Developing Alternative Shoreline Armoring Strategies: The Living Shoreline Approach in North Carolina

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Abstract. This paper reviews the scientific data on the ecosystem services provided by shoreline habitats, the evidence for adverse impacts from bulkheading on those habitats and services, and describes alternative approaches to shoreline stabilization, which minimize adverse impacts to the shoreline ecosystem. Alternative shoreline stabilization structures that incorporate natural habitats, also known as living shorelines, have been popularized by environmental groups and state regulatory agencies in the mid-Atlantic. Recent data on living shoreline projects in North Carolina that include a stone sill demonstrate that the sills increase sedimentation rates, that after 3 years marshes behind the sills have slightly reduced biomass, and that the living shoreline projects exhibit similar rates of fishery utilization as nearby natural fringing marshes. Although the current emphasis on shoreline armoring in Puget Sound is on steeper, higher-energy shorelines, armoring of lower-energy shorelines may become an issue in the future with expansion of residential development and projected rates of sea level rise. The implementation of regulatory policy on estuarine shoreline stabilization in North Carolina and elsewhere is presented. The regulatory and public education issues experienced in North Carolina, which have made changes in estuarine shoreline stabilization policy difficult, may inform efforts to adopt a sustainable shoreline armoring strategy in Puget Sound. A necessary foundation for regulatory change in shoreline armoring policy, and public support for that change, is rigorous scientific assessment of the variety of services that natural shoreline habitats provide both to the ecosystem and to coastal communities, and evidence demonstrating that shoreline armoring can adversely impact the provision of those services.

Introduction

North Carolina has an estimated 9,000 mi of estuarine shoreline, and most of that shoreline has relatively low-relief, with adjacent uplands less than 3 m in elevation (fig. 1). Estuarine erosion rates have been determined primarily for the shoreline north of Cape Lookout, with estimates ranging between -0.25 and -8.8 m y^{-1} (Riggs and Ames, 2003; Cowart, 2009). In response, property owners attempt to stabilize their shoreline using a variety of methods. The most frequently employed practice in North Carolina is to build a bulkhead, a vertical structure that may be constructed of wood, concrete, metal, or vinyl. In addition, shoreline stabilization approaches incorporating natural vegetation (salt marsh) have been developed (Broome and others, 1992), and in 2004 the state issued a General Permit to promote the implementation of shoreline stabilization projects that incorporated rock (riprap) sills in combination with coastal wetlands. This alternative approach, which has also been promoted by environmental groups, is often termed a ‘living shoreline’. To date, however, there has not been an appreciable reduction in the demand for bulkheads by property owners in North Carolina, and only limited changes to the permit process allowing bulkhead installation.

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Ecosystem Services Provided by Natural Shoreline Habitats

A variety of habitats comprise the intertidal and shallow subtidal areas of the estuarine shoreline along the relatively low-relief coast of the southeastern United States. These include salt marshes, oyster reefs, tidal flats, seagrasses, and shallow unvegetated bottom. Each of these habitats provides a suite of ecosystem services, including primary production, provision of fish and shellfish habitat and nursery areas, biogeochemical cycling of nutrients, carbon (C) sequestration, sediment trapping, and wave attenuation. In North Carolina and other east coast states, *Spartina alterniflora* is particularly emphasized in living shoreline designs because of its wave attenuation and sediment-trapping functions, which help to stabilize the estuarine shoreline. In the Pacific Northwest, however, *Spartina spp* are invasive and the target of control efforts (Hacker and others, 2001; Civille and others, 2005).

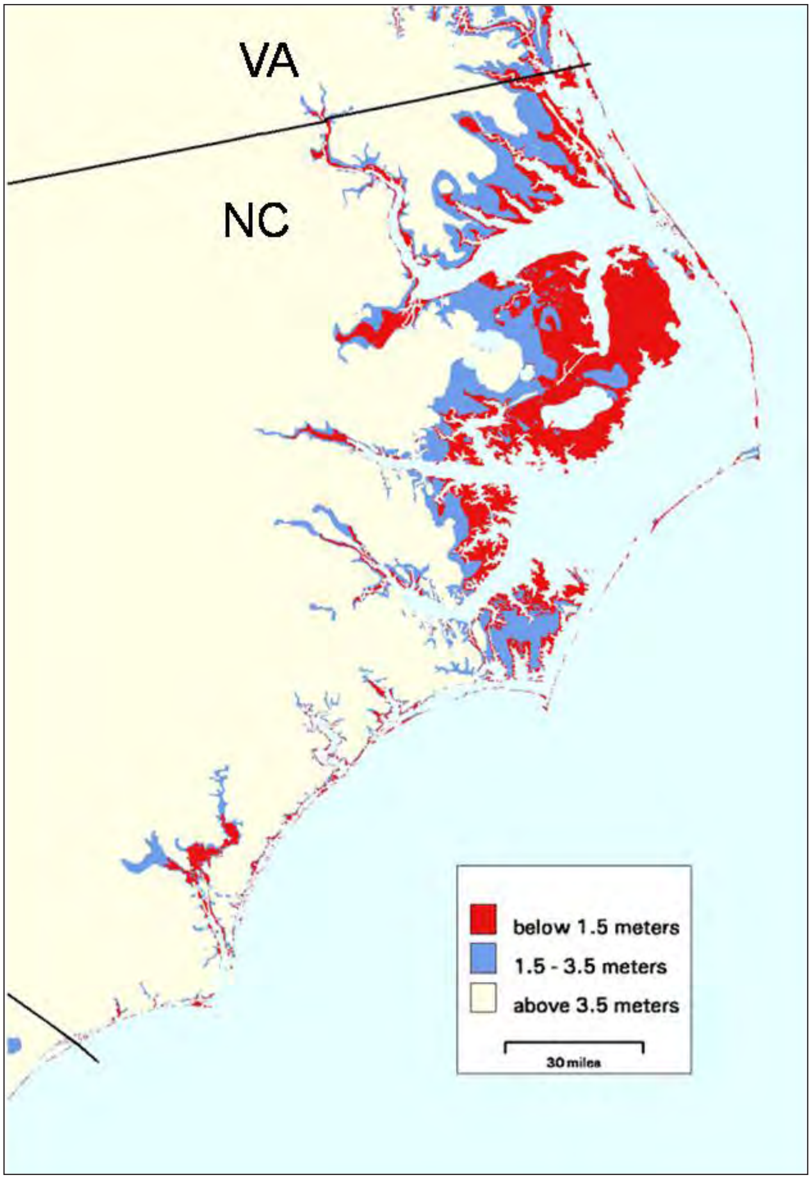

Figure 1. Map of eastern North Carolina showing elevation of coastal lands. Source: U.S. Environmental Protection Agency Climate Change Web site.

In the microtidal setting of North Carolina, salt marshes dominated by *S. alterniflora* can reduce wave height by 90 percent within 20 m of the marsh edge (Knutson and others, 1982). The effectiveness of marsh vegetation in attenuating wave energy is limited by stem height, water depth, and tidal amplitude (Moller, 2006). Along the macro-tidal shorelines of northwest Europe, salt marshes dominated by *S. anglica* are estimated to reduce wave heights by more than 50 percent in the first 20 m of marsh (Moller, 2006). Salt marshes have a well-documented ability to trap sediments, which is related to their ability to baffle currents and wave energy (Leonard and Croft, 2006). For intertidal marshes, the amount of sediment accretion varies with sediment supply, tidal range, marsh elevation, and plant biomass (Morris and others, 2002). Salt marshes may also increase their surface elevation through the production of below-ground biomass, which is incorporated into the sediment (Cahoon and others, 2004).

Salt marshes also exhibit some of the highest primary production rates found in coastal ecosystems (Mitsch and Gosselink, 1993). This plant production, including vascular marsh grasses, epiphytic and benthic algae, is an important component of the food web supporting estuarine secondary production (Currin and others, 1995; Deegan and others, 2000). The high rates of above ground and below ground biomass production by estuarine marsh plants contribute to high estimates of their role in C sequestration, an increasingly valuable ecosystem service in light of projected global climate change (Choi and Wang, 2004). Marshes provide important nursery habitat for many species of estuarine-dependent fish, whose larvae are transported into the estuary and spend their juvenile stages in shallow estuarine waters (Ross, 2003). Juvenile fish, as well as small resident species, find refuge from predators in the dense marsh canopy, and may be found in high numbers (>1,000 per 10 m marsh edge) in salt marsh habitats (Hettler, 1989).

Seagrass beds, tidal flats, and oyster reefs, which are shoreline habitats found throughout Puget Sound, also may be incorporated into living shoreline designs. These habitats provide many of the same ecosystem services as do salt marshes. Seagrasses, which are rooted vascular plants, exhibit relatively high rates of primary production (McRoy and McMillan, 1997), which is augmented by the epiphytes, benthic diatoms and macroalgae that are associated with seagrass beds (Moncreiff and others, 1992; Kaldy and others, 2002). Seagrass bed primary production in turn supports secondary production of fish and invertebrates (Moncreiff and Sullivan, 2001). Seagrass beds also offer refugia to fishery organisms, and the habitat value of seagrass beds is well-documented, as both greater diversity and higher abundance of fishes are found in seagrass beds compared to unvegetated habitats (Heck and others, 2003). Finally, the seagrass canopy can reduce wave energy (Fonseca and Callahan, 1992), and the reduction of current velocity within the canopy results in sediment trapping (Fonseca, 1996).

Shallow-water unvegetated habitats, which lack macrophytes and include tidal flats and sub-tidal bottom, have been described as a ‘secret garden’ because of the productive benthic microalgal community that occurs there (MacIntyre and others, 1996; Miller and others, 1996). The primary production of the microscopic diatoms and cyanobacteria in estuarine sediments has been estimated to provide between 25 and 50 percent of total ecosystem primary production (Pinckney and Zingmark, 1993). Benthic microalgae are more palatable than vascular plants, and are an important component of estuarine foodwebs (Sullivan and Currin, 2000). Apart from food resources, unvegetated shallow water habitat also provides valuable refuge for juvenile fish and crustaceans (Ruiz and others, 1993). Because of these ecosystem services, the loss of shallow-water unvegetated habitats via erosion or deepening should be minimized, and these unvegetated habitats can be incorporated into living shoreline designs.

Oyster reefs, which were historically present in Puget Sound, are another unvegetated habitat that provides primary production, via algae, and even higher rates of secondary production (Grabowski and Peterson, 2007). The structure and food resources associated with oyster reefs in the southeastern U.S. result in higher abundance, biomass, and species richness of finfish species than found on unstructured estuarine habitats (Coen and others, 1999). Oyster reefs also have the ability to trap sediments, build reefs, and stabilize estuarine shorelines (Meyer and others, 1997; Allen and others, 2003). These functions, in addition to the potential of the filter-feeding activity of the oysters to improve water quality and alter nitrogen cycling, have resulted in oyster restoration efforts throughout the southeast and mid-Atlantic (Coen and others, 2007; Grabowski and Peterson, 2007). Currently, scientists in North Carolina are evaluating the utilization of oyster reefs as part of natural shoreline stabilization designs.

Eutrophication, or an excess of nutrients, has altered primary and secondary production rates in estuaries throughout the United States. Excess nitrogen in the water column increases the growth of phytoplankton, which can lead to declines in overall water quality and submerged aquatic vegetation (seagrasses), and increases in hypoxia and harmful algal blooms. Another important function of shallow-water habitats is the removal of dissolved inorganic nutrients, particularly nitrogen (N), from the estuarine water column. Shallow-water habitats occupied by vascular plants and benthic algae remove nitrogen both through direct plant uptake of N, and via denitrification, a microbial process that transforms dissolved inorganic N to dinitrogen gas, which is lost to the atmosphere (Joye and Anderson, 2008). Shoreline stabilization structures that lead to an increase in nearshore water depth effectively reduce the amount of benthic habitat that receives sunlight, which in turn reduces the distribution and productivity of benthic plants that utilize dissolved nitrogen (Fear and others, 2004).

Living shoreline projects typically involve the conservation or restoration of a fairly narrow (<30 m) band of marsh habitat, and the question of whether a narrow band of intertidal habitat provides a full suite of ecosystem services is a topic of concern to resource managers. Studies of marsh nekton usage have demonstrated preferential utilization of the marsh edge (Minello and others, 1994; Peterson and Turner, 1994). In addition, adult blue crabs utilize marsh edge habitat in preference to open-water habitats, perhaps taking advantage of the abundant prey as well as avoiding predation themselves (Micheli and Peterson, 1999). Currin and others (2008) found that fish utilized fringing marshes in North Carolina in similar numbers as have been reported for more extensive marshes. Similarly, the marsh edge provides the highest rates of wave attenuation and sediment trapping (Leonard and Croft, 2006; Morgan and others, 2009). Fringing marshes have also been demonstrated to effectively remove groundwater nitrate inputs (Tobias and others, 2001). Together, these studies suggest that even relatively narrow fringing marshes, such as those incorporated into living shoreline designs, can provide a tremendous return in ecosystem services.

Adverse Impacts of Shoreline Hardening on Ecosystem Services

Bulkheads can have adverse impacts on coastal habitats, including accelerated erosion, loss of shallow intertidal bottom, loss of fringing marshes, and increased scouring and turbidity in nearshore waters (Pilkey and Wright, 1989; Pilkey and others, 1998; Rogers and Skrabal, 2001; Bozek and Burdick, 2005; National Research Council, 2007). During construction, use of heavy equipment and backfilling above the high water line, where bulkhead construction is allowed, may destroy wetlands and transitional vegetation. Rather than allowing native vegetation to recolonize landward of a bulkhead, property owners often replant with landscape shrubs and lawn grasses. These plants are not as effective at reducing and treating stormwater laden with nutrients and toxins as is natural vegetation, and are less apt at deterring erosion (Watts, 1987; National Research Council, 2007). Once bulkhead construction is complete, changes in hydrography and geomorphology often follow, with resultant negative effects on shallow nursery habitats. Scouring at the toe of bulkheads erodes the shoreline, undercuts the living root mass of marsh grasses, and deepens the adjacent water, thereby reducing or eliminating vegetated and unvegetated intertidal and/or shallow subtidal habitat (Riggs, 2001; Bozek and Burdick, 2005). Hardened structures along the North Carolina oceanfront were banned for similar indirect effects and resulting loss of intertidal beach. Garbisch and others (1973) showed that marsh vegetation seaward of bulkheads suffered 63 percent mortality post-construction due to stress from increased turbulence and scour. The change in hydrography and deepened water at the base of bulkheads prevent wetland vegetation from reestablishing itself once it is lost (Knutson, 1977; Berman and others, 2007). As sea level rises, bulkheads also obstruct shoreward migration of fringing wetlands, resulting in the eventual drowning and loss of wetland vegetation, particularly in the upper transition zone (Titus, 1998; Bozek and Burdick, 2005; National Research Council, 2007). Construction of bulkheads also reduces shallow water habitat by preventing transport of sediment to adjacent shorelines, diminishing the extent of nearby intertidal and shallow subtidal zones (Riggs, 2001; National Research Council, 2007).

Deepening of waters adjacent to the bulkhead structure allows large piscivorous fish access to previously shallow nursery areas, enhancing their feeding efficiency on small and/or juvenile fishes looking for shallow water (Rozas, 1987). Bulkheads also degrade spawning and nursery habitat for many species, including river herring and striped bass, which utilize the vegetated marsh edge (O'Rear, 1983). Vertical structures effectively remove narrow marsh fringes, thereby making areas adjacent to bulkheads less suitable as nurseries, even where seagrass beds or oysters are present offshore.

Numerous studies have documented lower relative abundance and diversity of fishes and invertebrates adjacent to bulkheaded shorelines compared to that in unaltered marsh, beach, or forested wetland habitats. In the James River, Virginia, fish community integrity was reduced along bulkheaded shorelines with both low and high density upland development as compared to natural and riprap shorelines with low density upland development. Species diversity was also lower along bulkheaded shorelines, with many tidal marsh species absent from this habitat (Bilkovic and Roggero, 2008). In the Pascagoula River estuary, Mississippi, Partyka and Peterson (2008) found that epifaunal-nekton and infaunal species richness and density were always greater at natural shore types than at hardened ones. Bilkovic and others (2006) showed that in the Chesapeake Bay, two indices of macrobenthic biological integrity were reduced significantly when the amount of developed shoreline exceeded 10 percent. In the lower Chesapeake Bay, bivalve abundance and diversity were higher in subtidal habitats adjacent to natural marsh than those in habitats adjacent to bulkheaded shorelines. Fish and blue crab density and diversity also tended to be higher adjacent to natural marsh shorelines than in bulkhead habitats (Seitz and others, 2006). On the Gulf coast, the most abundant fauna along unaltered marsh and beach shorelines, including penaeid shrimp, blue crab and bay anchovy, were least abundant along bulkhead or rubble shorelines. In addition, diversity was lowest adjacent to bulkheads (Peterson and others, 2000).

Although the effect of a single bulkhead on the adjacent habitat complex may be comparatively small, the cumulative impact of multiple bulkheads can result in significant habitat degradation with associated ecosystem effects (National Research Council, 2007). McDougal and others (1987) found that nearshore wave impact increases in relation to the horizontal length of the bulkhead structure. This higher wave energy renders the waterward and surrounding areas unsuitable for wetland vegetation. Therefore, multiple, contiguous bulkheads have a greater impact on the adjacent natural shoreline than that of spatially distinct structures. The cumulative impact of shoreline hardening on a broader ecosystem level is a subject that requires further study.

The 'Living Shoreline' Alternative to Shoreline Stabilization

In an effort to minimize the adverse impacts of hardened shorelines, alternative approaches to estuarine shoreline stabilization have been developed (Broome and others, 1992; Rogers and Skrabal, 2001; National Research Council, 2007). The term 'living shoreline' has been popularized by a number of environmental groups and regulatory agencies along the mid-Atlantic coastline to describe these alternatives (Burke and others 2005; Duhring and others, 2006). The living shoreline approach is an effort to incorporate natural habitats into a shoreline stabilization design, maintain the connectivity between aquatic, intertidal and terrestrial habitats, and minimize the adverse impacts of shoreline stabilization on the estuarine ecosystem. These efforts range from maintaining or transplanting natural shoreline vegetation, particularly *Spartina alterniflora,* without additional structural components, to incorporating shoreline vegetation with hardened features, such as rock sills or wooden breakwaters, in settings with higher wave energy (fig. 2). The combination of hardened structures and natural vegetation is also termed a 'hybrid' approach to shoreline stabilization. Several states, including North Carolina, Maryland, and Delaware, have implemented a regulatory process designed to encourage, or even require, the use of a living shoreline approach instead of a bulkhead (table 1).

Site specific conditions of wave energy, tidal currents and amplitude, elevation and underlying geomorphology dictate the specific design of a living shoreline installation. The nature of the shoreline adjacent to the project is an additional consideration. A generic design that meets the specifications of the North Carolina General Permit (GP) is illustrated in figure 3. The regulatory guidance offered by states usually includes information on the physical setting in which various living shoreline designs are appropriate, with fetch, proximity to navigation channels, and total channel width the primary considerations (table 1; Durhing and others, 2006). Fetch and navigation channel proximity are proxies for the wind wave and boat wake energy, respectively, which may be experienced at a living shoreline site. Because winds are not evenly distributed around the compass, fetch may not be an accurate representation of the relative wind energy experienced at a site. Calculation of relative wave energy (RWE), utilizing wind direction and intensity, in addition to fetch and bathymetry (Malhotra and Fonseca, 2007) provides a more accurate measure of site-specific wave energy. This may aid efforts to determine appropriate living shoreline design, in particular whether natural vegetation will provide adequate erosion protection, or the appropriate heights for structural components.

In North Carolina, there are no significant regulatory concerns in regard to a living shoreline project that includes only the preservation or transplanting of vegetation, and this is recommended as the most desirable approach to estuarine shoreline stabilization by all the states listed in table 1. However, property owners and contractors often prefer a hardened structure to further attenuate wave energy, and there are several regulatory concerns about the inclusion of rock sills into living shoreline projects. These concerns include the replacement of shallow-water habitat with rock and consequently an alteration in ecosystem services of the site, filling of intertidal lands with potential for loss of public trust resources (particularly in states where MHW represents the private/state boundary), loss of connectivity between aquatic and intertidal and terrestrial habitats, introduction of a foreign substrate that may harbor invasive species, increased erosion to adjacent property owners, scouring at the base of the sill, and possible hazards to navigation. Therefore, there are restrictions on the amount of fill, the height and water-ward placement of the sill, and requirements for providing sill openings (drop-downs) to promote access by nekton.

A reduction in the adverse ecosystem impacts of estuarine shoreline stabilization structures is consistent with North Carolina's Coastal Habitat Protection Plan (Street and others, 2005), and the N.C. Coastal Resources Commission and the Division of Coastal Management (DCM) have worked to develop policy, regulatory changes and educational tools to accomplish that goal. To develop shoreline stabilization rules that take into account the dynamic nature of the estuarine system and consider the benefits and impacts of various shoreline stabilization methods on biological communities and physical processes, DCM formed a science-based panel, the Estuarine Biological and Physical Processes Work Group, in 2002 (North Carolina Division of Coastal Management, 2006). The Work Group evaluated erosion control methods, including land planning, vegetation control, beach fill, sills, groins, breakwaters, sloped structures (that is riprap revetments or cast concrete), and seawalls/bulkheads, to determine which would be appropriate for various shorelines, considering the ecological functions and values of each North Carolina shoreline type. Among its recommendations, the Work Group determined that bulkheads should be the last resort to stabilize estuarine shorelines where marsh, seagrasses and oyster reefs are present. In 2005, a GP for marsh sills was implemented in an effort to simplify the application process for a property owner. In addition, an environmental group, the North Carolina Coastal Federation, has obtained grants to construct several living shoreline projects and worked to promote this approach (North Carolina Coastal Federation, 2009).

Figure 2. Photographs of shoreline stabilization projects in North Carolina that illustrate the living shoreline approach (*A*) Project to replace failing seawall includes fill, marsh transplanting, and rock sill; 2 years post-construction. (*B*) Project to protect marsh edge, which included rock sill, no fill, and minimal transplants; 4 years post-construction. A drop-down in the sill provides marsh access to nekton. Oysters can be seen colonizing the lower rock surfaces. (*C*) Project to protect eroding sandy beach includes only natural habitats, achieved with salt marsh transplants and oyster reef restoration; 4 years post-installation.

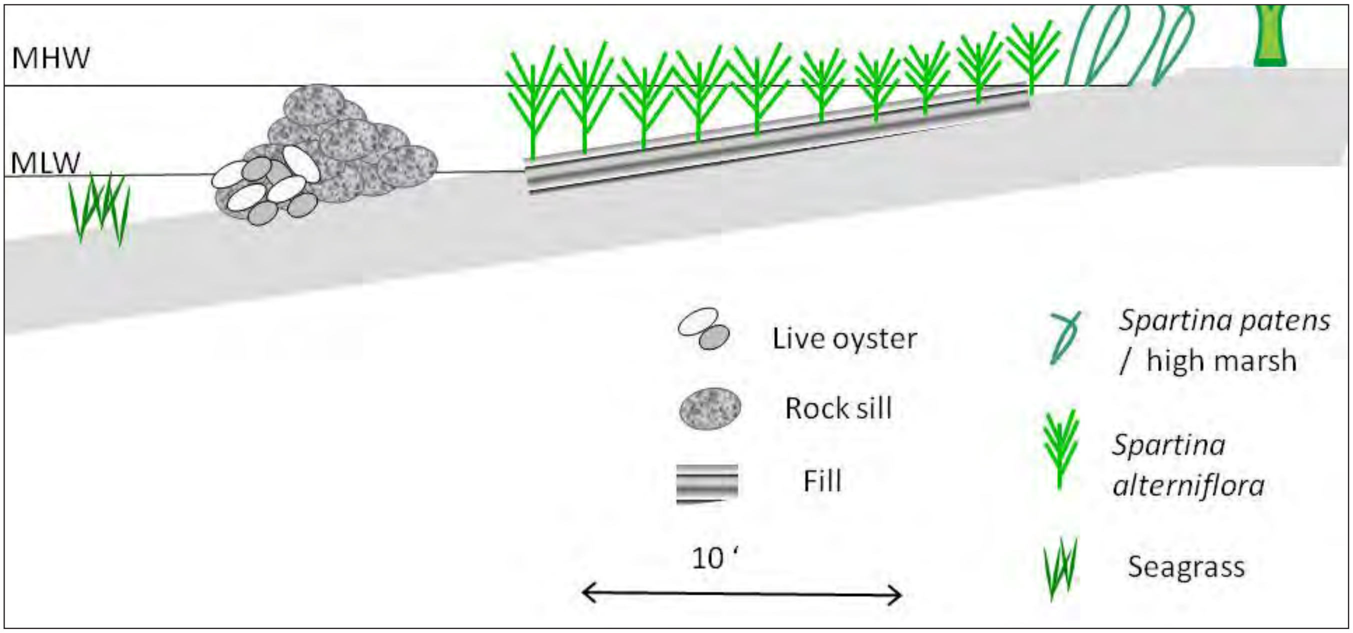

Figure 3. Schematic of a generic living shoreline design appropriate to permit requirements in North Carolina (MHW, mean high water; MLW, mean low water).

Table 1. Description and availability of regulatory and guidance documents available from state agencies in regard to living shorelines.

[Boundary locations include mean high water (MHW) and mean lower low water (MLLW). Information provided for North Carolina (NC), Virginia (VA), Maryland (MD) and Delaware (DE)]

State	Regulatory permit / guidance document title	Private / state boundary	Link to guidance material
NC	General Permit for the construction of riprap sills for wetland enhancement in estuarine and public waters	MHW	http://dcm2.enr.state.nc.us/rules/Text/t15a-07h.2700.pdf
VA	Local wetlands boards make determination; no state permit	MLLW	http://ccrm.vims.edu/livingshorelines/index.html
MD	Living Shoreline Protection Act	MHW	http://mlis.state.md.us/2008rs/chapters_noln/Ch_304_hb0973E.pdf
DE	Regulations governing the use of sub-aqueous lands	MLLW	http://regulations.delaware.gov/AdminCode/title7/7000/7500/7504 shtml#TopOfPage

Despite these actions, since 2000, only 19 living shoreline projects have been constructed with a Major Permit and 9 projects have been completed under the 2005 GP, for a total of approximately 1.5 mi of shoreline (North Carolina Division of Coastal Management, 2009). During this same period, an estimated 167 mi of bulkheads were permitted (North Carolina Division of Coastal Management, 2009). One of the difficulties in encouraging property owners in North Carolina to employ a living shoreline approach rather than constructing a bulkhead, is that the current bulkhead General Permit (table 1) has few site-specific considerations, does not require review by other agencies, and can usually be obtained within 2 days, whereas a marsh sill permit has numerous site-specific conditions and requires an outside review by state agencies, a process that often takes more than 30 days to complete. To further encourage the utilization of the living shoreline approach in N.C., in July 2009 the N.C. Soil and Water Conservation Community Assistance Program approved marsh sills as a Best Management Practice for reducing stormwater impacts, a designation that allows partial reimbursement for construction costs. However, it is likely that there will not be significant change in the utilization of living shoreline approaches by N.C. property owners until the permits for bulkheads and living shoreline projects have similar costs, review requirements and time constraints. In Maryland and Delaware, states that have had considerable success in reducing the number of bulkheads installed on estuarine shorelines, the permit process for installing a bulkhead along low-energy shorelines is at least as time-consuming and costly as is the permit process for installation of a living shoreline (table 1).

Evaluation of Living Shoreline Projects

At present (2010), there are few peer-reviewed, quantitative evaluations of living shoreline projects, although several researchers and state agencies are currently designing or have recently implemented evaluation projects (Berman and others, 2007). Several aspects of three living shoreline projects in North Carolina, including marsh vegetation cover, sediment characteristics, sediment elevation change, and nekton utilization, were compared to values from adjacent natural reference marshes (Currin and others, 2008). In that study, there was no significant difference in the nekton utilization of natural fringing marshes and marshes behind stone sills. The sills examined in that study either had drop-downs every 20 m, and/or were open at the ends. Sediments in both marsh types were sandy, with low organic matter content. Marsh stem density and percent cover was higher at two of the natural reference sites than at adjacent living shoreline sites. Sediment accretion rates in the marshes behind the stone sills were approximately 1.5 to 2-fold greater than those recorded in the adjacent natural marshes, and Currin and others (2008) noted that this elevation increase could result in the conversion of low marsh to high marsh, and reduce the fishery habitat value of the marsh. The observed accumulation of sediment behind the sill is similar to that reported in the evaluation by Airoldi and others (2005) of offshore breakwaters in a high energy setting off the coast of England. Subsequent to that study, Currin and colleagues continued their evaluation of sediment accretion rates and surface elevation changes in marshes associated with stone sills (hereafter sill marshes) using the Surface Elevation Table (SET) methodology (Cahoon and others, 2004). SETS were established at the lower and upper extent of *Spartina alterniflora* in four paired sill marshes and adjacent natural fringing marshes. Measures of marsh surface elevation were made every fall and spring between March 2005 and March 2008. As demonstrated in table 2, sediment elevation increased significantly more in sill marshes than in natural fringing marshes. This study also demonstrated that natural fringing marshes were losing elevation at the lower edge, while the upper edge was closer to maintaining elevation relative to the local sea level rise. The rate of sediment elevation increase in the sill marshes was nearly twice the rate of relative sea level rise, and the lower marsh vegetation moved seaward into the rock sill (fig. 2*B*), while the upper marsh in some cases became high enough to exhibit a vegetation change (table 2, Currin, unpub. data).

An evaluation of 36 living shoreline projects in Virginia, based on field evaluation and observation, was presented in Duhring and others (2006). Most of the projects were judged to provide effective erosion control, and about half (55 percent) were also judged to be effective as living shoreline treatments, based on marsh condition. Unlike the North Carolina results based on SET measures, authors of the Virginia report concluded that little sediment had accreted behind the sill and noted that an unvegetated border persisted between the rock sill and marsh at several sites (Duhring and others, 2006).

A review of the permits approved for marsh sill, or living shoreline, projects in North Carolina since 2000 was

Table 2. Results from Surface Elevation Tables placed at the lower and upper edges of *Spartina alterniflora* in marshes behind stone sills (Sill) and nearby natural fringing marshes (Natural).

[Elevation data were collected approximately every 6 months between October 2005 and March 2008. Letters indicate statistically significant effect of marsh type on accretion rates ($p<0.001$) by location within the marsh (Lower, Upper), n equals number of marshes sampled, with one SET per location per marsh]

Marsh type	Marsh edge location	Net sediment accretion (mm y^{-1})	n
Natural	Lower	-6.92 A	4
Sill	Lower	5.36 B	4
Natural	Upper	1.18 A	4
Sill	Upper	4.73 B	4

completed by NC Division of Coastal Management (DCM) staff in July 2009 (North Carolina Division of Coastal Management, 2009). As noted previously, 19 projects were established with a Major Permit and 9 projects were established under the new General Permit. The Major Permit projects were an average length of 370 ft, while the General Permit projects averaged 114 ft, and the average height of all projects was 0.5 ft above MHW. Overall, the amount of shallow bottom converted to marsh habitat was approximately equal to the amount of shallow bottom covered by rock sill. The state will be conducting an on-site evaluation of marsh sill projects in summer 2010 to further evaluate their effectiveness and impacts on adjacent habitats and property.

These limited studies of alternative estuarine shoreline stabilization projects support the need for careful permit review policies, as well as the need for site-specific design recommendations. Variables such as sediment supply, wave exposure (wind waves and boat wakes), and sediment type must be accounted for to insure that a living shoreline project creates or preserves sustainable natural habitat. Resource managers will need to weigh the costs and benefits of the habitat trade-offs inherent in converting one habitat and bottom type to another. A problem noted in both North Carolina and Virginia is the use of shoreline stabilization measures in situations where no shoreline erosion is occurring (Duhring and others, 2006; Currin, personal observation, 2009). To many homeowners, a straight bulkhead edge is aesthetically more pleasing than the curves and variability of a natural shoreline. Public education on the economic and ecological benefits of natural shoreline habitats, and on the adverse impacts of bulkheads and other shoreline armoring structures, is the key to successfully implementing a sustainable shoreline stabilization policy.

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