Developing Monitoring Plans for Living Shoreline Projects in Delaware: A Goal-Based Framework

A step-wise procedure for the selection of relevant metrics and appropriate methods to assess performance and adaptive management needs of tidal shoreline restoration projects

Acknowledgements

This document was produced by the Delaware Living Shorelines Committee, whose membership includes a diverse array of public, private, and academic entities engaged in the restoration activities and processes in the State of Delaware. The text and information provided in this document was compiled and edited by the Standards of Practice Subcommittee, which would like to acknowledge the contribution of concurrent work by the New Jersey Coastal Resiliency Collaborative, Science Subcommittee (formally the NJ Measures and Monitoring Workgroup), whose document A Framework for Developing Monitoring Plans for Coastal Wetland Restoration and Living Shoreline Projects in New Jersey provided a developmental foundation, and to which this document is intended to be complimentary.

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Recommended Citation

Delaware Living Shoreline Committee. *Developing monitoring plans for living shoreline projects in Delaware: A goal-based framework.* A report prepared by the Delaware Living Shorelines Committee Standards of Practice Subcommittee. April, 2018.

https://www.delawarelivingshorelines.org/

DELAWARE LIVING SHORELINES COMMITTEE

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Introduction

Delaware's natural tidal shorelines are home to a diverse array of ecological functions. In addition to being a key part of the natural aesthetics of our coastline, shoreline habitats help provide a variety of ecosystem services including**:** water filtration and nutrient cycling; carbon sequestration; erosion and flooding abatement; nursery habitat for recreational and commercial fisheries; and the bolstering of Delaware's tourist economy. In addition, natural shorelines retain key connections between the water to land which is critical for wildlife and a highly functioning and resilient coastal ecosystem.

Despite these shorelines having a certain level of adaptability and resilience, severe rates of coastal habitat degradation and loss, due to anthropogenic disturbances (e.g., shoreline hardening, development, hydrological alterations, and past agricultural practices), sea level rise, and changes in storm frequency, severity, and tracking, have translated into losses of ecosystem services and functions. In the Delaware Estuary, approximately an acre per day of coastal wetlands are converting into mud flats and then open water (Partnership for the Delaware Estuary 2012). Recent data for New Jersey indicated a loss of approximately 1,755 acres of wetlands per year between the years of 1986 and 1995 (Balzano et al. 2002). In addition, Delaware's status and trends shows a net loss of 238.2 acres of estuarine vegetated wetland loss between 1992-2007 (Tiner et al. 2011).

When natural habitats are restored or enhanced through a variety of treatments and technologies (a.k.a. tactics) to benefit both wildlife and human communities, the restoration community describes these tactics as being in the family of *natural and nature-based solutions* (NNBS). Natural and nature-based solutions have been utilized for decades, but interest in these techniques (including living shorelines) has increased significantly since Superstorm Sandy which devastated portions of our developed North Atlantic coastline while more natural areas fared much better, demonstrating a remarkable natural resilience. This simple and obvious observation, experienced by the public, NGOs, agencies and politicians alike, formed the basis of numerous NNBS initiatives. Living shorelines represents one family of NNBSs.

Living shorelines utilize nature-based treatments and techniques which provide a net ecological benefit (uplift) along segments of the shoreline cross section (i.e., supratidal, intertidal, or subtidal). For tidal systems, the term "Living Shoreline" represents a number of treatments and techniques that:

- Offer resilience to shorelines from acute wave and/or surge energies, chronic tidal and wake energies, and/or rises in sea level;
- Utilize predominantly natural materials and/or processes exclusively, or in combination with, a structural (hybrid) component; and
- Sustain, enhance, and/or restore ecological functions and connections between uplands and aquatic areas.

NATURAL AND NATURE-BASED SOLUTIONS (NNBS)

NNBS generally refer to the sustainable management and use of nature for tackling societal challenges such as climate change, water security, food security, human health, and disaster risk management, which provides ecosystem services and ecological uplift benefits.

The goal of a living shoreline is to provide net ecological uplift to the project area. Generally, the term "living shoreline" is not used to describe standalone structural techniques such as rip-rap, bulkheads, groins, sills, jetties, artificial reefs, wave breaks, and/or pure beach nourishment projects, where an ecological function focus is typically absent or limited. But, restoration efforts constructed in conjunction with the techniques listed above, can be considered a part of living shoreline effort when the result of the project is a measureable increase in ecological function- the "living" portion of the living shoreline.

The Statewide Activity Approval (SAA) for Shoreline Stabilization Projects in Tidal and Non-tidal Waters of the State of Delaware has segregated the various types of living shorelines into three categories: Conventional; Energy Dissipating; and Armored. The conventional category of living shorelines represents traditional, predominantly natural, forms of living shorelines. The Energy Dissipating and Armored categories represent two types of "hybrid" living shorelines, normally consisting of a conventional component with a structural component incorporated to address wave energies in excess of conventional living shoreline tolerances. The two types of hybrids are segregated based upon how wave energy interacts with the structural component and the ecological potential of the structural component. The three types of living shorelines are defined in the SAA as follows:

A ***Conventional Living Shoreline*** consists of treatments and techniques consisting entirely of naturally based treatments.

- These naturally based treatments can include, but are not limited to: living biomass (e.g., vegetation and shellfish), dead biomass (e.g., coir fiber materials, logs, natural organic debris and litter), and natural earthen material (clays, silts, sands, shell, and similar up to gravel-sized grain size) acquired from or are representative of that naturally occurring at, or near, the site.
- Conventional Living Shorelines typically are constructed in low energy systems.
- The most common examples of conventional methods include: coir fiber logs and oyster shell bags.

Conventional Living Shorelines are typically constructed in low energy systems, and at sites where active accretion is desired.

An ***Energy Dissipating (attenuating) Living Shoreline*** consists of treatments and techniques that may be used for Conventional Living Shorelines, but will also have the addition of structural features prepared and deployed in a pattern that:

- Functions predominantly to attenuate energy and ideally provide for measureable accretion or sediment accumulation;
- Has the documented ability to provide aquatic habitat improvement on, within, and/or nearby the structure itself; and
- Allows for the passage of macro aquatic organisms in and throughout its deployment area (predominantly linear deployments of structure with occasional gaps or deployment breaks do not generally meet this criterion).

Energy Dissipating Living Shorelines are typically constructed in moderate to high energy systems, and at sites where passive accretion is desired.

An ***Armored Living Shoreline*** consists of treatments and techniques used for Conventional Living Shorelines, plus the addition of a hard structural feature (such as marsh-toe revetments and sills). A marsh toe revetment consist of a line of free standing rock constructed in front of an existing functioning marsh, while a marsh toe sill consists of a line of free standing rock (sill) placed just offshore of an eroding shoreline with sandy fill placed between the sill and the eroding bank upon which marsh grasses are planted to create a protective marsh fringe. Armored Living Shorelines are constructed and deployed in a pattern that:

- Functions predominantly to diffract and/or deflect energy through the creation of a continuous or near continuous structural deployment (e.g., marsh-toe revetments and sills). ;
- Has lower ability to provide aquatic habitat improvements on and within the structure itself, but may provide aquatic habitat improvements in other indirect ways (e.g., lower energy zones, current edges, topographic variations); and
- Allows for the passage of macro aquatic organisms at specified gaps or deployment breaks.

Armored Living Shorelines are typically constructed in moderate to high energy systems.

The United States Army Corps of Engineers Nationwide Permit for living shorelines (NWP 54) Decision Document describes a living shoreline as follows:

> *"A living shoreline has a footprint that is made up mostly of native material. It incorporates vegetation or other living, natural "soft" elements alone or in combination with some type of harder shoreline structure (e.g., oyster or mussel reefs or rock sills) for added protection and stability. Living shorelines should maintain natural continuity of the land-water interface, and retain or enhance shoreline ecological processes. Living shorelines must have a substantial biological component, either tidal or lacustrine fringe wetland or oyster or mussel reef structure."*

Although agency/group-specific definitions of living shorelines can vary, the general core concepts associated with living shorelines are consistent among most agencies.

Recently, living shoreline adaptation techniques are emerging aimed at using living shoreline tactics to retrofit, or provide a more natural façade, to developed shorelines. Since there is typically some form of pre-existing structure, armoring, and/or infrastructure in place, the design has to integrate the existing components and needs into the NNBS applications. Living shoreline retrofits may be unable to meet the full level of ecological uplift potential that exists for undeveloped reach of shoreline, however, when considering the pre-existing level of ecological function present in an urban setting relative to an undeveloped reach of shoreline, the *net gain* in ecological function is often comparable between the two settings. Furthermore, living shoreline retrofits may offer greater potentials for outreach, aesthetics, and ecosystem services. Whether working with a natural undeveloped shoreline or in more developed areas, this framework is applicable.

Although acute events, such as Superstorm Sandy, have generated increased interest in living shorelines, there have been relatively few local case studies regarding their effectiveness in meeting site-specific goals under a variety of conditions. A structured monitoring approach is an effective way to increase our understanding regarding the development and impacts of living shorelines. Through the implantation of standardized monitoring techniques across practitioners, data generated at unique projects can be used to inform, and track, the trajectories of projects utilizing similar designs, and assess the effectiveness of specific techniques in meeting specific goals.

This document provides guidance on developing monitoring plans for tidal living shoreline projects in Delaware, and includes a process for selecting and integrating ecological and ecosystem services monitoring metrics across a spectrum of project specific, technological development, and coastline resilience needs. By following the process outlined in this framework, the data collected can be utilized to improve project design, site-specific tactic selection, adaptive management, and fill data gaps on benefits provided by restored or enhanced coastal habitat.

Objective and Scope

Objective

This document is intended to be used as a framework to guide Delaware living shoreline practitioners, from a variety of backgrounds, in the development of a monitoring plan to assess their projects' performance (both in terms of the general effectiveness of the living shoreline tactic, and of a project's ability to meet its specific ecological and/or ecosystem service goals), and to help inform adaptive management actions. The intended user groups of this document include, but are not limited to, academic institutions, environmental non-profits, regulatory agencies, restoration professionals, community organizations, funding agencies, citizen science groups, and private landowners. To address varying levels of user experience, a wide range of monitoring methods are offered. Rigorous methods require a greater level of expertise, expense, and/or time investment. Alternatives to rigorous methods are identified where applicable which can be employed on little to no monitoring budget, are less time-intensive, and/or can be performed by citizen science groups and landowners.

In addition to tracking and improving individual projects, adoption of this framework by practitioners in Delaware is intended to pave the way for increased implementation of NNBS projects. This document has been developed for the purpose of providing the following benefits:

- Improvement of living shoreline project designs in order to meet specific ecological and ecosystem services goals as they pertain to the factors and influences "driving" the project (Drivers);
- Guiding restoration practitioners in the development of monitoring plans for living shorelines aimed to assess their living shoreline project's ability to meet the identified goals;
- Guiding the metric and methodology selection for data collection, which will help pave the way for the implementation of appropriate and resilient NNBS projects;

- Provide for more consistent across-project data collection, leading to improved: standard of project design; appropriate identification of goals; tactic selection; temporal and resilience expectations; and adaptive management needs;
- Informing the permitting process with regard to living shoreline tactics; and
- Communicating the ecological and ecosystem services benefits of coastal habitats to stakeholders and the general public, which in turn can lead to increased funding and support for NNBS and the conservation and restoration of coastal habitats.

Scope

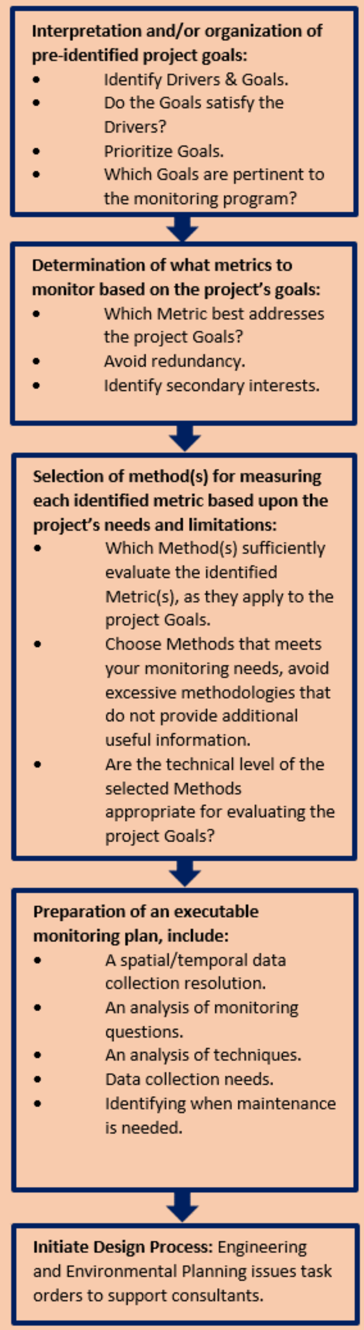
This document is intended to provide the practitioner with a step by step approach for the development of a monitoring plan for a living shoreline project. More specifically, the document offers direction and guidance for the following (see Figure 1):

1. Statement of project goals and objectives;
2. Identification of relevant metrics for determining whether a project is, or will likely meet its goals (i.e. developmental trajectory)
3. Selection of appropriate methods based on a variety of user-specific qualities and conditions
4. Preparation of an executable monitoring plan that will include:
    a. Relevant metrics with their paired appropriate methods;
    b. Applicable spatial/temporal data collection resolution;
    c. Analysis question(s) and method(s);
    d. Links to appropriate methodological SOPs;
    e. Intervention guidance
5. Provide guidance on information sharing (e.g., pass on lessons learned from the project to the applicable restoration community).

A monitoring plan developed using this document may support the development of a Quality Assurance Project Plan (QAPP), which may be required if a project received federal funds.

This document is not intended to guide the practitioner in choosing a restoration technique for their project, nor is it intended to help the practitioner choose project goals. It is important that these be established while developing a project and associated monitoring plan. However, the user may find that reviewing the description of Project Goals (Section V) and

Figure 1



the recommended metrics in this document to be useful for clarifying existing project goals and/or developing a monitoring budget. Also, this framework is meant to be a starting point, and additional guidance may be needed to satisfy special requirements issued by funders or regulatory agencies.

Monitoring Framework Overview

This framework provides a set of tables that guide the user in the selection of relevant metrics and appropriate methods to the development of a monitoring plan and for delivering results in a succinct manner. There is a broad spectrum of monitoring options available to gauge the performance of living shoreline projects. Decisions regarding which metrics and methods to implement are dependent on the project type, project drivers, project goals, the end-uses of the data, and user constraints that may limit monitoring efforts, such as budget and expertise. These considerations are used to tailor the development of a project specific monitoring plan. Monitoring plan development follows a stepwise process (Figure 1):

1. Identify and prioritize the project drivers and goals
2. Quantify/State project objectives
3. Select relevant metrics for each goal
4. Select appropriate methods for each metric
5. Design monitoring plan:
    a. Fill out monitoring plan template
    b. Extract output tables for insertion into pre-existing plan template
6. Collect monitoring data
7. Conduct metric analysis

Monitoring Plan Design

Living shoreline projects are developed to meet one or more overall goals, described in more detail in the next section. From those goals, objectives (e.g. specific target outcomes) are developed which define the desired conditions intended to result from implementation of a specific project. Objectives do not have to be numerous or detailed, but they should be SMART – Specific, Measurable, Achievable, Relevant, and Time-fixed (Adamcik et al. 2004). Many agencies conducting natural resource management and restoration utilize these concepts in their planning (e.g., NOAA, IWRR, and USFWS National Wildlife Refuges). This section provides an overview of the relationship between these project planning elements and the development of a suitable monitoring plan.

Monitoring is intended to measure whether a living shoreline project is meeting its goal(s) through achieving outlined objectives, and/or to identify potential adaptive management needs. It is important that there is a targeted set of outcomes pre-defined for a project before implementation, against which progress can be measured. A strong monitoring plan will contain specific questions related to the objectives which will be answered through the analysis of data collected during monitoring plan implementation. This document is intended to guide the user in identifying metrics relevant to their projects goals, and in selecting methods appropriate to their experience level, skill set, and budgetary requirements.

As a monitoring plan is developed, consider the overall monitoring design that is possible for the project, given its setting and the resources available, and that would best meet the level of rigor desired. Four basic reasons for monitoring a living shoreline project are:

1) Evaluation of project effectiveness – It is important that specific metrics are measured to evaluate whether or not goals and objectives are being met. This is the most basic reason for monitoring.
2) Maintenance – Monitoring of certain metrics could reveal when a project is in need of maintenance, in order to continue meeting its stated objectives, and to preserve the overall investment that has gone into the project.
3) Adaptive management – Similarly, project monitoring allows the project owner to determine when changes in the design or construction may be necessary
4) Enhancement of science and management understanding – Because living shorelines are still an emerging approach to coastal restoration and management, monitoring projects of all types will help improve future design and implementation on other sites.

The design of the monitoring plan may depend in part on which of these reasons are important to the agency or entity constructing the project (e.g., a private homeowner may not have the resources or desire to increase scientific and management understanding, but a state natural resource agency will).

Ideally, the monitoring plan will follow a "**BACI**" design – **Before, After, Control, Impact**. At a minimum, most monitoring should begin prior to installation of the project, as well as be conducted after completion (Before-After). When possible, monitoring should involve measuring and comparing metrics in both the project area, and a nearby untreated location (Control-Impact). This level of design may not be possible or appropriate for all projects, but should be implemented as feasible, in order to increase the level of confidence in the causal connection between the project and the outcomes observed. Implementing monitoring before a project is constructed enables the user to monitor progress through all of these monitoring stages:

1) Baseline Monitoring – Collection of data prior to the installation of the project represents the baseline ecological conditions against which future data would be compared.
2) As-Built Survey – This monitoring ensures that the project was constructed according to design specifications. It is often conducted by the contractor that builds the project, but also contributes to a baseline understanding of site conditions and metrics that are expected to change over time as the user continues monitoring.
3) Performance Monitoring – This is the monitoring that will provide the user with information over time on how well the project is meeting the stated goals and objectives, by measuring progress toward defined target outcomes.

Although the BACI implies a high level of rigor and statistical training to employ, in its essence it is merely a spatial and temporal scheme for collecting data- where and when are data collected? When data is collected at the appropriate spatial and temporal resolutions, analysis can answer questions related to the overall objectives of the projects goals (e.g.):

- Has the position of the contiguous vegetated edge moved waterward since project implementation?
- Has the percent cover of invasive species been reduced since project implementation?
- Has the shellfish community density increased since project implementation?

By explicitly stating a question relevant to a specific metric and the projects stated objectives, users of this framework are able to verify that the data intended for collection will have analytical value. Analysis can be conducted using high and low rigor methodologies as well. A two-way ANOVA design is recommended as a high rigor analysis method of data in a BACI format (or one-way ANOVA if using either BA or CI data), but simple comparisons of averages over time would be an appropriate low-rigor method to assess trends and trajectories. All together, these elements – goals, objectives, and the overall sampling design – will form the backdrop of the monitoring plan. The specific metrics to measure and methods used to measure them, discussed below, will be developed against that backdrop. Ultimately it will all be documented in a concise but thorough monitoring plan, as described in Section IX.

Project Drivers

Drivers represent the source and nexus of a project, that is:

- Why is the project necessary? and,
- What fundamental elements control the project's trajectory?

Examples of drivers may be the result of a community's concern about the reoccurring damage along a portion of their shoreline. Drivers could also be associated with larger landscape-level Federal or State policy, mission, or legislature. Fundamental elements of the project may be associated with: funding sources, including restrictions and/or limitations; specifically-required species management endpoints or measureable improvements; or a court settlement requirement. Identification of project drivers provides a context for project implementation, and as such, the project objectives and scope must successfully address their intents and/or requirements. Proper project monitoring provides the means to demonstrate that project drivers have been successfully addressed.

Project Goals

The goals of a living shoreline project should be a general description of the desired long-term ecological or biological outcomes associated with the project (IWWR 2003). Goals address the primary purpose or purposes and drivers of the living shoreline project to be implemented. The following is a list of the project goals that have been identified as most important for living shoreline projects in Delaware and are addressed in this framework:

Shoreline Position (Horizontal/Vertical)

Living shorelines are constructed alone the linear edge of beaches, coastal wetlands, and developed shorelines. These edges are under pressure from natural erosional forces including waves, storm surge, tides, and upland drainage, in concert with sea level rise, and possible human-induced forces such as boat wakes. Projects with a primary goal of influencing shoreline position are designed to stabilize the coastlines where they are installed, thus reducing the horizontal landward migration of the shoreline and/or creating conditions for the facilitation of vertical sediment accretion. One of the most common reasons that living shorelines are constructed is to slow rates of erosion along a targeted stretch of shoreline.

Habitat

Delaware's coasts include important feeding, roosting, and nursery habitat for a number of fish and wildlife species of concern, including some which are commercially valuable, important to recreation, or are threatened or endangered. Some living shoreline projects may be intended to either protect sensitive coastal wetland habitats situated just behind them, create conditions for the expansion of such wetlands, and/or to improve the habitat quality of the coastline itself, such as reefs and beaches.

Water Quality

One of the most important ecosystem services of Delaware's coastal habitats is that of improving water quality, through filtering that takes place in coastal wetlands or is conducted by shellfish that rely on coastal habitats. Heavily altered shorelines are less capable of providing this service effectively. Some living shoreline projects may be implemented primarily to maintain or improve water quality by facilitating reductions the concentrations of nutrients, contaminants, and/or suspended solids that can negatively impact ecosystems, fish and wildlife, and human health.

Selection of Project Goals

This framework is not intended to guide the selection of goals for a living shoreline project. We recommend that goals be defined in advance with the input of a variety of stakeholders who have an interest in the project, to ensure all stakeholder values are taken into consideration and to increase support for the project. These goals represent the likely purposes for the development of living shorelines projects. The chosen goal or goals will depend on a number of factors, such as the location of the project, the primary responsibility of the entity developing the project, the values of the various stakeholders, and/or the funding source being used. However, it is also true that these goals are often interconnected – a project designed primarily to stabilize the shoreline position along a sensitive and eroding stretch of beach may result in improved habitat quality, as sediment is captured and vegetation is increased. They are not mutually exclusive, but it is important that goals be identified in advance, because they will drive not only the details of project design, but the restoration targets, or objectives, defined for monitoring the progress toward meeting the project goals.

Defining Project Objectives

Project objectives should be derived from the goal statement, defining specific, measurable targets. One goal may generate multiple objectives. In this application, objectives could also be considered target outcomes. A target outcome may define specific outcome (such as a targeted elevation, percent cover by vegetation, or population of oysters), or may define a desired trajectory, or directionality and rate (for example, shoreline erosion rate reduced over time to an acceptable annual rate).

Objectives do not need to be numerous or extremely detailed. But, they should contain the elements that make them "**SMART**" – **Specific, Measurable, Achievable, Relevant, Time-fixed** (Adamcik et al. 2004). This will keep monitoring focused and enable the effective selection of metrics to be measured in order to monitor progress toward meeting goals. Defining objectives can be accomplished though asking questions related to the goals of the project – e.g., "How will I know if shoreline position is being maintained? How can I measure it given my resources?" and "How will I know if habitat quality is improved? How can I measure it given my resources?" This approach would lead to objectives which can vary in level of detail depending on the user. Some goals may lead to more than one stated objective and associated target outcome. In some cases, more than one monitoring activity may be necessary to measure progress toward the target outcome. Selection of Metrics and Methods is discussed further in the next section. The following are brief examples of goals and potential objectives, illustrating the relationship between these elements.

Goal – <u>Shoreline Position</u>
Objective a – Along 300 feet of shoreline where the project is installed, the rate of landward shoreline erosion will be reduced by at least 50% (compared to the rate prior to installation) over the next 5 years
Objective b – Along the 500 feet of shoreline, the elevation along 75% will be positioned between mean water and mean high water within 3 years

Goal – <u>Habitat Quality</u>
Objective a – Within 5 years, the project area will develop 1.5 acres of vegetated tidal marsh
Objective b – Within 5 years, the project area will support 75% or more coverage by native tidal marsh vegetation
Objective c – Within 5 years, the project area will support a tidal marsh community with belowground biomass and integrity comparable to nearby reference marshes

Relevant Metrics

After project goals and objectives have been designated, metrics can be selected to measure the project's success. **Metrics are specific parameters used to assess project performance and determine if project goals have been, or are on a trajectory to be, satisfied.** Metrics are delineated into two groups: core metrics which we recommend collecting on all projects; and conditional metrics which may only be relevant for specific project designs. For example, not all projects will be designed to increase biodiversity, but if it is a goal of the project, it is recommended that it be monitored. It is also recommended that photo documentation occur for every metric being measured. In addition to providing evidence that a project is either currently, or is on track to, meet its goal(s), goal based metrics can also help inform the need for adaptive management (e.g. evidence of nuisance species encroachment driving action to reduce their presence). Project metrics for each goal are listed in its associated Metric and Method Table in Appendix A.

Users should determine early in the process if they have enough resources to cover monitoring for all goals. This document provides multiple methods for each metric that will require varying levels of resources to complete. It is important to understand what level of data will be collected from the chosen method and if it is rigorous enough for the project at hand. It's also possible that one method may provide data for multiple metrics (e.g., estimating percent plant cover per meter squared can provide data for both vegetation structure and cover of nuisance species). Successful monitoring of the project is directly related to having sufficient resources for the chosen methods and that the project goals are answered by the data collected.

Identifying Restoration Targets

Restoration targets are set for each metric that has been selected. Restoration targets are the uplift or change that is expected to occur in the project. The changes the user expects to see over the course of the project monitoring are considered restoration targets. The goals of the project are translated into statements that can be proven by the metric and methods being measured. “Targets may be expressed in terms of a set desired outcome, a change from baseline condition, a difference from control site conditions, or even a desired trajectory” (Yepsen et al. 2016, pg. 14). When incorporating new designs and technologies into a project it is important to leave room for uncertainty in how these projects will perform and the time frame for them to mature and achieve the desired results. Achieving restoration targets can take time. Physical conditions (e.g. near-shore wave climate, shoreline buffering, elevation along an intertidal area, etc…) are altered during the implementation phase of a project which the local biological community, the living component of a living shoreline, will respond to over time. Biological response time may differ among community components (e.g. vegetation may colonize a restoration project more quickly than sub-surface invertebrates), and as such the temporal targets for various targeted responses may differ. It is encouraged to use the most recent scientific literature relating to living shoreline design and success in identifying restoration targets. Newer restoration techniques will likely require more generalized targets and may need to be redefined as monitoring data are evaluated. However, if a project is using a well-documented design, detailed restoration targets may be appropriate. “For example, a project using an established and well-understood technique with a goal of decreasing shoreline erosion may have a target outcome of a reduction in erosion to less than 5” per year by 2020, whereas the target outcome for a less established technique could be a simple decrease in erosion rate from baseline conditions or control site conditions” (Yepsen et al. 2016, pg. 15).

Monitoring plans can be developed to have one defined end target that indicate if the project goals have been achieved or they can be setup with interim targets. Having interim targets at set intervals throughout the monitoring period can allow the user to perform adaptive management if the project is not on the desired trajectory. “For example, if a living shoreline project has an end habitat goal target of 85% vegetation cover by 2020, an interim target for 2018 could be set at 50%. If the vegetation monitoring in 2018 indicates less than 50% vegetation cover, the user could decide to supplement natural vegetation with plantings to ensure 85% cover is reached by 2020” (Yepsen et al. 2016, pg. 15). Limited monitoring timeframes may preclude some metrics from achieving their restoration targets. For example, if the target is an increase in a target species such as black ducks, it may take several years for the project to provide the desired habitat necessary and require an extensive monitoring timeframe to meet the target outcome. Multiple options are available to the user if this is the case. Options include using less expensive ways to continue monitoring into the future by using less rigorous methods, decreasing monitoring frequency, using citizen scientists or other volunteer groups and partnering with additional agencies. Another option is to collect enough data while monitoring resources are available to show that restoration targets will be accomplished based on data showing the establishment of satisfactory trajectories. Trajectories should be based on existing scientific studies. Using several of the options listed above in creative ways can improve the likelihood of meeting the projects monitoring goals.

Appropriate Methods

Once metrics and restoration targets are defined based on project goals, monitoring methods can then be selected for each metric. **Methods are the actual techniques that are used to collect data on a metric, whether it be in the field or a computer based assessment** (Yepsen et al. 2016)**.** Multiple methods spanning a wide range of resources and expertise have been identified for each metric. It's also imperative to determine if the user has the technical ability to assess the methods appropriately. Methods options are listed in the metrics tables in Appendix A. The list of methods provided in the tables is not intended to be exhaustive, rater, they are intended to include a suite of methods (minimum of 2) that represents a range of rigor, have been peer-reviewed, and have associated standard operating procedures available. This document includes citations of SOPs for some methods, additional SOPs will be added as time and resources allow.

Doubling-Up on Methods

It may be practical for users to implement both intensive and less intensive methods at the start of a project to extend the monitoring timeframe. Cross-calibrating more intensive methods to less intensive methods during the initial phases of data collection may allow for continued long-term monitoring of a project using the less intensive methods after the close of a grant or depletion of monitoring funds. For example, shoreline position is listed as a core metric for projects. Shoreline position can be collected with high precision and rigor using advanced GPS equipment, or with lower precision and rigor by measuring the change in the position of the shoreline over time from an established benchmark. If both methods are employed during the first few years of the project when more funds are available for monitoring, the project will have high resolution data that is helpful for assessing initial trajectories and calibrating low resolution methods. Low resolution data that can be continued by citizen scientists or landowners past the initial few years of monitoring funding is important to track major changes and flag any issues that might arise (Yepsen et al. 2016, pg. 16).

Photo Documentation

It's highly recommended that photo documentation is provided for all metrics in addition to quantitative assessments. For example, if horizontal position of the vegetated edge is a selected metric, using fixed point photo documentation and a RTK-GPS survey would provide ample data on how the horizontal position of the marsh is changing. For photo documentation it is important to consider tidal stage and weather conditions during monitoring that may affect the comparability of sampling events. Determining a photo documentation strategy for each metric is an approach that is suited for all user groups and can easily extend monitoring past funding limits using citizen scientists.

Additional User Considerations

The Additional User Consideration column in the Goal-Based Metric Tables (Appendix A) is intended to help the user select the appropriate method for metric assessment. The appropriate method for a user is depended on variety of user and project-specific qualities including the following as described in Yepsen et al. (2016 pg. 16-17):

- **Technical Expertise:** The degree of technical knowledge needed by the user to employ the method or data analysis varies. For example, measurements of elevation change using an RTK-GPS require survey and GIS training, whereas the installation of measuring posts with height demarcations does not. The inclusion of this consideration informs the user that this method requires the user to have some degree of technical expertise and/or training.

- **Temporal Requirements:** Time requirements to document a change or seasonal considerations for a metric or method vary. It is important to consider the timeframe of the project and funding when selecting metrics and methods. Some methods cannot be used to evaluated metrics in short timeframes (e.g., elevation processes via SETs), whereas others can (e.g., position of shoreline via RTK survey). Additionally, some metrics may require that data is collected in specific seasons (vegetation metrics need to be taken during the summer). Time-frames also apply to the collection of baseline data, where more time may be needed to reduce the error from abnormal variations that may have occurred in a single year. Developing a monitoring plan within a known time-frame required by the data or funding group will enable the user to select metrics and methods that are the most useful in evaluating progress toward meeting restoration targets and goals. The inclusion of this consideration informs the user that this method has temporal requirements regarding sample collection.

- **Collection Time Investment:** Different methodological techniques may require different time commitments in terms of data collection, sample processing, and analysis. For example, evaluating vegetation productivity is a time intensive metric because processing above-ground and below-ground biomass samples are both time intensive methods. Conversely, the measurement of accretion, whether using a ruler, marker horizon, or a RTK-GPS is a metric that can be collected more quickly. However, there can be tradeoffs between rapid and time intensive methods. For example, for the metric vegetation structure, stem counts are a more labor intensive method than horizontal vegetative obstruction, but may have differences in resolution or data transferability that are meaningful to the user. The inclusion of this consideration informs the user that this method will require a relatively greater time investment than a rapid method; including, but not limited to, multiple measurements, and/or extended sensor collection/installation time.

- **Cost:** Cost may increase based upon the relative expense of the method and/or the study design. Being aware of the range of costs associated with method options will help in deciding which method to adopt within the constraints of the monitoring budget. The inclusion of this consideration informs the user that this method requires monetary investment in order to collect data, including, but not limited to, equipment costs, contracting costs, and/or processing costs.

- **Permitting:** In some cases, permits or permission may be needed for a particular method. For example, shellfish harvesting or fish collection as part of monitoring may require a state or federal permit and flying a drone will require landowner and other agency permissions. Different states have different state, regional and local regulations so it is important to know what is needed at the local, regional, state, and national levels. Some permits can take a while to obtain and can be costly and these considerations should be built into the timeline and budget. The inclusion of this consideration informs the user that this method may require a special permit or general permission of local officials. The requirements may differ by location, but the user will want to clarify this within their locality.

- **Suited for All User Groups:** Some methodologies do not require any of the above considerations, and as such, are appropriate for users of any skill level. Even though these may not be technical in their application, these methods will provide usable data for the evaluation of relevant metrics for each project goal. For example, to measure the horizontal change in shoreline position, a technical methodology such as a RTK-GPS survey is commonly used by restoration professionals. But this metric can also be evaluated through the change in distance between the shoreline edge and a permanent marker (e.g. PVC post) over time. Although there is a potential difference in resolution, accuracy, and precision between the two methods, both provide quantitative data regarding change over time. Another example of a method suitable for all user groups is the counting of plant stems in permanent monitoring plot. The inclusion of this consideration informs the user that this methods is applicable for all levels of experience and technical ability.

It is recommended that SOPs are consulted prior to method selection to ensure that chosen methods are appropriate for both the user and the project parameters.

Monitoring Plan Development

A monitoring plan is a document specifically describing the methods and extent (spatial and temporal) of data collection for the evaluation of specific metrics. It should be developed prior to project implementation to maximize relevant data acquisition. As certain agencies/entities may already have specific monitoring documentation formats, while other groups may be without any formal templates, the aim of this document is to provide the user with two choices regarding output:

A. A series of three tables describing the monitoring plan and data collection process including:
    1. Monitoring Metric Table
    2. Monitoring Timeline Table
    3. Performance Tracking Table

B. A monitoring plan template to be filled-out by the user, including the three tables above

Tabular Output

The purpose of providing tabular output is to offer the user a succinct way to summarize the monitoring processes and results that can be inserted into agency-specific reporting formats.

Monitoring Metric Table

The monitoring metric table provides a singular overview of the entire monitoring and analysis processes of a project. Columns in this table summarize the majority of the output of this monitoring framework and include:

A. Goal: The overall goal which the subsequent metric is relevant to
B. Objective: The desired outcome for the subsequent metric
C. Metric: The specific parameter to be evaluated
D. Method: the chosen methodology for data collection
E. Temporal Resolution: When data collection for this metric will take place
F. Spatial Resolution: Where data collection for this metric will occur (e.g. number of replicates and spacing; stratified vs. equal intervals)
G. Analysis Question: Question to be tested by analytical method
H. Analysis Methods: Methodology to answer analysis question (e.g. calculate averages and compare annually-low rigor; BACI 2-way ANOVA-high rigor)

Monitoring Timeline Table

The monitoring timeline table summarizes and tracks all monitoring activities over the course of the project. This table will organize the monitoring timeline and may be useful for identifying the temporal resolutions appropriate for certain metrics (e.g. certain metrics may have longer timeframes for discerning changes and thusly spacing between sampling dates can be extended; certain metrics may display a high level of variability through time and thusly spacing between sampling dates may be shortened to capture a higher resolution of data). Columns include:

A. Collection Window: Dates between which data are collected
B. Monitoring Stage: Time period relative to project implementation when data are collected (i.e. baseline data; as-built data; after-built)
C. Metric: The specific parameters to be evaluated
D. Method: the chosen methodology for data collection
E. Collected On: the actual date of collection

Performance Tracking Table

The performance tracking table provides an overview of the changes in each metric throughout the projects history to gauge whether the project is meeting its goal-based objectives. This table acts as snapshot of project trajectories and how they may change over time. Columns include:

A. Goal: The overall goal which the subsequent metric is relevant to
B. Objective: The desired outcome for the subsequent metric

C. Metric: The specific parameter to be evaluated
D. Analysis Question: Question to be tested by analytical method
E. Baseline Value: The original value collected during baseline monitoring
F. As-Built Value: The value collected during baseline monitoring (this may be a more relevant value to compare against; e.g. if fill is brought in subsequent values may be compared to the as-built value to determine changes, but placed in context of the baseline values as what would be present if no-action occurred)
G. After-Built (1, 2, 3 ,etc.): Columns to document the values and changes from either the Baseline or As-Built values for each time period

Monitoring Plan Template

If a full monitoring plan document is needed, this document provides a template from which a complete, including the tables described above, monitoring plan can be written. The monitoring plan should clearly state the monitoring strategy for gauging whether a living shoreline project is either currently meeting, or on track meet its stated goals. It should clearly state its goals and objectives and summarize the relevant metrics for which data will be collected and the methods appropriate to the user which will be employed for data collection, as well as the spatial and temporal scale at which it will be collected. Sections to provide this information are explicitly delineated within the monitoring plan template, and the summary tables provide an "at-a-glance" view of all relevant information. A monitoring plan template is provided in Appendix D.

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Appendix A: Goal-Based Metric Tables

Materials			
Class	Metric categories	Method options	Additional user considerations
Core	Visual Description	Photo from Permanent Marker	Suited For All User Groups
	Position of Structure	RTK-GPS	Technical Expertise; Cost
		Aerial Photograph	Technical Expertise; Cost; Temporal Requirements
		Surveying Instrument (Barcode Leveling)	Technical Expertise; Cost
		Distance from Installed Post or Existing Structure	Suited For All User Groups
	Structural Integrity of Materials	Observation	Suited For All User Groups

Appendix B: Description of Metrics

Goal: Shoreline Position

Class	Metric	Methods	Additional User Considerations
Core	Visual Discription	Photo from Permanent Marker	Suited For All User Groups
	Horizontal Position	RTK-GPS	Technical Expertise; Cost
		Aerial Photograph	Technical Expertise; Cost
		LiDAR	Technical Expertise; Cost
		Surveying Instrument (barcode leveling)	Technical Expertise; Cost
		Distance from Permanent Post of Other Structure to Shoreline	Suited For All User Groups
Conditional	Vertical Position (Elevation)	Rtk gps	Technical Expertise; Cost
		Lidar	Technical Expertise; Cost
		Surveying Instrument (Barcode Leveling)	Technical Expertise; Cost
		Laser Level Height Relative to Position on Permanent Post or Other Structure	Suited For All User Groups
	Foreshore Slope (Area Between High and Low Water)	RTK-GPS	Technical Expertise; Cost
		LiDAR	Technical Expertise; Cost
		Laser Level Height Relative to Position on Permanent Post or Other Structure	Suited For All User Groups
		Thermal Imaging	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
	Accretion (m/year)	Surveying Instrument (Barcode Leveling)	Technical expertise; Cost
		Sedimentation Disc/Tile/Plate/ Marker Horizon	Temporal Requirements; Collection Time Investment; Cost
	Wave Energy or Height and Amplitude (Wind/Wake)	Measuring Stick/Monuments	Suited For All User Groups
		Gauges and Buoys (e.g., Acoustic Doppler Current Profilers for Wave Energy and Stream/Creek Flow)	Technical Expertise; Collection Time Investment; Cost
		Water Level Loggers	Technical Expertise; Collection Time Investment; Cost
		Graduated Survey Rod	Temporal Requirements; Collection Time Investment; Cost
		Plaster or Gypsum Ball/ Clod Card Dissolution	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
	Vegetation Productivity	Biomass (Above and/or Belowground)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
	Vegetation Community Composition	List of Species Found at Site/Plant Diversity	Suited For All User Groups, Temporal Requirements
	Nuisance Species	Cover per m2, Stem Counts per m2, or Presence/Absence	Suited For All User Groups, Temporal Requirements
	Vegetation Structure	Horizontal Vegetative Obstruction	Temporal Requirements; Cost
		Vertical Light Attenuation	Temporal Requirements; Cost
		Cover per m2	Suited For All User Groups, Temporal Requirements
		Number of Stems per m2	Temporal Requirements; Collection Time Investment

Goal: Habitat			
Clas	Metric	Method	Additional User Considerations
Core	Visual Discription	Photo from Permanent Marker	Suited For All User Groups
	Vegetation Community Composition	List Species Found At Site (Plants)	Suited For All User Groups, Temporal Requirements
Conditional	Target Species (Flora and/or Fauna)	Observations/Counts (E.G., Horseshoe Crabs, Terrapins)	Suited For All User Groups, Temporal Requirements
		Biomass (Wet Weight Or Dry Weight/ M2) (E.G., Plants, Nekton, Mussels)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost; Permitting
		Cover Per M2 Or # Per M2 (E.G., Percent Cover Of Sav, # Of Fiddler Crab Boroughs, # Of Fish In A Sample, Ribbed Mussel Lip Counts)	Suited For All User Groups, Temporal Requirements
		Morphometric (E.G., Length Of Nekton Or Oysters)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost; Permitting
		Health (E.G., Condition Index, Of Bivalves)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost; Permitting
		List Of Species Found At Site (E.G., Nekton Or Benthic Infauna)	Suited For All User Groups, Temporal Requirements
		Recruitment (E.G., Oysters)	Suited For All User Groups, Temporal Requirements
		Feeding And Breeding Behavior (For Avian Target Species)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost; Permitting
	Soil Texture	Grain Size And Soil Type Analysis	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
	Belowground Stability	Vane Shear Strength	Technical Expertise; Cost
		Bearing Capacity	Cost
	Vegetation Productivity	Photograph (Fixed Point)	Suited For All User Groups; Temporal Requirements
		Plant Tissue Nutrient Analysis (C/N)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
		Landsat/Infrared Imagery	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
		Biomass (Above And/Or Belowground)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
		Number Of Stems Per M2 And Stem Height Of Dominant Species	Temporal Requirements; Collection Time Investment
	Salinity	Refractometer	Cost
		Meter (Total Dissolved Solids)	Cost
	Dissolved Oxygen	Meter (Total Dissolved Oxygen)	Cost
	Area of Habitat	GPS	Cost
		Aerial Photography	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost
	Nuisance Species	Nuisance Number Of Stems Per M2	Suited For All User Groups; Temporal Requirements; Collection Time Investment
		Nuisance Cover Per M2	Suited For All User Groups; Temporal Requirements
		Presence/Absence	Suited For All User Groups; Temporal Requirements
	Inhibition of Fauna Movement	Observations	Suited For All User Groups; Temporal Requirements
	Vegetation Structure	Horizontal Light Obstruction	Temporal Requirements; Cost
		Vertical Light Attenuation	Temporal Requirements; Cost
		Cover Per M2 (For Each Plant Species Or Total Cover By Plant Species)	Suited For All User Groups; Temporal Requirements
		Stem Heights Of Dominant Species	Temporal Requirements; Collection Time Investment
		Number Of Stems Per M2	Temporal Requirements; Collection Time Investment
		Habitat Type %, 50M Radius (E.G., High Marsh, Low Marsh, Invasives, Pannes And Pools Etc.)	Temporal Requirements; Collection Time Investment
	Horizontal Position	RTK-GPS	Technical Expertise; Cost
		Aerial Photograph	Technical Expertise; Cost
		LiDAR	Technical Expertise; Cost
		Surveying Instrument (barcode leveling)	Technical Expertise; Cost
		Distance from Permanent Post of Other Structure to Shoreline	Suited For All User Groups
	Vertical Position (Elevation)	Rtk gps	Technical Expertise; Cost
		Lidar	Technical Expertise; Cost
		Surveying Instrument (Barcode Leveling)	Technical Expertise; Cost
		Laser Level Height Relative to Position on Permanent Post or Other Structure	Suited For All User Groups

Goal: Water Quality			
Class	**Metric**	**Methods**	**Additional User Considerations**
Conditional	Dissolved Oxygen	Meter (Do)	Cost
		Titration Kit	Cost
		Winkler Titration	Technical Expertise; Cost; Temporal Requirements
	Turbidity	Meter (Turbidity)	Cost/expense; specialized equipment
		Clarity Tube	Suited for all User Groups
		Secchi Disc	Suited for all User Groups
	Sediment Supply / Total Suspended Solids	Filtration	Technical Expertise; Cost; Temporal Requirements
	Pollutants (Nutrient or Other)	Filtration (Lab Tests Tkn, Etc.)	Technical Expertise; Cost; Temporal Requirements
		Laboratory Analysis	Technical Expertise; Cost; Temporal Requirements
		Manometric Method	Technical Expertise; Cost; Temporal Requirements
		Colorimeter	Technical Expertise; Cost; Temporal Requirements
	Water - Bacteria	Lab Analysis (Cfus)	Technical Expertise; Cost; Temporal Requirements
	Ph	Titration Kits	Cost
		Colorimeter	Cost
		Meter (Ph)	Cost
	Salinity	Refractometer	Cost
		Meter (Total Dissolved Solids)	Cost
	Algal Bloom	Chl A Tests (Lab Or Sensor)	Technical Expertise; Cost; Temporal Requirements
	Water BOD	Dilution Method Epa Method 5210B	Technical Expertise; Cost; Temporal Requirements
	Temperature	Meter	Cost
		Thermometer	Suited for all User Groups
	Filtration Capacity	Field Counts/Measurements And Calculations	Technical Expertise; Temporal Requirements

Appendix C: Monitoring Plan Tables

Rows populated in the following table provide example of what a final, completed table should include. Text in red indicated low rigor methods for the data collection, resolutions, and analysis of listed metrics.

Figure 1 Monitoring Metric Table

Goal	Objective	Metric	Methods	Temporal Resolution	Spatial Resolution	Analysis Question	Analysis Method
Shoreline Position	Vegetated edge moves waterward from original position	Horizontal Position of Vegetated Edge	1. Photo-Doc 2. RTK-GPS Survey 3. Distance from permanent marker	Annual: Spring and Late Summer/Fall	Collected along the contiguous vegetated edge (~1m) Three equally spaced transects	Did the horizontal position of the marsh change; in what direction?	1. PhotoPoint-FixedPoint 2. DSAS (Timeseries) ArcGIS 3D Analyst 3. Average change in position per year
Shoreline Position	Marsh surface elevates to be between mean water and mean high water	Vertical Position of Marsh	1. Photo-Doc 2. RTK-GPS Survey 3. Elevation above a permanent marker	Annual: Spring and Late Summer/Fall	Collected along each transect (~1m) and in each monitoring plot (n=15)	Is the vertical position of the marsh appropriate for marsh vegetation?	1. PhotoPint-FeatureBased 2. BACI ArcGIS 3D Analyst 3. Average change in vertical position

Figure 2 Monitoring Timeline Table

Collection Window	Monitoring Stage	Metric	Method	Collected On
March 2014	Baseline	1. Platform Elevation 2. Position of Shoreline	1. RTK Grid Survey 2. RTK Targeted Point Survey	1. Date 2. Date
April 2014	As-built	Material Vertical/Horizontal Position	1. RTK Targeted Point Survey	1. Date
March 2015	After-built 1	1. Platform Elevation 2. Position of Shoreline 3. Material Position	1. RTK Grid Survey 2. RTK Targeted Point Survey 3. RTK Targeted Point Survey	1. Date 2. Date 3. Date
March 2016	After-built 2	1. Platform Elevation 2. Position of Shoreline 3. Material Position	1. RTK Grid Survey 2. RTK Targeted Point Survey 3. RTK Targeted Point Survey	1. Date 2. Date 3. Date
March 2017	After-built 3	1. Platform Elevation 2. Position of Shoreline 3. Material Position	1. RTK Grid Survey 2. RTK Targeted Point Survey 3. RTK Targeted Point Survey	1. Date 2. Date 3. Date

Figure 3 Progress Tracking Table

Goal	Objective	Metric	Analysis Question	Baseline	As-Built	After-Built 1		After-Built 2		After-Built 3	
Shoreline Position	Vegetated edge moves waterward from original position	Horizontal Position of Vegetated Edge	Did the horizontal position of the marsh change; in what direction?	Measured Value	Measured Value	Measured	Change	Measured	Change	Measured	Change
Shoreline Position	Marsh surface is between mean water and mean high water	Vertical Position of Marsh	Is the vertical position of the marsh appropriate for marsh vegetation?	Measured Value	Measured Value	Measured	Change	Measured	Change	Measured	Change

Appendix D: Monitoring Plan Template

Site

Dates Active

Project Lead

Partners

Project Design Team:

Point of Contact:

Monitoring Plan Design Team:

Point of Contact:

Monitoring Implementation Team:

Point of Contact:

Project Type

Description of the over-all project including the type of living shoreline being installed (bio-based, hybrid, etc...) or restoration technique being employed that requires a structured monitoring program.

Project Drivers, Goal(s), and Objectives

List project goal and provide reasoning for this goal being selected (e.g.: erosion control as goal due to value of infrastructure behind shoreline or value of habitat, etc...). State project objectives as monitoring actions that will be taken to assess the ability of the project to meet its defined goal. See PDE monitoring framework for a listing and description of restoration types and goals.

Drivers:

Goal(s):

Objectives:

Project Location

Provide GPS coordinates of project centroid and short description of the project area/location. Provide map as Figure 1.

Treatment Description

Description of treatment and control (if applicable) designs including: relationships to existing structures on site; replications; and components. Detail should be reflective of the current stage of project and should be updated throughout the course of the project to reflect any, and all changes or adaptive management activities. Previous entries should not be altered, but a new section should be added by date. This section will serve as a journal of the conception and evolution of treatments/installations.

Endpoints

Description of the parametric value or temporal scale that will dictate the completion of the project according to permit(s).

Monitoring Tasks

Metrics of interest required by monitoring plan and associated methods used for data collection. Provide monitoring table from Monitoring Frame work including reasoning for methodologies chosen. Methods in red indicate techniques that require specialized equipment, knowledge, permitting, or training. Methods in green indicate techniques that do not require and specialized, equipment, knowledge, permitting, or training besides on-site instruction for from trained staff. **Photo documentation is a mandatory monitoring task at ALL visits to a project site as well as a monitoring task on all monitoring dates.**

Table 1 Monitoring Metric Table

Goal	Objective	Metric	Methods	Temporal Resolution	Spatial Resolution	Analysis Question	Analysis Method
Shoreline Position	Vegetated edge moves waterward from original position	Horizontal Position of Vegetated Edge	1. Photo-Doc 2. RTK-GPS Survey 3. Distance from permanent marker	Annual: Spring and Late Summer/Fall	Collected along the contiguous vegetated edge (~1m) Three equally spaced transects	Did the horizontal position of the marsh change; in what direction?	1. PhotoPoint-FixedPoint 2. DSAS (Timeseries) ArcGIS 3D Analyst 3. Average change in position per year
Shoreline Position	Marsh surface elevates to be between mean water and mean high water	Vertical Position of Marsh	1. Photo-Doc 2. RTK-GPS Survey 3. Elevation above a permanent marker	Annual: Spring and Late Summer/Fall	Collected along each transect (~1m) and in each monitoring plot (n=15)	Is the vertical position of the marsh appropriate for marsh vegetation?	1. PhotoPint-FeatureBased 2. BACI ArcGIS 3D Analyst 3. Average change in vertical position

Sampling Frame

Description of the area within which data will be collected, referenced to existing structures, relative position within the local tidal spectrum, and three-dimentional fetaures of interest (e.g: tops of structural components). GPS coorinadtes (4 minimum) demarcating the bounds of the sampling frame are to be listed. These corrdinates are to be collected during the first survey (see Table 2 below). Include a map of the sampling frame as Figure 2.

Sampling Frame Coordinates

A.
B.
C.
D.

Sampling Design Type and Spatial Resolution

Description of the sampling methodologies/techniques employed (e.g. systematic non-random grid sampling, targeted point sampling, stratified random sampling, etc...), the spatial resolution at which the methodologies will be employed, and their associated metrics from Table 1. **All metrics from Table 1 need to be accounted for under one of the Sampling Design Types listed below**.

Sampling Temporal Resolution

Description and table of planned sampling events including large scale factor level events such as site characterization, baseline data collection, as-built surveying and annual monitoring, as well as seasonally focused monitoring such as vegetation monitoring occurring during maximum growth seasons and aerial survey during leaf-off seasons.

Table 2 Monitoring Timeline Table

Collection Window	Monitoring Stage	Metric	Method	Collected On
March 2014	Baseline	1. Platform Elevation 2. Position of Shoreline	1. RTK Grid Survey 2. RTK Targeted Point Survey	1. Date 2. Date
April 2014	As-built	Material Vertical/Horizontal Position	1. RTK Targeted Point Survey	1. Date
March 2015	After-built 1	1. Platform Elevation 2. Position of Shoreline 3. Material Position	1. RTK Grid Survey 2. RTK Targeted Point Survey 3. RTK Targeted Point Survey	1. Date 2. Date 3. Date
March 2016	After-built 2	1. Platform Elevation 2. Position of Shoreline 3. Material Position	1. RTK Grid Survey 2. RTK Targeted Point Survey 3. RTK Targeted Point Survey	1. Date 2. Date 3. Date
March 2017	After-built 3	1. Platform Elevation 2. Position of Shoreline 3. Material Position	1. RTK Grid Survey 2. RTK Targeted Point Survey 3. RTK Targeted Point Survey	1. Date 2. Date 3. Date

Recommended Minimum Long-Term Monitoring

Description of the recommended monitoring past the duration of the stated monitoring timeline

It is recommended that all metrics with associated methods that do not require and specialized, equipment, knowledge, permitting, or training besides on-site instruction for from trained staff (indicated in green in the Monitoring Tasks Table (1) above) continue to be collected annually subsequent to the end date of the project with the following exception:

- Photo Documentation from Fixed Photo Points: This metric should be collected twice annually
    - A. Early Spring: before the plants emerge from senescence
    - B. Late Summer: When maximum vegetative growth is visible

Statistical Methodology

Description of the statistical methods that will be used to evaluate data (e.g. BACI design, 2-way ANOVA, multiple-regression, etc...)

A before-after statistical analysis will be conducted as a one way ANOVA to detect changes in metrics as a result of the installation. Factor levels will be: Before Installation; As-Built; and After Installation. Additionally, changes in metrics of interest will be evaluated for coincidences with changes in other metrics and correlative relationships.

Sampling Methodologies

Progress Tracking

Goal	Objective	Metric	Analysis Question	Baseline	As-Built	After-Built 1		After-Built 2		After-Built 3	
Shoreline Position	Vegetated edge moves waterward from original position	Horizontal Position of Vegetated Edge	Did the horizontal position of the marsh change; in what direction?	Measured Value	Measured Value	Measured	Change	Measured	Change	Measured	Change
Shoreline Position	Marsh surface is between mean water and mean high water	Vertical Position of Marsh	Is the vertical position of the marsh appropriate for marsh vegetation?	Measured Value	Measured Value	Measured	Change	Measured	Change	Measured	Change