Quality Assurance Project Plan (QAPP) For Monitoring Demonstration "Living Shorelines" Projects in Maine

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Abbreviations and Acronyms

Abbreviation	Meaning
CBEP	Casco Bay Estuary Partnership
MGS	Maine Geological Survey
QAPP	Quality Assurance Project Plan
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
RTK GPS	Real Time Kinematic Global Positioning System
MTS	Maine Technical Source
DMR	Maine Department of Marine Resources
CORS	Continuously Operating Reference Station

Project/Task Organization

Maine Coastal Program is the Maine Lead on a NOAA-funded project to demonstrate use of "living shorelines" (LS) in New England. The project, titled "Increasing Resilience and Reducing Risk through Successful Application of Nature Based Coastal Infrastructure Practices in New England," will construct and study multiple demonstration projects in New England using nature-based strategies for reducing shoreline erosion along a variety of shoreline types. TNC New England is coordinating state efforts.

Here in Maine, the project will construct test erosion control structures at three demonstration sites in Casco Bay. Contractors under the direction of Maine Coastal Program and Maine Geological Survey will design and construct the projects. CBEP is responsible for developing monitoring protocols and carrying out the bulk of monitoring and supports outreach and education programs and coordination of volunteers for construction and monitoring.

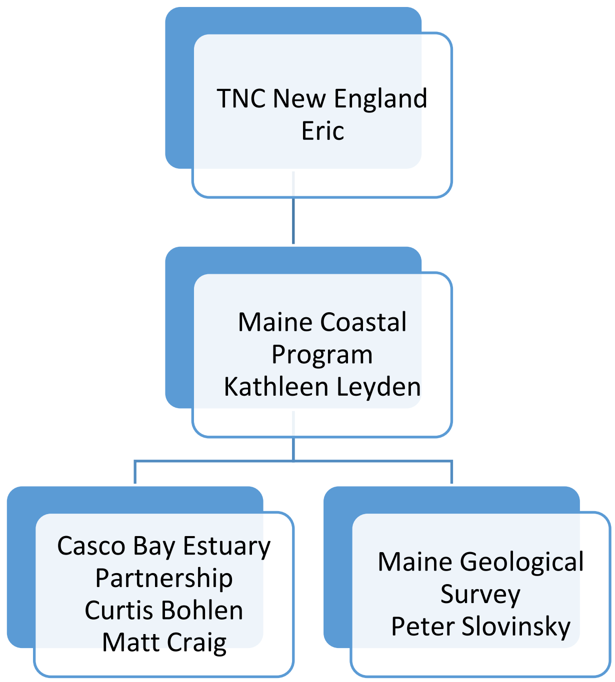

Figure 1: Project Organization

As monitoring lead, CBEP will establish the monitoring schedule, maintain paper and electronic records, organize site visits, and ensure that all personnel and equipment needed to complete monitoring are available. Monitoring will be carried out by CBEP and MGS staff. Bohlen will lead planning of monitoring, Craig will lead monitoring during site visits. Craig will be assisted as needed by Bohlen, Slovinsky, CBEP interns, and MGS interns. Additional assistance may come from other CBEP, MGS, and Coastal Program staff (seasonal staff and interns) as well as interested colleagues and volunteers. CBEP lead staff and seasonal staff will manage data entry, organization, and review.

Senior staff will lead all site visits, and directly supervise seasonal staff, colleagues, and volunteers in the field. Data collection will always be supervised, so training will happen one-on-one, either immediately before field work (e.g., for instruction on using equipment) or in the field (e.g., for identification of non-native plants). Senior staff will go over the day's planned activities and review equipment and data sheets with everyone daily, before data collection begins. No separate documentation of training will be maintained, but all field data sheets document who was involved with data collection, thus providing indirect documentation of staff and volunteer experience.

CBEP senior staff will work closely together and with seasonal staff to facilitate data entry, review, and management. All data entry work will be reviewed by senior staff for completeness and accuracy.

MGS owns two Leica RTK GS receivers, and has prior experience working with RTK GPS survey techniques. They will take the lead on collection of RTK-derived positional data in 2019, or until site-specific procedures have been established and CBEP staff have gained familiarity with the equipment and its use.

Problem Definition/Background

"Nature-based" erosion control strategies, sometimes referred to as "Living Shorelines," have been used in the mid-Atlantic region for decades. Tidal marshes have been planted along shorelines in the Chesapeake since at least the 1980s to slow erosion. Related technologies have received increased attention nationwide over the past decade, especially along the mid-Atlantic and Gulf coasts. These tools have become increasingly important for supporting both ecosystem integrity and coastal resilience along developed shorelines.

These technologies, however, have been relatively little used in New England. Maine's waters have a higher tidal range than areas south of Cape Cod, where most "living shoreline" or "nature based" erosion reduction technologies have evolved. Some technologies (e.g. artificial oyster reefs) pose significant practical or permitting challenges when implemented in meso- or macro-tidal coastal waters. Colder waters make northern New England less suitable for some species (e.g., American oyster) that play a major role in living shoreline technologies along the Gulf coast and mid-Atlantic. Furthermore, few LS technologies have been tested in environments with significant winter ice.

Project Description

As part of a NOAA-funded regional "Living Shoreline" consortium, Casco Bay Estuary Partnership and Maine Coastal Program are constructing three demonstration projects in Brunswick and Yarmouth Maine. The goals of these projects are:

(1) To test alternatives to hardened shoreline structures for reducing erosion along Maine shorelines;
(2) To study how these structures function in Maine waters, especially with regards to structural integrity and ecosystem response in the context of Maine's colder waters, winter ice, and higher tidal ranges;
(3) To work with regulatory agencies to improve understanding of permitting issues raised by these approaches to shoreline protection; and
(4) To evaluate methods for monitoring Living Shorelines projects, and to identify monitoring methods useable at different levels of technical sophistication and cost.

This last goal is important for understanding how this QAPP is constructed. This QAPP includes narrative descriptions of methods that we may employ as we test monitoring methods and learn more both about the problem domain and available monitoring techniques. We do not expect that all of the methods described will be used, but at this time we cannot be certain which methods will prove both effective and cost-effective due to uncertainty with living shoreline designs.

Locations

Shoreline protection project designs are in development for three locations in central and northern Casco Bay as shown in Figure 2. Approximate geographic coordinates of these locations are provided in Table 1.

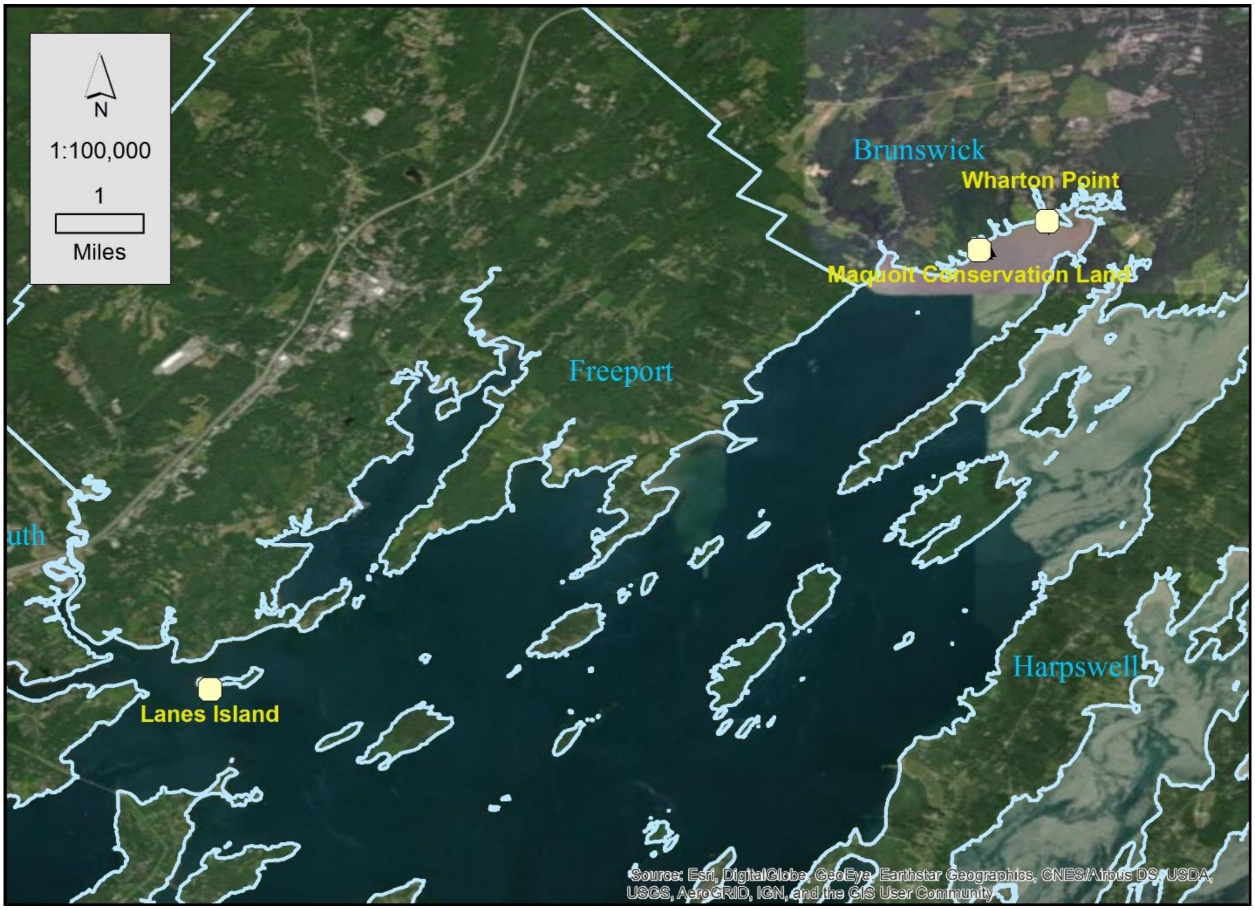

Figure 2: Map of Proposed "living shoreline" demonstration projects in Casco Bay

Table 1: Approximate locations of three "living shoreline" demonstration projects (WGS 1984)

Site Name	Latitude	Longitude
Lanes Island	43°47'26.13"N	70° 7'50.47"W
Maquoit Conservation Lands	43°51'46.64"N	70° 0'13.42"W
Wharton Point	43°52'2.68"N	69°59'34.09"W

Lanes Island

The site on Lanes Island, owned by Maine Coast Heritage Trust, is an eroding sandy bluff behind a narrow beach. The bluff is eroding rapidly, as evidenced by numerous recent tree falls, an oversteepened and in places overhanging bluff, a dynamic sandy foreshore, and a narrow and weakly developed band of *Spartina alterniflora* vegetation, which is periodically buried by sand. The site faces south over tidal flats towards Cousins Island and the Yarmouth boat channel to marinas in the Royal River.

Maquoit Conservation Lands

The site at the Maquoit Conservation Lands (owned by the Town of Brunswick, with a conservation easement held by Brunswick-Topsham Land Trust) is an eroding salt marsh, backing up against an undeveloped forested hillside. A small stream or creek enters Maquoit Bay slightly to the south and west of the project site, and provides a local source of fine sediment. The shore faces south or southeast, over the tidal flats and Maquoit Bay, towards Merepoint. Surface water runoff and groundwater discharge from the adjacent hill may be exacerbating erosion at this site.

Wharton Point

The site at Wharton Point is owned by the State of Maine and managed by the Department of Inland Fisheries and Wildlife. The shore is largely an eroding high marsh plateau, with tidal flats and patches of *Spartina alterniflora* growing in front of the present-day tidal marsh scarp. The site is immediately adjacent to an active boat launch facility owned by the Town of Brunswick. A tidal creek enters Maquoit Bay at the eastern end of the site. The boat launch is heavily used by clammers for access to the tidal flats of Maquoit Bay by airboat, and the adjacent treatment site is regularly crossed by clammers hauling canoes to and from the tidal creek.

"Living Shoreline" Project Designs

Detailed project designs for the three sites are not yet available, but are envisioned to incorporate low-cost application of natural materials, including bagged oyster shell and logs, to protect eroding marsh edges at Wharton Point and Maquoit Bay Conservation Lands, and the eroding bluff at Lanes Island. Project areas at the two salt marsh sites are approximately 150 to 200 feet long, allowing treatment of about 100 feet of shoreline, while still leaving room for a suitable untreated control area with similar wave exposure. The Lanes Island site is somewhat longer, but initial plans call for limiting treatment to 100 to 150 feet of shoreline. The landowner has agreed to regrading the eroding slope at Lanes Island to improve bluff stability, but the likelihood of incorporating regrading into the site plan is uncertain.

Project designs may include both application of materials at the eroding marsh or bluff face, and also construction of structures in the intertidal zone nearshore (perhaps 30 to 50 feet offshore of the MHW tide line) to reduce wave energy before waves reach the shore. .

Site specific monitoring plans depends, in part, on design of the projects that will be constructed. This QAPP provides a description of methods that would be used regardless of final designs, and spells out logic about how final monitoring choices will be made once designs are complete and approved by permitting agencies.

Site-specific monitoring plans will be developed for each of the monitoring sites, and incorporated as addenda to this QAPP. These monitoring plans will include:

- Monitoring goals and related data quality objectives
- A list of the specific field methods to be used,
- A description of the number and location of monitoring locations used for each method

- Any other information needed to document data collection and facilitate future monitoring that meets all monitoring goals.

Monitoring Design

The New England regional (TNC-led) "Living Shorelines" consortium is working on developing a shared approach to monitoring living shorelines projects. Those regional discussions about monitoring are ongoing. The information provided here has been informed by the regional discussions, and our experience with monitoring will in turn inform the regional program.

Monitoring design for the project will follow a classic Before-After-Control-Impact (BACI) design to track how the living shoreline treatments perform. This design relies on both collection of baseline (pre-project construction) data, and data from a nearby control site (both before and after construction) to provide insight into project performance. Accordingly, data will be collected at both the project site and at an adjacent control site both pre- and post- construction. For our three project sites, the "control site" will be a section of shoreline adjacent to experimental treatments, with generally similar shore profile, orientation, and wave exposure. Comparison of the before and after data from both the project site and the control site will document the effects of implementing living shoreline treatments and separating those effects from naturally occurring variation.

For understanding how components of the living shorelines treatments themselves function over time, we will compare long-term characteristics not with pre-project conditions, but with the "as built" condition that pertains immediately following project construction.

Primary Data Collection Goals

Data collection will focus on five principal subjects:

(1) CONTEXT: Understanding the context of the project site. Context refers to the features of the site that are unaffected by the project itself, but may have a significant effect on project design, effectiveness or longevity. Context includes understanding such site-specific features as the wave energy environment, salinity of surface waters, climate, tidal range, local land use, or groundwater discharge.

(2) GEOPHYSICAL: Documenting the geophysical environment of the site and how that is altered by the project. Geophysical observations include observations of elevations and position of shoreline features, documentation of sediment characteristics, material scour and deposition.

(3) EROSIVE FORCES: Evaluating erosive processes at the site both before and after project construction. Dominant erosive processes at our sites are thought to include direct erosion by wave energy, especially during storms, impact of ice (via rafting, shoving heaving and "needling"), and the impact of surface water runoff and groundwater discharge on bluff stability.

(4) BIOTA AND HABITAT: Documenting condition of and changes in the biota at the sites. At the small scale of our projects, and given design and site characteristics, impact on the biota are likely to be small. We will use rapid assessment methodologies to document condition of the biota, with a focus on species composition, invasive species, and habitat quality.

(5) STRUCTURAL INTEGRITY: Assessing the structural integrity of the erosion control structures themselves.

Data Collection Schedule

Data collection under CBEP leadership will begin as soon as we have complete project designs, and can finalize site-specific monitoring plans. We currently expect to have final designs available by the end of May. Pre-project data must be collected before construction begins, so data collection should begin no later than mid-June, or as soon as this QAPP is approved.

The current project has limited duration, and thus provides funding only for the first two to three years of data collection post-construction. We anticipate collecting data for a longer period of time, both to enhance the value of demonstration projects and because permit conditions may require longer monitoring. The monitoring schedule is laid out to include pre-construction monitoring, immediate post-construction (as built) monitoring, and then monitoring on an annual schedule as long as monitoring continues.

(1) Pre-Project Data
  a. Data collected before project construction to document the context of the living shoreline project.
  b. Data collected before project, to characterize existing shoreline erosion rates and processes, and document pre-project vegetation and topography. (Pre-project monitoring will be similar to seasonal post-construction seasonal monitoring, described below).

(2) As-Built Data
  a. Data collected to characterize "as built" conditions at the site immediately post-construction, especially to document position of constructed and planted elements of the living shoreline system.

(3) Spring or early summer (April-June) site visits
  a. Spring site visits will include delineation of the position of the shoreline and site topography, as well as assessment of structural condition. A primary purpose of these visits will be to document changes in site conditions occurring over the winter. Due to ice and winter storms, we anticipate that erosion over the winter may be especially severe.

(4) Fall or late summer (August-October) site visits
  a. Fall visits constitute the main annual data collection effort. Goals include:
    i. Documenting the position of shoreline features.
    ii. Describing the biota.
    iii. Measuring site topography at key locations for multi-year comparisons.
    iv. Documenting topography and shoreline position before erosion due to winter storms and ice.

(5) Winter Data Collection
  a. Due to access and safety constraints, we do not plan to collect quantitative data during the winter months, but we will conduct at least one winter site visit annually to observe site conditions. Where feasible, an automated camera will be deployed to take photographs on an at least daily basis, for a minimum of three weeks during the winter to document shoreline processes. Where we are unable to deploy automated cameras, staff or volunteers will visit the site at least twice to take winter photographs.

(6) Pre- and Post-storm monitoring (Beginning fall/winter 2019)

a. Once a year, when weather forecasts predict a significant storm event, we will visit each site both before and after (as soon as practicable and safe) the storm to document impacts on the structure and shoreline. Because nor'easters, not summer convective storms, likely dominate erosion processes, and since in mid-winter, ice may preclude collection of comprehensive data on topography and shoreline position, we will focus on capturing pre- and post- conditions of fall and early winter storms (October through December).

Data Quality Objectives for Key Measures

The data quality objectives for each metric stem from our project goals, specifically, to evaluate the performance of "living shorelines" erosion control practices over a 3 to 5 year period, while collecting data to inform future projects. Data quality indicators (precision and accuracy goals) are presented in the following table. Completeness, comparability and representativeness are discussed below.

Table 2: Principal measures used to assess living shorelines projects, with narrative description of purposes and accuracy goals

Group	Measure	Data Quality Objectives	Data Quality Indicators	Principal Methods
Context	Geospatial Data	Document spatial context of the site, including topography, land use and proximity to key resources.	Map products with scale of 1:24,000 or better, or highest resolution available	GIS analysis of available data
	Establish Local Vertical Benchmark	Baseline information for other elevation observations. Accuracy sufficient to support optical leveling as a back-up method where RTK GPS is ineffective.	+/- 2.5 cm	Identification of existing nearby vertical control points or estimating of elevation of a new control point using RTK GPS.
	Tidal Range / Sea Level	Document elevation of tides, especially high tides, for project design.	Relate water surface elevations to NOAA tide data at Portland to a nominal accuracy of +/- 10 cm	NOAA/NOS VDATUM provides approximate datums; Pressure transducer and comparison to NOAA Portland Tide Station data provide higher accuracy.
	Wave/Wake Energy	Characterize the wave energy environment to assess suitability of living shorelines technologies.	Assessment based on best available map data. Fetch calculations +/- 100m.	Characterization of fetch via geospatial analysis, by distance and direction.
Geophysical	Horizontal Position	Estimation of rates of erosion and movement of structure to detect effectiveness of shoreline treatments. Document a 15 cm or greater change in position.	Individual observations should be +/- 5 cm with RTK +/- 20 cm with other techniques.	RTK GPS. Back-up method measures distance from two or more fixed points using tape measures.
	Elevation (Vertical Position)	Elevation measurement underlies multiple other monitoring goals.	Individual observations should be +/- 2.5 cm with RTK	RTK GPS; Back-up method is optical level and stadia rod.

		Should reliably detect a 10 cm change in elevation.	+/- 5 cm with other techniques	Accuracy is often limited by field conditions.
	Lateral Erosion Rate	Document rate of shoreline erosion, to compare effectiveness of shoreline treatments. Document change in horizontal position of ca. 15 cm.	Individual observations should be +/- 2.5 cm with RTK +/- 5 cm with other techniques	Erosion pins placed in bank, measure exposed portion of pins at each site visit.
	Sediment deposition / accretion	Document patterns of erosion, deposition, and remobilization. Data may be both qualitative and quantitative. If quantitative, document changes in elevation at selected locations of 5 cm or more.	Replicate observations should be +/- 2 cm.	Feldspar marker horizon and periodic sampling; RTK GPS vertical positions; visual inspection and photo documentation.
	Sediment type and grain size	Document qualitative changes in sediment texture due to erosion or deposition.	Detect +/- 20% changes in abundance of either silt or sand	Visual observation, in-hand estimates of texture; laboratory analysis.
	Shoreline position (horizontal)	Document lateral movement of shoreline features of > 25 cm	Individual observations should be +/- 2.5 cm with RTK +/- 5 cm with other techniques	RTK GPS, backup using measurement of distances from a line drawn tight between two fixed points on shore.
	Site topography, elevation and slope	Map surface elevations (includes shore cross-sections) with sufficient accuracy to document 10 to 20 cm changes in elevation over the course of the study	Individual observations should be +/- 5 cm vertical, with horizontal spacing no less than 5 m	RTK GPS, 3 to 5 meter on center, and at topographic breaks. Optical survey where RTK reception is poor.
	Soil Strength	Detect poor bearing strength or high susceptibility to erosion.	Qualitative assessment	"Walk test" on tidal flats; penetrometer and shear vane tester to measure strength of soils and sediments.
Erosive Forces	Ice needling, rafting, and shoving	Evaluate the qualitative impact of ice on shoreline erosion,	Qualitative assessment	Visual observation; time-lapse photography.

		effectiveness of LS technologies, and persistence of structures.		
	Storm Impact	Evaluate the impact of storms on shoreline erosion and effectiveness of LS technologies.	Qualitative assessment	Visual observation, photographs, time-lapse photography, and survey before and after storms.
	Surface water runoff or groundwater discharge	Identify presence of surface water runoff or groundwater discharge that may affect design of LS installations, stability of slopes, or rates of shoreline erosion.	Qualitative assessment	Visual observation.
	Wave/Wake Energy	Document changes in the wave energy environment striking the shoreline behind any structural components designed to reduce waves.	Principally qualitative; Estimate height of waves to +/- 10 cm	Visual observation of waves; photo documentation; time-lapse photography; use of marker stakes to document highest waves.
Biota and Habitat	Invasive species presence/abundance	Document presence and relative abundance of noxious invasive plant and animal species most likely to occur.	Correctly identify invasive species of concern	Meander surveys of entire site and nearby untreated areas for invasive plants and non-native marine invertebrates; periodic observation, documentation, and adaptive management as needed.
	Shellfish and marine invertebrate community	Document presence and condition of shellfish resources. Provide narrative description of condition of marine habitats.	Qualitative assessment	Maine DMR rapid assessment protocols.
	Vegetation Structure/Robustness	Detect significant changes in community structure or vegetation health of tidal marsh vegetation.	All dominant and common species and 80% of all species correctly identified; Plant height +/- 2.5 cm; Number of stems +/- 10%; Greenness: +/1 1 index value	Rapid vegetation survey; detailed observations in designated sampling plots, including species composition, height of tallest leaves of selected salt marsh species, and “relative greenness” health index.

	Vegetation Types and Extent	Detect changes in tidal marsh vegetation type (e.g., high marsh to low marsh transition).	Correctly identify vegetation type; +/- 10% estimated area	Visual observation, vegetation rapid assessment protocols, sketch maps; RTK GPS.
Structural Integrity	Anchor or tie-in integrity	Assess changes in tightness, strength, or condition of components that hold structures in place.	Qualitative assessment	Visual observation, manual checks, photographs as needed.
	Erosion around the structure	Document presence of scour, especially at ends of structures, or at locations between structural components.	Qualitative assessment	Visual observation; photo documentation; strategic placement of marker horizons; RTK GPS.
	Location/position, dimensions, elevation, and stability of structure	Detect movement of selected structural components	Detect changes in position of 15 cm or more horizontally or 10 cm or more vertically.	RTK GPS of marked structural components.
	Material integrity	Document changes in physical condition of wood, shell, and other natural materials used.	Qualitative assessment	Visual inspection; check for ease of penetration with knife, screwdriver or awl.

Completeness, Comparability, and Representativeness

The primary purpose of the study design is to document changes over time at “Living Shoreline” monitoring locations. The strategy is to use a flexible, but structured approach to data collection to document changes at each site over time. Because we are only tracking a handful of living shoreline projects, we have neither the sample size nor variety of geographic contexts to draw conclusions about a larger population of (potential or actual) living shoreline projects. Our goal is description of changes at specific demonstration projects, as case studies. Completeness, comparability, and representativeness are thus questions of whether the data can be used to describe what is happening on a site by site basis.

Details of site-specific monitoring will be provided in the site-specific monitoring plans, to be developed once we have preliminary structural designs available. Study designs will be developed to generate data to support case studies of individual living shoreline projects.

Completeness

In this setting completeness principally implies temporal completeness (within data sets or sampling locations). As the goal is to track changes at specific locations, collection of repeat, comparable data is required for any trend analysis. The annual schedule of data collection is intended to allow tracking of both seasonal and interannual phenomena. For analysis of seasonal patterns, we will require at least three direct seasonal comparisons (either spring to subsequent fall or fall to subsequent spring) to assess seasonal effects. For interannual change, we will require samples collected in three different calendar years.

While the goal is for all data series to follow those requirements, a primary purpose of this study is to learn more about how best to study living shoreline projects in New England. We may add, drop, or modify monitoring tasks (samples, methods, locations, etc.) as we learn about monitoring these projects, or as site conditions change (e.g., a sampling location is eroded away). Such modifications may generate shorter data records, which will be considered incomplete, and used only with appropriate caveats. Such data will generally not be suitable for assessment of trends, but may prove useful for assessing monitoring methods or documenting spatial variability.

Comparability

Since project goals are for describing phenomena occurring at each study project, the primary issue of comparability is to make sure that data collected at one time period are adequately comparable to data collected at other times. A primary challenge

Practical limitations limit the accuracy with which we can locate exactly the same sampling locations in subsequent years.

- Data on the position of shorelines will be (in part) interpolated based on point locations collected along the shoreline using RTK GPS. We will make no effort to collect those locations at comparable locations along the shore from year to year, but will instead ensure that a sufficient density of points are collected to ensure that the resulting collection of points adequately traces the shoreline (see methods, below).
- Topographic data will similarly be collected using a generalized point cloud, and with no effort to collect elevation data at precisely the same locations sampled in other years.

- Shoreline cross-sections (transects) will be located based on positions of semi-permanent markings on shore (e.g., stakes or marked trees), and aligned from those fixed points by compass direction, by ranging on distant landscape features (islands, trees, rocks), and (where appropriate) by reference to marked location of the living shoreline structures themselves. Based on prior experience using similar methods in tidal wetland monitoring, we believe we can locate transects and sample locations along transects close to the same locations year to year (within one meter, unless markers are damaged or destroyed).

- Point observations not collected along transects will be re-located principally by homing in on visual cues, such as the location of the structure, or by using RTK GPS.

Representativeness

Because of the strong spatial structure (both lateral and vertical) of shorelines and additional spatial structure imposed by the designs of the living shoreline structures, we are not using random sampling for this study. Instead, we will use multiple, approximately evenly distributed sampling locations selected to provide spatially explicit understanding of site conditions. Examples of this kind of sampling include:

- Documentation of site topography using a grid of RTK-based elevation instruments
- Collecting data on the position of the shoreline based on closely spaced RTK position estimates.
- Use of shoreline transects to document shoreline cross-sections and vegetation

Representativeness is provided by approximately equal sampling to capture major features of the structure and shoreline, and by attending to placement of transects in relation to features of the shoreline or structure to capture phenomena of interest.

We will also monitor selected locations where erosion, deposition, scour or structural movement are expected, to provide insight into processes occurring on-site. These sites are not selected to be representative of “average” or “typical” conditions at the site, but to assess local changes at selected locations.

Table 3: Principal Monitoring Measures and Monitoring Times

Group	Measure	Pre-Project	As Built	Spring	Fall	Winter	Pre/Post Storm
Context	Geospatial Data	✓					
	Establish Local Vertical Benchmark	✓					
	Tidal Range / Sea Level	✓					
	Wave/Wake Energy	✓					
Geophysical	Elevations	✓	✓	(✓)	✓		
	Lateral Erosion Rate	✓		✓	✓		(✓)
	Sediment deposition / accretion	✓		✓	✓		
	Sediment type and grain size		✓		✓		
	Shoreline position (horizontal)	✓		✓	✓		(✓)
	Site topography, elevation and slope	✓			(✓)		
	Soil Strength	✓		✓	✓		
Erosive Forces	Storm Impact						✓
	Ice needling, rafting, and shoving					✓	
	Surface water runoff or groundwater discharge	✓			✓		
	Wave/Wake Energy	✓		✓	✓		✓
Biota and Habitat	Invasive species presence/abundance	✓			✓		
	Shellfish and marine invertebrate community	✓			✓		
	Vegetation Structure/Robustness	✓			✓		
	Vegetation Types and Extent	✓			✓		
Structural Integrity	Erosion around the structure			✓	✓		✓
	Anchor or tie-in integrity	✓		✓	✓		✓
	Location/position, dimensions, elevation, and stability of structure		✓	✓	✓		✓
	Material integrity		✓	✓	✓		

Monitoring Methods

In the following section, we present detailed consideration of data quality objectives, data quality indicators, and methods we plan to use to achieve those objectives. The discussion mirrors the structure of Tables 2 and 3, by Context, Geophysical, Erosive Forces, Biota and Habitat, and Structural

Integrity Categories. Because of uncertainty about final Living Shoreline project designs, and related uncertainty about method performance and relevance, we often present multiple methods for collecting data to address specific measures, and described in Table 2.

Context

Geospatial Data

Numerous sources of information are tapped in preparation of site assessments and development of preliminary designs for Living Shorelines projects. Desktop analysis of potential project sites relies heavily on available geospatial data, principally accessed from CBEP archives, through the Maine Office of GIS / Maine Geolibrary or Google Earth. Data reviewed includes, but is not limited to:

- Recent aerial photography
- LIDAR data (Maine's derived raster LIDAR data coverages are nominally ~ 18 cm RMSE, 2 meter spacing).
- Maine marine habitat maps, (generally mapped at 1:24,000 scale) including:
    - Eelgrass
    - Shellfish resources
    - Waterfowl and wading bird habitat
    - Locations of aquaculture leases and Limited Purpose Aquaculture (LPA) leases
- Locations of shorelines (water and land at a minimum of 1:24,000), derived from Maine Office of GIS cnty24p data and the National Hydrography Dataset.
- Bathymetry, as available.

These data sources are the best readily available, and are used with full awareness of data limitations based on extensive experience working with these and similar data layers.[1]

Tidal Range / Sea Level

Approximate tidal datums for Living Shoreline locations can be derived using NOAA/ NOS's VDatum software (https://vdatum.noaa.gov/welcome.html) or by programmatically accessing an API (See https://vdatum.noaa.gov/docs/services.html). As we are principally interested in point estimates of tidal dynamics for our living shoreline project locations, the VDatum API is sufficient for our immediate needs. We have developed a simple Python program to assemble and send requests to the VDatum API for conversion of elevations among datums at a specific latitude and longitude. We can use that program to access NOAA VDdatum estimates of tidal datums for our locations.

NOAA estimates that maximum cumulative uncertainty for datum transformations for sites in the Gulf of Maine is +/- 13.4 cm (5.3 inches). VDatum estimates are valid for open-water conditions, and do not fully capture tidal dynamics in tidal creeks or shallow embayments. In enclosed tidal bodies, frictional processes reduce water flow, especially during low tides. VDatum-derived low tide tidal datums (MLW, MLLW) are thus not representative of conditions at intertidal sites, like our LS demonstration sites, but high tide tidal datums (MHW, MHHW, HAT) are accurate enough for project planning.

Tidal datums are important during design and construction for delineating State and Federal permitting jurisdictions. For monitoring purposes, the most sensitive use of elevation data for project planning for

[1]. Where accuracy of geospatial data may impact other metrics, data quality requirements are discussed in more detail in the context of those metrics.

Living Shorelines is for assessing elevations of natural or existing marsh species. Maine tidal marshes show marked changes in vegetation composition near mean tide level (MTL), Mean High Water (MHW) and Highest Annual Tide (HAT). Mean High Water is especially important, as the usual dividing line between low marsh, dominated by *Spartina alterniflora*, and high marsh, dominated by *Spartina patens*.

We can improve on the VDatum estimates, if necessary to guide planting plans or evaluate planting success, based on local data. To do so, we monitor water elevations using pressure transducers placed near the living shoreline location. Pressure transducers are placed as close to the project location as possible, contingent upon being continuously submerged. Elevations of the sensors are determined by optical leveling to a single local vertical benchmark, or estimated directly using RTK GPS. An atmospheric pressure transducer is installed near the deployment location (within one mile), to allow correction of estimated water depths based on atmospheric conditions.

Data are collected using Hobo Data loggers (Appendix C) at six-minute intervals for a period of at least one month. Those data provide a local estimate of tidal elevations and tidal range over the period of measurement, reflecting on-site tidal dynamics. Because these data represent local conditions, they are immediately and directly informative of site conditions, however, they represent a short-term record only, and are not necessarily reflective of long-term tidal dynamics.

The pressure sensor in each HOBO Water Logger is individually calibrated at the factory, and requires no calibration by the user. The HOBO loggers measure absolute pressure, so water level is estimated based on pressure differential between a submerged sensor and barometric pressure. Uncompensated depth estimates can be off by a foot or more. Although in principal, one could correct water level data based on data from weather stations, in practice it is convenient to use Onset's proprietary software (Hoboware Pro, Barometric Compensation Assistant) and sensors (either another water level logger or an Onset Smart Barometric Pressure Sensor). Onset barometric pressure sensor is also factory calibrated, and needs no calibration by the user. Both water level sensors and barometric pressure sensors are checked annually for accuracy (by comparison with weather station data and checking values submerged under a known depth of water, respectively), as recommended by Hobo. Hobo recommends using barometric pressure data from within 10 miles of where water level sensors are deployed. In practice CBEP typically deploys barometric pressure sensors within a few hundred feet.

Tidal datums are defined over a 19 year tidal epoch. In order to estimate local tidal datums, we correlate our local data with water levels observed at the nearby Portland Tide Station (where a long-term data record provides excellent estimates of datums based on a full tidal epoch). NOAA's Computational Techniques for Tidal Datums Handbook (NOAA 2003)[2] contains recommended methodology for estimating local tidal datums with a minimum of one month of observations. An on-line calculator provides ready access to computational methods and results.[3] Two methods are recommended for east coast locations:

- The Modified-Range Ratio Method, based on being able to observe the full tidal cycle and calculate appropriate all local tidal metrics and tidal ranges.

[2] https://tidesandcurrents.noaa.gov/publications/Computational_Techniques_for_Tidal_Datums_handbook.pdf
[3] https://access.co-ops.nos.noaa.gov/datumcalc/

- Direct Method (used when all tidal metrics are not available because low tide elevations are not observable).

As our existing LS demonstration sites are all intertidal, and thus lack data on low tides, the Direct Method is preferred. The Direct Method amounts to correcting high tide tidal datums (MHW, MHHW) at the site by a correction factor equal to the mean difference between the elevation of high tide elevations at the field site and at the Portland gauge.

Accuracy (as RMS error of prediction) are reported in the Handbook to be on the order of 4cm for extrapolations based on one month of data, although it is not clear whether those estimates apply to both methods. We expect that the actual error budget is likely to be greater, as it includes the following components:

(1) Methodological uncertainty - - estimated here using the 4cm value reported in the Manual.
(2) Statistical error estimating the mean difference in elevation between site and the Portland Gauge, which will depend on instrument noise, local hydrodynamics, weather, etc.
(3) Error for measuring the elevation of the instruments (+/- 2.5cm using RTK, +/- 5cm using leveling from a local benchmark)
(4) Bias caused by rising seas since the period over which the Portland tidal datums were defined. Portland's current tidal epoch was based on data collected from 1983 through 2001. Local sea level has been increasing over the last few decades at a rate of a few millimeters a year.

We are also evaluating methods to make better use of high frequency water level observations. The Direct Method throws out all data collected by the data logger except the elevation of each high tide. Better (lower error) estimates should be available by calculating corrections based on multiple measurements collected close to each high tide. Multiple measurements should minimize the impact of short-term variation in field measurements, thus improving performance.

We will extract data from only the upper portion of the observed tidal range (probably the upper ¼, but this requires testing). We will then use linear models to estimate observed water levels on site based on tides at Portland. The linear models will calculate least squares fits to calculate both a temporal offset of tides (expected to be only a few minutes based on NOAA data) and a linear relationship between water elevations (subject to that offset) on site and at Portland. We can then apply those high tide corrections to tidal datums. As these methods are experimental, results of applying the Direct Method will also be reported.

Wave/Wake Energy

Waves and wakes are thought to provide a primary mechanism of shoreline erosion at many locations in Casco Bay. However, accurate measurement of the wave and wake energy spectrum requires deployment of costly high accuracy, high throughput pressure transducers. Because erosion may be dominated by a few large storm events, long-periods of deployment or rapid deployment in anticipation of storms is required to fully characterize the wave energy spectrum.

For our purposes (to compare relative exposure at different sites) the high costs of transducer deployments are not justified. Instead of directly measuring wave energy, we estimate the wave environment, by analyzing fetch. Simple assessment is based on estimating length of longest linear fetch using GIS. More sophisticated analyses are possible using the USGS's Fetch Tool (Rohweder et al. 2012)[4].

The Fetch Tool allows calculation of estimate s of:

- Significant wave height,
- wave length,
- spectral peak wave period,
- shear stress, and
- maximum orbital wave velocity

The USGS Fetch Tool is based on analysis of continuous open water distances ("fetch") along selected compass directions, informed by understanding of local winds. Documentation of the tool provides general model validation, but no simple measure of method accuracy.

Geophysical

Elevation and Position

A core requirement for monitoring our living shorelines projects is accurate and consistent measurement of elevations and position. Accuracy needs vary depending on the context.

The primary technology we will use for estimating both elevation and position will be Real Time Kinematic GPS. RTK GPS allows rapid collection of positional data accurate to within a few centimeters in both vertical and horizontal directions. Because of the speed of data collection, RTK GPS receivers are often the most cost-effective approach to collecting positional data in field settings. RTK data can be collected by a single person working alone. Each position requires only a few seconds to collect, making high-density point clouds practical. Data collection rates are several times what is available using other technologies, such as optical leveling. Savings in labor costs more than make up for costs of equipment rental.

Under certain circumstances, RTK GPS technologies do not work reliably. This is especially true when hills, bluffs, or dense vegetation block satellite signals or Network RTK signals needed to provide high accuracy positions in real time. Under those conditions, we will estimate elevation using optical leveling from local benchmarks, and horizontal position by measuring distance (using a 100m fiberglass tape measure) and angle (using the optical level) from benchmarks established with RTK GPS or other permanent positional markers. This will result in significantly lower accuracy than available using RTK GPS.

Our most demanding measurement for horizontal position will be repeated measurement of the position of marked features of the Living Shoreline structures used to detect movement of the structure itself. We would like to reliably detect movement of the structure by more than 15 cm horizontally or 10 cm vertically.

We can estimate measurement accuracy to achieve that level of precision 95% of the time, as follows:

[4] https://www.umesc.usgs.gov/management/dss/wind_fetch_wave_models_2012update.html

An approximate 95% confidence interval has width ~ 2* SE of an observation (here the observation is a CHANGE in position, or DIFFERENCE in horizontal position between two measurements).

$$15\text{cm} = 2 * \text{SE}_{difference}$$

$$7.5\text{cm} = \text{SE}_{difference}$$

For uncorrelated errors, the variance of a difference between two observations is the sum of the variances. Assuming successive measurements are uncorrelated, and measured with the same error distribution.

$$\text{SE}_{difference} = \sqrt{2 * \text{Var}_{observation}}$$

$$7.5\text{cm} = \sqrt{2 * \text{Var}_{observation}}$$

$$\frac{7.5cm}{\sqrt{2}} = \text{SD}_{Observation}$$

$$5cm \cong \frac{7.5}{1.414} = \text{SD}_{Observation}$$

So, to have high confidence that we can observe movement of the structure by as little as 15 cm, we should strive for observations that are accurate horizontally to within +/- 5 cm. This is well within the nominal accuracy of the RTK GPS receivers, but likely unachievable using our alternative low cost methods.

For vertical accuracy, our highest level of precision will be successive measurements of sediment surface elevation in areas of erosion or deposition. For this application, we would like to be able to detect erosion or deposition of on the order of 5 cm. A similar calculation to the last suggests that required individual measurements of elevation to be accurate on the order of:

$$1.75\text{cm} \cong \frac{2.5\text{cm}}{\sqrt{2}} = \text{SD}_{Observation}$$

Again, this is well within the nominal accuracy of RTK GPS technologies. In this case it is also within the nominal accuracy of optical leveling, which serves as our backup technology.

Other high precision uses for estimation of elevation include establishing local vertical benchmarks and documenting the elevation of pressure transducers used for establishing tidal datums. For each of these goals, accuracy to within +/-2.5 cm would be sufficient for our purposes, although lower error would be preferred.

RTK Technology

Maine Geological Survey has two RTK units (Leica GS-14 receiver with a CS-15 controller, running Leica Viva SmartWorx software (Appendix C), which will be used when they are available. Nominal accuracy of the Leica GS-14 depends on operating mode. The lowest resolution, available via Single Baseline or Real Time Kinematic GPS using Network RTK produces nominal 8mm +/- 1 ppm horizontal and 15 mm +/- 1 ppm vertical accuracy. Higher data accuracy is available with longer observations and data post-processing.

When those units are not available, Maine Technical Source (MTS), a local surveying equipment supplier, rents similar units for under $250 per day. MTS rents Leica equipment, but the model and specifications vary depending on availability. Methods are similar and performance of rental units is similar or better to the MGS equipment.

In practice, vagaries of field data collection (placement of the GPS receiver, presence of soft sediments, wind effects, etc.) induce errors of the order (5 to 20 mm) of the nominal accuracy of the RTK GPS receivers or more. In practice, precision of data collected by RTK GPS is limited more by field data collection conditions and protocols than by nominal equipment precision.

Optical Leveling and Vertical Controls ("Benchmarks")

CBEP currently uses a Topcon AT-B3 Automatic Level and Crain SVR-25-Tenths, Model #98010 Stadia rod to measure relative elevations via optical leveling. The stadia rod permits estimation of relative elevations to within ~ 2 mm. That precision is on par with nominal accuracy of the autolevel over moderate distances, (+/- 1.5 mm). In practice, accuracy of leveling data is limited by field data collection conditions (wind, soft sediments, etc.). Realistic vertical accuracy based on leveling from a single local benchmark is likely to be on the order of +/- 3 mm to 5mm over the short distances involved for this project.

A critical limitation on the accuracy of optical leveling at these sites is proximity of suitable vertical benchmarks. None of our sites has an existing vertical control point located near enough to make double run leveling from an existing benchmark to the site practicable. Instead, local benchmarks will be established using RTK GPS technologies. Suitable locations for semi-permanent benchmarks have been identified at Wharton Point and Maquoit Conservation Lands where GPS technologies can be used directly.

The mobile shore and dense forest cover at Lanes Island mean that GPS reception is relatively poor where structures (tree roots and rocks) that could host a permanent benchmark are located. Benchmarks at Lanes Island may be based on transferring elevations from temporary working benchmarks established using GPS to semi-permanent locations using optical leveling.

Triangulation

Horizontal positions are significantly more difficult to estimate with precision in the field without RTK GPS equipment. CBEP uses Keson English/Metric Open Reel Fiberglass Tapes (100m /300ft in length) to measure distances in the field. These tapes are marked out in 2mm increments, allowing estimation of distances to one mm, however, tape sag, wind induced sway etc. mean accuracies better than +/- 5 cm are doubtful in practice.

The concept of triangulation is that given two known points, one can determine the position of a third point by measuring the distance from each. Accuracy depends on geometry of the three points, with highest precision available when the angle from fixed point to unknown position fixed point) is close to 90 degrees. Unfortunately, that geometry can be difficult to obtain along a shoreline.

If we need to use triangulation to monitor shifting position of structures or shoreline features, or to relocate sampling locations, we will base estimates on measuring distances from at least two marked fixed points (trees, large rocks, or specially placed stakes or posts) that are not expected to move during the study. To improve precision, fixed points will be marked to within ½ cm using paint, markers, or nails, as appropriate. To detect shifts in position of these "fixed points", distances between fixed points will be checked prior to collecting data on positions by triangulation.

Innovative Methods

We may experiment with use of "structure from motion" (SFM) techniques, using multiple imagery derived from drones or handheld cameras, to derive estimates of location of features. Presence of trees and brush on site limit use of these technologies at Lanes Island and the Maquoit Conservation Lands, so if we use these methods, we will do so principally to learn about the technologies, and any SFM-derived data will be compared to data derived using other methods. SFM techniques are reported to achieve accuracies of +/- 5 cm, with better accuracies available if SFM is combined with ground control points (established, for example, with RTK GPS).

Lateral Erosion Rate

Lateral erosion is defined here as the lateral loss of removal of soil or sediment because of shoreline erosion. Our goal is to be able to detect and document erosion of 10 cm or more at selected points. We will use erosion pins to measure lateral erosion.

Erosion pins are pieces of rebar (usually 3 to 6 feet long) embedded horizontally into a bank or bluff until the end of the pin is flush with the sediment surface. On subsequent visits, a photograph is taken and the length of exposed pin is measured to the nearest half centimeter using a tape measure, meter stick or other linear measuring device, thus providing an estimate of rate of erosion with resolution on the order of one centimeter between visits.

Approximately eight to twelve pins will be placed at each site, spread along the length of the study reach (treatment area plus adjacent control), with at least two pins within the control area. Where multiple treatment variations are involved at each site, at least two pins will be located in areas protected by each treatment combination.

At Maquoit Bay and Wharton Point, the pins will be emplaced at the edge of the eroding tidal marsh escarpment, approximately 35 to 50 cm below the top of the embankment. At Lanes Island, pins will be located in pairs, with on pin emplaced low on the bank, the other, high on the eroding bluff.

Sediment deposition / accretion

Successful living shorelines projects often result in deposition of sediment behind protective structures or among the stems of established or re-established plants. Two methods may be used to assess sediment accretion: Use of marker horizons, and measurement of sediment elevations. In both cases, it is not yet clear how valuable the techniques will be in our setting.

Marker Horizons

Marker horizons are widely used in wetland research to document accumulation of sediments (e.g., Lynch et al. 2015). The method consists of placing distinctively colored mineral material (often brick dust, feldspar, or kaolin) onto the sediment surface within a marked rectangle, and returning to the site periodically to collect cores and measure the thickness of material overlying the marker horizon. We will follow the standard operating procedure laid out by USGS in Lynch et al. 2015 to establish and sample marker horizons. Selection of locations for marker horizons will be modified, since we are establishing coordinating rSETs.

We will only use marker horizons at sites where one or more treatments can reasonably be expected to reduce wave energy or increase sediment accumulation on intertidal flats. At those sites, we will place two 0.5m x 0.5m patches of kaolin clay on intertidal sediments behind each treatment (including the control). Oak stakes will be driven at the four corners of the square. Position of the marked sediments will also be recorded using RTK GPS. In subsequent sampling visits, a PVC sampling frame, with markers every 10 cm will be emplaced over the four corner stakes, dividing the area into 25 sub-areas. At each visit, cores will be collected from two of the 25 sub areas and the amount of material present over the marker horizon recorded to the nearest millimeter.

We will need to experiment with methods for core retrieval at our sites. Lynch et al. recommend cryogenic coring in soft or wet sediments, but we do not have the budget to build the necessary equipment. We will test methods for sampling both with hand-held soil corers (which can compress sediments, thus biasing estimated accumulation rates low, but can retrieve samples from soft sediments) and cutting sediment blocks with a knife as described in Lynch et al. 2015 (which works poorly in soft of very soft sediments).

The second method we will use to estimate rates of deposition will be to compare measurements of elevation collected at different times. Given the limited accuracy of our abilities to collect positional information, this approach is only valid for documenting rather large deposition rates (more than ~ 5cm between observations. We currently anticipate that this method will only be suitable for estimating deposition of sands adjacent to the eroding sandy bluff at Lanes Island. We have already witnessed during site visits (And documented with photographs) changes in the shoreline profile due to local deposition well in excess of 5 cm.

Sediment type and grain size

Higher velocity water is capable of mobilizing larger sediment particles, and so as we alter the local hydrodynamic environment, we may see related changes in sediment composition or texture. Areas where wave energy is diminished may see accumulation of fine mineral sediment or organic matter, leading to observable changes in sediment characteristics (e.g. silts and clays covering coarser sands). Conversely, areas subjected to increases scour (due perhaps to end effects of structures) may see a reduction in fines or an increase in coarse particles like sand and fine gravels.

Sediment composition is spatially variable, based on parent material, wave energy environment, land use history, and other factors. Accordingly, characterizing sediment composition across each site has little utility. Instead, we will gather data on sediment composition at specific sampling points to elucidate changes in sediment transport processes.

Sample locations to study deposition will include areas behind and adjacent to intertidal structures intended to reduce wave energy.

Sites to study scour will include the ends of any structures, areas immediately seaward of structures, and other sites selected opportunistically where we observe signs of scour or deposition after project construction.

Methods for assessing sediment composition, in order of increasing level of effort include:

- Visual assessment (often used in rapid stream geomorphological assessments)
- “in hand” assessment (commonly used in agriculture)

Identification of scour will be based principally on visual assessment of sediment composition, in concert with assessment of any changes in microtopography. Deposition will be evaluated by tracking changes in particle size distributions in surface sediments (<2.5 cm) based on visual assessment or laboratory analyses.

Visual assessment of sediment is most useful for documenting relative abundance of coarse to very coarse particles (sands, pebbles, cobbles) and the degree of embeddedness of larger particles by fines. In our context, visual assessment will be used at every field visit as part of efforts to look or evidence of scour. Data will consist of field notes recording a visual assessment of the percent of rock, cobble, gravel, sand, and fines on the surface at selected locations, backed up by photographs.

Methods for characterizing sediment composition 'in-hand' in the field are commonly used for agricultural assessment of soil "texture" (e.g., USDA Undated and Ritchey at al 2015) [5]. The method requires minimal training, and is reliable for identifying significant changes in sediment composition, such as replacement of sands by silts, or visa-versa. Given the high proportion of silts and low abundance of clays at our field sites, in-hand methods will be used during site visits principally to check for presence and relative abundance of sands in surface sediments and as a rapid assessment method, with results recorded in field notes.

Shoreline position (horizontal)

Shoreline position is a key summary metric of erosion processes. We will assess rates of shoreline erosion in part by measurement of the changing position of shoreline features. All three of our study sites are characterized by a steep or near vertical erosion face, making it straight forward to identify the top of the eroding face (a tidal marsh scarp at the two Brunswick sites, and a sandy bluff at Lanes Island).

We will document the position of the shoreline scarp at all three sites. We will record the position of the top of the scarp at least every meter, and at key locations like cuts or promontories as needed to document the shape and position of the scarp. In practice in the field, some judgement is required to ascertain the position of the scarp. Moreover, the RTK GPS unit cannot be placed without physical support provided by solid sediments. We can only measure the location of points along the top of the scarp to within about +/- 10 cm. Error will be compounded somewhat by linear interpolation between measurement points. Using RTK GPS, we believe we can document the position of the scarp sufficiently to detect a shift in the position of the scarp on the order of 25 cm.

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[5] https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054311 or https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1139&context=anr_reports

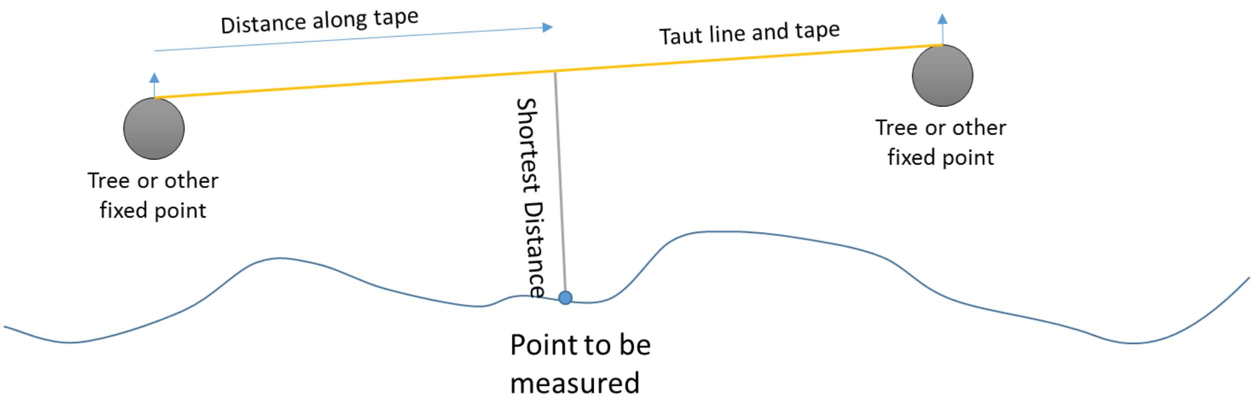

Figure 3: Diagram of simplified technique for estimating position of scarp at Lanes Island, if RTK GPS is ineffective.

In the open environment of the tidal wetlands at Wharton's Point and Maquoit Conservation Lands, we can document the position of the scarp directly using RTK GPS. At Lanes Island, where dense forest cover can interfere with GPS data collection, we may have to document the shoreline position by measuring the distance between the top of the scarp and a taught line (like a chalk line) drawn between fixed points affixed to trees in the woods at the top of the scarp.

In this method, we will establish two fixed points on the Lanes Island shore, by driving nails into trees or posts, and drawing a chalk line or mason's line tight between them, and as close to the ground as practicable. We will draw a tape measure between the two fixed points to mark approximate distances along the line. With one person at the scarp selecting points to be measured, and another at the tape, we will record both the minimum distance from scarp to line, and record the length along the tape where that minimum distance is observed. As minimum distances should be observed when the measurement is being made perpendicular to the line, this allows us to estimate the lateral position of our measurement point as well. This method is not as accurate as triangulation, because of the subjectivity involved with estimating when the minimum distance is observed, but it is also considerably faster for collecting numerous points along a roughly linear feature.

We may experiment with using optical surveying techniques to collect data on the position of the eroding scarp. Our prior experience, however, suggests that estimation of positions from measurement of distance and angle from a single turning point offers no advantage in terms of horizontal accuracy. The primary advantage is that optical estimation of locations may reduce impact to the shoreline by reducing foot traffic.

Site topography, elevation and slope

We will collect topographic data principally along cross-sections (a minimum of four per site), from seaward of the "living shoreline" structures to above the intertidal zone (above the top of the eroding bluff at Lanes Island). At least one cross section will be aligned with each erosion control treatment, allowing comparison of treatments and controls at each site. We will use RTK GPS to map cross sections. If RTK reception is too poor to allow use of that technology, we will use optical leveling to document elevations along the cross sections.

Where RTK reception is adequate, we may also generate a surface survey of the project area. We will not try to collect detailed site topography for sites or portions of sites where we are unable to use RTK GPS technology. We will collect topographic data on an approximate 10 m density grid, from seaward of the project area to above the intertidal zone (or bluff, at Lanes Island). We will post-process this point cloud in ArcGIS using inverse distance weighted interpolation (IDW) to generate an approximate smooth surface.

If engineering firms collect topographic data for design purposes using other technologies, we will retain those data as well, but will only compare data if the data is tied to the vertical control points at each site or otherwise provided with adequate vertical controls (+/- 5cm)

Soil Strength

Our concerns about soil strength relate principally to two matters: The bearing strength of marine sediments, especially in the intertidal zone, and resistance of eroding sediments to shear.

We will assess bearing strength simply by walking out onto the intertidal sediments. Roughly speaking, a person in boots or waders exerts a pressure of only about 20 to 25 kPa when walking. As a practical matter, if a person's weight causes them to sink into the sediments, the sediments are unlikely to be suitable for supporting structures, including artificial reefs, reef balls, or oyster bags.

A primary erosion process at our sites is wave-driven mobilization of sediment. Sediment strength is a common metric used in stream geomorphology to assess the vulnerability of soils to erosion due to water flow. Soil cohesiveness (and thus resistance to erosion) can be measured with a Torsional Vane Shear Tester (Forestry Suppliers #77299) and a soil penetrometer (Forestry Suppliers #77114). Each tester is a spring-loaded device that moves an indicator while a load is being applied to the soil until the soil fails, at which point the amount of force required to cause the soil to fail can be read off of a scale.

The smallest division on the penetrometer is 0.250 kg/cm^2. Values can be interpolated to approximately half of that. The smallest division on the dial of the torsional vane shear tester is 0.05 kg/cm^2, allowing visual interpolation to 0.01 kg/cm^2.

Ten shear strength measurements and ten penetrometer measurements will be made, approximately evenly spaced along the erosion face of the bluff or the marsh annually.

Erosive Forces

Ice needling, rafting, and shoving

We will use informal field observations, photographs, and where practical, time lapse photography to assess the role of ice in shoreline erosion and impact on structures. No quantitative information will be collected.

Storm Impact

Storm impact will be assessed by collecting limited data during site visits immediately before and after one storm each year. Specific methods are described elsewhere. Data that will be collected include:

- Position of Shoreline
- Position of Structure
- Visual assessment of scour and deposition
- Assessment of the condition of anchors or tie-downs

- Visual assessment of site, including condition of vegetation and presence of wrack or debris.

Photographs will be used document visual site assessment.

Surface water runoff or groundwater discharge

Surface water or groundwater discharge can cause or exacerbate erosion on shorelines. Accordingly, on every site visit, we will look for visual evidence of surface water runoff affecting the site (e.g., presence of flowing water, recent gullying) and groundwater discharge (e.g., darkened soils, or presence of "seeps"). Photographs will be used to document any significant observations.

Wave/Wake Energy

Our purpose in assessing the wave and wake environment is to get a qualitative sense of the effectiveness of intertidal structures (if uses at each site) in reducing small and moderate waves striking the eroding scarp. We do not believe it is practical to collect data on wave energy during large storm events, which are expected to dominate erosion processes. Our goal, therefore, is simply to document that any intertidal structures intended to reduce wave energy have that effect on typical (summer) waves.

A quantitative assessment of the wave energy environment requires deployment of high frequency pressure transducers or other sensors and is cost-prohibitive. We will document changes in the wave energy environment qualitatively, by observing the wave environments behind intertidal structures designed to reduce waves (should any be included in our LS designs) and on adjacent unprotected shorelines (thus allowing comparison of a treatment and an adjacent control).

We will collect data on waves, principally during seasonal site visits or opportunistically as we are on site for other monitoring duties, provided tides are high enough to allow waves to pass the intertidal structures. We do not anticipate making special trips to the sites to observe the wave environment under high wind or storm conditions.

We will characterize the wave environment by estimating wave heights and frequency. Observations will be made for three one-minute periods, estimating the height of the tallest wave observed and counting waves passing during that time. We will experiment with temporarily placing stakes marked off in 10cm intervals in the intertidal sediments to provide a vertical reference against which to estimate wave heights.

Biota and Habitat

Invasive species presence/abundance

Sites will be systematically surveyed during the fall site visits for the presence of non-native species commonly found on the coast of Maine. The survey will consist of having a trained observer, familiar with selected species and their ecological preferences, walk the site systematically looking for invasives in areas of suitable habitat or refuge.

When invasives are identified, they will be logged, and their approximate location recorded with a sketch map, narrative description or GPS.

Initially, we anticipate surveying each site for the following species, although the list may yet change depending on the final design of our LS projects and recommendations from regulatory agencies.

Species were selected because they are common on Maine's coast, readily identified, and serious invasive pests.

Vegetation

Common Name	*Botanical Name*
Eurasian Bittersweet	*Celastrus orbiculata*
Japanese Barberry	*Berberis thunbergii*
Common Reed	*Phragmites australis*
Black Swallow-wort	*Cynanchum louiseae*
Bush honeysuckles	*Lonicera morrowii* and *Lonicera tatarica*
Japanese Knotweed	*Fallopia japonica*

Marine Invertebrates

Common Name	*Botanical Name*
Green Crab	*Carcinus maenas*
Asian Shore Crab	*Hemigrapsus sanguineus*

The relatively short list of non-native marine invertebrate species reflects the fact that our sites are all in the upper intertidal zone, and thus are unlikely to offer good habitat for many of our most readily-identified non-native marine species, which thrive in the lower intertidal or subtidal. Mobile invasives, like our two dominant non-native shore crabs, however, can move in and out of our sites with the tides.

Shellfish and marine invertebrate community

Maine DMR has developed rapid assessment protocols to document habitat condition and relative population abundance of important harvestable shellfish via a "walkover survey". The method, which is still in development, is intended to provide rapid, replicable data on shore resources. The method consists of walking the site, sketch-mapping mapping and documenting areas of distinctive habitat types, recording relative abundance of species on the sediment surface, and sampling for clams in upper, mid, and lower intertidal zone (See Appendix F).

Our sampling design will differ from that described in the DMR protocol, because our goal is to evaluate impacts of living shoreline projects. We will focus our survey on the area immediately surrounding the living shorelines projects (within approximately 50 meters). We will not examine conditions in the lower intertidal zone, as recommended by DMR, because the lower intertidal at our sites is hundreds of meters away. This means we can conduct the walkover surveys during any low tide, not only unusually low tides, as suggested in the DMR method.

At each site, we will dig a minimum of six plots to provide a qualitative assessment of shellfish present, three in each of the upper and mid intertidal zones. This is a higher level of effort per unit area of tidal flat than DMR uses. If any of our living shorelines projects involve offshore treatments, at least one sample will be collected in the area of the upper intertidal protected by those treatments. Otherwise, four samples will be located offshore of shoreline treatments, and two will be located adjacent to nearby unprotected shoreline.

The DMR method includes the option to conduct quantitative sampling to document the abundance of softshell clams by size. We do not anticipate doing any quantitative sampling.

We will be using our own data sheet (Appendix A), rather than the one developed by Maine DMR. The DMR data sheet includes spaces for qualitative assessments of habitat quality and for management recommendations. These are not relevant to our study, and CBEP staff are not qualified to make such assessments.

The DMR walkover surveys will be part of our fall site visits, and thus completed annually.

Vegetation Structure/Robustness

In order to detect changes in community structure or health of tidal marsh vegetation, we will conduct either rapid (plotless) vegetation surveys or structured (plot-based) vegetation analysis. In either case, we will supplement data on species composition with data on the relative health of dominant plant species at the site.

Rapid Vegetation Monitoring

Draft project concepts did not call for modification of the tidal marsh, nor tidal marsh plantings as part of our Living Shoreline projects. Consequently, monitoring the health of (largely unaltered) tidal marshes adjacent to our projects is only a secondary monitoring goal. Accordingly, we anticipate using rapid (plotless) methods for vegetation analysis.

During rapid field assessments of tidal wetlands, CBEP uses a simplified "relevé" method to characterize vegetation in terms of dominant and conspicuous plant species. Sample locations are selected in the field and are not randomly located. They are selected to be representative of vegetation zones or transitions between them, such as low marsh, high marsh, high marsh-upland transition, or brackish marsh.

The observer stands at one location (recorded in the notes, marked on the site map, or recorded via GPS), records all plant species readily observed in adjacent vegetation, and adds a measure of relative abundance for each (using rough percent cover estimates or Braun-Blanquet cover classes). The area observed is not formally defined (hence this is a "plotless" method) but left up to the judgement of the observer. In herbaceous tidal wetlands, the area sampled will typically be approximately five meters in diameter.

Sampling Design for Rapid Assessment

The tidal marsh adjacent to the Wharton Point site is largely *Spartina patens* dominated high marsh, grading into a weedy tidal marsh – upland transition zone still strongly influenced by salt spray. At this site, we anticipate placing three sampling points within the high marsh, and two sample points in the high marsh-upland transition. (The small area of low marsh at the site contains only a single species (*S. alterniflora*) of vascular plant, and so there is little value in collecting species composition data.

At the Maquoit Conservation Lands site, the high marsh directly abuts a steep hillside, limiting the transition zone to just a few feet in width. However, the vegetation is less homogenous across the site, with portions dominated by either *Spartina patens* or *Spartina alterniflora*. Here we anticipate placing five sampling points in different vegetation zones based on professional judgement in the field.

The Lanes Island site contains only a small amount of low marsh, dominated by *S. alterniflora*. Since only a single species grows in the intertidal marsh, there is little point in collecting low intensity data on species composition at the site.

Plot-based Vegetation Monitoring

If project designs call for disturbance of existing tidal wetland vegetation, or planting of new tidal wetland, we will use more labor-intensive plot-based sampling techniques. In more intensive monitoring, vegetation is sampled using $1m^2$ quadrats set on the marsh surface at specific locations. The quadrats are placed at specific positions along well-defined transects from ocean to upland, to facilitate sampling nearly the same location in subsequent years.

Transects will, where possible, correspond to surveyed cross-sections, so that we can relate vegetation characteristics to elevation. Transects will be monumented and documented in the field using permanent or semi-permanent features of the site, such as rocks or trees, and documented in our record using cameras, field notes (narrative description, length, compass direction), and RTK GPS.

Five vegetation plots will be included along each transect, with at least one plot placed in low marsh and two in high marsh along each transect (where suitable vegetation occurs). Plots will not be placed with less than two meters separation along any one transect. As in plotless sampling, species composition and estimates of percent cover for each plant species are recorded. Plot-based sampling facilitates collection of data OTHER than data on species composition, such as plant density, stem counts, or plant health (see below).

Sampling Design for Plot-based Sampling

If high intensity vegetation sampling is deemed necessary, sample design will be as follows:

- At Wharton Point, we will establish five transects running from the tidal flats to the upland. At this site, we will place three sampling points within the high marsh, and two sample points in the high marsh-upland transition. (The small area of low marsh at the site contains only a single species (*S. alterniflora*) of vascular plant, and so there is little value in collecting species composition data.
- At the Maquoit Conservation Lands, we anticipate placing five transects, spaced approximately evenly along the shore, from marsh scarp to the adjacent uplands.
- The Lanes Island site contains only a small amount of low marsh, dominated by *S. alterniflora*. We do not anticipate collecting data on species composition at this site, but regularly spaced quadrats may be essential for tracking changes in stem density of plant health. If necessary, five plots will be laid out along each of five transects from ocean to the base of the eroding bluff in locations where *Spartina alterniflora* (or other intertidal vegetation) is observed.

Plant Identification

Plant identification follows Haines and Vining 1998. Identifications in the field are made by experienced observers, based on general plant characteristics, and sometimes with the use of a hand lens. Field staff must spend at least one day in the field with experienced observers and pass an informal assessment of their ability to identify common salt marsh plants before being allowed to collect vegetation data on their own. CBEP maintains a “Cheat Sheet” of common tidal wetland species, with useful field characteristics to help facilitate identification and year-to-year consistency in plant identifications

Not all plants or species need to be identified. Tidal marsh vegetation structure is dominated by just a handful of common and dominant species. For vegetation data to be of acceptable quality, all dominant species (cover > 50% in any plot) and all common species (present in more than 20% of plots) will be identified, and at least 80% of plant species and 80% of plant cover in each plot will be identified to species.

Samples of any plant species not readily identified in the field will be collected for later identification in the laboratory. Samples are placed in plastic bags, which are labeled by the site, station, and plot in which the species was observed. Each unknown species is given a temporary identification (e.g., "Unknown grass # 3") so that data on its relative abundance can be collected even in the absence of definitive identification. Once in the laboratory, unknown plants are identified with the aid of a dissecting microscope. Once identifications are confirmed by senior project staff, the field data sheets are amended in pen (all field data are recorded in pencil) to add the correct identification. Plants that cannot be identified are recorded as unknown.

Observers are trained by senior staff to use standard methods to estimate percent cover. A percent cover reference sheet (Carlisle et al 2002, App. A) is used to promote consistency. Quadrats are constructed out of PVC pipe. Additional design specifications for quadrats are provided in Carlisle et al 2006, p. 6.

Documenting Health of Tidal Wetland Vegetation

If project designs call for disturbance of existing tidal wetland vegetation, or planting of new tidal wetland, we will supplement data on vegetation composition with data on health of the dominant salt marsh species at each sampling location. These data will consist of (1) heights of the tallest leaves, (2) stem counts, and (3) a measure of the relative "greenness" of dominant salt marsh plants.

Data will be collected non-destructively at four locations associated with each sampling point or sampling plot. For low intensity samples, these locations will be one pace away from the nominal sampling point along the cardinal compass directions. For plot-based samples, they will correspond to the four quarters of the 1m x 1m plot.

At each location, a species will be designated as the dominant tidal marsh graminoid (*Spartina patens* or *Juncus gerardii* on high marsh; *S. alterniflora* on low marsh), based on the results of vegetation sampling. The height of the three tallest leaves of that species within approximately 10cm of the sample point will be recorded. The number of plant stems of the dominant tidal marsh species within a small subplot delineated by a PVC sampling frame (10cm x 10 cm in high marsh, 20cm x 20cm in low marsh) will be recorded. The vegetation at the sample point will be given a "greenness score", based on a five point scale, based on approximate percent of leaf area that remain green as follows:

Greenness Score	Percent of Leaves that are Green	Heuristic Description
1	0% to 20%	Very little green
2	21% to 40%	More non-green than green
3	41% to 60%	About half green
4	61% to 80%	More green than not green
5	81% to 100%	Almost all green

Scores are based on visual inspection of the vegetation as a whole, supplemented by inspection of individual plants and leaves. Areas of leaves are counted as green if they retain any green pigment, even pale green. Use of only five categories of greenness, based on both quantitative and heuristic definitions minimizes the importance of variation among observers and even variation by one observer on different days.

To minimize differences among observers, staff and volunteers will be trained by experienced observers by working together on collecting robustness data, including plant height, stem density and greenness before collecting similar data independently.

Vegetation Types and Extent

To document any changes in tidal marsh vegetation type (e.g., high marsh to low marsh transition), we will record sketch maps of tidal marsh vegetation zones at each fall site visit. Where deemed necessary in the field, positions on the boundaries between vegetation zones may be recorded using RTK GPS.

At all three sites, RTK GPS will be used to document the extent of *S. alterniflora* growing at the edge of the tidal flats, below each site's erosion scarp. Patches of vegetation will be documented by recording positions along the edge of live *S. alterniflora* patches approximately with a spacing between successive positions on the order of 3 to 5 meters. Intertidal *S. alterniflora* can be quite sparse, making it difficult to ascertain the exact boundary of a patch. The relatively wide spacing of measurements ensures that the focus is on delineating the general shape of the patch, and not mapping every wiggle of an uneven vegetation margin.

Structural integrity

Anchor or tie-in integrity

Many LS technologies are anchored to the shore or the sediment to prevent them from casting loose due to the forces impinging upon them due to waves or ice. Common methods for anchoring in muddy or sandy environments often stakes, bags, boxes, or cables. The physical integrity of anchoring elements is essential to the long-term stability of the structure.

On every site visit, we will manually check for play in the anchoring or tie-down elements of the LS structures, if any. A check of tie-down integrity will involve a visual check of the material integrity of the tie-down, and a manual check for lateral play in the tie-down element.

Results will be recorded in field notes. Structures showing signs of failure or excessive wear will be photographed.

Erosion and Scour around the Structure

At each site visit, we will search visually for scour around living shoreline structures, focusing attention on the ends of structural components and the faces of structures towards wave exposure. Signs of scour will include presence of scour holes or depressions in the sediment surface, and presence of different materials on the sediment surface adjacent to the structure. Any signs of scour will be documented in field notes and photographed.

Depending on the final design of structures, scour may also be documented by using strategically placed marker horizons (adjacent to likely locations for scour, or sequential measurements of elevation adjacent to the structures, as described already.

Location/position, dimensions, elevation, and stability of structure

Post construction of each living shoreline structure, we will permanently or semi-permanently mark specific structural components (like logs or rock) with nails, paint, or other marks (depending on the material). Large structural elements (like logs or root wads) will be marked at least two locations so that the structure's orientation in space can be reconstructed from the data on the position of the marker points. We will document movement or changes in dimension of the structure by measuring the position of those marks in subsequent site visits using RTK GPS.

For composite structures built of separate components, such as a log revetment, or a wave break constructed of oyster shell, we will use RTK GPS to measure the position of the rectangular envelope containing the structure by measuring the locations of two ends of the structure, two widest points, and the highest point. We will document both movement and changes in dimension of the structure by tracking the evolution of the envelope containing the structure, and with successive photographs.

Position of all marked points will be described in the field notes and documented by photographs. For each site, a list will be maintained of where marked points are located, to minimize the chances of a marker being overlooked. If the location of any designated point is not measured in subsequent site visits, a note will be added to the field notes explaining why.

Additional data on position of structures may be collected, or additional marked points on structures established may be added at the discretion of the field staff.

We will use photographs of the structure taken from standard positions to visually document changes in the structure or positions of its components. Automated cameras (time lapse photography) may be especially valuable for this purpose over winter months, when a majority of structural changes are anticipated.

Material integrity

On every site visit, field staff will assess the physical integrity of the materials of which the structure is composed. Principally this will involve a visual inspection of the structure, but if signs of deterioration are observed, it may also involve manual checks, such as poking at the structure with a knife, or testing the strength of shell fragments. Results will be recorded in the field notes.

Documentation and Records

Original paper data sheets and field notes will be stored at CBEP for a period of at least five years. Electronic records, including photographs, will be assembled by CBEP in a project-specific folder on the University of Southern Maine network computer drives. Records will be organized in folders by Living Shoreline Site, and by date of site visit when the data was collected.

Data will be shared with the Maine Coastal Program, TNC, and other project partners upon request, but it is expected that CBEP principally will share reduced versions of the data, rather than complete data archives with partners. The CBEP archive will be considered the definitive version of project data.

Matching Electronic Records with Field Notes

A principal challenge for data management for this project will be organization of digital photographs and RTK GPS positional data. Photographs and GPS-derived positional information must be correctly related to locations and observations described in field notes and data sheets. This process involves matching up information on the sequence and timing of photographs and observations of position with the sequence and timing of observations recorded in field notes and data sheets.

Photographs

Many digital cameras do not reveal filenames, making it difficult quickly to record image filenames in the field. This requires us to record information about each photograph (such as its content) as the photo is taken. Later, we align photos with monitoring tasks based on those field notes.

To facilitate this process, we will maintain a photo log each day in the field for each site we visit. We will record information in the log about each photograph taken. Data recorded includes a sequence number, the photographer, the purpose of the photo (which relates images back to data collection tasks), and a brief description of the image.

On each field data sheet, we record related photographs by writing down the sequence number of the image on the day's photo log, thus establishing a cross-referencing system.

Based on our experience in the field, we anticipate that not all photographs will be properly recorded in the log and on the data sheets. To check for and correct for inconsistencies, we review all photographs, data sheets, and images within one week of field work. Using the sequence of images, the image content, metadata recorded within each image file (including date and time, and with modern cell phones and CBEP's field cameras, GPS position and sometimes even compass direction), and our memory of site conditions, we complete a photo assignment list (example included in the Appendix) . This list is essentially a completed and double checked version of the field photo log, with all photos assigned a purpose, and fully described, and cross referenced to data sheets.

For photographs of smaller features, where background and context provide few clues about the content of an image (for example, with photographs of an eroding bank, or an exposed erosion pin), we will include a small white board or notebook in the image, on which is recorded relevant information in sharpie, dry erase marker, or similar dark ink.

RTK GIS Data

RTK data is automatically labeled with date and location, making it easier to properly assign electronic data to different purposes. However, the key way we will match RTK data with data collection goals or actions is by systematic use of "Codelists". Codelists allow one GPS unit to collect different types of data, keeping them organized in categories, and allowing collection of attribute data at the time the positional data is acquired (see details on use of the RTK units and Codelists in Appendix E).

Data will be transferred from the RTK unit to a desktop computer via a USB drive. Maine Geological Survey have developed a custom export format using Leica Viva SmartWorx software, which outputs pertinent data fields, including Point, Date, Time, Easting, Northing, Elevation (orthometric), Latitude, Longitude, Ellipsoidal Elevation, number of satellites, and signal quality. The data output is a raw text file that can be imported into other software, including spreadsheets, data analysis tools, and GIS. Data will also be stored on the RTK Controller on a micro SD card, until the success of the download has been confirmed.

Data Reduction

Positional data derived from field measurements other than RTK need to be converted from raw forms into appropriate three dimensional positions. We will run al related calculations in spreadsheets, which will be retained with project records.

Sample Handling and Custody Requirements

Most data collection described here do not involve collecting any samples, so no sampling handling and custody requirements are needed. The only exception is if we decide to collect surface sediment samples to document changes in sediment texture.

- Samples will be collected and immediately labeled with a unique identifier consisting of site abbreviation, date, and sample sequence number;
- The sequence number will be connected to a specific sampling location based on field collection notes.
- Samples will be returned to CBEP for preliminary processing (drying; milling if necessary) and packaging for shipping.
- Samples will be shipped to the University of Maine Soils Lab
- Results sent back to CBEP via Electronic Data Delivery, tagged by original sample ID.

Reports

CBEP staff will prepare annual monitoring reports and a final monitoring report at the end of the initial monitoring period required by permit agencies (probably five years).

Annual monitoring reports will include:

- Documentation of monitoring conducted and description of any changes in monitoring compared to site-specific monitoring plans;
- Tabular or graphical summaries of observations and data collection, supplemented by photographs where necessary;
- A discussion of lessons learned regarding monitoring practice; and
- Preliminary discussion of findings regarding effectiveness and longevity of "living shorelines" projects in Maine.

The final report will be similar, but will include more in-depth discussion of lessons learned and findings about performance of the demonstration projects.

Data Review

Most data we will collect will consist of qualitative information. Post-data collection review consists of reviewing field data sheets and field notes within one week of completing a site visit to ensure that notes are complete, clear, and properly recorded.

Aligning photographs with field notes can be complex, because most modern digital cameras assign file names sequentially, but do not display those numbers on the camera at the time images are recorded. All modern digital cameras, including cameras in cell phones, record date and time of each image in the image metadata. Where images are difficult to characterize based on content alone, the image metadata can help.

The most abundant quantitative data to be collected during site visits will be data derived from RTK GPS on locations of various structures. RTK data arrives in the laboratory as electronic records, and the principal risk is mislabeling or misattributing data collected for one purpose to another purpose. Data will be downloaded from RTK GPS units upon return from the field, and reviewed for outliers within 3 working days. Each RTK point will be loaded into GIS, plotted over site maps and aerial photographs, to confirm that its nominal position corresponds to its labelling. Questionable data will be flagged in derived data products with a comment explaining the reasons the data were considered problematic.

Other quantitative data, including approximate positions determined by leveling and triangulation, and characterization of the vegetation, will be treated similarly. All data sheets containing field-collected data will be reviewed within one week of collection to detect field transcription errors and omissions while memory of activities in the field are still fresh. Data entry will be completed within one month, and reviewed by a second person for accuracy. Data will then be reduced to a form that allows review of the data for obvious inconsistencies (such values outside a reasonable range). Data will be mapped or plotted to facilitate spotting of outliers. Problematic data will either be corrected (if a clear cause for the problem such as a transcription error can be identified) or flagged in derived data products with explanatory comments.

Continuous Improvement

Project leads work closely together and with seasonal staff and volunteers during data collection and data review. Senior staff demonstrate all procedures, observe work practices, and review products for completeness, legibility and accuracy. The approach we use is to emphasize the importance of data quality at every step from preparation for field work through note taking, data entry, data analysis and presentation. Any problems or misunderstandings are addressed as they crop up.

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Appendix A: Checklists, Data Sheets and Log Sheets

(See attached PDF Files)

All checklists, data sheets and log sheets have been drafted based on previous field experience, but at this point have not been tested in the field. As we gain experience with our Living Shoreline monitoring, data sheets may be modified to improve data collection.

Site Visit Checklists

These checklists are used to ensure that all required monitoring tasks are completed during principal annual field visits.

- *Fall Living Shoreline Field Checklist*
- *Spring Living Shoreline Field Checklist*
- *Storm-Event Living Shoreline Field Checklist*
  Used for both pre- and post-storm monitoring.

Data Sheets

These data sheets structure field data collection, minimizing the risk that field staff collect incomplete data .Datasheets may sometimes need to be supplemented with additional sheets to record additional detail (e.g., more data points than fit on a single sheet, or to provide space for a larger sketch map).

Data sheets as filled out in the field sometimes do not include all information needed for data entry. This typically happens because not all plants (or other organisms) can be identified in the field. Often, accurate identification or confirmation of identification requires work in the laboratory with collected specimens. When this happens, temporary descriptive names (e.g., "Unknown narrow-leaved sedge" or "Unknown grass") are used to allow preliminary data collection. Specimens are collected from sample locations or nearby, and labeled to identify where they were collected (site, transect, and plot). After samples are identified in the laboratory, corrected identification information is entered onto field data sheets. To ensure that we can determine which data was recorded in the field, and how the data was amended in the laboratory later, we record data in the field in PENCIL, and make any later corrections or additions in PEN. The original field-collected data is never erased, so the effect of these changes is always evident.

During data review, we sometimes also add

- *Invasive Species Inspection Form*
- *Erosion Pin Observations Data Sheet*
- *Sediment Strength Data Sheet*
- *Sediment Type and Grain Size Form*
- *Shore Cross Section Data Sheet*
- *Vegetation Transect Data sheet*
- *"Walkover" Marine Habitat Survey Cover sheet*
- *"Walkover" Marine Habitat Survey Detail sheet*
- *Wave Height and Period Data Sheet*

Log Sheets

Log Sheets gather information on data that has been collected electronically, principally GPS data and photographs, to facilitate QA/QC during laboratory review of field-collected data. Review of data will be completed within one week of completing field work.

- *GPS Log for Living Shorelines Monitoring*
- *Photo Assignment List*
  (For use in the laboratory for reconciling images with field data sheets)
- *Photo Log*
  (For use in the field for recording information on images as they are taken)

Appendix B: Equipment Specifications and Manuals for Estimating Position and Elevation

RTK Unit Specifications

Leica GS-14 receiver with a CS-15 controller, running Leica Viva SmartWorx software. Accuracy is principally controlled by the receiver (gs14) and the operating settings.

See attached PDF: Leica_Viva_GS14_DS.pdf

Stadia rod specifications: Crain SVR-25-Tenths, Model #98010

- 25 feet long, fully extended
- Measurements to the hundredth of a foot
- Six extendable sections

Automatic level specifications: Topcon AT-B3 Automatic Level

- 28x magnification
- Accuracy 1 km
- Double level run: +/- 1.5 mm
- Coarse sighting: Peep sight
- Weight: 3.75 lbs.
- Other Specifications: http://www.forestry-suppliers.com/Documents/1206_msds.pdf

Tape reel specifications: Keson English/Metric Open Reel Fiberglass Tape

- Graduated both sides meter/cm/2 mm; feet/tenths/hundredths other side

Appendix C: Hydrology & Conductivity/Salinity SOPs, Onset HOBO

Manufacturer:

Onset Computer Corporation

470 MacArthur Blvd.

Bourne, Massachusetts 02532

www.onsetcomp.com

1-877-564-4377

Manuals

- Onset HOBO U20 Water Level Logger: User manual available at: http://www.onsetcomp.com/files/manual_pdfs/12315-E-MAN-U20.pdf

- Onset HOBO U24 Conductivity Logger Manual: http://www.onsetcomp.com/files/manual_pdfs/15070-C-MAN-U24x.pdf

- Onset HOBO USB Micro Station Data Logger: http://www.onsetcomp.com/files/manual_pdfs/20874-C%20MAN-QSG-H21-USB.pdf

- Onset Smart Barometric Pressure Sensor: http://www.onsetcomp.com/files/manual_pdfs/12291-F%20MAN-S-BPB.pdf

Software:

- HOBOWare User's Guide Available at: http://www.onsetcomp.com/files/manual_pdfs/12730-W%20HOBOware%20User's%20Guide.pdf

- HOBOWare Pro Barometric Compensation Assistant User's Guide: http://www.onsetcomp.com/files/manual_pdfs/Barometric-Compensation-Assistant-Users-Guide-10572.pdf

- HOBOWare Pro Conductivity Assistant User's Guide: http://www.onsetcomp.com/files/manual_pdfs/Conductivity-Assistant-Users-Guide-15019.pdf

Cleaning:

Onset Product Cleaning Reference Guide: http://www.onsetcomp.com/files/manual_pdfs/15667-D-Product-Cleaning-Reference-Guide.pdf

Deployment:

National Park Service report: Continuous water level data collection and management using Onset HOBO data loggers: A Northeast Coastal and Barrier Network methods document. https://irma.nps.gov/DataStore/DownloadFile/563851

Appendix D: USFWS Marker Horizon SOPs

USFWS Marker Horizon SOPs are in the following publication. See SOP 5: Establishing and Sampling Marker Horizons. Much of the discussion outlies methods for cryocoring (using liquid nitrogen to quickly freeze sediments to collect an uncompressed core), which is beyond the scope of the current study. We will use the simpler if less precise methods of cutting sediment plugs described on page SOP 5-29.

https://irma.nps.gov/DataStore/Reference/Profile/2225005

Appendix E: RTK GPS Manuals, SOPs

Real Time Kinematic Global Positioning Systems

Strictly speaking , the positioning devices we will use are no longer correctly termed “GPS receivers”, since they are capable of collecting positional data based on signals from several different satellite navigation systems, not just the US Global Positioning System (GPS) The correct term is (GNSS), for “Global Navigation Satellite System.” However, we will continue to use the acronym (RTK GPS for convenience.

“Real Time Kinematic” GPS refers to a technology that improves accuracy of estimated positions to the centimeter range. It is a sophisticated generalization of “differential GPS” technology, in which estimates of the position of one GPS receiver (the “rover”) is enhanced by knowing properties of the GPS signal received by a nearby receiver at a known, fixed location (the “base station). RTK technologies further improve accuracy by incorporating not only the digital content of the GPS signals, but also the phase of the carrier wave. This allows much more precise estimation of position.

Manufacturer

Leica Geosystems Inc.

5051 Peachtree Corners Circle #250

Norcross, GA 30092

(800) 367-9453

https://leica-geosystems.com/en-us/

Models

Primary Equipment: Leica GS14 with CS15 Controller

Maine Geological Survey has two Leica GS14 “Smart Antennae”, with the CS15 controller, running Leica SmartWorx Viva software. All data quality estimates in the QAPP assume these instruments are used.

Backup Equipment: Leica GS16 using the CS20 Controller

When MGS equipment is not available, CBEP may rent similar equipment from Maine Technical Source (“MTS”, with offices in in Yarmouth, Maine). MTS rents Leica Geosystems units, principally the GS16, with the CS20, running Leica’s Captivate field software. Methods are similar, but not identical, and performance is similar or better than achievable with the MGS equipment.

We do not provide full manuals and SOPs for the backup equipment here, as (a) exact equipment may vary, depending on availability, and (b) operation of all Leica Geosystems GNSS systems are similar. If we do use rental equipment:

- Field staff will be fully trained by MTS on correct operation of the devices;
- We will practice collecting mock positional data outdoors, and confirm that data collection was successful before we collect real data;

- We will carry forward all RTK GPS data quality assurance practices (data dictionaries, field checks on nominal data quality, retaining field data quality maintenance of data quality metrics, rejection of points with insufficient accuracy, etc.).

MTS provides a useful "quick start" guide for their equipment at:

http://blog.mainetechnical.com/wp-content/uploads/2017/11/Leica-MTS_GS16CS20-DC-Network-RTK-Rover-Quick-Setup-Steps-Rev1.2.pdf

Manuals

Leica Geosystems' business model places most manuals and related materials behind a paywall. Access to most materials requires an account, which is tied to equipment serial numbers, making things inconvenient for users of borrowed or rented equipment. Maine Geological Survey shared an electronic copy of a manual for their equipment, and we have assembled copies of other relevant manuals from equipment sales and rental company web sites.

See Attached PDF files:

- Leica_Viva_GNSS_Getting_Started_Guide.pdf
  Written for general use, some information, like physical set-up, emphasizes other models of receivers and controllers. This manual contains the best description of operation of the software in the field.
- Leica GS14 User Manual.pdf
  Provides information on equipment set-up and operation for the GS14 "smart antenna" GPS receiver. Since the receivers are controlled indirectly via the CS15 Controller, this manual is of most use for describing equipment set-up and configuration of the Receiver.
- Leica_Viva_CS10_CS15_User_Manual.pdf
  This manual contains the best information on physical management of the CS15 controller, such as charging batteries, installing a memory card, or connecting to a PC for data transfer. Additional helpful information is available here: https://helpdesk.microsurvey.com/index.php?/Knowledgebase/Article/View/1298/149/leica-cs15-to-pc-connection-with-usb-cable
- Leica Viva TechRef_en.pdf
  This manual provides technical details about the Viva software and hardware.

Software

For MGS Equipment

Leica SmartWorx Viva Field Software

Convenient summaries of the software are included in the manuals. The most useful summary is included in

- Leica_Viva_GNSS_Getting_Started_Guide.pdf

Although the manual refers to other models of Leica receivers and controllers, Section 2 focuses on the software, which is similar on all Leica systems on which it is installed, including the MGS GS14/CS15 equipment.

For MTS (Rental) Equipment

Leica Geosystems Captivate Software

While more complex and more capable than SmartWorx Viva, this software was designed with a similar user interface, which will simplify training and set-up for staff with prior experience on the MGS devices.

User Training

All field staff will be fully trained on operation of the devices. We will practice collecting mock positional data outdoors, and confirm that data collection was successful before we collect real data.

Standard Operating Procedures

SOPs described here provide an overview of data collection best practices using the GS14/CS15 equipment provided by the MGS.

Pre-Deployment Steps

Check Battery levels

Both the GS14 and the GS15 run on either internal or external batteries, and are expected to provide over 10 hours of continuous operation on a single charge, but only if the devices are fully charged before we deploy.

Confirm Presence of Memory Card(s)

Both the CS15 and the GS14 can optionally store data on on-USB drives or board memory cards. We plan to use SD cards principally for data backup.

It is essential that a memory card is inserted into the controller before field work begins. The SD card is inserted into a slot inside the top of the CS15. Instructions for installing an SD card from the manual

- Leica_Viva_CS10_CS15_User_Manual.pdf

Are as follows:

1. Refer to "Fixing the slot cover to the CS step-by-step". Loosen the screws inside the slot cover on top of the CS10/CS15 using the screwdriver end of the stylus.
2. Detach the slot cover from the CS10/CS15.
3. Slide the card firmly into the slot until it clicks into position. Do not force the card into the slot.
4. The card must be held with the contacts facing the slot.
5. Attach the slot cover and tighten the screws.
6. To remove the card, detach the slot cover of the CS10/CS15.
7. Gently press the top of the card to release it from the slot.
8. Remove the SD card and attach the slot cover.

Set up a Codelist

Leica SmartWorx Viva Field Software uses the concept of a “Codelist” to organize data collection in the field. Codelists provide away to specify what types of data are being collected, and ensure that any necessary ancillary data is entered onto the instrument keypad when positional data is generated. Codelists can either be generated on a PC running Leica’s Geo Office software, or created on the CS15 Controller, as described here.

For information on setting up a codelist on the CS15 Controller, see

- Leica_Viva_GNSS_Getting_Started_Guide.pdf section 3.2, Page 97

We will use Code Lists to minimize risk of forgetting to collect ancillary data or misattributing position data.

Our Code Lists will contain a data code for each type of high resolution location data we collect. While the detailed code list may evolve as we gain experience with monitoring, the proposed Code List is as follows:

Creating the Codelist

1. From the Main Menu, select Jobs & Data and press OK.
2. Select Job properties from the Jobs & Data menu and press OK.
3. Press Page to change to the Codelist page.
4. Tap on the selectable list to open the Codelists screen.

If an existing Living Shoreline Codelist is already listed, you do not need to create a new one or edit the existing one.

5. If you need to create a new Codelist, press New...
6. Type in a Name for the new Codelist. For Spring Site Visits, name it “LSSPRING”, For Fall, call it “LSFALL”. For Storm event sampling, name it “LSSTORM”, depending on which type of monitoring you are conducting. (Description and Creator are optional).
7. Press Codes... to open the Codes screen.

You will need to create a separate Code for each type of data you plan to collect.

Category	Code	Description	Attributes	Code Type	Linework
Topographic Survey	TOPO	Topographic	None	Point	None
Cross Section Elevations	CROSS	Cross Section	Transect ID (number)	Line	Line
Position of Scarp	SCARP	Scarp	None	Line	Line
Marked Features of Structure	STRUCT	Structure	MapCode (String) Description (String)	Point	None
Deposition Points	DEPO	Deposition Point	MapCode (String)	Point	None
Scour Points	SCOUR	Scour Point	MapCode (String)	Point	None
Vegetation Boundaries	VEG	Vegetation	VegType (String)	Area	Area

a. Press New.. to create a new code.

i. Type in Code and Description, as shown in the table above

ii. Code Groups are a convenience feature to more readily associate related data, such as linking locations of electrical poles with the location of electrical wires. We will not use any code groups. You should leave the Code Group Blank.

iii. Enter the Code type,(Point) and the Linework (None) From the table, above

iv. Attributes allow you to record related information in the field, and include it in the data exported from the RTK system. Data entry on the handheld device can be slow, so we will use it only to record information that can disambiguate what data we were collecting, such as the from Create an attribute as called for, above.

v. Press Store to save the new code.

vi. Press OK to return to the New Codelist screen.

Select CORS network

Maine DOT maintains a state-wide CORS (Continuously Operating Reference Station) network, with CORS base stations located on Gorham and Brunswick, providing excellent coverage for most of Casco Bay. Data is collected at one second intervals. MaineDOT CORS data is provided free of charge to users who have a Login and Password via cell phone modem. Maine Geological Survey has such a password, and their equipment is set up to receive the Maine DOT signals by default. MGS also has access to Leica's SmartNet North America CORS network for one of their receivers.

Maine Technical Source provides summaries of how to connect to a real time CORS network via a cellular modem, both for the SmartWorx Viva and Captivate software.

- Connecting to MassCors, via SmartWorx Viva (for MGS instruments):

  https://blog.mainetechnical.com/2015/03/30/ma-cors-network-access-with-viva/

- And for New York, using the Captivate software (For MTS Instruments):

  https://blog.mainetechnical.com/2017/11/21/quick-guide-for-new-york-cors-setup-using-leica-gs16-with-cs20-data-collector/

During Deployment (Field Procedures)

Ordinarily, we will configure the RTK GPS unit (or units) as a “rover”, connected to the Maine DOT CORS network via cellular modem. Once we have collected RTK GPS data at each of our sites once or twice, we will have a good idea of which categories of positional data can be collected using CORS corrections via cell phone. Where cell phone reception is poor, but satellite reception and geometry are acceptable, we may set up one unit as a “base station”, and the second as a “rover”, connecting the two via a direct radio link. Where satellite reception or geometry are poor, however, we will revert to our alternative methods (optical level and tape measures).

To avoid collecting low-quality RTK data, the receivers will be configured to reject points unless there is an active RTK (corrected) fix, and also reject points with estimated less than 10 cm accuracy.

Equipment Set-up

Equipment set-up is straight forward, once you are familiar with the configuration of the equipment. Details are provided in the manuals, see especially:

- Leica GS 1416 User Manual.pdf

As a Data Rover

Equipment is configured as a Rover (on a pole) if it will be used principally to collect multiple positions on a site. This is the most common equipment configuration. Set-up consists principally of assembling the GS14 on a pole mount, and turning the GS14 Receiver and CS15 Controller on in the proper order, and waiting for the two instruments to establish a Bluetooth connection.

(See Leica GS 14 User Manual.pdf, Section 4.1.3, Page 26)

Step by step instructions, modified from the manual:

1. Attach the GHT62 holder to the pole.
2. Insert the SD card or CompactFlash card and the battery into the CS15 field controller.
3. For real-time setup with radio: Attach the CGR radio to the CS field controller.
4. Clip the CS field controller into the holder and lock it by pushing the locking pin into the locked position.
5. Press ON/OFF button on the CS field controller to switch on.
6. Insert the data storage device and the batteries into the GS14.
7. Press ON/OFF button on the GS14 to switch on.
8. Screw the GS14 to the top of the pole.

9. CS field controller and GS14 are connected via Bluetooth.
    a. As a connection is established, the Bluetooth LED on the GS14 receiver should change from GREEN (waiting for a connection) to BLUE (Connection Established)

As a Real Time Base Station

Equipment is configures as a base station (on a tripod over a local benchmark) if it will be left in place while another unit is used to collect positional data. This configuration is used when the cell phone signal is inconsistent, making it impractical to use CORS data to provide real time correction. Deployment must be over a well characterized benchmark, within radio communication distance, but it need not be immediately adjacent to the field site.

(See Leica GS 14 User Manual.pdf, Section 4.1.2, Page 23)

Step by step instructions, modified from the description in the Manual are as follows:

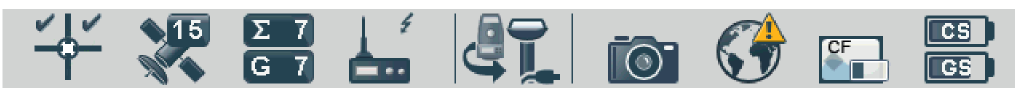
1. Set up the tripod.
2. Mount and level the tribrach on the tripod. The “Tribrach” is the leveling device mounted on top of the tripod.
3. Ensure that the tribrach is over the benchmark.
4. Place and lock the carrier in the tribrach.
5. Insert the data storage device and batteries into the GS14.
6. Press the ON/OFF button on the instrument for at least 2 s to switch on the instrument.
7. Screw the GS14 onto the carrier.
8. Check that the tribrach is still level.
9. Insert the SD card and the battery into the CS15 field controller.
10. Connect the CS field controller to the instrument if necessary.
11. To hang the CS field controller on the tripod leg, use the hook on the hand strap. Refer to the CS15 User Manual
12. Insert the height hook into the carrier.
13. Measure the antenna height using the height hook.
14. Press the ON/OFF button on the CS15 for at least 2 s to switch on the instrument.

In the Field

The screen immediately after start-up looks as follows:

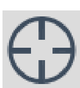
The top row shows status icons. Understanding these icons is important for maintaining data quality, as they indicate whether the system cannot record high-quality positional information.

A B C D E F G H I

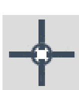


a) GNSS position status

Displays the status of the current position.

 Autonomous (not corrected) position available. Under these conditions, positions are accurate to a few meters, little or no better than would be available using a consumer grade hand-held GPS. Survey data should not be collected when this version of the icon is visible. Position LED on the GS14 should be YELLOW.

 An RTK "Float" position is available. Resolution likely to be on the order of ¼ to ½ meter. Survey data should not be collected when this version of the icon is visible. Position LED on the GS14 should be Flashing GREEN

 An RTK "Fix" is available. The Position LED on the GS14 should be SOLID GREEN, indicating a reliable, survey-grade position is available. Data collection can begin.

b) Number of visible satellites

This shows the number of satellites that are theoretically visible, based on their geometry in the sky, it does not show the actual number of satellites that are detected. Satellites can be blocked from view due to hills or trees.

c) Number of satellites contributing to position solution.

A minimum of four satellites are needed to establish a position. Accuracy can be improved with additional satellites.

d) Real-time device and real-time status

Is a real time device connected, and if so, how (radio send/receive or Wi-Fi)?

e) Current active instrument

f) Camera

Turns internal device camera on. Useful for geotagged images.

g) Internet online status of CS field controller.

This tells whether the controller is connected to the internet via cell phone modem. An internet connection is essential for calculating RTK positions. Data should not be connected if a yellow warning triangle appears on this icon. Position quality degrades rapidly (in tens of seconds) in the absence of a connection.

h) Memory storage

Indicates whether data is being recorded internally, or to a removable device, such as an USB drive or SD card.

Indicates data is being stored on an SD card.


Icons allows access to data management pages for Points, Lines, or Areas.

Data Download

Data from the GS14 and CS10 are stored directly on an SD card, a “Compact Flash” card, or a USB drive. He USB drive provides the most convenient path to data download. Internal SD cards provide the potential for data backup.

Appendix F: Maine DMR "Walkover Survey" of Marine Habitats

Protocol Description

(From Draft Method as of 2/15/2019, received from Denis Marc-Nault via e-mail, May 3, 2019.)

(We use a more detailed data sheet than DMR, configured for our needs. See appendix A.)

(Original document reformatted, with some headers added for inclusion here.)

DMR Shellfish Management Program

Intertidal Walkover Survey

Intertidal walkover surveys are designed to provide a qualitative overview of intertidal habitat types, as well as species composition of shellfish and shellfish predators. Shellfish harvesting activity is also noted. The procedure is supposed to provide a total biological assessment of the survey area.

Prior to heading out in the field to conduct the walkover, review a map of the area to be surveyed. Review the pollution closure status of the location. Notify Marine Patrol if you will be working in an area closed for public health reasons.

Equipment needed for walkovers:

Survey box; GPS; camera; clam hoes; clipboard/pencil/field sheet; bucket (potentially tablets for data entry in the field?)

Definition of Abundance Categories

Species composition is defined using relative abundance categories. The general definitions for each are as follows:

<u>Absent:</u> Physically absent from the area surveyed.

<u>Occasional:</u> A limited number of animals/plants detected only after close and thorough investigation (turning over rocks/mud, picking up algae) of the habitat. Animals/plants may occur in small (< ½ sq. ft.) patches or clumps throughout the zone. Not found repeatedly in large numbers.

<u>Common:</u> Readily detected with little investigation, but not visually obvious. Readily found repeatedly throughout the habitat. Occurring in numerous patches throughout the zone.

<u>Abundant:</u> Visually obvious throughout the area surveyed with no disturbance of habitat or limited disturbance of specific microhabitats (under rocks or rockweed). Having a high abundance compared to other fauna and flora.

To complete the field survey sheet:

1. Walk through the survey area and note the locations of all dominant habitat types. Take photos and/or mark areas on a map.
2. Search through each of the intertidal zones: high, mid, and low. Record the species observed on the surface and their relative abundance.
3. Using a clam hoe, turn over sediments throughout each of the intertidal zones: high, mid, and low. Identify to species and estimate relative abundance. Note relative proportion of clams > 2" vs < 2".

4. Record other observations such as presence/absence of worm holes, clam holes, harvesting activity.

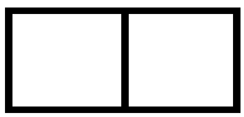
Walkover surveys are completed during the best available low tide between early spring and late fall.

Quantitative Sampling (If necessary)

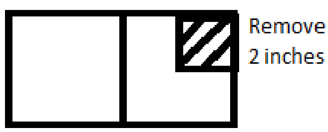
For some survey areas, quantitative sampling may be warranted. Use the following guidelines for collecting data in 1’ x 2’ plots. Digging of the plots follows the Clam Population Survey methodology:

1. The survey box should be dropped to the ground in a random fashion, making no effort to place the survey box on a visible concentration of clams.

2. The plot is outlined by pressing the survey box into the flat two times so that the total sample area is two square feet in size.



3. Spat collection (less than 10 millimeters): to specifically sample spat, remove sediment from one-eighth of the plot to an estimated depth of 1-2 inches.



4. Place the sediment in the screened survey box and sieve the sediment with water. Count and record the number of spat on data sheet.

5. Prior to digging the plot, clean the sediment away from the outside of one of the edges of the plot to make access to the plot easier.

6. The digger should make every effort to retrieve every clam in each plot. Be sure to dig deep enough to ensure no clams are left behind (at least 8”). Clams falling outside of the plot boundaries do not get counted and measured.

Sampling Design

Use the following guidelines for determining how many plots to sample:

1. Area > 1 acre: collect data at three plots/intertidal zone/acre (9 total)

2. Area between ½ acre and 1 acre: collect data at two plots/intertidal zone (6 total)

3. Area < ½ acre: collect data at a minimum of three plots, one per intertidal zone (3 total)

4. For extremely large survey areas, a greater number of samples may need to be collected.

Timed or transect sampling of green crabs may be conducted at some locations.