A Framework for Developing Monitoring Plans for Coastal Wetland Restoration and Living Shoreline Projects in New Jersey

Recommended data collection and evaluation of project performance to facilitate adaptive management and improve future project designs

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Executive Summary

Monitoring of coastal restoration projects is needed in order to assess project performance (both in the general effectiveness of the restoration technique and in regard to meeting project-specific ecological and/ or socioeconomic goals) and to inform adaptive management. This document provides guidance on how to select monitoring metrics and develop a monitoring plan for coastal wetland restoration and living shoreline projects in New Jersey. Because it is important for all projects to have some level of monitoring, this framework is intended to cover a variety of coastal wetland restoration and living shoreline techniques and be adaptable to the needs of users from a range of backgrounds - from those with little experience and small budgets, to experts with larger budgets who may plan to publish their findings and advance the understanding of living shoreline and wetland restoration activities.

The document was written by the NJ Measures and Monitoring Workgroup, whose membership included experts from ecological non-profits, universities, state and federal agencies, National Wildlife Refuges, and an environmental consulting firm. This is the first working draft of what we hope will be a living document that evolves with the field of restoration. The framework itself has been kept intentionally inclusive and concise so that it will be accessible to a wide range of users. The framework is meant to be applied after project goals have been selected and does not cover project design. We recommend consulting with restoration professional regarding method selection, data analysis, and result interpretation. **Although the document was written with NJ restoration projects in mind, the document does not have any regulatory implications for federal or state permitting requirements.**

The framework walks through the process of developing a monitoring plan for living shoreline and wetland restoration or enhancement projects. During this process, users select metrics that are relevant to their projects' goals and restoration type. The document then provides a list of common methods for collecting data on each metric. Finally, recommended components of a monitoring plan are suggested with a monitoring plan template that can be filled out for specific projects. Tables that facilitate the selection of metrics and methods, metric definitions and lists of resources are located in the appendices.

In addition to assisting in the development of monitoring plans for individual projects, this framework encourages the use of standardized metrics, common data collection methods, and sharing of data and lessons learned from projects. This will help to enhance local understanding of the ability of specific restoration techniques in meeting their goals and hopefully pave the way for increased implementation of appropriate natural and natural-based solutions. By assessing coastal restoration projects with a common set of metrics and sharing lessons learned, we can expect three major advantages: 1) improved technique selection and project design that better meets site-specific ecological and socioeconomic goals, 2) a better informed and interactive permitting process, and 3) increased funding and support for natural and nature-based solutions based upon the greater understanding of the ecological and socioeconomic benefits.

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I. Introduction

Coastal habitats, like wetlands and natural shorelines, provide a myriad of socioeconomic and ecological benefits that have been widely acknowledged. Beyond being a key part of the natural aesthetics of our coast, these vital habitats provide a variety of services including water filtration, carbon sequestration, reduced erosion and flooding, nursery habitat for recreational and commercial fisheries, nesting and foraging ground for important avian species, and they help boost the tourist economy through spending by visitors. In addition, wetlands and natural shorelines provide a smooth transition from water to land which is critical for wildlife and healthy ecosystems.

However, severe rates of coastal habitat degradation and loss, due to development, sea level rise, and increasing storm frequency and severity, translate into a loss of socioeconomic and ecological habitat benefits. In the Delaware Estuary, approximately an acre per day of coastal wetlands are vanishing and converting into mud flats and then open water (Partnership for the Delaware Estuary 2012). Recent data for New Jersey shows a loss of approximately 1,755 acres of wetlands per year between 1986 and 1995 (Balzano et al. 2002).

When natural habitats are restored or enhanced through a variety of methods to benefit both wildlife and human communities, we call it **natural and nature-based solutions (NNBS)**. Since Superstorm Sandy, there has been increased interest in using NNBS as a defense against coastal storms and sea level rise. These innovative coastal resilience techniques, such as living shorelines and tidal wetland restoration and enhancement[1], provide promising new approaches to shoreline protection and enhancement. Since 2007, partners have been developing NNBS for the Mid-Atlantic region and a handful of pilot projects have been installed.

> **NATURAL AND NATURE-BASED SOLUTIONS (NNBS)**
>
> *Solutions to societal challenges (such as property loss due to coastal erosion, water quality degradation, or a decline in commercial fish species) that utilize natural features in a way that provides economic, social, and environmental benefits.*

As additional coastal restoration and enhancement projects are planned and designed to meet ecological and socioeconomic goals, it has become more important to have a process to gauge project performance. Although many studies have demonstrated the benefits that NNBS provide, data gaps exist (Barbier 2013; Cunniff and Schwartz 2015). For instance, while it is known that salt marshes provide coastal resilience benefits to communities during storms, little is known about how those benefits vary during larger and smaller events; faster and slower moving events; and storm events of varying durations (Sutton-Grier, Wowk, and Bamford 2015). This framework provides that much-needed process for selecting and integrating ecological and socioeconomic metrics, and developing a monitoring plan for coastal wetland restoration and living shoreline projects. By following the process outlined in this framework, the data collected can be utilized to improve project design, site-specific technique selection, adaptive management, and fill data gaps on benefits provided by restored or enhanced coastal habitat.

This document provides guidance on developing monitoring plans for two types of NNBS projects that

[1] The terms restoration and enhancement are used interchangeably in this document because the same process for developing a monitoring plan and selecting metrics can be used on both types of projects.

are of particular interest in coastal New Jersey: living shorelines and tidal wetland restoration. **Living shorelines** are built or engineered structures that incorporate native flora and fauna to stem erosion and provide an ecological benefit to the surrounding habitat (i.e., ecological uplift). Techniques currently being investigated include: bio-based tactics, comprised solely of natural materials and native plants and animals; and hybrid tactics (e.g. marsh sills) which couple bio-based designs with harder structures that reduce wave energy and provide ecological enhancement. **Tidal wetland restoration and enhancement techniques** are varied and typically are larger scale than living shoreline projects. They can be used to: help marshes gain elevation, restore natural tidal hydrology, and/or maintain native wetland plant and animal communities. These restoration practices include, but are not limited to, beneficially reusing dredge material to increase marsh elevation or restore spatial extent, restoring hydrologic function to marshes previously altered for human purposes (e.g., mosquito ditching, diking, Open Marsh Water Management (OMWM), etc.), and rebuilding native plant communities.

The science and coastal management community has a shared interest in improving the design of NNBS projects. However, there has been little assessment of the performance of these projects under a wide range of conditions and limited analysis of the long-term viability of these practices. ***It is therefore vital that the performance of implemented projects be assessed with regard to their ability to 1) stem the loss of coastal habitats; 2) meet ecological and socioeconomic goals such as habitat enhancement, clean water, and flood reduction; and 3) hold up under increasingly severe environmental conditions and under daily stresses.*** This is best accomplished by having some level of monitoring on every project, increased standardization of monitoring used to assess project performance, and the sharing of data and lessons learned from local projects.

II. Objective and Scope

OBJECTIVES

This document is intended to be used as a framework to guide New Jersey coastal restoration practitioners, from a variety of backgrounds, in the development of a monitoring plan to assess their coastal restoration projects' performance (both in terms of the general effectiveness of the restoration technique and in terms of a project's ability to meet its specific ecological and/ or socioeconomic goals), and to inform adaptive management or maintenance actions. **The intended user groups of this document include, but are not limited to, academics, environmental non-profits, regulatory agencies, restoration professionals, community organizations, funding agencies, citizen science groups, and private landowners.** Because of the broad range of project sizes and user groups, an equally broad range of methods are offered - from those that are rigorous and might be expensive and/or time-consuming, to those that are less rigorous, and can be done on little to no monitoring budget and/or are less time-intensive.

Beyond improving individual projects, adoption of this framework by practitioners in New Jersey is intended to pave the way for increased implementation of NNBS projects. It promotes more consistent data collection and sharing of lessons learned from projects, which in turn can be used to: 1) improve restoration and living shoreline project designs in order to meet specific ecological and socioeconomic goals, 2) inform the permitting process, and 3) communicate the ecological and socioeconomic 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 walk the practitioner through the steps shown in Figure 1, which are necessary for developing a monitoring plan for a living shoreline or tidal wetland restoration project. More specifically, the document covers the following areas, *after* a project type and goal have been selected:

1. decide what aspects (referred to in this document as **metrics**) of the project to monitor based on the project's design and goals,
2. select methods for measuring each metric based on the user's skill, budget, and other considerations,
3. provide a process for integrating ecological and socioeconomic metrics and data collection when appropriate, and
4. write an executable monitoring plan that will help the practitioner to collect data, identify when maintenance is needed, and pass on lessons learned from the project to the local restoration community.

A monitoring plan developed using this document will be helpful in developing 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,[2] and it is also not intended to help the practitioner choose project goals – it is important that these be established while developing your project and before developing a monitoring plan. However, the user may find that reviewing the description of Project Goals (Section V) and the recommended metrics in the tables in Appendix A is useful for clarifying existing project goals and/or developing a monitoring budget.

Most importantly, **this framework is meant as a starting point**, and additional guidance may be needed to satisfy special requirements issued by funders or regulatory agencies. There are many existing, and more extensive, guidance documents available on monitoring for coastal systems (an incomplete list can be found in Appendix E). That being said, this framework is among the only existing frameworks that provides the user with such clear guidance on recommended ecological and socioeconomic metrics (found in Appendix A).

III. How to Use This Framework

This framework is built around a number of tables (located in Appendix A) that guide the user from the selection of metrics and methods based on their project design, goals, and other user considerations, to

[2] Developed as part of the Resilience Coastlines Initiative, the Restoration Explorer is an on-line tool that supports the initial step in identifying and planning potential shoreline enhancement projects to help stabilize and strengthen New Jersey's shorelines. http://coastalresilience.org/project-areas/new-jersey-introduction/

the development of a monitoring plan. There is one table for each project type (tidal wetland restoration and living shoreline) and one for each goal (the five goals covered by this document are discussed in the next section). The users select each table that is relevant to their projects and extract the metrics and methods appropriate for their projects from the tables.

There is a broad spectrum of monitoring options available to gauge the performance of wetland restoration and living shoreline projects. Decisions regarding which metrics and methods to implement are dependent on the project type, 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) in which the user, in collaboration with the restoration project team:

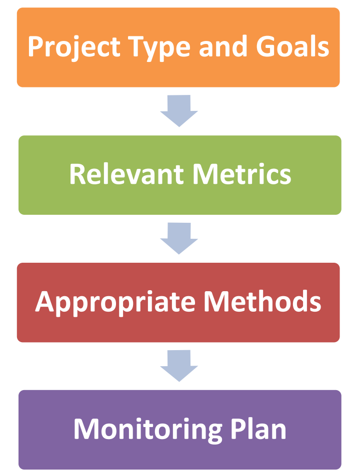

Figure 1. Stepwise progression of monitoring plan development

1. Identifies the project type and goal(s), including prioritization of goals if there are multiple;
2. Identifies relevant metrics for both the project type and goal(s);
3. Selects appropriate methods to measure the metrics based on user considerations and planned uses for the monitoring data; and
4. Develops a monitoring plan.

There are two **Project Type** tables: Living Shoreline and Tidal Wetland Restoration. Project type tables contain metrics regarding the basic structure and function of the project (e.g., is the wetland a functioning wetland or is the living shoreline maintaining its form and function).

There are five **Project Goal** tables. Project goal tables contain metrics used to evaluate whether or not a project-specific goal has been met (e.g., if the living shoreline has a goal of reducing erosion, tracking changes in shoreline position is important; if the wetland restoration project has a goal of increasing fish production, it is important to monitor fish in the project site). The five categories of goals covered by this document are:

Monitoring Tip #1:

*A **metric worksheet** that can be filled out as the user goes through the document is located in Appendix F.*

- Erosion Control,
- Water Quality,
- Habitat Enhancement,
- Hydrologic Enhancement, and
- Socioeconomic Enhancement.

Project goals are discussed further in Section V. Metrics selection is discussed further in Section VI. The metrics tables, located in Appendix A, provide a list of recommended metrics for each project type or goal, as well as a short list of the most likely socioeconomic metrics associated with a project type or goal. There are very few resources on monitoring of coastal restoration projects that provide such concise metric tables with specific recommended metrics; thus, the tables provided in Appendix A are a valuable resource for those who adopt this framework. The metric tables are organized as follows:

Layout and Definitions for Metric Tables

Class	Metric categories	Method options	Additional user considerations

Class (Column 1): Differentiates core metrics from conditional metrics and identifies socioeconomic metrics that are likely to be applicable to the project type or projects with this goal. **Core** metrics should be collected on all projects of a given type or with a specific goal. **Conditional** metrics are those that will only apply to some projects, but that should be collected on all projects where the design or site specific conditions make the metric important. (See section V)

Metric (Column 2): Metrics are the actual parameters that are used to gauge whether a project has met its goals and design. Metrics are discussed in section VI. A description of each metric is provided in Appendix B. All core metrics and conditional metrics that are important to the project's success should be included in the monitoring plan as well as socioeconomic metrics associated with socioeconomic goals of the project.

Method (Column 3): For each metric, a variety of common method options are listed. **Methods** are the way that data is collected for a metric. An attempt was made to provide methodological options for a variety of projects and user types. Method selection is discussed in section VII. Compiling a complete list of peer-reviewed detailed methods or Standard Operating Procedures (SOPs) for recommended methods was beyond the scope of this project, but links to some detailed methods are included in Appendix D.

User Considerations (Column 4): Next to each method option, the user consideration column lists some top attributes of a method that need to be taken into account by the user before selection of the method. The information in this column allows the user to rule out certain methods based on the skill level of the user, required equipment, time, or expense. User considerations are discussed in section VII.

IV. Monitoring Plan Conceptualization

Project performance is gauged by the evaluation of metrics related to the goals or design of a project. **Metrics** are measurable physical, chemical, biological, and/or socioeconomic aspects of a restoration project or the areas they impact. They are used to estimate and track the state of critical aspects of the project. **Monitoring plans** document when, where and how data will be collected for the evaluation of these metrics (i.e., **methods**). Development of a monitoring plan early in the project design process, provides the user *a priori* knowledge regarding potential spatial and/or temporal data gaps, and ensures that all relevant information is collected in a meaningful and coordinated way.

Components of a monitoring plan include project goals; metrics and detailed methods; target outcomes; spatial and temporal sampling design; and data management and analysis approach. More detail on each of these is provided in section VIII. These plans are most useful if they include these basic ingredients and are implemented before installing the project. By implementing a monitoring plan before project installation, the practitioner is able to gauge project performance through a series of monitoring stages:

1. Baseline Monitoring
2. As-Built Survey
3. Performance Monitoring

- **Baseline monitoring:** monitoring and data collection conducted prior to installation that serves as the starting ecological and socioeconomic conditions of the site. Baseline monitoring documents the condition against which all future monitoring will be compared. This allows the practitioner to better make a causal linkage between actions and the changes that are observed. It can also suggest refinements to the restoration plan or changes to the metrics included in the monitoring plan (e.g., if one of the project goals is to improve water quality by reducing nitrate loads, but the baseline monitoring shows that nitrate levels are already below detectable levels, the user does not need to spend the resources to monitor nitrates or include it as a project goal).

> **Monitoring Tip #2**
>
> *To show a stronger causal link between the restoration project and an outcome, consider adding a control site for a full **BACI (Before, After, Control and Impact)** design. A **Control** site is an area that has the same baseline conditions as the **Impact** site where the project is installed, but that will not be affected by the restoration. By taking identical measurements at each site, both **Before** and **After** project implementation, the user can better evaluate the project's effect.*

- **As-built survey:** monitoring conducted soon after construction, typically by the contractor who builds the project, to demonstrate that the project meets engineering and design specifications. While some of the metrics used for the as-built survey will be the same as those used to gauge project performance, some will be different. This document does not cover developing an as-built survey plan, but ideally the two types of data collection will be coordinated. NNBS projects are not always built exactly to design, so the as-built survey data is also important data to have when considering management decisions and assessing the performance of a project.

- **Performance monitoring:** monitoring conducted periodically after installation that compares the condition of the site to the baseline and as-built conditions, or stated target outcomes, to document progress toward meeting project goals. Performance monitoring can also help inform the need for adaptive management or maintenance if the project is not performing as expected. For socioeconomic metrics, performance monitoring may take place at the project site, or may take place outside of the project site, as it is dependent upon where project beneficiaries are located.

V. Project Type and Goals

The first step in developing a monitoring plan involves identifying the project type and goals. Below are definitions of the project types and goals addressed within this framework.

PROJECT TYPE

This document can be used to develop monitoring plans for the following types of coastal restoration and enhancement projects:

1. *Living shorelines,* which include,
   - Natural living shorelines
   - Hybrid living shorelines
   - Structural living shorelines
2. *Tidal wetland restoration*, which include,
   - Elevation changes (i.e., proper positioning within local tidal range)
   - Rebuilding wetlands that have been lost due to excavation or erosion
   - Hydrologic changes (i.e., restoring optimal tidal flow)
   - Restoring native flora/fauna

A <u>living shoreline</u> is a method of shoreline stabilization that protects the coast from erosion while also preserving or improving environmental conditions (i.e., ecological uplift). Living shorelines are implemented in <u>coastal areas</u> that are tidally influenced, generally in the intertidal and shallow subtidal zones. Living shorelines represent a number of treatments and techniques that:

- Offer resilience to shorelines from acute or chronic wave energy and/or rises in sea level;
- Utilize predominantly natural materials and processes exclusively or in combination with a man-made structural component (hybrid); and
- Sustain, enhance, and/or restore ecological functions and connections between uplands and aquatic areas. A living shoreline must result in a net increase in ecological function (e.g., vegetation, substrate, water quality, wildlife utilization, etc.).

This is accomplished through the strategic placement of plants, stone, sand, or other structural and organic materials **that result in net ecological uplift**. There are three types of living shorelines:

1. **Natural living shorelines** include native vegetation, submerged aquatic vegetation, fill, and biodegradable organic materials.
2. **Hybrid living shorelines** incorporate native vegetation, submerged aquatic vegetation, fill, and/or biodegradable organic materials with low-profile rock structures such as segmented sills, stone containment, and/or living breakwaters seeded with native shellfish.
3. **Structural living shorelines** include, but are not limited to, revetments, break-waters, and groins that have been designed to increase ecological function to adjacent areas (more so than a traditional hardened structure) and maintain the gradual transition from land to water.

<u>Wetland restoration</u> for the purposes of this document refers to practices that either restore or enhance one or more functions of tidal wetlands that have been degraded or are threatened by human activities or sea level rise. "**Wetland functions** are defined as a process or series of processes that take place within a wetland. These include the storage of water, transformation of nutrients, growth of living matter, and diversity of wetland plants, and they have value for the wetland itself, for surrounding ecosystems, and for people" (Novitzki et al. 1997). Wetland restoration and enhancement methods include:

- Reintroducing or correcting tidal flow by breaching dykes, changing channel morphology, plugging or filling ditches, and other methods;
- Recreating marsh area that had been lost due to excavation or erosion;
- Changing the elevation of the marsh so that it receives optimal tidal flow by excavating fill or adding sediment to drowning marshes; and
- Managing flora and fauna; for example to remove nuisance or invasive species and re-establish native wetland species.

PROJECT GOALS

In order to evaluate the success of a living shoreline or wetland restoration project, the project must have well defined goals. The Society of Ecological Restoration defines ecological restoration goals as the desired "states and conditions that an ecological restoration effort attempts to achieve. Written expressions of goals provide the basis for all restoration activities, and later they become the basis for project evaluation" (Clewell et al. 2005). **Goals define the primary purposes of the project and should be specific, measurable, achievable, relevant, and time bound so that the user can select the appropriate metrics for evaluating whether or not the goal has been achieved.[3]** Selecting metrics based on project goals will help ensure that data provide meaningful and useful results. As projects are likely to have multiple goals, it is important to prioritize those goals so that the number of metrics selected for the project is manageable. As the user refines the metrics, target outcomes and goals, they should continue to consider the interests of stakeholders and partners. Stakeholder engagement, which ideally began before setting goals for the project, is important for ensuring compatibility between goals and stakeholders' values, and to increase stakeholder support for the project.[4]

We recommend convening an interdisciplinary work group to coordinate selection and collection of biophysical and socioeconomic data. Reiterating goals and agreeing on metrics and methods as a group will serve to improve coordination around data collection efforts, and identify linkages between the biophysical and socioeconomic metrics. In many cases, the analysis of a socioeconomic metric relies upon ecological data (e.g. the socioeconomic metric *Damage costs avoided to surrounding homes ($)* may rely upon ecological metrics related to vegetation).

The following is a list of the restoration project goals that have been identified as most important for coastal restoration in New Jersey and are addressed in this framework:

- **Erosion Control:** The linear edge of many beaches, coastal wetlands, and developed shorelines is changing under the pressure from natural erosional forces including waves, storm surge, and tides, in concert with sea level rise, and possible human-related influences such as boat wakes. Projects with a primary goal of erosion control are designed to stabilize our coastlines, thus

[3] For help setting goals for restoration projects, see Chapter 3 of *Returning the Tide* from the NOAA Restoration Center http://www.habitat.noaa.gov/toolkits/tidal_hydro/Chapter_3.pdf (NOAA Restoration Center & NOAA Coastal Services Center 2010)

[4] For more information on 1) identifying relevant ecosystem service benefits to people for an upcoming restoration project, 2) establishing socioeconomic goals and metrics, and 3) stakeholder engagement around coastal restoration projects, refer to *A user's guide for incorporating economics into the planning process for coastal restoration projects* (Schuster and Doerr 2015). http://www.nature.org/media/oceansandcoasts/ecosystem-service-valuation-coastal-restoration.pdf

reducing the lateral landward migration of the land-water interface of coastlines and/or creating conditions for the facilitation of sediment accrual.

- **Water Quality:** Ensuring high water quality in New Jersey's coastal waters is critical to the functioning of our coastal ecosystems, which support valuable biodiversity and local communities. Projects with a goal to maintain or improve water quality are designed to either facilitate reductions in, or reduce the rate of input of, concentrations of nutrients, contaminants and/or suspended solids that can inhibit ecosystem functions.

- **Habitat:** New Jersey's coasts contain critical habitat for hundreds of ecologically important species, some of which are also important commercially, recreationally, or are threatened or endangered. Projects with a goal of habitat enhancement are designed to increase biodiversity and improve the habitat provision services of coastal lands and waters (e.g., food, shelter and nursery habitat). This can include projects that restore or recreate habitat such as reefs, beaches or marshes and/or projects that provide improvements to existing habitat for fish and wildlife.

- **Hydrological Enhancement:** Historically, coastal wetlands have been hydrologically altered through ditching and diking for agriculture, development, mosquito population management, etc. Hydrological alterations often prevent optimal tidal inundation, either isolating areas from receiving inputs of nutrients and sediments by decreasing inundation, or drowning vegetation with increased depth or duration of inundation. Projects with the primary goal of hydrological enhancement are designed to promote optimal hydrologic connectivity usually through the filling of ditches, breakdown of dikes or the (re)creation of historic or new tidal creeks and channels.

- **Socioeconomic Enhancement:** New Jersey coastal habitats, like beaches and coastal wetlands, have significant social and economic value, providing livelihoods for fisherman, positively impacting tourism and ecotourism-related industries, providing opportunities for recreation, supporting historic community character, and reducing the costs of damage to coastal communities from flooding and storms, among other benefits. Projects with a goal of economic and/or social (socioeconomic) enhancement are specifically designed to enhance aspects of the environment that contribute to one or more aspects of human wellbeing. The total value of the benefits derived by a community will depend upon the number of beneficiaries impacted. Meeting a socioeconomic goal will be based upon a change in human wellbeing as a result of ecological change. Even when the primary goal of the project is not economic or social, the economic or social co-benefits provided by the project may be of sufficient magnitude that they are worth measuring. If key project stakeholders are interested in the economic or social benefits provided by a project, it may be worth collecting appropriate baseline data for a future ecosystem service valuation or economic impact study. Interdisciplinary projects that integrate the biophysical parameters with socioeconomic parameters throughout the project are becoming more common, as continual integration can lead to more accurate and cost-effective measurement of performance, outcomes and benefits.

LINKING ECOSYSTEM SERVICES TO SOCIOECONOMIC ENHANCEMENTS

Ecosystem services *are provided by a specific habitat type, either terrestrial or aquatic. The full list of ecosystem services provided by nature is broad in scope, but includes water filtration, flood attenuation, provision of food and water, and others. The type and quantity of ecosystem services provided by a coastal restoration project will vary depending upon a number of factors including habitat type and habitat attributes. The underlying premise is that the level of ecosystem services provided by a site will change as a result of a restoration or enhancement project.*

Ecosystem service <u>benefit</u> *is the term for the way in which ecosystem services support and contribute to human wellbeing. Examples of ecosystem service benefits provided by an ecological restoration project might include an increase in revenues to commercial fisherman from the increase in fisheries production, damage avoided to homeowners from the reduction of flooding, or an increase in the recreation opportunities to birders. The total value of ecosystem service benefits will depend upon the number of beneficiaries impacted.*

VI. Metrics Selection

Once the project type and goals(s) are established, metrics are selected to measure a project's success. **<u>Metrics</u> are specific parameters used to assess project success and gauge attainment of project goals, whereas <u>methods</u> are the actual techniques that are used to measure the metrics.** This section focuses solely on relevant metric identification. Method selection will be discussed in section VII.

Two categories of metrics are addressed in this framework: project type metrics and goal based metrics. It is the collection of project type metrics and goal based metrics that make up the monitoring plan. As such, both types of metrics should be collected on all coastal restoration projects (see Figure 2).

Figure 2. Selecting metrics for a monitoring plan based on project type and project goals.

Project Type Metrics are associated with each restoration project type (i.e., Living Shorelines and Tidal Wetlands Restoration). They serve to evaluate the general effectiveness of a restoration technique, inform adaptive management and address data/knowledge gaps. The project type metrics tables (located in Appendix A) identify a small number of **core metrics** that we recommend collecting on all projects of a specific *type*, as well as additional, **conditional metrics**, that we also recommend collecting for all projects when they apply to the specific project site or design. For example, oysters are not components of all living shoreline projects, but if the project design includes the use of oysters, like an oyster reef breakwater, then it is recommended to monitor oysters.

Monitoring Tip #3

***Citizen Science and volunteer monitoring** are cost effective, but not cost free options, and still involve a commitment of training volunteers, handing and care for equipment and communication between all partners including leads to the volunteer teams. Involving the local community member in these types of monitoring projects will raise the ecological awareness of the importance coastal wetlands and nature and natural-based restoration efforts.*

Goal Based Metrics are associated with project specific goals. These metrics are recommended to determine if the specific goals of a project are being met and can help inform the need to adaptively manage a project in order to meet those goals. All relevant goal metrics (**core** and **conditional**) listed in the goal based metric tables (located in Appendix A) should be collected for each project goal. An example of a conditional goal based metric relates to the socioeconomic impact of wetland restoration. If the goal of the wetland restoration project is to improve habitat quality and biodiversity, then the selection of a specific socioeconomic metric dependent upon the local conditions, project attributes, and stakeholder interests may be relevant. However, there is more than one option for a socioeconomic metric (e.g., c*hange in spending by birders ($)* and *change in revenues for commercial fisherman ($)*), and the selection of a specific metric of interest will be highly dependent on the project. Some of the same metrics found in the project type tables will also be found in the goal based tables.

RE-EVALUATING PROJECT GOALS

If the project has multiple goals, users should evaluate whether or not they have the resources to monitor all of the metrics recommended by this framework. It is worth noting that in some cases the same metric may be recommended by both a project type and a goal, and some methods of data collection may cover more than one metric (e.g., an RTK GPS survey can be used to document the position of a shoreline as well as the elevation). Conversely, one metric may require a great deal of resources and may preclude the user from assessing multiple goals. In this case, the user can either select less resource intensive methods or refine the stated project goals.

IDENTIFYING RESTORATION TARGETS

With both ecological and socioeconomic goals, the selected metrics will be used to evaluate whether goals were successfully met. Once metrics are identified, restoration targets are set for select metrics. **Restoration targets** indicate the changes the user expects to see over time in the restoration project; they are a restating of the goals in terms that directly relate to a metric and method. Targets may be expressed in terms of a set desired outcome, a change from baseline conditions, a difference from control site conditions, or even a desired trajectory. For new technologies and projects design types, the user may be uncertain of how the project will perform and the time frames within which results can be expected. For these newer restoration techniques, targets will be more general and will likely need to be evaluated and modified over time as data are evaluated. For example, a project using an established and well-understood technique with a goal of decreasing shoreline erosion may have the 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 or control site conditions.

It is important to select restoration targets carefully so that the specificity and precision of the target properly reflects the current scientific knowledge regarding the technique and the ability of the user. The monitoring plan may have only one set of target outcomes for the end of the project that indicate whether or not the project has met its goals, or there may be interim targets at set intervals throughout the monitoring period that allow the project manager to address issues early on. Interim targets can be thresholds, or indicators, that trigger maintenance or adaptive management of the project. For example, if a wetland restoration project has and end target of 85% cover by vegetation by 2020, an interim target for 2018 could be set at 50%. If the vegetation monitoring in 2018 indicates less than 50% cover by vegetation, the project manager could decide to do some planting that would help ensure 85% cover will be reached by 2020.

> **Monitoring Tip #4**
>
> *Not all projects will have large enough budgets or access to the expertise needed to do professional/scientific research level monitoring. However, in many cases less rigorous methods are sufficient to identify when maintenance is needed and assess whether the goals of the project have been met.*

For some environmental and socioeconomic metrics, the target outcomes for the project won't be achieved during the limited timeframe that monitoring funds are available. For example, some water quality parameters will require more than five to ten years to be able to quantify changes. In these cases a combination of options are available. One option is to find less expensive ways to continue monitoring the metric. This may include using less rigorous methods, decreasing the frequency of monitoring, working with citizen scientists or existing volunteer monitoring organizations to conduct the monitoring, or establishing other creative partnerships such as working with local schools or borrowing equipment or lab space. Another option is to collect data frequently enough during the period where monitoring resources are available to establish that the metrics are on satisfactory trajectories toward meeting target outcomes. If this last option is selected, a satisfactory trajectory should be defined based on existing studies. Meeting your monitoring goals may include one or many of these suggested collaborative efforts.

VII. Methods Selection

Once metrics and endpoints are selected based on the project type and project goals, monitoring methods can be selected for each metric. **<u>Monitoring methods</u> are the actual techniques that are used to collect data on a metric.** In order to make monitoring accessible to all coastal restoration projects, we have identified a variety of common methods for each monitoring metric that span a variety of resources and expertise. For socioeconomic methods, we include data collection and data analysis methods in the metrics tables. Method options are listed in the metrics tables in Appendix A.

The list of methods included in the metrics tables is far from comprehensive, but we attempted to have at least two common, peer-reviewed methods per metric and include a common standard operating procedure (SOPs) or other citation for those methods. This document includes citations of SOPs for some methods, but a fuller SOP directory is needed, perhaps as subsequent versions of this monitoring framework become available.

DOUBLING-UP ON METHODS

It may be practical for users to implement both intensive and less intensive methods at the start of a project. 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 a core metric for living shoreline projects. Shoreline position can be collected with high precision and rigor using an RTK-GPS, or with lower precision and rigor by measuring the change in the position of the shoreline over time from PVC poles. 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.

ADDITIONAL USER CONSIDERATIONS

The **Additional User Considerations** column in the metrics tables is designed to help the user select the best method for their project. The expert working group that developed this document has begun to identify common methodological attributes. This list of attributes is not intended to be exhaustive, but to allow the user to narrow down the methodological options based on the needs and abilities of the user and project. **The presence of one of the considerations in the User Consideration column does NOT imply that the method is exclusive to those who either have a large amount of expertise, a large budget, or highly specialized equipment.** The user will need to look at detailed methodologies to determine which method will be best suited for the project. Monitoring may be conducted either by the user or other groups (e.g., citizen science groups or contractors). This section is only intended to highlight, and generally comment on, requirements of the user regarding some of the following considerations for each method:

- **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 same considerations apply to socioeconomic methods (e.g., surveys will require more expertise than interviews) and analysis (i.e., certain ecosystem service valuation methods require knowledge of specialized software). **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 for a metric or method vary either in the number of years needed to document a change or seasonal considerations for data collection. 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. Time-frame considerations are also relevant for socioeconomic metrics. Certain changes to human wellbeing as a result of biophysical changes will not be quantifiable for many years (e.g., if it takes 3-5 years for vegetation to fully establish after restoration and the resulting storm surge reduction services to be achieved). Seasonal considerations, like times of year for recreational birding or fishing, also vary depending upon the goal and which benefit is being measured. 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.**

If a method does not require that the user take any of the preceding considerations into account, the phrase "**Suited for all User Groups"** will appear in the Additional User Considerations column. This indicates that the method is accessible to users of all backgrounds. **It is recommended that the user reach out to the author of the associated SOP (or a local/regional group/agency that employs the**

method) for initial guidance in its usage. Orientation to the methodology by an appropriate group will ensure that the user understands the method precisely before employing is on their own.

Additionally, in many cases one monitoring method will provide data that can be used to assess a variety of metrics. A good example of this is an RTK-GPS survey which provides horizontal as well as vertical position. Horizontal position also may aid in assessing a socioeconomic metric such as *number of homes or structures benefitting*. It is therefore recommended that multi-metric methodologies are utilized when available.

Monitoring Tip #5

Do not underestimate the contribution of citizen science to a project. Community members and citizen scientists can tend to the restoration site and collect data after the formal project has ended. The latest ***estimated value of volunteer time is $23.07 per hour****.*

The expert workgroup acknowledges that this list of user considerations is not comprehensive, but has identified these five attributes as being the most informative and applicable to a wide variety of users, goals and project types. Other considerations that may have value to the user when choosing a methodological option, but are not included in the tables, include:

- **Rigor/Confidence:** Does this methodological option provide data at an acceptable level of confidence (e.g. statistically, spatially, temporally, etc...) to show the results of the project in a way that is meaningful to stakeholders?
- **Scalability/Transferability of Data:** Ideally each method will enable comparison of metrics across projects of different scales, but this will not always be possible. Some methodologies may be widely used in a variety of contexts and therefore allow for easy transferability to other projects at multiple scales. Pay attention to the units of measure in which the data will be collected. Some units of measure are easily converted (e.g., inches to meters) while others are more difficult to compare (e.g., number of oysters per m^2 cannot be compared to number of oysters per reef ball).
- **Availability of Existing Data:** For some methods, existing data may be publically available and not need to be collected by the user. For example, geo-referenced aerial photography is widely available or in the case of property values, assessed or actual sale price of homes are also commonly available.[5]

Citizen science and Community involvement: Successful restoration projects are tended to like productive gardens. They need to be frequently visited and monitored and one way to do this is through the involvement of local community groups, schools and citizen scientists. As mentioned in Section VI, volunteer monitoring is cost effective but not cost free, and the cultivation of these types of partnerships require community outreach, information sharing, training and resources. Once the

[5] If the user is interested in finding out if there is existing ecological data on or near the site, they can check out the Water Quality Portal at http://www.waterqualitydata.us/ The Water Quality Portal (WQP) is a cooperative service sponsored by the United States Geological Survey (USGS), the Environmental Protection Agency (EPA) and the National Water Quality Monitoring Council (NWQMC) that integrates publicly available water quality data from the USGS National Water Information System (NWIS) the EPA STOrage and RETrieval (STORET) Data Warehouse, and the USDA ARS Sustaining The Earth's Watersheds - Agricultural Research Database System (STEWARDS). The Portal is not just for water quality data and has been storing wetlands data in the Northwestern US and the Great Lakes. There data is available for download and is a searchable platform.

project/grant requirements are completed, the citizen scientists and community members can be the "eyes and ears" on the site.

VIII. Monitoring Plan Development

Once appropriate metrics and methods are chosen based on project type and goals, a monitoring plan should be developed that summarizes the strategy for gauging performance of the project. The plan should be developed and implemented prior to construction of the project. As depicted in Figure 1, the monitoring plan concisely summarizes the metrics and methods, as well as the project specific strategy for collecting data (e.g., sample timing, location, and number). Some monitoring plans may also clarify roles and responsibilities when projects are being assessed by teams of partners and staff with different skill sets. Depending on the size of the project or the funding agency, varying levels of details in the monitoring plan will be appropriate. For example, a detailed quality assurance/ quality control plan for digital data is likely not necessary for a small living shoreline project on private property installed by the landowner. Figure 3 provides a list of questions that may be useful in guiding the writing of a monitoring plan.

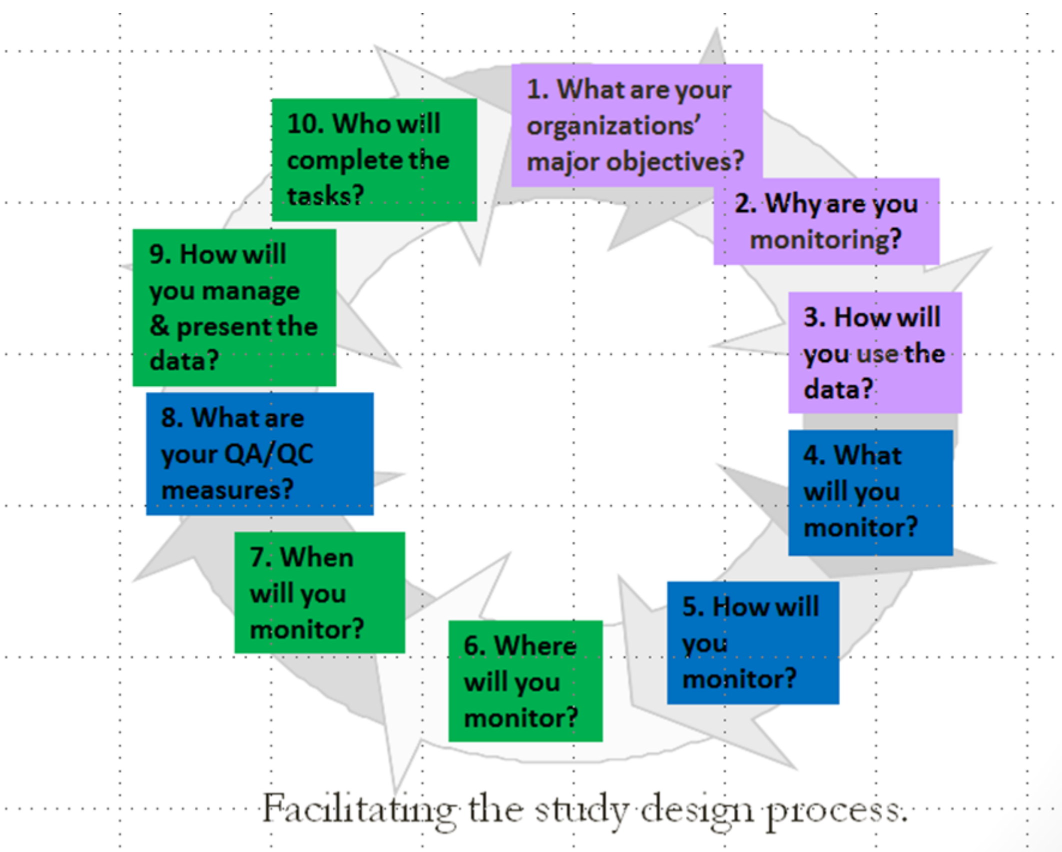

Figure 3. Questions to be answered in a project specific monitoring plan (Adapted from the Alliance for Aquatic Resource Monitoring (ALLARM), Dickenson College).[6]

[6]http://www.dickinson.edu/info/20173/alliance_for_aquatic_resource_monitoring_allarm/2911/volunteer_monitoring

The following are suggested content and considerations for developing the monitoring plan. A template for building a monitoring plan is included in Appendix C.

- *Project Overview:* A project overview should include a description of the restoration project design, location, partners, and project goals.

- *Monitoring Metrics:* List the monitoring metrics associated with the project as well as any interim targets and end targets that describe how the user expects the metric to change as a result of the project. For example, “50% cover by native plants by year 2020” may be listed as an interim target. If a project is not performing as expected or is not meeting its interim targets, then the project manager can decide whether or not maintenance or a corrective action may help the project meet its goals.

- *Monitoring Design:* For each metric, provide details on when and where the data will be collected. This should include the number or density of samples, where sampling occurs, when sampling occurs, as well as a justification for why these designs were selected. The number of samples needed will depend on the size of the project and the variability in the samples. The user will need enough samples to be able to evaluate the entire project and not just one small area. If the user is aiming for a high level of rigor, consultation with a statistician regarding the experimental design and statistical evaluation is recommended. There are a variety of ways to select sampling locations, and specific types of sampling may require certain time frames. For example, vegetation monitoring typically occurs at a time when the vegetation is in full growth (i.e. late summer). Therefore vegetation monitoring might occur during July and August in years 0, 1, and 5. Maps of sample locations should be included in an appendix. When collecting socioeconomic data, consider seasonality as well - for example, on tourism and recreation metrics, certain birds only come in spring (red knots) or fall. If the user is aiming for high level of rigor with regard to socioeconomic metrics, consultation with an experienced environmental economist or social scientist is recommended.

- *Detailed methods:* **Document step-by-step field and lab procedures so that they can be repeated consistently.** Where possible, use a common and established method that has been peer-reviewed.

- *Data management and Quality Assurance/Quality Control (QA/QC)*: Document how data quality will be ensured on the project. This includes ensuring that data is collected in a standard way (QA), transferred to digital form accurately (QA/QC), and that the data is an accurate representation of the conditions observed (QC). The monitoring plan may also document how and where the data will be stored. We encourage projects to make their data publicly available. The Water Quality Exchange (WQX) is one public place to store data. It is less common to share socioeconomic data in public databases. In cases where socioeconomic data contains proprietary information on individuals, it is not advisable to post the data in a publicly accessible format.

- *Data analysis and reporting:* Describe how the monitoring data will be used, including detail on any statistical analyses that will be performed (e.g., equations or formulas used), and the relationships between data that will be explored. **We encourage everyone conducting monitoring on coastal restoration projects to have a way of sharing the results of their monitoring and general lessons learned with the informed public and partners so that this information can be used to improve the site selection and design of future projects.**

- *References:* List the monitoring method documents that the plans were based off of, where appropriate, and any other references cited in the plan.

- *Appendix:* An appendix can include standardized field and lab data sheets, maps of the project site, sampling locations, and more. For socioeconomic metrics, any survey or interview questions used, maps with locations of beneficiaries, or other relevant information should be included.

IX. Summary and Next Steps

Monitoring is essential for all coastal restoration and enhancement projects. Information collected can help practitioners improve living shoreline and wetland restoration techniques, indicate when maintenance or adaptive management is needed, document the benefits of these projects to coastal communities, and make the case for why these types of projects are needed. For the coastal restoration and enhancement techniques that are new to New Jersey, monitoring is especially important to vet their local applicability under a range of conditions.

There are monitoring methods to fit all scales of restoration projects, from photo documentation of a ten foot living shoreline installed on private property to LiDAR collected by airplane on a 500-acre salt marsh restoration on federal lands. This document helps the user identify what metrics to monitor on their project, provides an array of methods for each metric to fit projects of different scales, and details what needs to be included in a monitoring plan.

Developing a monitoring plan is just the first step in preparing to track the progress of a coastal restoration or enhancement project. The plan may need to be updated as methods are field tested or change to better fit the needs of the project. It is a good idea to field test methods and equipment before the first day of monitoring. Once data collection has begun, changes to the monitoring methods will make it more difficult to analyze –and to draw conclusions from. For instance, if one wants to show that a restoration led to an increase in ecotourism at the site, it is recommended to ask visitors the exact same set of questions before and after the restoration, and not change the set of questions, wording of questions, or sampling method during the process.

Using standardized field and lab datasheets promotes good data collection. Along with planned monitoring data, it can be helpful to take notes and photos of general observations that may explain findings or capture issues that the monitoring does not. Transcribing both data sheets and field notes soon after returning from the field also helps to ensure that data is entered accurately. For socioeconomic data, if surveys will be conducted, spending ample time doing background research and interviewing relevant stakeholders will ensure that survey questions are relevant and easily understood by those being surveyed.

At set times throughout the life of the project, the monitoring data should be reviewed to evaluate progress towards the goals set for the project. If the project meets expectations then conclusions can be drawn about the success of the technique that may be used to improve future project selection and design. If the project is not meeting goals, then the monitoring data and other observations can help identify what is causing the impairment as well as actions that can be taken to correct the project's trajectory**. Lessons learned from techniques that do not meet goals are equally important to those that succeed.** For example, a living shoreline project built out of materials that worked well in the Gulf of Mexico may be found to fail in New Jersey when exposed to freezing and thawing.

Promotion and dissemination of the lessons learned and results from a project is important, whether in the form of a peer-reviewed journal article, a presentation during a community gathering, or a report to permitting agencies.

The goal of this framework is to provide enough information to empower coastal restoration practitioners to develop a monitoring plan. Please don't hesitate to reach out to us with questions or suggestions about how we can improve the guide.

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Appendices

Appendix A. Metric Tables

Living Shoreline Metric Table			
Class	**Metric categories**	**Method options**	**Additional user considerations**
Core	Position of living shoreline structure AND Lateral Position of Shoreline (i.e., horizontal change, erosion)	RTK GPS (m/y)	Technical expertise; cost/expense; specialized equipment
		Aerial photograph (m/y)	Technical expertise; temporal requirements; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
		Distance from installed post or perm structure	Suited for all user groups
		LiDAR	Technical expertise; cost/expense; specialized equipment
	Vegetation Structure	Horizontal vegetative obstruction	Temporal requirements; specialized equipment
		Vertical light attenuation	Temporal requirements; specialized equipment
		Cover per m2	Suited for all user groups; temporal requirements
		Number of stems per m2	Temporal requirements; collection time investment
	Structural integrity of materials (e.g. how well is the breakwater holding together)	Observation	Suited for all user groups
		Photograph (fixed point)	Suited for all user groups
Conditional	Sediment capture/ accretion	Sedimentation disc/tile/plate/ marker horizon	Cost/expense (for some methods); temporal requirements; specialized equipment (for some methods)
		Measuring stick	Suited for all user groups
	Wave energy or height and amplitude (wind/wake)	Gauges and Buoys (e.g., Acoustic Doppler Current Profilers)	Technical expertise; cost/expense; collection time investment; specialized equipment
		Water level loggers	Technical expertise; cost/expense; temporal requirements; specialized equipment
		Graduated rod	Temporal requirement; collection time investment
		Plaster or gypsum ball/ clod card dissolution	Technical expertise; temporal requirements; collection time investment; specialized equipment
	Vegetation Productivity	Biomass (above and/or belowground)	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
	Vegetation Community Composition	List of species found at site	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

Living Shoreline Metric Table (continued)			
Conditional (continued)	Nuisance species (cont.)	Observation of grazing or other disturbance	Suited for all user groups
	Debris	Observation	Suited for all user groups
	Target species (e.g. Oysters…)	See habitat/ biodiversity goal table	
	Elevation (i.e. Vertical change): of the shoreline	RTK GPS (m/y)	Technical expertise; cost/expense; specialized equipment
		Lidar	Technical expertise; cost/expense; specialized equipment
		Laser level height relative to position on permanent post or other structure	Cost/expense; specialized equipment
		Thermal imaging	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
	Foreshore slope	RTK GPS (m/y)	Technical expertise; cost/expense; specialized equipment
		Lidar	Technical expertise; cost/expense; specialized equipment
		Laser level height relative to position on permanent post or other structure	Cost/expense; specialized equipment
		Thermal imaging	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
	Planted species (e.g. Mussels or vegetation)	Percent survival (of all if small area or quadrat samples if large area)	Suited for all user groups
Socioeconomic	Difference in cost between hardened structure and a living shoreline ($)	Data collection method: Project budgets and existing data sources; Analysis method: substitute cost method	Technical expertise and specialized software needed. *If using a BACI design*, may require a large collection time investment (need to wait several years to have enough weather events to compare changes in damage per storm over time).
	Cost-effectiveness of structure for shoreline stabilization (rate of erosion reduction per unit cost)	Data collection method: Project budgets; Analysis method: Cost effectiveness analysis	Technical expertise and specialized software needed. *If using a BACI design*, may require a large collection time investment (need to wait several years to have enough weather events to compare changes in damage per storm over time).
	Number of homes or structures benefitting (#)	Data collection methods: visual assessment or GIS analysis	Some technical expertise needed; may require additional collection time.
	Public awareness of living shorelines	Data collection methods: Surveys; focus group meetings; Analysis methods: NA	Note that the value placed on individual experience represents the *social value* of the visitor experience, or the value *beyond* the actual amount spent. Some technical expertise needed; may require additional collection time.

Tidal Wetland Restoration or Enhancement Metric Table			
Class	**Metric categories**	**Method options**	**Additional user considerations**
Core	Elevation	Rtk gps	Technical expertise; cost/expense; specialized equipment
		Surface elevation table	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
		Lidar	Technical expertise; cost/expense; specialized equipment
		Laser level height relative to position on permanent post or other structure	Suited for all user groups
	Vegetation structure	Horizontal vegetative obstruction	Temporal requirements; specialized equipment
		Vertical light attenuation	Temporal requirements; specialized equipment
		Cover per m2	Suited for all user groups; Temporal Requirements
		Stem heights	Collection time investment; temporal requirements
		Number of stems per m2	Collection time investment; temporal requirements
		Habitat Type %, 50m Radius (e.g., High marsh, low marsh, invasives, pannes and pools etc.)	Collection time investment; temporal requirements
	Vegetation community composition and diversity	List of species (plants)	Suited for all user groups, Temporal Requirements
Conditional	Hydroperiod (i.e. Flood duration)	Water level loggers	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Vegetation productivity	Biomass (above and/ or belowground)	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Photograph (fixed point)	Suited for all user groups; Temporal Requirements
		Plant tissue nutrient analysis (C/N)	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
	Vegetation productivity (cont.)	LANDSAT/infrared imagery	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Number of stems per m2 and stem height of dominant species	Suited for all user groups; Temporal Requirements; Collection Time Investment
	Sediment capture (e.g. Capture, accretion)	Sedimentation disc/tile/ feldspar marker horizon	Cost/Expense (for some methods); Temporal Requirements; Specialized Equipment (for some methods)
		Measuring stick	Suited for all user groups

Tidal Wetland Restoration or Enhancement Metric Table (continued)			
Conditional (continued)	Sediment supply (e.g. TSS)	Filtration	Technical expertise; cost/expense; temporal requirements; specialized equipment
		Turbidity meter	Cost/expense; specialized equipment
		Secchi disc	Suited for all user groups
	Erosion rate/ shoreline position	RTK GPS (m/y)	Technical expertise; cost/expense; specialized equipment
		Aerial photograph (m/y)	Technical expertise; temporal requirements; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
		Distance from installed post or permanent structure to shoreline (m/y)	Suited for all user groups
		Lidar	Technical expertise; cost/expense; specialized equipment
		Aerial photographs (GIS analysis)	Technical expertise; temporal requirements; cost/expense; specialized equipment
	Foreshore slope	RTK GPS (m/y)	Technical expertise; cost/expense; specialized equipment
		Lidar	Technical expertise; cost/expense; specialized equipment
		Laser level height relative to position on permanent post or other structure	Cost/expense; specialized equipment
		Filtration	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
	Drainage density/ position	Aerial photographs (GIS analysis)	Technical expertise; temporal requirements; cost/expense; specialized equipment
		Rtk gps	Technical expertise; cost/expense; specialized equipment
	Survival of planted species	Percent survival (all if small area or quadrat samples if large area)	Suited for all user groups
	Nuisance species (e.g. Invasives, herbivory)	Cover per m2, number of stems per m2, or presence/absence	Suited for all user groups; Temporal Requirements
		Observation of grazing and other disturbance	Suited for all user groups; Temporal Requirements
	Debris	Observation	Suited for all user groups
	Target habitat: salinity	Refractometer	Specialized equipment
		Meter (total dissolved solids)	Cost/expense/ specialized equipment

Tidal Wetland Restoration or Enhancement Metric Table (continued)			
Socioeconomic	Damage costs avoided to surrounding homes ($)	Data collection method: Surveys; existing data sources; Analysis method: Avoided cost method; HAZUS modeling or other modeling that simulates changes in flood levels	Technical expertise and specialized software needed. *If using a BACI design*, may require a large collection time investment (need to wait several years to have enough weather events to compare changes in damage per storm over time).
	Damage costs avoided to surrounding structures, roads or other public infrastructure ($)	Data collection method: Surveys; existing data sources; Analysis method: Avoided cost method; HAZUS modeling or other modeling that simulates changes in flood levels	Technical expertise and specialized software needed. *If using a BACI design*, may require a large collection time investment (need to wait several years to have enough weather events to compare changes in damage per storm over time).
	Spending by birders ($)	Data collection methods: surveys; existing data sources; Data analysis methods: Economic impact assessment	Some technical expertise needed; may require additional collection time.
	Value of visitors place on the improved water quality (boaters, anglers, beach visitors, etc.) ($)	Data collection methods: surveys; existing data sources; Data analysis methods: Contingent valuation or choice experiment	Note that the value placed on individual experience represents the *social value* of the visitor experience, or the value *beyond* the actual amount spent. Some technical expertise needed; may require additional collection time.

Goal: Erosion Control Metrics Table

Class	Metric categories	Method options	Additional User Considerations
Core	Lateral position or shoreline or Erosion (i.e., horizontal change) of the shoreline (m/year)	RTK GPS	Technical expertise; cost/expense; specialized equipment
		Aerial photograph	Technical expertise; cost/expense; specialized equipment
		Lidar	Technical expertise; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
		Distance from permanent post of other structure to shoreline	Suited for all user groups
	Elevation of shoreline (m/year)	Rtk gps	Technical expertise; cost/expense; specialized equipment
		Lidar	Technical expertise; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
		Laser level height relative to position on permanent post or other structure	Cost/expense; specialized equipment
	Foreshore slope	Rtk gps	Technical expertise; cost/expense; specialized equipment
		Lidar	Technical expertise; cost/expense; specialized equipment

Goal: Erosion Control Metrics Table (continued)

Core (continued)	Foreshore slope (cont.)	Laser level height relative to position on permanent post or other structure	Cost/expense; specialized equipment
		Thermal imaging	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Surveying Instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
Conditional	Accretion (m/year)	Sedimentation disc/tile/plate/ marker horizon	Cost/Expense (for some methods); temporal requirements; specialized equipment (for some methods)
		Measuring stick	Suited for all user groups
	Wave energy or height and amplitude (wind/wake)	Gauges and buoys (e.g., acoustic doppler current profilers for wave energy and stream/ creek flow)	Technical expertise; cost/expense; collection time investment; specialized equipment
		Water level loggers	Technical expertise; cost/expense; temporal requirements; specialized equipment
		Graduated survey rod	Temporal requirement; collection time investment
		Plaster or gypsum ball/ clod card dissolution	Technical expertise; temporal requirements; collection time investment; specialized equipment
	Vegetation Structure	Horizontal vegetative obstruction	Temporal requirements; specialized equipment
		Vertical light attenuation	Temporal Requirements; Specialized Equipment
		Cover per m2	Suited for all user groups; Temporal Requirements
		Number of stems per m2	Temporal Requirements; Collection Time Investment
	Vegetation Productivity	Biomass (above and/ or belowground)	Technical Expertise; Temporal Requirements; Collection Time Investment; Cost/Expense; Specialized Equipment

Goal: Erosion Control Metrics Table (continued)			
Potential socioeconomic metrics	Change in property value due to reduction in rate of erosion ($)	Data collection method: Existing data sources; Analysis method: Hedonic valuation	Technical expertise needed.
	Difference in cost between hardened structure (e.g. bulkhead) and a living shoreline ($)	Data collection method: Project budgets and existing data sources; Analysis method: substitute cost method	Little technical expertise required; this method is suited for most user groups.
	Number of homes or structures benefitting (#)	Data collection methods: visual assessment or GIS analysis; Analysis method: NA	Suited for all user groups. Note that this metric only shows number, not the magnitude of the benefit.

Goal: Habitat/ Biodiversity Enhancement Metrics Table

Class	Metric categories	Method options	Additional user considerations
Core	Vegetation community composition and diversity	List species found at site (plants)	Suited for all user groups; temporal requirements
	Vegetation Structure	Horizontal light obstruction	Temporal requirements; specialized equipment
		Vertical light attenuation	Temporal requirements; specialized equipment
		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
		Photographs (fixed point)	Suited for all user groups; temporal requirements
Conditional	Target species for restoration (e.g. black duck or oysters) or biodiversity	Observations (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/expense; specialized equipment; permitting requirements
		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

Goal: Habitat/ Biodiversity Enhancement Metrics Table (continued)

Conditional (cont.)	Target species for restoration (e.g. black duck or oysters) or biodiversity (cont.)	Morphometric (e.g., length of nekton or oysters)	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment; permitting requirements
		Health (e.g., condition index, of bivalves)	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment; permitting requirements
		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; permitting requirements
	Soil texture	Grain size and soil type analysis	Technical expertise; collection time investments; cost/expense; specialized equipment
	Belowground stability	Shear vane strength	Technical expertise; cost/expense; specialized equipment
		Bearing capacity	Specialized equipment
	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/expense; specialized equipment
		LANDSAT/infrared imagery	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Biomass (above and/or belowground)	Technical expertise; temporal requirements; collection time investment; cost/expense; specialized equipment
		Number of stems per m2 and stem height of dominant species	Collection time investment; temporal requirements
	Salinity	Refractometer	Specialized equipment
		Meter (total dissolved solids)	Cost/expense; specialized equipment
	Dissolved oxygen	Meter (total dissolved oxygen)	Cost/expense; specialized equipment
	Area of habitat	GPS	Cost/expense; specialized equipment
		Aerial photography	Technical expertise; temporal requirements; cost/expense; specialized equipment
	Nuisance species	Number of stems per m2	Collection time investment; temporal requirements
		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
Goal: Habitat/ Biodiversity Enhancement Metrics Table (continued)			
Potential socioeconomic metrics	Economic impact of ecotourism ($)	Data collection methods: surveys; existing data sources; Data analysis methods: IMPLAN or other regional economic modeling, such as input/output models	Technical expertise and specialized software needed; only relevant for large enough projects to have a meaningful impact; if existing data sources are not available, may require additional collection time.
	Spending by birders ($)	Data collection methods: surveys; existing data sources; Data analysis methods: Economic impact assessment	Some technical expertise needed; may require additional collection time.
	Revenues for commercial fisherman ($)	Data collection methods: surveys; interviews; existing data sources; Data analysis methods: Partial budget analysis	Some technical expertise needed; only relevant for large enough projects to have a meaningful impact.
	Value visitors to the site place on their experience ($)	Data collection methods: surveys; existing data sources; Data analysis methods: Contingent valuation or choice experiment	Note that the value placed on individual experience represents the *social value* of the visitor experience, or the value *beyond* the actual amount spent. Some technical expertise needed; may require additional collection time.
	Number of students benefiting from environmental education/research (#)	Data collection methods: Surveys; Focus group meetings; Tracking with a log; Data analysis methods: NA	Suited for all user groups.

Goal: Water Quality Metrics Table

Class	Metrics: Target water quality parameter- select one or more based on project goals	Method options	Additional user considerations
Conditional	Dissolved Oxygen	Meter (DO)	Cost/expense; specialized equipment
		Titration kit	Cost/expense; specialized equipment
		Winkler titration	Technical expertise; cost/expense; temporal requirements; specialized equipment
	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/expense; temporal requirements; specialized equipment

	Nutrients nitrate, nitrite, ammonia	Filtration (lab tests TKN, etc.)	Technical expertise; cost/expense; temporal requirements; specialized equipment

Goal: Water Quality Metrics Table (continued)

Conditional (continued)	Nutrients nitrate, nitrite, ammonia (cont.)	Laboratory Analysis	Technical expertise; cost/expense; temporal requirements; specialized equipment
		Colorimeter	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Water - bacteria	Lab analysis (CFUs)	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Nutrients: phosphates	Lab analysis	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Ph	Titration kits	Cost/expense; specialized equipment
		Colorimeter	Cost/expense; specialized equipment
		Meter (pH)	Specialized equipment
	Salinity	Refractometer	Specialized equipment
		Meter (total dissolved solids)	Cost/expense; specialized equipment
	Algal bloom	Chl a tests (lab or sensor)	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Water BOD	Dilution method EPA method 5210B	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Pollutants	Manometric method	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Temperature	Meter	Cost/expense; specialized equipment
		Thermometer	Suited for all user groups
Potential socioeconomic metrics	Number of beach closing days (#)	Data collection method: existing data sources; analysis method: NA	Suited for all user groups.
	Value of visitors place on the improved water quality (boaters, anglers, beach visitors, etc.) ($)	Data collection methods: surveys; existing data sources; data analysis methods: contingent valuation or choice experiment	The value placed on individual experience represents the *social value* of the visitor experience, or the value *beyond* the actual amount spent. Some technical expertise needed; may require additional collection time.
	Number of shellfisheries closing days (#)	Data collection method: existing data sources; analysis method: NA	Suited for all user groups.
	Delisting of a waterway from EPA 303d	Data collection method: existing data sources; analysis method: NA	Suited for all user groups. Note that this metric will only be relevant for large enough projects that would have a quantifiable impact on water quality.

	Change in property value due to water clarity improvements ($)	Data collection method: existing data sources; analysis method: hedonic valuation	Technical expertise needed. Note that this metric will only be relevant for large enough projects that would have a quantifiable impact on water quality.

Goal: Hydrological Enhancement Metrics Table

Class	Metrics	Method options	Additional user considerations
Core	Stream flow	Flowmeter	Technical expertise; cost/expense; temporal requirements; specialized equipment
		Gauges and Buoys (e.g., Acoustic Doppler Current Profilers)	Technical expertise; cost/expense; collection time investment; specialized equipment
	Creek/channel morphometry	Aerial Photography or satellite imagery	Technical expertise; temporal requirements; cost/expense; specialized equipment
		Survey instrument (barcode leveling)	Technical expertise; cost/expense; specialized equipment
		RTK GPS transects	Technical expertise; cost/expense; specialized equipment
Conditional	Hydroperiod	Water level loggers	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Sediment supply (e.g., TSS)	Meter (turbidity)	Cost/expense; specialized equipment
		Secchi disc	Suited for all user groups
		Filtration	Technical expertise; cost/expense; temporal requirements; specialized equipment
	Sediment capture/ accretion	Sedimentation disc/tile/plate/ marker horizon	Cost/expense (for some methods); temporal requirements; specialized equipment (for some methods)
		Measuring stick	Suited for all user groups
	Salinity	Refractometer	Specialized equipment
		Meter (total dissolved solids)	Cost/expense; specialized equipment
	Dissolved oxygen	Meter (total dissolved solids)	Cost/expense; specialized equipment
	Vegetation community composition	List of plant species in site	Suited for all user groups; temporal requirements
	Vegetation structure	Horizontal vegetative obstruction	Temporal requirements; specialized equipment
		Vertical light attenuation	Temporal requirements; specialized equipment
		Cover per m2	Suited for all user groups; temporal requirements
		Number of stems per m2	Collection time investment; temporal requirements
		Stem heights	Collection time investment; temporal requirements

		Habitat Type %, 50m radius (e.g., high marsh, low marsh, invasives, pannes & pools etc.)	Collection time investment; temporal requirements
Goal: Hydrological Enhancement Metrics Table (continued)			
Potential socioeconomic metrics	Damage costs avoided to surrounding structures, roads or other public infrastructure ($)	Data collection method: Surveys; existing data sources; Analysis method: Avoided cost method; HAZUS modeling or other modeling that simulates changes in flood levels	Technical expertise and specialized software needed. *If using a BACI design*, may require a large collection time investment (need to wait several years to have enough weather events to compare changes in damage per storm over time).
	Number of homes or structures benefitting (#)	Data collection methods: visual assessment or GIS analysis	Suited for all user groups. Note that this metric only shows number, not the magnitude of the benefit.
	Number of days per month that road is flooded (#)	Data collection method: Surveys; existing data sources; Analysis method: Modeling that simulates changes in flood levels	Some technical expertise required. Note that this metrics shows only the number of days, not the number of people benefitting.
	Change in property value due to decrease in flood risk ($)	Data collection method: Existing data sources; Analysis method: Hedonic valuation	Technical expertise needed.

Goal: Socioeconomic Metrics Table			
Class	**Metric categories**	**Method options**	**Additional user considerations**
Community resilience	Damage costs avoided to surrounding structures, roads or other public infrastructure ($)	Data collection method: surveys; existing data sources; analysis method: avoided cost method; HAZUS modeling or other modeling that simulates changes in flood levels	Technical expertise and specialized software needed. *If using a BACI design*, may require a large collection time investment (need to wait several years to have enough weather events to compare changes in damage per storm over time).
	Damage costs avoided to surrounding homes ($)	Data collection method: surveys; existing data sources; analysis method: avoided cost method; HAZUS modeling or other modeling that simulates changes in flood levels	Technical expertise and specialized software needed. *If using a BACI design*, may require a large collection time investment (need to wait several years to have enough weather events to compare changes in damage per storm over time).
	Value of time saved by individuals driving on a road where flooding is reduced ($)	Data collection method: surveys; existing data sources; analysis method: avoided cost method	Technical expertise required; specialized software may be needed, depending upon if hydrological modeling is used to supplement the analysis.
	Change in property value due to decrease in flood risk ($)	Data collection method: existing data sources; analysis method: hedonic valuation	Technical expertise needed.
	Difference in cost between hardened structure (e.g. bulkhead) and a living shoreline ($)	Data collection method: project budgets and existing data sources; analysis method: substitute cost method	Little technical expertise required; this method is suited for most user groups.
	Number of homes or structures benefitting (#)	Data collection methods: visual assessment or GIS analysis	Suited for all user groups. Note that this metric only shows number, not the magnitude of the benefit.
	Change in property value due to reduction in rate of erosion ($)	Data collection method: existing data sources; analysis method: hedonic valuation	Technical expertise needed.
Recreation and tourism	Spending by birders, boaters or anglers ($)	Data collection methods: surveys; existing data sources; data analysis methods: economic impact assessment	Some technical expertise needed; may require additional collection time.
	Number of visitors to the restoration site (#)	Data collection methods: car counter; surveys; geospatially referenced social media methodology; analysis methods: NA	Suited for all user groups. Note that this metric only shows number, not the magnitude of the benefit.
Water quality	Number of shellfisheries closing days (#)	Data collection method: existing data sources; analysis method: NA	Suited for all user groups. Note that this metric will only be relevant for large enough projects that would have a quantifiable impact on water quality.

Appendix B. Description of metrics

Algal Bloom (Biological): Describes the presence or quantity of algal blooms. This metric can be used as a proxy indicator for nutrient enrichment in water.

Belowground stability (physical): Describes the below-ground stability of the wetland. The wetland substrate can becomes less firm due to natural and anthropogenic influences that decrease below-ground organic material and soil bearing capacity. Reduced below-ground organic material can be a good indicator of stress. Reduced belowground stability can make the marsh more susceptible to erosion.

Change in property value due to decrease in flood risk ($) (Socioeconomic): Through a method called hedonic valuation, shows the portion of the property value that is influenced by flood risk and describes how that portion of the property value changes with a change in flood risk. This metric is more likely to be applicable if there are a sufficient number of homes within the zone influenced by the marsh.

Change in property value due to reduction in rate of erosion ($) (Socioeconomic): Through a method called hedonic valuation, shows the portion of the property value that is influenced by rate of erosion at the parcel edge and describes how that portion of the property value changes with a change in erosion rate. This metric is more likely to be applicable if there are a sufficient number of homes benefitting from the erosion reduction benefits of the project.

Change in property value due to water clarity improvements ($) (Socioeconomic): Through a method called hedonic valuation, shows the portion of the property value that is influenced by water clarity and describes how that portion of the property value changes with a change in water clarity. This metric is more likely to be applicable if there are a sufficient number of projects taking place in the bay that quantifiable changes in water clarity are likely to result and if there are a sufficient number of homes benefitting in the region surrounding the project site.

Cost-effectiveness of structure for shoreline stabilization (rate of erosion reduction per unit cost) (Socioeconomic): Cost-effectiveness is the calculation of the change in a benefit over the total project cost to give a benefit per unit cost. In this example, the benefit is the change in the rate of erosion, and cost-effectiveness may be compared to a hardened structure such as a bulkhead.

Creek/Channel Morphometry (Physical): Describes the shape and size of specific creeks and channels, including: slope from banks to trough center. This metric can be used to measure creek/channel changes in drainage capacity and creek erosion.

Currents (Physical): Describes properties related to the flow of water, including spatial and temporal variability related to direction, rate, and stratification.

Damage costs avoided to surrounding homes ($) (Socioeconomic): Describes the change in damages costs to homes as a result of lower levels of flooding (and not due to raising homes or other structural changes), taking into consideration equivalent level weather variables (e.g. precipitation). This metric is more likely to be relevant when resources are available to conduct a more rigorous analysis and if there are a sufficient number of homes within the zone influenced by the marsh.

Damage costs avoided to surrounding structures, roads or other public infrastructure ($) (Socioeconomic): Describes the change in damages costs to structures, roads or other public infrastructure as a result of lower levels of flooding (and not due to raising homes or other structural changes), taking into consideration equivalent level weather variables (e.g. precipitation). This metric is more likely to be relevant when resources are available to conduct a more rigorous analysis and if there are a sufficient number of structures or other infrastructure within the zone influenced by the marsh

Debris (e.g. trash capture) (Physical): Describes the presence, change in density, or impact of debris and wrack on a restoration project. This metric can be used to determine whether management of debris in the project area is warranted.

Delisting of a waterway from EPA 303d (Socioeconomic): Describes the action of a waterway being delisted for a single pollutant due to the water quality of that waterway meeting or going below the EPA maximum amount. This metric is likely to be most relevant for larger-scale restoration projects, or a salt marsh restoration or living shoreline project that is in conjunction with a series of other actions to improve water quality in a bay or estuary.

Difference in cost between hardened structure (e.g. bulkhead) and a living shoreline ($) (Socioeconomic): Using the substitute cost method, this metric shows the difference in cost between the living shoreline and a hardened alternative such as a bulkhead, assuming equivalent level of functionality for both options. Typically the calculation includes both construction and maintenance costs over the long-term (i.e. 25 or 50 years).

Drainage density/ position (Physical): Describes density of drainage creeks sometimes in relation to other features of interest, including upland habitats, main channel edge, and infrastructure. This metric can be used to evaluate larger scale marsh characteristics, including duration of flooding, changes in vegetated area, and sediment/nutrient inputs.

Economic impact of ecotourism ($) (Socioeconomic): Describes the economic impact from increased spending by visitors in the ecotourism segment of the tourism market, as a result of ecological restoration project(s). This metric is more likely to be relevant for projects with a site access component, projects implemented in conjunction with an ecotourism strategy led by local partners, and/or for cases where projects are large enough to have a direct impact on ecotourism (for instance through the quantifiable increase in bird abundance or diversity).

Elevation (vertical change) (Physical): Describes the relative (e.g. tidal prism) or specific (e.g. datum) vertical position of a feature of interest (e.g., marsh platform, shoreline edge, shellfish). This metric can be used when project targets are elevation dependent.

Foreshore Slope (Physical): Describes the gradient of elevation running perpendicular to a living shoreline or wetland edge. This metric can be used to evaluate changes in the foreshore as a result of project implementation, or to assess the effects of different physical conditions on the success or persistence of a project type.

Hydroperiod (Physical): Describes the frequency and duration of flooding in a marsh or other area of interest. This metric can be used to evaluate habitat suitability or erosion/drowning potentials. Hydroperiod can be either relative to the tidal prism or specific to a tidal datum.

Inhibition of fauna movement: Describes the interruption of wildlife movement by materials used in a restoration project (e.g., rock sills may prevent the fish and crabs from swimming between water and land). This metric should be used at all projects that involve the addition of structural materials, including those used for construction of living shorelines and hardened structures, as well as temporary equipment used for monitoring measurements.

Lateral Position or Erosion (i.e., horizontal change) (Physical): Describes the latitudinal and longitudinal position of the shoreline (defined as either the water ward line of vegetation or the continuous defining edge feature ,e.g., front terrace, mussel line, etc.) or of a living shoreline structure (e.g., oyster reef breakwater. This metric can be used to measure the horizontal marsh movement rate (i.e. erosion or accretion).

Nutrients (Chemical): Describes the concentration of nutrients (e.g., Nitrate, nitrite, ammonia, phosphate) in soils, vegetation, or water. This metric can be used to evaluate changes in water/soil quality or the uptake/utilization by plants. It can also be used to evaluate the effect of a treatment type on point source pollution.

Number of beach closing days (#) (Socioeconomic): Describes the change in number of days in which beaches used for swimming are closed as a result of changes in water quality. This metric is likely to be most relevant for larger-scale restoration projects, or a salt marsh restoration or living shoreline project that is in conjunction with a series of other actions to improve water quality in a bay or estuary.

Number of days per month that road is flooded (#) (Socioeconomic): Describes the change in number of days per month that a road adjacent to a restored marsh is flooded as a result of lower levels of flooding, taking into consideration equivalent level precipitation and storm surge. This metric is more likely to be applicable if there are roads within the zone influenced by the marsh.

Number of homes or structures benefitting (#) (Socioeconomic): Describes the number of homes or structures that are located within the marsh-influenced zone and thus are benefitting from the marsh due to the flood reduction services provide from the restoration OR to the number of homes or structures directly benefitting from the erosion reduction benefits of a living shoreline project. This metric is only relevant to projects with expected flood reduction or erosion reduction benefits.

Number of shellfisheries closing days (#) (Socioeconomic): Describes the change in number of days in which shellfisheries (e.g. oyster fisheries) are closed as a result of changes in water quality. This metric is likely to be most relevant for larger-scale restoration projects, or a salt marsh restoration or living shoreline project that is in conjunction with a series of other actions to improve water quality in a bay or estuary.

Number of students benefiting from environmental education/research (#) (Socioeconomic): Describes the number of students directly benefiting from environmental education at the restoration site or involved in research directly linked to some aspect of the restoration project. This metric may apply to students of all ages and levels and is only applicable for projects where there exists a strong link to environmental education programs or research.

Number of visitors to the restoration site (#) (Socioeconomic): Describes the change in number of visitors to a restoration site due to the restoration project. The reason for the increase in visitation may be due to the improvement in aesthetics or site access, increase in the abundance or diversity of birds, improvement in water quality, and/or increase in number of fish caught; only applicable to projects with a public access point within or in close proximity to the site.

Nuisance species (e.g. invasive, herbivory) (Biological): Describes the presence, change in density, or impact of nuisance species. This metric can be used determine whether management of invasive species like *Phragmites australis* or installation of goose fencing to prevent new plantings from being eaten is needed.

Other target pollutants (Chemical): Describes the concentrations of a specific pollutant in soils, vegetation, or water. This metric can be used to evaluate changes in concentration over time and can be used to evaluate the effect of a treatment type on point source pollution.

pH (Chemical): Describes the acidity or alkalinity in soils or water. This metric can be used to evaluate changes in overtime in relation to water/soil quality.

Planted species (e.g. mussels or vegetation) (Biological): Describes fate of planted/relocated species into a restoration site including, but not limited to, vegetation and shellfish. This metric can be used to describe survivorship of transplants.

Position of Structure (Physical): Describes the lateral and/or vertical position of structural materials used in the restoration project (e.g., biologs, breakwaters, shell bags, etc.). This metric is used to evaluate whether or not the structure is maintaining the shape and position needed to meet the project goals and can inform the need for maintenance.

Public awareness of living shorelines (Socioeconomic): Describes the level of public awareness of the term "living shorelines." Typically, the awareness is gauged through administration of surveys, polls or through focus groups, and can include questions on perceived benefits and perceived effectiveness of living shorelines.

Revenues for commercial fisherman ($) (Socioeconomic): Describes the change in revenues for commercial fisherman due to the increase in number or quality of fish harvested. Only applies to fish species which directly benefit from salt marshes (e.g. blue crabs), or who prey upon species directly benefiting from salt marshes.

Salinity (Chemical): Describes the concentration of dissolved salts in water. This metric can be used to evaluate changes in these levels over time in relation to water quality, habitat suitability, or saltwater intrusion. Salinity is typically measured in grams of salt per one kilogram of water.

Sediment capture/ accretion (Physical): Describes either the volume or depth of sediment deposited in the project site either naturally or as a result of a restoration action. This metric can be used measure changes in elevation due to the deposition of sediment on projects aiming to enhance elevation.

Sediment supply (e.g. TSS) (Physical): Describes the concentration of suspended material in the water column (mg/L). This metric can be used to evaluate water quality, habitat suitability, or material available to accrete naturally within project sites.

Shoreline slope (Physical): Describe the changes in elevation between the water bottom and the shoreline. This metric is useful for tracking changes to the shoreline caused by erosion and accretion.

Soil texture (physical): Describes the relative proportion of sand, silt, and clay sized particles present within a soil. Soil texture will affect how quickly a site drains, how easy it will be for vegetation to establish, and often the bearing capacity of the ground.

Stream flow (Physical): Describes the velocity of water movement within a stream or creek. This metric can be used to evaluate the transport ability of a drainage creek/stream.

Structural integrity of materials (Physical): Describes the ability of materials used for restoration to withstand environmental forces overtime. This metric should be used at all restoration sites that involve structural materials, including those used for construction of living shorelines and hardened structures. This metric is used to evaluate the ability of the material to function overtime and withstand environmental forces such as storms and icing, which can inform the need for maintenance.

Spending by birders, boaters or anglers ($) (Socioeconomic): Describes the change in spending at restaurants, hotels, or other stores, from birders, boaters or anglers to the restoration site as a result of the restoration project. The reason for the increase in visitation may be due to the improvement in aesthetics or site access, increase in the abundance or diversity of birds, improvement in water quality, and/or increase in number of fish caught; only applicable to projects with a public access point within or in close proximity to the site.

Surrounding land use (Physical): Describes land use/land cover of areas neighboring or surrounding the restoration project. This metric is used to evaluate changes that coincide with the restoration.

Target habitat (Biological): Describes changes in the extent, type, or quality of a habitat as a result of a restoration. This metric can be used when a specific habitat is targeted for the restoration project, in some cases because the habitat provides food or shelter for a species of interest (target species).

Target species (Biological): Describes the change in number, spatial extent, natural recruitment, or health of a species in the restorations site. This metric can be used when enhancement of a specific species is a goal of the restoration project.

Temperature (Physical): Describes the temperature of water, air, soil, etc. This metric can be used to evaluate habitat suitability.

Value of time saved by individuals driving on a road where flooding is reduced ($) (Socioeconomic): Describes the value placed by individuals on their time saved due to a reduction in flooding on a road due to a restoration project. This metric does not represent spending by individuals, but rather, the *value* that individual places on their time and/or wages that were lost on days in which the road was flooded prior to the restoration. This metric is more likely to be applicable if there are roads within the zone influenced by the marsh.

Value of visitors place on the improved water quality (boaters, anglers, beach visitors, etc.) ($) (Socioeconomic): Describes the change in value that visitors to a site place on the experience as a result of the improved water quality. This value does not represent spending, but the value beyond the amount spent. This metric is likely to be most relevant for larger-scale restoration projects, or a salt marsh restoration or living shoreline project that is in conjunction with a series of other actions to improve water quality in a bay or estuary.

Value visitors to the site place on their experience ($) (Socioeconomic): Describes the change in value that visitors to a site place on the experience as a result of the ecological restoration. This value does not represent spending, but the value beyond the amount spent; only applicable to projects with a public access point within or in close proximity to the site.

Vegetation community composition and diversity (Biological): Lists the plant species that make up the plant communities within a restoration project. This metric can be used to track changes plant native species diversity and habitat types. Plant communities can also be used as a proxy for tidal inundation. This describes what plants are there.

Vegetation Structure (Biological): Describes the relative abundance of plant species within a plant community as well as the vertical and/or horizontal structure of vegetation (either for all species or for each species). This metric can be used to characterize the density or robustness of vegetation at a restoration site. This describes how the plants cover the area - whether the vegetation cover is robust or sparse.

Vegetation Productivity (Biological): Describes the growth rate of vegetation, above and/or below ground biomass, overtime. This metric can be used a number of different ways – as a general indicator of health, lopsided ratios of above to belowground biomass can indicate excessive nutrient input, belowground biomass is important for soil stabilization and accretion, and above ground biomass is important for reducing wave energy. This describes what the vegetation is doing by providing a rate of plant production.

Water - Bacteria (Biological): Describes the presence or quantity of bacteria in the water. This is often used

Water Biological Oxygen Demand (Chemical): Describes the amount of dissolved oxygen needed to maintain decomposition processes without promoting hypoxic or anoxic conditions. This metric is used to assess water quality and habitat parameters necessary to sustain healthy waters.

Water Dissolved Oxygen (Chemical): Describes the amount of dissolved oxygen present in water. This metric is used to assess water quality and habitat suitability.

Wave energy or height and amplitude (wind/wake) (Physical): Describes physical characteristics of waves. This metric can be used when a reduction of wave energy is a restoration project goal.

Appendix C. Sample Monitoring Outline

Monitoring Plan Title

Project Lead

Date of last edit of the document

Monitoring Personnel

Names and contact information for those developing and executing the monitoring plan

Project Overview
Description of the restoration project design, project site, location, etc,

Project Goals and Objectives
List project goals and provide reasoning for why goals were selected (e.g.: erosion control as goal due to value of infrastructure behind shoreline or value of habitat, etc...).

Monitoring Metrics

- *List monitoring metrics for each project goals (e.g., vegetation percent cover)*
- *Interim targets and target outcomes for each metric (where appropriate)*

Monitoring Design

Spatial design for each metric

# of samples will be taken

How sample locations will be chosen

Temporal design for each metric
When sampling will happen

Detailed methods
Field Methods
Data collection
Data management and QA/QC
Data storage
Data analysis
Provide detail on statistical analyses to be performed, any equations or formulas used, and the relationships that will be explored.

Reporting

References

Appendix
Standardized field and lab data sheets
Figures
Map of project site
Map of sampling locations

Appendix D. Citations for More Information on Monitoring Methods

The follow are a list of resources for more information on methods listed in the Metrics Tables. This is far from complete. All methods will have to be adapted for each project and when samples will be sent to a lab for analysis, instructions from the lab should be followed rather than any protocols below. Despite these limitations, the resources below will help the user to get an idea of what is involved in collecting and processing data for each method and select the method that is the best fit for their project. Please scroll to the end of the list for resources related to socioeconomic methods.

Aerial photographs

- Smith, S. M. (2009). Multi-decadal Changes in Salt Marshes of Cape Cod, MA: Photographic Analyses of Vegetation Loss, Species Shifts, and Geomorphic Change. NORTHEASTERN NATURALIST 16(2):183–208.http://www.nps.gov/caco/learn/nature/upload/Northeastern-Naturalist-_Smith-2009_compressed_version.pdf (accessed March 2016)
- TidalMarshMonitoring.org. Habitat: Aerial Photography and Remote Sensing http://www.tidalmarshmonitoring.org/monitoring-methods-aerial-photography-remote-sensing.php (accessed March 2016)

Bearing capacity

- Mid-Atlantic Tidal Wetland Rapid Assessment Method Version 3.0 (June 2010) Delaware Department of Natural Resources. http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Tidal%20Rapid_Protocol%203.0%20Jun10.pdf (accessed March 2016)
- The Partnership for the Delaware Estuary has detailed methods upon request

Biomass

- The Partnership for the Delaware Estuary has detailed methods upon request for above and belowground plant biomass as well as shellfish biomass
- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)

Bivalve demographics, recruitment, health

- The Partnership for the Delaware Estuary has detailed methods upon request
- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring and Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)
- Burrows, F., Harding, J. M., Mann, R., Dame, R., Coen, L. (2005). Chapter 4, Restoration monitoring of oyster reefs, pages 4.2-4.73. In: Thayer, G. W., McTigue, T. A. , Salz, R. J., Merkey, D. H., Burrows, F. M., Gayaldo, P. F. (Eds.), Science-Based Restoration Monitoring of Coastal Habitats, Volume Two: Tools for Monitoring Coastal Habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA

National Centers for Coastal Ocean Science, Silver Spring, M.D. USA. http://www.oyster-restoration.org/wp-content/uploads/2012/06/Volume2ch4oys.pdf (accessed March 2016)

Chlorophyll a

- YSI Tech Note, The Basics of Chlorophyll Measurement https://www.ysi.com/File%20Library/Documents/Technical%20Notes/T606-The-Basics-of-Chlorophyll-Measurement.pdf (accessed March 2016)

Clarity tube

- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. https://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

Colorimeter

- Orhel, R. L., Register, K. M., (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. https://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

Cover per m2 or # per m2 (e.g., percent cover of vegetation, # of fiddler crab boroughs, # of fish in a sample, ribbed mussel lip counts)

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring and Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp.http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)
- Neckles, H.A. and M.Dionne, (eds.) (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf. (accessed March 2016)
- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. https://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)
- TidalMarshMonitoring.org has SOPs for monitoring tidal marsh flora and fauna. **http://www.tidalmarshmonitoring.org/monitoring-methods.php** (accessed March 2016)

Dilution method EPA Method 5210B

- NEMI.gov is a great source for water quality monitoring protocols

Distance from installed post or permanent structure to shoreline (m/y)

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)
- The Partnership for the Delaware Estuary has detailed methods upon request

Feeding and breeding behavior (for avian target species)

- The SOP use by USFWS can be supplied upon request.
- Neckles, H.A. and M.Dionne, (eds.) (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf. (accessed March 2016)
- TidalMarshMonitoring.org Bird Monitoring Methods http://www.tidalmarshmonitoring.org/monitoring-methods-birds.php (accessed March 2016)

Filtration

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp.http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ **(**accessed March 2016)
- The Partnership for the Delaware Estuary has detailed methods upon request

Flow meter

Graduated rod

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ **(**accessed March 2016)
- Miller, J. K., Rella, A., Williams, A., Sproule, E. (2015). Living Shorelines Engineering Guidelines. Stevens Institute of Technology, Davidson Laboratory Technical Report SIT-DL-14-9-2942, Hoboken, NJ, USA, 101pp. http://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf (accessed March 2016)

Grain size and soil type analysis

- Merkey, D., Burrows, F., McTigue, T., Foret, J. (2005). Chapter 10: Restoration Monitoring Of Coastal Marshes, pages 10.17-10.19. In: G.W., Thayer, T. A. McTigue, R. J. Salz, D. H. Merkey, F. M. Burrows, Gayaldo, P. F.(eds.), Science-Based Restoration Monitoring of Coastal Habitats, Volume Two: Tools for Monitoring Coastal Habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD, USA. https://coastalscience.noaa.gov/research/docs/rmv2/Ch10Bundle.pdf **(**accessed March 2016)

Gauges and Buoys (e.g., Acoustic Doppler Current Profilers for wave energy and stream/ creek flow)

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ **(**accessed March 2016)

- Miller, J. K., Rella, A., Williams, A., Sproule, E. (2015). Living Shorelines Engineering Guidelines. Stevens Institute of Technology, Davidson Laboratory Technical Report SIT-DL-14-9-2942, Hoboken, NJ, USA, 101pp. http://www.nj.gov/dep/cmp/docs/living-shorelines-engineering-guidelines-final.pdf **(**accessed March 2016)
- TidalMarshMonitoring.org Hydrology: Flow and Hydrodynamics http://www.tidalmarshmonitoring.org/monitoring-methods-hydrology-hydrodynamics-adcp-profile.php **(**accessed March 2016)

Habitat Type %, 50m Radius (e.g., High marsh, low marsh, invasives, pannes & pools etc.)

- The SOP used by USFWS can be supplied upon request.

Health

- The Partnership for the Delaware Estuary has detailed methods upon request
- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)
- Burrows, F., Harding, J. M., Mann, R., Dame, R., Coen, L. (2005). Chapter 4, Restoration monitoring of oyster reefs, pages 4.2-4.73. In: Thayer, G. W., McTigue, T. A. , Salz, R. J., Merkey, D. H., Burrows, F. M., Gayaldo, P. F. (eds.), Science-Based Restoration Monitoring of Coastal Habitats, Volume Two: Tools for Monitoring Coastal Habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD USA. http://www.oyster-restoration.org/wp-content/uploads/2012/06/Volume2ch4oys.pdf (accessed March 2016)

Horizontal vegetative obstruction

- Mid-Atlantic Tidal Wetland Rapid Assessment Method Version 3.0 (June 2010) Delaware Department of Natural Resources. http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Tidal%20Rapid_Protocol%203.0%20Jun10.pdf (accessed March 2016)

Lab analysis (water quality)

Orhel, R. L., Register, K. M., (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. https://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

LANDSAT/infrared imagery

Laser level height relative to position on permanent post or other structure

LiDAR

- TidalMarshMonitoring.org Elevation: Terrestrial and Aerial LiDAR http://www.tidalmarshmonitoring.org/monitoring-methods-terrestrial-aerial-lidar.php (accessed March 2016

List of species found at site (e.g., fish, plants, birds)

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)
- Neckles, H.A., Dionne, M. (eds.) (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf.(accessed March 2016)

Manometric method

Measuring stick (for measuring accretion)

- The Partnership for the Delaware Estuary has detailed methods upon request

Meter (e.g., total dissolved solids, dissolved oxygen, pH, etc.)

- Orhel, R. L., Register, K. M., (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. https://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)
- TidalMarshMonitoring.org Hydrology: Discrete and Continuous Water Quality SOPs http://www.tidalmarshmonitoring.org/monitoring-methods-hydrology.php (accessed March 2016)

Morphometric (e.g., length of nekton or oysters)

Nekton (identity, density, length, biomass, species richness)

- The SOP use by USFWS can be supplied upon request

Number of stems per m2

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)
- Neckles, H.A. and M.Dionne, Editors. (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf.(accessed March 2016)

Observations (e.g., grazing or other disturbance)

- Neckles, H.A., Dionne, M. (eds.) (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf (accessed March 2016)

- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. https://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

Percent survival of planted animals or plants (of all if small area or quadrat samples if large area)

Photograph (fixed point)

- Neckles, H.A., Dionne, M. (eds.) (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf (accessed March 2016)
- TidalMarshMonitoring.org Habitat: Photo-Points http://www.tidalmarshmonitoring.org/monitoring-methods-photo-points.php
- The Partnership for the Delaware Estuary has detailed methods upon request

Plant tissue nutrient analysis (C/N)

Plaster or gypsum ball/ clod card dissolution

Presence/ absence

- Mid-Atlantic Tidal Wetland Rapid Assessment Method Version 3.0 (June 2010) Delaware Department of Natural Resources. http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Tidal%20Rapid_Protocol%203.0%20Jun10.pdf (accessed March 2016)

Recruitment

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)

Refractometer

- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. http://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

RTK GPS

- TidalMarshMonitoring.org Elevation: Ground-based Topographic Mapping. Elevation Topographic Mapping RTK GPS SOP http://www.tidalmarshmonitoring.org/monitoring-methods-ground-based-topographic-mapping.php (accessed March 2016)
- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring and Assessment Handbook. The Nature Conservancy,

Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)

Secchi disc

- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. http://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

Sedimentation disc/tile/plate/ marker horizon

- USGS Website: Surface Elevation Table (SET) https://www.pwrc.usgs.gov/set/ (accessed March 2016)
- Lynch, J. C., P. Hensel, Cahoon, D. R., (2015). The Surface Elevation Table And Marker Horizon Technique: A Protocol For Monitoring Wetland Elevation Dynamics. Natural Resource Report NPS/NCBN/NRR—2015/1078. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/Profile/2225005 (accessed March 2016)

Shear vane strength

Stem heights

- Neckles, H.A. Dionne, M. (eds.) (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf (accessed March 2016)
- TidalMarshMonitoring.org Habitat: Vegetation http://www.tidalmarshmonitoring.org/monitoring-methods-vegetation.php (accessed March 2016)
- The Partnership for the Delaware Estuary has detailed methods upon request

Surface elevation table

- USGS Website Surface Elevation Table (SET) https://www.pwrc.usgs.gov/set/ (accessed March 2016)
- Lynch, J. C., P. Hensel, Cahoon, D. R., (2015). The Surface Elevation Table and Marker Horizon Technique: A Protocol For Monitoring Wetland Elevation Dynamics. Natural Resource Report NPS/NCBN/NRR—2015/1078. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/Profile/2225005 (accessed March 2016)

Surveying Instrument (barcode leveling)

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)

Thermal imaging

Thermometer

- Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring and Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/ (accessed March 2016)
- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. http://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

Titration kits

- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. http://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

Turbidity meter

Vertical light attenuation

- The Partnership for the Delaware Estuary have detailed methods upon request

Water level loggers

- USFWS and The Partnership for the Delaware Estuary have detailed methods upon request

Winkler test

- Orhel, R. L., Register, K. M. (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. http://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual (accessed March 2016)

The following are resources related to socioeconomic methods. All socioeconomic methods shown include both a data collection method and an analysis method.

Data collection method: Existing data sources; Analysis method: Hedonic valuation

- Gopalakrishnan, S., Smith, M. D., Slott, J. M., & Murray, A. B. (2011). The Value Of Disappearing Beaches: A Hedonic Pricing Model With Endogenous Beach Width. Journal of Environmental Economics and Management, 60(3): 297–310.
- Bin, O., Dumas, C., Pouter, B., Whitehead, J. (2007). Measuring the impacts of climate change on North Carolina coastal resources. Report prepared for National Commission on Energy Policy, Washington, DC, USA.
- Michael, H., Boyle, K., Bouchard, R. (2000). Does the Measurement of Environmental Quality Affect Implicit Prices Estimated from Hedonic Models? *Land Economics,* 76(2): 283-298.
- Walsh, P., Milon, J. (2015). Nutrient Standards,Water Quality Indicators, and Economic Benefits fromWater Quality Regulations. *Environmental and Resource Economics*: 1-19.

Data collection method: Project budgets and existing data sources; Analysis method: substitute cost method, *and also* **Analysis method: Cost effectiveness analysis**

- Alleman, L., Carrera, J., Maxwell, E., Smith, E., Freed, A., Kaiser, C., Percifull, E., Thorbourne, C., Bassetti, L., Bayram, A., Bohn, B., Goldstick, J., Kealy, M., McConnell, K., Ostroff, G., Robinson, P., Weier, J., Wilson, M. (2015). Urban Coastal Resilience: Valuing Nature's Role. Case Study: Howard Beach, Queens, New York. New York. The Nature Conservancy, with technical support from CH2M Hill and Davey Resource Group. http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newyork/climate-energy/natural-infrastructure-study-at-howard-beach.xml (accessed March 2016)

Data collection method: Surveys; existing data sources; Analysis method: Avoided cost method; HAZUS modeling or other modeling that simulates changes in flood levels

- Federal Emergency Management Agency (2016). HAZUS software. https://www.fema.gov/hazus-software (accessed March 2016)

Data collection method: Surveys; existing data sources; Analysis method: Modeling that simulates changes in flood levels

Data collection methods: Car counter; Surveys; Geospatially referenced social media methodology; Analysis methods: NA

- Wood, S. A., Guerry, A. D., Silver, J. M., Lacayo, M. (2013). Using Social Media To Quantify Nature-Based Tourism And Recreation. Scientific Reports. 3(2976).

Data collection methods: surveys; existing data sources; Data analysis methods: Contingent valuation or choice experiment

- Haab, T., McConnell, K. (2002). Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation. New Horizons in Environmental Economics, Northampton, Massachusetts.
- Johnston, R.J., Whelchel, A.W., Makriyannis, C., & Yao, L. (2015a). Adapting to coastal storms and flooding: Report on a 2014 survey of Old Saybrook residents. Worcester, MA. George Perkins Marsh Institute, Clark University, and The Nature Conservancy, Connecticut Chapter.
- Johnston, R.J., Whelchel, A.W., Makriyannis, C., & Yao, L. (2015b). Adapting to coastal storms and flooding: Report on a 2014 survey of Waterford residents. Worcester, MA. George Perkins Marsh Institute, Clark University, and The Nature Conservancy, Connecticut Chapter.

Data collection methods: surveys; existing data sources; Data analysis methods: IMPLAN or other regional economic modeling, such as input/output models *and also***, Data analysis methods: Economic impact assessment**

- Thompson, M., Wagenhals, E. (2002). Economic Impact Of Nature Tourism And Cultural Activities In Worcestor County, Maryland. http://msa.maryland.gov/megafile/msa/speccol/sc5300/sc5339/000113/002000/002269/unrestricted/20063302e.pdf (accessed March 2016)
- Carver, E., Caudill, J. (2013). Banking on Nature: The Economic Benefits to Local Communities of National Wildlife Refuge Visitation. Washington, D.C. Division of Economics, U.S. Fish and Wildlife Service.
- IMPLAN. (2016). http://www.implan.com/ (accessed March 2016)

Data collection methods: Surveys; Focus group meetings; Tracking with a log; Data analysis methods: NA

Data collection methods: surveys; interviews; existing data sources; Data analysis methods: Partial budget analysis

Data collection methods: visual assessment or GIS analysis; Analysis method: NA

Appendix E. Other Guidance Documents on Developing Monitoring Plans for Coastal Habitats

Baggett, L. P., S. P. Powers, Brumbaugh, R., Coen, L.D., DeAngelis, B., Greene, J., Hancock, B., Morlock, S. (2014). Oyster Habitat Restoration Monitoring And Assessment Handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/oyster-habitat-restoration-monitoring-and-assessment-handbook/

Neckles, H.A. and M.Dionne, (eds.) (2000). Regional standards to identify and evaluate tidal wetland restoration in the Gulf of Maine. Wells National Estuarine Research Reserve Technical Report, Wells, ME. 21 p. plus appendices. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf

Thayer, G. W., McTigue, T. A., Bellmer, R. J., Burrows, F. M., Merkey, D. H., Nickens, N. A., Lozano, S. J., Gayaldo, P. F., Polmateer, P. J., Pinit, P. T. (2003). Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457). NOAA Coastal Ocean Program Decision Analysis Series No. 23, Volume 1. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD. 35 pp. plus appendices. http://coastalscience.noaa.gov/research/docs/rmv1/restorationmntg.pdf

Thayer, G. W., McTigue, T. A., Salz, R. J., Merkey, D. H., Burrows, F. M., Gayaldo, P. F. (eds.), (2005). Science-Based Restoration Monitoring of Coastal Habitats, Volume Two: Tools for Monitoring Coastal Habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD. 628 pp. plus appendices. http://coastalscience.noaa.gov/research/docs/rmv2/WholeDocument.pdf

Orhel, R. L., Register, K. M., (eds.) (2006). Volunteer Estuary Monitoring: A Methods Manual. Second Edition, U.S. Environmental Protection Agency; Office of Water; Washington, DC, USA. http://www.epa.gov/nep/volunteer-estuary-monitoring-methods-manual

Roman, C.T., James-Pirri, M., Heltshe, J.F. (2001). Monitoring Salt Marsh Vegetation: A Protocol for the Long at Cape Cod National Seashore. Long-term Coastal Ecosystem Monitoring Program, Cape Cod National Seashore Wellfleet, MA 02667

Appendix F. Metric Worksheet

Metric Name	Metric Category	Restoration Type(s) and Class	Goal(s) and Class	Method Choice