ☐ From storm-induced erosion (caused by major storm events such as nor'easters and hurricanes)?

   What is the rate of erosion?
   - ☐ Highly Erosional (2 feet or more per year)
   - ☐ Moderately Erosional (1-2 feet per year)
   - ☐ Slightly Erosional (less than 1 foot per year)
   - ☐ Stable (no change)
   - ☐ Accretional (growing seaward)

   Is the toe of the bluff eroding?
   ☐ No ☐ Yes

   Need more information? See Shoreline Change.

6. **Is there infrastructure at risk?**
   ☐ No ☐ Yes

7. **Is the upland bank vegetated?**
   ☐ No ☐ Yes

   Has the bluff been planted?
   ☐ No ☐ Yes

Graded?
☐ No ☐ Yes

8. **Is there evidence of rainfall impacts or surface runoff?**
☐ No ☐ Yes

9. **Is there evidence of groundwater in the slope (seepage, damp surfaces on slope face, etc.)?**
☐ No ☐ Yes

10. **What is at the toe of your bluff?**
☐ Beach?
☐ Marsh?
☐ Ledge?

Do waves or normal tides reach the base of the bluff?
☐ No

☐ Yes.

What is the wave climate?
During normal conditions? __________ feet
Occasionally? _________________ feet
Frequently? __________________feet

During a storm conditions? _________ feet
Occasionally? _________________ feet
Frequently? __________________feet

From boat traffic? _________________ feet
Occasionally? _________________ feet
Frequently? __________________feet

For more information on wave conditions and wakes, see Wave Climate and Fetch.

11. **Is the site affected by tidal, riverine or alongshore currents?**
☐ No ☐ Yes

12. **What is the shoreline geometry?**
☐ Pocket
☐ Irregular
☐ Straight
☐ Headland

Unsure? Check out Shoreline Geomorphology.

13. **Does the bluff have**

Mature upland vegetation?
☐ No ☐ Yes

Fallen or uprooted trees?
☐ No ☐ Yes

Will existing vegetation shade created or restored marsh?
☐ No ☐ Yes

14. **What is the intertidal slope/nearshore bathymetry? Is the slope**
☐ Gradual
☐ Moderate
☐ Steep

For more information see Nearshore Bathymetry.

15. **What is the tidal range?**

____________________feet

Need more information. See Tidal Range.

16. **Is the project site affected by ice?**
☐ No ☐ Yes

For more information see the section on Ice.

17. **Does the site have submerged aquatic vegetation?**
☐ No ☐ Yes

Nearshore oyster beds?
☐ No ☐ Yes

18. **What is the nearshore region?**

- [ ] Fine
- [ ] Medium-coarse sediment
- [ ] Rocky or cobbles
- [ ] Ledge
- [ ] Offshore Sand Bars
- [ ] Tidal Flats

19. What is the condition of the adjacent properties? Are they experiencing similar rates of erosion?

☐ No ☐ Yes

Do they have existing coastal structures?

☐ No ☐ Yes

How will this project affect the adjacent properties?

____

____

____

20. Is the project site accessible for construction from land?

☐ No ☐ Yes

Water?

☐ No ☐ Yes

22. How will the shoreline be used?

- [ ] Walking
- [ ] Swimming
- [ ] Boating
- [ ] Fishing
- [ ] Nature watching
- [ ] Other

21. What is the current rate of sea level rise?

____________________feet

What is the predicted rate of rise?

____________________feet

What are the potential effects of sea level rise on the project site?

____

____

____

6.6 Printable Currently Defended Checklist

1. **Is there an existing Engineered Structure (seawall, groin, revetment, etc.) at the site?**
   ☐ No ☐ Yes

2. **Is functional or easily repaired?**
   ☐ No ☐ Yes

3. **Is the property experiencing erosion?**
   ☐ Yes

   ☐ No.
   If not, consider removing the structure

4. **Is there evidence that the seawall or revetment is regularly overtopped and overwashed by waves, and/or that flooding occurs landward of the structure's crest?**
   ☐ No ☐ Yes

5. **Does the coastal structure have a history of being damaged on a regular basis?**
   ☐ No ☐ Yes

6. **Is the structure being flanked (erosion around the ends of the structure)?**
   ☐ No ☐ Yes

7. **Is there a need to increase the protection provided by the existing structure?**
   ☐ No ☐ Yes

8. **Is the shoreline usage changing?**
   ☐ No ☐ Yes

9. **Are the neighbors changing their shoreline protection?**
   ☐ No ☐ Yes