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Final Report to the Keith Campbell Foundation for the Environment, Inc.

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ABSTRACT

Using tidal marshes and other vegetated treatments for upland erosion control has been an accepted practice for years, yet the scientific understanding and established guidelines for this approach are limited. This survey was conducted to evaluate the efficacy of existing marsh toe protection structures, a particular type of erosion control treatment associated with tidal marshes on Chesapeake Bay shorelines. Field evaluations were conducted at 36 sites in 6 localities on the Middle Peninsula and Northern Neck of Virginia. General dimensions of each structure were recorded and observations made of erosion evidence, structural integrity, construction access impacts, and adjacent landscape settings. Most of the projects provide effective erosion protection for the tidal marsh and adjacent upland bank. Twenty projects (55%) were also determined to be effective as living shoreline treatments based on tidal marsh condition and because the riparian and wetland vegetation cover was interconnected. Common design standards from these projects have been incorporated into advisory guidelines.

INTRODUCTION

Shoreline modifications for erosion control have been traditional along Virginia's tidal shorelines. Accepted justifications for erosion control structures, such as bulkheads and rock revetments, include protecting private property from coastal hazards and reducing sediment input from natural and anthropogenic sources. Other motivating factors for tidal shoreline modifications include flood reduction, improving riparian access & landscape aesthetics, improving navigation, and to create recreational beaches.

There is a growing concern among regulatory agencies, scientists, citizens and others that extensive shoreline stabilization and hardening for these purposes results in cumulative adverse impacts to coastal habitats (Burke et al, 2005). The private and public benefits of shoreline modification for erosion control and other purposes should be weighed against the adverse effects on ecological services provided by the riparian, wetland, and shallow water habitats.

According to the Virginia Institute of Marine Science (VIMS) permit records database, Virginia regulatory agencies have permitted new "hardening" of an average 18.5 miles of tidal shoreline per year since 1993. In 2004, this average was surpassed when 19.8 miles of new erosion control structures were permitted (Duhring, 2005). Much of this shoreline development in recent years is associated with coastal population growth and the conversion of waterfront property from forested, rural and agricultural uses to single family and commercial recreation uses like marinas. Shoreline protection and stabilization is an integral component of this land use conversion in Virginia.

National guidelines for reducing non-point source pollution include protecting wetland and riparian habitats from changes that would degrade their existing pollution abatement functions (USEPA, 2005)**.** Wetlands and riparian buffers have natural assimilative capacity that can be degraded when exceeded by point source discharge or non-point source runoff. Degraded wetland and riparian habitats have less ability to attenuate peak flows and provide other water quality functions for the adjacent aquatic habitat. Restoration and enhancement of these habitats is challenging with the current expectations for shoreline stability, unimpeded water views and other aesthetic and economic benefits of developed tidal shorelines.

Virginia's waterfront property owners are encouraged to leave shorelines experiencing mild or no active erosion in as natural a condition as possible and to avoid unnecessary alteration and armoring practices. For properties experiencing mild erosion, there are non-structural solutions possible under some circumstances that have less overall impact than a hard structure. There are also techniques that include structures, but also incorporate aquatic and terrestrial habitats that provide ecological functions as well as serve as erosion buffers (CCRM, 2005). Many property owners actually prefer a more natural, "soft" or "living" approach. Some are even interested in riparian and wetland habitat restoration above and beyond the need for erosion protection.

Living Shorelines Stewardship Initiative

The Chesapeake Bay Living Shorelines Stewardship Initiative was recently launched to provide a network of collaborative partners and resources throughout the Chesapeake Bay region. The partners in this initiative advocate the use of vegetative treatment systems and other techniques where possible to reduce impacts to the Bay's living resources that result from traditional shoreline modifications.

A "**living shoreline treatment**" has been defined as a shoreline management practice that provides erosion control benefits; protects, restores or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill and other structural and organic materials (e.g. bio-logs, oyster reefs, etc.) (Burke et al. 2005). This approach for erosion control incorporates aspects of the living landscape to maintain rather than sever the ecological connections between upland, wetland and aquatic habitats.

Successfully using planted marshes and other techniques to control upland erosion depends on the shoreline location and wave climate (Garbisch & Garbisch, 1994; Hardaway & Byrne, 1999). High-energy sites with regular wave action and exposure to storm events are usually armored with traditional structures. In contrast, the site suitability characteristics used in Maryland illustrate the conditions that are most conducive for non-structural and vegetative treatments (Table 1). The fetch or distance across open water should be narrow, the erosion trend moderate, and the water depth near the shoreline should be shallow. Another indicator of suitable growing conditions for a vegetated treatment is plenty of sunlight and existing marshes or submerged aquatic vegetation (SAV) in the general vicinity.

Table 1. Maryland guidelines for erosion control treatment options based on shoreline characteristics (from Luscher & Hollingsworth, 2005).

	Low Energy	**Medium Energy**		**High Energy**
Shoreline Location	Creek or cove	Minor river	Major tributary	Main stem of Bay
Water Depth (ft)	Less than 1.0	1.0 – 2.0	2.0 - 4.0	4.0 - 15.0
Fetch (miles)	0.5 - 1.0	1.0 - 2.0	2.0 or more	2.0 or more
Erosion Rate (ft/yr)	Less than 2	2 to 4	4 to 8	8 to 20
Erosion Control Treatment Options	Non-Structural Projects Beach replenishment Fringing marsh creation Marshy islands Coir log edging or groins	Hybrid Projects Marsh fringe w/ groins Marsh fringe w/ sills Marsh fringe w/ breakwaters Beach replenishment w/ breakwaters		Structural Projects Bulkheads Revetments Stone reinforcing Groins & jetties

However, guidelines and references are not readily available for hybrid and non-structural project designs for tidal shorelines in Virginia and there is increasing public demand for this information. In particular, design standards for hybrid projects that combine rock structures, sand fill and wetland plants may require "bio-engineering" to design a beach or marsh where they do not occur naturally. There is also minimal peer-reviewed scientific evidence to support the growing volume of empirical evidence that this approach is successful for erosion control.

PROJECT DESCRIPTION

The primary purpose for this survey was to determine how marsh toe protection structures are used in Virginia. This survey focused on two types of rock structures with slight differences in placement in relation to the edge of a tidal marsh. The term "**marsh toe revetment**" has been assigned to structures placed immediately against the erosion scarp of a tidal marsh. A "**marsh sill**" is a free-standing structure offset from the marsh edge or used at a non-vegetated site (Figure 1). Both types of revetment are collectively referred to as "**marsh revetments**" for the purposes of this study and to reduce confusion about the two terms used for essentially the same type of structure.

Figure 1. The two types of marsh revetments included in this study were “marsh toe revetments” placed directly against the edge of an eroding tidal marsh (left) and “marsh sills” offset from the edge of the marsh vegetation (right) or adjacent to non-vegetated intertidal area. Collectively, these rock revetments are referred to as “marsh revetments” for the purpose of this study.

Marsh revetments are low-profile in design to match the relative position and elevation of the marsh surface. They are typically located close to shore in the intertidal area or in shallow water habitat. Marsh toe revetments and sills are distinguished from other rock revetments, including upland revetments and offshore breakwater systems, which were not included with this evaluation (Table 2). The tidal marshes protected by these structures may be naturally occurring or created by placing sand fill landward from the revetment and planting appropriate salt marsh plants in relation to tidal inundation zones.

Table 2. Description of marsh revetments included with this survey compared to other types of quarry stone revetments typically used for erosion control purposes in Virginia.

Structure Type	Description
Marsh toe revetment	Linear rock structure that follows shoreline contours, placed against the eroding channelward edge of a tidal marsh in the intertidal or subtidal zone
Marsh sill	Same type of low-profile rock structure as a marsh toe, but free-standing and offset from the channelward marsh edge; may be combined with marsh creation by adding sand and tidal wetland plants
Upland revetment	Linear rock defensive structure placed against eroding upland bank landward from tidal marsh or non-vegetated sand or mud flats
Offshore breakwater system	Detached, offshore rock structures used offensively to reduce wave energy; typically a system of breakwater units in high energy locations with beach nourishment and long reaches of sandy beach shoreline

These structures are considered to be “hybrid” type projects that incorporate both non-structural and structural elements for successful stabilization. Presently, there are no promulgated guidelines for determining when marsh toe protection structures are appropriate and how they should be designed. It is widely assumed that the use of these structures is beneficial because they reduce erosion of tidal marshes, an important living component in the Chesapeake Bay estuary. However, there has been little recent scientific investigation of these or other erosion control structures to more accurately determine the magnitude of their benefits or possible adverse impacts (e.g. Carroll, 2002; Burke et al, 2005).

The VIMS Center for Coastal Resources Management maintains a Shoreline Permits Database, which tracks permitted activities on Virginia’s tidal shorelines authorized through the Joint Permit Application process (JPA). Marine scientists are responsible for tracking and entering data about projects in their assigned territories. The database is used to generate advisory reports and evaluate the cumulative results of regulatory permit decisions; such as the total length of new shoreline hardening approved each year. The database records are also available to answer specific questions, such as how a particular type of structure is being applied.

The VIMS Shoreline Permit database was first queried for records of previously permitted marsh toe protection structures. Field assessments were then conducted at a representative number of sites where the revetments were actually installed. The shoreline characteristics at each site were described and compared to the structure design as indicated in the permit application. Effectiveness criteria were developed based on erosion control success and living resource habitat quality. The projects that best represented successful applications were identified and their common characteristics were evaluated.

Another objective of the study was to collect evidence that the use of marsh revetments can be consistent with the principles of “living shorelines” and to provide updated advisory guidance for their proper location and design. Construction and design criteria for marsh revetments based on the results of this survey will assist regulatory decision makers, marine contractors and property owners with the proper design and placement of marsh toe protection structures that promote the living shoreline approach.

SHORELINE PERMITS DATABASE QUERY

Standard definitions for the different types of rock structures were not adopted for data entry purposes until 2001. Prior to that date, upland revetments and marsh revetments were not tracked separately. The database query for marsh toe revetments and marsh sills therefore produced mostly recent cases permitted between 2001-2004. A few older structures were also revealed through this database query or through previous knowledge and were included in the study.

The final database query and search of other permit records produced a list of 134 marsh revetments in 17 Tidewater Virginia localities. A vast majority (80%) of these cases were located in six counties on the Middle Peninsula & Northern Neck. The case selection for field evaluations focused on these localities (Table 3).

Some cases from the original query were not eligible for field evaluations due to data entry error or misrepresentation of the project, or because the structure was not permitted, the structure was permitted after June 2003, or the structure was permitted but not built. Projects were also considered not eligible for field evaluations if the marsh revetment was only a small section within a larger upland revetment or bulkhead project. Site access was also denied or not possible in a few cases.

Table 3. Six Virginia localities with a majority of permitted marsh toe protection structures.

Locality	**Potential projects from database query**	**Not Eligible**	**Field Evaluations Completed** June 2004 – August 2005
Essex County	1	0	1
Middlesex County	11	3	5
Mathews County	19	3	9
Gloucester County	11	4	3
Lancaster County	25	4	7
Northumberland County	36	5	11
Total	103	19	36 (35%)

FIELD EVALUATIONS

Field evaluations were conducted to examine 36 structures in six localities from June 2004 – August 2005. Baseline information was collected through the review of permit records that depicted the proposed layout and design specifications. Various parameters about the structure and associated tidal marshes were recorded during the field evaluations (Table 4).

These project assessments were primarily qualitative based on observations of VIMS scientists. Property owner impressions and observations were also collected where possible. The permit records, original VIMS assessments and site photographs were the only benchmark information available.

Table 4. Parameters used for field evaluations of marsh toe revetments and sills.

Site Information	Site ID	assigned ID based on locality and project number within locality
	GPS	GPS end point coordinates
	JPA	Joint Permit Application number
	Immediate waterway	common name
	Site Visit	date(s) of field evaluation(s)
Shoreline Condition	Wave Energy	Low (tidal creeks; fetch < 1 mile); Medium (tributaries; fetch 1-5 miles); High (mainstem Bay; fetch > 5 miles)
	Widest Fetch	nautical miles, measured from ArcView project from original permit GPS point (not project GPS end points)
	Orientation	primary exposure
	Shoreline Type	marsh geomorphology, upland habitat type
	Bank Height	<5 ft, 5-10 ft, >10 ft
	Boat Wakes	proximity to marked navigation channel, existing piers
Structure Design	Structure type	marsh toe revetment = placed against eroding marsh scarp; marsh sill = offset from marsh edge, scarp may or may not be present
	Material	quarry stone, gabion baskets
	Est. construction date	estimated date of project completion, sometimes reported by property owners
	Height above substrate (ft)	estimated crest elevation above substrate
	Height above MHW (ft)	estimated crest height above mean high water (usually based on stone coloration)
	Base (ft)	estimated base width from average toe on both sides
	Length (approx)	estimated length based on permit records and site observations
	Tidal Opening	presence of tidal gaps, including between and at ends
Tidal Marsh Condition	Tidal Marsh Type	Tidal wetland types based on dominant plant species
	Natural or Planted	existing natural marsh, planted marsh, or combination
	Marsh Width (ft)	estimated marsh width from structure to landward edge based on vegetation transition & standard tidal wetland delineation
	Marsh Condition	general observations about percent cover, biomass, vitality (evidence of seed production, propagation), evidence of marsh growth or "accretion" directly caused by structure

Table 4. (continued)

Tidal Marsh Condition	Marsh Erosion	general observations of marsh scarps, overwash, marsh retreat
	Bank Erosion	general observations of upland scarps, undercutting, exposed soil
	Upstream (flood)	shoreline condition adjacent to project site upstream (flood tide)
	Downstream (ebb)	shoreline condition adjacent to project site downstream (ebb tide)
Other Comments		relevant project-specific notes & observations; unique features; anecdotal information provided by property owner

Effectiveness Criteria

Effectiveness criteria were developed in order to categorize these projects based on how successfully they provided erosion protection for the tidal marsh and upland bank. A second set of criteria was used to determine if water quality and habitat functions of the tidal marsh and adjacent riparian area were improved because of the project.

Each project was considered to be very effective for erosion control if evidence of erosion was reported before construction, but then there was no evidence of marsh or upland bank erosion observed during the field evaluation. A project was considered not effective for erosion control if there was no apparent effect on pre-existing conditions and significant erosion of the marsh and/or upland bank was observed. If only isolated erosion spots were observed, then the project was labeled somewhat effective for erosion control.

Evidence of tidal marsh functions, necessity for the structure and the connections between upland, wetland and aquatic habitats were the criteria used to determine if each project was effectively supporting living resources (Table 5). The structure should be a secondary feature with the tidal marsh providing the primary erosion control functions. The rock structure itself should be necessary, i.e. the tidal marsh would not persist without the wave dissipation it provides. The revetment should also be properly sized and designed for the location. There should not be any noticeable adverse effects on the habitats where they are placed, the connections between the marine, wetland and upland environments should be maintained and there should be no adverse effect on adjacent properties as a result of the structure.

Table 5. Criteria used to determine if projects effectively provided tidal marsh habitat and water quality functions as a "living shoreline" treatment.

	Not Effective	Somewhat Effective	Very Effective
Tidal Marsh Functions	Tidal marsh not primary erosion control method; water quality & habitat functions not provided	Tidal marsh preserved as primary erosion control method, but minor interruptions to marsh functions (water quality & habitat)	Tidal marsh preserved as primary erosion control method with water quality & habitat functions intact
Structure Design	excessive / unnecessary / inappropriate structure for shoreline situation	not appropriately designed; excessive or persistent construction access impacts	appropriately designed for longevity
Connections	aquatic-marsh-upland connections severed	aquatic-marsh-upland connections intact but compromised	aquatic-marsh upland connections intact

If a marsh toe protection structure was considered to be excessive or unnecessary or if it is not the appropriate type of structure for the particular shoreline situation, then it is not effective as a living shoreline treatment. Other disqualifying criteria included interruptions to the natural connections between aquatic, wetland and upland habitats. Also, construction access impacts to install the revetment should be temporary and minor.

Additional effectiveness criteria were considered to further evaluate projects that were supporting the basic principles of the hybrid approach to reveal minor discrepancies or improvements needed to reduce adverse impacts. These criteria focused on the interruption of tidal exchange and primary productivity, sediment transport and trapping plus nekton access to the marsh (Table 6).

Table 6. Additional criteria used to determine if projects were very effective as living shoreline treatments or if there were minor discrepancies or improvements needed and the criteria were only somewhat met.

	Somewhat Effective	Very Effective
Tidal Inundation	tidal inundation interrupted (crest height > +1 MHW & no tidal gaps)	tidal inundation (mostly) unimpeded (crest height ≤ +1 MHW &/or tidal gaps)
Primary Productivity / Detritus Exchange	detritus movement interrupted (excessive wrack trapped because of revetment; marsh included in routine landscape maintenance)	Nutrient cycling, primary productivity evident in marsh condition (marsh expansion, plant diversity, landscape condition)

RESULTS

Wave Climate

The wave energy at each site was categorized as low, medium or high energy based on a standard fetch model (Hardaway & Byrne, 1999). Most of the marsh toe protection structures were located in low energy settings where the widest fetch was less than 1 mile (N=23). The fetch at all but three of the low energy sites was actually less than 0.5 mile.

Existing guidelines suggest that a planted marsh alone without structural support from a marsh revetment is feasible where the fetch is less than 0.5 mile. However, there was baseline evidence of marsh erosion in at least half of the cases (N=10) that met this fetch criteria and the marsh erosion was expected to continue if the marsh revetments were not installed. Only 1 of the structures located where the fetch was less than 0.5 mile was actually considered to be excessive and unnecessary.

It appears that fetch alone may not be a reliable factor to determine if a structure is necessary to support a vegetated marsh sufficient for erosion protection. Shoreline orientation and boat wakes also have an influence on determining the need for a structure, especially where the marsh is located in close proximity to a navigation channel (Figure 2).

Figure 2. Boat wakes were observed washing over this marsh toe protection structure located in close proximity to a navigation channel. Boat wakes influence the wave climate in low energy settings.

There were 9 projects at medium energy settings with the widest fetch between 1-5 miles located on minor rivers and major tributaries. Four projects were located in high energy settings with a fetch greater than 5 miles. These 4 projects were located on major tributaries with Bay influence, but not the mainstem of the Bay. Typically, only structural approaches such as a breakwater system are considered adequate for high-energy settings. Erosion control approaches that emphasize the use of vegetation are generally not as feasible. While all 4 of the projects at high-energy locations were very effective for erosion control, only 2 demonstrated characteristics of a “living” shoreline. One was bio-engineered for the site (MA06) and the other has a wide, natural tidal marsh and no additional upland erosion control structures (MA05).

Upland Bank Elevation

The upland bank height in most of these cases was less than 5 feet (N=25).   A few banks were greater than 5 but less than 10 feet above the shoreline level (N=10). There were also a few cases where the marsh was adjacent to high banks greater than 10 feet (N=3; MX01, NU01, NU07). In all three cases, the high banks were also treated by grading or bulkhead installation in addition to the marsh toe protection structure.

Approximate Structure Age

Estimated construction dates ranged from 1984 – 2003, including some structures installed just prior to Hurricane Isabel in September 2003. A majority of the structures were less than 5 years old (N=28) and only 4 had been in place longer than 10 years. The remaining 4 projects ranged between 6-10 years.

Structure Design

All of the projects were quarry stone revetments, except for 2 cases that used gabion baskets to contain the stone (LA04 & NU12). The stone size used in most cases was VDOT Class A1 & 1 stone. A few projects at medium and high-energy settings included larger Class II stone. There were 21 marsh “sills” and 15 “marsh toe revetments”.

Almost all of these structures were installed without any additional backfill, including 2 with backfill included with the design but not actually brought in. Only the 6 projects that included planted marshes also included sand fill in the design.

Additional erosion control structures were sometimes included as part of the same project or were already installed in the immediate vicinity.

Structural Integrity

The integrity of all 36 marsh toe protection structures was stable. In a few cases, it appeared the stone had settled and spread out, but it still provided a wave dissipation function. Small stone was also observed washed over the marsh surface in a few cases. Filter cloth was observed at almost all of the projects. Property owners’ reports of maintenance and repairs indicated only minor work was performed after storm events. No routine or frequent maintenance was apparent or reported.

Both gabion projects were examined for evidence of deterioration and cage separation. In the most recent project, the hardware did not appear to be PVC coated and rusting was evident. These structures were apparently not intended for deployment in the marine environment, but were available as surplus material and their use was cost-effective.

Structure Length

The total project length ranged from 60 to 840 feet of shoreline, with an average length of about 271 feet. All but 2 of the projects were greater than 100 feet in length, including 17 projects that were greater than 200 lf. There were 7 long continuous sills greater than 100 feet without tidal openings and 10 with tidal openings included in the design.

Structure Base Width

The base width of these marsh toe protection structures varied from 3-14 feet. In low energy settings, the average width of the structures was 6.5 feet. Four projects at low energy settings had base widths greater than 8 feet, which may be excessive for those particular sites (MX01, MX04, NU03, GL03) but it depends on the influence of boat wakes. At medium and high-energy locations, the base width had a similar range from 4-14 feet with an average of 7.5 feet. The 4 projects at the highest energy location had base widths of approximately 6, 8, 12 & 14 feet.

Structure Height Above Substrate and Mean High Water

These structures were all low-profile by design and were not raised more than 4 feet above the bottom where they were placed. Only 3 of the structures had an estimated height between 3-4 feet, the remaining projects all appeared to be less than 3 feet high over the substrate.

The wave dissipation function of the structures during high tide events also depends on the crest height above the mean high water elevation. This exposure was estimated primarily by the stone coloration difference between wet and dry areas plus fouling organisms in a few cases, such as oysters and barnacles.

Fifteen structures had a crest height below or less than 1 foot above MHW, which is the height currently advised for maintaining adequate tidal inundation for marsh functions. The crest height was estimated to be greater than +1 ft MHW in 21 cases, including 7 sites where it was a high-energy setting or the structures were excessively designed for the marsh condition.

Other Adjacent Structures

A majority of these marsh toe protection structures were located in association with other erosion control structures present to stabilize upland erosion. This observation illustrates a trend for Virginia property owners to address all erosion on their parcel by choosing to install both marsh revetments and upland erosion control structures. Only 8 of the 36 projects were found to be isolated from other erosion control structures.

Tidal Openings

The placement of rock structures at the channelward edge of tidal marshes impacts tidal exchange as well as the movement of aquatic organisms into and out of the marsh (Carroll, 2002). A study of marsh sills in Maryland discovered that these structures reduce tidal flushing considerably and can restrict water circulation leading to high temperatures in the marsh (Burke et al, 2005). In addition to aquatic nekton, such as fish and blue crabs, wildlife species anecdotally reported to be affected by marsh revetments during this study included horseshoe crabs, terrapins and wading birds that depend on the flats channelward from marshes.

Several projects in this study were long, continuous structures without tidal gaps incorporated into the design. Some also tied into adjacent upland structures instead of leaving the ends open for tidal exchange. In some cases, the revetments without tidal openings severed and prevented nekton access into and out of the marsh, especially where the crest height was greater than +1 ft MHW.

Tidal openings were specifically included in the design of 15 out of 36 projects (Figure 3). These breaks in the revetments are important for reducing the interruption of tidal exchange, which provides nekton access to the marsh and regulates water temperatures in the marsh. Tidal openings were either straight or off-set and overlapping to prevent diffracted wave action and erosion scour at the opening. These openings were strategically placed along the length of long, continuous structures, at the tidal openings to ponds and pocket marshes or at the ends of the structures.

Figure 3. Three different types of tidal openings are illustrated, including a straight gap (left), offset gaps at a pocket marsh (center), and an end opening instead of tying into the upland bank or other erosion control structure (right).

Tidal Marsh Types & Condition

Natural vs. Planted Marshes

Almost all of the projects evaluated involved a naturally occurring tidal marsh (N=28). The width of the natural marshes varied considerably. The natural marsh width was between 20-50 feet in 25 of these cases. In 3 cases, natural marshes greater than 50 feet in width were observed.

Tidal marsh creation was included with 8 project designs. Only 1 of these planted marshes was not successful. The total marsh width at these planted sites ranged from 0-40 feet. There were 4 “bio-engineered” projects identified by this survey that involved habitat conversions from essentially non-vegetated tidal wetlands and subaqueous bottom to a vegetated tidal marsh.

These projects are referred to as Poplar Grove in Mathews County (MA06), Sturgeon Creek in Middlesex County (MX01), Town Creek in Lancaster County (LA02) and the VIMS Boat Basin (GL03). The reported design criteria for these projects included a 10:1 slope for the created marshes. The target height at the upland bank face was +3 ft MHW or the top of the bank if it was lower than this elevation. These design standards are consistent with previous recommendations for controlling erosion with created tidal marshes (Garbisch & Garbisch, 1994).

Marsh Geomorphology

Three different geomorphic types of tidal marshes were targeted by these projects, including fringing marshes (N=18), spit marshes (N=12) and pocket marshes with tidal ponds (N=4) (Figure 4). Fringing marshes were the most common marsh type and most of these were long, continuous features greater than 100 linear feet. There was also one project located in a small tidal channel that connected a larger inland marsh with a major tributary. Only one project involved the complete creation of a tidal marsh where it did not naturally occur (Poplar Grove, MA06).

Figure 4. Three different geomorphic types of tidal salt marshes were the targets for erosion protection, including fringing (left), spit (center) and pocket marshes with open tidal ponds (right).

Marsh Vegetation Communities

Eleven (11) sites contained only low marsh plant species (*Spartina alterniflora*, *Juncus roemerianus*), 8 sites contained only high marsh species (*Spartina patens*, salt bushes) and there was a combination of high and low marsh zones observed at 16 sites. One site had no marsh vegetation remaining (LA06).

Vegetation transects were not evaluated as part of this study. However, general observations about marsh condition were made. Generally, these marshes appeared to be stable and healthy with at least 75% cover. There were a few cases where the natural marsh was patchy and there was no new planting included, but the structures had only recently been installed. There was evidence of natural marsh accretion channelward toward the revetments in 4 cases.

The channelward expansion of the marsh vegetation may have been the result of either reduced wave action, sediment accretion or a combination of both factors. There was no obvious evidence of sediment accretion landward from any of these structures. There was also no evidence of erosion and scour behind “sills” offset but near the marsh edge.

Construction Access Impacts

Gaining access to properly install the revetments without permanent impacts is an important consideration for these projects. The method of construction access was not always reported in the permit records, but is known to include both upland and water access. The use of temporary access ramps was reported for hand-placement from piers or for equipment access across the marsh. Construction access impacts were evident in only 4 cases, including bare un-vegetated areas in linear, track patterns, compaction and imported gravel spread into the marsh for stability.

Structure Necessity & Appropriateness

There were 2 cases where the marsh protection structure was considered unnecessary or inappropriate (Figure 5). If a particular shoreline erosion situation can be addressed with either no action or a non-structural solution, then a marsh revetment would be considered unnecessary. One project was considered to be unnecessary for erosion control purposes (MA03). In this case, there was no pre-existing marsh or upland erosion condition due to the protected, very low energy setting in a small tidal channel.

Figure 5. Unnecessary and inappropriate applications of marsh revetments are illustrated with these examples. The project on the left was located in a tidal channel and is excessive and unnecessary for erosion control (MA03). The project on the right was designed to perform like an upland revetment (LA07).

Inappropriate applications occur if the structure is placed or designed with no intentions to preserve the tidal marsh. There was 1 case that fit this description where a large, continuous marsh revetment was installed to protect three floodprone building sites (LA07). Protecting the tidal marsh was apparently not the reason for this revetment, which had a 10-12 ft base width and was 740 feet long. Also, there is an adequate sand supply and sand beach in this case. An alternative approach, such as headland control or gapped offshore breakwaters, could have been designed to take advantage of the natural erosion protection provided by a wide sand beach.

Marsh revetments are excessively designed if a smaller footprint or other modifications would still result in effective erosion control. There was one case where the 10-ft base width as constructed was twice as large as the design width (NU03).

Effectiveness for Erosion Control

Upland Bank Erosion Control

Most of the structures in this study were very effective for erosion control based on reported baseline conditions and the absence of erosion indicators after the structure was installed. Most of the project sites had low banks less than 5 feet high and upland erosion was not always present before installation. Continuing upland bank erosion was observed in 5 cases at medium or high energy settings and where the revetment crest height was less than +1 ft MHW, the marsh width was less than 15 feet, and/or the upland was low and floodprone on a regular basis (Figure 6).

Figure 6. Spots of upland bank erosion were observed where the crest height of the marsh toe protection structure was less than +1 ft MHW in a medium energy setting. The white stakes indicate a proposed upland revetment (MA05). Raising the crest height of the marsh toe protection structure was encouraged instead to preserve the natural connections between the upland and wetland habitats.

Tidal Marsh Erosion Control

Generally, these revetments are very effective for reducing the erosion of marsh edges, especially fringing marshes. There were some cases where the pre-existing erosion trend was reversed with obvious evidence of marsh recovery and expansion, particularly salt marsh cord grass (*Spartina alterniflora*). Isolated areas of continuing marsh erosion were observed at 8 sites, particularly where the off-set distance of the revetment from the marsh edge was greater than 10 feet with open water between the revetment and the marsh edge (Figure 7).

Figure 7. Erosion of the marsh edge continued at one section of this project where the offset distance of the marsh sill was greater than 10 feet. There was no erosion observed where the same sill was closer to the marsh edge.

There was only one case of a marsh sill having no apparent effect on the gradual disappearance of a spit marsh (Figure 8). This phenomenon has been observed at other spit marshes and is probably due to the combined effect of gradual sea level rise and sediment supply interruption. Spit marshes depend on sediment supply and transport to maintain suitable elevations for marsh vegetation. "Drowning" spits have been observed and reported by property owners where the adjacent upland sediment supply has been reduced by erosion stabilization projects. The additional marsh revetment structure alone is not always sufficient to reverse this trend.

Figure 8. If upland revetments sever the landward end of a marsh spit, then marsh toe protection structures may not reverse the trend of "drowning" spit marshes. This is the only case where the revetment was not at all effective for erosion control (LA06).

It is also possible that the marsh toe structures interrupt sediment transport along and to the end of the spit (Figure 9). Additional research is needed to evaluate spit marshes and how to preserve these features in the landscape, especially when they are surrounded by erosion stabilization projects and increased boat wake activity.

Figure 9. The placement of marsh toe protection structures along the entire length of marsh spits may adversely interrupt the sediment transport process that maintains suitable elevations for marsh vegetation. In this case, the revetment base width also seemed to be excessive (8 ft) compared to the width of the existing marsh (NU08).

Effectiveness as Living Shoreline Treatments

The 7 projects determined to be excessive or unnecessary for erosion control, inappropriate for the site conditions or not at all effective for erosion control were also not considered to be effective as living shoreline treatments.

Twenty projects were determined to be very effective for both erosion control and for supporting living resources and connections between habitats (Table 7). There were several characteristics that these projects had in common, including structural necessity, erosion control effectiveness, the lack of significant adverse impacts resulting from the structure or construction access, and evidence of habitat functions.

These common characteristics included:

- Marsh toe protection structures were necessary for effective erosion reduction, a non-structural approach would not be effective
- Tidal marsh is primary erosion control treatment with no additional upland structures
- Tidal marsh width greater than 15 feet
- No or minor erosion of upland bank and marsh evident after structure
- Appropriate structure design, with a revetment base width generally <8 feet in low energy settings and < 15 feet in medium energy settings
- Tidal exchange provided either with crest height $\leq$ 1 ft above MHW and/or strategically placed tidal connections

- Marsh and bank connected with vegetation cover in natural condition
- Future sedimentation by storm erosion of upland bank will be captured and retained in local vicinity instead of being transported away from site
- Evidence of habitat value (e.g. nekton access, mammal utilization)

Table 7. Twenty marsh revetment projects were determined to be effective for both erosion control and supporting living resources.

Project ID	Wave Climate	Est. Marsh Width	Natural or Planted Marsh	Est. Crest Height Above MHW (ft)	Tidal Openings
MA01	Medium	20 +	Natural	1.5	No
MA04	Medium	20 +	Natural	1	Yes
MA05	High	25 – 35	Natural	0 – 1	No
MA06	High	25 – 30	Planted	2	Yes
MA08	Medium	35	Natural	0 – 1	Yes
MA09	Low	35	Natural	0	Yes
MA10	Low	45 – 50	Natural	0	No
MX01	Low	20	Planted	1	Yes
MX04	Low	15	Natural	2	Yes
MX05	Medium	25	Natural	0 – 1	Yes
GL01	Medium	30	Natural	0 – 1	No
GL03	Low	25	Planted	1 – 2	Yes
LA01	Low	35 – 50	Natural	1	Yes
LA02	Low	25 – 30	Planted	1 – 3	Yes
LA03	Medium	12	Natural	-0.5	Yes
LA05	Low	10 – 50	Natural	1	Yes
NU01	Low	30 – 40	Natural	0 – 1	No
NU02	Low	50 +	Natural	0 – 1	Yes
NU09	Low	15	Natural	0 – 1	Yes
ES01	Low	200	Natural	1	No

CONCLUSIONS

Most of the marsh protection structures in this study were used to protect existing tidal marshes with eroding edges. “Bio-engineered” projects including strategically placed sills, sand fill and created marshes were not as common.

Fetch models alone may not be sufficient to predict the necessity for structures in low energy settings. The widest fetch was less than 0.5 mile at 20 out of 36 sites, which is typically considered a wave climate suitable for non-structural methods alone. Yet only 1 of these projects was considered to be excessive and unnecessary for erosion control purposes. Boat wake influence appears to be the underlying cause for this observation.

The revetments were very effective for both upland and marsh erosion control. Upland bank erosion observed before the structures was reduced. Future upland erosion will be delayed or prevented in other cases by reducing the erosion rate and landward retreat of a wide, protective marsh.

Both high and low marsh components were present in most cases (preferred), 8 sites included only high marsh vegetation. The marsh condition was generally stable with a high percent cover of vegetation in almost all cases.

Tidal marsh condition appeared good in almost all cases, but the effects of the structures on tidal flushing, primary productivity, nekton access and other wildlife utilization was not evaluated. While the marsh vegetation appeared healthy, it was not clear if these structures are adversely interfering with other habitat conditions and functions.

Structural integrity was generally sound for all 36 marsh revetments evaluated, including older structures more than 10 years old where no regular repair or maintenance has been needed.

Twenty projects (56%) were considered to be consistent with the principles of living shoreline treatments, with some room for improvement. Additional tidal openings in particular may be needed at long, continuous structures. Increasing the stone size, crest height and marsh width in the design can provide a successful treatment at medium energy settings.

DESIGN CRITERIA

The feasibility of taking no action and leaving the shoreline in the existing condition or non-structural alternatives should always be considered first, such as bank grading, marsh enhancement and beach nourishment. These alternatives are preferred under the following circumstances:

- No active marsh erosion or upland bank erosion is evident
- Natural marsh absent but marshes without eroded edges exist in general area
- Boat wake influence is negligible and expected to remain negligible
- Feasible to establish or restore vegetation cover connecting upland with high marsh

If a hybrid project that includes a structure is considered necessary, then the recommended approach for revetment placement and marsh creation (or restoration) depends on marsh and upland bank conditions (Table 8).

Table 8. Recommended approaches for hybrid projects that include tidal marsh and marsh revetments based on existing marsh and upland bank conditions.

Eroding Marsh Condition	Upland Bank Erosion	Recommended Approach
High + Low Marsh	No	Marsh toe revetment placed at eroding edge of low marsh
High + Low Marsh	Yes	Upland bank grading for additional high marsh creation and to move bank toe landward from tidal action OR marsh sill with created high or low marsh to achieve desired width at 10:1 slope
High Marsh Only	No	Marsh sill with low marsh creation at 10:1 slope
High Marsh Only	Yes	Upland bank grading and/or marsh sill with created high and low marsh to achieve desired width at 10:1 slope
Low Marsh Only	No	Marsh toe revetment placed at eroding edge of low marsh
Low Marsh Only	Yes	Upland bank grading with created high and low marsh to achieve desired width, sill placement channelward of created marsh

Additional design criteria include the tidal openings plus specifications for structural integrity.

- Quarry stone revetments preferred over gabions, if gabions are used they should be marine grade, lashed together (with gaps as needed), routinely monitored.

- Filter cloth should be placed under the revetment to reduce settling.

- Base width – 4-6 ft in low energy settings; 8-14 ft in medium & high-energy settings.

- Crest height – < +1 ft MHW where fetch is less than 0.5 mile or marsh width is > 20 ft; +1 MHW at medium & high energy locations or if marsh width < 20 ft in low energy setting.

- Tidal openings – strategic placement depending on shore morphology, such as at tidal ponds and creeks, at pocket marshes, at structure ends; also need to consider wave diffraction & shoaling at gap.

- Target slope for created or enhanced marshes is 10:1. If existing nearshore slope is steeper, backfill or bank grading with cut and fill is advised to create stable planting area.

- Target height at bank face should be at least +3 ft MHW or higher for a specific design storm event.

- Construction access from the water whenever possible; temporary mats or ramps should be used if existing marsh must be traversed; gravel & other roadbed material should not be placed into marsh to gain access.

- Periodic maintenance includes replacing scattered stone, capping with larger stone if necessary; removing excessive tidal debris & solid waste; replacing washed out marsh plants; replacing washed out upland bank vegetation; pruning overhanging limbs for sufficient sunlight penetration to marsh.

REMAINING RESEARCH QUESTIONS

Tidal Marsh & Riparian Vegetation Cover Design for Effective Erosion Control

- What is the minimum marsh width needed for effective wave dissipation given different bank heights & wave climates? One study indicates almost 90% loss of wave energy for a cordgrass marsh with a width of 32 feet, a 70% loss for a 16-ft marsh and a 60% loss for an 8-foot marsh (CCRM, 2005). Is this wave dissipation sufficient to prevent the real or perceived need for an upland erosion control structure?

- Should both low and high marsh components be included in created marsh design?

- How should riparian bank face vegetation be designed and managed to enhance the erosion control effectiveness of the tidal marsh?

Structure Types and Placement

- Is it appropriate to place marsh revetments along eroding or “drowning” spit marshes?

- Are there similar hybrid projects not captured by this survey that should be similarly assessed, such as nearshore marsh sills classified as breakwaters and off-shore breakwaters with beach nourishment and dune restoration?

- How do “mid-tide” bulkheads compare with marsh revetments for effective erosion control and habitat restoration?

Predicting Wave Climate & Structure Necessity

- How resistant are planted and natural marshes to boat wake energy?

- How does the level of boating activity affect wave climate predictions?

- How do marsh protection structures interrupt boat wakes ?

- What is the appropriate fetch model or prediction method for determining structure necessity?

Adverse Ecological Effects

- What are the effects of marsh revetments on sediment transport from landward sources (bank erosion) and channelward sources (littoral transport, wave driven “overwash” & storm deposition)?

- What number and size of tidal openings are needed to support productive marshes?

- What are the effects of marsh revetments on nekton & wildlife utilization, e.g. juvenile blue crabs and fish, shorebird foraging & fiddler crab habitat? How do marsh revetments impact the benthic community under various circumstances, e.g. hard, sandy bottom with medium-high energy, soft bottom with low energy?

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