Living Shorelines in New England:

Site Characterization and Performance Monitoring Guidance

The Nature Conservancy

NOAA

NROC Northeast Regional Ocean Council

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Acknowledgements

Development of this New England Living Shorelines Site Characterization and Performance Monitoring Guidance (Guidance Document) is part of the project, *Increasing Resilience and Reducing Risk through Successful Application of Nature-Based Coastal Infrastructure Practices in New England*. This project was made possible with support from the National Oceanic and Atmospheric Administration's (NOAA) Office for Coastal Management under the FY 2017 Coastal Resilience Grants Program Federal Funding Opportunity (Award Number: NA17NOS4730141).

Many individuals and organizations contributed to developing this Guidance Document. Project team members (listed below) implemented and monitored living shoreline demonstration projects to inform development of this guidance and advance knowledge about implementing nature-based approaches to coastal resilience in New England. Eric Roberts, Katie Castagno, and Steve Kirk from The Nature Conservancy, and Joan LeBlanc from the Northeast Regional Ocean Council prepared this document with guidance from the project team. See Appendix F for individual project team members.

- Casco Bay Estuary Partnership
- Connecticut Department of Energy and Environmental Protection, Land and Water Resources
- Great Bay National Estuarine Research Reserve
- Maine Department of Marine Resources / Maine Coastal Program
- Maine Geological Survey
- Massachusetts Office of Coastal Zone Management
- National Oceanic and Atmospheric Administration
- New Hampshire Department of Environmental Services / New Hampshire Coastal Program
- Northeast Regional Ocean Council
- Rhode Island Coastal Resources Management Council
- Sacred Heart University
- The Nature Conservancy
- University of Connecticut
- University of New Hampshire

The project team also appreciates the contributions of stakeholders who participated in a workshop at the outset of this project to provide early guidance about the development of characterization and monitoring metrics for living shoreline approaches. Workshop participants are listed in Appendix G.

Finally, the project team recognizes the resilience and adaptive approach taken by all those who made this project possible despite the ongoing challenges of navigating the COVID-19 pandemic. Appropriate steps were taken to protect public health of the project team and volunteers who helped construct and monitor living shoreline demonstration projects throughout New England. Innovative, adaptive approaches were used to achieve project goals and outcomes despite challenges.

Cover photos clockwise from upper left: Stratford Point, CT (J. Mattei); Maquoit Bay Conservation Lands, Brunswick, ME (P. Slovinsky); Wagon Hill Farm, Durham, NH (NH DES); Rose Larisa Park, East Providence, RI (RI CRMC); Wharton Point, Brunswick, ME (P. Slovinsky); and Collins Cove, Salem, MA (MA CZM).

Executive Summary

Living Shorelines in New England: Site Characterization and Performance Monitoring Guidance

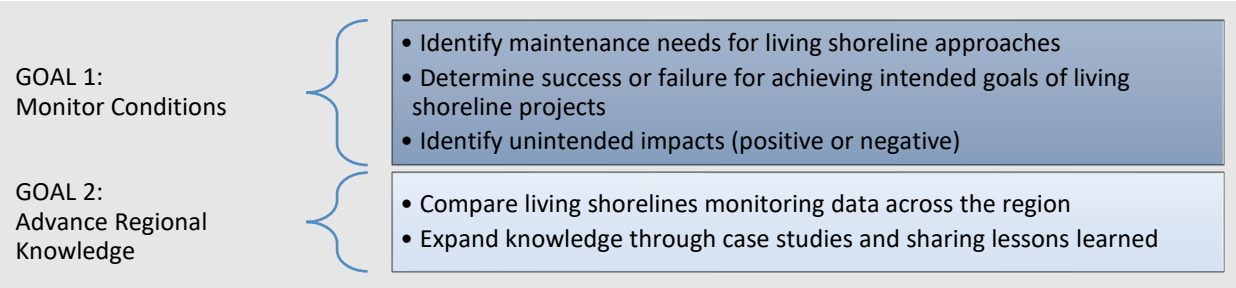
This Guidance Document was developed to promote standardized data collection efforts and increase knowledge about the site characterization and performance of living shoreline approaches in New England. Assessing living shoreline projects in New England with a standard set of metrics is expected to:

- help improve site suitability analysis, selection of approaches, and project design;
- inform permitting processes for living shoreline projects; and
- provide guidance for adaptive management for implemented projects.

Greater understanding about the effectiveness, impacts, benefits, and limitations of living shorelines will help advance appropriate use of living shoreline approaches in New England environments. Because living shorelines are an emerging area of practice in the region, the metrics for characterizing and monitoring living shoreline approaches provided in this Guidance Document are geared toward the demonstration projects that were part of this grant-funded project. These metrics are expected to evolve as more living shorelines projects are implemented and monitored for performance in the Northeast.

There are two primary goals for performance monitoring of living shoreline projects with a regional, standardized set of metrics and protocols. The first goal is to compare conditions before and after living shoreline implementation at project sites to identify maintenance needs and assess the success or failure of the projects to achieve the intended goals (e.g., tidal energy attenuation, shoreline stabilization, habitat creation, or other goals specific to the project site, type, and/or environmental conditions). Site-specific monitoring is also useful to identify unintended impacts, both positive and negative, that a living shoreline project may cause. The second goal is to advance regional knowledge about the practice of living shorelines through case studies and lessons learned, which will inform site suitability assessment and design, permitting and construction, and monitoring and maintenance practices.

Figure 1. Goals for Monitoring Living Shoreline Projects

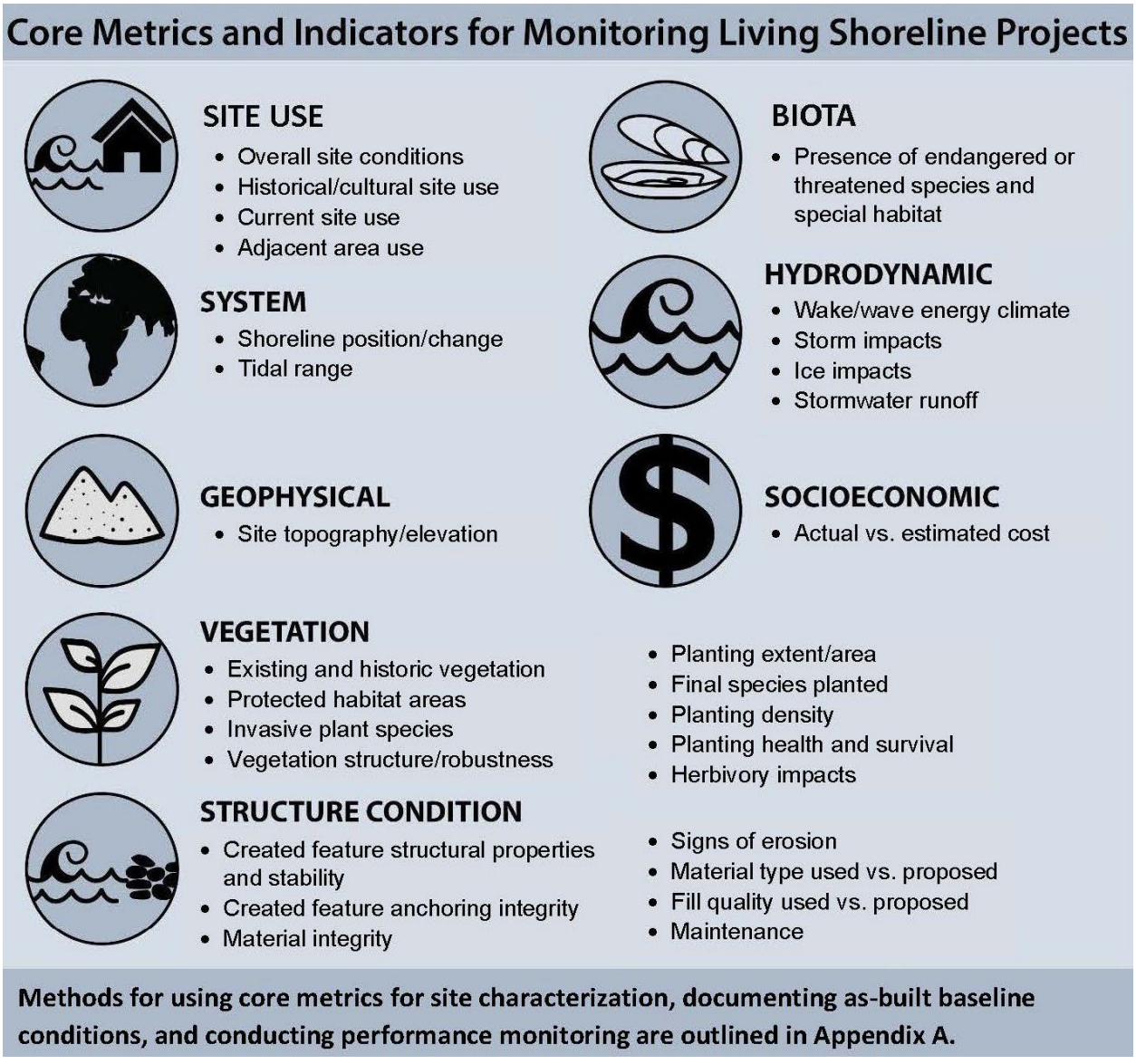


This Guidance Document was developed primarily for the project team and partners to inform performance monitoring of existing living shoreline projects and/or site characterization, design, construction and monitoring new living shoreline demonstration projects as part of the NOAA funded

project, *Increasing Resilience and Reducing Risk Through the Successful Application of Nature Based Coastal Infrastructure Practices in New England*.

Practitioners (engineers, landscape architects, restoration ecologists, and other consultants), project developers/owners, conservation organizations, landowners, and others are encouraged to use a streamlined version of core metrics (Figure 2) while developing monitoring plans for living shoreline projects in Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine. Project managers in New England are encouraged to collect data for core metrics using the protocols provided in this guidance document and then share results with colleagues to increase knowledge and advance implementation of living shorelines in New England.

Figure 2. Core Metrics



This document is intended to evolve as knowledge about living shoreline approaches and monitoring tools change. Given the diversity of habitats, shorelines, and living shoreline projects in New England,

the information in this guidance is not a definitive list of metrics that could or should be monitored at every living shoreline project site. Rather, the document provides guidance for specific demonstration projects that may be applied as appropriate to other living shoreline projects. Site characterization and performance monitoring efforts should be designed to track metrics that are relevant to the specific goals of a living shoreline project. Nevertheless, the goals of shoreline stabilization/erosion management, wave attenuation, habitat provision, and coastal resilience/hazard reduction are commonly cited reasons for the consideration and application of living shoreline approaches. This Guidance Document was developed with these common goals in mind.

Contents

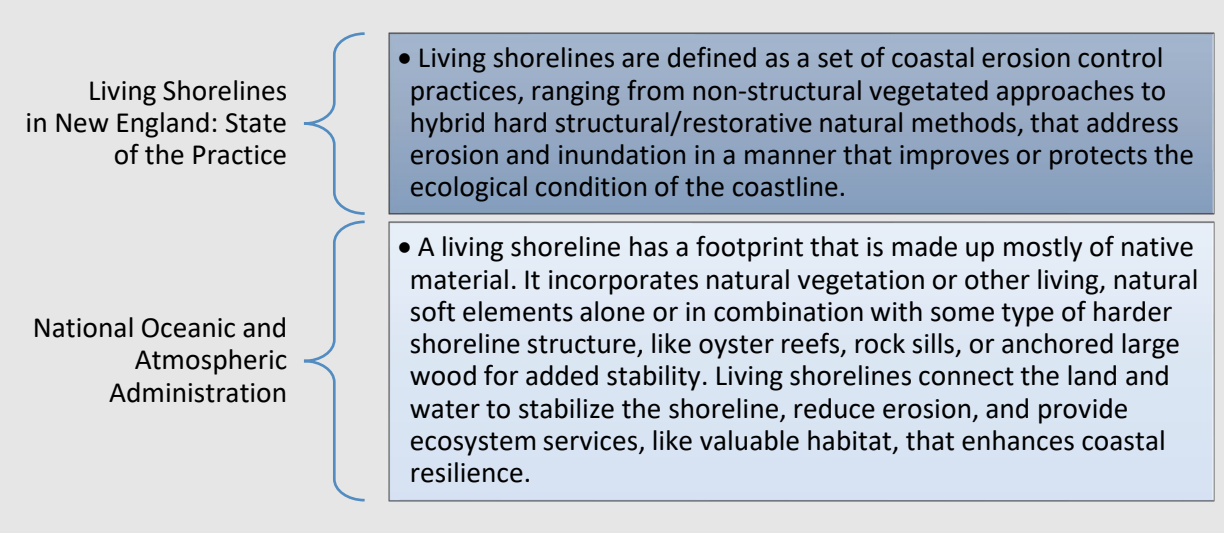
1. Background

Changing weather patterns, rising water levels, and ongoing development pressure along the already highly-developed New England coastline threaten the region's shorelines, habitats, buildings, and infrastructure. Sea level rise and storm systems of greater frequency and intensity produce strong winds and large waves causing widespread coastal erosion and flooding at higher elevations than previously experienced. Seeking to protect their investments, many landowners in New England are considering hardened shoreline stabilization approaches such as seawalls, rip rap, or revetments. However, these traditional hardened approaches can change sediment transport patterns, leading to increased erosion or scour at the lateral ends of the structure and scour at lower intertidal habitat elevations seaward of the structure. By themselves, hardened shoreline approaches afford limited habitat value.

Providing alternatives to hardened shorelines is more urgent than ever. If the current trends in weather patterns and sea levels continue as predicted, New England will lose coastal resources that support economically important recreation areas, fisheries economies, natural storm damage protection, and other critical habitat function. Hardened shoreline stabilization practices will expedite those losses. Living shoreline approaches, a type of green infrastructure best management practice used to stabilize shorelines and protect properties while enhancing ecological conditions, provide a potential alternative to traditional hardened shorelines.

Many similar working definitions exist for the term "living shorelines", including those from the report, *Living Shorelines in New England: State of the Practice* (Woods Hole Group, 2017), and from the National Oceanic and Atmospheric Administration (NOAA, n.d.) as shown in Figure 3.

Figure 3. Living Shoreline Definitions



Some coastal New England states operate under a state-specific definition or "working definition" not yet written into statute or regulation, or a definition included in state-specific policy or legal documents such as a United States Army Corps of Engineers (USACE) Programmatic General Permit.

The following key concepts associated with living shorelines are consistent among various definitions:

- maintaining and/or restoring the natural land-water interface to promote the continuation of dynamic natural coastal processes and function, especially as sea levels rise;
- providing/enhancing habitat for wildlife;
- shoreline stabilization via tidal energy attenuation using vegetation alone or in combination with biotic and/or abiotic structures, and;
- providing coastal resilience/hazard reduction benefits (e.g., reducing the extent or frequency of coastal erosion and localized flooding).

The performance of coastal living shorelines in New England is just beginning to be documented and understood. While still a relatively new approach for shoreline management, coastal living shoreline projects have a longer history of use in the Gulf of Mexico and the South- and Mid-Atlantic regions than in New England. Aspects of living shorelines have been implemented extensively in stream and river restoration projects in New England and a limited number of coastal living shoreline projects have been implemented. However, the transfer of living shoreline techniques from riverine systems to coastal and estuarine systems is a relatively new development in New England. The design, construction, and performance of New England's existing coastal living shoreline projects have also not been assessed using a standardized approach to elucidate lessons learned that could be applied throughout the region. Moreover, the performance data that exists from the Gulf and South- and Mid-Atlantic regions does not necessarily translate to the different conditions of New England, where shorter vegetation growing seasons, ice and winter storm conditions, larger tidal ranges, rocky shorelines, and sediment-poor geological conditions influence the design and performance of living shoreline projects (O'Donnell, 2017).

Following completion of a previous regional project funded by NOAA (Award Number: NA16NOS4730013), the New England Coastal Zone Management programs and their local partners, as well as the Northeast Regional Ocean Council (NROC), the Connecticut Institute for Resilience and Climate Adaptation (CIRCA)/Connecticut Department of Energy and Environmental Protection (CT DEEP), and The Nature Conservancy are actively addressing some of the key themes documented in *Living Shorelines in New England: State of the Practice* (Woods Hole Group, 2017). In particular, the project team is addressing the following identified needs: 1) increase the quantity of living shoreline demonstration projects in New England, 2) create and apply a regional, standardized monitoring approach covering existing conditions assessment, design, permitting, construction, and monitoring of living shoreline demonstration projects in New England and 3) develop guidance regarding state and federal regulatory policy to facilitate the appropriate use of living shoreline practices.

This Guidance Document was created to further the science, policy, and practice of living shorelines in New England, and ultimately, to increase community resilience and reduce risk to people, infrastructure, and habitats from coastal flooding and erosion while also restoring or enhancing coastal ecosystem function. The purpose of the Guidance Document is to provide a resource for those considering

investing in a living shoreline by suggesting standardized data collection efforts across living shoreline projects, to the extent possible, and to advance knowledge about the performance of these approaches in New England's conditions. Since living shoreline projects by definition require more consistent monitoring than hard structures, standardization of the monitoring process could aid in the mainstreaming of living shorelines across New England.

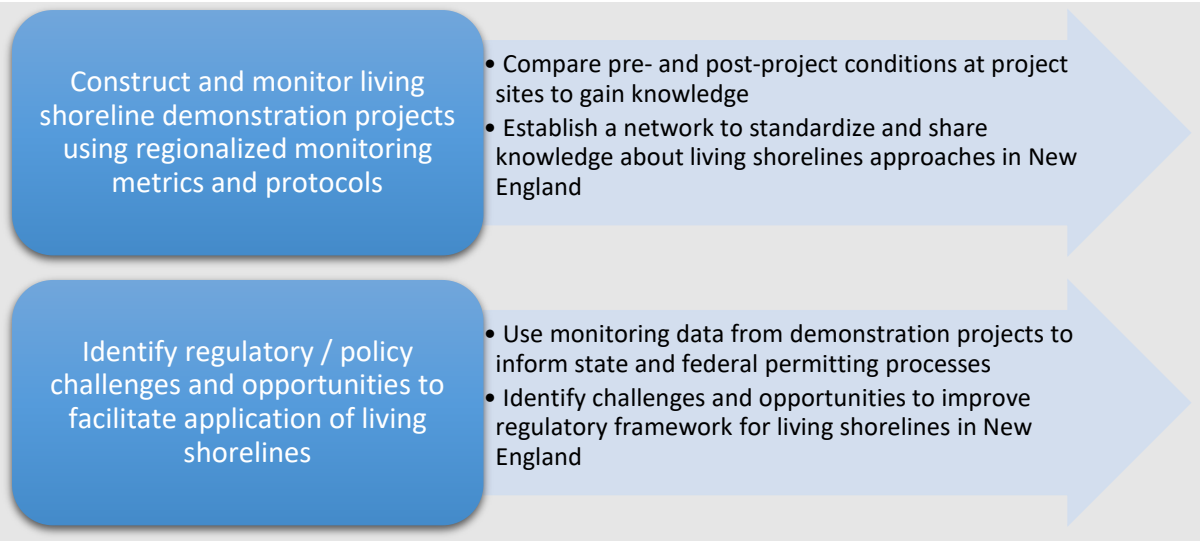
2. Purpose of the Guidance Document

The Guidance Document was developed to standardize data collection efforts across living shoreline projects and learn about the performance of these approaches in the unique conditions of New England. Living shorelines represent a relatively new technology in the region and therefore there aren't agreed upon design standards from a practitioner or regulator perspectives. Collecting data in a systematic way should help determine the best approaches from the perspectives of performance and impacts to natural resources and communities. This document and the metrics and protocols listed in the appendices are provided for guidance only, and are not intended as a rigid set of standard operating procedures for all living shoreline projects. Assessing living shoreline demonstration projects in New England with a standardized set of metrics and sharing lessons learned is expected to achieve the following outcomes:

- improved site characterization and suitability analysis, selection of living shoreline approach, and project design;
- better informed and more efficient permitting processes for living shoreline projects;
- guidance for adaptive management post-implementation; and
- increased support for the appropriate use of living shorelines due to a greater understanding of the effectiveness, impacts, benefits, and limitations of these projects in New England environments.

Development of this Guidance Document is part of a broader project that seeks to advance the science, policy, and practice of living shorelines through two primary pathways. The first pathway involves construction of living shoreline demonstration projects and monitoring those projects with a regional, standardized set of monitoring metrics and protocols. The second pathway involves identifying regulatory challenges and opportunities to facilitate and enhance the application of living shorelines for the benefit of both people and nature.

Figure 4. Project pathways to advance the science, policy, and practice of living shorelines



There are two primary goals for monitoring the demonstration projects with a regional, standardized set of metrics and protocols. The first goal is to make comparisons between conditions before and after living shoreline implementation at project sites to identify maintenance needs and assess the success or failure of the project design to achieve the intended goals (e.g., tidal energy attenuation, shoreline stabilization, habitat creation/enhancement, hazard reduction, or other goals specific to the project site, type, and/or environmental conditions). This site-specific monitoring effort will also identify unintended impacts, both positive and negative. Monitoring may also satisfy permit conditions, though practitioners must confirm monitoring requirements with the appropriate permitting agencies. Case studies of several living shoreline demonstration projects have been developed into a story map format to share lessons learned from site characterization and design through implementation, maintenance and monitoring. The case studies are available at: https://www.nature.org/en-us/what-we-do/our-priorities/protect-water-and-land/land-and-water-stories/northeast-living-shorelines-case-studies/.

The second goal is to advance region-specific knowledge about application of living shorelines in New England to inform site suitability assessment and design, permitting and construction, and monitoring and maintenance practices. Standardized data collection on baseline existing conditions assessments (i.e., site characterization), as-built conditions, and performance metrics will facilitate comparisons across project outcomes. Comparisons across project sites will advance knowledge about performance between projects of similar design and construction but that were constructed in different environmental conditions (e.g., greater or lesser wind/wave energy climate). Conversely, comparisons could be made across projects built in similar environmental conditions but that were designed using different materials or applications (e.g., beneficially reuse of a fallen log vs. a coir log or a small rock-sill to attenuate wave energy).

Case studies and lessons learned from living shoreline demonstration projects may inform decisions about living shoreline site suitability and design, permitting and construction, and monitoring and maintenance activities for future projects. Lessons learned from the regional monitoring effort may also inform opportunities to streamline state and federal permitting processes for living shoreline projects, making the process as predictable and timely as the permitting processes of other traditional, hardened shoreline approaches.

Monitoring a regional set of living shoreline demonstration projects with a standard set of metrics and protocols will begin to answer the following questions:

- How effective are living shorelines at limiting the extent, severity, or frequency of coastal hazards (e.g., erosion or flooding)?
- What positive and negative impacts do living shoreline approaches have on existing and proposed habitat? If habitat conversion occurs, is it causing a net positive or negative ecological change?
- How well do living shoreline approaches fare in the environmental conditions of New England? How do storm events impact living shorelines? How does ice impact living shoreline projects?
- What factors during the design, permitting, construction, and monitoring and maintenance phases of a project increase the likelihood of positive outcomes (e.g., successful stabilization of an eroding shoreline, increases in overall ecological quality, reduction of coastal hazards, or

achievement of site specific project goals) and reduce the likelihood of negative outcomes (e.g., maintain or exacerbate the rate of erosion, decrease overall ecological quality, maintain or increase exposure to coastal hazards)?
- What are the time scales associated with expected short-term impacts (turbidity)?
- How do living shoreline projects change the human use of a project site or of adjacent properties and waterways?
- What are the estimated and real costs of planning, implementing, and maintaining a living shoreline project?

In tandem with development of this guidance, the project team reviewed the existing regulatory framework for permitting of living shorelines projects in New England and developed the document, Regulatory Challenges and Opportunities for Living Shorelines in New England (Davenport et al., 2022). To expand regional knowledge and share lessons learned about living shorelines, case studies (in story map format) were created for several living shorelines demonstration projects in New England. The regulatory guidance document and the case studies are available on the Northeast Regional Ocean Council website at https://www.northeastoceancouncil.org/committees/coastal-hazards-resilience/living-shorelines-group/.

3. Audience, Use, and Limitations of the Guidance Document

A. Intended Audience and Use

This Guidance Document was developed primarily for the project team and partners to inform performance monitoring of existing living shoreline projects and/or site characterization, design, construction and monitoring new living shoreline demonstration projects as part of the NOAA funded project, "Increasing Resilience and Reducing Risk Through the Successful Application of Nature Based Coastal Infrastructure Practices in New England" (Award Number: NA17NOS4730141; also known as "the regional coastal resilience project").

Practitioners, project developers/owners, conservation organizations, landowners, and others also are invited to use the Guidance Document to identify metrics and protocols while assessing site conditions and developing monitoring plans for living shoreline projects in Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine. This document is meant to provide guidance, rather than a set of standard operating procedures for all living shoreline projects.

It is important to note that this guide is meant as a resource for the intended audience and should not be referenced by regulators or resource managers when considering issuing permits for living shorelines (e.g., requiring an advanced/research grade monitoring protocol tier as a permit condition, which could result in undue burden on project proponents).

B. Description

This Guidance Document is intended to be a living document that proposes a set of regional, standardized metrics for baseline site characterization (i.e., existing conditions assessment), as-built baseline establishment, and performance monitoring phases of living shoreline projects. Both previously constructed projects (e.g., those built using similar approaches but before the living shorelines term gained popular use) and demonstration projects that were constructed as part of this regional resilience project were monitored to 1) assess performance at each individual site and identify maintenance needs, and to 2) compare the performance of living shoreline approaches across project goals, types, construction materials, energy parameters, etc. The Guidance Document was revised to incorporate knowledge gained by the project partners while applying the metrics to living shoreline demonstration projects throughout the region.

The Guidance Document is intended as a starting point and resource for monitoring the effectiveness and impacts of living shoreline projects. It provides a set of core metrics to monitor progress on the following set of goals, which are commonly associated with living shoreline projects:

- shoreline stabilization or erosion management,
- wave attenuation (where applicable),
- habitat provision or enhancement, and
- coastal resilience/hazard reduction.

The core metrics serve as a starting point to which other metrics could be supplemented depending upon site-specific project goals, local site conditions, and/or the project design/type. This Guidance Document also provides information about conditional metrics that could be collected in addition to the core metrics that are largely driven by project type.

The Guidance Document lists and describes metrics for site characterization, as-built baseline establishment and performance monitoring; provides the rationale for collecting the data on the metric; and information on a range of possible data collection protocols and frequencies to apply them. It also provides progressively more sophisticated levels of methods, including basic (low-tech) methods that could be implemented by trained volunteers and professional practitioners alike. Project team members were asked to utilize these basic methods, either as the primary monitoring method or to supplement more advanced (i.e., practitioner/research-level) monitoring methods, to consistently collect data on core metrics across previously constructed living shoreline projects and new demonstration project sites.

C. Limitations

Data collected through the regional monitoring effort and the resulting lessons learned will inform each of the steps of the living shoreline project lifecycle, from site characterization and design through implementation and performance monitoring. However, information presented in this Guidance Document is not intended as a "how to" for conducting site suitability analysis, or for designing, permitting, constructing, or maintaining living shoreline projects.

This Guidance Document does not provide a definitive list of metrics that could or should be monitored at every living shoreline project site. The diversity of habitats across New England, the variability in the condition of those habitats, the range of living shoreline project types, the variation in the scale of projects, as well as the variation in different techniques or materials that could be used to construct living shoreline projects prevents the development of a universal set of metrics. These factors have contributed to a circumstance where design standards have not yet been created for living shorelines.

Additionally, the project team believes that monitoring efforts must track metrics that are relevant to the specific goals of each living shoreline project. The range of potential project goals and the diverse array of stakeholders and interests that shape those goals further limit the ability to establish a universal set of metrics for living shoreline projects. Nevertheless, the goals of shoreline stabilization/erosion management, wave attenuation, habitat provision/enhancement, and coastal resilience/hazard reduction are commonly cited reasons for the consideration and application of living shoreline approaches. This Guidance Document was developed with these common goals in mind.

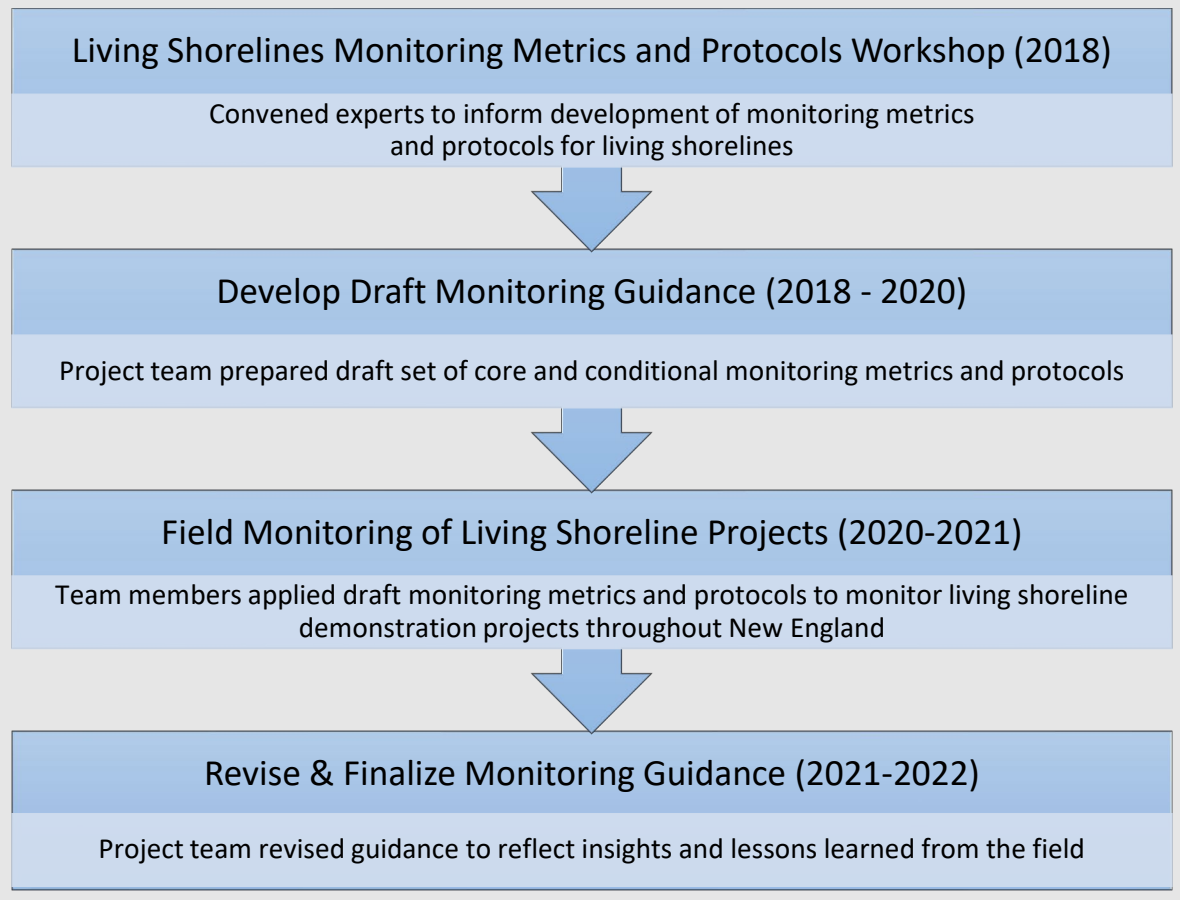
4. Process

This Guidance Document was developed with significant input, discussion, and revision from both project team members and other experts and stakeholders. At the outset of this project, a workshop was convened during May 2018 to bring experts from throughout the region together to share knowledge and expertise about development of monitoring metrics and protocols for living shorelines in New England. More than 60 coastal managers, scientists, and other experts provided guidance and advice about monitoring priorities, metrics, and protocols. A full list of workshop attendees can be found in Appendix G.

Members of the project team met on a regular basis throughout the project period to develop the monitoring metrics and protocols included in this Guidance Document. Project team members included representatives from The Nature Conservancy, National Oceanic and Atmospheric Administration, Northeast Regional Ocean Council, Maine Geological Survey, Casco Bay Estuary Partnership, Maine Coastal Program, Great Bay National Estuarine Research Reserve, New Hampshire Department of Environmental Services Coastal Program, University of New Hampshire, Massachusetts Office of Coastal Zone Management, Rhode Island Coastal Resources Management Council, Connecticut Department of Energy and Environmental Protection Land and Water Resources, University of Connecticut, and Sacred Heart University. A full list of team members is available in Appendix F.

Development of this Guidance Document was informed by the project team's experience monitoring living shoreline demonstration projects throughout New England. Insights from monitoring living shoreline demonstration projects were also highlighted in a series of case studies compiled into a story map to document and share project details, resources, and lessons learned. The overall process for development of this Guidance Document is outlined in Figure 5.

Figure 5. Process for Developing Guidance



5. Monitoring Plan Design Guidance

Although this Guidance Document is not intended to walk the user through the development of a monitoring plan, this section outlines several elements for consideration.

Goal-based approaches are recommended for developing site-specific monitoring plans to allow project proponents and interested stakeholders to identify site issues and define project goals and objectives accordingly. After establishing the goals and identifying the desired outcome of a living shoreline project, proponents can select appropriate metrics to measure progress, implement adaptive management practices, and identify maintenance needs. However, relying solely on a goal-based approach to monitoring plan development should not overshadow other important factors critical to measuring success or satisfying permit requirements. Site-specific conditions (e.g., presence of a protected species or critical habitat) or select project types (e.g., living breakwaters) may necessitate the inclusion of certain metrics. Similarly, if federal and state permitting agencies request updates on long-term structural integrity of the slopes, soils, and substrates of living shorelines or other resources of importance, then it will be necessary to identify and incorporate appropriate metrics into the monitoring plan. Many of the core metrics outlined in this Guidance Document will help users to provide the data and information necessary to inform project development and monitoring process, although early coordination with local, state, and federal regulatory agencies is strongly encouraged to ensure that appropriate data points are collected throughout the project.

Where possible, the project team recommends using a Before-After-Control-Reference-Impact (BACRI) monitoring design to show how a living shoreline approach performs. This approach relies on baseline data collection (i.e., site characterization of existing conditions), data from a control site, and post-implementation data collection (i.e., performance monitoring). The control is a site of similar characteristics and conditions (degraded/degrading conditions) that will not be impacted by the installation of a living shoreline project. In contrast, a reference site is defined as a “healthy” site with few to no signs of erosion or loss; a reference site is perhaps similar to the goal or desired end-state of the project site. Data should be collected at both the control site and the project site pre- and post-installation of the living shoreline project. Comparison of the before and after data from both the project site and the control site will elucidate the effects of implementing the living shoreline project and separate those effects from naturally occurring changes.

A suitable control site or reference site may not be available for every project. If a full BACRI design cannot be implemented, the project team recommends selecting a design in the following rank order (most preferred to least preferred):

- BACRI: Before and after data collection at the project site, the control site and a nearby reference site (goal)
- BACI: Before and after data collection at both the project site and control site
- Before and after data collection at both the project site and at a nearby reference (goal) site
- Before and after data collection at only the project site
- Data collection after installation only at the project site and a nearby control or reference site
- Data collection after installation only and only at the project site

Project proponents are encouraged to develop both adaptive management and contingency plans for living shoreline projects. Adaptive management plans that are integrated with routine monitoring enable project proponents to implement actions to help the project achieve the intended goals and objectives or identify when contingency plans should be implemented. An adaptive management plan needs a strong governance structure to ensure the project goals are met. Contingency plans should provide guidance on the implementation and monitoring of restoration activities in case of catastrophic project failure. The development of adaptive management and maintenance plans for demonstration projects will build a knowledge base around maintenance activities and which events trigger maintenance or management needs.

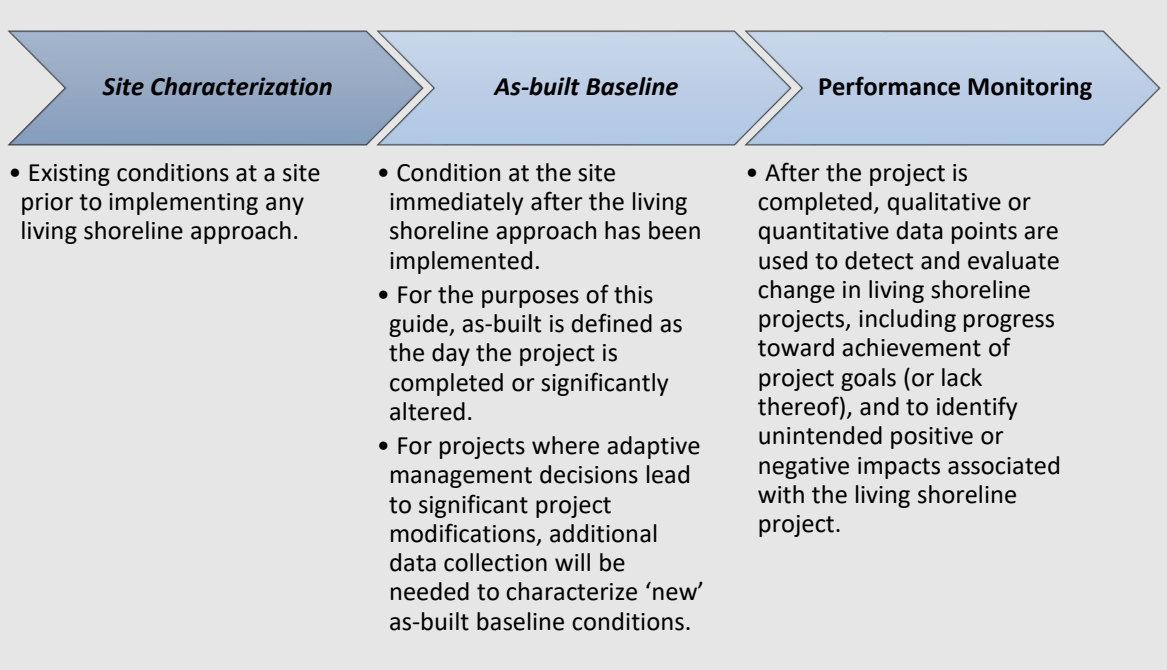
Project scale and risk (as well as project budget, timeframes, and the technical capacity of the monitoring team) influence the scope of the monitoring data collection effort in terms of intensity, frequency, and duration. For example, it may be more feasible to collect quantitative data on several metrics on a small-scale project than it is on a large-scale project. As the scale of a project increases, it may be necessary to reduce collection density and/or frequency or otherwise adjust methodology, although the scale at which this shift should occur is not clearly defined and may be different for each project. Untested/experimental projects may require more intensive and frequent data collection efforts over a longer timeframe than low-risk projects. It is critical that project proponents engage the relevant regulatory agencies early in the project development phase to identify site- or project-specific data collection needs.

6. Project Phases, Metric Classifications, and Protocol Tiers

In this section, the phases (site characterization, as-built baseline establishment, and performance monitoring) and classes (core and conditional) of metrics that could be collected for common living shoreline project goals are defined. The core metrics and protocols were proposed with the intent that their low cost would enable trained volunteers and professional practitioners alike to collect the data. Additionally, the core metrics and protocols are thought to be sufficiently accurate to provide data that can inform decision-making related to the design, permitting, construction, and monitoring and maintenance of living shoreline projects.

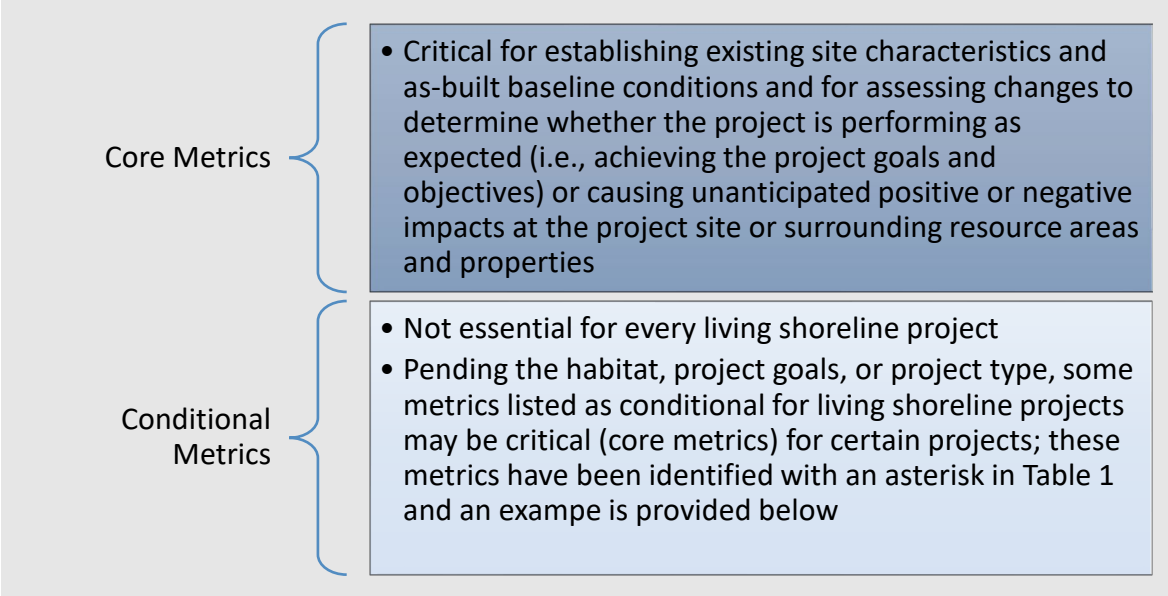
This Guidance Document proposes the following recommended phases for data collection:

Figure 6. Project Phases



The metrics for site characterization and performance monitoring project phases are further classified as either core or conditional metrics. The as-built baseline establishment project phase is considered a one-time assessment immediately post construction to validate and/or document differences from the project design. Additional survey or documentation may be necessary following major adaptive management activities as dictated during the performance monitoring phase. The two classifications of core or conditional metrics distinguish between metrics that are considered essential for monitoring most if not all living shoreline projects, and those that vary depending upon the type of living shoreline approach being applied (i.e., living breakwater), site conditions and habitat, the goals of the project, and the capacity of the monitoring team. Details are provided in Figure 7.

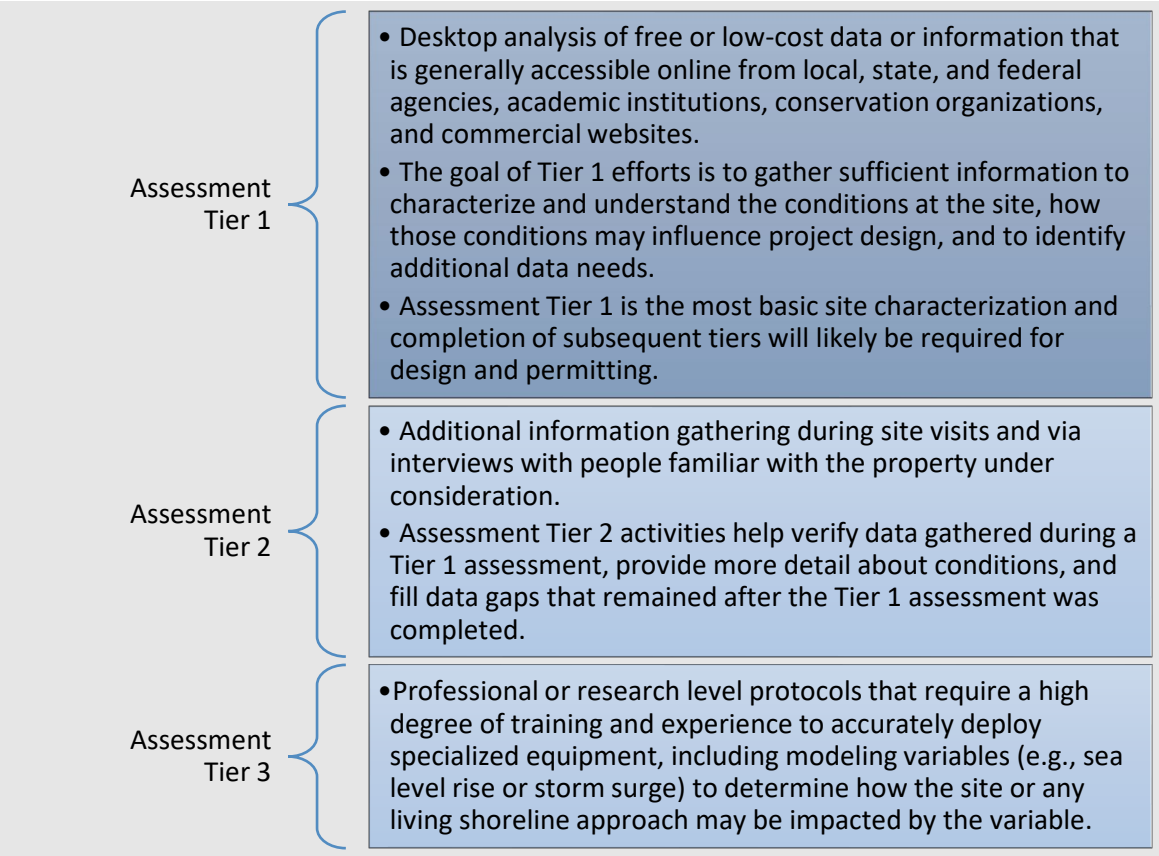
Figure 7. Core and Conditional Metric Classifications



Data collected and analyzed for metrics related to site characterization and performance monitoring phases are also assigned to tier classes. The Assessment Tier is assigned to site characterization metrics. The Monitoring Level is assigned to the performance monitoring metrics. In some cases, the same protocols are recommended for the site characterization, as-built baseline establishment, and performance monitoring (e.g., stormwater runoff).

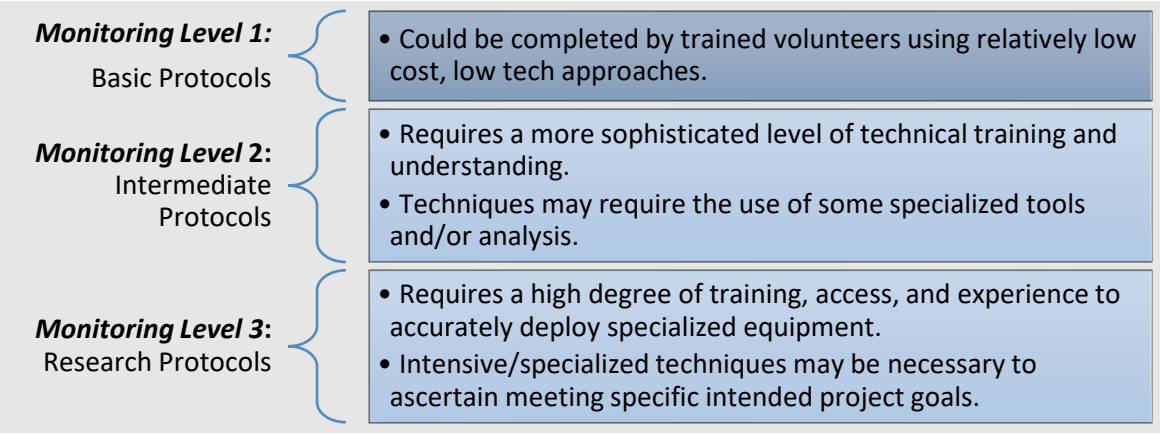
The Assessment Tier focuses on site characterization and reflects how the data is collected or analyzed to understand the site's existing conditions prior to and during the design phase. The Assessment Tier provides a sequence of data gathering with each subsequent tier allowing a finer understanding of the site to be achieved that often require a high degree of training and experience to accurately deploy specialized equipment. The Assessment Tier progresses from reviewing existing data, to collecting data on site, to modeling parameters to understand the site conditions. For some project types, higher Assessment Tiers may be required during the site characterization phase to support state and/or local permitting processes. The Assessment Tiers are described in Figure 8.

Figure 8. Assessment Tiers (apply to site characterization)



The Monitoring Levels reflect a range of data collection methodologies to assess performance monitoring over time of the biological, geological, and physical characteristics of the site. Similar to the Assessment Tiers, the Monitoring Levels are based on increasing levels of technical complexity, specialized equipment needed, and understanding required for implementation. The Monitoring Levels progress from less technically demanding protocols that could be implemented by citizen science teams and trained professionals (e.g., environmental consultants) alike to more technically demanding protocols that are better suited to professionally trained researchers with specialized skills, experience, and knowledge. Often, using the lower Monitoring Level(s) protocols are sufficient for assessing the intended management goals of living shoreline approaches. Higher level protocols may be more desired for a more robust, research level assessment. Investments of manpower, time, money, and analysis of the pros and cons of various technologies are also critical factors to consider when selecting a monitoring approach, however these characteristics were not explicitly considered in the monitoring level system. Standardized data collection protocols are recommended for a limited set of metrics to be collected as part of a regional living shorelines network.

Figure 9. Monitoring Levels (apply to performance monitoring)



7. Core and Conditional Metrics

Table 1 summarizes the metrics, the class assignment, the project phase when data collection should occur, and whether data collection could be completed at the desktop, in the field, and/or only with a camera (i.e., photo documentation/observations). The set of metrics outlined in Table 1 includes both core and conditional metrics and highlights the applicable project phase for each metric. Refer to Appendix A for descriptions of each metric, the rationale for measuring the metric, and a range of protocols (methods) and monitoring frequencies for collecting data on each metric.

Core and Conditional Metrics

Table 1: List of metrics, applicable project phase in which they are collected, and whether the metric is a core or conditional metric. Conditional metrics are those that vary depending upon the type of living shoreline approach, and thus are not applicable to all project types. The as-built baseline establishment project phase is a one-time assessment conducted immediately post-construction to validate and/or document differences from the project design. Additional survey or documentation may be necessary following major adaptive management activities as dictated during the performance monitoring phase.

D - indicates Desktop activities
C - indicates Camera/Photo
F - indicates Field activities beyond photo documentation
L - indicates Laboratory
* Denotes instances where a metric may change from conditional to core or vice versa pending the project type, goal, or phase

Metric		Project Phase and Metric Class		
		Site Characterization	As-built Baseline	Performance Monitoring
SITE USE	Overall site conditions	Core – C	Core – C	Core – C
	Historical and cultural site use and Impacts	Core – D, F		
	Current (and changes to) site use and impacts, existing infrastructure, and access point	Core – D, C, F		Core - C
	Adjacent area usage and impacts (and changes in use)	Core – D, C		Core – C
SYSTEM	Erosion history (site characterization phase)/shoreline position and horizontal change (as-built/performance monitoring)	Core – D, F	Core - C	Core – C, F
	Tidal range	Core – D		
	Sea-Level rise	Conditional – D		
	Sediment accretion	Conditional – D, F		Conditional* – F
	Suspended sediment supply	Conditional – D, F		
	Longshore transport	Conditional – D, F		Conditional* – F

Metric		Project Phase and Metric Class		
		Site Characterization	As-built Baseline	Performance Monitoring
GEOPHYSICAL	Site topography, profile (width, elevation, slope) and changes thereto	Core – D, C, F	Core – F, C	Core – F, C
	Nearshore slope and bathymetry	Conditional* – D, F	Conditional* - F	Conditional* - F
	Sediment type and grain size	Conditional – D, F	Conditional* – F, C	
	Soil bearing capacity and shear strength	Conditional* – D, F		
	Organic matter concentration	Conditional – F, L	Conditional* – F, L	Conditional* – F, L
HYDRODYNAMIC	Wave/wake energy climate	Core – D, F	Conditional* – F	Conditional* – F
	Storm surge	Conditional – D, F		
	Storm Impact	Core – C, D, F		Core – C, F
	Currents	Conditional* – D, F		Conditional* – D, F
	Ice needling, rafting, and shoving	Core – D, C		Core – C
	Stormwater runoff	Core – C	Conditional - C	Core – C
	Groundwater discharge	Conditional – C	Conditional - C	Conditional – C
VEGETATION / HABITAT QUALITY	Existing and historical vegetation/habitat	Core – D, C, F		
	Protected habitat areas/habitat utilization by species of concern	Core – D, C, F	Conditional – C, F	Conditional – C, F
	Invasive, non-native plant species	Core – C, F		Core – C, F
	Vegetation structure/robustness		Core – C, F	Core* – D, C, F
	Planting extent/area		Core* – D, C, F	
	Final species planted list and number of plants per species		Core – D, C	
	Comparison of planting density and minimum spacing requirements		Core* – F	
	Continued state of vegetation: Health and percent survival of planted vegetation,			Core* – F
	Herbivory and predation threats and other disturbance impacts	Core - F		Core - F
BIOTA	Presence of endangered or threatened species and special habitats	Core – D, F, C		
	Final list of bivalve species seeded		Conditional* – D	
	Density live bivalves	Conditional– D, F, C	Conditional* – D, F	Conditional* – F
	Area/extent of bivalve seeding		Conditional* – D, F	
	Bivalve size-frequency distribution	Conditional– D, F	Conditional* – D, F	Conditional* – F
	Species recruitment/colonization			Conditional* – F
	Marine invertebrate abundance and recovery	Conditional* – F		Conditional* – F
	Invasive biota species	Conditional* – D, F		Conditional* – F
	Fish population species/abundance	Conditional* – D, F		Conditional* – F
	Other biota of importance	Conditional* – D, F		Conditional* – F

Metric		Project Phase and Metric Class		
		Site Characterization	As-built Baseline	Performance Monitoring
CHEMICAL	Sediment/water quality	Conditional – F, L		Conditional – F, L
	Turbidity	Conditional* – F, L	Conditional* – F, L	Conditional* – F, L
	Water salinity	Conditional – F, L	Conditional – F, L	Conditional – F, L
	Water temperature	Conditional – F	Conditional – F	Conditional – F
STRUCTURE CONDITION	Created feature structural properties and stability		Core – C, F	Core – C, F
	Created feature anchor/tie-in integrity		Core – C, F	Core – C, F
	Material integrity (durability or decomposition of materials used in created features)		Core – C, F	Core – C, F
	Signs of erosion or erosion potential, including end effects		Core – C, F	Core – C, F
	Material types used vs. proposed		Core – C, F	
	Quantity of fill used vs proposed (including grain type/size)		Core - D	
	Maintenance			Core – C, F
HAZARD MITGAT	Flooding frequency and extent, and change thereto	Conditional* – D, F		Conditional* – F
	Berm over-topping			Conditional* - C
SOCIO-ECONOMIC	Actual cost vs estimated cost	Core – D	Core – D	Core – D
	Flood insurance claims, change in quantity	Conditional* – D		Conditional* – D
	Avoided damages or costs			Conditional* – D

8. Appendices

A. Metrics and Protocols Descriptions

This section provides detailed descriptions for all of the core and conditional metrics presented in Table 1 in the main narrative. The core metrics and protocols were proposed with the intent that their low cost would enable trained volunteers and professional practitioners alike to collect the data. Additionally, the core metrics and protocols are thought to be sufficiently accurate to provide data that can inform management-level decision-making related to the design, permitting, construction, and monitoring and maintenance of living shoreline projects. Most of the metrics outlined in this section are applicable to the site characterization phase (Assessment Tier protocols) and the performance monitoring phase (Monitoring Level protocols). In some cases, as-built base protocols are also noted.

The Assessment Tier methods for site characterization are sequenced to reflect a finer understanding of the site to be achieved that often require a high degree of training and experience to accurately deploy specialized equipment. The Assessment Tier progresses from reviewing existing data, to collecting data on site, to modeling parameters to understand the site conditions. For some project types, higher Assessment Tiers may be required during the site characterization phase to support state and/or local permitting processes.

Similar to the Assessment Tiers, the Monitoring Levels are based on increasing levels of technical complexity, specialized equipment needed, and understanding required for implementation. The Monitoring Levels progress from less technically demanding protocols that could be implemented by citizen science teams or trained professionals (e.g., environmental consultants) to more technically demanding protocols that are better suited to professionally trained researchers with specialized skills, experience, and knowledge. Often, using the lower Monitoring Level(s) protocols are sufficient for assessing the intended management goals of living shoreline approaches. Higher level protocols may be desired for a more robust, research level monitoring program/plan.

The metrics are presented in the same categories and order as highlighted in Table 1 of the main narrative. Each metric is presented using the following general framework:

- description of the metric,
- rationale for measuring the metric,
- applicable metric class and project phase,
- relevant project goals, and
- range of protocols (methods) and performance monitoring frequencies for collecting data for each metric.

SITE USE

Overall Site Conditions

Description: Site conditions during site characterization, as-built and performance monitoring phases will be monitored via photo documentation to capture photos from fixed points (capturing exact feature or landscape), similar vantage points (i.e., aerial), or opportunistically as need arises. Photos will document changes at the site over time.

Rationale: Maintaining a standardized photo monitoring record of a living shoreline project could serve multiple purposes. If captured consistently and accurately, photo documentation can show change over time in the physical and biological conditions at the site and in the way people and animals use the site. This metric and the primary method of photo documentation supports many of the other metrics listed in this Appendix. Overall site conditions could encompass photo documenting changes to: site use, system (shoreline position/erosion), geophysical (site topography/profile), hydrodynamic (storm impacts, ice impacts, groundwater discharge), vegetation (structure and state of health), and structural installations (stability, anchor ties). The time series nature of photo documentation also provides a compelling visual narrative that explores the opportunities and challenges of living shoreline approaches and highlights successes to promote the appropriate use of these techniques. Photo documentation could potentially be used to satisfy grant or regulatory requirements.

Metric class and project phase: Documenting site conditions through photo documentation is appropriate for all project phases. Photo documentation is useful by itself though it is often more useful in conjunction with quantitative data collection efforts (as detailed by the other metrics in this Appendix). Prior to establishing fixed photo points, the objectives of photo monitoring effort should be established and detailed plans for capturing images that support those objectives should be developed. See below for a list of the metrics that standardized photo monitoring of overall site conditions could support.

Metric class and project phase: Core for all project phases.

Relevant project goals: All living shoreline projects.

Metrics Supported by Overall Site Conditions through Photo Documentation:

- Current use of the site and adjacent land and water areas, existing infrastructure, potential impacts caused by current and historical use of the site and adjacent land and water areas.
- Erosion history/shoreline position and change (horizontal)
- Site topography, profile (width, elevation, slope) and changes thereto
- Sediment type and grain size
- Tidal range
- Ice needling, rafting, and shoving
- Stormwater and groundwater runoff
- Storm event impacts
- Existing (and potentially historical) vegetation and habitats

- Vegetation structure/robustness
- Planting extent/area
- Invasive species presence/abundance
- Herbivory and predation threats and impacts
- Habitat utilization by species of concern or species present
- Created feature location/position, dimensions, elevation, and stability
- Created feature anchor/tie-in integrity
- Material integrity of created features
- Signs of erosion or erosion potential, including end effects
- Material types used vs. Proposed of created features

Assessment and Monitoring Protocols:

Site Characterization Assessment:

- Tier 1: Planned and standardized photo documentation efforts for site-wide conditions (pre-construction) and specific variables. Examples include:
    - United States Department of Agriculture Quick Guide to Photo Point Monitoring provides background on establishing a photo monitoring plan at a site: https://efotg.sc.egov.usda.gov/references/public/NM/bio61a6_PhotoDocumentation_Protocol.pdf
    - Partnership for the Delaware Estuary Method for Fixed Photo Point Observations for capturing areas of interest: https://s3.amazonaws.com/delawareestuary/Standard+Methods+Bank+Documents/PDE-Method-51+Method+for+Fixed+Photo+Point+Observations+w.+datasheet.pdf
    - New Jersey Department of Environmental Protection's Citizen Scientist Monitoring of Nature-based Coastal Resilience and Restoration Projects Guidance Manual describes fixed point photographs for vegetation plot monitoring and general site conditions: https://s3.amazonaws.com/delawareestuary/Standard+Methods+Bank+Documents/Citizen+Scientist+Monitoring+Manual+4.2.pdf
- Tier 2: Picture posts with instructions installed on the posts. An example:
    - The Picture Post program at the University of New Hampshire: https://seagrant.unh.edu/volunteer/coastal-research-volunteers/current-projects/picture-post-monitoring
- Tier 3: Aerial photography from satellites, airplanes, drones, as well as low-cost balloon and kite mapping activities. Examples include:
    - Satellite and other aerial photography may be available from state and federal agency sources. If state or federal agencies will be flying an area to collect imagery, it may be possible to coordinate with them to collect images for the project site, if the site falls within or near the area the agencies planned to photograph.
    - Drone operation to collect aerial images and data must adhere to Federal Aviation Administration requirements and state and local requirements, if applicable.
    - Balloon and kite mapping kits and instructions from Public Lab: https://publiclab.org/wiki/balloon-mapping

Performance Monitoring and frequency: General (overall) condition site visits should be conducted quarterly and for pre/post-storm events during the first-year post-construction. Semi-annually or annually may be more appropriate as site becomes established.

- Level 1: Planned and standardized photo documentation efforts for site-wide conditions (post-construction) and specific variables.
- Level 2: Picture posts with instructions installed on the posts.
- Level 3: Aerial photography from satellites, airplanes, drones, as well as low-cost balloon and kite mapping activities.

Historical and Cultural Site Use and Impacts

Description: Describes the activities (e.g., cultural and/or industrial use) that historically occurred on the site and the effects of those activities on the soil, water, flora, and fauna; describes the cultural significance of the site, the historical and cultural resources that may be found on the site, as well as the presence of soil and/or water contamination.

Rationale: The historical site use information may help to determine activities (e.g., soil remediation if the site was used for industrial purposes) that may be necessary to establish a project. Cultural use assessments also may identify resources that are subject to special management. The National Environmental Policy Act compliance process will require a review pursuant to Section 106 of the National Historic Preservation Act of 1966. Consideration should also be given to the expected future uses of the site if the site is of current significance to the general public and/or to North American Tribes.

Metric class and project phase: Core metric for site characterization.

Relevant project goals: All living shoreline projects.

Site Characterization Assessment Protocols: The level of effort required to assess the historical and cultural site use and impacts may be dictated by relevance to the project site, existing site conditions, and the proposed project.

- Tier 1: To assess historical/cultural use, coordinate with the federal agency leading the NEPA review to submit a request to the appropriate State and/or Tribal Historic Preservation Office (SHPO/THPO) to complete a Section 106 review; complete additional historical and archeological reviews as requested by SHPO or THPO. To assess past site uses that may have contributed to contamination of onsite soil and water, conduct a records search for the property and review historical maps and aerial photographs.
- Tier 2: To assess historical/cultural use, conduct additional historical and archeological assessments on site pursuant to requests for additional information from SHPO/THPO. To assess site uses that may have contaminated soil and water, interview property owners, municipal staff, and, if warranted, conduct Environmental Site Assessments using licensed professionals.

Resources to Assess Historical and Cultural Use:

- Connecticut Department of Economic and Community Development: https://portal.ct.gov/DECD/Content/Historic-Preservation/01_Programs_Services/Environmental-Review/Fed-Review-and-Compliance---Section-106
- Maine Historic Preservation Commission: https://www.maine.gov/mhpc/programs/project-review
- Massachusetts Historical Commission: https://www.sec.state.ma.us/mhc/mhcrevcom/revcomidx.htm
- New Hampshire Division of Historical Resources: https://www.nh.gov/nhdhr/review/
- Rhode Island Historical Preservation and Heritage Commission: http://www.preservation.ri.gov/review/process.php

Resources to Assess Past Industrial Site Use:

- EPA Superfund Sites in Reuse: https://www.epa.gov/superfund-redevelopment-initiative/find-superfund-sites-reuse

Current (and Changes to) Site Use and Impacts, Existing Infrastructure, and Access Points

Descriptions: Describes the ongoing activities at the site and the impacts (e.g., erosion, soil compaction, contamination, excessive trampling of vegetation, etc.) of the activities/infrastructure on the soil, water, flora, and fauna; the critical above and belowground infrastructure (structures, pipelines, roadways, boat ramps, etc.); and the ease of entering or leaving the site during project construction and performance monitoring. Changes to the site use and impacts describes any changes in the type or extent of use occurring on the site as well as the impact (if any) of those changes resulting from the construction of a project.

Rationale: Documenting the current site use and existing infrastructure during the site characterization phase could help to determine the set of factors that contribute to the project need and may influence or constrain project design and construction. Documenting current site use also establishes a baseline to assess potential change in site use due to the living shoreline project. Documenting the access points during site characterization phase will help to determine the ease or difficulty of accessing the site for construction, monitoring, and maintenance.

Documenting changes during the performance monitoring phase in the type of activities or the extent of activities occurring on the project and adjacent areas, and the impacts of those changes, could elucidate factors influencing the success or failure of a living shoreline project. Documenting changes in shoreline access, recreation, fishing, or other uses may also inform adaptive management needs (e.g., signage, fencing, etc.).

Metric class and project phase: Core metric for site characterization and performance monitoring.

Relevant project goals: Applicable to all living shoreline projects.

Assessment and Monitoring Protocols and Frequency: At a minimum, changes to site use impacts should be conducted annually and post-storm events.

Site Characterization Assessment Protocols:

- Tier 1: Review and document publicly-available reports, files, records, maps, site plans, surveys, and/or other relevant documents through state or municipal websites.
- Tier 2: Onsite observation and photo documentation; interviews with property owner and/or users, municipal staff, and/or elected officials.
- Tier 3: Conduct site user surveys.

Performance Monitoring Protocols and Frequency:

- Level 1: Onsite observation and photo documentation; interviews with property owner and/or users, municipal staff, and/or elected officials.
- Level 2: Observe site users at selected days and times.
- Level 3: Conduct site user surveys (though trained volunteers could administer the surveys, training volunteers may be more effort than levels 1 and 2).

Adjacent area usage and impacts (and changes in use)

Description: Describes the current use, cover, and condition of the upland, lateral, and waterward areas adjacent to the project site, as well as the impacts of the current use and conditions of the adjacent areas on the project site; also describes the potential regional or cumulative impact resulting from development of a specific project and how that project may relate to other nearby locations.

Rationale: Documenting the current use, cover, and condition of the adjacent areas during site characterization can help to determine if future problems identified on the project site are caused or exacerbated by activities occurring on adjacent lands or waters. For example, installation of a bulkhead on an adjacent property may cause increased erosion on the project site. Similarly, the installation of a boat dock and/or ramp on the adjacent property may increase boat traffic and result in more frequent boat wake that exacerbates shoreline erosion on the project site.

Documenting the use and condition of the adjacent areas also establishes a baseline to assess how the construction of a living shoreline project may change either (and/or both) the way the adjacent areas are used or the cover and conditions of adjacent resource areas during the performance monitoring phase. For example, bluff erosion on the project site may cause a neighboring sand spit to become larger (i.e., this is the impact on nearby conditions), which in turn attracts boaters to use the spit as a gathering place. After construction of a living shoreline project to stabilize the bluff sediment, the growth of the sand spit may slow or cease. Boater use of the spit may continue until natural processes cause the sand spit to disappear.

Metric class and project phase: Core metric for site characterization and performance monitoring.

Relevant project goals: Applicable to all living shoreline projects.

Site Characterization Assessment Protocols:

- Tier 1: Review and document publicly available reports, files, records, maps, site plans, surveys, and other relevant documents through state or municipal websites.
- Tier 2: Onsite observation and photo documentation; interview property owner and/or site users, municipal staff, and/or elected officials.
- Tier 3: Conduct site user surveys.

Performance Monitoring Protocols and Frequency: At a minimum, changes to site use impacts should be conducted annually and post-storm events.

- Level 1: Onsite observation and photo documentation; interview property owner and/or users, municipal staff, and/or elected officials.
- Level 2: Observe site users at selected days and times.
- Level 3: Conduct site user surveys (though trained volunteers could administer the surveys, training volunteers may be more effort than levels 1 and 2).

SYSTEM

Erosion history/Shoreline position and change (horizontal):

Description: Erosion history is the average amount of horizontal shoreline loss or gain that has occurred over at least the last 10 years. This information describes whether and by how much the shoreline is accreting or eroding. Shoreline change is calculated by measuring the current linear distance between the shoreline and a known fixed marker and then subtracting the current distance from the linear distance measured during a previous site visit.

Rationale: Quantitative and/or qualitative erosion history for site characterization may provide evidence of erosion beyond seasonal or annual variability and justify the need for shoreline stabilization. Documenting the rate of shoreline erosion prior to and after project implementation can quantify the effectiveness of a living shoreline to stabilize the project site.

Metric class and project phase: Erosion history is a core metric for site characterization. Documenting changes to the shoreline position is a core metric for as-built baseline establishment, and performance monitoring.

Relevant project goals: Applicable to all living shoreline projects. Especially relevant to projects designed for wave attenuation and/or shoreline stabilization.

Site Characterization Assessment Protocols for Erosion History (horizontal):

Assessment should span the recent 10-15 years at a minimum and will ideally assess longer term trends (greater than or equal to 30 years) as well. Assessment should note whether erosion/accretion is an ongoing process or a recent and relatively new development. Assessment accuracy should be ± 20 cm horizontally.

- Tier 1: Analyze historic aerial images or digitized layers of the project site and utilize publicly available shoreline change data and tools to evaluate the rate of erosion or shoreline change. Additional useful information about shoreline change can be obtained via interviews with property owners, adjacent property owners, and local or state natural resource management staff.
    - State Shoreline Change Data:
        - Massachusetts Shoreline Change Browser: https://www.mass.gov/service-details/massachusetts-shoreline-change-project
        - Rhode Island Shoreline Change Maps: http://www.crmc.ri.gov/maps/maps_shorechange.html
        - New Hampshire Beaches: Shoreline Movement and Volumetric Change report: https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/r-co-17-01.pdf
        - New Hampshire Coastal Viewer: http://nhcoastalviewer.unh.edu/Html5Viewer/index.html?viewer=NHCoastalViewer

        - Connecticut Shoreline Change Analysis: https://shorelinechange.uconn.edu/
        - Connecticut Coastal Hazards Map Viewer: https://cteco.uconn.edu/viewer/index.html?viewer=coastalhazards
    - Aerial images can be obtained from:
        - Federal, state, and sometimes local GIS data repositories
        - Historic Aerials (www.historicaerials.com),
        - USGS topographic maps https://www.usgs.gov/programs/national-geospatial-program/topographic-maps
        - Google Earth (www.google.com/earth/),
        - USGS National Aerial Photography Program: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-aerial-photography-national-aerial-photography-program-napp#overview
        - Lidar and imagery from NOAA's Digital Coast Data Access Viewer: (https://coast.noaa.gov/dataviewer/#/),
    - Publicly-available shoreline change analysis tools:
        - Digital Shoreline Analysis System: https://woodshole.er.usgs.gov/project-pages/DSAS/version4/data/DSASv4_4_manual.pdf)
- Tier 2: Field verify the desktop analysis and collect additional information during a field visit to document the current shoreline position. Select and use a protocol that can achieve the desired data accuracy of ± 20 cm in a manner that is repeatable, transparent, and verifiable.
    - Along established permanent transects, use a tape measure to determine the linear distance from a known fixed point (e.g., a PVC pipe marker or metal or wooden survey stake) to the shoreline edge. To measure erosion in the case of a coastal bank, drive rebar erosion pins into the bank face until the end is flush with the bank and measure how much of the rebar is exposed during each site visit to determine the erosion rate. This is only applicable for systems that are consistently eroding, not accreting.
    - Use orthorectified imagery showing known permanent features and/or the markers of fixed points of transects to measure the distance between the fixed points and the shoreline edge.
    - Aerial images can be collected using a drone, kite, or balloon mapping kit.
    - Document the shoreline position using a total station or other surveying equipment, differential Global Positioning System (GPS), Real-Time Kinematic GPS (RTK GPS), or lidar. RTK-GPS is preferred, though Laser Level, Total Station, or similar technology can be used when GPS coverage is limited or nonexistent.

As-Built and Performance Monitoring Protocols for Shoreline Position and Change (horizontal) and Frequency:

Collect horizontal shoreline change data twice per year, once in late fall and in early spring. Effort should be made to result in the highest degree of horizontal accuracy possible and be repeatable, transparent, and verifiable. Additional measurements after major storm events that could alter the shoreline position are also recommended (see also the storm impact metric) if and when conditions are safe enough to access the site.

- Level 1: Along established permanent transects, use a tape measure to determine the linear distance from a known fixed point (e.g., a PVC pipe marker or metal or wooden survey stake) to the shoreline edge to measure shoreline position and change. Alternatively, and for a coastal bank, drive rebar erosion pins into the bank face until the end is flush with the bank and measure how much of the rebar is exposed during each site visit to determine the erosion rate. This is only applicable for systems that are consistently eroding, not accreting.
- Level 2: Use orthorectified imagery showing known permanent features and/or the markers of fixed points of transects to measure the distance between the fixed points and the shoreline edge. (Oyster handbook) Aerial images could be collected using a kite or balloon mapping kit.
- Level 3: Document the shoreline position and change thereto using a total station or other surveying instrumentation, or differential GPS, RTK GPS, or lidar. RTK-GPS is preferred, though Laser Level, Total Station, or similar technology can be used when GPS coverage is limited or nonexistent.

Tidal range

Description: Describes the vertical difference in height between the low and high tides as referenced to as tidal datum.

Rationale: Tidal range determines the height and width of features designed for wave attenuation, the range and locations of vegetation types, and the establishment or growth of shellfish communities on reef structures.

Metric class and project phase: Core metric for site characterization.

Relevant project goals: Applicable to all living shoreline projects. Especially relevant to projects focused on wave attenuation, shoreline stabilization, and/or habitat creation/enhancement.

Site Characterization Assessment Protocols:

- Tier 1: Desktop analysis of reference tidal gauge stations nearest to the project site to approximate the local tidal range found on the project site, particularly during growing season. Review historic tidal gauge data. Gauge locations and information about the range of error can be found on the following sources:
    - VDatum (http://vdatum.noaa.gov) (NOAA)
    - Tides and Currents (http://tidesandcurrents.noaa.gov) (NOAA)
    - NERACOOS Data Tools: http://neracoos.org/data/
- Tier 3: Collection of site-specific tidal range data may be needed to account for local variations in water levels depending upon the type of project. NOAA's Computational Techniques for Tidal Datums Handbook contains the recommended methodology for establishing local tidal datums (https://tidesandcurrents.noaa.gov/publications/Computational_Techniques_for_Tidal_Datums_handbook.pdf). Site-specific tidal range observations can be collected using the following approaches:
    - Automated water level recorder, pressure transducer, or similar device.
    - Manual high tide level marker such as a ruler/graduated rod or tide staff.

Sea Level Rise

Description: The increase in ocean water levels due to climatic changes.

Rationale: Sea level rise changes water levels and wave heights, which influence variables such as the tidal range, erosion rates, and the spatial range of various vegetation types. Sea level rise will also influence the design life of a living shoreline project, the ability of the project to achieve the intended goals, and the ability of vegetation to migrate landward.

Metric class and project phase: Conditional metric for site characterization pending the project type and goals.

Relevant project goals: Sea level rise will likely affect all living shoreline projects but may be especially relevant to projects with the goal of enabling marsh maintenance and/or migration.

Site Characterization Assessment Protocols:

- Tier 1: Assess the potential impact of sea level rise on the project site using the state recommended sea level rise projections (if available) forecasting 30 years into future while using a moderate high projection before the year 2100.
    - UCONN CIRCA Local Sea Level Rise Scenarios for the State of Connecticut: https://circa.uconn.edu/sea-level-rise/
    - Rhode Island Stormtools: http://www.beachsamp.org/stormtools/
    - Massachusetts Sea Level Rise and Coastal Flooding Viewer: https://www.mass.gov/service-details/massachusetts-sea-level-rise-and-coastal-flooding-viewer
    - New Hampshire Coastal Viewer: http://www.nhcoastalviewer.org/
    - Maine Sea Level Rise and Storm Surge Scenarios: https://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml
    - NOAA Sea Level Rise Viewer: https://coast.noaa.gov/digitalcoast/tools/slr.html
    - USACE
        - Sea Level Change Curve Calculator: http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html
        - Sea Level Tracker: https://www.usace.army.mil/corpsclimate/Public_Tools_Dev_by_USACE/sea_level_change/
    - USGS: Coastal Change Hazards Portal: https://marine.usgs.gov/coastalchangehazardsportal/
    - Forthcoming: Regional downscaled projections will be available in the coming years: https://necsc.umass.edu/projects/probabilistic-projections-local-sea-level-rise-and-vulnerability-along-northeast-coastline

Sediment accretion

Description: Measures the volume or depth of sediment deposited on a project site either naturally or as a result of restoration action. Sediment accretion can be used to measure changes in elevation due to

deposition of sediment on projects aiming to enhance elevation (can be challenging to measure as bottom surface is often obscured under turbid, tidally-influenced waters).

Rationale: Sediment accretion is a critical indicator of initial progress in tidal marsh restoration. In addition, certain ecosystems require specific elevations be maintained or that sediment accretion exist.

Metric class and project phase: Conditional metric for site characterization and performance monitoring. Core metric for dune performance monitoring.

Relevant project goals: Applicable to living shoreline projects with the goal of maintaining or increasing elevation.

Site Characterization Assessment Protocols:

- Tier 1: Desktop review of previous studies.
- Tier 2: Survey with GPS.
- Tier 3: Standard sediment core with marker horizons; plates/traps; sediment stakes/plates.
- Tier 3: Sub-bottom profiling to image and assess sediment layers.

Performance Monitoring Protocols: Collect sediment accretion data twice per year, once in late fall and in early spring. Level of accuracy will vary depending upon project type and goals.

- Level 1: Emery Rod method (https://seagrant.umaine.edu/wp-content/uploads/sites/467/2019/05/emerymethod.pdf)
- Level 2: Standard sediment core with marker horizons; plates/traps; sediment stakes/plates.
- Level 2: Surveying techniques such as surveyor's level, laser level and graduated rod, transit, total stations.
- Level 3: Surface Elevation Table (SET), Real-Time Kinematic GPS (RTK-GPS), or remote sensing with drones, lidar, Structure-From-Motion.

Suspended Sediment Supply

Description: Describes the ratio of solid material suspended in the water column (mg/L).

Rationale: Suspended sediment supply provides information about water quality, habitat suitability, and the amount of solid material available to accrete within a project site.

Metric class and project phase: Conditional metric for site characterization.

Relevant project goals: Applicable to living shoreline projects emphasizing shoreline stabilization and sediment accretion goals.

Site Characterization Assessment Protocols:

- Tier 1: Desktop review of previous studies.
- Tier 2: Standard field collection techniques and analysis in a laboratory setting. (https://www.epa.gov/sites/production/files/2015-06/documents/NE-States-Sample-Collection-Manual.pdf)

- Tier 3: Three-dimensional hydrodynamic modeling of the sediment supply.

Longshore Transport

Description: Describes the process by which sand and sediment is moved along the shoreline via a current flowing roughly parallel to the shoreline.

Rationale: The interaction between the speed and angle of waves breaking on the shoreline and the shoreline slope influences the rate at which sediment is moved on and off a project site. The direction of the net littoral sediment movement can inform where erosion may likely occur and where sediment eroded from the site may be deposited (sediment budget). At a minimum, a basic understanding of the dominant direction of the longshore transport at the site is needed to inform design and monitoring.

Metric class and project phase: Conditional metric for site characterization and performance monitoring.

Relevant project goals: Applicable to living shoreline projects emphasizing Shoreline stabilization and sediment accretion goals.

Site Characterization Assessment Protocols: Specific measurements should be based on the project type (e.g., measurements for beach nourishment projects may differ from marsh restoration projects).

- Tier 1: Review existing aerial photography and maps to assess historical shoreline change and identify where shoreline accretion and erosion are occurring (see resources listed under erosion history/shoreline position).
- Tier 2 Deploy sediment traps (four per transect; two transects behind the living shoreline and two transects at control sites).
- Tier 2: Utilize the Army Corps of Engineers Sediment Mobility Tool (https://navigation.usace.army.mil/SEM/SedimentMobility).
- Tier 3: Use of Delft3D-MOR Model to model longshore transport.

Performance Monitoring Protocols: As with assessment protocols, specific measurements should be based on the project type. Collect/analyze longshore transport data annually.

- Level 1: Review existing aerial photography and maps to assess historical shoreline change and identify where shoreline accretion and erosion are occurring (see resources listed under erosion history/shoreline position).
- Level 3: Deploy sediment traps (4 per transect; 2 transects behind the living shoreline and two transects at control sites).

GEOPHYSICAL

Site topography, profile (width, elevation, slope), and changes thereto

Description: Describes the vertical extent, gradients and contours of the site including the slopes of the upland and shoreline zones. Width refers to the area between the water's edge and the infrastructure, property, or habitat being protected.

Rationale: The site topography, profile (width, elevation, slope), and changes thereto are critical for determining the range and locations where various types of wetland vegetation are likely to survive as well as the potential for erosion to occur. Shoreline width is important because the amount of space available between the water's edge and bank, dune or infrastructure on the parcel will influence project design. Since living shoreline projects often require the establishment of a gentle slope, it is important to consider the options for creating a gentle slope, including shifting landward. In limited situations, a project may attempt to shift the shoreline seaward.

Metric class and project phase: Core metric for site characterization, as-built baseline, and performance monitoring.

Relevant project goals: All living shoreline project goals.

Site Characterization Assessment Protocols for topography, profiles (width, elevation, slope):

Assessment protocols and level of accuracy may vary depending on the type of habitat being assessed and the goals of the project.

- Tier 1: Analyze existing data sets including lidar topographic maps, or digital elevation models.
- Tier 2: Document shoreline topography/profile along established transects using the Emery Method referenced to a fixed benchmark (https://seagrant.umaine.edu/wp-content/uploads/sites/467/2019/05/emerymethod.pdf).
- Tier 3: Capture the topography and profile using differential Global Positioning System (GPS), Real-Time Kinematic GPS (RTK GPS), lidar or UAV, Laser Level, Total Station, or similar technology referenced to a fixed benchmark.

Performance Monitoring Protocols for topography, profiles (width, elevation, slope) and Frequency:

These monitoring protocols may depend on the type of project or habitat being monitored. Some project goals may require a higher level of desired vertical accuracy, though a protocol that is repeatable, transparent, and verifiable is likely sufficiently appropriate to inform adaptative management. Seasonal monitoring will depend on habitat and project type.

- Level 2: Along established transects perpendicular to the shoreline, collect topography/profile data using the Emery Method, referenced to a fixed benchmark (https://seagrant.umaine.edu/wp-content/uploads/sites/467/2019/05/emerymethod.pdf).

- Level 2: Document shoreline topography/profile along established transects using surveying equipment such as surveyor's level, laser level and graduated rod, referenced to a fixed permanent benchmark.
- Level 3: Capture the topography and profile using differential GPS, RTK GPS, Total Station, lidar or UAV.

Nearshore slope and bathymetry

Description: The gradient, contours, depths, and features of the underwater terrain.

Rationale: Nearshore slope and bathymetry influence wave size and current conditions, the location where waves break, and longshore sediment transport processes.

Metric class and project phase: Conditional for most projects. Core metric for site characterization, as-built baseline establishment, and performance monitoring when the project design includes the establishment of in-water features or vegetation.

Relevant project goals: Especially relevant to projects focused on shoreline stabilization, wave attenuation, and in-water habitat and/or feature creation.

Site Characterization Assessment Protocols: When collected during assessment and/or monitoring, the nearshore slope and bathymetric data should be collected within the project footprint and as needed to support project goals. For living breakwater projects, analysis of bathymetry and average wave trajectory are important to inform final placement.

- Tier 1: Analyze existing bathymetry data, if available for the project site. Data sources include:
  - NOAA: https://www.ngdc.noaa.gov/mgg/bathymetry/relief.html
  - USACE Joint Airborne Lidar Bathymetry Technical Center of Expertise: https://www.sam.usace.army.mil/Missions/National-Centers-in-Mobile/Joint-Airborne-Lidar-Bathymetry/
  - USGS: https://woodshole.er.usgs.gov/data/submergedlands/
  - International Hydrographic Organization Data Centre for Digital Bathymetry Viewer: https://maps.ngdc.noaa.gov/viewers/iho_dcdb/
  - CTDEEP Bathymetric Contours in Meters for Long Island Sound: http://www.cteco.uconn.edu/metadata/dep/document/LIS_BATHYMETRY_FGDC_Plus.htm
- Tier 2: Conduct bathymetric survey using depth sounder and GPS receiver from canoe or skiff.
- Tier 3: Use of lidar, sidescan sonar, or other bathymetric surveying technique.

Performance Monitoring Protocols and Frequency: When collected during assessment and/or monitoring, the nearshore slope and bathymetric data should be collected within the footprint of the project and as needed to support project goals.

- Level 2: Conduct bathymetric survey using depth sounder and GPS receiver from canoe or skiff.
- Level 3: Use of lidar, sidescan sonar, or other precise bathymetric surveying technique.

Sediment type and grain size

Description: Sediment type describes the classification of the sediment (e.g., mud, sand, silt, gravel, pebble, cobble, boulder, bedrock, etc.). Sediment grain size describes the dimensions of the grain.

Rationale: If sediment from offsite is used in a living shoreline project, the sediment type and grain size should be consistent with that of the sediment found naturally on the project site. Materials acquired offsite must be properly sourced and vetted prior to and periodically during placement on site.

Metric class and project phase: Conditional metric for site characterization. Core metric prior to onsite distribution or placement of fill and as-built baseline establishment, particularly for dune restoration and beach nourishment project types. Sediment type and grain size should be checked periodically during the filling process to ensure the appropriate type and size is used throughout. Spot checking the type and grain size after distribution is necessary to document as-built conditions (refer to structure condition category, sediment type and grain size metric).

Relevant project goals or types: Relevant to projects that will utilize fill material sourced from an offsite location in the construction of the living shoreline.

Site Characterization Assessment Protocols:

- Tier 1: On site observation.
- Tier 2: Surface sample and soil core sampling with visual classification; sieve analysis of site samples; textural/observational classification using a sand gauge and/or geotechnical gauge. Samples should be taken at the surface and, for marshes, below any peat.

As-Built Protocols:

- Level 1: Sieve analysis using ASTM procedures and/or textural/observational classification using a sand gauge and/or geotechnical gauge to verify the material matches that found on-site before unloading it from the truck onto the site, and periodically during distribution on-site.

Soil Bearing Capacity and Shear Strength

Description: An engineering metric that provides information about the capacity of a soil to support weight and about below ground stability. While the methods outlined in this section are useful to inform planning and design, creation of a small-scale pilot project is the most effective approach for determining the viability for a specific location to successfully support a large-scale living breakwater.

Rationale: Some living shoreline projects include the creation of sills or other features at specific heights to attenuate wave energy. If the soil bearing capacity of the substrate is low, meaning that features constructed on the substrate are likely to settle or sink into the substrate, then the capacity of the feature to attenuate wave energy will be reduced when the installed features settle below the design elevation. Identifying the soil bearing capacity prior to construction will allow for project designs that incorporate strategies to minimize or eliminate elevation loss due to soil compaction and settling.

Metric class and project phase: Conditional metric for site characterization; could be considered a core metric pending the project type, or project goals.

Relevant project goals: Creation of elevation dependent wave energy attenuation features (e.g., rock sill, breakwater, etc.).

Site Characterization Assessment Protocols:

- Tier 2: The availability of site-specific soil bearing capacity is unlikely and onsite assessment likely will be required. However, geotechnical studies, dredging and disposal studies, and topographical surveys completed on or near the site may provide an understanding about the site's soil characteristics. A general approach to assessing soil bearing capacity is to walk the proposed location of the sill or breakwater, and if the sediment can support a person's weight without sinking or "going quick", then it may support sills or other created features. "Going quick" describes heavily saturated sediment (i.e., mucky or mushy) that envelopes hefty objects as they sink into the sediment. A rough estimate of the bearing capacity can be determined if, for example, a 200-pound person stands with their feet together on the sediment and does not sink. This approximate soil bearing capacity of 200 pounds/square foot could be compared to an estimate of the pounds per square foot that may be needed for any load bearing feature (e.g., sill created with rock or bagged shell) (Hardaway, et al., 2017). This estimate should be field verified using an approach in assessment tier two.
- Tier 2: A range of approaches with varying degree of accuracy and consistency can be used to estimate the soil bearing capacity:
    - Use a Standard Penetration Test (SPT), a soil compaction tester, or vane shear stress tests according to standard procedures.
- Tier 3: Conduct a full geotechnical assessment of the site conditions with a licensed professional.

Organic matter concentration

Description: Describes the characteristics of sediments in the living shoreline project site.

Rationale: Organic matter concentration affects nutrient availability and plant growth.

Metric class and project phase: Conditional metric for site characterization, as-built, and performance monitoring depending on the project goals.

Relevant project goals: Applicable to living shoreline projects intent on establishing new vegetation for soil stability, wave attenuation, and habitat provision.

Assessment Protocols:

- Tier 1: Visual assessment on site.
- Tier 2: Assessment completed by professional.
- Tier 3: Standard loss on ignition (LOI) laboratory procedures to determine organic matter concentration (http://lrc.geo.umn.edu/laccore/assets/pdf/sops/loi.pdf).

Performance Monitoring Protocols:

- Tier 3: Assess soil moisture, bulk density, and organic matter concentration in years 1 and 5 of monitoring if vegetation was planted in the intertidal zone. Use standard procedures for determining bulk density (http://soilquality.org.au/factsheets/bulk-density-measurement) and organic matter concentration (Loss-On-Ignition, LOI; http://lrc.geo.umn.edu/laccore/assets/pdf/sops/loi.pdf).

HYDRODYNAMIC

Wave/Wake Energy Climate (Wave or Wake Height, Fetch, and Wind Speed, Direction, and Duration)

Description: The wave/wake energy climate is a measure of wave or wake energy impacting the site. Fetch is the distance wind travels over open water. Wind speed, direction, and duration describe the wind velocity, direction it is blowing, and how long it blows over open water.

Rationale: Wave and wake energy, whether from wind driven waves or vessel wakes, is a primary driver of coastal erosion. The size of waves/wakes influences both the strength with which the wave/wake breaks on an installed feature or the shoreline itself and the types of shoreline approaches that will be suitable in a given location.

As wind travels over open water, it transfers energy from the wind into the water/wave surface. A longer fetch results in greater energy transfer and larger waves. Measuring wave height or amplitude is the preferred method for measuring the wave energy climate at a site; but fetch and wind speed, direction, and duration can be used as a proxy to calculate the wave climate. The temporal nature of wave energy must also be considered, since wind and weather patterns shift with changing seasons and storms. Site characterization assessment and performance monitoring may be needed over several seasons, depending on the project type and goals.

Coastal erosion caused by vessel wakes has been a growing concern for some time (Parnell and Kofoed-Hansen, 2001; FitzGerald et al., 2011; LaPann-Johannessen et al., 2015). Boat wakes differ from wind wakes in that boat wakes may be of larger height and longer period but a shorter duration than wind driven waves. If vessel wakes are suspected to be a primary driver of coastal erosion at a site, then understanding the magnitude of the wake climate's influence may be needed to design the appropriate living shoreline project.

Metric class and project phase: Core metric for site characterization. Conditional metric for as-built baseline and performance monitoring when the project design includes the establishment of in-water features to attenuate wave and/or wake energy.

Relevant project goals: All living shoreline project goals for site characterization.

Site Characterization Assessment Protocols:
Wave height: When measuring and assessing wave heights, consider the tidal cycle and to better understand the number of hours the project would be exposed to waves or wakes given the rise and fall of the tides and the location/elevation of the project.

- Tier 1: Onsite observation using a graduated staff to assess wave heights, if appropriate to project scope. For projects where 1% wave data is important, refer to community's Flood Information Study (FIS) https://www.fema.gov/flood-maps/change-your-flood-zone/status/flood-insurance-study.

- Tier 3: Deployment of automated water/wave level gauge, pressure transducer or similar devices.
- Tier 3: Wave modeling:
    - Connecticut: https://circa.uconn.edu/crest/wave-model/
    - EM 1110-2-1100 Part II Chapter II (US Army Corps of Engineers, Coastal Engineering Manual, 2002); https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1100_Part-02.pdf?ver=2016-02-11-153511-290

Wind speed, direction, duration:

- Tier 1: Create a wind rose (shows % time wind is blowing from a certain direction, which allows determination of dominant wind direction and average speeds if that data is available) using data from NOAA or a local weather station.

Fetch:

- Tier 1: Derive the fetch from visual observations or aerial photography.
- Tier 2: Site survey using electronic distance measuring device.
- Tier 3: Use of tools such as state or federal (USGS) wind fetch model to capture dominant fetch direction/duration (https://www.umesc.usgs.gov/management/dss/wind_fetch_wave_models_2012update.html).

Wake:

- Tier 1: Visual analysis with graduated wake staffs and video-cameras during peak usage (periods when boat wakes are most frequent) and at high tide to document the wakes created by each passing vessel, the vessel characteristics, speed, and distance from shore the vessel passes. Wake height data collection could be done by trained volunteers, although study design and analysis should be completed by a professional. See Hudson River Wake Study (LaPann-Johannessen et al., 2015).
- Tier 3: Deployment of automated water/wave level gauge.

Performance Monitoring Protocols and Frequency:

Wave height (may only be needed for research level analysis of certain projects):

- Level 1: Depending on the project scope, annual onsite observation using a graduated staff can be completed to assess wave heights.
- Level 2: Deployment of automated water/wave level gauge, pressure transducer or similar devices could be used for increased accuracy.

Wake (may only be needed for research level analysis of certain projects):

- Level 1: Annual visual analysis with graduated wake staffs and video-cameras during peak usage (periods when boat wakes are most frequent) and at high tide to document the wakes created by each passing vessel, the vessel characteristics, speed, and distance from shore the vessel passes.
- Level 2: Deployment of automated water/wave level gauge.

Storm Surge

Description: Storm surge is the rise in water level above the normally predicted astronomical tide as caused by a storm event.

Rationale: Storm surge can overtop installed features such as sills or marsh plantings, lessening the ability of these features to attenuate wave energy. Considering storm surge during the site characterization could inform design specifications.

Metric class and project phase: Conditional metric for site characterization.

Relevant project goals: Applicable to all living shoreline projects.

Site Characterization Assessment Protocols:

- Tier 1: For projects where 1% event data is important, research community's Flood Information Study (FIS) for the area and extract stillwater, setup, surge and wave information. https://www.fema.gov/flood-maps/change-your-flood-zone/status/flood-insurance-study.
- Tier 2: Calculate recurrence intervals for storm surge using the nearest local or regional tide gauge data over a set period of 10 years.
- Tier 2: Sea, Lake, and Overland Surges from Hurricanes (SLOSH) modeling of storm surge (Jelesnianski et al, 1992). Not typically needed for most projects.
- Tier 3: Three-dimensional hydrodynamic modeling (Delft-3D, etc.).

Resources:

- Connecticut:
    - CT Environmental Conditions Online, Hurricane Surge Inundation: https://data.ct.gov/dataset/CT-Hurricane-Surge-Inundation/yhuz-kprd, and http://www.cteco.uconn.edu/guides/resource/CT_ECO_Resource_Guide_Hurricane_Surge_Inundation.pdf
    - Hurricane Surge Inundation: http://www.cteco.uconn.edu/guides/resource/CT_ECO_Resource_Guide_Hurricane_Surge_Inundation.pdf
- Rhode Island:
    - STORMTOOLS: http://www.beachsamp.org/stormtools/
- Massachusetts
    - Sea Level Rise and Coastal Flooding Viewer: https://www.mass.gov/service-details/massachusetts-sea-level-rise-and-coastal-flooding-viewer
    - MA - Climate Change Clearinghouse for the Commonwealth: https://resilientma.org/home.html
- New Hampshire:
    - NH Sea-Level Rise, Storm Surge, and Groundwater Rise Mapper: https://nhdes.maps.arcgis.com/apps/webappviewer/index.html?id=c231e2f3b1f94d05bc0c8faf0265f569
    - Tides to Storms: Assessing Risk and Vulnerability to Sea-level rise and Storm Surge: A Vulnerability Assessment of Coastal New Hampshire: http://www.rpc-nh.org/regional-community-planning/climate-change/tides-storms

    - Coastal Viewer: http://nhcoastalviewer.unh.edu/Html5Viewer/index.html?viewer=NHCoastalViewer
- Maine:
    - Sea Level Rise/Storm Surge Scenarios: https://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml
- NOAA:
    - https://coast.noaa.gov/stormwater-floods/
    - NOAA National Storm Surge Hazard Maps: https://noaa.maps.arcgis.com/apps/MapSeries/index.html?appid=d9ed7904dbec441a9c4dd7b277935fad&entry=1
- USGS
    - Coastal Change Hazards Portal: https://marine.usgs.gov/coastalchangehazardsportal/

Storm Event Impacts

Description: Post-storm (and if possible, pre-storm) impacts assessment using a subset of the metrics.

Rationale: How living shoreline approaches respond to stressors such as intense nor'easter storm events or hurricanes is not well understood. Documenting the intensity and direction of a storm and the pre- and post-storm conditions on a project site provides insight about how storms presently impact these structures, as well as how future storms may impact the structures. These considerations must go into design and maintenance to facilitate positive outcomes.

Metric class and project phase: Core metric for site characterization and performance monitoring.

Relevant project goals: All living shoreline projects.

Site Characterization Assessment Protocols:
Storm Conditions

- Tier 1: Review of previous studies; https://coast.noaa.gov/hurricanes/
- Tier 3: Establishment of baseline water level, wind, and wave data from tide gauges and wave buoys.
- Tier 3: Three-dimensional hydrodynamic or SLOSH modeling of previous and/or hypothetical storm tracks of varying intensities/directions.

Site Impacts (prior to project construction)

- Tier 2: Conversations with property owners and/or site users, municipal staff, etc.
- Tier 2: Collection of photo documentation / evidence.
- Tier 3: SLOSH or three-dimensional modeling of storm surge/sediment change.

Performance Monitoring Protocols: At a minimum, standardized photo documentation of the storm impacts should occur at the project site within three days of the storm's conclusion or as soon as it is feasibly safe to access the site; more intensive surveys (e.g., stem density, elevation) should be completed within two weeks of the storm event). Conducting pre- and post-storm event monitoring is

recommended if notice of a storm event is given well in advance of its arrival and the monitoring can be conducted safely.

Storm conditions (e.g., intensity and direction data):

- Level 1: Analysis of NOAA online wave buoy data. Wave heights can also be estimated through recorded fetch and wind speeds. Refer to community's Flood Information Study (FIS) where 1% wave information is needed (https://www.fema.gov/flood-maps/change-your-flood-zone/status/flood-insurance-study).
- Level 1: Onsite estimation of water levels using wrack or ice lines.
- Level 3: Deployment of wave/water level instruments, anemometers, or sediment traps (these must be deployed before the storm hits; since they may be lost in particularly intense storms, less costly instruments may be preferred). Modeling (SLOSH, Delft3D, others) using wind/wave/water level data.

Monitor the onsite storm impacts using the protocols associated with the following metrics:

- Shoreline position and change (horizontal)
- Site topography, profile (width, elevation, slope), and changes thereto
- Ice needling, rafting, and shoving
- Stormwater and/or groundwater runoff
- Signs of erosion or erosion potential, including scour end effects
- Vegetation structure/robustness
- Created feature location/position, dimensions, elevation and stability
- Created feature anchor/tie-in integrity
- Flooding extent and change in extent
- Berm over-topping

Currents

Description: Describes the movements of water from one place to another.

Rationale: Since patterns of water movement and velocity influence erosion processes, understanding the currents at a site can aid in understanding how and why erosion is occurring and inform site design.

Metric class and project phase: Conditional metric for site characterization and performance monitoring. Could be considered a core metric for site characterization and performance monitoring for project designs proposing the use of in-water features such as sills or living breakwaters.

Relevant project goals: Applicable to living shoreline projects emphasizing shoreline stabilization, wave attenuation, and in-water habitat creation/enhancement goals.

Site Characterization Assessment Protocols:

- Tier 1: Review data from the National Current Observation Program or NOAA tidal current predictions data sets. https://tidesandcurrents.noaa.gov/
- Tier 2: Conduct a float test to measure the speed of a floating object between two known points.

- Tier 3: Comprehensive hydrodynamic modeling.

Performance Monitoring Protocols and Frequency:

- Level 1: Conduct annual float test to measure the speed of a floating object between two known points.
- Level 2: Longer-term deployment of tilt meters.

Ice Needling, Rafting, and Shoving

Description: Ice needling, rafting, and shoving can potentially impact a living shoreline. Ice needling results in strands of ice "growing" vertically from the soil surface. Ice rafting occurs when sediment or particles sit on top of or are imbedded into ice blocks. Ice shoving occurs when strong winds push chunks of ice on shore.

Rationale: Reviewing historic ice data for the site, if available, could help to inform design to limit the potential negative impacts of ice. Monitoring ice conditions on the site after living shoreline establishment can identify whether ice is impacting the condition or placement of living shoreline features. Both ice needling and shoving have the potential to scour vegetation or features installed in a living shoreline project. Ice rafting has the potential to both scour vegetation or installed features and, when the ice melts, deposit a layer of sediment on top of the vegetation or feature that prevent the vegetation from growing or, in the case of a living reef, potentially bury and kill shellfish communities.

Metric class and project phase: Core metric for site characterization and performance monitoring.

Relevant project goals: Applicable to all living shoreline projects.

Site Characterization Assessment Protocols (presence/absence, impacts):

- Tier 1: Analysis of existing post-storm assessments. Analysis of existing aerial imagery and/or satellite data.
- Tier 2: Installation of game cameras for opportunistic photo documentation.
- Tier 3: Determining soil frost penetration through ground-penetrating radar (GPR; https://doi.org/10.1016/j.agrformet.2014.03.005) and/or modeling of potential ice flow conditions.

Performance Monitoring Protocols (presence/absence, duration, impacts) and Frequency: Monitoring of ice impacts should occur at least once during the winter through early spring, and post-storm events.

- Level 1: Onsite assessment post-storm, including duration of the event, presence/absence of ice or ice-rafted sediment (including area, thickness, and location), and any other visible impacts.
- Level 2: Installation of game cameras for opportunistic photo documentation.
- Level 3: Capture and analysis of aerial imagery and/or satellite data.

Additionally, the onsite impacts of ice can be monitored using the protocols associated with the following indicators/metrics:

- Photo documentation
- Shoreline position and change (horizontal)
- Site topography, profile (width, elevation, slope), and changes thereto
- Signs of erosion or erosion potential, including end effects
- Vegetation structure/robustness
- Created feature location/position, dimensions, elevation and stability
- Created feature anchor/tie-in integrity

Note: While other metrics document shift in location or position of created features, specifically documenting the impacts caused by ice, including shifts in location or position and damage to plantings or other vegetation, is important given this unique and understudied variable influencing living shoreline performance in New England. At a minimum, the ice assessment will document both the presence and absence of ice and the impacts (or lack thereof) on the living shoreline features.

Stormwater runoff

Description: Stormwater runoff is the flow of rainwater, snowmelt, or irrigation water over the ground surface.

Rationale: Stormwater runoff from upland areas, especially impervious upland areas, can erode the shoreline from the landward side and potentially destabilize a living shoreline. Observation of stormwater runoff issues during the site characterization phase can inform project designs that incorporate runoff control techniques both during and after project construction. Observation during as-built baseline establishment will document the presence or absence of erosion caused by stormwater runoff and highlight areas where stormwater runoff could become a concern. Performance monitoring for stormwater runoff will identify areas where corrective action is needed to minimize or eliminate the impacts of erosion caused by stormwater runoff.

Metric class and project phase: Core metric for site characterization and performance monitoring. Conditional metric for as-built baseline conditions.

Relevant project goals: Applicable to all living shoreline projects. Especially relevant for bank or shoreline stabilization and habitat provision goals.

Site Characterization Assessment Protocols and Frequency: Visit the site during and after storm events.

- Tier 1: Observe and photo document erosion caused by stormwater runoff. Document rills, channels, gullies, and fan-shaped sediment piles at the base of slopes that would indicate bank erosion, the appearance of slumping or collapsing features which may indicate erosion underneath or behind the feature, and other.
- Tier 3: Model runoff conditions using USGS TR-55, EPA SWMM, or develop with lidar, GIS, or similar protocols.

Performance Monitoring Protocols:

- Level 1: Visit the site during and after storm events to observe and photo-document erosion caused by stormwater runoff. Document rills, channels, gullies, and fan-shaped sediment piles at the base of slopes that would indicate bank erosion, the appearance of slumping or collapsing features which may indicate erosion underneath or behind the feature, and other.

Groundwater discharge (in coastal bank or bluff setting)

Description: Water from underground sources that emerges on the face of a coastal bank or bluff.

Rationale: Groundwater emerging on the face of a coastal bank or bluff can contribute to bank or bluff destabilization, which may impact the design and overall effectiveness of a living shoreline installation. If groundwater discharge is an issue at the site, it should be addressed before or in conjunction with the project implementation.

Metric class and project phase: Conditional metric for site characterization, as-built baseline, and performance monitoring.

Relevant project goals: Applicable to living shoreline projects emphasizing shoreline stabilization goals.

Site Characterization Assessment Protocols:

- Tier 1: Observation and photo documentation of seep zones, which may appear as horizontal layers of dark, moist soil along the bluff or bank face, and associated rills, gullies, or channels. Groundwater seeps often are more easily detectable in the early spring as ice and snow begin to melt.
- Tier 3: Photo documentation with thermal infrared imaging and recording thermal measurements at seep areas.

Performance Monitoring Protocols and Frequency: Visit the site annually and during and after storm events.

- Level 1: Observation and photo documentation of seep zones.
- Level 3: Photo documentation with thermal infrared imaging and recording thermal measurements at seep areas.

VEGETATION/HABITAT QUALITY

A key consideration for vegetation metrics is balancing the frequency of performance monitoring without (excessive) trampling on newly planted vegetation. Weekly to monthly performance monitoring may be beneficial through the first growing season as plants are becoming established, especially if planting occurs in late summer or fall. Semi-annual or annual frequency is likely sufficient after the initial growing season. Non-destructive methods are preferred during early monitoring visits post-planting.

Existing and Historical Vegetation and Habitats

Description: Delineates and describes the extent, density/abundance and species composition of native and invasive vegetation historically and currently found in the aquatic, intertidal, and upland areas of the site. Also delineates, quantifies, and illustrates the extent of rocky, sandy, subtidal, intertidal, and tidal habitats of interest.

Rationale: State and federal regulatory agencies will likely request information about the types and extent of existing vegetative communities and habitats (i.e., "natural resources") found on a project site. Mapping and documenting the extent, density/abundance, and composition of historical and currently existing vegetation and habitat establishes a baseline for assessment of target vegetation and habitat gains. The types of vegetation that thrived in the area historically and/or currently have a greater chance of being reestablished than vegetation that has not or is not currently located onsite. Similarly, elevation is a driving factor in the spatial distribution of plant species (e.g., low and high marsh vegetation) and evaluating the vertical limits of the vegetation communities onsite could define the target elevations needed to restore specific plant communities. Historical vegetation information, if available, could also provide justification to pursue a habitat restoration permit.

Metric class and project phase: Core metric for site characterization. Could be completed concurrently with the protected habitat areas assessment.

Relevant project goals: Applicable to most living shoreline projects.

Site Characterization Assessment Protocols:

- Tier 1: Use existing maps, surveys, reports, or aerial photography to document and map the extent of historical and/or the existing vegetation and habitats. Existing vegetation and habitat assessments may be available from the US Fish and Wildlife Service National Wetland Inventory (NWI) database or from state management agencies.
- Tier 2: Verify and quantify Tier 1 data using the quadrat method along established transects or randomly-located long-term plots to identify in each quadrat: 1) all plant species, 2) a visually estimated percent cover of each species and/or bare ground, 3) measure the height of the tallest three individuals of each species and compute the average height, and 4) the number of live stems of each species present within the quadrat. Measure the elevation of vegetation limits (i.e., plant zones) through survey techniques to determine tidal wetland boundaries.
- Tier 3: Remote sensing techniques.

Protected Habitat Areas/Habitat Utilization by Species of Concern

Description: Assessment of local, state, or federal protected habitat areas (e.g., habitat used by endangered or threatened species, state critical habitats, essential fish habitat (EFH), submerged aquatic vegetation, etc.) and usage of the site by species of concern. For example, the EFH Assessment is a preliminary step to determine if any direct or indirect effects will reduce the quality and/or quantity of EFH and whether an additional consultation process is necessary.

Rationale: State and federal regulatory staff will request information during the permitting process to determine whether or not protected habitats could be impacted by the project. Documenting the protected habitat areas onsite or within close proximity to the site enables project proponents to evaluate design and construction options that would limit impacts on the protected habitats and to establish monitoring protocols to detect changes to the habitat during and after project implementation.

Metric class and project phase: Core metric for site characterization; documentation of protected habitat areas or habitat usage by species of concern may indicate the need for specific monitoring protocols to be implemented during construction and performance monitoring. Could be completed concurrently with the existing and historical vegetation and habitats assessment.

Relevant project goals: Applicable to most living shoreline projects.

Site Characterization Assessment Protocols:

- Tier 1: Use existing maps, surveys, or reports if available to determine, document, and map the extent of protected habitats or near the project site; complete assessment worksheets as recommended by state and federal agency staff.
    - Maine
        - https://www.maine.gov/ifw/fish-wildlife/wildlife/endangered-threatened-species/essential-wildlife-habitat/maps.html
        - https://webapps2.cgis-solutions.com/MaineStreamViewer/
        - https://www.maine.gov/dacf/mnap/index.html
    - New Hampshire
        - http://nhcoastalviewer.unh.edu/Html5Viewer/index.html?viewer=NHCoastalViewer
        - https://www2.des.state.nh.us/nhb_datacheck/signin.aspx
    - Massachusetts
        - Regulatory Maps of Priority and Estimated Habitats to determine whether a project must be reviewed by the Natural Heritage and Endangered species Program: https://www.mass.gov/service-details/regulatory-maps-priority-estimated-habitats and http://massgis.maps.arcgis.com/home/webmap/viewer.html?layers=a953ef7fe0744ef2b2a8fb49118c51c7
    - Rhode Island
        - https://ridemgis.maps.arcgis.com/apps/webappviewer/index.html?id=87e104c8adb449eb9f905e5f18020de5

    - Connecticut
        - CTDEEP Natural Diversity Database Review: https://www.ct.gov/deep/cwp/view.asp?a=2702&q=323466&deepNav_GID=1628
        - CTDEEP NDDB Map Review: https://cteco.uconn.edu/viewer/index.html?viewer=advanced
    - Consult the US Fish and Wildlife Information for Planning and Consultation website
    - Complete the Essential Fish Habitat Assessment worksheet (https://www.greateratlantic.fisheries.noaa.gov/habitat/efh/efhassessment.html) drawing on information contained in NOAA's EFH Mapper (https://www.habitat.noaa.gov/protection/efh/efhmapper/index.html), the Habitat Consultation Division Consultation Website (https://www.fisheries.noaa.gov/national/habitat-conservation/consultations-essential-fish-habitat) and engagement with NOAA Habitat Conservation Division (HCD) staff.

- Tier 2: Conduct wildlife survey using cover per square meter, number per square meter (e.g., number of fish in sample, number of fiddler crab boroughs, percent cover), or list of species found at site (nekton or benthic infauna). Conduct site-specific surveys of habitat cover, submerged aquatic vegetation, and the intertidal zone.

Performance Monitoring Protocols and Frequency:

- Level 1: Conduct annual wildlife survey using cover per square meter, number per square meter (e.g., number of fish in sample, number of fiddler crab boroughs, percent cover), or list of species found at site (nekton or benthic infauna). Conduct site-specific surveys of habitat cover, submerged aquatic vegetation, and the intertidal zone.

Invasive, non-native plant species

Description: An assessment of the presence or absence of invasive, non-native plant species.

Rationale: Invasive, non-native species present a threat to native species and ecosystem function. If invasive species are present in the site characterization, they should be managed prior to habitat manipulation and management should continue throughout the performance monitoring phase.

Metric class and project phase: Core metric for site characterization and performance monitoring.

Relevant project goals: Applicable to all living shoreline projects.

Site Characterization and Assessment Protocols:

- Tier 1: Capture vegetation plot photo observations and fixed-point photo observations of the project site.
- Tier 2: Use the quadrat method along established transects or similar randomized plot selection to identify in each quadrat the presence and percent cover of invasive, non-native plant species.

Performance Monitoring Protocols and Frequency: Collect data annually.

- Level 1: Capture vegetation plot photo observations and fixed-point photo observations of the project site.
- Level 2: Use the quadrat method along established transects or similar randomized plot selection to identify in each quadrat the presence and percent cover of invasive, non-native plant species.

Vegetation Structure/Robustness

Description: An assessment of the cover provided by the vegetative community (both natural and planted); an overall measure of robustness (or lack thereof) based on plant species abundance and the vertical and horizontal density of the vegetation.

Rationale: Vegetation is often a critical element of any living shoreline because the roots and stems help to stabilize soils, attenuate wave energy, and trap sediment. Tracking how well the vegetative growth progresses will indicate how likely the shoreline is to persist and achieve the intended project goals.

Metric class and project phase: Core metric for as-built baseline and performance monitoring.

Relevant project goals: Applicable to most living shoreline projects.

As-built and Performance Monitoring Protocols:

- Level 1: Capture vegetation plot photo observations and fixed-point photo observations of the project site.
- Level 2: Use the quadrat method along established transects or similar randomized plot selection to identify in each quadrat: 1) all plant species, 2) a visually estimated percent cover of each species and/or barren ground, and 3) measure the height of the tallest three individuals of each species and compute the average height – measure as they stand (do not lift up the leaves).

Planting extent/area

Description: A map detailing the spatial extent or area of the vegetation/habitat planted as part of the living shoreline project.

Rationale: Establishing and maintaining vegetation is essential for many living shoreline projects since the vegetation provides vital functions such as soil stabilization, wave attenuation, or habitat provision. Documenting the planting extent and area after construction will help to determine if (and why) the planting extent differs from the original planting plan.

Metric class and project phase: Core metric for the as-built baseline conditions establishment, if plantings are included in the project design.

Relevant project goals: Applicable to all living shoreline projects that utilize plantings to achieve project goals.

As-built Protocols: If the planting extent differs from the design plans, document the decisions and rationale for the variation.

- Level 1: Delineate the planting area and use a tape measure to determine the extent. Sketch a map of the planting area based on the manual measurements.
- Level 2: Use traditional surveying equipment such as laser levels, optical surveys, etc. or aerial photography to document and map the planting extent.
- Level 3: RTK-GPS surveying of the boundaries of the planting area and transfer to GIS. RTK-GPS is preferred, though Laser Level, Total Station, or similar technology can be used when GPS coverage is limited or nonexistent.

Final species planted list and number of plants per species

Description: A list of the names of the species that were planted on a project site and the number of individual plants that were planted for each species. Specific plant species should be excluded from plantings in states in which they are considered rare. Consideration should be given to use plant species and genotypes local to the project geographic region.

Rationale: Documenting the names and numbers of plants for each species provides a baseline for monitoring vegetation survival and growth. Comparing the findings of future vegetation surveys to the final planted species list and plants could also indicate whether new species are colonizing the site.

Metric class and project phase: Core metric for as-built baseline conditions, if plantings are part of the project design.

Relevant project goals: Applicable to all living shoreline projects that utilize plantings to achieve project goals.

As-built Protocols: Request from the hired plant distributor a list detailing the names and quantities of each plant species that were supplied. If some of the supplied plants were not planted, subtract the number of unplanted plants of each species from the total number of plants supplied for each species and document why some of the plants were not utilized.

Comparison of planting density and minimum spacing requirements

Description: Planting plans usually describe minimum spacing and location requirements for plantings (e.g., plant *Spartina alterniflora* on one-foot centers between 0.5 feet Mean Sea Level and 4 feet Mean Sea Level). The density of planted vegetation compared to minimum spacing metric assesses whether the minimum spacing requirements were achieved.

Rationale: Many living shoreline projects include the installation of plantings, cuttings, or seeding of native species to expedite the growth of vegetation on bare soil. Achieving a minimum planting density facilitates the establishment of vegetation that will hold soil in place, attenuate wave energy and allow sediment to filter out, and provide habitat. Comparing the planting density to the minimum spacing requirements during the as-built baseline assessment will indicate whether additional plantings are necessary.

Metric class and project phase: Core metric for as-built conditions establishment, if the project utilizes plantings.

Relevant project goals: Applicable to all living shoreline projects that utilize plantings to achieve project goals.

As-built Protocols:

- Use the quadrat method or hoop method along established transects or similar randomized plot selection to determine whether planting densities were achieved. Plant health/condition and percent survival should be documented within the plot while also documenting planting density and minimum space requirements (see also the health of planted vegetation and percent survival metric).

Continued state of vegetation: health and percent survival of planted vegetation

Description: Measures the strength and well-being of planted vegetation and the percentage of planted vegetation surviving during the performance monitoring period.

Rationale: Establishing and maintaining vegetation is a primary component of many living shoreline projects since the roots, stems, leaves, flowers and fruits of vegetation provide vital functions such as soil stabilization, wave attenuation, and habitat provision. Monitoring plant health during and within the weeks following as-built conditions is necessary because some nurseries cultivate salt-water tolerant plants in freshwater. When salt-water tolerant plants grown in freshwater are planted into salt-water environments, it is common to experience plant die-off due to the shock of the new salt-water conditions. Salt-water vegetation that was raised with freshwater should be transitioned to salt-water irrigation several weeks prior to planting them in the salt-water environment.

Metric class and project phase: Core metric for performance monitoring.

Relevant project goals: Applicable to all living shoreline projects that utilize plantings to achieve project goals.

Performance Monitoring Protocols for Percent Survival and Frequency: Weekly to monthly performance monitoring may be beneficial through the first growing season as plants are becoming established, especially if planting occurs in late summer or fall. Semi-annual or annual frequency is likely sufficient after the initial growing season. Non-destructive methods are preferred during early monitoring visits post-planting.

- Level1: Using established transects and plot sampling approach, observe, count, and log the number of planted plugs that are surviving and that have died since the last count; convert the surviving plug number to a percentage.

Performance Monitoring Protocols for Plant Health and Frequency: Weekly to monthly performance monitoring may be beneficial through the first growing season as plants are becoming established, especially if planting occurs in late summer or fall. Semi-annual or annual frequency is likely sufficient after the initial growing season. Non-destructive methods are preferred during early monitoring visits post-planting.

- Tier 1: To monitor the health of each of the planted plug surviving in the plots along the established transects, measure each plant from the base of the stem to the tallest blade without touching the plant, recording the height in centimeters. If it is impossible to determine which plants were planted, skip this step and conduct measurements for overall vegetation health in the plot. To measure the overall vegetation health in the plot, randomly select up to 10 additional naturally occurring plants and measure from the base of the stem to the tallest blade of the plant, recording the height in centimeters. If fewer than 10 exist, measure those that exist. If it is impossible to determine which plants were planted, randomly select and measure up to 20 different stems.

Herbivory and Predation Threats and Other Impacts

Description: Document reasonable suspicion and/or evidence that planted vegetation or seeded biota may suffer from herbivory, predation, or other disturbance from humans and wildlife.

Rationale: Establishing and maintaining vegetation and seeded biota is a primary component of many living shoreline projects since the roots, stems, leaves, flowers and fruits of vegetation and the structures created by the biota (e.g., oyster reefs) provide vital functions such as soil stabilization, wave attenuation, and habitat provision. Monitoring for the threat of herbivory, predation, and other impacts should indicate if and when measures must be implemented to thwart the damage caused by the disturbance.

Metric class and project phase: Core metric for site characterization and performance monitoring.

Relevant project goals: Applicable to most living shoreline projects.

Site Characterization Assessment Protocols

- Tier 1: Interview property owners and/or site users about their observations of species likely to feed upon planted vegetation.
- Tier 2: Observe and document species on site that are likely to feed on planted vegetation.

Performance Monitoring Protocols:

- Level 1: Assess for signs of herbivory, predation, and other human and wildlife disturbance impacts while assessing the health and percent survival of plantings.
- Level 2: Observe and photo document species feeding on planted vegetation use game cameras.

BIOTA

Presence of endangered or threatened species and special habitats

Description: A list of endangered or threatened species and special habitats present in the vicinity of the site.

Rationale: Documentation of endangered or threatened species and special habitats is necessary for a fully-informed understanding of the location at which the living shoreline project is being implemented. Presence of endangered or threatened species or special habitats may restrict certain activities at the site or require different mitigation actions. An increase in the presence of endangered or threatened species after the implementation of the living shoreline project also speaks to its success.

Metric class and project phase: Core metric for site characterization.

Relevant project goals: Relevant for all living shoreline projects.

Site Characterization Assessment Protocols:

- Tier 1: Analysis of existing special habitat delineation and endangered/threatened species ranges.
- Tier 2: Visual inspection of site for presence of endangered or threatened species. Inspection techniques may be species-dependent and take place over several seasons. If applicable, quadrat plot sampling along established transects.
- Tier 3: Installation of game cameras to identify presence of endangered or threatened species not easily assessed through quadrat sampling.

Final List of Bivalve Species Seeded

Description: A list of the bivalve species that were seeded on the living shoreline feature, including the genetic/hatchery source and nursery location.

Rationale: Documenting the final list of bivalve species seeded on the feature provides an as-built baseline condition to which future assessments of species recruitment can be compared.

Metric class and project phase: Conditional as-built metric for living shoreline projects that involve bivalve seeding.

Relevant project goals: Applicable to living shoreline projects with in-water habitat for wave attenuation.

As-built Protocols:

- Follow state guidelines where available. Secure documentation from seed distributor.

Density of live bivalves

Description: The density of live bivalves seeded per square meter; includes both seeded and naturally recruited bivalves.

Rationale: Seeding often is completed in reef establishment projects where natural recruitment is limited or unlikely. Documenting the density of the bivalves can indicate progress toward establishing a population that will help to achieve project goals.

Metric class and project phase: Conditional site characterization, as-built and performance monitoring metric for living shoreline projects that involve bivalve seeding.

Relevant project goals: Applicable to living shoreline projects attempting to establish or enhance bivalve community development.

Site characterization, As-Built and Performance Monitoring Protocols and Frequency:

- Level 1: See density approaches and variations based on type of structure used to establish reefs in the Oyster Habitat Restoration Monitoring and Assessment Handbook: http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf. Performance monitoring should be conducted annually.

Area/extent of bivalve seeding

Description: Documents the area over which the bivalve seeding occurred.

Rationale: Documenting the area or extent of the bivalve seeding will allow for determination if bivalves have moved to other reef structures or outside the project footprint.

Metric class and project phase: Conditional as-built metric applicable for living shoreline projects that involve bivalve seeding.

Relevant project goals: Applicable to living shoreline projects attempting to establish or enhance bivalve community development; projects establishing living reefs to attenuate wave energy.

As-built Protocols:

- Reef areal dimension protocols for the project footprint and reef area measurements, as defined in the Oyster Habitat Restoration Monitoring and Assessment Handbook: http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf.

Bivalve size-frequency distribution

Description: Measures how the bivalve population is distributed across size classes and provides information about establishment, growth and survivorship.

Rationale: Bivalve size-frequency distribution is an important measure for evaluating how well biota is being established on a living shoreline. Results provide information about whether additional seeding or habitat adjustments are needed to promote long-term success of the project.

Metric class and project phase: Conditional metric for site characterization, as-built baseline establishment and performance monitoring.

Relevant project goals: Applicable to living shoreline projects with biota seeded on created feature.

Site Characterization, As-built and Performance Monitoring Protocols and Frequency:

- Level 2: Use calipers or a ruler to measure shell height to the nearest millimeter of at least 50 bivalves from each sample (or a minimum of 250 per reef). For additional details, see the Oyster Habitat Restoration Monitoring and Assessment Handbook: http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf. This measurement can be collected at the same time as the assessment of the density of live bivalves. Performance monitoring should be conducted annually.

Species recruitment/colonization (inclusive of marine invertebrates, bivalves, crustacea, infauna, fish)

Description: Provides information about the ability of species to establish healthy communities in ecosystems that are part of living shoreline projects.

Rationale: Successful living shoreline projects should enhance or create habitat that is conducive for successful species recruitment and colonization. This is an important measure of whether the living shorelines project is meeting this objective.

Metric class and project phase: Conditional metric for performance monitoring for projects with in-water habitat features.

Relevant project goals: Applicable to living shoreline projects with biota seeded on created in-water feature.

Performance Monitoring Protocols:

- Level 1: Perform visual observations. The type of survey will be targeted to the specific species being surveyed. Performance monitoring should be conducted annually.

Marine invertebrate abundance and recovery

Description: Provides information about the extent of marine invertebrates present at a particular site, including colonizing invertebrates, shellfish species, crabs, and marine worms.

Rationale: Because the range of many invertebrates is limited, they are useful for documenting changes in habitat over time. They are also good indicators of the overall health of a marine ecosystem.

Metric class and project phase: Conditional metric for site characterization and performance monitoring.

Relevant project goals: Applicable to certain living shoreline projects.

Site Characterization Assessment Protocols:

- Tier 2: Along established transects, quadrat plot sampling for upper edge of banks or marsh edge, D-Net sampling for shallow tidal areas; and auger or core for sediment sample that is then screened with a mesh sieve to collect and document infaunal invertebrate quantities per a defined area (e.g., m^2). Late summer is best time to survey for invertebrate abundance. This metric can be monitored during vegetation plot assessments.

Performance Monitoring Protocols and Frequency:

- Level 2: Along established transects, quadrat plot sampling for upper edge of banks or marsh edge, D-Net sampling for shallow tidal areas; and auger or core for sediment sample that is then screened with a mesh sieve to collect and document infaunal invertebrate quantities per a defined area (e.g., m^2). Late summer is best time to conduct annual survey for invertebrate abundance. This metric can be monitored during vegetation plot assessments.

Invasive biota species

Description: Documents the presence and extent of non-native or invasive biota species at a living shorelines site.

Rationale: Identification of invasive biota species is an important metric for triggering early removal efforts.

Metric class and project phase: Conditional metric for site characterization and performance monitoring.

Relevant project goals: Applicable for certain living shoreline projects.

Site Characterization Assessment Protocols:

- Tier 2: Site surveys along established transects indicating presence and abundance.

Performance Monitoring Protocols and Frequency:

- Level 2: Annual site surveys along established transects indicating presence and abundance.

Fish population

Description: Documents the fish species and abundance in or near the site.

Rationale: Fish presence is an important indicator of healthy estuarine ecosystems.

Metric class and project phase: Conditional metric for site characterization and performance monitoring.

Relevant project goals: Applicable to living shoreline project sites with valuable fish habitat or where restoration of fish habitat is a project goal. This is particularly important for projects with toe protection to determine the impacts of toe sills on fisheries.

Site Characterization Assessment Protocols:

- Tier 2: Protocols are potentially species dependent and may include cast nets, minnow traps, beach seines, or other techniques to collect and identify the species and abundance.

Performance Monitoring Protocols and Frequency:

- Level 2: Protocols and frequency are potentially species dependent and may include cast nets, minnow traps, beach seines, or other techniques to collect and identify the species and abundance. Performance monitoring should be conducted annually or as needed to support project goals.

Other biota of importance

Description: Other fauna (bird, rodent, insects, etc.) that may be of importance to monitor due to their importance to dune restoration, buffer, and bank restoration.

Rationale: Regulatory agencies may require assessment and monitoring of additional species to determine whether and to what extent the species are impacted by the living shoreline project.

Metric class and project phase: Conditional for site characterization and performance monitoring.

Relevant project goals: Potentially applicable to any living shoreline project.

Potential surveys (frequency would be determined by regulatory requirements):

- Horseshoe crab spawning surveys: pre- and post-construction surveys to determine change in number and location over time (http://www.gso.uri.edu/mjjp/HSC_survey_instructions.pdf).
- Terrapin surveys: pre- and post-construction surveys to determine change in number and location over time (https://www.pwrc.usgs.gov/terrapin/methods.cfm).
- Bird surveys: Pre and post construction aerial surveys to determine the numbers, locations, and species of birds over time. Consider use of the International Shorebird Survey Protocols or a modified version (https://www.manomet.org/wp-content/uploads/2018/07/ISS-Protocols.pdf).

CHEMICAL

Sediment / Water Quality

Description: Screening site substrates for contamination in soil and water samples when site history indicates suspected or known source of contamination.

Rationale: Historical or current site use and processes may have created potential sources of contamination that affect the floral and faunal growth. Remediating the site may be necessary prior to establishing a living shoreline to ensure the protection of animals and humans accessing the shoreline. Materials acquired offsite should be evaluated to demonstrate that the material is free from contamination or potentially invasive flora and fauna.

Metric class and project phase: Conditional metric for site characterization, prior to distributing fill materials on the site, and during performance monitoring if decreasing contamination is a project goal.

Relevant project goals: Applicable to living shoreline projects emphasizing water quality improvements, habitat provision, remediation of contamination project goals.

Site Characterization Assessment Protocols:

- Tier 2: Surrogate variables measured in the field (see monitoring protocols for turbidity, temperature, pH, etc.).
- Tier 3: Sampling and laboratory analysis using standard collection and analysis procedures, followed by comparison to appropriate ecotoxicological screening values. Site-specific ecological risk assessments may be required if potential contamination is identified; review state-specific guidance.

Performance Monitoring Protocols and Frequency:

- Level 2: Surrogate variables measured in the field annually or as needed to support project goals (see monitoring protocols for turbidity, temperature, pH, etc.).
- Level 3: Sampling and laboratory analysis using standard collection and analysis procedures, followed by comparison to appropriate ecotoxicological screening values. Site-specific ecological risk assessments may be required if potential contamination is identified; review state-specific guidance.

Turbidity

Description: A measure of the degree to which the water loses its transparency due to the presence of suspended particulates.

Rationale: The cloudiness or clarity of water, which is affected by the sediments or other solids suspended in the water column, influences the ability for sunlight to penetrate the water and sustain flora and fauna that depend directly or indirectly on sunlight. Elevated turbidity levels may also indicate

shoreline erosion issues. Regulatory agencies may have concerns about turbidity impacts during and after project construction.

Metric class and project phase: Conditional metric for site characterization, during construction, and potentially during as-built conditions establishment and performance monitoring.

Relevant project goals: Applicable to living shoreline projects emphasizing habitat provision, water quality project goals.

Site Characterization Assessment Protocols:

- Tier 2: Construction and use of a Secchi disk. (https://serc.carleton.edu/microbelife/research_methods/environ_sampling/turbidity.html).
- Tier 2: Deployment of a turbidity meter.

Performance Monitoring Protocols and Frequency:

- Level 1: Visual qualitative observations at site.
- Level 2: Construction and use of a Secchi disk.
- Level 3: Deployment of a turbidity meter.
- Performance monitoring should be conducted annually or as needed to support project goals.

Water Salinity

Description: The concentration of salt in water.

Rationale: Salinity levels influence dissolved oxygen levels and the growth and survival of vegetation and animal life.

Metric class and project phase: Conditional metric for all project phases; may be considered core metric if attempting to establish shellfish populations or specific vegetative communities.

Relevant project goals: Applicable to living shoreline projects emphasizing habitat provision, shoreline stabilization via vegetation, or wave attenuation via reef creation project goals.

Site Characterization Assessment Protocols:

- Tier 2: Use of a refractometer with standard operating procedures for the make and model.
- Tier 2: Deployment of an electrochemical water quality meter or other continuous data logger.

Performance Monitoring Protocols and Frequency:

- Level 1: Use of a refractometer with standard operating procedures for the make and model.
- Level 2: Deployment of an electrochemical water quality meter or other continuous data logger.
- Performance monitoring should be conducted annually or as needed to support project goals.

Water Temperature

Description: The degree of heat present within a waterbody.

Rationale: Temperature influences the amount of dissolved oxygen available in the water body, which influences the growth and survival of vegetation and animal life. High temperatures may increase the presence of pathogens and diseases that the threaten survival of aquatic species.

Metric class and project phase: Conditional metric for all project phases.

Relevant project goals: Applicable to living shoreline projects emphasizing habitat provision for aquatic shellfish species project goals.

Site Characterization Assessment Protocols:

- Tier 2: Use a digital waterproof and shockproof thermometer to measure the temperature as close to the reef as possible and near the substrate.
- Tier 2: Use a continuous data logger as close to the reef as possible and near the substrate.

Performance Monitoring Protocols and Frequency:

- Level 1: Use a digital waterproof and shockproof thermometer to measure the temperature as close to the reef as possible and near the substrate.
- Level 2: Use a continuous data logger as close to the reef as possible and near the substrate.
- Performance monitoring should be conducted annually or as needed to support project goals.

STRUCTURE CONDITION

Structural Stability

Description: The lateral and horizontal location/position of the created feature (e.g., nearshore sill); the length, width, and height of the constructed feature(s); the elevation/vertical position/height of the created feature above a fixed, known position; as well as the feature's stability relative to the originally constructed location, dimensions, and elevation.

Rationale: For some living shorelines to be successful, the structural components generally should remain intact or near the footprint in which they were originally established, depending on structure type (e.g., rock sill vs. coir log); however, natural processes--such as ice conditions, wave energy, or subsidence--and other human influences may cause the movement of some features. The vertical position of features created as part of a living shoreline (e.g., toe protection, sills, breakwaters, etc.) and its relation to water levels will influence the success of the created feature to function as intended (e.g., sills and breakwaters to attenuate waves, etc.). If created features lose elevation, then it is possible that some created features will fail (e.g., marshes will die due to excessive inundation, subsiding sills lose the ability to attenuate waves, etc.). Shifting location/position or changes in the length, width, and height of created features may indicate the need for maintenance to accommodate the conditions on the site or limit the potential for unintended impacts. Some created features such as coir logs are temporal in nature and therefore not intended to last forever.

Metric class and project phase: Core metric for as-built baseline establishment and performance monitoring.

Relevant project goals: Applicable to most living shoreline projects.

As-built and Performance Monitoring Protocols and Frequency: Site visits during the performance monitoring phase should be conducted annually and pre- and post-storm events.

- Elevation/vertical position protocols:
    - Level 1: Use of a level and rod or transit pole and self-leveling laser.
    - Level 2: Use of a Total Station.
    - Level 3: Use of RTK-GPS, see *Methods for RTK Point Collection and ArcGIS Methods for Topographic Elevation Modeling in an Area of Interest* (Moody, 2017); Structure-From-Motion; lidar or UAV. Laser Level, Total Station, or similar technology can be used when GPS coverage is limited or nonexistent.
- Location/Position (horizontal) Protocols[2]:
    - Level 1: Establish permanent reference points (permanent marker) with known x-y-z coordinates. Measure the distance from a permanent marker (natural or installed) to several points along the created feature using a tape measure. Fixed point photo documentation; potentially optical surveying or leveling.
    - Level 2: Using aerial photography/photogrammetry, analyze the change in the constructed feature's horizontal location/position in reference to natural or installed

permanent markers. Alternatively, use surveying instruments such as automatic laser survey levels, transits, or total stations.
    - Level 3: RTK-GPS, Structure from motion, or lidar. Laser Level, Total Station, or similar technology can be used when GPS coverage is limited or nonexistent.
- Dimension protocols[3]:
    - Level 1: Directly measure the length, width, and height with tape measure, rulers, etc. and compare to baseline conditions to assess change.
    - Level 2: Use surveying instruments such as automatic laser survey levels, transits, total stations to measure the length, width, and height of the features and compare to baseline conditions.
    - Level 3: RTK GPS, Structure from Motion, lidar. Laser Level, Total Station, or similar technology can be used when GPS coverage is limited or nonexistent.
- Stability/movement protocols
    - Level 1: Observation, assessment, and photo documentation of changes in the location/position, dimension, and elevation of the created features in coordination with the methods outlined above.

Created feature anchoring/tie-in integrity

Description: The strength and structural persistence of the materials, equipment, or components used to fasten created features (e.g., coir logs, bagged shell, etc.) to the site.

Rationale: The anchor/tie-in is a critical element to ensure that created features remain in place and able to perform as expected.

Metric class and project phase: Core metric for as-built baseline establishment and performance monitoring.

Relevant project goals: All living shoreline projects.

As-built and Performance Monitoring Protocols and Frequency: The appropriate tension test may depend on the type of feature. Site visits during the performance monitoring phase should be conducted annually and pre- and post-storm events.

- Level 1: Walk the length of the installed features and locate the anchor features. If not buried, evaluate the tension of the anchoring or tie-in components or equipment by pushing or pulling on it to evaluate whether it is secure and likely to remain in place or loose and likely to fail causing the feature to move or relocate. Photograph the anchor or anchored feature noting the exact location, whether the tension appears to be loose or secure, and whether the anchor or anchored feature appears to be degrading or maintaining its integrity/position.

Material integrity (durability or decomposition of materials used in created features)

Description: Documents the decomposition or decline in the strength or structure of created features.

Rationale: Most materials used in the creation of living shorelines are natural and expected to decompose over time, although some designs may integrate manmade materials. Pending the rate at which the material decomposes and the degree to which natural vegetation has been established, monitoring the material integrity could indicate the need for adaptive management actions such as placement of additional material until vegetation is established. Care should be taken to assess the integrity of materials immediately after feature construction to document conditions and ensure the installation process did not damage the material. Degradation of these materials does not necessarily indicate failure of the living shoreline itself, as some materials are only meant to stabilize the living shoreline temporarily before they decompose and vegetation is established.

Metric class and project phase: Core metric for the as-built baseline establishment and performance monitoring phases.

Relevant project goals: All living shoreline projects.

As-built and Performance Monitoring and Frequency: The method of assessment may depend on the material used in the feature. Site visits during the performance monitoring phase should be conducted annually and pre- and post-storm events.

- Level 1: Observation and photo documentation of the material integrity of the components (e.g., coir logs, bagged shell, etc.) during each visit and after storm events. Detailed field notes should indicate the precise location and degree to which the material appears to be failing or degrading and when corrective action may be warranted. Re-observe locations where previous documentation indicated failing or degrading materials.

Signs of erosion or erosion potential (including end-effects after project establishment)

Description: Erosion caused by waves, currents, stormwater runoff, human activities or installations on the site, or other. See also erosion history/shoreline change.

Rationale: Identifying the cause(s) of the erosion is essential for appropriately designing and maintaining a living shoreline project. Erosion is a natural process and expected to occur in dynamic coastal environments, thus not all erosion should be of concern. However, severe and quickly eroding areas may put valuable infrastructure and/or habitat at risk thus requiring management action. Conversely, erosion occurring at a slow rate and which does not threaten infrastructure or habitats could be left in the natural condition.

Metric class and project phase: Core for as-built baseline establishment and performance monitoring.

Relevant project goals: Applicable to all living shoreline projects with created features on-shore.

As-Built and Performance Monitoring Protocols and Frequency: Site visits during the performance monitoring phase should be conducted annually and pre- and post-storm events.

- Level 1: Observe and photograph the entire site, including any areas where erosion may likely occur to due coastal processes, stormwater or groundwater runoff, or other natural or constructed features, and adjacent to the edges of the project site where end-effect erosion may occur. Areas where previous observation indicated the beginning or continuation of erosion should also be assessed. Pre- and post-storm events observation is necessary to document and take corrective action in a timely manner to encourage project success.

Material types used vs. proposed, including grain type and size of sediment

Description: Information about the various materials proposed for use at the site and those ultimately used (including rationale for the use of materials that are different than those initially proposed) to create the living shorelines; includes the sediment/fill type and grain size distribution (including rock or premanufactured armor units) when applicable (see the geophysical category, sediment type and grain size metric).

Rationale: Documenting the material types (e.g., coconut coir logs, fallen logs, mesh bags filled with shell or other types of bags, etc.) and the reasons why specific materials were selected (if different from the original plan) will provide insight about the durability/longevity of various materials and inform future material selection. Grain type and sediment size are often required to be the same as those found naturally onsite. Sources of these material should also be documented.

Metric class and project phase: Core for all living shoreline projects from the design process through the as-built baseline project phase.

Relevant project goals: Applicable to all living shorelines.

As-built Protocols:

- Level 1: Refer to documentation from existing conditions assessment (site characterization phase) of sediment type and grain size, including contractor submittal documentation of final materials used to construct the site and compare to the materials proposed in the design/construction plans and existing conditions assessment. Walk the constructed site to observe and document the installation with photographs.
- Level 2: Before distributing fill sediment onsite and occasionally throughout the distribution process, use a sand gauge and/or geotechnical gauge to check that the imported sediment grain size and type match the size and type found naturally on site.

Quantity of fill used vs proposed

Description: The amount of fill that was anticipated during project planning and the amount of fill that was used to construct the site.

Rationale: This metric is intended to provide future projects with information to more accurately estimate the needs and costs of various projects.

Metric class and project phase: Core for as-built baseline establishment fill is added.

Relevant project goals: All living shoreline projects where fill is proposed and used during construction.

As-built Protocols:

- Level 1: Record the estimated fill amount prior to construction and solicit official documentation of the amount of fill that was used during construction from the fill supplier.

Maintenance

Description: Process for documenting what, when, and why maintenance and adaptive management activities are implemented.

Rationale: Documentation is necessary to advance our knowledge of the management of living shorelines in New England.

Metric class and project phase: Core metric for performance monitoring.

Relevant project goals: All living shoreline projects.

Performance Monitoring Protocols and Frequency: Apply as needed.

- Level 1: Document maintenance and adaptive management activities.

HAZARD MITIGATION

Flood frequency and extent, and change thereto

Description: The number of times flooding occurs over a set period of time, the area impacted by a flooding event, and changes in the frequency and amount of area impacted after implementation of the living shoreline.

Rationale: Quantifying and understanding ability of living shorelines to reduce coastal hazards such as flooding frequency and extent is necessary to more accurately characterize the opportunities and limitations of living shorelines and to encourage more wide-spread adoption of these techniques in the appropriate locations.

Metric class and project phase: Conditional metric for site characterization and performance monitoring if the project is designed to reduce flooding extent or frequency.

Relevant project goals: Applies to any living shoreline project designed to reduce flood hazards.

Site Characterization Assessment Protocols:

- Tier 1: Review historical records of past flooding events and data sources showing flood extent or anticipated extent.
- Tier 2: Interviews with property owners, emergency management staff, etc.
- Tier 3: Modeling flooding extent and frequency.

Performance Monitoring Protocols and Frequency: Assess annually and post-storm events.

- Level 1: Document the frequency and extent of flooding events after implementation and compare to the frequency and extent documented during the assessment phase.

Berm over-topping

Description: Document the extent of berm overtopping at a living shoreline project.

Rationale: Berm over-topping can lead to sediment transport and / or compromised integrity of a living shoreline.

Metric class and project phase: Conditional metric for performance monitoring.

Relevant project goals: Applies to any living shoreline project with a berm.

Performance Monitoring Protocols and Frequency: Assess post-storm events.

- Level 1: Visual observation and photo documentation of over-topping events and secondary evidence of berm over-topping (sediment deposition, etc.).
- Level 2: Utilize GPS to measure the extent of berm over-topping.

- Level 3: Deployment of wave/water level sensors or tilt meters to determine the amount of water present in front of a berm.

SOCIOECONOMIC

Actual cost vs. estimated cost

Description: The anticipated cost during the planning phase and the real cost of implementing a living shoreline project including the cost of in-kind services, monitoring, and maintenance activities.

Rationale: Documenting the estimated and actual costs will lead to more accurate cost estimates for the establishment and maintenance of living shoreline projects and provide crucial data for comparing the costs of living shoreline projects and traditional hardened approaches.

Metric class and project phase: Core for site characterization, as-built, and performance monitoring.

Relevant project goals: All living shoreline projects.

As-built Protocols: Document the proposed costs and solicit from project proponents, contractors, and other information about the actual costs as well as in-kind services provided from project conception through construction.

Note: Documenting costs related to monitoring and maintenance activities would also be beneficial to understand long-term project costs.

Flood insurance claims and change in quantity of claims

Description: The number of insurance claims submitted as a result of flooding events, and change in the number over time.

Rationale: Documenting the change in insurance claims due to flood events in the residential or business areas landward of the living shoreline implementation can help to determine if living shorelines are reducing exposure to coastal hazards.

Metric class and project phase: Conditional for site characterization (existing conditions) and performance monitoring of projects designed to reduce flooding hazards.

Relevant project goals: Applicable to projects designed to limit exposure to coastal flooding hazards.

Site Characterization Assessment Protocols:

- Tier 1: Obtain official documentation of the number of insurance claims from the National Flood Insurance Program (https://www.fema.gov/flood-insurance) and private flood insurance providers, both before and after implementation of a living shoreline. Care must be taken when attributing flood protection to the presence of a living shoreline vs. other characteristics of a given site.

Performance Monitoring Protocols and Frequency:

- Level 1: Obtain official documentation of the number of insurance claims from NFIP and private flood insurance providers, both before and after implementation of a living shoreline. Care must be taken when attributing flood protection to the presence of a living shoreline vs. other characteristics of a given site. Assess annually.

Avoided damages or costs

Description: Describes the reduction in costs for damages to structures, roads and other infrastructure resulting from lower levels of flooding. Other weather variables such as precipitation should be taken into consideration.

Rationale: This metric is valuable for understanding the economic benefits of avoiding damage and costs from flooding by implementing living shoreline projects.

Metric class and project phase: Conditional metric for performance monitoring.

Relevant project goals: Applicable to most living shoreline projects.

Performance Monitoring Protocols and Frequency: Assess annually.

- Level 2: A data collection method, utilizing a spatial inventory of property values, resident surveys, and analysis of existing datasets.
- Level 3: An analysis-based method, utilizing the avoided cost method (https://www.ecosystemvaluation.org/cost_avoided.htm), FEMA HAZUS (https://msc.fema.gov/portal/resources/hazus), or other modeling that simulates changes in flood levels to estimate potential losses.

APPENDIX B. Monitoring Guidance by Living Shoreline Type

Guidance for Dune Restoration (Natural and with Engineered Core)

This guidance is intended to build understanding about the performance, impacts, and operational needs of dune restoration projects (with or without an engineered core) constructed in coastal New England for the common project goals of:

- Buffering upland areas against wave action and minimizing shoreline erosion
- Maintaining or enhancing habitat for birds or other wildlife.

Common project objectives for dune restoration projects (with or without an engineered core) include:

- The position (vertical and horizontal) of the established shoreline features will remain constant or within an acceptable amount of variation during the expected design-life of the feature.
- The extent of native biological communities (vegetation or biota) will remain consistent or expand after project implementation (note that vegetation enhancement is often paired with dune restoration projects).
- Invasive vegetation will be reduced and/or eliminated from the project footprint.
- The topography of the project area will increase in elevation after implementation.
- Changes in the integrity of the materials will be identified and appropriate interventions planned and implemented to limit negative impacts on the environment.

As previously described in Section 5 of this document, BACRI design should be implemented (when possible) to track living shoreline performance. By collecting and comparing pre- and post-construction data at both the project and a control site, monitoring will reveal the effects of implementing the project and isolate those effects from natural variations. Data analysis is expected to show whether and to what extent a dune restoration project minimizes shoreline erosion and maintains or enhances habitat, as well as document any positive or negative impacts the project has on adjacent resource areas or properties. If full BACRI is not possible, pre-construction site characterization data could, at a minimum, be used to measure changes in conditions attributed to the completed project.

Performance monitoring is also intended to build understanding of how dune restoration projects function over time, identify operational needs including if, when, and to what extent maintenance activities are required, and identify whether the project is positively or negatively influencing resource areas. To document maintenance needs and operational function over time, “as-built” baseline surveys should be completed immediately after construction is complete to verify project design. The “as-built” survey will serve as the post-construction baseline to which all future performance monitoring measurements will be compared when assessing operational function and maintenance needs. Additional comprehensive surveys should be completed after major adaptive management activities to reflect the new baseline conditions.

What data will be collected and monitored for dune restoration (with and without an engineered core)? How will data be collected?

As mentioned in the main narrative, the table below provides guidance only and is not a rigid set of monitoring procedures for all dune restoration projects. The following metrics will help determine if the

dune restoration project will meet common project goals. Photo documentation is recommended during each site visit as well as during planned monitoring activities. A key consideration for dune creation / enhancement projects is balancing the frequency of performance monitoring without (excessive) trampling on newly planted dune vegetation. Monthly performance monitoring may be beneficial through the first growing season as plants are becoming established, especially if planting occurs in late summer or fall. Care must be taken to not trample planted dune grass during early monitoring visits post-planting. Annual frequency, typically in late summer/early fall, is likely sufficient after the initial growing season and should include post-storm visits. If possible, monitoring should continue for a few years post-construction, with a goal of five-year post-construction monitoring. As highlighted in the table below:

- **Level 1** methods are suitable for trained volunteers, while
- **Level 2** and **Level 3** methods usually require higher level training or professional expertise.

See Appendix A for much more detail regarding methods used for site assessment, establishing as-built baseline conditions, and monitoring.

Guidance for Dune Restoration (Natural and with Engineered Core)				
Metric		**Purpose**	**Method**	**Data Collection Phase (Performance Monitoring Frequency)**
SITE USE	Overall site conditions	To provide photo documentation for overall site conditions throughout the project	Level 1: Fixed-point photos throughout the site; narrative	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Historical and cultural site use and impacts	To help determine if certain activities such as soil remediation are needed, or if the site contains resources that are subject to special management	Level 1: Document search and coordination with federal agencies	Site Characterization
	Current (and changes to) site use and impacts, existing infrastructure, and access points	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; narrative	Site Characterization, Performance Monitoring (Annual), Post-Storm Events
	Adjacent area usage and impacts (and changes in use)	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; document review; narrative	Site Characterization, Performance Monitoring (Annual), Post-Storm Events

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
SYSTEM	Erosion history/shoreline position and change (horizontal)	To document horizontal erosion or stability of the dune	Level 1: Fixed-point photos; document review (historic); field survey and measurement	Site Characterization, As-Built Baseline, Performance Monitoring (Spring & Fall), Post-Storm Events
	Tidal range	To document vertical difference in height between high and low tide	Level 1: Review tide gauge data	Site Characterization
	Sediment accretion	To document vertical sediment loss or accretion	Level 1: Photos Level 2: Profiling with emery rods or GPS	Site Characterization, Performance Monitoring (Annual), Post-storm Events
GEOPHYSICAL	Site topography, profile (width, elevation, slope) and changes thereto	To document vertical extent, gradient and contours of the site	Level 1: Photos Level 2: Emery Method	Site Characterization, As-Built Baseline, Performance Monitoring (Spring & Fall), Post-Storm Events
	Nearshore slope and bathymetry (Applicable for research projects)	To document gradient, depths, and features of underwater terrain	Level 2: Bathymetric surveying	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
HYDRODYNAMIC	Storm impact	To assess resilience to and damage from storms	Level 1: Fixed-point photos; narrative Level 2: Emery method Level 3: GPS or total station	Site Characterization, Post-Storm Events
	Ice needling, rafting, and shoving	To identify damage to the restored dune from ice events	Level 1: Fixed-point photos; narrative	Site Characterization, Post-Storm Events
	Stormwater runoff	To identify areas onsite of increased erosion in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Post-Storm Events
	Groundwater discharge	To identify areas of destabilization in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Performance Monitoring (Annual), Post-Storm Events

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
VEGETATION / HABITAT QUALITY *(if application to dune restoration project)*	Existing and historical vegetation and habitat	To document existing and historical vegetation and habitat	Level 1: Document	Site Characterization
	Protected habitat areas/Habitat utilization by species of concern	To document necessary habitats for protection	Level 2: Field survey	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Invasive, non-native plant species	To identify invasive/non-native species for removal and document change over time	Level 1: Fixed-point photos Level 2: Field survey	Site Characterization, Performance Monitoring (Annual)
	Vegetation structure/robustness	To track planted vegetation growth as it relates to dune stability	Level 1: Fixed-point photos Level 2: Field survey	As-Built Baseline, Performance Monitoring (Annual)
	Continued state of vegetation: Health and percent survival of planted vegetation, presence/abundance of invasive species	To track planted vegetation survival as it relates to dune stability	Level 1: Fixed-point photos Level 2: Field survey	As-Built Baseline, Performance Monitoring (Annual), Post-storm Events
	Herbivory and predation threats and other disturbance impacts	To assess threats to dune vegetation	Level 1: Fixed-point photos Level 2: Field survey	As-Built Baseline, Performance Monitoring (Annual)
BIOTA	Presence of endangered or threatened species and special habitats	To inform project goals and design	Level 1: Document review Level 2: Field inspection	Site Characterization, Performance Monitoring (Annual)
	Other biota of importance	To assess impacts of project on these species	Level 2: Field survey	Site Characterization, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
CHEMICAL	Turbidity	To illuminate sediment erosion and water quality concerns	Level 2: Instrument deployment	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
STRUCTURE CONDITION *(for dunes with engineered core)*	Created feature structural properties and stability	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Created feature anchor/tie-in integrity	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Material integrity (durability or decomposition of materials used in created features)	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Signs of erosion or erosion potential, including end effects	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Maintenance	To record maintenance actions	Level 1: Document; narrative	Performance Monitoring (Annual)
HAZARD MITGATN	Flooding frequency and extent, and change thereto	To promote understanding of living restored dune during flooding conditions	Level 1: Fixed-point photos; field survey Document review	Site Characterization, Performance Monitoring, Post-Storm Events
	Berm (dune) over-topping	To assess performance of restored dune during storm events	Level 1: Fixed-point photos; field survey Level 2: Field survey (with GPS measurements)	Post-Storm Events

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
SOCIO-ECONOMIC	Actual cost vs estimated cost	To assess accuracy of project cost estimate	Level 1: Document	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Flood insurance claims, change in quantity	To assess cost-effectiveness of project	Level 1: Document	Site Characterization, Post-Storm Events
	Avoided damages or costs	To assess cost-effectiveness of project	Level 1: Document	Performance Monitoring (Annual)

Guidance for Beach Nourishment

This guidance is intended to build understanding about the performance, impacts, and operational needs of beach nourishment projects constructed in coastal New England to achieve the common project goals of:

- Buffering upland areas against wave action and minimizing shoreline erosion
- Maintaining or enhancing habitat for macroinvertebrate, finfish, and bird species

Common project objectives for beach nourishment projects include:

- The position (vertical and horizontal) of the established shoreline features varies according to expectations
- The extent of native biological communities (vegetation or biota) will remain consistent or expand after project implementation
- Invasive vegetation will be reduced and/or eliminated from the project footprint.
- The topography of the project area will increase in elevation after implementation
- Changes in the integrity of the materials will be identified and appropriate interventions planned and implemented to limit negative impacts on the environment.

As previously described in Section 5 of this document, BACRI design should be implemented (when possible) to track living shoreline performance. By collecting and comparing pre- and post-construction data at both the project and a control site, monitoring will reveal the effects of implementing the project and isolate those effects from natural variations. Data analysis is expected to show whether and to what extent a beach restoration project minimizes shoreline erosion and maintains or enhances habitat, as well as document any positive or negative impacts the project has on adjacent resource areas or properties. If full BACRI is not possible, pre-construction site characterization data could, at a minimum, be used to measure changes in conditions attributed to the completed project.

Performance monitoring is also intended to build understanding of how beach nourishment projects function over time, identify operational needs including if, when, and to what extent maintenance activities are required, and identify whether the project is positively or negatively influencing resource areas. To document maintenance needs and operational function over time, “as-built” baseline surveys should be completed immediately after construction is complete to verify project design. The “as-built” survey will serve as the post-construction baseline to which all future measurements will be compared when assessing operational function and maintenance needs.

What data will be collected and monitored for beach nourishment? How will data be collected?

As mentioned in the main narrative, the table below provides guidance only and is not a rigid set of monitoring procedures for all beach nourishment projects. The following metrics will help determine if the beach nourishment project will meet common project goals. Photo documentation is recommended during each site visit as well as during planned monitoring activities. Monitoring is suggested to continue

for five years after project completion. A longer-term monitoring program is preferable to better manage problems as they arise. As highlighted in the table below:

- **Level 1** methods are suitable for trained volunteers, while
- **Level 2** and **Level 3** methods usually require higher level training or professional expertise.

See Appendix A for much more detail regarding methods used for site assessment, establishing as-built baseline conditions, and monitoring.

Guidance for Beach Nourishment *(Note: some Core metrics do not apply to beach nourishment)*				
Metric		**Purpose**	**Method**	**Data Collection Phase (Performance Monitoring Frequency)**
SITE USE	Overall site conditions	To provide photo documentation for overall site conditions throughout the project	Level 1: Fixed-point photos throughout the site	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Historical and cultural site use and impacts	To help determine if certain activities such as soil remediation may be needed, or if the site contains resources that are subject to special management	Level 1: Document search and coordination with federal agencies	Site Characterization
	Current (and changes to) site use and impacts, existing infrastructure, and access points	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; narrative	Site Characterization, Performance Monitoring (Annual), Post-Storm Events
	Adjacent area usage and Impacts (and changes in use)	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; document review; narrative	Site Characterization, Performance Monitoring (Annual), Post-Storm Events

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
SYSTEM	Erosion history/ shoreline position and change (horizontal)	To document horizontal erosion or stability of the beach	Level 1: Fixed-point photos; document review; field survey and measurement	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Tidal range	To document vertical difference in height between high and low tide	Level 1: Review tide gauge data	Site Characterization
	Sediment accretion (Applicable for research projects)	To document vertical sediment loss or accretion and trajectory of vegetative community over time	Level 1: Fixed-point photos; sediment cores/traps/plates	Site Characterization, Performance Monitoring (Annual), Post-Storm Events
GEOPHYSICAL	Site topography, width, elevation, slope, profile and changes thereto	To document vertical sediment loss/accretion	Level 1: Fixed-point photos; emery method	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Nearshore slope and bathymetry	To determine gradient, depths, and features of underwater terrain	Level 1: Review bathymetry data Level 2: Bathymetric survey	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
HYDRODYNAMIC	Wave energy climate (Applicable for research projects)	To document the wake/wave energy impacting the site and living shoreline feature	Level 2: Instrument deployment	Site Characterization
	Storm impact	To assess resilience of beach to damage from storms	Level 1: Fixed-point photos; narrative Level 2: Field survey	Site Characterization, Post-Storm Events
	Ice needling, rafting, and shoving	To identify damage from ice events	Level 1: Fixed-point photos; narrative	Site Characterization, Post-Storm Events
	Stormwater runoff	To identify areas of increased erosion related to stormwater runoff from upland areas in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Post-Storm Events
	Groundwater discharge	To identify areas of destabilization in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Performance Monitoring (Annual), Post-Storm Events
HABITAT	Protected habitat areas/Habitat utilization by species of concern	To document necessary habitats for protection	Level 2: Field survey	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
BIOTA	Presence of endangered or threatened species and special habitats	To inform project goals and design	Level 1: Document review Level 2: Field survey	Site Characterization, Performance Monitoring (Annual)
	Marine invertebrate abundance and recovery (Applicable for research projects)	To assess changes in habitat over time	Level 1: Field survey	Site Characterization, Performance Monitoring (Frequency dependent on community of interest)
	Other biota of importance	To assess impacts of project on these species	Level 2: Field survey	Site Characterization, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
CHEMICAL	Sediment/water quality	To assess potential water and soil contamination	Level 1: Field sampling	Site Characterization, Performance Monitoring (Annual)
	Turbidity	To illuminate sediment erosion and water quality concerns	Level 2: Instrument deployment	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
STRUCTURE CONDITION	Maintenance	To record maintenance actions	Level 1: Document maintenance activities; narrative	Performance Monitoring (Annual or as needed)
HAZARD MITGATN	Flooding frequency and extent, and change thereto	To assess performance of the nourished beach during storm events	Level 1: Fixed-point photos; field survey	Site Characterization, Post-Storm Events
SOCIO-ECONOMIC	Actual cost vs estimated cost	To assess accuracy of project cost estimate	Level 1: Document	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Avoided damages or costs	To assess effectiveness of project	Level 1: Document	Performance Monitoring (Annual)

Guidance for Coastal Bank Protection (Natural and with Engineered Core)

This guidance is intended to build understanding about the performance, impacts, and operational needs of coastal bank protection projects (with or without an engineered core) constructed in coastal New England to achieve the common project goals of:

- Buffering wave action and minimizing shoreline erosion
- Maintaining or enhancing habitat for macroinvertebrate, finfish, and bird species

Common project objectives for coastal bank projection projects (with or without an engineered core) include:

- The position (vertical and horizontal) of the established shoreline features will remain constant or within an acceptable amount of variation
- The extent of native biological communities (vegetation or biota) will remain consistent or expand after project implementation
- Invasive vegetation will be reduced and/or eliminated from the project footprint.
- Changes in the integrity of the materials will be identified and appropriate interventions planned and implemented to limit negative impacts on the environment.

As previously described in Section 5 of this document, BACRI design should be implemented (when possible) to track living shoreline performance. By collecting and comparing pre- and post-construction data at both the project and a control site, monitoring will reveal the effects of implementing the project and isolate those effects from natural variations. Data analysis is expected to show whether and to what extent a coastal bank protection project minimizes shoreline erosion and maintains or enhances habitat, as well as document any positive or negative impacts the project has on adjacent resource areas or properties. If full BACRI is not possible, pre-construction site characterization data could, at a minimum, be used to measure changes in conditions attributed to the completed project.

Performance monitoring is also intended to build understanding of how coastal bank protection projects function over time, identify operational needs including if, when, and to what extent maintenance activities are required, and identify whether the project is positively or negatively influencing resource areas. To document maintenance needs and operational function over time, “as-built” baseline surveys should be completed immediately after construction is complete to verify project design. The “as-built” survey will serve as the post-construction baseline to which all future measurements will be compared when assessing operational function and maintenance needs. Additional comprehensive surveys should be completed after major adaptive management activities to reflect the new baseline conditions.

What data will be collected and monitored for coastal bank protection projects (with or without an engineered core)? How will data be collected?

As mentioned in the main narrative, the table below provides guidance only and is not a rigid set of monitoring procedures for all coastal bank protection projects. The following metrics will help determine if the coastal bank protection project will meet common project goals. Photo documentation

is recommended during each site visit as well as during planned monitoring activities. While it is suggested that monitoring continue for at least five years after project completion, this will likely depend on project funding. A longer-term monitoring program is preferable to better manage problems as they arise. As highlighted in the table below:

- **Level 1** methods are suitable for trained volunteers, while
- **Level 2** and **Level 3** methods usually require higher level training or professional expertise.

See Appendix A for much more detail regarding methods used for site assessment, establishing as-built baseline conditions, and monitoring.

Guidance for Coastal Bank Protection (Natural and with Engineered Core)				
Metric		**Purpose**	**Method**	**Data Collection Phase (Performance Monitoring Frequency)**
SITE USE	Overall site conditions	To provide photo documentation for overall site conditions throughout the project	Level 1: Fixed-point photos throughout the site	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Historical and cultural site use and impacts	To help determine if certain activities such as soil remediation may be needed, or if the site contains resources that are subject to special management	Level 1: Document search and coordination with federal agencies	Site Characterization
	Current (and changes to) site use and impacts, existing infrastructure, and access points	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; narrative	Site Characterization, Performance Monitoring (Annual), Post-Storm Events
	Adjacent area usage and impacts (and changes in use)	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; document review; narrative	Site Characterization, Performance Monitoring (Annual), Post-Storm Events

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
SYSTEM	Erosion history/shoreline position and change (horizontal)	To document horizontal erosion or stability of the coastal bank	Level 1: Fixed-point photos; document review (historic); field survey and measurement	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Tidal range	To document vertical difference in height between high and low tide	Level 1: Review tide gauge data	Site Characterization
GEOPHYSICAL	Site topography, width, elevation, slope, profile and changes thereto	To document vertical sediment loss	Level 1: Fixed-point photos; field survey Level 3: RTK-GPS; remote sensing	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
HYDRODYNAMIC	Wave/wake energy climate (Applicable for research projects)	To document the wake/wave energy impacting the site and living shoreline feature	Level 2: Instrument deployment	Site Characterization
	Storm impact	To assess resilience of the coastal bank to damage from storms	Level 1: Fixed-point photos; narrative	Storm Characterization, Post-Storm Events
	Ice needling, rafting, and shoving	To identify damage from ice events	Level 1: Fixed-point photos; narrative	Storm Characterization, Post-Storm Events
	Stormwater runoff	To identify areas of increased erosion in need of corrective action	Level 1: Fixed-point photos	Storm Characterization, Post-Storm Events
	Groundwater discharge	To identify areas of destabilization in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Performance Monitoring (Annual), Post-Storm Events

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
VEGETATION / HABITAT QUALITY	Existing and historical vegetation and habitat	To document existing and historical vegetation and habitat	Level 1: Document	Site Characterization
	Protected habitat areas/Habitat utilization by species of concern	To determine necessary habitats for protection	Level 1: Field survey	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Invasive, non-native plant species	To identify invasive/non-native species for removal and document change over time	Level 1: Fixed-point photos; field survey	Site Characterization, Performance Monitoring (Annual)
	Vegetation structure/ robustness	To track vegetation growth as it relates to coastal bank stability	Level 1: Fixed-point photos; field survey	As-Built Baseline, Performance Monitoring (Annual)
	Continued state of vegetation: Health and percent survival of planted vegetation, presence/ abundance of invasive species	To track planted vegetation survival as it relates to coastal bank stability	Level 1: Field survey	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Herbivory and predation threats and other disturbance impacts	To assess threats to coastal bank vegetation	Level 1: Fixed-point photos; field survey	As-Built Baseline, Performance Monitoring (Annual)
BIOTA	Presence of endangered or threatened species and special habitats	To inform project goals and design	Level 1: Document review Level 2: Field inspection	Site Characterization, Performance Monitoring (Annual)
	Invasive biota species	To identify threats to project and need for removal efforts	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
	Other biota of importance	To assess impacts of project on these species	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
STRUCTURE CONDITION	Created feature (engineered component) structural properties and stability	To assess the component's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Created feature (engineered component) anchor/tie-in integrity	To assess the anchor's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Material integrity (durability or decomposition of materials used in created feature/ engineered component)	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Signs of erosion or erosion potential, including end effects	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Maintenance	To record maintenance actions	Level 1: Document; narrative	Performance Monitoring (Annual)
HAZARD MITGATN	Flooding frequency and extent, and change thereto (for low elevation banks)	To assess performance of bank during storm events	Level 1: Fixed-point photos; field Survey	Site Characterization, Post-Storm Events
SOCIO-ECONOMIC	Actual cost vs estimated cost	To assess accuracy of project cost estimate	Level 1: Document	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Avoided damages or costs	To assess effectiveness of project	Level 1: Document	Performance Monitoring (Annual)

Guidance for Tidal Marsh Creation/Enhancement (with and without toe protection)

This guidance is intended to build understanding about the performance, impacts, and operational needs of tidal marsh creation/enhancement projects (with or without toe protection) constructed in coastal New England to achieve the common project goals of:

- Buffering wave action and minimizing shoreline erosion, and flooding
- Maintaining or enhancing habitat for macroinvertebrate, finfish, and bird species

Common project objectives for tidal marsh creation/enhancement (with or without toe protection) include:

- The position (vertical and horizontal) of the established shoreline features will remain constant or within an acceptable amount of variation
- The extent of native biological communities (vegetation or biota) will remain consistent or expand after project implementation
- Invasive vegetation will be reduced and/or eliminated from the project footprint.
- The topography of the project area will increase in elevation after implementation
- Changes in the integrity of the materials will be identified and appropriate interventions planned and implemented to limit negative impacts on the environment.

As previously described in Section 5 of this document, BACRI design should be implemented (when possible) to track living shoreline performance. By collecting and comparing pre- and post-construction data at both the project and a control site, monitoring will reveal the effects of implementing the project and isolate those effects from natural variations. Data analysis is expected to show whether and to what extent a tidal marsh creation/enhancement project minimizes shoreline erosion, maintains or enhances habitat, and document any positive or negative impacts the project has on adjacent resource areas or properties. If full BACI is not possible, pre-construction site characterization data could, at a minimum, be used to measure changes in conditions attributed to the completed project.

Performance monitoring is also intended to build understanding of how tidal marsh creation/enhancement projects (built with or without toe protection) function over time, identify operational needs including if, when, and to what extent maintenance activities are required, and identify whether the project is positively or negatively influencing resource areas. To document maintenance needs and operational function over time, “as-built” baseline surveys should be completed immediately after construction is complete to verify project design. The “as-built” survey will serve as the post-construction baseline to which all future measurements will be compared when assessing operational function and maintenance needs. Additional comprehensive surveys should be completed after major adaptive management activities to reflect the new baseline conditions.

What data will be collected and monitored for tidal marsh creation/enhancement (with and without toe enhancement)? How will data be collected?

As mentioned in the main narrative, the table below provides guidance only and is not a rigid set of monitoring procedures for all marsh creation/enhancement projects. The following metrics will help determine if the marsh creation/enhancement project will meet common project goals. Photo documentation is recommended during each site visit as well as during planned monitoring activities. A key consideration for marsh creation / enhancement projects is balancing the frequency of performance monitoring without (excessive) trampling on newly planted vegetation. Weekly to monthly performance monitoring may be beneficial through the first growing season as plants are becoming established, especially if planting occurs in late summer or fall. Semi-annual or annual frequency is likely sufficient after the initial growing season. Low-impact methods are preferred during early monitoring visits post-planting. While it is suggested that monitoring continue for at least five years after project completion, this will likely depend on project funding. A longer-term monitoring program is preferable to better manage problems as they arise. As highlighted in the table below:

- **Level 1** methods are suitable for trained volunteers, while
- **Level 2** and **Level 3** methods usually require higher level training or professional expertise.

See Appendix A for much more detail regarding methods used for site assessment, establishing as-built baseline conditions, and monitoring.

Guidance for Marsh Creation/Enhancement (Natural and with Toe Protection)				
Metric		**Purpose**	**Method**	**Data Collection Phase (Performance Monitoring Frequency)**
SITE USE	Overall site conditions	To provide photo documentation for overall site conditions throughout the project	Level 1: Fixed-point photos throughout the site	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Historical and cultural site use and impacts	To determine if activities such as soil remediation may be needed, or if the site contains resources subject to special management	Level 1: Document search and coordinate with federal agencies	Site Characterization
	Current (and changes to) site use and impacts, existing infrastructure, and access points	To document changes in use over time that may influence project success	Level 1: Fixed-point photos; narrative	Site Characterization, Performance Monitoring (Annual)
	Adjacent area usage and impacts (and changes in use)	To document changes in use over time that may influence project success	Level 1: Fixed-point photos; document review; narrative	Site Characterization, Performance Monitoring (Annual)
SYSTEM	Erosion history/shoreline position and change (horizontal)	To document horizontal erosion or stability of the marsh's waterward edge	Level 1: Fixed-point photos; document review (historic); field survey and measurement	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Tidal range	To document vertical difference in height between high and low tide	Level 1: Review tide gauge data	Site Characterization
	Sediment accretion	To document vertical sediment loss or accretion and trajectory of vegetative community over time	Level 1: Fixed-point photos Level 2: Marker horizons or standard locations Level 3: RTK-GPS; remote sensing	Site Characterization, Performance Monitoring (Annual), Post-Storm Events

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
GEOPHYSICAL	Site topography, width, elevation, slope, profile and changes thereto	To document vertical sediment loss/accretion and trajectory of vegetative community over time	Level 1: Fixed-point photos Level 3: RTK-GPS; remote sensing	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Organic matter concentration (Applicable for research projects)	To identify concentrations that will influence nutrient availability and plant growth	Level 1: Field sampling	As-Built Baseline, Performance Monitoring (Annual)
HYDRODYNAMIC	Wave/wake energy climate	To document the wake/wave energy impacting the site and living shoreline feature	Level 2: Instrument deployment	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Storm impact	To assess resilience of marsh to damage from storms	Level 1: Fixed-point photos; narrative	Site Characterization, Post-Storm Events
	Ice needling, rafting, and shoving	To identify damage from ice events	Level 1: Fixed-point photos; narrative	Site Characterization, Post-Storm Events
	Stormwater runoff	To identify areas of increased erosion in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Post-Storm Events
	Groundwater discharge	To identify areas of destabilization in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Performance Monitoring (Annual), Post-Storm Events
VEGETATION / HABITAT QUALITY	Existing and historical vegetation and habitat	To document existing and historical vegetation and habitat	Level 1: Document	Site Characterization
	Protected habitat areas/Habitat utilization by species of concern	To determine necessary habitats for protection	Level 1: Field survey	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Invasive, non-native plant species	To identify invasive/non-native species for removal and document change over time	Level 1: Fixed-point photos; field survey	Site Characterization, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
VEGETATION / HABITAT QUALITY *(continued)*	Vegetation structure/ robustness	To track vegetation growth as it relates to shoreline stability	Level 1: Fixed-point photos; field survey	As-Built Baseline, Performance Monitoring (Annual)
	Continued state of vegetation: Health and percent survival of planted vegetation, presence/ abundance of invasive species	To assess success of project and need for adaptive management	Level 1: Field survey	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Herbivory and predation threats and other disturbance impacts	To assess threats to shoreline vegetation	Level 1: Fixed-point photos; field survey	As-Built Baseline, Performance Monitoring (Annual)
BIOTA	Marine invertebrate abundance and recovery	To assess changes in habitat over time	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
	Invasive biota species	To identify threats to project and need for removal efforts	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
	Fish population species/ abundance	To assess the health of the ecosystem	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
	Other biota of importance	To assess impacts of project on these species	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
CHEMICAL	Sediment/water quality	To assess potential water and soil contamination	Level 3: Field sampling	Site Characterization, Performance Monitoring (Annual)
	Turbidity	To illuminate sediment erosion and water quality concerns	Level 2: Instrument deployment	Site Characterization, Performance Monitoring (Annual)
	Water salinity	To assess potential for changes in vegetation and biota	Level 2: Field sampling; instrument deployment	Site Characterization, Performance Monitoring (Annual)
	Water temperature	To monitor potential for vegetation and biota survival	Level 1: Instrument deployment	Site Characterization, Performance Monitoring (Annual)
STRUCTURE CONDITION	Created feature structural properties and stability	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Event
	Created feature anchor/tie-in integrity	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Material integrity (durability or decomposition of materials used in created features)	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Signs of erosion or erosion potential, including end effects	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Maintenance	To record maintenance actions	Level 1: Document; narrative	Performance Monitoring (A)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
HAZARD MITGATN	Flooding frequency and extent, and change thereto	To assess performance of shoreline during storm events	Level 1: Fixed-point photos; field survey	Site Characterization, Post-Storm Events
SOCIO-ECONOMIC	Actual cost vs estimated cost	To assess accuracy of project cost estimates	Level 1: Document	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Avoided damages or costs	To assess effectiveness of project	Level 1: Document	Performance Monitoring (Annual)

Guidance for Living Breakwaters

This guidance is intended to build understanding about the performance, impacts, and operational needs of living breakwaters constructed in coastal New England to achieve the common project goals of:

- Buffering wave action and minimizing shoreline erosion
- Maintaining or enhancing habitat for macroinvertebrate, finfish, and bird species

Common project objectives for living breakwaters include:

- The position (vertical and horizontal) of the established shoreline features will remain constant or within an acceptable amount of variation
- The extent of native biological communities (vegetation or biota) will remain consistent or expand after project implementation
- Invasive vegetation will be reduced and/or eliminated from the project footprint.
- The topography of the project area will increase in elevation after implementation
- Changes in the integrity of the materials will be identified and appropriate interventions planned and implemented to limit negative impacts on the environment.

As previously described in Section 5 of this document, BACRI design should be implemented (when possible) to track living shoreline performance. By collecting and comparing pre- and post-construction data at both the project and a control site, monitoring will reveal the effects of implementing the project and isolate those effects from natural variations. Data analysis is expected to show whether and to what extent a living breakwater minimizes shoreline erosion and maintains or enhances habitat, as well as document any positive or negative impacts the project has on adjacent resource areas or properties. If full BACRI is not possible, pre-construction site characterization data could, at a minimum, be used to measure changes in conditions attributed to the completed project.

Performance monitoring is also intended to build understanding of how living breakwaters function over time, identify operational needs including if, when, and to what extent maintenance activities are required, and identify whether the project is positively or negatively influencing resource areas. To document maintenance needs and operational function over time, “as-built” baseline surveys should be completed immediately after construction is complete to verify project design. The “as-built” survey will serve as the post-construction baseline to which all future measurements will be compared when assessing operational function and maintenance needs.

What data will be collected and monitored for living breakwaters? How will data be collected?

As mentioned in the main narrative, the table below provides guidance only and is not a rigid set of monitoring procedures for all living breakwater projects. The following metrics will help determine if the living breakwater project will meet common project goals. Photo documentation is recommended during each site visit as well as during planned monitoring activities. While it is suggested that monitoring continue for at least five years after project completion, this will likely depend on project

funding. A longer-term monitoring program is preferable to a shorter-term monitoring program to better be able to manage problems as they arise. As highlighted in the table below:

- **Level 1** methods are suitable for trained volunteers, while
- **Level 2** and **Level 3** methods usually require higher level training or professional expertise.

See Appendix A for much more detail regarding methods used for site assessment, establishing as-built baseline conditions, and monitoring.

Guidance for Living Breakwaters				
Metric		**Purpose**	**Method**	**Data Collection Phase (Performance Monitoring Frequency)**
SITE USE	Overall site conditions	To provide photo documentation for overall site conditions throughout the project	Level 1: Fixed-point photos throughout the site	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Historical and cultural site use and impacts	To help determine if certain activities such as soil remediation may be needed, or if the site contains resources that are subject to special management	Level 1: Document search and coordination with federal agencies	Site Characterization
	Current (and changes to) site use and impacts, existing infrastructure, and access points	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; narrative	Site Characterization, Performance Monitoring (Annual)
	Adjacent area usage and Impacts (and changes in use)	To visually document changes in use overtime that may influence project success	Level 1: Fixed-point photos; document review; narrative	Site Characterization, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
SYSTEM	Erosion history/shoreline position and change (horizontal)	To document horizontal erosion or stability of marsh's waterward edge	Level 1: Fixed-point photos; document review (historic); field survey and measurement	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Tidal range	To document vertical difference in height between high and low tide	Level 1: Review tide gauge data	Site Characterization
	Sediment accretion	To document vertical sediment loss or accretion and trajectory of vegetative community over time	Level 1: Fixed-point photos Level 3: Sediment cores/traps/plates; RTK-GPS; remote sensing	Site Characterization, Performance Monitoring (Annual), Post-Storm Events
	Suspended sediment supply	To determine water quality, habitat suitability, and amount of solid material for accretion	Level 1: Field collection Level 2: Modeling	Site Characterization, Performance Monitoring (Quarterly)
	Longshore transport	To document how sediment moves along the shoreline	Level 2: Sediment traps	Site Characterization, Performance Monitoring (Quarterly)
GEOPHYSICAL	Site topography, width, elevation, slope, profile and changes thereto	To document vertical sediment loss/accretion and trajectory of vegetative community over time	Level 1: Fixed-point photos Level 3: RTK-GPS; remote sensing	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Nearshore slope and bathymetry	To determine gradient, depths, and features of underwater terrain	Level 2/3: Bathymetric surveying	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Organic matter concentration	To identify concentrations that will influence nutrient availability and plant growth	Level 1: Field sampling	As-Built Baseline, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
HYDRODYNAMIC	Wave/wake energy climate	To document the wake/wave energy impacting the site and living shoreline feature	Level 2: Instrument deployment	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Storm impact	To assess resilience to and damage from storms	Level 1: Fixed-point photos; narrative	Site Characterization, Post-Storm Events
	Currents	To identify water movement that may influence erosion processes	Level 2: Instrument deployment	Site Characterization, Performance Monitoring (Annual)
	Ice needling, rafting, and shoving	To identify damage from ice events	Level 1: Fixed-point photos; narrative description	Site Characterization, Post-Storm Events
	Stormwater runoff	To identify areas of increased erosion in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Post-Storm Events
	Groundwater discharge	To identify areas of destabilization in need of corrective action	Level 1: Fixed-point photos	Site Characterization, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
VEGETATION / HABITAT QUALITY	Existing and historical vegetation and habitat	To document existing and historical vegetation and habitat	Level 1: Document	Site Characterization
	Protected habitat areas/Habitat utilization by species of concern	To determine necessarily habitats for protection	Level 1: Field survey	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Invasive, non-native plant species	To identify invasive/non-native species for removal and document change over time	Level 1: Fixed-point photos; field survey	Site Characterization, Performance Monitoring (Quarterly)
	Vegetation structure/robustness	To track vegetation growth as it relates to shoreline stability	Level 1: Fixed-point photos; field survey	As-Built Baseline, Performance Monitoring (Quarterly)
	Continued state of vegetation: Health and percent survival of planted vegetation, presence/abundance of invasive species	To assess success of project and need for adaptive management	Level 1: Field survey	As-Built Baseline, Performance Monitoring (Quarterly)
	Herbivory and predation threats and other disturbance impacts	To assess threats to shoreline vegetation	Level 1: Fixed-point photos; field survey	As-Built Baseline, Performance Monitoring (Quarterly)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
BIOTA	Density live bivalves	To assess project goals	Level 1: Field survey	As-Built Baseline, Performance Monitoring (Annual)
	Bivalve size-frequency distribution	To assess project goals	Level 1: Field survey	As-Built Baseline, Performance Monitoring (Annual)
	Species recruitment/colonization	To assess project goals	Level 1: Field survey	Performance Monitoring (Annual)
	Marine invertebrate abundance and recovery	To assess changes in habitat over time	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
	Invasive biota species	To identify threats to project and need for removal efforts	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
	Fish population species/ abundance	To assess the health of the ecosystem	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
	Other biota of importance	To assess impacts of project on these species	Level 1: Field survey	Site Characterization, Performance Monitoring (Annual)
CHEMICAL	Sediment/water quality	To assess potential water and soil contamination	Level 1: Field sampling	Site Characterization, Performance Monitoring (Annual)
	Turbidity	To illuminate sediment erosion and water quality concerns	Level 2: Instrument deployment	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Water salinity	To assess potential for changes in vegetation and biota	Level 1: Field sampling Level 2: Instrument deployment	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Water temperature	To monitor potential for vegetation and biota survival	Level 2: Instrument deployment	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)

Metric		Purpose	Method	Data Collection Phase (Performance Monitoring Frequency)
STRUCTURE CONDITION	Created feature structural properties and stability	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Created feature anchor/tie-in integrity	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Material integrity (durability or decomposition of materials used in created features)	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Signs of erosion or erosion potential, including end effects	To assess the material's ability to withstand physical forces	Level 1: Fixed-point photos; field survey; narrative	Site Characterization, As-Built Baseline, Performance Monitoring (Annual), Post-Storm Events
	Maintenance	To record maintenance actions	Level 1: Document; narrative	Performance Monitoring (Annual)
HAZARD MITGATN	Flooding frequency and extent, and change thereto	To assess performance of shoreline during storm events	Level 1: Field survey; fixed-point photos	Site Characterization, Post-Storm Events
	Berm over-topping	To assess performance of shoreline during storm events	Level 1: Fixed-point photos; field survey; instrument deployment;	Post-Storm Events
SOCIO-ECONOMIC	Actual cost vs estimated cost	To assess cost-accuracy of project	Level 1: Document	Site Characterization, As-Built Baseline, Performance Monitoring (Annual)
	Flood insurance claims, change in quantity	To assess cost-effectiveness of project	Level 1: Document	Site Characterization, Post-Storm Events
	Avoided damages or costs	To assess cost-effectiveness of project	Level 1: Document	Performance Monitoring (Annual)

APPENDIX C. Site Characterization Assessment Check List

Goal: Document the existing conditions and forces found on site to inform the design and permitting of the living shoreline.

Driving Questions:

- ☐ What is the context surrounding the site and how is it affecting the site?
- ☐ Why is the project needed? What is the driver of the problems or issues that have generated interest in exploring a living shoreline approach?
- ☐ What is being protected or created (e.g., are you protecting existing habitat, a structure, or something else?)
- ☐ What type of shoreline is it?
- ☐ What are the existing biological, geologic, and physical characteristics of the site?
- ☐ Is the site already armored or are adjacent properties armored?
- ☐ Is the site eroding? If yes, what is the extent and rate of erosion? What is the cause of the erosion? Is the erosion occurring year-round or is it mostly during large storm events?
- ☐ What habitats are present on or adjacent to the site? Where do they fall in relation to the HTL, MHW, MLW, and MLLW? Consider all habitat types: tidal, intertidal, subtidal, mudflats, submerged aquatic vegetation, rocky habitats including pebble, cobble, boulder, and ledge, and sand habitats.
- ☐ How have the site and adjacent land and water areas been used historically? How are the site and adjacent land and water areas currently used? What impacts have resulted from historical and/or current use?

Metric Check List: (the asterisk denotes conditional considerations)

<u>Site use</u>

- ☐ Who owns the site? Who owns the adjacent properties?
- ☐ How have the site and adjacent land and water areas been used historically?
- ☐ How are the site and adjacent land and water areas used currently?
- ☐ What impacts have resulted from historical and/or current use?
- ☐ Are hardened shoreline stabilization approaches used on adjacent or nearby properties?
- ☐ How is the site accessed?

<u>System</u>

- ☐ Is the shoreline eroding? If yes, what is the extent and rate of erosion?
- ☐ What is the cause of the erosion? Is the erosion occurring year-round or mostly during large storm events?
- ☐ What is the site-specific tidal range?
- ☐ How will sea level rise impact the site in the near term (10-30 years)?*
- ☐ What is the sediment supply at the site?*

- What is the dominant longshore transport at the site?*

Geophysical

- What is the existing profile (width, elevation, and slope) of the site?
- How does the nearshore slope and bathymetry influence the site?*
- What type of sediment is found on the site? What is the sediment grain size and color?*
- What is the shear strength and soil bearing capacity of the sediment on the site where features could be constructed? *

Hydrodynamic

- How severe is the wave and wake energy climate on the site?
- How does storm surge impact the site?*
- How do the currents affect the site?*
- How has or does ice impact the site?
- Is stormwater causing erosion at the site?
- Is groundwater runoff causing erosion at the site?*

Vegetation and Habitat Quality

- What vegetation comprises the existing and historical vegetative communities?
- What is the size or extent of the existing habitats on the project site or in adjacent lands and waters (tidal, intertidal, subtidal, mudflats, submerged aquatic vegetation, rocky habitats including pebble, cobble, boulder, and ledge, and sand) that may be impacted by the living shoreline project?
- Are any of the habitats on the project site or in the adjacent waters and lands habitat that may be used by species of special interest?
- Is there any presence of invasive (non-native) plant species at the site?

Biota

- Is there any presence of endangered or threatened species and special habitats at the site? What are they?
- Which marine invertebrates are found on or near the site and how abundant are they?*
- What invasive species are found on or near the site and how abundance are they?*
- What fish species are found on or near the site and how abundant are they?*
- What other species of interest are found on the site or adjacent properties and waters and how abundant are they?*

Hazard Mitigation

- How frequently does the area landward of the proposed living shoreline flood?*
- What is the extent of the flooding landward of proposed the living shoreline?*
- What is the rate of erosion and the risk it poses to people, infrastructure, or natural communities? See system metrics for coastal erosion

Socioeconomic

- What is the estimated total cost of the proposed living shoreline project?
- How many flood insurance claims have been submitted for the properties that the proposed living shoreline may protect? Over what time period were the claims submitted?*

APPENDIX D. As-Built Baseline Establishment Check List

Goal: To establish a baseline for future performance monitoring, document the as-built conditions as well any deviations from the design plans and the rationale for those deviations. The as-built baseline establishment project phase is considered a one-time assessment immediately post construction to validate and/or document differences from the project design. Additional survey or documentation may be necessary following major adaptive management activities as dictated during the performance monitoring phase.

Driving Questions:

- Which (and how) metrics will be field surveyed to create a consistent, long-term data set capable of detecting changes and trends overtime to evaluate the effectiveness and impacts of the living shoreline?
- Was the site built according to the design plans? If it was not built according to the design plans, what was changed and why was it changed?
- What are the physical and biological characteristics of the site after the living shoreline was constructed?

Metric Check List: (the asterisk denotes conditional considerations)

<u>System</u>

- ☐ What is the horizontal position of the as-built shoreline?

<u>Geophysical</u>

- ☐ What is the new profile (width, elevation, and slope) of the as-built living shoreline?
- ☐ What sediment type and grain size were utilized on the living shoreline? *
- ☐ After construction of the living shoreline, what is the new slope and bathymetry of the nearshore? *

<u>Hydrodynamic</u>

- ☐ Are there signs of either groundwater or stormwater runoff impacting the living shoreline?*
- ☐ What are the new wave and wake energy conditions after construction of the living shoreline? *

<u>Vegetation</u>

- ☐ Was a list provided detailing the final list of species planted as well as the number of plants per species?
- ☐ What is the extent or area of the as-built planted vegetation?
- ☐ What is the density of the planted vegetation compared to the minimum spacing requirements?
- ☐ Have structures been installed to prevent herbivory, if it is anticipated to occur?*

Biota

- Were any species of special interest impacted during construction? How so and how many, if known?*
- If applicable:
    - Was a final list obtained of bivalve species seeded on the site?
    - What is the density of live bivalves?
    - What is the size-frequency distribution of the bivalves?

Condition of the Created Features

- What is the exact position/location of the created features?
- What are the dimensions of the created features?
- What are the elevations of the created features?
- Is the anchoring or tie-in hardware securely holding features in place?
- Did installation damage the structural integrity or otherwise compromise the durability of the materials used in the created features?
- Was the type of material used to create and/or anchor the features the same or different from the material that was proposed for use?
- Was the quantity of fill material that was used to create the living shoreline less than or greater than the amount of fill that was proposed for the construction?

Socioeconomic

- What were the actual and estimated costs of constructing the living shoreline?

APPENDIX E. Performance Monitoring Check List

Goal: Document changes in key metrics to assess living shoreline performance and identify maintenance needs that may help to achieve the project goals.

Driving Questions:

- How has the overall site responded to implementation of the living shoreline?
- Is the living shoreline achieving the intended project goals?
    - Has the living shoreline reduced the force or height of wakes or waves crashing on the shoreline?
    - Is the living shoreline eroding or accreting sediment?
    - Is the living shoreline creating positive ecological benefits?
    - Is the living shoreline limiting the frequency or extent of coastal flooding or providing other resilience benefits?
- Is the living shoreline stable? Have any of the installed features changed lateral or vertical position since the as-built baseline?
- Is the living shoreline causing negative impacts on the ecology of the site, in the water, or along adjacent areas?
- Is the living shoreline changing the way the property, waters, or adjacent properties are used?
- Are target species of plants and animals repopulating or using the living shoreline habitat?
- Is ice impacting the living shoreline? When or how?
- How are storms impacting the living shoreline?
- What maintenance may be needed to ensure the living shoreline performs as intended?

Metric Check List: (the asterisk denotes conditional considerations)

<u>Site Use</u>

- ☐ How has the human use of the project site or the adjacent areas (land and water) changed as a result of constructing the living shoreline?

<u>System</u>

- ☐ Is the horizontal position of the shoreline changing from the as-built baseline position? How?
- ☐ Is sediment accreting on site? *
- ☐ How has suspended sediment supply changed as a result of the living shoreline? *
- ☐ How has longshore transport changed as a result of the living shoreline? *

<u>Geophysical</u>

- ☐ How is the profile (width, elevation, and slope), changing from the as-built baseline conditions?
- ☐ How is the slope and bathymetry of the nearshore changing from the as-built conditions? *
- ☐ How has the sediment shear strength changed? Organic matter concentration? *

Hydrodynamic

- How is ice needling, rafting, and/or shoving impacting the living shoreline?
- How are storms and storm surge impacting the living shoreline?
- How is stormwater runoff impacting the living shoreline?
- How is groundwater runoff impacting the living shoreline? *
- How have wave and wake energy conditions changed since the as-built baseline measurements were collected? *
- How have the currents changed since the as-built baseline measurements were collected? *

Vegetation

- How robust is the vegetative community?
- What plant species are present? What is the estimated percent cover of each species and of the barren ground? What is the average height of the tallest three individuals of each species?
- Which, if any, invasive species are present? How abundant are the invasive species?
- What is the density of the planted vegetation compared to the minimum spacing requirements?
- How many of the planted plants are surviving? How healthy are the planted plants that are surviving? How healthy is the vegetation on the site overall?
- Is herbivory occurring? How much damage has herbivory caused, if so?

Biota

- How have species that were present on the site been impacted by construction of the living shoreline project? Have their presence and abundance numbers returned to pre-construction levels? *
- Have new species been identified on the site that had not been documented prior to construction?
- If applicable:
    - What is the density of live bivalves?
    - What is the size-frequency distribution of the bivalves?

Condition of the Created Features

- What is the exact position/location of the created features?
- What are the dimensions of the created features?
- What is the elevation of the created features?
- Are the created features stable?
- Is the anchoring or tie-in hardware securely holding features in place?

Hazard Mitigation

- Did the flooding frequency and extent of flooding landward of the living shoreline change?
- Has the rate of coastal erosion slowed down? Has the living shoreline reduced the vulnerability of people, infrastructure, and natural communities that were previously threatened by coastal erosion?

Socioeconomic

- What was estimated and actual cost of constructing and monitoring the living shoreline project?
- Have the number of insurance claims submitted for structures near the living shoreline increased, decreased, or remained the same over time?*

APPENDIX F. Project Team Members

First	Last	State	Organization
Joan	LeBlanc	--	Northeast Regional Ocean Council
Kim	Bradley	CT	University of Connecticut
Pete	Francis	CT	CT Dept. of Energy and Environmental Protection, Land and Water Resources
Katie	Lund	CT	University of Connecticut, CIRCA
Jennifer	Mattei	CT	Sacred Heart University
Jim	O'Donnell	CT	University of Connecticut, CIRCA
Brian	Thompson	CT	CT Dept. of Energy and Environmental Protection, Land and Water Resources
Harry	Yamalis	CT	CT Dept. of Energy and Environmental Protection
Alison	Bowden	MA	The Nature Conservancy
Katherine	Castagno	MA	The Nature Conservancy
Theresa	Davenport	MA	The Nature Conservancy
Jessica	Dietrich	MA	The Nature Conservancy
Steve	Kirk	MA	The Nature Conservancy
Julia	Knisel	MA	MA Office of Coastal Zone Management
Margot	Mansfield	MA	MA Office of Coastal Zone Management
Eric	Roberts	MA	The Nature Conservancy
Jeremy	Bell	ME	The Nature Conservancy
Curtis	Bohlen	ME	Casco Bay Estuary Partnership
Matt	Craig	ME	Casco Bay Estuary Partnership
Kathleen	Leyden	ME	Maine Coastal Program
Amanda	Moeser	ME	The Nature Conservancy
Peter	Slovinsky	ME	Maine Geological Society
Geoffry	Smith	ME	The Nature Conservancy
Tom	Ballestero	NH	University of New Hampshire
David	Burdick	NH	University of New Hampshire

First	Last	State	Organization
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Adrianne	Harrison	NH	National Oceanic and Atmospheric Administration
Kirsten	Howard	NH	NH Department of Environmental Services, Coastal Program
Alix	Laferriere	NH	The Nature Conservancy
Steve	Miller	NH	Great Bay National Estuarine Research Reserve
Cory	Riley	NH	Great Bay National Estuarine Research Reserve
Caitlin	Chaffee	RI	Coastal Resources Management Council
Leah	Feldman	RI	Coastal Resources Management Council
Janet	Freedman	RI	Coastal Resources Management Council
Kevin	Ruddock	RI	The Nature Conservancy
John	Torgan	RI	The Nature Conservancy
Jeff	Willis	RI	Coastal Resources Management Council

APPENDIX G. May 2018 Workshop participants

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Audie	Arbo	Maine Department of Environmental Protection
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Tom	Ballestero	University of New Hampshire
Rick	Bennett	United States Fish & Wildlife Service
Bob	Boeri	Massachusetts Office of Coastal Zone Management
Curtis	Bohlen	Casco Bay Estuary Partnership
Alison	Bowden	The Nature Conservancy
Kim	Bradley	Connecticut Institute for Resilience and Climate Adaptation
David	Burdick	University of New Hampshire
Edith	Carson	National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Protected Resources Division
Caitlin	Chaffee	Rhode Island Coastal Resources Management Council
Mel	Coté	Environmental Protection Agency
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Rachel	Freed	Massachusetts Department of Environmental Protection
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Dan	Goulet	Rhode Island Coastal Resources Management Council
Rebecca	Haney	Massachusetts Office of Coastal Zone Management
Adrianne	Harrison	National Oceanic and Atmospheric Administration, Office for Coastal Management
Amy	Hoenig	Massachusetts Natural Heritage & Endangered Species Program

First	Last	Organization
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Eric	Hutchins	National Oceanic and Atmospheric Administration, Restoration Center
Christine	Jacek	United States Army Corps of Engineers, Regulatory Division
Mike	Johnson	National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Habitat Conservation Division
Steve	Kirk	The Nature Conservancy
Julia	Knisel	Massachusetts Office of Coastal Zone Management
Ruth	Ladd	United States Army Corps of Engineers, Regulatory Division
Alix	Laferriere	The Nature Conservancy
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Joan	LeBlanc	Northeast Regional Ocean Council
Eben	Lewis	New Hampshire Department of Environmental Services, Land Resources Management
Kathleen	Leyden	Maine Department of Marine Resources, Maine Coastal Program
Kevin	Lucey	New Hampshire Department of Environmental Services, Coastal Program
Margot	Mansfield	Massachusetts Office of Coastal Zone Management
Jennifer	Mattei	Sacred Heart University
Mark	McCullough	United States Fish & Wildlife Service
Steve	Miller	Great Bay National Estuarine Research Reserve
Ivy	Mlsna	Environmental Protection Agency
Amanda	Moeser	The Nature Conservancy
Pete	Murdoch	United States Geological Survey
Denis	Nault	Maine Department of Marine Resources
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Betsy	Nicholson	National Oceanic and Atmospheric Administration, Office for Coastal Management
Jim	O'Donnell	Connecticut Institute for Resilience and Climate Adaptation
Adrienne	Pappal	Massachusetts Office of Coastal Zone Management

First	Last	Organization
Cheri	Patterson	New Hampshire Fish and Game Department
Ed	Reiner	Environmental Protection Agency
Cory	Riley	Great Bay National Estuarine Research Reserve
Nathan	Robbins	Maine Department of Environmental Protection
Eric	Roberts	The Nature Conservancy
Cori	Rose	United States Army Corps of Engineers, Regulatory Division
Mark	Rousseau	Massachusetts Division of Marine Fisheries
Kevin	Ruddock	The Nature Conservancy
Chris	Schillaci	Massachusetts Division of Marine Fisheries
Alison	Sirois	Maine Department of Environmental Protection
Peter	Slovinsky	Maine Geological Survey
Rachel	Stevens	Great Bay National Estuarine Research Reserve
John	Torgan	The Nature Conservancy
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APPENDIX H. References

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Jelesnianski, C., Chen, J., Shaffer, W. (1992). *SLOSH: Sea, Lake, and Overland Surges from Hurricanes.* NOAA Technical Report NWS: 48. https://repository.library.noaa.gov/view/noaa/7235

LaPann-Johannessen, C., Miller, J., Rella, A. & Rodriquez, E. (2015). *Hudson River Wake Study*. Stevens Institute of Technology, TR- 2947. Hudson River Sustainable Shorelines Project. Staatsburg: NY.

Moody, J. (2017). *Methods for RTK Point Collection and ArcGIS Methods for Topographic Elevation Modeling in an Area of Interest*. Partnership for the Delaware Estuary. PDE Method No. 47. https://s3.amazonaws.com/delawareestuary/Standard+Methods+Bank+Documents/PDE-Method-47+Methods+for+RTK+Point+Collection+and+ArcGIS+Methods+for+Topographic+Elevation+Modeling+in+an+Area+of+Int.pdf

NOAA. (n.d.). *Habitat Blueprint: Living Shorelines*. [Website]. https://www.habitatblueprint.noaa.gov/living-shorelines/

O'Donnell, J. (2017). Living shorelines: A review of literature relevant to New England coasts. *Journal of Coastal Research* 33(2), 435–451. https://doi.org/10.2112/jcoastres-d-15-00184.1

Parnell, K. & Kofoed-Hansen, H. (2001). Wakes from large high-speed ferries in confined coastal waters: Management approaches with examples from New Zealand and Denmark. *Coastal Management*, 29(3), 217-237. https://doi:10.1080/08920750152102044

APPENDIX I. Resources

1. Living Shorelines: General Resources

NOAA. *Habitat Blueprint: Living Shorelines*. https://www.habitatblueprint.noaa.gov/living-shorelines/

NOAA. (2015). *NOAA Guidance for Considering the Use of Living Shorelines*. https://www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf

NOAA Fisheries. NOAA Restoration Center. *Building Coastal Resilience through Living Shorelines*. https://www.habitatblueprint.noaa.gov/wp-content/uploads/2019/10/Fact-Sheet-2019-Living-Shorelines.pdf

NOAA Fisheries. *Understanding Living Shorelines.* https://www.fisheries.noaa.gov/insight/understanding-living-shorelines

NOAA National Ocean Service. *What is a Living Shoreline?* https://oceanservice.noaa.gov/facts/living-shoreline.html

Northeast Regional Ocean Council. *Coastal Hazards and Resilience Committee: Living Shorelines Group*. https://www.northeastoceancouncil.org/committees/coastal-hazards-resilience/living-shorelines-group/

O'Donnell, J. (2017). Living shorelines: A review of literature relevant to New England coasts. *Journal of Coastal Research* 33(2), 435–451. https://doi.org/10.2112/jcoastres-d-15-00184.1

The Nature Conservancy. (2021). *Piloting Living Shorelines in New England*. https://www.nature.org/en-us/what-we-do/our-priorities/protect-water-and-land/land-and-water-stories/northeast-living-shorelines/

The Nature Conservancy. *Case Studies: Living Shorelines in New England. An in-depth look at five living shoreline demonstration projects TNC and partners piloted throughout the Northeast*. https://www.nature.org/en-us/what-we-do/our-priorities/protect-water-and-land/land-and-water-stories/northeast-living-shorelines-case-studies/

Woods Hole Group. (2017). *Living Shorelines in New England: State of the Practice.* https://www.conservationgateway.org/ConservationPractices/Marine/Pages/new-england-living-shorelines.aspx#:~:text=Living%20shorelines%20are%20a%20coastal,in%20place%20of%20hard%20infrastructure

2. Living Shorelines: Technical Resources

Bathymetry

- CT DEEP Bathymetric Contours in Meters for Long Island Sound: http://www.cteco.uconn.edu/metadata/dep/document/LIS_BATHYMETRY_FGDC_Plus.htm
- International Hydrographic Organization Data Centre for Digital Bathymetry Viewer: https://maps.ngdc.noaa.gov/viewers/iho_dcdb/
- NOAA National Centers for Environmental Information: Bathymetry – Ocean Depths: https://www.ngdc.noaa.gov/mgg/bathymetry/relief.html
- USACE Joint Airborne Lidar Bathymetry Technical Center of Expertise: https://www.sam.usace.army.mil/Missions/National-Centers-in-Mobile/Joint-Airborne-Lidar-Bathymetry/
- USGS Maps of America's Submerged Lands: https://woodshole.er.usgs.gov/data/submergedlands/

Cost Analysis

- Ecosystem Valuation: https://www.ecosystemvaluation.org/cost_avoided.htm
- FEMA HAZUS: https://msc.fema.gov/portal/resources/hazus
- FEMA National Flood Insurance Program: https://www.fema.gov/flood-insurance

Longshore Transport

- Utilize the Army Corps of Engineers Sediment Mobility Tool: https://navigation.usace.army.mil/SEM/SedimentMobility

Photo Observations and Monitoring

- Balloon and kite mapping kits and instructions from Public Lab: https://publiclab.org/wiki/balloon-mapping
- NJ Department of Environmental Protection. Citizen Scientist Monitoring of Nature-based Coastal Resiliency and Restoration Projects: A Guidance Manual: https://s3.amazonaws.com/delawareestuary/Standard+Methods+Bank+Documents/Citizen+Scientist+Monitoring+Manual+4.2.pdf
- Partnership for the Delaware Estuary, Science Group. Method for Fixed Photo Point Observations: https://s3.amazonaws.com/delawareestuary/Standard+Methods+Bank+Documents/PDE-Method-51+Method+for+Fixed+Photo+Point+Observations+w.+datasheet.pdf
- US Department of Agriculture. Quick Guide to Photo Monitoring: https://efotg.sc.egov.usda.gov/references/public/NM/bio61a6_PhotoDocumentation_Protocol.pdf
- University of New Hampshire picture post program (example): https://seagrant.unh.edu/volunteer/coastal-research-volunteers/current-projects/picture-post-monitoring

Protected Species and Habitat

State Resources

- CT Department of Energy and Environmental Protection Natural Diversity Database State Listed Species Review: https://www.ct.gov/deep/cwp/view.asp?a=2702&q=323466&deepNav_GID=1628
- CT Environmental Conditions Online Advanced Viewer: https://cteco.uconn.edu/viewer/index.html?viewer=advanced
- Maine Department of Inland Fisheries and Wildlife. Essential Habitat Maps: https://www.maine.gov/ifw/fish-wildlife/wildlife/endangered-threatened-species/essential-wildlife-habitat/maps.html
- Maine Stream Habitat Viewer: https://webapps2.cgis-solutions.com/MaineStreamViewer/
- Maine Department of Agriculture, Conservation & Forestry, Maine Natural Areas Program: https://www.maine.gov/dacf/mnap/index.html
- MA Natural Heritage & Endangered Species Program. Regulatory Maps of Priority and Estimated Habitats: https://www.mass.gov/service-details/regulatory-maps-priority-estimated-habitats
- MA Natural Heritage & Endangered Species Program: Priority Habitats of Rare Species Map: http://massgis.maps.arcgis.com/home/webmap/viewer.html?layers=a953ef7fe0744ef2b2a8fb49118c51c7
- NH Coastal Viewer: http://nhcoastalviewer.unh.edu/Html5Viewer/index.html?viewer=NHCoastalViewer
- NH Natural Habitat Bureau DataCheck Tool: https://www2.des.state.nh.us/nhb_datacheck/signin.aspx
- RI Department of Environmental Management, Environmental Resource Map: https://ridemgis.maps.arcgis.com/apps/webappviewer/index.html?id=87e104c8adb449eb9f905e5f18020de5

Federal Resources

- US Fish and Wildlife Section 7 Consultations, Endangered Species Act https://www.fws.gov/service/section-7-consultations
- NOAA, Essential Fish Habitat Assessment: https://www.greateratlantic.fisheries.noaa.gov/habitat/efh/efhassessment.html
- NOAA's Essential Fish Habitat Mapper https://www.habitat.noaa.gov/protection/efh/efhmapper/index.html
- NOAA Essential Fish Habitat Consultations: https://www.fisheries.noaa.gov/national/habitat-conservation/consultations-essential-fish-habitat

Sea Level Rise

State Resources

- Maine Sea Level Rise and Storm Surge Scenarios: https://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml
- Massachusetts Sea Level Rise and Coastal Flooding Viewer: https://www.mass.gov/service-details/massachusetts-sea-level-rise-and-coastal-flooding-viewer
- New Hampshire Coastal Viewer: http://www.nhcoastalviewer.org/
- Rhode Island STORMTOOLS: http://www.beachsamp.org/stormtools/
- University of Connecticut, CIRCA Local Sea Level Rise Scenarios for the State of Connecticut: https://circa.uconn.edu/sea-level-rise/

Federal and Northeast Region Resources

- NOAA Sea Level Rise Viewer: https://coast.noaa.gov/digitalcoast/tools/slr.html
- Northeast Climate Adaptation Center, University of Massachusetts, Amherst. Probabilistic projections of local sea level rise and vulnerability along the Northeast coastline: https://necsc.umass.edu/projects/probabilistic-projections-local-sea-level-rise-and-vulnerability-along-northeast-coastline
- USACE, Sea Level Change Curve Calculator: http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html
- USACE, Sea Level Tracker: https://www.usace.army.mil/corpsclimate/Public_Tools_Dev_by_USACE/sea_level_change/
- USGS: Coastal Change Hazards Portal: https://marine.usgs.gov/coastalchangehazardsportal/

Shoreline Change

State Resources

- Connecticut Shoreline Change Analysis: https://shorelinechange.uconn.edu/
- Connecticut Coastal Hazards Map Viewer: https://cteco.uconn.edu/viewer/index.html?viewer=coastalhazards
- Massachusetts Shoreline Change Browser: https://www.mass.gov/service-details/massachusetts-shoreline-change-project
- New Hampshire Beaches: Shoreline Movement and Volumetric Change report: https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/r-co-17-01.pdf
- New Hampshire Coastal Viewer: http://nhcoastalviewer.unh.edu/Html5Viewer/index.html?viewer=NHCoastalViewer
- Rhode Island Shoreline Change Maps: http://www.crmc.ri.gov/maps/maps_shorechange.html

National Tools

- Google Earth: www.google.com/earth/
- Historic Aerials: www.historicaerials.com
- NOAA's Digital Coast: https://coast.noaa.gov/dataviewer/#/
- USGS Digital Shoreline Analysis System: https://woodshole.er.usgs.gov/project-pages/DSAS/version4/data/DSASv4_4_manual.pdf
- USGS National Aerial Photography Program: https://www.usgs.gov/centers/eros/science/usgs-eros-archive-aerial-photography-national-aerial-photography-program-napp#overview
- USGS Topographic Maps: https://www.usgs.gov/programs/national-geospatial-program/topographic-maps

Site Use

Historical / Cultural

- Connecticut Department of Economic and Community Development: https://portal.ct.gov/DECD/Content/Historic-Preservation/01_Programs_Services/Environmental-Review/Fed-Review-and-Compliance---Section-106
- Maine Historic Preservation Commission: https://www.maine.gov/mhpc/programs/project-review

- New Hampshire Division of Historical Resources: https://www.nh.gov/nhdhr/review/
- Massachusetts Historical Commission: https://www.sec.state.ma.us/mhc/mhcrevcom/revcomidx.htm
- Rhode Island Historical Preservation and Heritage Commission: http://www.preservation.ri.gov/review/process.php

Prior Industrial Site Use

- EPA Superfund Sites in Reuse: https://www.epa.gov/superfund-redevelopment-initiative/find-superfund-sites-reuse

Soil (Organic Matter, Bulk Density, Frost Depth)

- Loss on Ignition (LOI) standard operating procedures to determine organic matter concentration: https://drive.google.com/file/d/1gl0y4H-3xYWnuFL3uDikVWyh6GwKDweI/view ~~http://lrc.geo.umn.edu/laccore/assets/pdf/sops/loi.pdf~~
- Standard procedures for determining soil bulk density: http://soilquality.org.au/factsheets/bulk-density-measurement
- Measuring soil frost depth in forest ecosystems with ground penetrating radar: https://doi.org/10.1016/j.agrformet.2014.03.005

Storm Impacts

State Resources

- CT Environmental Conditions Online, Hurricane Surge Inundation: https://data.ct.gov/dataset/CT-Hurricane-Surge-Inundation/yhuz-kprd, and http://www.cteco.uconn.edu/guides/resource/CT_ECO_Resource_Guide_Hurricane_Surge_Inundation.pdf
- Maine Sea Level Rise/Storm Surge Scenarios: https://www.maine.gov/dacf/mgs/hazards/slr_ss/index.shtml
- MA Sea Level Rise and Coastal Flooding Viewer: https://www.mass.gov/service-details/massachusetts-sea-level-rise-and-coastal-flooding-viewer
- MA - Climate Change Clearinghouse for the Commonwealth: https://resilientma.org/home.html
- NH Tides to Storms: Assessing Risk and Vulnerability to Sea-level rise and Storm Surge: A Vulnerability Assessment of Coastal New Hampshire: http://www.rpc-nh.org/regional-community-planning/climate-change/tides-storms
- NH Coastal Viewer: http://nhcoastalviewer.unh.edu/Html5Viewer/index.html?viewer=NHCoastalViewer
- NH Sea-Level Rise, Storm Surge, and Groundwater Rise Mapper: https://nhdes.maps.arcgis.com/apps/webappviewer/index.html?id=c231e2f3b1f94d05bc0c8faf0265f569
- RI STORMTOOLS: http://www.beachsamp.org/stormtools/

Federal Resources

- NOAA Adapting Stormwater Management for Coastal Floods: https://coast.noaa.gov/stormwater-floods/

- NOAA National Storm Surge Hazard Maps: https://noaa.maps.arcgis.com/apps/MapSeries/index.html?appid=d9ed7904dbec441a9c4dd7b277935fad&entry=1
- USGS Coastal Change Hazards Portal: https://marine.usgs.gov/coastalchangehazardsportal/

Tidal Conditions

- NOAA's Computational Techniques for Tidal Datums Handbook: https://tidesandcurrents.noaa.gov/publications/Computational_Techniques_for_Tidal_Datums_handbook.pdf
- NOAA Vertical Datum Transformation (VDatum): http://vdatum.noaa.gov
- NOAA Tides and Currents: http://tidesandcurrents.noaa.gov
- NERACOOS Data Tools: http://neracoos.org/data/

Topography

- Emery Method: https://seagrant.umaine.edu/wp-content/uploads/sites/467/2019/05/emerymethod.pdf
- RTK-GPS: Methods for RTK Point Collection and ArcGIS Methods for Topographic Elevation Modeling in an Area of Interest

Water Quality

- Standard field collection techniques and analysis in a laboratory setting. https://www.epa.gov/sites/production/files/2015-06/documents/NE-States-Sample-Collection-Manual.pdf
- Secchi disk (construction): https://serc.carleton.edu/microbelife/research_methods/environ_sampling/turbidity.html

Waves (Modeling, Height, Fetch)

- FEMA Flood Insurance Study: https://www.fema.gov/flood-maps/change-your-flood-zone/status/flood-insurance-study
- University of Connecticut, CIRCA Wave Model: https://circa.uconn.edu/crest/wave-model/
- USACE Coastal Engineering Manual Part II: https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1100_Part-02.pdf?ver=2016-02-11-153511-290
- USGS Application of Wind Fetch and Wave Models for Habitat Rehabilitation and Enhancement Projects: https://www.umesc.usgs.gov/management/dss/wind_fetch_wave_models_2012update.html

Wildlife Survey and Assessment

- Bird surveys: https://www.manomet.org/wp-content/uploads/2018/07/ISS-Protocols.pdf
- Horseshoe crab spawning surveys: http://www.gso.uri.edu/mjjp/HSC_survey_instructions.pdf
- Oyster Habitat Restoration Monitoring and Assessment Handbook: http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf.
- Terrapin surveys: https://www.pwrc.usgs.gov/terrapin/methods.cfm