Living Shorelines for Ecological Benefits and Shoreline Erosion Control in Maryland: Rapid Assessment Tool and Data Management Methodology

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Executive Summary:

Living shorelines are highlighted as a more natural solution to protect coastal communities from storm and wave energy and preserve tidal wetland resources, compared to traditional “hardened” methods like bulkheads and revetments. However, limited information is available on their effectiveness and ecological impact throughout Maryland’s portion of the Chesapeake Bay estuary. This report was prepared by James Beauregard for the Maryland Department of the Environment (MDE) Tidal Wetlands Division as one of his projects during his year with the Department as a Chesapeake Bay Trust Chesapeake Conservation Corps Member. The purpose of this study was to identify 1) how living shoreline projects compare to natural tidal wetlands in terms of wetland functions throughout Maryland and 2) which indicators contribute the most to their success.

A rapid assessment (RA) method was developed to evaluate the success of a living shoreline project based on the vegetative cover and ability to stabilize the shoreline. A representative sample of 49 living shoreline projects was selected from a list of total living shoreline authorizations between 2011-2017 and evaluated based on vegetation composition and erosion control to determine success. Project dimensions, location, adjacent land use and structures, and the presence of natural tidal wetlands or SAV beds were analyzed to determine if they impact the success of living shoreline projects. Below are the key findings:

- Overall, living shoreline projects were found to be widely successful when evaluated based on vegetation composition and erosion control. Over 80% of the projects were rated as “very successful” or “successful”.
- On average, living shoreline projects were found to function similarly to natural wetlands, with the most successful projects even slightly outperforming reference wetland sites.
- The success of living shorelines seems to depend on proper structural component installation and care for vegetation, which entails routine inspections and necessary adjustments made during the marsh’s establishment period, such as trash removal and goose prevention measures.
- Project size, adjacent land use, and adjacent structures were found to not affect the overall success of the living shoreline.

The study’s results indicate that routine maintenance during the project’s establishment period and proper site design are key to ensuring a successful living shoreline project. Due to a lack of correlation between the factors explored and project success, an increase in systematic and standardized monitoring of living shoreline projects is needed to pinpoint site characteristics and other factors that would impact the success of living shorelines. Further efforts to evaluate the performance of living shoreline projects are essential in promoting living shorelines as a solution to shoreline erosion while safeguarding wetland ecosystems in Chesapeake Bay.

Introduction

Despite being some of the most crucial ecosystems on the planet, tidal wetlands are also some of the most vulnerable to the effects of anthropogenic climate change caused by commercial and recreational human activities (Bosch et al. 2006, Day et al. 2008, Baustian et al. 2012). Major effects of anthropogenic climate change, such as sea-level rise and excessive erosion, have significantly impacted the biological and geomorphological networks of tidal wetlands, including those found throughout the Chesapeake Bay. A few of these impacted biological and geomorphological networks involve nutrient inputs, the amount of habitat for commercially valuable organisms, and rates of sediment delivery and subsidence rates (Shepard et al. 2011, Kirwan and Megonigal 2013). Although erosion is a natural process throughout coastal ecosystems, and varies among the shorelines of Maryland from zero to four feet per year, anthropogenic effects are increasing the rates of erosion to excessive levels, which are greater than four feet per year (MDE 2008). The increasing rates of sea-level rise and excessive erosion constantly threaten the Bay and its wide variety of plants and animals, including its local human populations (Bosch et al. 2006, Day et al. 2008). The vulnerability of the Bay is expected to grow as its human population and development continue to increase (Gittman et al. 2016). With the ecological integrity of tidal wetlands diminishing and vulnerability to storms and flooding on the rise, coastal communities on the Bay, and throughout the world, are desperately seeking solutions for these coastal hazards (Gittman et al. 2016, Anderson 2020).

To counter these anthropogenic effects, a potential shoreline protection strategy coastal communities have been incorporating are living shoreline (LS) projects. An LS project refers to any shoreline stabilization technique that incorporates the use of coastal habitats and is primarily composed of marsh vegetation (Pilkey et al. 2012, Davis et al. 2015, Bilkovic et al. 2016). Other materials that are used in the implementation of LS projects include organic materials such as submerged aquatic vegetation (SAV), sand fills, oyster shells, and limited use of structural materials such as stone and coir fiber logs (Pilkey et al. 2012). The application of LS projects is being promoted as a less harmful shoreline stabilization approach compared to armored shoreline structures (Bilkovic et al. 2013).

While armored shoreline structures, such as bulkheads and revetments, can provide barriers to coastal communities from storm and wave energy, they contribute to the loss of wetlands by interrupting natural sediment flow, promoting chemical runoff, and causing habitat fragmentation (MDE 2008, Bilkovic et al. 2013). Armored shoreline structures can also induce the erosion of adjacent tidal marshes by redirecting storm and wave energy toward said marshes (Gittman et al. 2016). Therefore, LS projects attempt to be a middle ground between the needs of coastal communities and tidal wetlands. Living shoreline projects serve as a solid adaptation strategy due to having multiple different designs. Many LS projects follow a "hybrid" design", which incorporates rocks as structural components (ex. breakwaters and low profile sills) to contain and accumulate sediment for marsh establishment (Smith 2006, Duhring 2006). The inclusion of various structural methods in LS designs are meant to allow habitat restoration and creation as long as there are no substantial impacts on ecological services (Duhring 2006). Despite this promising potential, social science research has shown that the public requires more exposure to the benefits of LS projects since they are not as well understood or trusted as traditional structural methods (Duhring 2013).

Although LS projects can provide critical habitat, nutrient retention, and shoreline stabilization, limited information is available to determine their effectiveness and ecological impact throughout the Maryland portion of the Chesapeake Bay (Bosch et al. 2006, Subramanian et al. 2006, Davis et al. 2015, Bilkovic et al. 2016). This knowledge gap is the result of a lack of quantitative data in long-term monitoring for effectiveness as a shoreline stabilization strategy (Mason 2013, Polk and Eulie 2018). For example, an LS project can be considered "successful" in terms of engineering design by establishing wetland vegetation, yet would not be successful ecologically if said project does not support estuarine faunal communities or prevent excessive shoreline erosion (Bilkovic et al. 2017). Furthermore, the ecological succession around an LS project may need years or decades to complete. On average, it can take five to ten years for vegetation composition and wildlife biodiversity to be equivalent to natural wetlands, with some LS projects still ecologically maturing 20 years after their creation (USEPA 2002 #10, Bilkovic et al. 2016).

Other studies have shown that the amount of ecological services produced by LS projects can be influenced by the size of the LS project, the age of the marsh establishment, and the main agent of degradation (Meli et al. 2014). Therefore, the success of many LS projects is site specific since some shorelines require more protection than others (Smith 2006, Hardaway, Jr. et al. 2016). For instance, tidal marshes in different locations may have varying tidal ranges which can influence the species composition and percent coverage of wetland vegetation (Cahoon and Guntenspergen 2010). In this study, the term "success" is utilized the same way it was in the 2006 Bosch study, in which it describes an LS project's ability to produce erosion control and critical habitat in relation to the age of marsh establishment and in comparison to nearby natural tidal wetlands. Therefore, strong assessment methods for wetland field research must be implemented to determine the overall ecological and physical condition of LS sites, and what specific biotic and abiotic components need to be focused on in various restoration efforts throughout the Chesapeake Bay (Meli et al. 2014, Davis et al. 2015, Bilkovic et al 2017).

A wetland assessment method's main purpose is to evaluate wetland functions, stressors, and other potential drivers of wetland conditions (Fennessy et al. 2004, Sutula et al. 2006, Haering and Galbraith 2010). In regards to regulations from the Maryland Department of the Environment (MDE), wetland functions are defined in terms of services, which refers to "the benefits that human populations derive, directly or indirectly, from ecosystem functions" (Costanza et al. 1997, Haering and Galbraith 2010). While it is rather difficult to find the exact degree a certain wetland can perform its functions, these functions can be estimated by indicators. In wetland assessments, indicators are defined as "easily observed characteristics that are correlated with quantitative or qualitative observations of a function" (Stein et al. 2009, Haering and Galbraith 2010). This study aimed to answer the following research questions: 1) Are LS projects providing ecological services that are equivalent or greater than that of natural tidal wetlands throughout the Chesapeake Bay and its tributaries? 2) Which indicators (or other factors) are contributing the most to the success of LS projects?

Based on previous studies, and wetland field assessment guidelines, three major indicators to measure are: 1) vegetation composition; 2) wildlife biodiversity; and 3) erosion control (Bradshaw 1991, Fennessy et al. 2004, Bosch et al. 2006). These indicators are often the most critical to assess in wetlands due to encompassing the majority of biogeochemical feedback loops, such as carbon sequestration and nutrient retention; and are also key elements of habitat function and the impetus for LS designs (Fennessy et al. 2004, Haering et al. 2009, Haering and Galbraith 2010). Of these three major indicators, vegetation is the most frequently assessed for wetland health because it is able to influence the hydrology and sediment regime through various processes including shoreline stabilization (USEPA 2002 #10). Furthermore, the value of wetland vegetation contributing to erosion control was determined in previous wetland studies by measuring elevation change and surface accretion rates in several un-vegetated salt marshes that were recently subsided (Baustian et al. 2012). When it comes to the preservation of wetlands in the face of sea-level rise, rates of sediment deposition must be equal to or greater than the local rates of sea-level rise (Wolanski et al. 2009, Cahoon and Guntenspergen 2010, Ypsilantis 2011). This can be achieved with a high percent coverage and high species composition of wetland vegetation, which will also provide enhanced habitat for a plethora of estuarine organisms from fish to macroinvertebrates to shorebirds (Kirwan and Megonigal 2013, Yepsen et al. 2016). More above ground biomass present in a tidal wetland results in lower energy of incoming waves and enhancement of sediment deposition (Reynolds et al. 2021).

This current study developed a rapid assessment (RA) method and datasheet that researchers and MDE staff can apply at various LS sites to determine their success based on their ecological benefits and shoreline stabilization (Bosch et al. 2006). This RA method also intends to refine and expand upon the MDE's current LS field assessment procedure, which requires a minimum of 85% coverage of native vegetation. According to the U.S. Environmental Protection Agency (USEPA), an RA is a methodology that can measure the complex ecological condition of an ecosystem through a finite set of observable indicators (ex. vegetation percent coverage, fish biodiversity, and records of erosion rates) and a core set of visible field metrics (ex. square feet, Shannon-Wiener Index, cm/year) (Stein et al. 2009). Valid RA methods are structured tools that combine scientific understanding of process and function with strong professional judgment in a consistent, systematic, and repeatable manner (Sutula et al. 2006, Stein et al. 2009). In previous studies, for any field assessment to be considered "rapid", the field study methods were conducted by no more than two people and performed no longer than half a day (Fennessy et al. 2004, Rogerson et al. 2016). In the case of this particular study, the RA should be capable of being performed by a trained individual and a field assistant in the span of two to three hours on an LS study site or natural wetland. Thus, a field researcher applying the currently proposed RA should ideally be able to cover two to three LS study sites a day. The statistical analyses and success rankings of the LS study sites shall be calculated during days in between site visits, and the results of study sites will be compared and contrasted to a set of natural reference wetlands.

Methods

Study Design & Field Data Collection

During the field research of the RA, a site visit datasheet (see pages 28-31) was used to record biological and physical characteristics of LS sites that relate to their overall success toward ecological benefits and shoreline stabilization (Bosch et al. 2006). The biological (or biotic) aspects recorded were vegetation composition and fish biodiversity, and the physical (or abiotic) aspect involved erosion rates. Potential factors that influence the three indicators, such as the physical dimensions of a marsh, slope, and fetch, were also recorded (Bosch et al. 2006, Palinkas et al. 2017). Additionally, adjacent land use and structures, and the presence of natural tidal wetlands or SAV beds were recorded at each LS study site to assess possible direct or indirect correlations to LS success (Fennessey et al. 2004, Bosch et al. 2006, Haering and Galbraith 2010). The datasheet divided the areas of exploration into methodology categories, for ease of raw data recording. Furthermore, the GPS coordinates along with photographs of the current condition of each LS site were collected in order for this study to be replicated (Rogerson et al. 2016).

Site Selection & Scheduling Site Visits

This study took place in the physiographic region of Maryland known as the Coastal Plain province, which includes the State's Eastern and Western shores (Tiner and Burke 1995, Clearwater et al. 2000). Furthermore, the LS study sites and natural reference wetlands in this RA are located in Maryland's tidal estuarine areas. According to the Code of Maryland Regulations (COMAR) tidal wetlands are defined as: "all State and private tidal wetlands, marshes, submerged aquatic vegetation, lands, and open water affected by the daily and periodic rise and fall of the tide within the Chesapeake Bay and its tributaries, the coastal bays adjacent to Maryland's coastal barrier islands, and the Atlantic Ocean to a distance of 3 miles offshore of the low watermark" (Haering et al. 2009). This study, in line with previous ones conducted by MDE, aimed to include LS sites from Maryland counties with tidal shoreline on the Chesapeake Bay and its tributaries (Fig. 1). The MD counties with potential LS study sites and natural reference wetlands in this study included: Anne Arundel, Baltimore, Baltimore City, Calvert, Caroline, Cecil, Charles, Dorchester, Kent, Prince George's, Queen Anne's, Somerset, St. Mary's, Talbot, Wicomico, and Worcester. Study sites were randomly selected through an MDE spreadsheet of property owners throughout the Maryland Chesapeake counties who applied for LS projects from 2011 to 2017.

Figure 1: Maryland counties on the Chesapeake Bay. Image courtesy of the Maryland Department of Natural Resources. Image from: https://dnr.maryland.gov/criticalarea/pages/contact.aspx.

Although previous wetland studies had selected study sites which incorporated similar topography and vegetation structures, this project had its representative sample of LS study sites selected based on the age of the marsh establishment and the percentage of tidal wetlands licenses issued in each county as identified in the MDE Environmental Tracking System (ETS) database from 2011 to 2017 (Bradshaw 1991, Ghigiarelli and Conn 2010) (Table 1). Potential LS study sites were reviewed in the MDE ETS database, along with the Maryland Department of Natural Resources' MERLIN and the Watershed Resources Registry (WRR) online mapping tools. Through the MDE ETS database, potential LS study sites were checked to see if the projects were approved and constructed. The MERLIN and WRR online mapping tools were used to determine if there were natural salt marshes adjacent to the potential LS study sites to be used as reference wetlands.

Table 1. The total number and approximate percentage of LS projects from 2011-2017 in each Chesapeake MD county from the MDE ETS database (n = 651).

MD County	Total LS Projects	Percentage (%)
Anne Arundel	190	29.0
Baltimore	10	1.0
Baltimore City	3	0.5
Calvert	35	5.0
Caroline	5	1.0
Cecil	2	0.5
Charles	13	2.0
Dorchester	25	4.0
Kent	26	4.0
Ocean City	20	3.0
Prince George's	3	0.5
Queen Anne's	38	6.0
Somerset	11	2.0
St. Mary's	93	14.0
Talbot	139	21.0
Wicomico	2	0.5
Worcester	36	6.0

The MDE ETS, MERLIN, and WRR databases were critical in developing a tracking spreadsheet for potential LS study sites and natural reference wetlands. The tracking spreadsheet contained the property owner's name, address, county, and contact information. The spreadsheet also recorded the dimensions of LS projects, slope of LS projects, age of vegetation, average fetch on the study sites, and natural reference wetlands. Factors such as slope and fetch were chosen for observation and recording due to influencing the vegetation composition, wildlife biodiversity, and erosion control of tidal wetlands, yet are not fully associated with any of the three major indicators (Bosch et al. 2006, Davis et al. 2006). A spreadsheet of the collected fieldwork data will be posted on MDE's website along with the published report of this study.

Up to 277 property owners on the MDE spreadsheet were notified by mail to ensure that an ideal representative sample size of 62 to 80 sites were surveyed (Fewster et al. 2005, Bosch et al. 2006, Davis et al. 2006). Property owner information was obtained from the MDE ETS database and the State Department of Assessments and Taxation (SDAT), and shall remain confidential. All approved LS study sites and natural reference wetlands were listed under survey codes (ex. AA 1 = Anne Arundel County Study Site #1, RW 2 = Reference Wetland #2). Selected property owners were contacted in late February 2021 to request permission to visit their LS site. Property owners were initially contacted via survey participation permission letters sent to the mailing address of each property owner's tidal wetlands license. Permission to visit the LS study sites was obtained via the property owners filling out a questionnaire postcard enclosed with the project notification letter and returning the postcard to MDE headquarters, or by completing an electronic version of the questionnaire. Responses to the permission letters and questionnaires were anticipated to be received no later than April 15th, 2021. By April 15th, 2021, a total of 88 property owners gave permission for their LS project to be assessed. Once permission was granted, site visits were scheduled with the property owners by phone or email. Field research at the representative LS study sites was conducted from late April 2021 to early July 2021. By July 9th, 2021, the final day of fieldwork, a total of 49 LS study sites and ten natural reference wetlands were assessed. Data processing occurred during and after fieldwork.

Reference Wetlands

To determine the overall success of LS projects in regards to vegetation composition, wildlife biodiversity, and erosion control, it is crucial to have a wetland reference system (Ehrenfeld 2000, USEPA 2002 #10, Bosch et al. 2006). Reference sites in this study refer to natural tidal wetlands that are in close proximity to the LS projects and should correspond with the highest levels of ecological function (USEPA

2002 #10, Bosch et al. 2006, Rogerson et al. 2016, Reynolds et al. 2021). All natural wetlands in the reference system are located throughout the Chesapeake Bay or its tributaries on the Coastal Plain province, and have a similar climate along with potentially similar plant and animal species (USEPA 2002 #10, Bosch et al. 2006, Rogerson et al. 2016). In regards to this particular study, the type of natural reference wetland focused upon were tidal wetlands. One of the most common critical habitats of tidal wetland ecosystems are tidal salt marshes, on which the majority of LS project designs in Maryland are based (USACE Environmental Laboratory 1987, Ghigiarelli and Conn 2010).

For greater representation, both State and private tidal wetlands regulated by MDE were potential parts of the representative sample of study sites. Based on the standards of COMAR, State tidal wetlands include low marsh, intertidal mud and sand flats, and all other lands beneath tidal waters up to the mean high water line (MHWL) that are typically flooded and exposed twice a day (McCormick and Somes, Jr. 1982, Tiner and Burke 1995, Clearwater et al. 2000). Private tidal wetlands on the other hand occur around high marsh to support aquatic growth, are landward of the MHWL, and are subject to regular or periodic tidal action (McCormick and Somes, Jr. 1982, Tiner and Burke 1995, Clearwater et al. 2000, Correll et al. 2018) (Fig. 2).

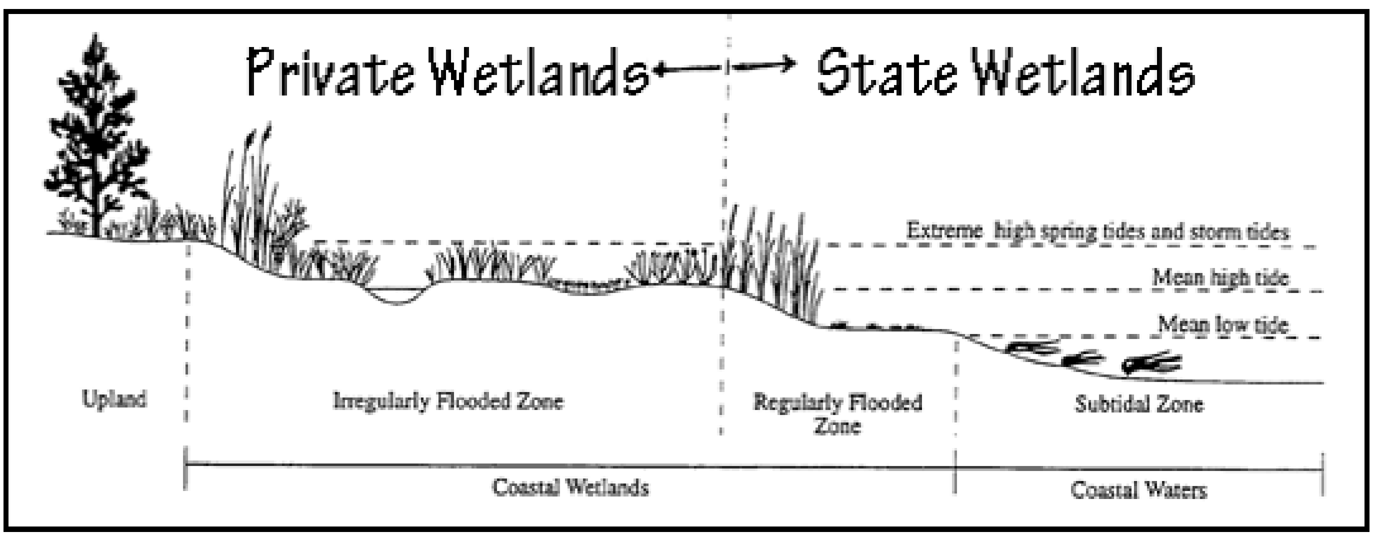

Figure 2. Hydrology diagram of State (low marsh) and private (high marsh) tidal wetlands regulated by MDE; from Tiner, R.W. and D.G. Burke. 1995. Wetlands of Maryland. U.S. Fish and Wildlife Service, Ecological Services, Regional 5, Hadley, MA, and Maryland Department of Natural Resources, Annapolis, MD. Page 51. Image from: https://dnr.maryland.gov/criticalarea/Pages/private_vs_state_tidal_wl.aspx

For a strong reference domain, it is key to incorporate a range of natural wetlands in various conditions due to ecological systems not remaining static (Bosch et al. 2006). Furthermore, a wide range of “reference standards" can integrate any possible natural disturbances that occur during the RA, thus removing potential biases (USEPA 2002 #10). With the majority of the reference wetlands being natural tidal salt marshes, they should be similar to a majority of the LS study sites in terms of size, geomorphology, and potential tidal range (Neckles et al. 2002). Previous studies advise assessing a nearby natural tidal wetland for every LS project based on geographic range (USEPA 2002 #4, Bilkovic et al. 2013). However, for this study still to be considered a “rapid assessment”, it was best to aim for a total of ten to twelve reference wetland sites as the control method (USEPA 2003). To keep the reference wetland system simple to access, this study devised to have all reference wetlands be located on public land. Finally, to avoid additional biases, a focus on biotic and abiotic indicators was necessary to create an effective framework to judge the success of both the natural reference wetlands and the LS study sites (Bosch et al. 2006, Rogerson et al. 2016). To satisfy this guideline, and from reviewing previous rapid assessments, the three indicators chosen to examine were: 1) vegetation composition; 2) wildlife biodiversity; and 3) erosion control.

Vegetation Analysis

The first key indicator to be explored in this RA was vegetation. Vegetation serves as a major indicator to the success and health of wetlands due to being the base of food chains, providing critical habitat for a multitude of taxonomic groups, and a regulator of wetland hydrology and shoreline stabilization (USEPA 2002 #10, Baustian et al. 2012, Gittman et al. 2016). Wetland vegetation also serves as a critical component of combating the effects of anthropogenic climate change by diminishing the risk of excessive coastal flooding and erosion, and reducing amounts of greenhouse gases (GHGs) (Bilkovic et al. 2017). For wetlands to mitigate the effects of sea-level rise, it must accrete vertically at a rate equal to the water rising; which is made possible by how much vegetation is present to partake in feedback loops with organic and inorganic materials (Day et al. 2008, Bilkovic 2017).

The prevalent vegetation of tidal wetlands are hydrophytic macrophytes, which have the ability to survive, compete, and reproduce in anaerobic soil conditions due to morphological, physiological, and/or reproductive adaptations (USACE Environmental Laboratory 1987). Additionally, the vegetation of nearby natural tidal wetlands were assessed in order to provide reference sites to determine the success of LS vegetation (USEPA 2002 #10, Bosch et al. 2006). This RA, like previous MDE studies, analyzed LS vegetation based on general plant species composition and percent coverage via the transect-quadrat method (Bosch et al. 2006). This method was selected to determine vegetation composition and percent coverage due to its relatively quick execution and being easily adaptable in various locations (USEPA 2002 #10). A part of the vegetation analysis that was expanded upon was assessing the overall health of observed vegetation in terms of native plant species percentages. All of these data components shall help determine the overall vegetation ranking (OVR) of the LS study sites.

The vegetation of LS study sites and natural reference wetlands was analyzed in an assessment area through 1 m^2 quadrats on a transect line (Bosch et al. 2006, Rogerson et al. 2016, Milligan et al. 2019). With a team of two, this method can take thirty minutes to an hour. Three transects were generally used at each LS site, though only one transect could be done if a site is less than 10 m (30 ft.) long, and its vegetation was relatively homogenous (Bosch et al. 2006, Milligan et al. 2019). However, the study tried to sample areas that are distinctly different in vegetation. All transect lines were located at intervals that are randomly perpendicular to the shoreline and a baseline (USEPA 2002 #10, Milligan et al. 2019). The baseline in this study refers the upper limits of the assessment area parallel to the shoreline and should encompass the entire length and width of the study site (USEPA 2002 #10, Milligan et al. 2019). Transect location perpendicular to the baseline and shoreline around a sill was determined randomly through site design plans and satellite imagery to target different portions of the site for sampling in order to encompass the full complexity of the assessment area within the LS study sites and natural reference wetlands (USEPA 2002 #10, Milligan et al. 2019) (Fig 3). Transect deployment began from the baseline and ended around the sill walls (Milligan et al. 2019). The randomized placement of transects can be unbiased as long as the randomization ensures that all vegetation in the assessment area has *a priori* equal probability of being included in samples (Fewster et al. 2005). Once transects were deployed, quadrats were placed at fixed intervals on the transects (USEPA 2002 #10, Bosch et al. 2006). Quadrats accompanied the transects in order to provide quantitative estimates of vegetation (USEPA 2002 #10, Milligan et al. 2019).

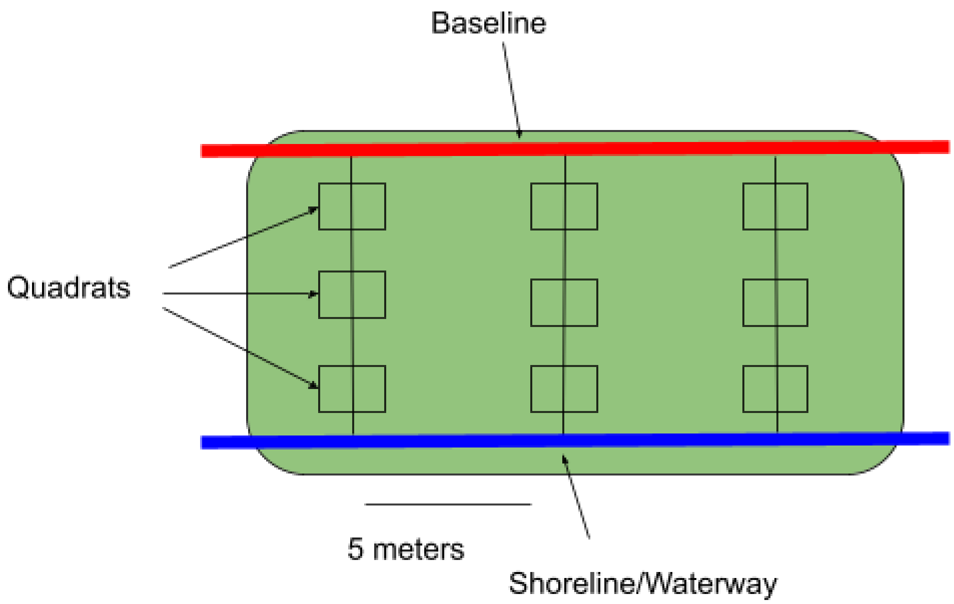

Figure 3. Example of a random transect vegetation sampling schematic. The baseline occurs along the upland/marsh boundary. Transects are selected from site plans and satellite imagery. The quadrats are at fixed intervals.

The number of 1 m^2 quadrats on a transect line shall systematically depend on the width of the marsh. On average, this study aimed for three quadrats per transect (USEPA 2002 #10, Bosch et al. 2006, Rogerson et al. 2016). If the marsh width was less than 6 m (20 ft.), then only one quadrat was deployed. The quadrats were placed evenly on each transect line in order to keep vegetation percent coverage readings consistent and valid (Neckles et al. 2002). The first quadrat was located at the 25% point of the transect, the second quadrat was at 50%, and the third quadrat was at 75%. All transects had their latitude and longitude recorded with a portable GPS unit. Thus, three transects with three quadrat plots behind the sill of an LS project was the typical model (Milligan et al. 2019). Additionally, all plant species were identified through plant keys, the app iNaturalist, and guidebooks, recorded in a data table, and given an estimation of their percent coverage (USEPA 2002 #10, Bosch et al. 2006). Samples of plant species that were difficult to identify were collected for future identification.

Throughout this particular study, vegetation percent coverage refers to the amount of ground surface area obscured by a given plant species on that surface (Peet et al. 1998). Vegetation percent coverage is estimated by visual inspection of vegetation in quadrat samples, and can be used to develop a cover class system (Peet et al. 1998, Milligan et al. 2019). The cover class system, as seen in Table 2, provided a uniform method for recording the amount of overall vegetation percent coverage in each quadrat, and can be an easy way of recording data for future statistical analysis (Peet et al. 1998, Bosch et al. 2006, Milligan et al. 2019). The listed cover class values were based on previous RA projects which involved replicating quadrat samples (Peet et al. 1998, Bosch et al. 2006).

Table 2. Vegetation cover class system based on Peet et al. 1998 and Bosch et al. 2006.

Cover Class	Vegetation Percent Cover Estimate
1	0
2	<1
3	1-<2
4	2-<5
5	5-<10
6	10-<25
7	25-<50
8	50-<75
9	75-<95
10	>95

The next parameters for the vegetation analysis in this study were plant health and species composition which were determined by using the Floristic Quality Assessment Index (FQAI). The FQAI is designed to assess the "naturalness" of an area by taking into account the presence of both native and non-native vegetation (USEPA 2002 #10). According to MDE, an LS project and natural tidal wetland site are considered healthy if they have ≥85% coverage of native plant species. The FQAI was estimated by listing all present native and non-native vegetation in each quadrat and assigning the overall vegetation in the quadrats a tolerance value (USEPA 2002 #10). The tolerance values ranged on a scale of 1-10, in accordance with the approximate percent coverage ratios of native and non-native vegetation in a quadrat (USEPA 2002 #10). As in previous studies, an FQAI tolerance number of one indicated a site only had opportunistic native invaders or only non-native species, and a scale of ten referred to an area having over 95% native plant species (USEPA 2002 #10, Lotze 2019) (Table 3).

Table 3. The FQAI system for the LS study sites and natural reference wetlands (n = 59), based on Lotze 2019.

FQAI Value Number	FQAI Description
1	<1% native or invasive vegetation, >99% non-native vegetation
2	1-9% native vegetation, 91-99% non-native vegetation
3	10-24% native vegetation, 76-90% non-native vegetation
4	25-49% native vegetation, 51-75% non-native vegetation
5	50-59% native vegetation, 41-50% non-native vegetation
6	60-69% native vegetation, 31-40% non-native vegetation
7	70-79% native vegetation, 21-30% non-native vegetation
8	80-89% native vegetation, 11-20% non-native vegetation
9	90-95% native vegetation, 5-10% non-native vegetation and/or small pockets of invasive vegetation adjacent to LS Site
10	>95% native vegetation, less than 5% non-native vegetation on or adjacent to LS Site

The score of the overall vegetation ranking (OVR) was based on the sum of the average cover class and FQAI values divided by two (Table 4). The OVR of LS study sites and natural reference wetlands were scored on a scale of 1 to 10, with one being practically no vegetation present and ten being 100% coverage of native vegetation (Bosch et al. 2006). Additionally, the OVR scale numbers encompass a certain range due to the cover class and FQAI averages usually not being round numbers.

Table 4. The OVR scale ranges for the LS Study sites and natural reference wetlands (n = 59).

OVR Scale #	OVR Description
1	(FQAI average + CC average)/2: 1.0-1.99
2	(FQAI average + CC average)/2: 2.0 - 2.99
3	(FQAI average + CC average)/2: 3.0 - 3.99
4	(FQAI average + CC average)/2: 4.0-4.99
5	(FQAI average + CC average)/2: 5.0-5.99
6	(FQAI average + CC average)/2: 6.0-6.99
7	(FQAI average + CC average)/2: 7.0-7.99

8	(FQAI average + CC average)/2: 8.0-8.99
9	(FQAI average + CC average)/2: 9.0-9.49
10	(FQAI average + CC average)/2: 9.50-10.0

Wildlife Biodiversity Analysis

Fish were the wildlife focus of this study. Fish serve as strong wildlife biodiversity indicators for tidal marshes due to occupying upper levels of tidal marsh food webs, and because their dependence on several food and habitat resources can reflect the conditions of other major ecological indicators (Neckles et al. 2002). Prior to the site visits, species assemblage databases for fish and species in the Bay were examined (Rosenberg et al. 1998, Vasconcelos et al. 2015). Some of these databases which were explored included the Chesapeake Bay Monitoring programs and MDNR's Natural Heritage programs (Rosenberg et al. 1998, Powers 2010).

For a group of two to sample fish and biodiversity levels, a 30 ft. long, ¼ in. mesh seine net was used. Previous studies incorporated a dip net as their main method of collecting fish and other estuarine organisms; however, this study used a small fishing net to transfer specimens from the seine net to five gallon buckets. All latitudes and longitudes of the seine net pulls were marked with a GPS unit on a smartphone. To obtain a solid context of fish species abundance and biodiversity, previous studies took five dip net swipes from three different depths (Bosch et al. 2006). However, this study was limited to doing a single seine pull parallel to the shoreline whenever suitable aquatic habitat was found. A second seine pull was done only if no organisms were caught in the first seine pull and if time permitted.

Previous studies recommend conducting seine pulls from the shoreline and remaining in open water sections between marsh establishment and low-profile sills, breakwaters, and groins (USEPA 2003). The distance of seine pulls often depends on the length of the seine net being used, though to maintain a RA time-frame, it is advised to seine 3-5 m (10-16 ft.) parallel to the shoreline (USEPA 2003, Reynolds et al. 2021). Thus, this RA study performed seine net pulls 16 ft. parallel to the shoreline. Along with the seine nets, two minnow wire traps were deployed and submerged near the low-profile sills or other structural components of the LS projects to increase the chances of obtaining specimens. The minnow traps were also used at the natural reference wetlands, and were usually placed around the edges of the reference sites. Fish and other captured organisms were immediately transferred to a five gallon bucket until identified and recorded on the data sheet. All signs of wildlife presence, including those on the marsh, such as feathers, tracks, and scat were also noted (Bosch et al. 2006).

All organisms were released immediately after identification and counting, and biodiversity values were later calculated via the Shannon-Weiner Diversity Index (Nolan and Callahan 2006, Seitz et al. 2006) (Fig. 5). This biodiversity equation was chosen since it combines species richness (the number of species in a given area) and their relative abundances (Nolan and Callahan 2006, Seitz et al. 2006). Measuring biodiversity values in terms of species richness and evenness can help display differences in response to restoration at various levels of ecological complexity (Meli et al. 2014).

$$H = -\Sigma[pi * ln(pi)]$$

Figure 5. The Shannon-Weiner Diversity Index Equation.

In the Shannon-Wiener Index, pi represents the proportion of the total sample represented by species i, which is found by dividing the number of individuals of species i by the total number of the sample (Nolan and Callahan 2006). Later, $-\Sigma[pi * ln(pi)]$ is calculated, which results in the Shannon-Wiener Index value (Nolan and Callahan 2006, Seitz et al. 2006). To find the maximum possible biodiversity value (H_{max}), the natural log of Species richness (S) or the number of species must be calculated (Nolan and Callahan 2006). The H_{max} value can then be divided by H to find the value of species evenness, which is often measured on a scale of 0 to 5, with values closer to zero indicating lower species diversity (Nolan and Callahan 2006, Seitz et al. 2006).

The score of the overall wildlife ranking (OWR), as seen in Table 5, was based on the Shannon-Weiner Diversity Index values and rated on a scale of 1 to 10, with one being no biodiversity, and ten being extremely high biodiversity (Bosch et al. 2006). Along with the Shannon-Weiner Diversity Index values, OWR scores were determined based on mean individual sizes (Rosenberg et al. 1998).

Table 5. The OWR scale ranges for the LS study sites and natural reference wetlands (n = 59).

OWR Scale #	OWR Description
1	Shannon-Wiener Index: <0.1, very low mean individual size
2	Shannon-Wiener Index: 0.1-0.99, low mean individual size
3	Shannon-Wiener Index: 1.0-1.49, low mean individual size
4	Shannon-Wiener Index: 1.50-1.99, low mean individual size
5	Shannon-Wiener Index: 2.0-2.49., moderate mean individual size
6	Shannon-Wiener Index: 2.5-2.99, moderate mean individual size

7	Shannon-Wiener Index: 3.0-3.49, moderate mean individual size
8	Shannon-Wiener Index: 3.5-3.99, high mean individual size
9	Shannon-Wiener Index: 4.0-4.49, high mean individual size
10	Shannon-Wiener Index: 4.5-5.0, very high mean individual size

Erosion Control Analysis

Prior to assessing the current shoreline stabilization state of the LS study sites, previous shoreline conditions and erosion rates of the study sites were reviewed in association with their license site plans, and through geological databases (ex. Google Earth, NOAA, WRR) regarding erosion rates throughout the Bay. To determine the current overall state of the study sites, in terms of shoreline stability and vegetation composition, photographs of each LS site were taken (Fig. 6). Furthermore, when at each LS site, all signs of undercutting, slumping, and scouring were considered as signs of erosion (Bosch et al. 2006, Palinkas et al. 2017). For the erosion control analysis, the photographs were compared with their previous shoreline condition records.

Figure 6. A photograph from LS study site DO 13, in Dorchester County. This picture was taken on the pier of the study site. James Beauregard was determining the vegetation percent coverage and FQAI in a quadrat throughout a transect line of the vegetation analysis. This photograph also was used to compare the current shoreline stability of the site to its previous states.

Along with comparing LS site plans to their current conditions, this erosion control analysis incorporated factors from previous studies that used the VIMS Wetland Rapid Assessment Method (Bradshaw 1991) to identify if the site is experiencing erosion or is stable. These factors include: obvious signs of erosion and site plan similarity (Bradshaw 1991, Renard et al. 1991). Study sites were classified as "high" if there were obvious signs indicating massive amounts of undercutting, slumping, or scouring, which do not represent a stable environment, "moderate" if there were a few signs of erosion, and "low" if there is little to no evidence of these erosion signs (Bradshaw 1991, Bosch et al. 2006) (Table 6).

Table 6. Signs of erosion rankings for LS study sites and natural reference wetlands (n = 59).

Signs of Erosion Scale #	Description	Signs of Erosion Classification
1	About >95% of Study Site has signs of undercutting, slumping, and/or scouring	Critical
2	About 90-95% of Study Site has signs of undercutting, slumping, and/or scouring	High
3	About 80-89% of Study Site has signs of undercutting, slumping, and/or scouring	High
4	About 70-79% of Study Site has signs of undercutting, slumping, and/or scouring	High
5	About 60-69% of Study Site has signs of undercutting, slumping, and/or scouring	Moderate
6	About 50-59% of Study Site has signs of undercutting, slumping, and/or scouring	Moderate
7	About 25-49% of Study Site has signs of undercutting, slumping, and/or scouring	Moderate
8	About 10-24% of Study Site has signs of undercutting, slumping, and/or scouring	Low
9	About 1-9% of Study Site has signs of undercutting, slumping, and/or scouring	Low
10	About <1% of Study Site has signs of undercutting, slumping, and/or scouring	Low

Another major parameter used to assess the erosion control indicator was site plan similarity. This parameter was determined by comparing and contrasting a site's current condition to its site plan. For natural reference wetlands, this was determined by comparing the current condition to satellite imagery from the last ten years. Site plan similarity was ranked on a scale of 1 to 10 based on the estimated percentage a site's current condition matched its original design (Table 7). Site plan similarity was rated "high" if a site had a score of eight to ten. A level of "moderate" site plan similarity was if there was a score five to seven. Finally, site plan similarity was considered "low" if there was a cover class of one to four, thus indicating a shoreline's design was in serious need of maintenance or a brand new design.

Table 7. Similarity percentage system between the current condition and records of LS study sites and natural reference wetlands (n = 59).

Similarity to Site Plans Scale #	Similarity Percent Estimate	Similarity Classification
1	<1	Low
2	1-9	Low
3	10-24	Low
4	25-49	Low
5	50-59	Moderate
6	60-69	Moderate
7	70-79	Moderate
8	80-89	High
9	90-95	High
10	>95	High

The score of the overall erosion ranking (OER), shown in Table 8, is based on its current state and information from the LS sites' original plans and geological databases. The OER was the result of combining the averages of site plan similarities and signs of erosion values and dividing them by two. The OER was rated on a scale of 1 to 10, with one being no erosion prevention occurring or reported, and ten being a highly stabilized shoreline (Bosch et al. 2006).

Table 8. The OER system for the LS study sites and natural reference wetlands (n = 59), based on current and recorded conditions.

OER Scale #	OER Description
1	(Signs of Erosion average + Site Plan Similarity average)/2: 1.0-1.99
2	(Signs of Erosion average + Site Plan Similarity average)/2: 2.0-2.99
3	(Signs of Erosion average + Site Plan Similarity average)/2: 3.0-3.99
4	(Signs of Erosion average + Site Plan Similarity average)/2: 4.0-4.99

5	(Signs of Erosion average + Site Plan Similarity average)/2: 5.0-5.99
6	(Signs of Erosion average + Site Plan Similarity average)/2: 6.0-6.99
7	(Signs of Erosion average + Site Plan Similarity average)/2: 7.0-7.99
8	(Signs of Erosion average + Site Plan Similarity average)/2: 8.0-8.99
9	(Signs of Erosion average + Site Plan Similarity average)/2: 9.0-9.49
10	(Signs of Erosion average + Site Plan Similarity average)/2: 9.5-10.0

Overall Marsh Ranking/Statistical Analysis

Each LS site shall have an overall marsh ranking (OMR), which is the sum of the OVR and OER divided by two. With both the OVR and OER being scored on a scale of 1 to 10, the OMR was also scored out of ten possible points (Bosch et al. 2006) (Table 9). The lowest possible score is a total of one point, and the highest possible score is ten points. The OMR also took into consideration how accurately LS projects followed their original site plan (Bosch et al. 2006). The OWR was a stand-alone assessment due to fish not being sampled at some of the site visits as a result of extremely high or low tides and structural obstructions. Any further comments regarding the overall success of the LS study sites, such as concerns from the property owners were documented. For the first part of the statistical analyses, the averages, medians, modes and frequencies of the OVR, OWR, and OER scores were calculated (Bosch et al. 2006). The LS study sites and natural reference wetlands were also compared in terms of success rates. Summaries of the general characteristics of the five highest and lowest OMR scores will be provided in the upcoming results. This way the results of this study can be compared to previous MDE RA studies. Not only can this comparison assess how effective this RA methodology is compared to previous studies, it can also indicate if LS projects are increasing in ecological function success over time.

Table 9. The OMR System for the LS study sites and natural reference wetlands (n = 59).

OMR Scale #	OMR Score Description	Rate of Success for LS Project
1	(OVR + OER)/2: 1-1.99	Unsuccessful
2	(OVR + OER)/2: 2-2.99	Unsuccessful
3	(OVR + OER)/2: 3-3.99	Unsuccessful
4	(OVR + OER)/2: 4-4.99	Unsuccessful
5	(OVR + OER)/2: 5-5.99	Moderately Successful
6	(OVR + OER)/2: 6-6.99	Moderately Successful

7	(OVR + OER)/2: 7-7.99	Successful
8	(OVR + OER)/2: 8-8.99	Successful
9	(OVR + OER)/2: 9-9.49	Very Successful
10	(OVR + OER)/2: 9.5-10	Very Successful

To determine if significant variability exists between the OWR and OMR scores of each LS site and natural reference wetland, linear regressions were performed, with the OWR and OMR compared with a multitude of variables to find visual correlation (Bosch et al. 2006). In order to avoid circular logic, it is best to choose site characteristics not fully associated with the major indicators, such as adjacent structures and square foot area size of each LS study site (Bosch et al. 2006, Davis et al. 2006). Since a site characteristic like fetch was not involved in calculating OVR, OWR, OER or OMR, it is statistically valid to compare with the OMR (Bosch et al. 2006, Davis et al. 2006). Thus, this regression would show the percentage of variability in OMR that is tied to changes in square foot area from the LS study sites (Bosch et al. 2006). Other possible site characteristics to compare the major indicators in the regression analysis include the width of LS buffers, adjacent land use, and the slope of the LS project. Additionally, an analysis of variance (ANOVA) test was run to compare the rates of success to adjacent land use and adjacent structures to see if there was any statistical significance.

Results

Number and Types of Sites Assessed

From April 28th, 2021 to July 9th, 2021, 49 LS study sites and ten natural reference wetlands were visited and assessed by the previously described methods. The number of selected LS study sites from each MD county aimed to reflect their percentage in the MDE ETS database (Table 10). Anne Arundel County had the majority of the LS study sites (31%, n = 15), followed by Talbot County (22%, n = 11), with the remaining site visits split roughly equally among the other counties that the study was able reach (Baltimore, Calvert, Caroline, Charles, Dorchester, Kent, Prince George’s, Queen Anne’s, St. Mary’s, Wicomico, and Worcester). Furthermore, 98% of the LS study sites (n = 48) had low-profile sills as the primary structural component, while the other two percent had groins (n =1). Up to 43% of the LS study sites (n = 21) had additional shoreline measures within their permits. Of these 21 study sites with additional shoreline controls, 81 % had revetments (n = 17), 14% had groins (n = 3), and 5% had bulkheads (n = 1). Of all the LS study sites surveyed, the average dimensions based on the MDE ETS database were 299.59 ft. long and 22.66 ft. wide.

For the natural reference wetlands, three were in Anne Arundel County. Other counties that had natural reference wetlands included Baltimore, Calvert, Dorchester, Kent, Prince George's, Queen Anne's, and St. Mary's (Table 10). The counties and number of natural reference wetlands in said counties were chosen based on the number of LS study sites and to represent the general area. Among all of the reference wetlands, the average dimensions were 2,950.26 ft. long and 1,214.48 ft. wide.

Table 10. The summary of the total number and approximate percentages of LS projects and natural reference wetlands in MD by county assessed in 2021 compared to the MDE ETS database.

MD County	Total LS Projects in MDE ETS	Percentage (%)	LS Study Sites Visited	Percentage (%)	Natural Reference Wetlands Visited	Percentage (%)
Anne Arundel	190	29.0	15	31.6	3.0	30%
Baltimore	10	1.0	1	2.0	1.0	10.0
Baltimore City	3	0.5	0	0	0	0
Calvert	35	5.0	2	4.0	1.0	10.0
Caroline	5	1.0	2	4.0	0	0
Cecil	2	0.5	0	0	0	0
Charles	13	2.0	3	6.0	0	0
Dorchester	25	4.0	5	10.0	1.0	10.0
Kent	26	4.0	1	2.0	1.0	10.0
Ocean City	20	3.0	0	0	0.0	0
Prince George's	3	0.5	1	2.0	1.0	10.0
Queen Anne's	38	6.0	5	10.0	1.0	10.0
Somerset	11	2.0	0	0	0	0
St. Mary's	93	14.0	1	2.0	1.0	10.0
Talbot	139	21.0	11	22.4	0	0
Wicomico	2	0.5	1	2.0	0	0
Worcester	36	6.0	1	2.0	0	0

The Characteristics of the Indicators

Wildlife (Fish). Due to not every seine net pull resulting in the capture of fish, the wildlife biodiversity analysis became a stand-alone assessment. Aside from fish, other organisms the seine net pulls captured included crabs, grass shrimp, moon jellies, comb jellies, mussels, oysters, and macroinvertebrates. Organisms observed during the biodiversity analysis included ducks, Canada geese, herons, ospreys, and bald eagles. Some property owners also reported seeing foxes and turtles at certain LS sites. In terms of the Shannon-Wiener Index, the LS projects had an average index score of 0.95, with an average of five fish species caught per seine pull. When it came to the reference wetlands, they had an average index score of 0.62, with an average of three fish species per seine pull. The most frequent fish species found at the LS study sites and natural reference wetlands were Striped killifish (*F. majalis*), Mummichog (*F. heteroclitus*), and Atlantic silverside (*M. menidia*).

The frequency distribution of the OWR scores were compared between the LS projects and the natural reference wetlands (Fig. 7). For the LS projects, the average OWR was 2.61, and the median was 3. The LS projects OWR distribution also had a range of 1-5, and a mode of 3. The natural reference wetlands had an OWR average of 2.22 and a median of 2. Additionally, the natural reference wetlands' OWR score ranged from 1-4, and had a mode of 2.

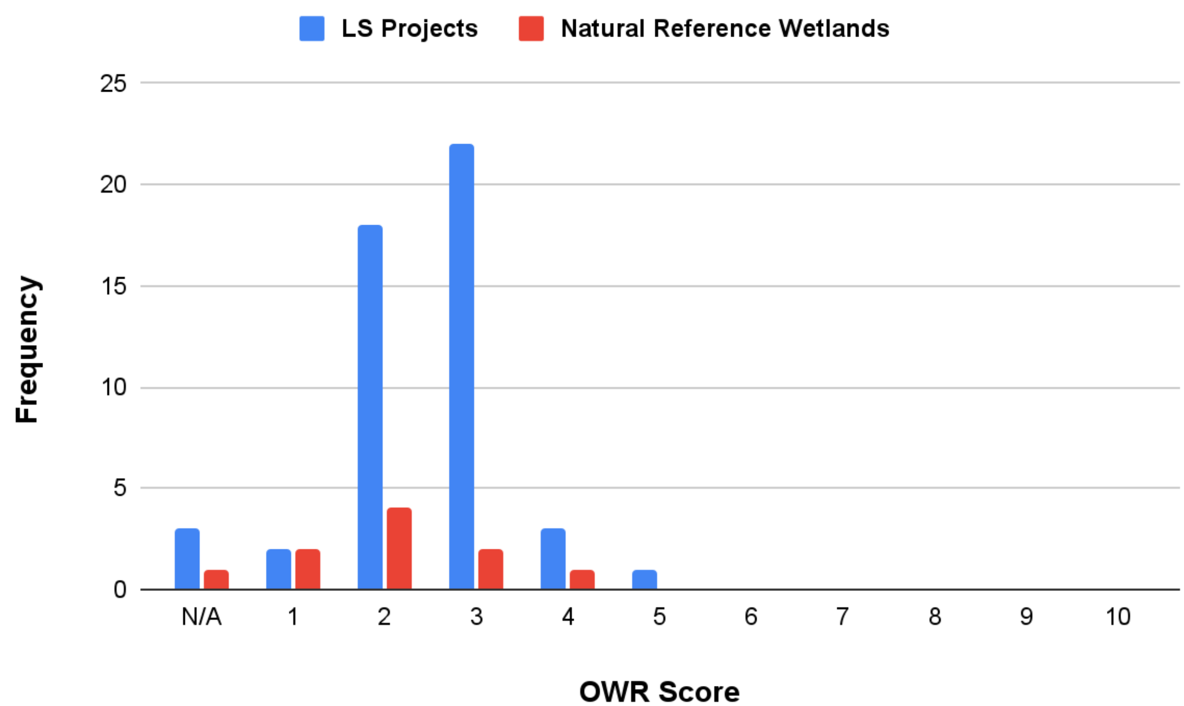

Figure 7. Frequency distributions of overall wildlife ranking scores among the LS study sites and natural reference wetlands (n = 59).

Vegetation. For the vegetation analysis, the LS projects had a cover class average of 7.91 and an FQAI average of 8.34. As for the natural reference wetlands, the cover class average was 8.42 and the FQAI average was 8.07. The frequency distribution of the OVR was then compared between the LS projects and the reference wetlands (Fig. 8). Between the LS projects, the OVR average was 7.63, and the median was 8. The OVR ranged from 1-10 among the LS projects, and the mode was 8. The reference wetlands' OVR average was 7.9, with a median of 8. The OVR scores of the reference wetlands ranged from 4-10, and the modes were 8 and 9. The most frequent plant species found at the LS study sites and natural reference wetlands were Saltmeadow cordgrass (*S. patens*), Smooth cordgrass (*S. alterniflora*), and Common reed (*P. australis*).

Erosion Control. Among the LS projects, the signs of erosion average was 8.7 and the site plan similarity average was 8.4. In regards to the natural reference wetlands, the signs of erosion average was 8.6 and the site plan similarity average was 9.1. The frequency distribution of the OER was then compared between the LS projects and the reference wetlands (Fig. 8). The LS projects had an OER average of 8.57, and a median of 10. The range of the LS projects' OER was from 1-10, and the mode was 10. Within the reference wetlands, the OER average was 8.8, and the median was 9.5. The reference wetlands' OER ranged from 7-10, and the mode was 10.

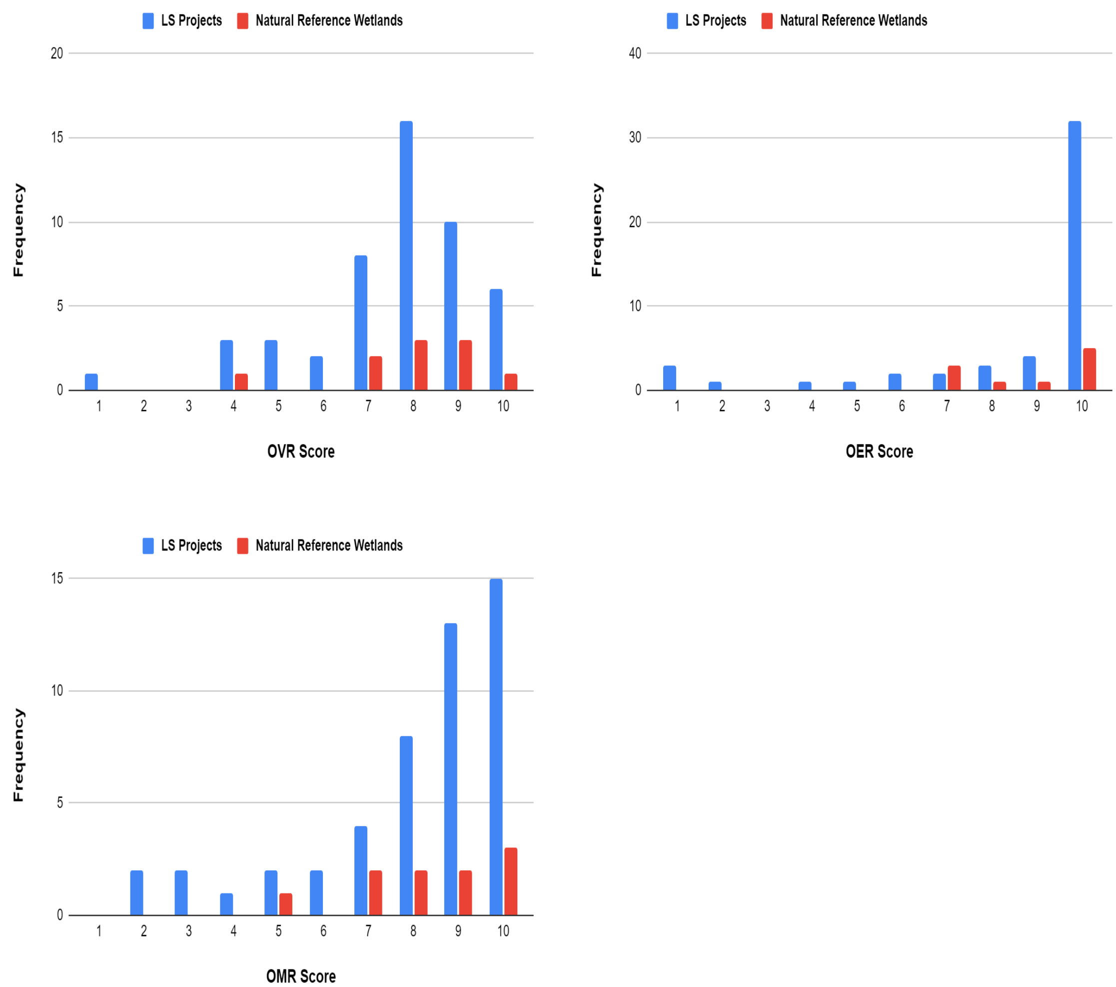

Figure 8. Frequency distributions of vegetation, erosion control, and overall marsh ranking scores among the LS study sites and natural reference wetlands (n = 59). The overall marsh ranking (OMR) for a site is the sum of the individual vegetation and erosion control rankings divided by two.

Overall Marsh Ranking. The final frequency distribution assessed between the LS projects and natural reference wetlands were the OMR scores (Fig. 8). When it came to the LS projects, the OMR average was 8.06, with a median of 9. The OMR scores of the LS projects ranged from 2-10, with a mode of 10. For the natural reference wetlands, the OMR average was 8.3, with a median of 8.5. Additionally, the reference wetlands' OMR scores ranged from 5-10, with a mode of 10.

The OMR scores of the LS study sites and natural reference wetlands were then compared in regard to their success rate percentages (Fig. 9). Out of the 49 LS study sites that were visited, 10.2% had an unsuccessful rating (n = 5), which ranged from 1.0-4.99 (with an average of 3.2). The LS projects had an 8.2% of moderately successful sites (n = 4), with OMR scores ranging from 5.0-6.99 (with an average of 5.7). About 24.5% of the LS projects had sites that were successful (n = 12), with OMR scores ranging from 7.0-8.99 (with an average of 8.0). Additionally, 57.1% of the LS projects had a very successful rating (n = 28), with an OMR score range of 9.0-10.0 (and an average of 9.4).

For the ten natural reference wetlands visited, one reference wetland was moderately successful and had an OMR score of 5.5. Forty percent of the reference wetlands were considered successful (n = 4), with an OMR average of 7.8. Finally, 50% of the reference wetlands were very successful (n = 5), with an OMR average of 9.4.

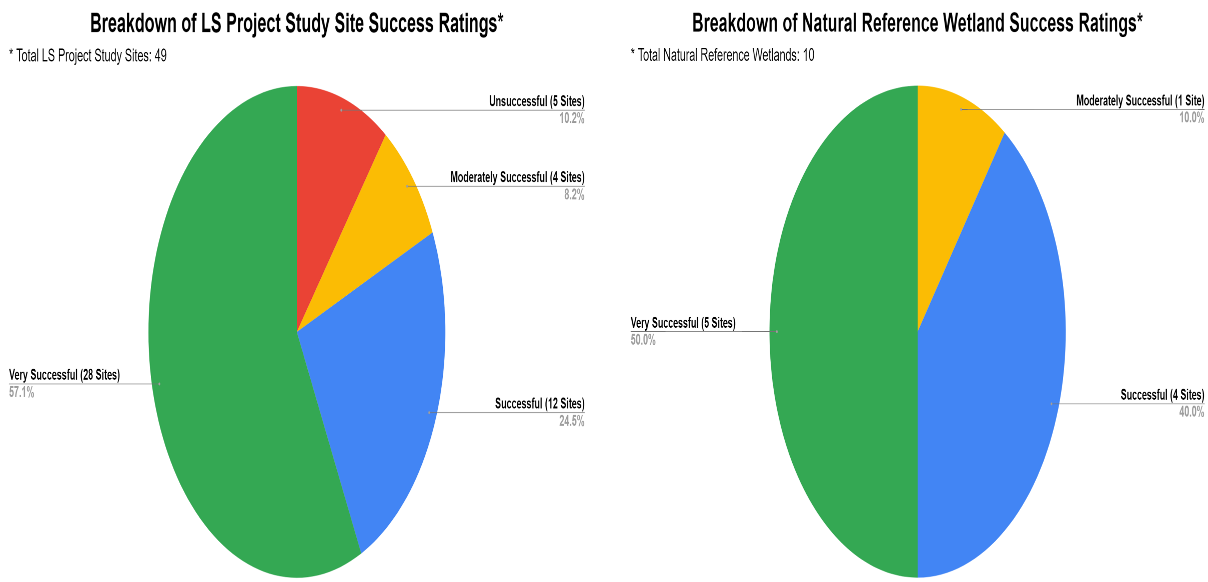

Figure 9. The breakdown of success ratings between the LS study sites and natural reference wetlands based on OMR scores (n = 59). The scores were placed into four categories: Very Successful (9.0-10.0), Successful (7.0-8.99), Moderately Successful (5.0-6.99), and unsuccessful (1.0-4.99).

Square Feet Area Effects on OMR

For the linear regressions, the main site characteristic chosen to compare the OMR scores between LS projects was the site area size in square feet. There was no strong significant correlation to the massive variation between square feet area and OMR scores, (Fig. 10, Table 11). While the site with the biggest square foot area (58,830.00 sq. ft.) was successful with an OMR of 8, many LS projects with areas less than 10,000 sq. ft. had OMRs of 8 or higher.

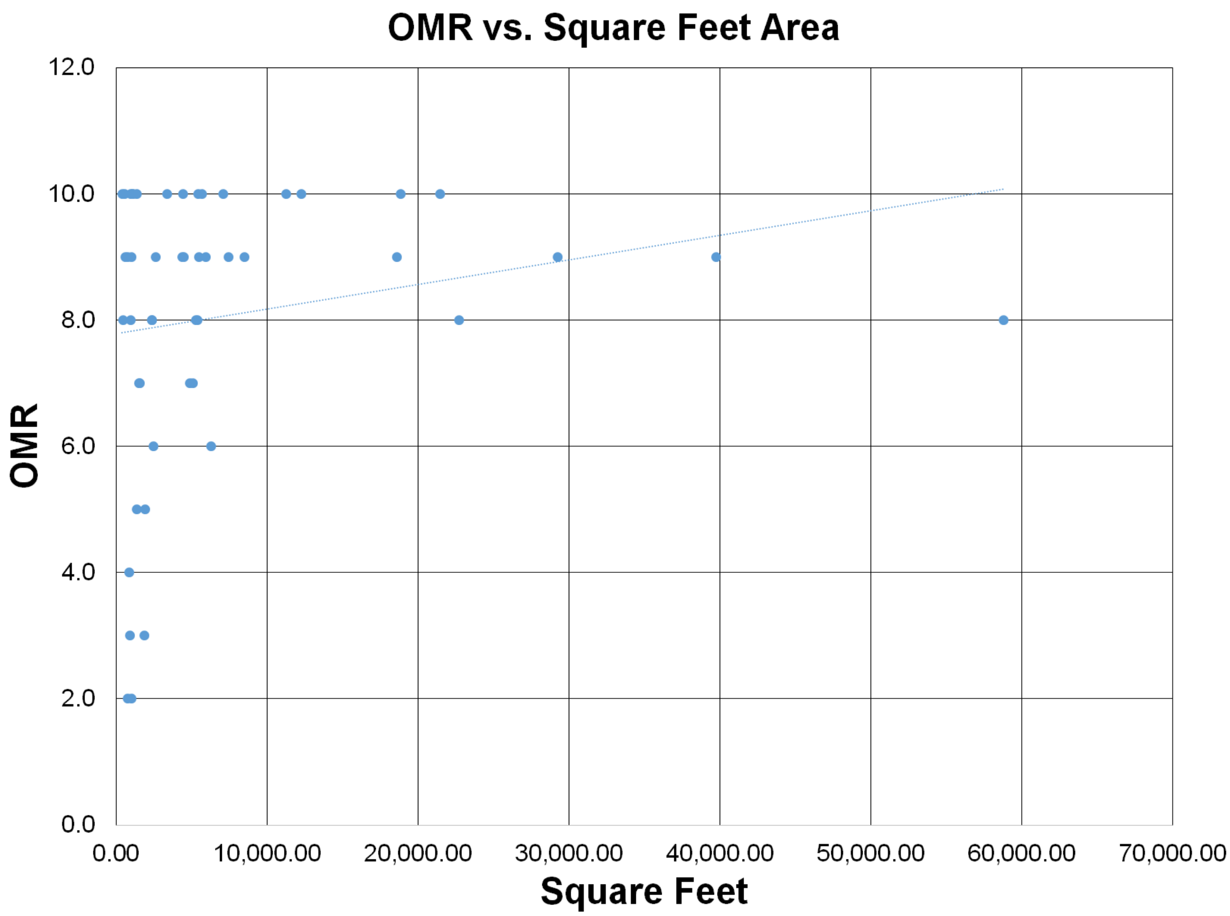

Figure 11. Relationship between overall marsh rank and square feet area of LS study sites and natural reference wetlands (n = 59, P>0.05).

Table 10. Summary of regression analysis of square feet area effects on OWR and OMR scores among the LS study sites (n = 49). For P-values, P<0.05 is marginally significant.

Parameter	Regression Equation	r2	P
OMR	y = 7.80 + 3.91E-05x	0.0336	0.2126

Adjacent Land Use Effects on OMR

The next characteristic evaluated was how the types of adjacent land uses impacted the OMR scores. This was performed through an ANOVA test. Although land uses such as agriculture and low density residential had high numbers of “very successful” LS projects, no overall significant difference was found among the types of adjacent land use (Fig. 12, Table 12).

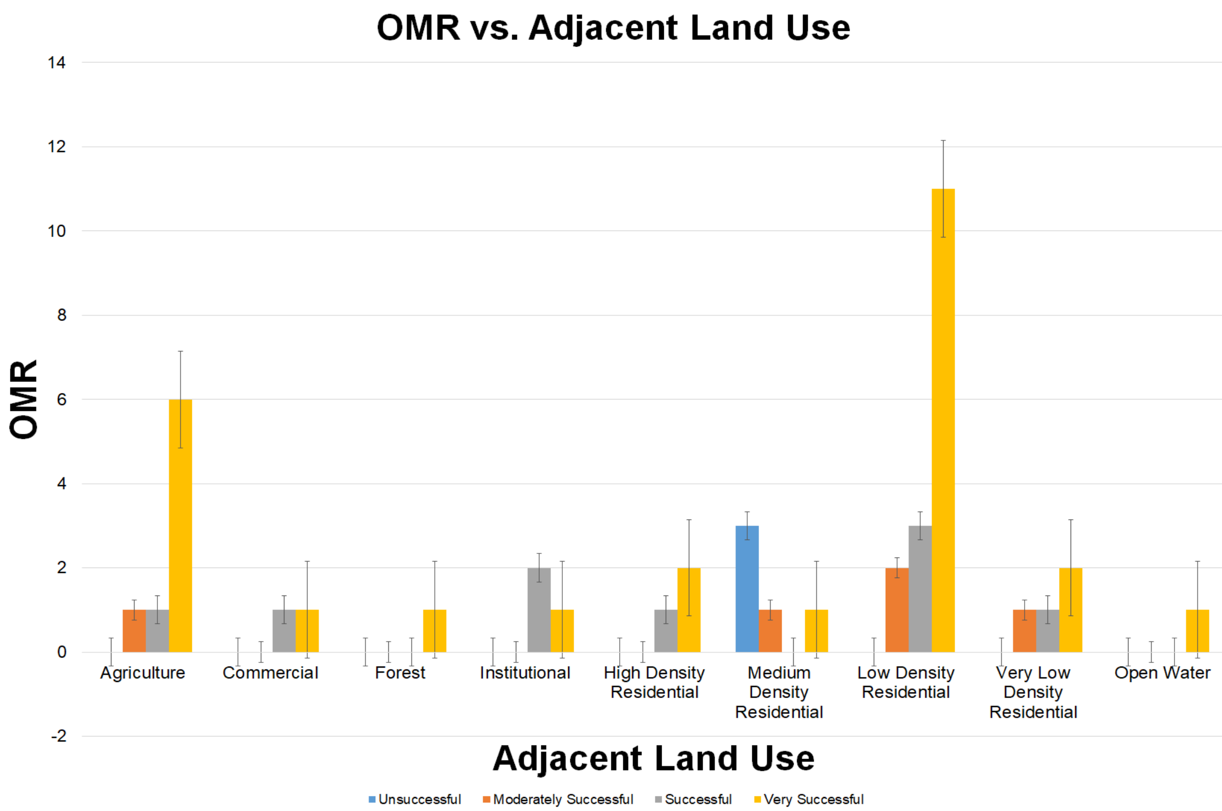

Figure 12. Frequency distribution of success ratings (±SE) based on OMR scores in relation to types of adjacent land use among LS study sites and natural reference wetlands (n = 49, ANOVA: P>0.05).

Table 12. Summary of ANOVA results for adjacent land use effects on OMR scores among the LS study sites (n = 49). For P-values, P<0.05 is marginally significant.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	44.88889	8	5.611111	1.419204	0.233556	2.305313
Within Groups	106.75	27	3.953704			
Total	151.6389	35				

Adjacent Shoreline Structure Effects on OMR

Another characteristic assessed alongside adjacent land use was how different types of shoreline structures next to the LS projects affected their success. This evaluation was also done through an ANOVA test, with a similar outcome. Even though LS sites with adjacent piers and revetments had the most "very successful" projects compared to other structures, no overall significant difference was found between the different groups of structures (Fig. 14, Table 13).

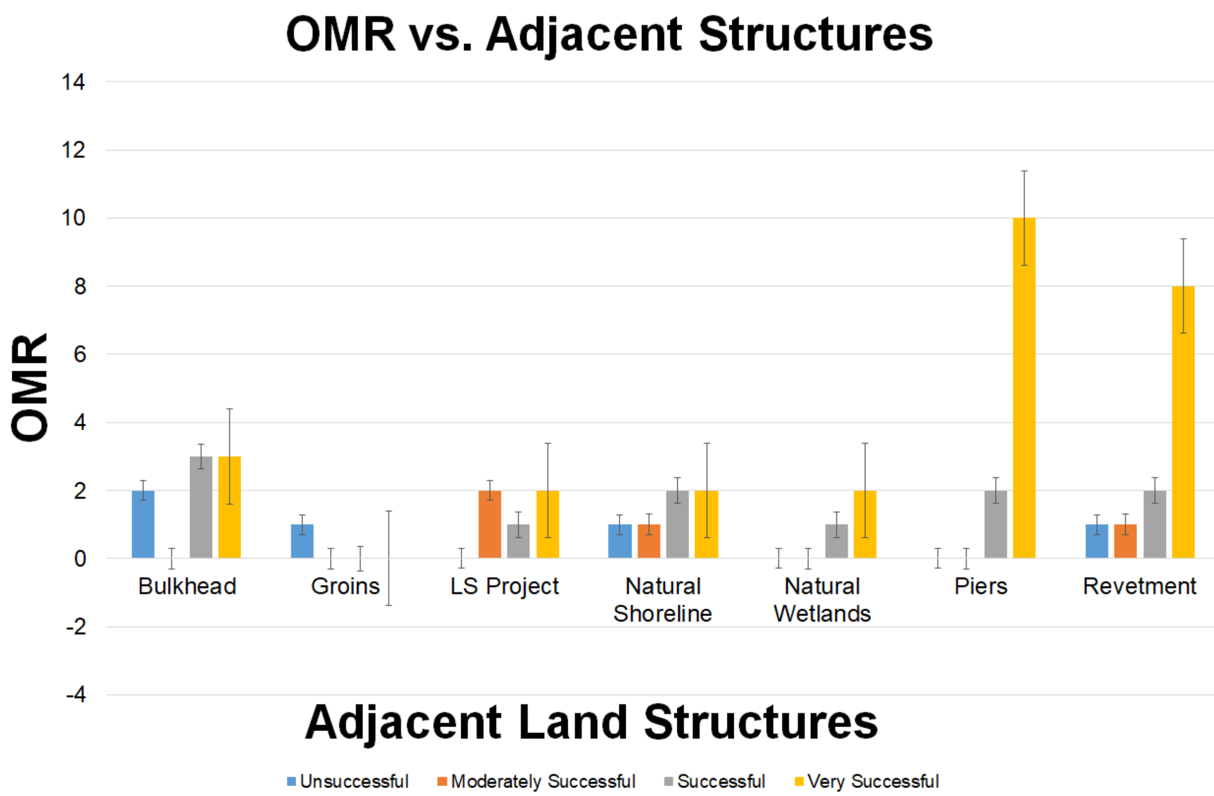

Figure 14. Frequency distribution of success ratings (±SE) based on OMR scores in relation to types of adjacent structures among LS study sites and natural reference wetlands (n = 49, ANOVA: P>0.05).

Table 13. Summary of ANOVA results for adjacent structure effects OMR scores among the LS study sites (n = 49). For P-values, P<0.05 is marginally significant.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	26.85714	6	4.47619	0.815618	0.569904	2.572712
Within Groups	115.25	21	5.488095			
Total	142.1071	27				

Conditions of the Most Successful and Least Successful LS Study Sites

The top five most successful and least successful LS study sites were compared to determine common conditions and characteristics among them. The most successful were reviewed first (Table 14, Fig. 15). For the most successful LS projects their vegetation had a cover class average of 8 or higher, and an FQAI average of 9 or higher. A high FQAI average indicates a high ratio of native plant species such as Saltmeadow cordgrass (*S. patens*), Smooth cordgrass (*S. alterniflora*). In terms of erosion control, the most successful sites had low signs of erosion, and had a site plan similarity rating of 9 or higher.

Table 14. Summary of ratings from the top five most successful LS study sites (n = 5).

SURVEY CODE	COUNTY	WATERWAY	MARSH TYPE	STRUCTURAL COMPONENT	OVERALL VEGETATION RANKING (OVR)	OVERALL EROSION RANKING (OER)	OVERALL MARSH RANKING (OMR)	RATE OF SUCCESS
AA 23	Anne Arundel	Almshouse Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
AA 35	Anne Arundel	South River	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
AA 38	Anne Arundel	Duvall Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
QA 18	Queen Anne's	Macum Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
TA 25	Talbot	Island Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful

Figure 15. Photographs of the five highest ranked LS study sites. For each photograph, survey code and overall marsh rank are given. Refer to Table 14 or appendix for additional information.

AA 23, OMR = 10.0

AA 35, OMR = 10.0

AA 38, OMR = 10.0

QA 18, OMR = 10.0

TA 25, OMR = 10.0

The least successful LS study sites were then compared (Table 15, Fig. 16). While some of these sites had moderate to high cover class averages, they had an FQAI average of 6.3 or lower. This indicates a high ratio of invasive plant species such as Common reed (*P. australis*). For the erosion ranking, the sites had critical signs of erosion from extreme weather and high-wave energy. Additionally these sites did not match the site plans. A summary of all the LS study sites and natural reference wetlands can be found in the appendix.

Table 15. Summary of ratings from the top five least successful LS study sites (n = 5).

SURVEY CODE	COUNTY	WATERWAY	MARSH TYPE	STRUCTURAL COMPONENT	OVERALL VEGETATION RANKING (OVR)	OVERALL EROSION RANKING (OER)	OVERALL MARSH RANKING (OMR)	RATE OF SUCCESS
AA 55	Anne Arundel	Parish Creek	Marsh Establishment	Low Profile Sill	4.00	1.0	2.0	Unsuccessful
BA 4	Baltimore	Browns Creek	Marsh Establishment	Low Profile Sill	1.00	6.0	3.0	Unsuccessful
DO 1	Dorchester	Blackwater River	Marsh Establishment	Low Profile Sill	7.00	1.0	4.0	Unsuccessful
PG 2	Prince George's	Swan Creek	Marsh Establishment	Low Profile Sill	4.00	1.0	2.0	Unsuccessful
TA 50	Talbot	Kirks Creek	Marsh Establishment	Low Profile Sill	5.00	2.0	3.0	Unsuccessful

Figure 16. Photographs of the five lowest ranked LS study sites. For each photograph, survey code and overall marsh rank are given. Refer to Table 14 or appendix for additional information.

AA 55, OMR = 2.0

BA 4, OMR = 3.0

DO 1, OMR = 4.0

PG 2, OMR = 2.0

TA 50, OMR = 3.0

Discussion

This study aimed to evaluate: 1) if LS projects are capable of providing ecological services that are on par or greater than natural tidal wetlands, and 2) which indicators or other factors were impacting LS success. In regards to the LS projects success rate, although a few were unsuccessful, there were far more study sites that were rated successful and very successful. The very successful rating of the LS projects was also slightly greater than the reference wetlands. Based on the five most successful projects, their high scores appear to be the result of proper structural component installation and care for vegetation. If a structural component of an LS project, such as a low-profile sill, is not installed properly or given adequate gaps for sediment flow, then shoreward marsh may not develop (Smith 2006). In terms of vegetation care, it is key to have frequent inspections and necessary adjustments during an LS project's establishment period, for there to be natural ecological succession (Bilkovic et al. 2016). Therefore, by treating an LS project as an extension of your backyard can guarantee its success in the long run.

The OMR scores appeared to be influenced equally by its vegetation and erosion control indicators. The dominant vegetation species of the successful LS projects were mainly composed of Saltmeadow cordgrass (*S. patens*), and Smooth cordgrass (*S. alterniflora*). In a similar LS assessment done in the Newport River Estuary of North Carolina, *S. alterniflora* was capable of supporting an entire LS project (Davis et al. 2015). With a high percent coverage of vegetation, the effective LS projects could allow sediment to accrete and elevate at a constant rate, with the potential of producing new areas for the vegetation to expand (Neckles et al. 2002). Aside from the indicators of vegetation, fish biodiversity, and erosion control, the factors of square foot area size, adjacent land use, and adjacent structures were evaluated in regard to their impact on OMR. Even though minor positive relationships were seen in the linear regression and ANOVA tests, no statistical significance was found from the additional factors when assessing them with OMR. Thus, the current results of this study indicated that neither overall size or neighboring structures and activities are not the main agents driving the OMR scores. These results also imply that an increase in systematic and standardized monitoring of LS projects is necessary to find the site specific and overall agents and limitations of LS success (Bilkovic et al. 2016). During the fieldwork, some site specific limitations were massive amounts of detritus preventing plant growth and goose predation on vegetation. Some site specific agents of LS success were low-wave energy and high accretion rates. Overall limitations to the success of the observed LS study sites were high abundances of invasive plant species (ex. Phragmites) and high-wave energy; while overall agents for LS success were proper care of native vegetation and effective installation of structural components. This shall require enhanced public acceptance and coordination for LS projects, since up to 85% of the Chesapeake Bay is privately owned property (Bilkovic et al. 2016, Hardaway, Jr. et al. 2016).

Due to the limited time of this project, there is still much that could have been accomplished. If given more time, this project can include LS projects and reference wetlands from every MD county on the Bay for a stronger representative sample. Another aspect to expand upon is being more effective at collecting fish specimens, so that OWR can be fully incorporated into the LS success ratings. This could be done by trying different sampling methods, such as a casting net. Moreover, other factors such as fetch and tides can be incorporated to evaluate their possible effects on LS project success rates. This project can serve as a foundation for a long term study that can be done to assess the success of LS projects over the years. This potential long term study can be conducted by members of the MDE Tidal Wetlands Division, the Chesapeake Conservation Corps, and other organizations dedicated to the preservation of the Chesapeake Bay. Finally, it is hoped that the results of this project can be applied to provide proper LS project designs and promote them as a better ecological alternative to shoreline erosion control than armored structural controls.

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Appendix

MDE Living Shoreline Rapid Assessment Site Visit Data Sheet

Visit Information/Site Characteristics

Study Site: __________ Researchers: ____

Date: __________ Time: __________ Weather: ______________________________________

Tide at Visit (Circle One): High In-Between Low

Today's High Tide: ____________________ Today's Low Tide: _________________________

Gauge Station:____

Property Owner Present? (Circle One): Yes No Shoreline Orientation: _____________

Latitude: ____________________________ Longitude: ______________________________

Length: ________________ Width: ___________________ Fetch: ___________________

Adjacent Land Use (facing the water): Left ______________ Right _________________

Vegetation

Transect #/Qudrat #	Lat.	Long.	Species	Native/Invasive	Cover Class	FQAI	Health

CC Average: ___________ FQAI Average: ___________

Dominant (Top 3) Plant Species in Marsh:

____

OVR (1 = No vegetation; 10 = Highly diverse and healthy):_________

Wildlife

Seine	Lat.	Long.	Organism	# of Organisms
Seine 1				

OWR (1 = No signs of biodiversity; 10 = Extremely high biodiversity):_________

Erosion Control

Observations (ex. undercutting, slumping, scouring, or siltation):

____

Signs of Erosion Score (1-10): __________

Sight Plan Similarity Score (1-10): __________

OER (1 = Extremely excessive; 10 = None/Highly Stable):__________

Overall Marsh Ranking (Total of Previous Ranking): _________/30________

Additional Comments (ex. Sustainability, and Concerns of Property Owners):

____

Does it seem the Tidal Wetlands License plans were followed?

____

Table 16. Summary of success ratings from the LS study sites and natural reference wetlands (n = 59).

SURVEY CODE	COUNTY	WATERWAY	MARSH TYPE	STRUCTURAL COMPONENT	OVERALL VEGETATION RANKING (OVR)	OVERALL EROSION RANKING (OER)	OVERALL MARSH RANKING (OMR)	RATE OF SUCCESS
AA 9	Anne Arundel	Severn River	Marsh Establishment	Low Profile Sill	5.00	5.0	5.0	Moderately Successful
AA 12	Anne Arundel	Severn River	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
AA 43	Anne Arundel	Back Creek	Marsh Establishment	Low Profile Sill	8.00	6.0	7.0	Successful
AA 23	Anne Arundel	Almshouse Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
AA 20	Anne Arundel	Almshouse Creek	Marsh Establishment	Low Profile Sill	9.00	8.0	8.0	Successful
TA 19	Talbot	Tred Avon River	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
TA 31	Talbot	Goldsborough Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
TA 33	Talbot	Goldsborough Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
TA 34	Talbot	Balls Creek	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
TA 37	Talbot	Broad Creek	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
DO 2	Dorchester	Hudson Creek	Marsh Establishment	Low Profile Sill	6.00	4.0	5.0	Moderately Successful
DO 4	Dorchester	Fishing Creek	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
DO 1	Dorchester	Blackwater River	Marsh Establishment	Low Profile Sill	7.00	1.0	4.0	Unsuccessful
DO 13	Dorchester	Chesapeake Bay	Marsh Establishment	Low Profile Sill	7.00	9.0	8.0	Successful
RW 1	Dorchester	Blackwater River	Natural Wetlands	N/A	9.00	7.0	8.0	Successful

DO 8	Dorchester	Heron Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
BA 4	Baltimore	Browns Creek	Marsh Establishment	Low Profile Sill	1.00	6.0	3.0	Unsuccessful
RW 2	Baltimore	Saltpeter Creek	Natural Wetlands	N/A	4.00	7.0	5.0	Moderately Successful
AA 2	Anne Arundel	Stony Creek	Marsh Establishment	Low Profile Sill	6.00	7.0	6.0	Moderately Successful
RW 3	Anne Arundel	Chesapeake Bay	Natural Wetlands	N/A	9.00	10.0	10.0	Very Successful
PG 2	Prince George's	Swan Creek	Marsh Establishment	Low Profile Sill	4.00	1.0	2.0	Unsuccessful
RW 4	Prince George's	Patuxent River	Natural Wetlands	N/A	8.00	10.0	9.0	Very Successful
TA 30	Talbot	Trippe Creek	Marsh Establishment	Low Profile Sill	7.00	7.0	7.0	Successful
RW 5	Kent	Chester River	Natural Wetlands	N/A	8.00	10.0	9.0	Very Successful
QA 13	Queen Anne's	Chester River	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
QA 8	Queen Anne's	Little Greenwood Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
RW 6	Queen Anne's	Piney Creek	Natural Wetlands	N/A	7.00	7.0	7.0	Successful
QA 2	Queen Anne's	Shipping Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
TA 22	Talbot	Wye River East	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
TA 50	Talbot	Kirks Creek	Marsh Establishment	Low Profile Sill	5.00	2.0	3.0	Unsuccessful
AA 55	Anne Arundel	Parish Creek	Marsh Establishment	Low Profile Sill	4.00	1.0	2.0	Unsuccessful
AA 65	Anne Arundel	Jack Creek	Marsh Establishment	Low Profile Sill	7.00	10.0	8.0	Successful

RW 7	Anne Arundel	Jack Creek	Natural Wetlands	N/A	9.00	10.0	10.0	Very Successful
AA 10	Anne Arundel	Duvall Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
AA 38	Anne Arundel	Duvall Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
TA 25	Talbot	Island Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
TA 24	Talbot	Island Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
CA 1	Caroline	Choptank River	Marsh Establishment	Low Profile Sill	8.00	8.0	8.0	Successful
CA 3	Caroline	Choptank River	Marsh Establishment	Low Profile Sill	4.00	9.0	6.0	Moderately Successful
TA 10	Talbot	Holmes Creek	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
QA 5	Queen Anne's	Wye River	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
KE 3	Kent	Fairlee Creek	Marsh Establishment	Low Profile Sill	5.00	9.0	7.0	Successful
RW 8	Calvert	Chesapeake Bay	Natural Wetlands	N/A	7.00	8.0	7.0	Successful
CT 5	Calvert	Mears Cove	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
CT 4	Calvert	Battle Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
RW 9	Anne Arundel	Duvall Creek	Natural Wetlands	N/A	8.00	9.0	8.0	Successful
AA 11	Anne Arundel	Severn River	Marsh Establishment	Groin	9.00	10.0	10.0	Very Successful
AA 66	Anne Arundel	Mill Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
AA 16	Anne Arundel	Lake Ogleton	Marsh Establishment	Low Profile Sill	8.00	9.0	8.0	Successful

AA 35	Anne Arundel	South River	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
WO 5	Worcester	Ayer Creek	Marsh Establishment	Low Profile Sill	7.00	8.0	7.0	Successful
WI 1	Wicomico	Wicomico River	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
QA 18	Queen Anne's	Macum Creek	Marsh Establishment	Low Profile Sill	10.00	10.0	10.0	Very Successful
AA 57	Anne Arundel	West River	Marsh Establishment	Low Profile Sill	7.00	10.0	8.0	Successful
SM 14	St. Mary's	Smith Creek	Marsh Establishment	Low Profile Sill	8.00	10.0	9.0	Very Successful
RW 10	St. Mary's	Lake Conoy	Natural Wetlands	N/A	10.00	10.0	10.0	Very Successful
CH 11	Charles	Wicomico River	Marsh Establishment	Low Profile Sill	9.00	10.0	10.0	Very Successful
CH 3	Charles	Wicomico River	Marsh Establishment	Low Profile Sill	7.00	10.0	8.0	Successful
CH 4	Charles	Perry Branch	Marsh Establishment	Low Profile Sill	7.00	10.0	8.0	Successful