A Strategy for Developing a Salt Marsh Monitoring and Assessment Program for the State of Rhode Island

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March 1, 2016




Acknowledgements

This document was prepared by the Narragansett Bay National Estuarine Research Reserve (NBNERR) and Save The Bay in cooperation with the RI Coastal Resources Management Council (CRMC). Consistent with its mission to "preserve, protect and restore coastal and estuarine ecosystems of Narragansett Bay through long-term research, education and training," the NBNERR has historically been at the forefront of long-term research and monitoring of the state's salt marshes. As a proponent and facilitator of community-based salt marsh restoration for almost two decades, Save The Bay is a leading authority on anthropogenic impacts to salt marshes. As the state coastal zone management agency, the CRMC relies on sound science to promote "the preservation, protection, development and where possible the restoration of the coastal areas of the state," and supports long-term monitoring efforts that will help to inform its resource management decisions.

Preparation of this document was supported in part with funds from a federal Wetlands Program Development Grant provided by the United States Environmental Protection Agency pursuant to the Clean Water Act and made available through the RI Department of Environmental Management. Development of the strategy was coordinated with the Rhode Island Environmental Monitoring Collaborative (RIEMC), which identifies environmental monitoring priorities for the state of Rhode Island, establishes statewide environmental indicators, and works to provide the public and elected leaders with a deeper understanding of the status of Rhode Island's environment and natural resources. The RIEMC brings together stakeholders from executive agencies, university-based programs, non-governmental organizations, and others to enhance coordination and collaboration. The data compiled by the RIEMC informs sound environmental management decisions and provides insight for how to best prepare for the escalating impacts of climate change on our natural resources.

In addition to its authors, many individuals provided valuable input to the development of this strategy. The authors would like to thank the following individuals for their contributions:

Mike Bradley, URI-Environmental Data Center
Amanda Freitas, RI-DEM
Andrew Neil, URI-Environmental Data Center
Suzanne Paton, USFWS
Scott Rasmussen, URI-Environmental Data Center
Courtney Schmidt, Narragansett Bay NEP
Mark Stolt, URI
James Turek, NOAA Restoration Center
Elizabeth Watson, Drexel University

Executive Summary

Tidal salt marshes are valuable coastal habitats that provide a wide array of ecosystem services, including shoreline protection, provision of fish and wildlife habitat, water quality improvement, and carbon sequestration. However, the majority of Rhode Island's salt marshes have been negatively impacted by human activity and exhibit signs of degradation due to a variety of stressors, which have been further exacerbated by the effects of climate change. Extensive research and monitoring throughout Rhode Island salt marshes has provided insights into their ecology, condition, impacts from stressors, and response to management and restoration actions. However, given the apparent acceleration in the degradation of the state's salt marshes in recent years and their importance to the overall resiliency of the RI shoreline, there is an urgent need for more information.

This document represents a collaborative effort to improve long-term salt marsh monitoring in Rhode Island and presents a strategy for developing a comprehensive statewide monitoring and assessment program. The proposed Salt Marsh Monitoring and Assessment Program (SMMAP) is a three-tiered framework for application in assessing changes in salt marsh condition, spatial extent, and community composition over space and time. Tier 1 involves a statewide, landscape-scale analysis based on automated classification of aerial imagery. Tier 2 involves the development of a rapid assessment protocol that would be implemented annually at a subset of marshes throughout RI. Tier 3 would build upon the existing Narragansett Bay National Estuarine Research Reserve's Sentinel Sites Program to carry out more intensive monitoring at a smaller subset of 6 to 8 sites throughout RI. Tier 3 metrics would also be developed for use in monitoring specific projects and management actions, such as enhancing marsh drainage networks or beneficially reusing dredged material to build marsh elevation. The results from this monitoring and assessment program will be used to evaluate the overall status and condition of RI's salt marshes, track changes over time, evaluate management outcomes, and prioritize areas where resources should be directed towards management actions.

1. Introduction

Rhode Island's tidal salt marshes provide a suite of ecosystem services including shoreline protection (Gedan et al. 2011; Shepard et al. 2011), nutrient and pollutant filtration (Valiela and Cole 2002), carbon sequestration (Mcleod et al. 2011; Kirwan and Mudd 2012), and habitat provision for fish and wildlife (Roman et al. 2000; Raposa and Roman 2001; Hanson and Shriver 2006; McKinney and Wigand 2006). These and other functions, however, are often compromised by historic human impacts such as marsh filling, mosquito ditching, and tidal flow restrictions. These historic impacts are further compounded by current and ongoing threats including eutrophication, climate change, herbivory, crab burrowing, invasive species, and sea-level rise (Bertness et al. 2002; Bertness et al. 2014; Watson et al. 2014; Raposa et al. in press).

It is estimated that RI has already lost 53% of its original salt marsh habitat due to human activities (Bromberg and Bertness 2005), and current research indicates that most marshes in RI are highly susceptible to impacts (including submergence) from accelerating rates of sea-level rise (Watson et al. 2014). In fact, evidence is mounting that RI's salt marshes are already degrading rapidly in response to sea-level rise, herbivory, and possibly other stressors. For example, research now indicates that 1) the area of RI salt marshes is declining over time (Berry et al. 2015), 2) the salt meadow foundation species *Spartina patens* is being replaced by *S. alterniflora* as sea levels rise (Donnelly and Bertness 2001; Raposa et al. in press), 3) salt marshes closer to the mouth of Narragansett Bay are lower in elevation and have proportionally more low marsh vegetation than upper Bay marshes (Cole Ekberg et al. 2015), and 4) marsh accretion rates are far lower than recent and anticipated future rates of sea-level rise (Carey et al. in press). Additional changes are being observed more frequently throughout the state, including high marsh ponding and vegetation die-off, creek-bank vegetation dieback, marsh bank erosion and channel edge calving, an increase in channelization and drainage features, increased crab burrowing and grazing, and *Fusarium* spp. fungal infections. Clearly, salt marshes in RI are showing multiple signs of continuing degradation due to sea-level rise and other potentially synergistic stressors. In order to better understand the individual and cumulative effects of these stressors on marsh structure and functions and to make marsh condition inferences necessary to inform adaptation activities, standardized monitoring and assessment protocols and data are needed to elucidate patterns across multiple sites and studies. State environmental agencies and partners have identified the need for developing a comprehensive and robust statewide monitoring and assessment program to help resource managers and restoration practitioners address marsh resiliency in the face of multiple stressors.

Researchers have been studying and monitoring RI's salt marshes for decades to better understand their ecology, impacts from anthropogenic and natural stressors, and condition. Much of this monitoring was (and continues to be) conducted in an ad hoc fashion, over relatively short time-scales (generally 2-5 years), and usually in association with specific tidal restoration projects, e.g., Sachuest Point (Roman et al. 2002), Galilee (Myshrall et al. 2000), and Potter Pond (Raposa 2008). Even now, multiple agencies continue to develop and use their own salt marsh monitoring and assessment programs, with little thought given to coordinating activities at the statewide level. These include the Narragansett Bay National Estuarine Research Reserve's (NBNERR) Sentinel Sites Program (NERRS 2012a), the US Fish and Wildlife Service's Salt Marsh Integrity assessment (Neckles et al. 2013), the Narrow River Salt Marsh Adaptation Monitoring Plan (Ferguson and Cole, unpublished manuscript), and the Rhode Island Salt Marsh Assessment (Cole Ekberg et al. 2015), among others. Monitoring clearly needs better coordination at the statewide level and over a longer period of time in order to document and understand how the condition of RI's salt marshes is changing spatially and temporally. As climate change is also affecting marshes beyond RI's borders, data compatibility with regional and national datasets would further allow researches and managers to analyze RI salt marsh response to sea-level rise and other stressors in a broader regional or national context.

Because RI salt marshes are exhibiting signs of degradation from accelerating sea-level rise and other stressors, a comprehensive strategy is needed to improve the coordination of long-term salt marsh monitoring. To this end, the RI Coastal Resources Management Council (RI CRMC), the Rhode Island Department of Environmental Management (RIDEM), NBNERR, and Save The Bay (STB) have secured input from researchers and coastal resource managers to develop this salt marsh monitoring and assessment strategy, which will guide the development of a statewide Salt Marsh Monitoring and Assessment Program (SMMAP). The SMMAP will facilitate coordinated ecological salt marsh monitoring throughout the state of RI in order to document spatial and temporal patterns in salt marsh conditions and help inform restoration, adaptive management, and prioritization of salt marsh management projects, statewide. The SMMAP will establish standardized protocols for salt marsh monitoring, assessment, data formatting, and data archiving, and will initiate and maintain a long-term salt marsh monitoring and assessment dataset for the state. Data collected according to the SMMAP will also be compatible with established regionally and nationally-implemented programs. When completed, the SMMAP will serve as a component of the broader RI Environmental Monitoring Collaborative Monitoring Strategy.

2. Objectives and Monitoring Questions

Coupling long-term quantitative monitoring with shorter-term, discrete research projects can provide an understanding of how RI salt marshes are changing over time in response to both natural and anthropogenic drivers. Considerable short-term research examining the effects of climate change (Gedan and Bertness 2009), sea-level rise (Donnelly and Bertness 2001), eutrophication (Wigand et al. 2003), herbivory (Bertness et al. 2014), and other stressors has already been conducted in RI marshes. Salt marsh monitoring is also extensive in RI, but it is generally driven by organizational needs and agency-specific programs rather than by a coordinated effort at the state level. This lack of statewide coordination makes it difficult to understand how RI marshes are collectively responding to major agents of change because protocols may differ among projects and there is no formal framework for data sharing, archiving, and comparison. The development and adoption of the SMMAP will help address these issues.

The SMMAP will be used to better integrate and coordinate existing large-scale marsh monitoring programs and to integrate shorter-term monitoring associated with specific restoration or adaptation projects. In RI, multiple marsh restoration/adaptation projects are currently underway, including projects to increase drainage through shallow creek or runnel excavation, projects to increase marsh elevations through dredge material deposition, and integrative projects to restore the salt marsh structure and function through a variety of techniques. If these and all future projects used the same or complementary monitoring protocols and standardized methods, analyses could be conducted across projects, time, and space to provide researchers and managers with a broader understanding of how RI salt marshes collectively respond to restoration and adaptation efforts. As possible, consistency with nationally and regionally-implemented protocols, such as the NERRS Sentinel Site and System-wide Monitoring programs (http://nerrs.noaa.gov/research/), and the Salt Marsh Habitat and Avian Research Program (SHARP; http://www.tidalmarshbirds.org/) will allow for direct comparisons with national or regional salt marsh monitoring data. The SMMAP will also integrate with an ongoing effort to develop a Coastal Wetland Restoration Strategy for the State of Rhode Island (Chaffee et al. in prep.) to ensure that monitoring data can inform adaptive salt marsh management in the most efficient and effective way possible.

The primary objectives of the SMMAP will be to:

1. Provide a tiered framework for assessing condition and monitoring changes in RI salt marshes over space and time;
2. Establish standardized protocols for salt marsh monitoring, assessment, data formatting, and data archiving that will be used to compile long-term datasets for the state;
3. Enhance coordination of salt marsh monitoring and assessment activities throughout the state to facilitate an increased understanding of patterns of salt marsh change and conditions at a statewide scale;
4. Promote compatibility of protocols and data with regional and national programs to facilitate analysis in a broader spatial context;
5. Identify monitoring and assessment needs;
6. Produce, distribute, and apply a set of user guides that outline tested, standardized protocols to address specific monitoring and assessment needs.

Currently identified monitoring and assessment needs include:

1. Identify major gaps in monitoring data;
2. Assess marsh conditions and change over time;
3. Help direct funding to priority monitoring efforts and required equipment;
4. Identify specific marshes that are in need of restoration or adaptive management;
5. Provide a means for better understanding of how salt marshes respond to specific restoration and adaptation projects;
6. Provide a means for better understanding of how salt marshes will respond to ongoing changes in climate and accelerating rates of sea-level rise;

7. Develop, test, and implement a marsh migration monitoring protocol;
8. Quantify rates of marsh migration and assess the functions and values of marsh migration areas;
9. Assess the accuracy and utility of the recently completed RI Sea Level Affecting Marshes Model (SLAMM) project results;
10. Evaluate the performance of restoration and intervention actions.

Examples of some specific questions that may be addressed with consistent and coordinated monitoring through the SMMAP include:

1. How fast is the salt meadow *Spartina patens*-dominated community being replaced by the more flood tolerant *Spartina alterniflora*?
2. Is this plant community conversion rate uniform across the state, or does it vary with tidal range and/or elevation?
3. Can any geomorphic changes to RI salt marshes be attributed specifically to eutrophication and/or sea-level rise?
4. How fast is creek-bank vegetation loss occurring in RI salt marshes, and what are the causes?
5. What are the relationships among resident crab populations, changing salt marsh habitats, climate-related stressors, and other factors?
6. What are the ecological responses of salt marshes to adaptive management projects (e.g., increasing drainage, increasing elevation using dredged materials)?
7. How rapidly are salt marshes transgressing into adjacent upland and freshwater wetland habitats, and what factors are affecting this rate?
8. How will marsh migration affect ecosystem services, including habitat use by fish and wildlife, carbon sequestration, nutrient uptake, shoreline stabilization, etc.?
9. How do the results of the RI SLAMM project compare with field assessments of marsh migration opportunity?

To address these objectives, management needs, and research questions, the SMMAP will consist of three conceptual tiers for monitoring salt marshes in RI (Table 1), following the successful strategies developed for freshwater wetlands and submerged aquatic vegetation (USEPA 2006; Neckles et al. 2012). The first tier of the SMMAP will focus on landscape-scale analysis of wetland conditions, aiming to quantify changes in marsh extent and community distributions over time, including landward marsh transgression and seaward edge erosion. Tier 1 is intended to provide coarse but reliable information on marsh conditions over a broad spatial area with a relatively small investment of money and time per assessed unit area. An initial step in developing this tier will be the testing of a landscape-scale method of classifying and mapping salt marsh habitat types and overall marsh extent throughout all of coastal RI. The method will use aerial photographs and a semi-automated classification procedure that is currently under development at NBNERR with funding from the RI Coastal and Estuarine Habitat Restoration Trust Fund. If the initial mapping project is successful (i.e., accuracy is sufficient to reliably classify habitats and detect community changes over time), landscape-scale habitat maps could be generated every 3-5 years in conjunction with ongoing eelgrass and other submerged aquatic vegetation (SAV) mapping in RI.

Successful maps will provide insight into how the habitat composition and overall area of marshes are changing over time throughout the state.

Table 1. The three tiers of the Rhode Island SMMAP.

Tier	Description	Frequency	Spatial extent
1	Landscape-scale marsh habitat mapping	3-5 years	Statewide
2	Salt marsh rapid assessments	Annually	~40 marshes statewide (a subset is assessed each year)
3	Intensive site monitoring	Annually, and as needed for restoration/adaptation projects	6-8 marshes statewide and specific individual marshes

The second tier of the SMMAP will focus on further developing and testing a rapid assessment method for efficiently characterizing and assessing the condition of salt marshes. Rapid assessment is intended to provide useful observational or quickly-measured data to characterize the type and condition of a marsh with a single site visit and desktop analysis, not requiring more than one day per marsh (USEPA 2006). Rapid assessment data can be validated against known measurement data to provide a decision-support and analysis tool that can reliably classify the conditions of individual marshes for prioritization, research, or other needs. Two rapid assessment methods have been tested in RI. These include the New England Rapid Assessment Method (NERAM; Wigand et al. 2011) and the Rhode Island Salt Marsh Assessment (RISMA, Cole Ekberg et al. 2015), but these methods are insufficient to characterize current conditions. To facilitate analyses of marsh condition, vulnerability, and resilience, a rapid assessment method needs to capture the effects of all potential stressors (e.g., disturbances, sea-level rise, eutrophication, landscape stressors, grazing). Additionally, the rapid assessment should include easily-attainable, relevant classification information to categorize salt marshes and further facilitate analysis. When completed, Tier 2 will be capable of providing annual rapid, on-the-ground assessments of numerous marshes in RI, while also providing ground-truthing information for Tier 1 assessments.

The third tier of the SMMAP will focus on intensive question-driven monitoring at a sub-set of strategic marshes in RI. The monitoring elements of this tier have been well-established and extensively used to document changes in salt marsh properties resulting from restoration activities or changes in environmental conditions. However, metrics and criteria have not been fully developed that would allow certain Tier 3 biological and physical parameters to specifically serve in the assessment of condition or vulnerability, or in the evaluation of restoration success. For example, trends in specific nekton metrics (e.g., species richness, abundance, community composition) may be useful to indicate marsh integrity, change in marsh status, or restoration success (James-Pirri et al. 2014), but such metrics and trends would need to be developed and validated to serve those purposes. Purposing Tier 3 parameters toward assessment, evaluation, and management prioritization will therefore be a focus of SMMAP development. Another focus of the SMMAP will be to identify specific suites of parameters that should be monitored for specific restoration or adaptation projects. For example, salt marsh restoration projects aiming to increase salt marsh sparrow habitat may require monitoring a different suite of Tier 3 parameters than a salt marsh restoration program aimed specifically at flood impact abatement. Due to an emerging dire need to respond to marsh drowning due to accelerating sea-level rise, Tier 3 will initially focus on quantifying the effects of accelerating sea-level rise on RI marshes, relying heavily on the ongoing NBNERR Sentinel Sites Program, which has been underway since 2008. Ideally, aspects of Sentinel Sites monitoring will be expanded to additional RI marshes, which could be selected from the initial round of the RISMA (Cole Ekberg et al. 2015). We anticipate that the Tier 3 component will be modified or expanded in future years as our understanding of the effects of sea-level rise on salt marshes develops, and as other monitoring and assessment needs are identified. However, it is intended that a main function of Tier 3 will be to conduct intensive long-term monitoring at a small number (6 to 8) of marshes to address specific resource management issues or research questions.

3. Environmental Parameters

The SMMAP will target specific environmental parameters that are appropriate for each of the three monitoring tiers (Table 2), while recognizing that this list will evolve with Tier 3 program development as described below. Each of these parameters is known to respond to one or more of the major stressors outlined above or to specific management and restoration activities. Many are also widely incorporated into existing monitoring programs that are in use by one or more state and federal agencies across the Northeast and beyond.

Table 2. Environmental parameters targeted for inclusion in the Rhode Island SMMAP (see Section 5 below for detailed descriptions of methods for each).

Category	Parameter	Tier 1	Tier 2	Tier 3
Geomorphic	Channel widening rate	X		X
	Landward transgression rate	X		X
	Seaward erosion rate	X		X
	Marsh area	X		
	Ponding area	X	X	
Habitat	Habitat composition and zonation	X	X	X
Physiochemical	Edaphic conditions (e.g., soil strength)		X	X
	Elevation			X
	Elevation change/accretion			X
	Inundation/hydrology			X
	Nutrients			X
	Total Suspended Solids (TSS)			X
Biological	Emergent vegetation		X	X

Marsh crabs	X
Nekton	X
Marsh sparrows	X
Wading birds	X

4. Monitoring Program Components

Tier 1. Broad-scale salt marsh mapping.

The first tier of the SMMAP will focus on mapping salt marsh distribution, extent, and habitat composition and zonation. The NBNERR will test a mapping protocol across all of coastal RI using a geographic object-based image analysis and classification of integrated multi-spectral imagery and LIDAR data. It is designed to rapidly capture simple structural marsh metrics throughout the entire study system. Rhode Island salt marshes will be classified into a minimum of three classes (high, low, and transitional [high/low] marsh) using object-based classification methodologies and techniques developed and tested by the NOAA Coastal Services Center for a variety of applications. The overall procedure consists of a sequential development of image segmentation and classification using a decision rule structure or supervised classification approach such as Classification and Regression Tree Analysis (CART), which relies on the use of training polygons. The process is iterative, requiring multiple analyses of raw-image data to extract unique sets of identifying characteristics of the vegetation cover types based on spectral response signature, generating interim map products; review of interim map products to identify areas of poor fit; and a repeat of the process to further refine the rule structure or model. In addition to supplemental field data, RISMA data from multiple sites will be used as necessary to train the classification process and to provide final classification accuracy assessments. Salt marsh maps developed for multiple time periods as future imagery is acquired will allow for high resolution change detection analysis.

The foundations of this monitoring tier are already in place in RI. Statewide coastal ortho-imagery taken during peak growing season and low tide are already planned every 3-5 years for mapping eelgrass and other SAV. The NBNERR, URI EDC, Save The Bay and RI CRMC are working cooperatively to secure a reliable funding source for this effort. This imagery can be applied directly to Tier 1 monitoring with little or no expansion in coverage. Tier 1 will also use existing protocols and expertise available at the NBNERR and through its NOAA partners (the NBNERR is currently conducting the first round of this high resolution mapping using existing 2012 multi-spectral imagery). Aside from the cost-share of imagery, this monitoring tier should require very little additional funding every 3-5 years because NBNERR has expertise and software to conduct the analyses in house.

Tier 2. Salt marsh rapid assessments

Two rapid assessments of salt marshes have been conducted in RI (Wigand et al. 2011; Cole Ekberg et al. 2015). Wigand et al. (2011) tested the NERAM (Carullo et. al. 2007) for application and relevance in RI. The NERAM focuses on anthropogenic impacts, and includes parameters such as vegetation, soils, on-site disturbances, and watershed land use and land cover. Wigand et al. (2011) included 23 RI marshes out of a total of 81 between CT, MA, and RI and found a good correlation of the NERAM results with previous, more intensive assessments of reference marshes. However, NERAM does not capture marsh degradation and change associated with factors influenced by sea-level rise, which is now considered to be a dominant driver of salt marsh condition in southern New England (Watson et al. 2014; Raposa et al. in press).

The RISMA (Cole Ekberg et al. 2015) focuses on documenting condition of marsh vegetation and soil structure within the context of sea-level rise. Three parameters are assessed to characterize marsh conditions: vegetation species composition, plant zonation, and marsh soil bearing capacity. Marsh zonation is measured by the distribution of characteristic vegetation communities within belt transects spanning from the upland boundary to the tidal water's edge. Vegetation species composition and relative abundance are measured using a point-intercept method along the same belt transects. Bearing capacity is measured using a soil penetrometer in six predominant marsh zones, following the method of Twohig and Stolt (2011). RISMA was conducted in 39 marsh units in RI and southeastern Massachusetts and demonstrated that marsh zonation and vegetation composition are correlated with marsh elevation and latitude (Cole Ekberg et al. 2015). Bearing capacity was generally lower in vegetation communities associated with more frequent flooding and ponding, suggesting reduced marsh resiliency with increasing inundation due to sea-level rise and marsh substrate subsidence (Cole Ekberg et al. in review).

To facilitate analyses of marsh condition, vulnerability, and resilience, a rapid assessment method needs to capture the effects of all potential stressors, including human disturbances and sea-level rise. A rapid assessment should also include easily-attainable, relevant classification information to categorize salt marshes and further facilitate analysis. For the SMMAP, initial Tier 2 work will therefore focus on methods development and further testing, including analyzing and combining, adapting, or augmenting the two existing methods to fully assess and characterize all expected stressors observed at a site in a single day, and testing the method against other levels of data.

We recommend that Tier 2 monitoring be conducted at a sub-sample of RISMA sites to detect changes in salt marsh conditions over time. The sample set should be comprised of randomly-selected marshes, stratified across a gradient of latitudes within Narragansett Bay and across longitudes along RI's south coast to obtain a broad and unbiased representation of marshes. Previous work has shown that a strong marsh elevation gradient exists in Narragansett Bay, with elevation increasing while moving north towards the head of the Bay. Coincident with this elevation gradient is a shift in marsh habitat composition; marshes at lower elevations are composed of relatively higher amounts of stunted short-form *S. alterniflora* and vegetation die-off areas (Cole Ekberg et al. 2015). Random selection of Tier 2 focus marshes will span these gradients in elevation and vegetation composition, thus ensuring a comprehensive assessment across dominant biophysical gradients in RI. The focus of Tier 2 should be on large meadow marshes rather than smaller fringing marshes that do not necessarily provide the same level of services.

Tier 3. Intensive site monitoring

Tiers 1 and 2 of the SMMAP will provide broad-scale and rapid indications of salt marsh condition, respectively. More intensive on-site monitoring will be needed to provide scientists and managers with a more detailed understanding of marsh conditions and how they are changing over time in response to multiple stressors or management activities. Tier 3 sets a standardized framework for intensive field monitoring. Intensive biological and physical monitoring methods for salt marshes have been well established in RI, regionally, and nationally. The intent of the SMMAP will be to identify and document the methods that are most appropriate for the state's monitoring objectives. For example, specific suites of Tier 3 monitoring parameters may be needed to meet the varying needs of long-term monitoring, marsh condition assessment, quantification of reference conditions, detection or prediction of response to sea-level rise, prediction of transgression opportunities and response, monitoring of the function and value of migration areas, prioritization of marsh restoration activities, and evaluation of restoration performance. Additionally, metrics may need to be developed to quantify and compare conditions and to meet certain objectives. The SMMAP will develop specific protocols utilizing a particular suite of intensive parameters and metrics most effective for addressing each of these and other important objectives.

A protocol for long-term monitoring has already been developed for the NBNERR Sentinel Sites program, which was designed to document marsh responses to sea-level rise and inundation. To accomplish this, two marshes in the Reserve are intensively monitored each year, including transect/quadrat vegetation sampling, marsh surface elevation, and surface elevation tables (SETs). In addition, each site is equipped with an intensive vertical control network which allows for all marsh elevations and any monitoring infrastructure to be tied into the national vertical reference datum (NAVD 1988). Under this protocol, elevations on the marsh are typically collected using a dual frequency GPS receiver and a real-time kinematic survey style (RTK). This survey method is capable of centimeter accuracy in both the horizontal and vertical dimensions. Already, this approach is documenting rapid and dramatic changes in marsh vegetation at both sites, and has identified sea-level rise as the likely driver of this change (Raposa et al. in press). Another example is the new USFWS salt marsh integrity assessment (Neckles et al. 2013; Neckles et al. 2015), which recommends a suite of complementary parameters for monitoring at a given site to comprehensively document marsh condition and change over time. Portions of the USFWS protocol are currently being implemented at two RI marsh complexes, John H. Chafee National Wildlife Refuge and Sachuest Point National Wildlife Refuge. Tier 3 of the SMMAP will follow these examples and encompass intensive monitoring at a small number of strategically targeted marshes throughout RI; these marshes could also serve as long-term reference marshes for comparison with ongoing or future marsh adaptation and restoration projects.

The needs for implementing long-term monitoring using this tier of the SMMAP include identifying the specific marshes where intensive monitoring will occur and then selecting the suite of parameters that will be monitored at each site. Ideally, Tier 3 monitoring will occur in marshes where both Tier 1 and 2 data are collected and where shorter-term intensive monitoring data have already been collected and analyzed. These could include the Nag West and Coggeshall Marshes in the NBNERR on Prudence Island, the USFWS marshes along the Narrow River, Sachuest Marsh and in Ninigret Pond, as well as any of the tide-restored marshes throughout the state (e.g., Sachuest Point in Middletown, Galilee in Narragansett, Jacobs Point in Warren, and Gooseneck Cove marsh in Newport). However, aside from Coggeshall and Nag marshes, each of these marshes does not represent a valid reference marsh because specific adaptive management and restoration activities have occurred at each site.

Instead, Tier 3 long-term annual monitoring could be initiated at a small number of viable reference marshes in Narragansett Bay and the salt ponds selected for Tier 2 monitoring, and continued at Nag West and Coggeshall. One strategy then is to establish six Tier 3 marshes along the Bay-wide elevation gradient (see Tier 2 recommendations), with two marshes each in the lower, middle and upper Bay regions. Because Coggeshall and Nag marshes already represent the mid-Bay region, this approach would require the establishment of four new Tier 3 marshes. Potential candidates include the Round and Fox Hill marshes, both in Jamestown in the lower Bay, the Chase Cove and Jacob's Point marshes in the upper Bay, and marshes where the USFWS has been collecting avian, vegetation, and RTK data over the past three or more years, such as the USFWS reference marsh in Ninigret Pond. This approach would expand intensive monitoring (similar to Sentinel Sites) across a broader region in RI and simultaneously allow for monitoring of marshes spaced along the existing gradient of vulnerability with respect to sea-level rise.

Regardless of the marshes that are selected, there exists a wide variety of potential parameters that could be monitored at each of the Tier 3 reference marshes. In addition to long-term annual monitoring at the established subset of Tier 3 sites, Tier 3 parameters and metrics could also be applied to monitoring of specific management activities such as restoration or adaptation projects to address a variety of specific research questions (see Section 2). It is anticipated that these project-based monitoring efforts would be shorter-term, and would not necessarily include the full suite of Tier 3 parameters.

The selection of parameters should be inclusive enough to cover the suites of parameters required for the main monitoring goals and management activities identified in the region. For example, if sea-level rise is a primary stressor of concern, the existing NBNERR Sentinel Site parameters might be chosen. If the application of a model to predict marsh responses to sea-level rise is desired, then additional parameters will be needed (e.g., total suspended solids, TSS). If eutrophication is the target stressor, then other parameters should be included (e.g., *in situ* nutrient concentrations, above- and below-ground biomass, edaphic conditions, etc.). Clearly the specific parameters chosen for analysis will depend on the goals and questions raised in any given project. However, when chosen, each parameter can be monitored in a similar, standardized way to ensure comparability of data among marshes (see Section 5, below).

5. Monitoring Parameters

1. Geomorphic parameters. There are a variety of geomorphic parameters that function as useful indicators of marsh condition (Table 2). Each of these parameters can be affected by multiple stressors including sea-level rise, eutrophication, herbivory, and bioturbation. These parameters include (but are not limited to):

a. Channel and marsh edge erosion and calving rate. Eutrophication, sea-level rise and grazing can all result in the erosion of the seaward marsh edge and drainage features such as creeks and ditches (Bertness et al. 2008; Smith 2009; Deegan et al. 2012). This parameter can be obtained over time from the Tier 1 monitoring component and will reflect the annual rate of change in marsh edge and channel width. For this parameter and transgression rate (below), it may take a decade or longer to derive meaningful estimates depending on how fast erosion is occurring; each parameter can therefore also be derived at Tier 3 sites using permanent stakes or erosion pins.
b. Landward transgression rate. This is the rate at which salt marsh habitat migrates into adjacent upland habitats in response to sea-level rise. This parameter can be measured from Tier 1 and Tier 3 components (although a field-based transgression monitoring protocol has not been developed or adopted for RI; see Section 12, below).
c. Marsh area and ponding area. Multiple stressors can result in a net loss of marsh area, and sea-level rise specifically can lead to an increase in the area of shallow ponds on the marsh surface (Hartig et al. 2002). Both of these parameters can be estimated using Tier 1 methods, while relative ponding area can also be estimated using Tier 2 methods.

2. Habitat composition. Habitat community composition and plant zonation can reflect various marsh conditions such as localized inundation, salinity, and nutrient regimes. Information on habitat composition and plant zonation can be measured in all three SMMAP tiers. Ideally, Tier 1 mapping will result in habitat classification maps for the entire state at regular 3-5 year intervals, allowing for habitat and zonation change analyses to be conducted. Tier 2 could characterize the zonation and composition of vegetation communities in the field following RISMA protocols. These same parameters could also be measured annually at selected Tier 3 monitoring sites or in conjunction with restoration/adaptation projects following the real-time kinematic (RTK) GPS procedures outlined in Raposa and Weber (2011). However, thought must be given to redundancy; if these measures are already being monitored at a site using Tier 2, it may not be time or cost-effective to also do it with the RTK-GPS (unless elevation data are also desired).

3. Edaphic conditions. During the initial round of RISMA, bearing capacity was measured using a soil penetrometer following the methods of Twohig and Stolt (2011). Bearing capacity was selected because it can provide insight into the degree of marsh degradation (i.e., organic materials in degraded marshes are more decomposed and cannot support as much weight or resist as much force). However, the first round of RISMA illustrated that the penetrometer was invasive to the marsh surface and not as rapid as anticipated. Another method for measuring soil strength is the Turner (2011) shear stress method. This method uses a hand held shear vane to measure soil strength at different depths. The shear vane is readily portable and measurements are rapid. The shear vane has been used by numerous researchers to assess marsh soil condition (Darby et al. 1986; Howes et al. 2010; Wigand et al. 2014). However, an advantage to continuing to use the soil penetrometer method is that baseline information exists from the RISMA. One way to reconcile this would be to use both methods in the first year of SMMAP. If the results are comparable, the shear stress method could be used going forward.

4. Elevation. The elevation of a marsh relative to local water levels is a key determinant of marsh sustainability over time and should therefore be a core monitoring parameter within the SMMAP. If part of a marsh sits too low in the tidal frame, it is at risk of prolonged flooding, whereas high-elevation areas may not support native salt-marsh plant species. Marsh elevations can either be obtained via remote sensing (e.g., LIDAR) or through field surveys using leveling or RTK-GPS equipment. LIDAR is advantageous in that datasets already exist for all of coastal RI, but the accuracy of these data is dependent on a number of factors and can vary across marsh vegetation types. Field surveys are much more accurate (2-5 cm for RTK-GPS; sub-cm for leveling surveys) but are labor intensive, especially if the goal is to create whole-marsh digital elevation models (DEMs). Additionally, field surveys generally require vertical control to be established prior to the surveys, which can also be time and labor intensive. It is recommended that vertical control be established for any Tier 3 marsh (refer to Raposa and Weber 2011 and Weber 2012), and that elevation surveys be conducted using either conventional leveling or RTK-GPS, or both. Wherever possible, leveling surveys should be used to capture elevations of water level loggers, SETs, vegetation plots, and any other monitoring infrastructure that requires sub-cm accuracy; RTK-GPS can be used for collecting large amounts of marsh platform data (e.g., by conducting profiles along transects, or for creating DEMs). All marsh elevation data can then be related to a local tidal datum that is derived from concurrent hydrology monitoring (see below).

5. Elevation change and accretion.
In order for a marsh to survive as sea-level rise continues to accelerate, the marsh surface must be able to rise in elevation at rates comparable to local sea-level rise. One of the primary mechanisms by which marshes rise in elevation is via the accumulation (i.e., accretion) of organic and inorganic materials onto the marsh surface. These parameters should therefore be monitored at all Tier 3 marshes and included in any marsh restoration/adaptation project. Elevation change and accretion are easily measured using surface elevation table-marker horizon (SET-MH) stations (http://www.pwrc.usgs.gov/set/ provides a thorough description). One drawback to this

approach is that SETs can be expensive in marshes with very thick peat layers, and they are generally labor intensive during installation. They also only provide information from the locations in which they are installed, requiring a relatively large sample size to account for within-marsh spatial variability. However, the use of SET-MH stations is a well-vetted approach that is in use worldwide, and it is recommended here that they be used for Tier 3 monitoring to determine changes in marsh elevation and accretion or erosion over time.

Sediment accretion can also be assessed using sediment tiles, which have been successfully used in riverbank habitats. This methodology has recently been applied to salt marshes to increase the spatial resolution of accretion data over marker horizon stations alone, and it is currently being piloted at control and restoration marshes in Ninigret Pond. An analysis of the utility of the information gained from the tiles will inform the SMMAP whether this newer technology is worth applying at Tier 3 marshes.

6. Hydrology and inundation.
Water levels influence many marsh attributes and functions including emergent vegetation, soils, and marsh use by nekton and birds. Water levels are affected by accelerating rates of sea-level rise, tidal restoration projects, and adaption projects that seek to increase drainage or raise the elevation of the marsh surface. Simple, standardized methods already exist for monitoring hydrology in tidal marshes (outlined in both Neckles et al. 2013 and Raposa and Weber 2011), and these methods should be used for hydrology monitoring in RI marshes as part of the SMMAP. The approach involves installing multiple small PVC wells into the marsh substrate (generally in association with nearby existing emergent vegetation plots) and using water level loggers (e.g., Hobo loggers from Onset Corp.) to collect high-resolution data on water levels. By taking field measurements from the well and logger, it is relatively straightforward to calculate marsh surface inundation and groundwater depth. Another approach is to deploy loggers in adjacent creeks, survey them into the local vertical reference system, and couple that with marsh surface elevations (see above) to calculate inundation across a broader area. Regardless of the specific methods, parameters of interest include tide range, inundation frequency and duration, and groundwater depth. If deployed long enough in tidal creeks, site-specific tidal datums can also be determined (NOAA 2000).

7. Nutrients. Eutrophication of salt marshes due to excess nutrients can adversely affect marsh structure and function. Salt marshes exposed to higher rates of nitrogen loading may be more susceptible to erosion (Turner 2011; Deegan et al. 2012), higher decomposition due to higher soil respiration rates (Wigand et al. 2003), and invasion of non-native species such as *Phragmites australis* (Bertness et al. 2002). Nitrogen concentrations (a proxy for eutrophication) can be monitored directly, or they can estimated from surrounding land use. Direct monitoring is via the *in situ* collection of nitrogen entering salt marshes through surface or groundwater, but this can be labor and time intensive. As an alternative, GIS analyses of land use can be coupled with nitrogen loading models to serve as an indicator of eutrophication. One efficient method is a GIS analysis of land use in the 150-m buffer surrounding a salt marsh according to RISMA (Cole Ekberg et al. 2015). This could be conducted in conjunction with the Tier 1 marsh

habitat composition assessment. Another, more intensive GIS analysis measures land use in the entire marsh watershed, as conducted by Wigand et al. (2003) in a limited number of RI marshes. The results of a landscape-scale assessment could be used to run a nitrogen loading model for each marsh to estimate the extent of nitrogen loading and the relative load from different sources such as wastewater, fertilizer and atmospheric deposition (Valiela et al. 1997; Valiela et al. 2000).

8. Total Suspended Solids (TSS). Salt marshes need adequate sediment supplies to be able to accrete vertically as sea levels continue to rise, and these sediment supplies can be quantified for marshes by collecting total suspended solids (TSS) samples over time. An additional benefit of collecting TSS samples is that this is a primary input if a goal is to eventually use the Marsh Equilibrium Model (MEM) at a given marsh (Schile et al. 2014). Unfortunately, almost no TSS data currently exist for marshes in RI, and collecting these data is not trivial. Samples are now being collected from multiple stations throughout Narragansett Bay by the Atlantic Ecology Division of the EPA lab in Narragansett, and these will provide estimates of sediment availability from estuarine sources. However, TSS also needs to be collected from within individual marshes to understand true sediment availability since some sediment sources are localized (e.g., from dunes facing back-barrier marshes). It is therefore recommended that TSS sampling be included in Tier 3 monitoring and that the methods should generally follow those currently under development for use throughout NERR salt marshes (Ferner et al. in prep). Unfortunately, this approach can be labor intensive; it requires the collection of samples from multiple locations within a marsh at regular intervals over a long period of time (e.g., monthly over two years) to account for spatial and temporal variability and to improve data accuracy. Alternately, samples could be collected in association with storms to capture major sediment deposition events (E. Watson personal communication to K. Raposa).

9. Emergent vegetation. Emergent vegetation is a key component of virtually any salt marsh monitoring program, and is assessed in Tiers 2 and 3 of the SMMAP. Vegetation is affected by all of the major stressors outlined above, and multiple structural vegetation metrics can provide excellent indicators of marsh condition. In addition, standard methods for monitoring vegetation are available and are already in use throughout RI and in other states/regions. Tier 3 emergent vegetation monitoring in RI should follow the protocols developed for use in the National Park Service (Roman et al. 2001), as this is a vetted and widely-accepted protocol used in regional and national long-term datasets. This methodology involves establishing multiple transects that run from estuary to upland and multiple square-meter monitoring plots at intervals along each transect. Power analyses show that approximately 20 monitoring quadrats are needed per marsh study unit (James-Pirri et al. 2007). Specific vegetation metrics that are associated with this method include species composition, species richness, percent cover of all species, and heights and stem densities of dominant/target species. These methods have been employed in the NBNERR since 2000 and by STB and NBNERR at multiple restoration projects in RI dating back to at least 1997; continued monitoring using these same methods will build a robust emergent vegetation database over time in RI.

An additional assessment of emergent vegetation could include the measurement of aboveground and belowground plant biomass. Belowground vegetation is important for the development of peat, providing structure for sediment retention as well as subsurface elevation processes. In addition, the differentiation of resource allocation between above and below-ground biomass is an indicator of ecosystem function. We initially recommend that aboveground biomass be measured following the non-harvest technique of Valiela et al. (1976) and belowground biomass be measured with the use of cores following Neill (1992). However, these methods may change depending on results from pilot implementation of both methods by US EPA/AED in Ninigret Marsh in 2015.

10. Marsh crabs. Fiddler (*Uca* spp.), green (*Carcinus maenas*), purple marsh (*Sesarma reticulatum*), and other crab species are conspicuous residents of RI salt marshes. At low numbers, fiddler crabs are actually beneficial for *Spartina* grasses as their burrows help to aerate the soil. However, there is mounting evidence that crabs of multiple species are becoming overabundant (possibly due to sea-level rise and/or predator depletion) in New England salt marshes and are contributing to pervasive salt marsh die-off (Bertness et al. 2014). Crabs could therefore serve as a useful monitoring component of the SMMAP. There are multiple methods for monitoring salt marsh crab populations, but different methods often provide different results (Raposa unpublished data) and, unfortunately, a standardized salt marsh crab monitoring protocol does not exist for use in New England marshes. Until such a protocol is developed, it is recommended here that replicated crab burrow counts be conducted along creek banks within each target marsh. Sample size estimations from pilot data suggest that approximately 15-20 0.25-m^2 quadrats need to be sampled at least once between June and August along creek banks in each marsh.

11. Nekton. Nekton (fish and decapod crustacean) communities are an excellent bioindicator of marsh condition and function (Raposa et al. 2003). A vetted quantitative monitoring protocol already exists for nekton that focuses on using throw traps and ditch nets (James-Pirri et al. 2012). This protocol has been in use across the northeastern US for over a decade (e.g, Raposa and Talley 2012) and, specifically, at over a dozen sites in RI. Thus, nekton monitoring using the throw trap and ditch net protocols (James-Pirri et al. 2012; Neckles et al. 2013) should be included in Tier 3 SMMAP monitoring. This typically involves monitoring from approximately 20 randomly-selected stations within each marsh in both July and September each year. This approach provides data on nekton community composition, richness, density, and size class.

12. Birds. Similar to nekton, marsh birds integrate multiple aspects of marsh function and can therefore serve as excellent bioindicators of marsh condition. We recommend that bird monitoring also be included as part of the SMMAP. It is challenging to target multiple bird guilds (e.g., cryptic passerines, waterbirds, secretive marsh birds) that comprise marsh bird communities with a simple, rapid monitoring protocol. Most problematic is the secretive marsh bird guild because it requires the use of pre-dawn or early morning call back surveys (Conway 2012). The SHARP program has used these call-back protocols to collect marsh-obligate bird data over multiple years at several marshes throughout the region. If this guild is not included, then more rapid daytime transect and point count surveys can be conducted on multiple dates throughout the warm

season to monitor cryptic passerines and waterbird species (James-Pirri et al. 2002). We recommend that long-term marsh bird monitoring, as part of the Tier 3 SMMAP, focuses on transect and point-count surveys of passerines and waterbirds following the methods described in James-Pirri et al. (2002), and that question-driven monitoring involving secretive marsh birds follows SHARP protocols (http://www.tidalmarshbirds.org/) as possible.

6. Preliminary list of parameters for Tier 3 long-term monitoring

Here we present a compiled list of monitoring parameters that are recommended for inclusion in any marsh where Tier 3 long-term monitoring is to be conducted (Table 3). This same list could be applied to any marsh where restoration/adaptation activities are planned. Recognizing that it is often not feasible to monitor such a comprehensive list of parameters, we have grouped them into primary measures that should be included in all marshes, when possible, and secondary measures that could be added as resources permit.

*Table 3. Parameters for Tier 3 long-term monitoring according to the SMMAP proposed in this strategy; *primary metrics, all others are secondary.*

Monitoring parameter	Method	Suggested protocol/reference
Geomorphic		
Erosion rate	Stakes/pins	Gabet (1998)
Transgression rate*	Stakes/pins	Moore (2012)
Habitat		
Composition and zonation	RTK-GPS	Raposa and Weber (2011)
Edaphic conditions		
Soil strength*	Shear vane	Turner (2011)
Elevation		
Marsh elevations*	RTK-GPS	Raposa and Weber (2011)
Elevation change and accretion		
Elevation change and accretion*	SETs and marker horizons	Cahoon et al. (2002)
Sediment accretion	6" ceramic tiles	Pasternack and Brush (1998)
Hydrology and inundation		
Water levels and inundation*	Water level loggers	Neckles et al. (2013)
Nutrients		
Nitrogen concentrations	In situ sampling	NERRS (2012b)
Total suspended solids		
Total suspended solids	NERRS method	Ferner et al. (in prep.)
Emergent vegetation		
Species composition and cover*	Point-intercept	Roman et al. (2001)
Plant height (dominant species)*	Measurement of plants	Roman et al. (2001)
Stem density (dominant species)	Stem counts	Roman et al. (2001)
Aboveground biomass	Non-harvest	Valiela et al. (1976)

Belowground biomass	Soil cores	Neill (1992)
Crabs and nekton		
Species composition and density	Throw traps	James-Pirri et al. (2012)
Crab burrow density*	Burrow counts	Raposa (unpublished data)
Birds		
Species composition and abundance	Point counts	James-Pirri et al. (2002)

7. Quality Assurance

To ensure scientific validity of sampling and analysis activities, quality assurance and quality control (QA/QC) protocols will be developed and documented for the SMMAP. These will take the form of standard operating procedures, monitoring implementation plans or quality assurance project plans (QAPPS) as applicable. QAPPs will be prepared in a manner consistent with EPA guidance. Procedures for QA/QC will be documented by the partners carrying out the monitoring activities for each tier of the strategy.

8. Data Management

Data generated through salt marsh monitoring is currently collected and managed by multiple partners. To support effective management, state managers need to develop data management tools that provide easy access to data and support data analysis and synthesis. As resources allow, it is expected that CRMC and DEM will collaborate with partners to design, develop and implement needed data system improvements. Consistent with state law, it will be an objective to make salt marsh monitoring data publicly accessible via the internet. Improved capacity for data management is also needed to support reporting.

9. Reporting

Salt marsh monitoring results characterizing condition will be reported in RI's biennial Integrated Water Quality Monitoring and Assessment Report and the Wetland Status and Trend reports published by the DEM Office of Water Resources. In addition to being included in these required reports, information on the condition of wetlands in RI is intended to be shared (available via the web) with state and local groups and non-profit organizations responsible for or interested in the protection and management of wetlands.

10. Evaluation

To develop timely adaptive management strategies, three-year reviews of this salt marsh monitoring and assessment strategy should be conducted, resulting in revisions and updates to best guide development and implementation of the SMMAP. Partners implementing the SMMAP will assess field monitoring procedures periodically and revise written protocols as needed as part of ongoing QA/QC. Review of the program will also occur during updates to the RI Water Monitoring Strategy being prepared by DEM and the continuing development of RI's comprehensive environmental monitoring strategy by the RI Environmental Monitoring Collaborative. Review of the SMMAP activities, as well as the overall strategy, will be evaluated by the monitoring workgroup and other appropriate reviewers to determine if strategy objectives are being met, and whether the information being shared with decision makers is contributing to improved protection and management of salt marshes. The proposed timeline and required resources will also be evaluated and necessary revisions will be made.

11. Monitoring program needs/recommendations

The goal of this document is to outline and provide recommendations for a comprehensive, three-tier monitoring program (i.e., SMMAP) that can be used throughout the state of RI and beyond. Considerable program development will be needed before such a program can be fully implemented. An initial action item will be to create a comprehensive budget that reflects resources needed to support necessary program development steps, which include, but are not necessarily limited to: :

- Bolstering state capacity to coordinate and manage the SMMAP;
- Formalizing a salt marsh working group;
- Finalizing priority monitoring objectives for the state;
- Testing and assessing the utility and effectiveness of recommended Tier 1 methods;
- Improving and expanding upon existing protocols to serve as Tier 2;
- Identifying and testing particular Tier 3 metrics and suites of monitoring parameters for specific monitoring and assessment objectives;
- Developing a standardized and/or rapid monitoring protocol for marsh crabs;
- Developing and adopting a field protocol for monitoring statewide marsh transgression rates;
- Documenting standardized, tested methods and protocols in user guides and other reports;
- Selecting additional marshes where Tier 3 can be expanded and implemented;
- Developing an inventory of shared monitoring equipment available throughout RI;
- Developing SMMAP data collection and analysis protocols;
- Developing a web-based system for storing and making available all marsh monitoring data;
- Identifying dedicated funding sources to implement all three tiers of the SMMAP.

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