

# 'How to' Guide

## FOR SYNTHESIZING NERRS MARSH MONITORING DATA

### PROJECT GOAL

Creation of a user-friendly guide on how to synthesize salt marsh data at a regional scale

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The purpose of this guide is to provide a user-friendly and informative guide on 'How to' synthesize salt marsh data from the National Estuarine Research Reserve System (NERRs). In this guide, we outline and detail the steps taken from requesting/cataloguing data to summarizing these data through visual and statistical analysis. These methods can be used at a single or multiple site(s) as well as over multiple years. Though this guide is specific to NERRs and focuses on plant community data, it may also be useful for other monitoring parameters and programs to guide protocol design and analyses. Here, we conduct a synthesis of New England salt marshes using NERRs data collected from the past decade.



Catalogue



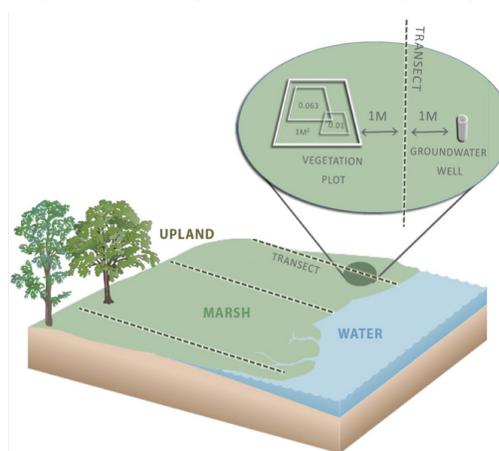
Standardize



Summarize

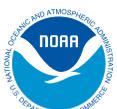
The NERRs is comprised of 29 Reserves around the country, federally designated to protect and study estuarine environments. Reserves serve as "living laboratories", providing long-term monitoring data of water quality and habitats as well as research opportunities to professionals and students. Because of the NERRs shared mission and its dedication to long-term tidal marsh monitoring through its 'Sentinel Sites' Program, the NERRs data is ideal for understanding the effects of climate change, including the impact of Sea-Level-Rise (SLR). In New England, all four Reserves established 'Sentinel Sites' by the 2011 growing season.

The NERRs Sentinel Sites Program utilizes permanent survey plots along transects to monitor long-term changes in tidal marshes. Transects typically run perpendicular from the main tidal hydrologic feature to the upland, which is specifically designed to detect changes in plant distributions with water level



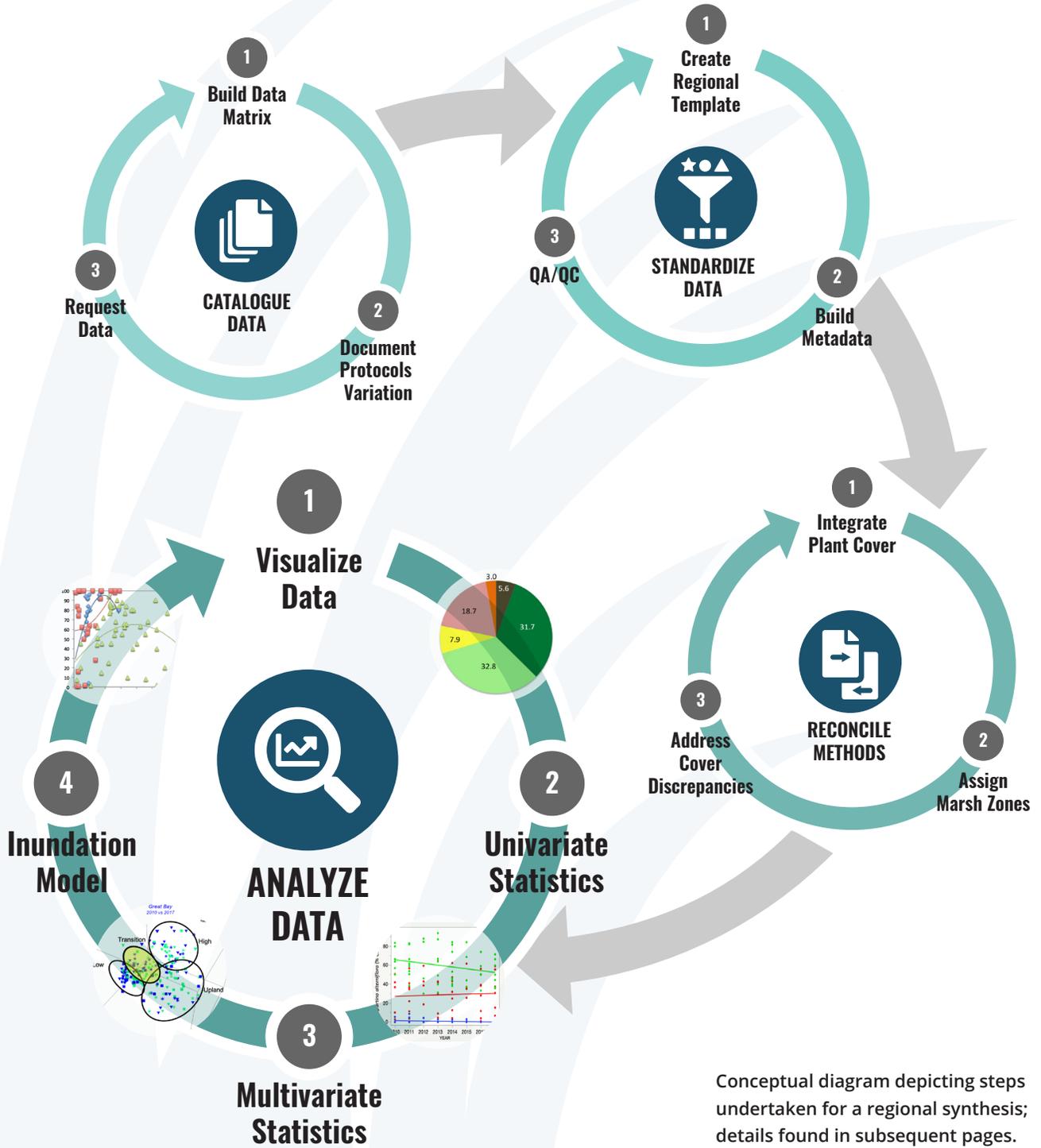
changes associated with SLR or other climate related factors. Monitoring components include plant community (cover, height, density), Surface Elevation Tables (SET), and other auxiliary data (elevation, groundwater, local tides). See NOAA/NERR 2016 for further details on all monitoring components and Moore 2013 for specific vegetation monitoring protocols.

Graphics by Rachel Stevens, with appreciation to the Integration and Application Network, University of Maryland Center for Environmental Science.



# OVERALL WORKFLOW

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Conceptual diagram depicting steps undertaken for a regional synthesis; details found in subsequent pages.

# CATALOGUE DATA

1. **Build Data Matrix**
2. **Document Protocol Variations**
3. **Request Data**

## BUILD DATA MATRIX

Available data, collection method, and to a lesser extent, format, are all critical to identify prior to designing data formats and analyses. As such, our first step was to identify all available datasets pertinent to our project scope, which included data from the NERRs Sentinel Site Monitoring Program. The below table summarizes data availability for all four New England Reserves. Data availability fluctuates annually and by data type. Sentinel Site data has a higher availability and frequency for the main monitoring components: vegetation and surface elevation table (SET) and lesser availability for auxiliary data (porewater salinity, elevation, local tides).

## DOCUMENTING PROTOCOL VARIATIONS

In any synthesis, it is equally critical to identify variations in methodologies as they can have a large impact on interpretation. The NERRs Sentinel Site Monitoring Program is an established and nationally recognized program that attempts to achieve consistent application system-wide, however there are a few inconsistencies that were identified in regards to describing the vegetation community, which are issues inherent to any nation-wide program. These inconsistencies stem from Reserves instituting data

collection pre-dating the Sentinel Site Program, and diverse environmental conditions, plant communities and wildlife, to name a few. For example, half the New England Reserves use relative, non-binned ocular estimates of plant cover, while the other half use a point-intercept system. Both cover estimates are commonly used in tidal marshes, however our results show these different methods can lead to different interpretations of important cover categories. Other differences in methods were also identified, documented and reconciled when possible, which are further discussed in the section titled *“Reconciling Methods”* on page 5”.

## DATA REQUEST

NERR Sentinel Site monitoring data are typically housed in two different locations, distributed upon request: (1) NERR Centralized Data Management Office (CDMO); and (2) individual Reserves. For our purposes, data were requested and compiled directly from all four New England Reserves. We considered requesting data from CDMO because they house NERR Sentinel Site data system-wide in one consistent format, however, less than half of all available data had been currently submitted to CDMO and their format, designed for archival purposes, was not conducive to many statistical and graphing programs. Future considerations of archival and dissemination formats should look to streamline this process on both ends: CDMO could improve availability as well as data format for uses beyond archival, while individual users would benefit from employing programming language to standardize formats and categories.

	Vegetation			Ecotone		Porewater Salinity	Hydrology **	Elevation	SET	Local Tide Data
	Cover	Density	Height	Boundary*	Plots*					
2010	2	2	1		1	2	1	2		1
2011	4	4	4		1	3	3	1	2	2
2012	2	2	2			1	1	2	3	2
2013	3	2	3		1	1	1	1	4	2
2014	4	3	4	1	1	1	1	2	4	2
2015	2	1	2	1				1	2	2
2016	4	3	4	1	1	2	1	2	4	2
2017	4	3	4	1	1	1		1	3	3

New England Reserve data availability throughout the project scope. Values in each cell represent number of reserves with available data, color coded from fewest (white) to most (dark blue). Note: ecotone monitoring can be conducted using two methods: \*Boundary = detect horizontal shifts in marsh zone (upland edge, high/low transition, mudflat); \*Plots = detect changes in plant communities by adding plots in transition zones (upland edge, high/low transition, mudflat). \*\*Hydrology = continuous water level data collection within the marsh for at least one lunar cycle (28 days).

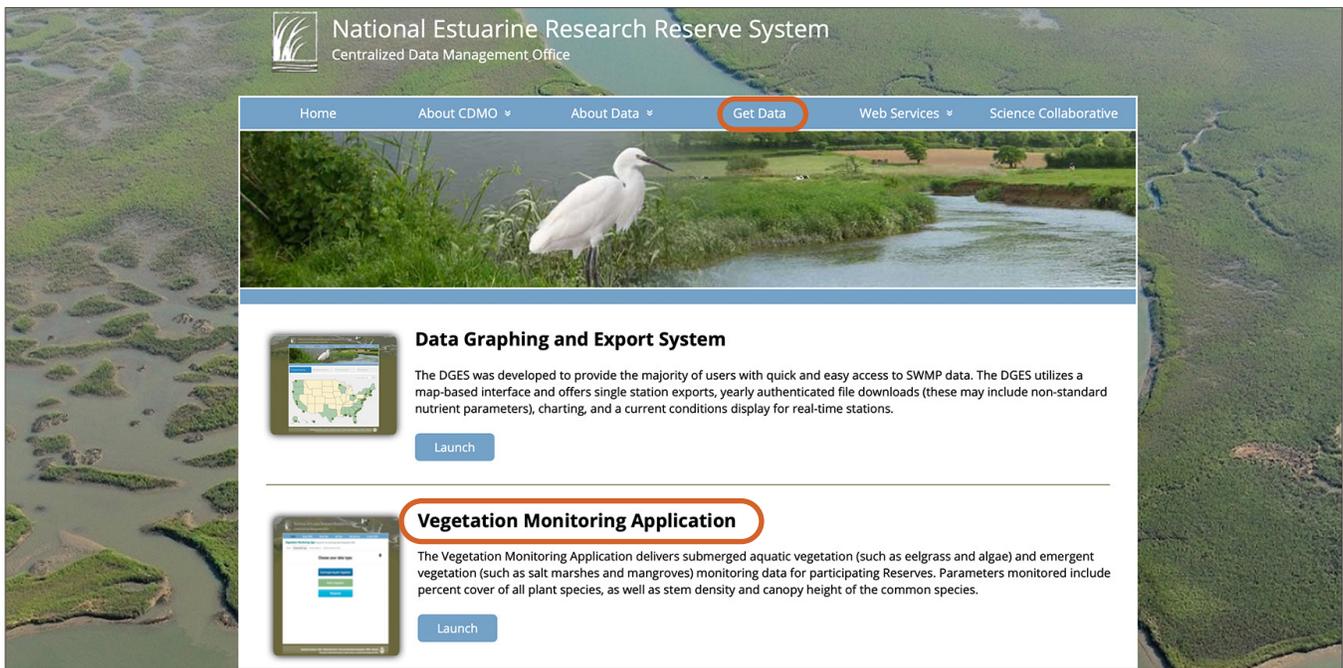


Image of NERR Centralized Data Management Office (CDMO) data portal. Navigate to the Vegetation Monitoring Application by using the web link (<http://cdmo.baruch.sc.edu/>), clicking on “Get Data”, scrolling down and selecting “Vegetation Monitoring Application.”

# STANDARDIZE DATA

1. **Create Regional Templates**
2. **Build Metadata**
3. **QA/QC**

## CREATE REGIONAL TEMPLATES

From the four New England Reserves, we received data housed in six different formats. Formatting inconsistency is likely due to individual Reserve utility as well as the lack of a national data template beyond that of the CDMO which is not data-analysis friendly nor widely utilized in New England. Our first challenge to synthesize data across New England was developing a regional data template that could house all of the region’s data in a consistent format, which was user-friendly in several areas:

- Data entry
- Data archival
- Data visualization and analysis

We also needed to address differences across Reserves including: species, methods, lumped data (e.g., bare and dead covers combined) and additional data (e.g., *S. alterniflora* parsed into tall and short forms). Regional templates were created for all types of data used in this project:

1. Vegetation: taxa, cover, heights & density
2. SET and marker horizon
3. Elevation of vegetation plots
4. Water Levels

## BUILD METADATA

Regional datasets should include metadata that completely describe the template and data housed within. Specific descriptions from our metadata include field protocol differences, column header information, summary parameters, species nomenclature and groupings, corrected, suspect or omitted data, etc.

Reserve Code	Site	Season	Date	Year	Transect #	Elevation (NADV88)	Distance to Water (m)	Plot ID	Serial #	Marsh Zone	TOTAL	Bare Ground	Dead	Wrack	F	U	H	B	B	A	U	H	F	H	F	F	U	U	H	A	B	F	H		
															<i>Acer rubrum</i>	<i>Achillea millefolium</i>	<i>Agalinus maritima</i>	<i>Agropyron pungens</i>	<i>Agrostis stolonifera</i>	Algae	<i>Alnus spp.</i>	<i>Amaranthus cannabinus</i>	<i>Amelanchier canadensis</i>	<i>Ammophilla breviligulata</i>	<i>Aptos americana</i>	<i>Aquilegia canadensis</i>	<i>Arachis spp.</i>	<i>Aralia nudicaulis</i>	<i>Argentina anserina</i>	<i>Ascophyllum nodosum</i>	<i>Asparagus officinalis</i>	<i>Athyrium angustatum</i>	<i>Atriplex patula</i>		
GRB	Sandy Point	Fall	8/23/11	2011	1	0.608	6.3	SP1-1	SP1-1-40778	L	100	20	1																						
GRB	Sandy Point	Fall	8/23/11	2011	1	0.654	7.1	SP1-2	SP1-2-40778	T	100	12	2	21																					
GRB	Sandy Point	Fall	8/23/11	2011	1	0.654	8.1	SP1-3	SP1-3-40778	T	100	22	1																						
GRB	Sandy Point	Fall	8/23/11	2011	1	1.148	16.3	SP1-4	SP1-4-40778	H	100	12	25	7																					
GRB	Sandy Point	Fall	8/23/11	2011	1	1.293	26.3	SP1-5	SP1-5-40778	H	100	5	45																						
GRB	Sandy Point	Fall	8/23/11	2011	2	0.581	2.9	SP2-1	SP2-1-40778	L	100	78																							
GRB	Sandy Point	Fall	8/23/11	2011	2	0.956	8.2	SP2-2	SP2-2-40778	T	100	7	1																						
GRB	Sandy Point	Fall	8/23/11	2011	2	0.956	9.2	SP2-3	SP2-3-40778	T	100	2	3	2																					
GRB	Sandy Point	Fall	8/23/11	2011	2	1.003	12.9	SP2-4	SP2-4-40778	H	100			96																					
GRB	Sandy Point	Fall	8/23/11	2011	2	1.044	22.9	SP2-5	SP2-5-40778	H	100	20	2																						
GRB	Sandy Point	Fall	8/23/11	2011	2	1.089	32.9	SP2-6	SP2-6-40778	H	100	5	50																						
GRB	Sandy Point	Fall	8/23/11	2011	2	1.562	42.9	SP2-7	SP2-7-40778	U	101	2	13																						
GRB	Sandy Point	Fall	8/23/11	2011	3	0.459	1.2	SP3-1	SP3-1-40778	L	100	15	2																						
GRB	Sandy Point	Fall	8/23/11	2011	3	0.728	9.4	SP3-2	SP3-2-40778	T	100	4	15	1																					
GRB	Sandy Point	Fall	8/23/11	2011	3	0.728	10.4	SP3-3	SP3-3-40778	T	100	5	5	1																					
GRB	Sandy Point	Fall	8/23/11	2011	3	1.006	11.2	SP3-4	SP3-4-40778	H	100	8	5	1																					
GRB	Sandy Point	Fall	8/23/11	2011	3	1.120	31.2	SP3-5	SP3-5-40778	H	100	3	10																						
GRB	Sandy Point	Fall	8/23/11	2011	3	1.537	51.2	SP3-6	SP3-6-40778	U	100	3	3	61																					
GRB	Sandy Point	Fall	8/24/11	2011	3	1.586	65.9	SP3-7	SP3-7-40779	U	100	16	16																						
GRB	Sandy Point	Fall	8/23/11	2011	4	0.388	4.2	SP4-1	SP4-1-40778	L	100	20	2																						
GRB	Sandy Point	Fall	8/23/11	2011	4	0.872	18.6	SP4-2	SP4-2-40778	T	100	9	7																						
GRB	Sandy Point	Fall	8/23/11	2011	4	0.872	19.6	SP4-3	SP4-3-40778	T	100	2	9																						

Image of regional data template showing abiotic covers and species (alphabetical order). Colors and letters above cover categories represent different ecological groups: (H)alophyte, (B)rackish, (U)pland, etc. Associated metadata, describing all columns is not shown.

### QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

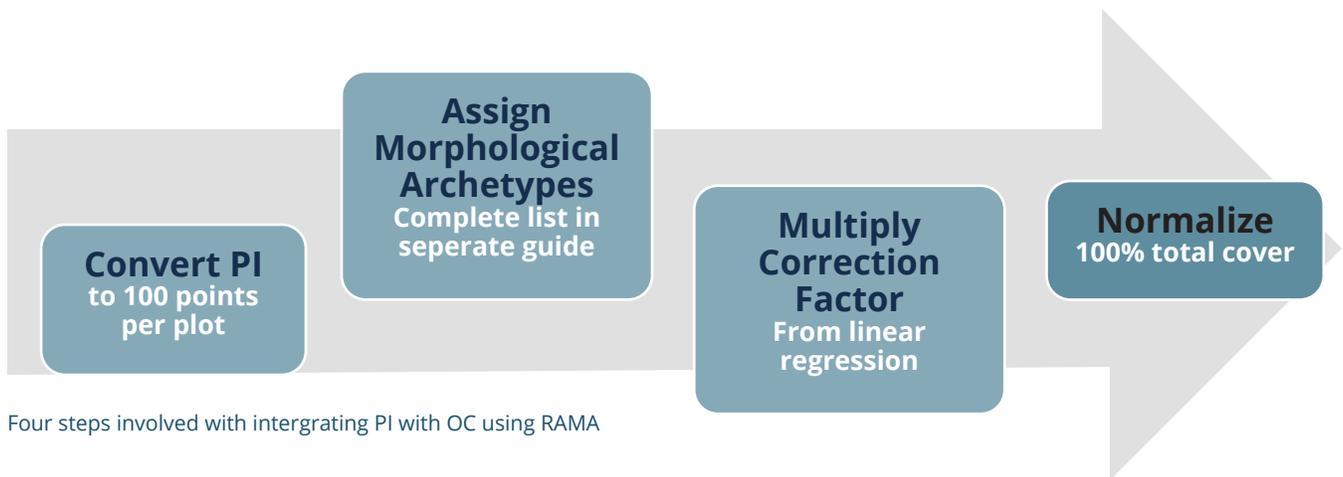
We employed multiple levels of additional quality control checks beyond the measures taken at each Reserve.

- Data Transfer** - During transfer from individual Reserve datasets to regional templates, each row of data was reviewed.
- Identify Suspect Data** - These were identified through graphing and for relative non-binned ocular plant cover, summing totals to 100%. Examples of suspect data include: individual or total covers beyond the limit of detection (i.e., 100% for relative ocular cover, 100 points for point-intercept per cover type), species occurring outside their typical habitat distribution, significant annual plot changes.
- Address Suspect Data** - Regional data handlers would first investigate suspect data, reviewing individual Reserve datasets, field datasheets (upon request) and plot photos if available (pictured). Secondly, we requested review from data originators. Suspect data were corrected, noted or omitted. All unresolved data were noted in the metadata.



Plot photo taken at the time of monitoring. Several Reserves collect photos.

# RECONCILE METHODS



Four steps involved with integrating PI with OC using RAMA

1. **Integrate Plant Cover**
2. **Assign Marsh Zone**
3. **Address Cover Discrepancies**

## INTEGRATE PLANT COVER

Two common plant cover data collection methodologies are used in New England Reserves: Point Intercept (PI) and Ocular Cover (OC). We found these different methodologies can influence interpretation. Through a separate but related project, we provide a novel and more accurate approach to integrate the two most common methods using Regressions Across Morphological Archetypes (RAMA). For step-by-step details, see our separate guide: “*A Guide to Integrate Plant Cover Data from Two Different Methods: Point Intercept and Ocular Cover*” ([www.nerrssciencecollaborative.org/project/Burdick18](http://www.nerrssciencecollaborative.org/project/Burdick18), Peter et al. 2020).

## ASSIGN MARSH ZONES

Marsh zonation is evident in many salt marsh systems, typically divided into two distinct zones primarily based off of mean high water: low and high marsh (Nixon 1982). The distribution of marsh plants is heavily influenced by hydrology; it is typical for SLR to cause a species to show decreased vigor or abundance at the lowest elevations of its distribution. This is evident with thinning and gradual disappearance of *S. alterniflora* at the seaward edge. SLR can also cause species to shift upslope into elevations they couldn't previously occupy due to competition, such as *S. alterniflora* increasing at the higher portion of its elevation distribution. Incorporating marsh zones into data visualizations and analyses helps parse out responses of plant communities to SLR. In addition, preliminary analyses for this project with marsh zones incorporated into the model as a

predictive factor explained considerably more variability. While some Reserves assigned marsh zones in the field at the time of plot establishment, others did not. To reconcile this, a marsh zone calculation was created a priori to help distinguish between low and high marsh zones and was assigned to each plot based on its first, Year 1, vegetation survey:

$$\text{Zone ratio} = \frac{(\text{Total cover of low marsh species})}{(\text{Total cover of vascular plants})}$$

If zone ratio > 0.9, we initially classified the plot as low marsh, and vice versa. For our study, low marsh species included *S. alterniflora*, *Atriplex patula*, *Ruppia maritima*, and *Salicornia spp.*; algal cover was not included in these calculations. Note, the zone ratio helped guide marsh zone assignment but was not treated as an irrefutable rule. Marsh zone assignments were additionally scrutinized by utilizing aerial imagery for landscape context, plot community data, plot photos, and discussions with each Reserve to ensure accuracy of initial zone determination. See Appendix for exceptions to the a priori calculations. Of the subset of plots that were assigned to the high marsh zone, we further examined these to assign a third zone to our dataset, upland edge. Upland edge plots were simply plots that bordered or extended into an upland or completely freshwater system (based on plant communities), which were also determined by plot location, species composition, aerial imagery and plot photos.

Typical marsh zone designations. Example from Bunker Creek marsh in Great Bay, NH.



## ADDRESS COVER DISCREPANCIES

**Bare and Dead:** Cover types measured within plots differed between New England Reserves. Most notably, half the Reserves parse out bare and dead covers, while the other half lump these categories together. Thus, for visualization and analysis purposes, bare and dead were combined. Other potential discrepancies in measuring dead cover relate to how it is defined. For the two Reserves which measured dead cover, both specified dead as having grown and died in the monitoring plot in the years prior to avoid counting early senescing plants (e.g., *Argentina anserina*, *Juncus gerardii*) or dead material brought in by the tides (i.e., wrack). We have also observed other protocols outside NERRs that do not distinguish between timing and origination for classification of dead or wrack cover.



Plot completely covered in *Spartina* and *Zostera* wrack in Great Bay, NH. Bunker Creek marsh in Great Bay, NH.

**Wrack:** Some marshes in this study rarely have wrack in their monitoring plots, whereas others can have the entire plot covered. As a result, some Reserves measure plots as they find them (i.e., 100% wrack cover; pictured to the bottom left), while others remove what little they find and do not record it as a cover.



Overstory covering the upland edge plot at Bunker Creek in Great Bay, NH.

**Algae, water, overstory:** For algae, most Reserves treat it equally with vascular species, but one Reserve does not record it. Half the Reserves record the presence of water, noting it only when there is standing water at low tide (e.g., pannes, pools) and not including it into the 100% total cover estimates (for ocular cover), but instead treating it as an extra 'canopy' layer. Lastly, overstory measurements were recorded by two Reserves because overstory can impact marsh vegetation. As a result of regional inconsistencies, analyses with all these types of cover data were excluded in regional analyses.

# ANALYZE DATA

1. Visualize Data
2. Univariate Statistics
3. Multivariate Statistics
4. Inundation Model

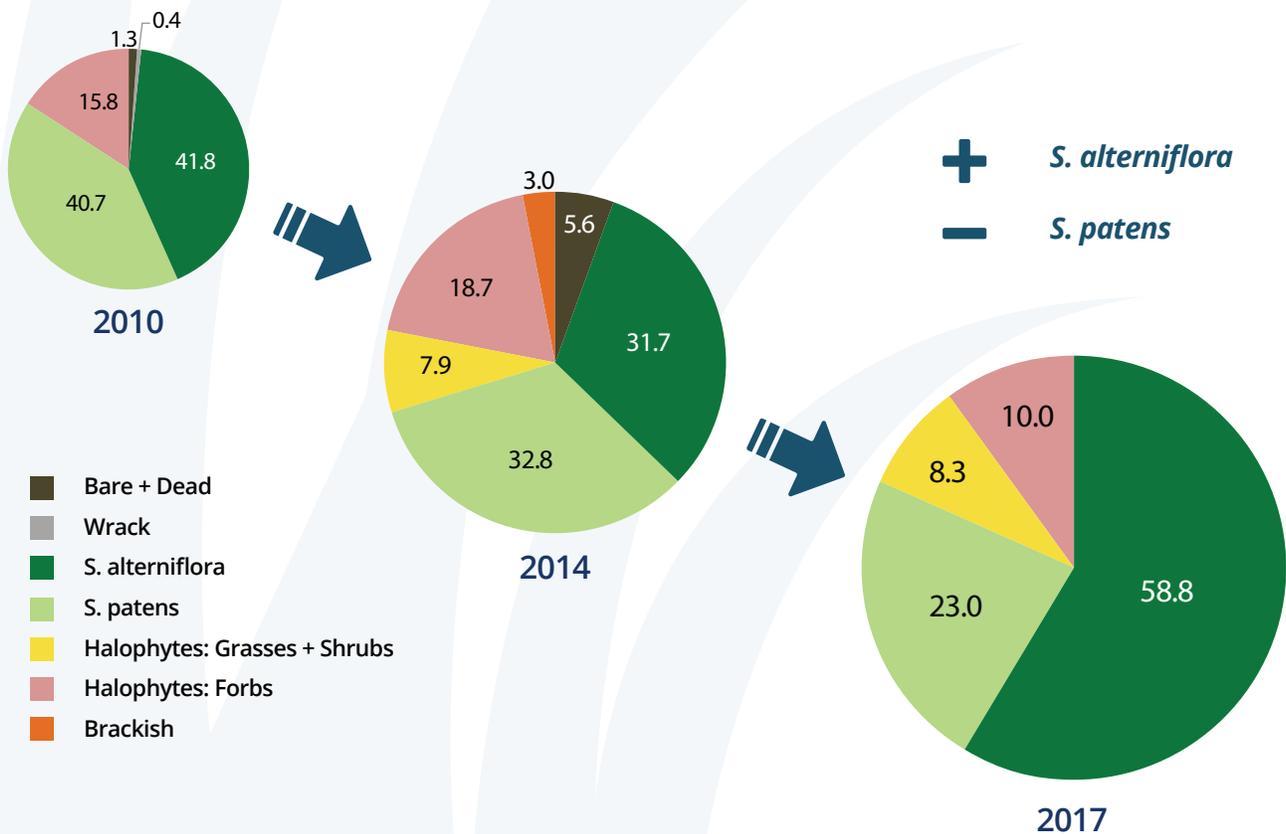


2011 2016

Visualizations and statistical analyses focused on several important questions: What is the year-to-year variability? Do changes over time represent a significant trend? Are responses in southern Reserves (small tide ranges) different than that of northern Reserves (large tide ranges)? In addition, plot elevation and tidal records were combined with plant abundance data to produce inundation models showing species elevation distributions over time.

## VISUALIZE DATA

Changes in marsh vegetation composition were visualized by the creation of pie charts, using cover estimates for each year of data between 2010 and 2017 for each marsh and marsh zone for all New England Reserves. Plant and abiotic covers (e.g., bare ground, dead) were individually highlighted (*S. alterniflora*, *S. patens*) or summarized into categories (Halophytic forbs, brackish species, etc.) for ease of visual interpretation. Individual or categories of cover were set to 100%. For relative, non-binned ocular cover (visual estimates), no data modification was needed. For point intercept data, which is quantified by point 'hits' on individual species or cover types and is not limited to 100%, required modification to (1) integrate with to ocular cover, and (2) normalize covers that exceed 100%. Both of these steps are also detailed in: "A Guide to Integrate Plant Cover Data from Two Different Methods: Point Intercept and Ocular Cover".



Example of pie charts from high marsh plots in the Webhannet marsh, Wells, ME

## UNIVARIATE STATISTICS

### Metrics Tested

*S. alterniflora* Forbs  
*S. patens* SA : SP

Total halophytic cover  
 High marsh perennials  
 Non-living cover  
 Species richness

Analyses were designed to identify changes in plant community over time at several scales. Univariate analyses, where one dependent variable is examined at a time (listed to the left), were conducted using JMP software (JMP® Pro 14.0.0, SAS Institute

Inc.). A small group of variables were selected from the plant cover data based on dominance and presence. Uncommon species were avoided because a large number of '0' observations would make the error distribution uneven and non-normal, two important assumptions of parametric statistics. However, less common species/abiotic covers could be incorporated into the analysis by grouping them together. For example, groupings of all salt tolerant species (halophytes) or non-living cover (bare, dead and wrack) were used as dependent variables. Because *S. patens* is uncommon in the low marsh zone and *S. alterniflora* is less common in the high marsh, we developed a ratio of the two that is sensitive to changes in their relative abundance:

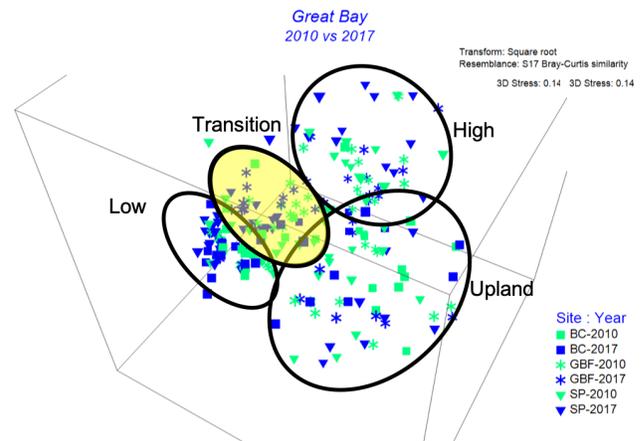
$$SA : SP = \frac{S.alterniflora}{S.alterniflora+S.patens}$$

Analyses of covariance (ANCOVA) were run for all of New England by marsh and sub-region (northern vs. southern Reserves) as well as individual Reserves. The best explanatory model that accounted for most of the variation

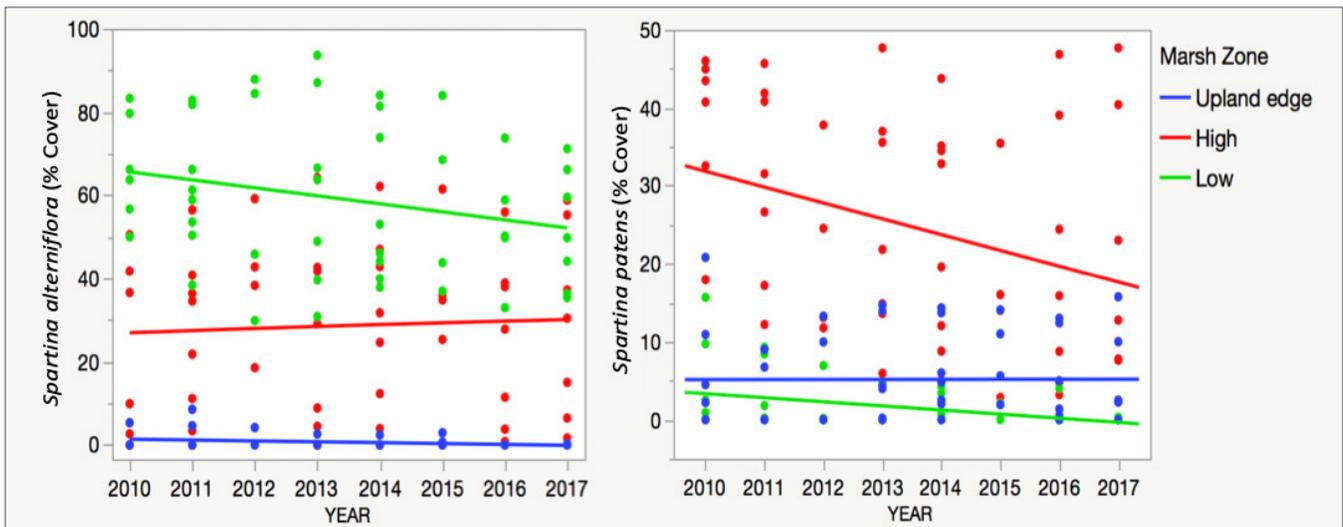
(except for forb plant cover) included marsh site, marsh zone, and year as covariable, with all two-way interactions. To provide an equal sample size for each marsh zone, a mean generated for each marsh zone was analyzed. Residuals were examined, and some variables were transformed to ensure even variance with changes in abundance as well as a normal distribution.

## MULTIVARIATE STATISTICS

Marsh plant communities were further analyzed using non-metric multivariate tests using PRIMER 6 version 6.1.9 (Clarke and Gorley, 2001), which included non-metric multi-dimensional scaling (MDS), analysis of similarity (ANOSIM),



Non-metric multi-dimensional scaling plot of Great Bay, NH, showing data from 2010 and 2017. Black circles approximate marsh zone. Yellow highlights significance across years via ANOSIM



Examples of univariate analyses conducted using eight New England marshes, examining *Spartina alterniflora* (left) and *Spartina patens* (right) over time for each marsh zone. The broad scatter seen here resolves when the model accounts for differences among the eight marshes monitored.

and contributions to similarity analysis (SIMPER). These tests were chosen for their flexibility to handle non-parametric datasets as well as their ability to simultaneously account for multiple community characteristics (e.g., composition, abundance, diversity). Plant community data, in the form of percent cover, were standardized using either a square-root or 4th root transformation, where appropriate, then analyzed as a Bray-Curtis similarity matrix. For each comparison, MDS were run using 100 iterations and ANOSIM were run using 999 permutations. Stress shown on the MDS ordination plots indicate how well the Bray-Curtis similarity matrix matches up with the dimensional relationships among samples. PRIMER's guidance on interpreting stress values (Clarke and Gorley 2001):

<0.05	Excellent
>0.05 x <0.1	Great
>0.1 x <0.2	Good
>0.2	Poor

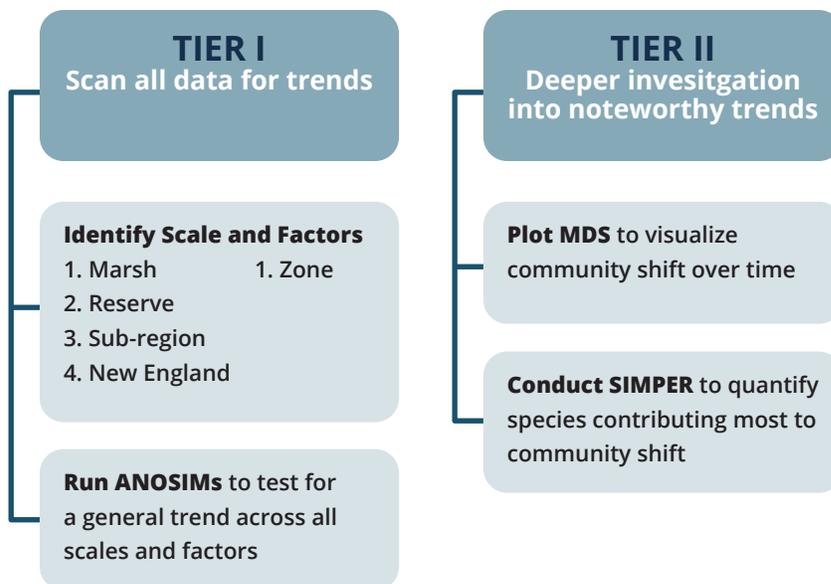
Cover Categories	Average Cover		Dissimilarity		
	1st year	Last year	Avg	%	Cum %
Water	23.80	26.89	10.46	21.93	21.93
Bare Ground	33.85	37.19	10.09	21.15	43.07
<i>Spartina alterniflora</i>	55.03	48.24	9.42	19.75	62.82
Dead	3.27	5.26	4.65	9.74	72.56
Algae	0.45	3.57	2.37	4.96	77.52
Wrack	2.16	1.43	2.16	4.52	82.04
<i>Spartina patens</i>	2.09	0.71	1.65	3.46	85.50
<i>Salicornia spp.</i>	0.34	0.92	1.65	3.45	88.96
<i>Distichlis spicata</i>	1.01	0.13	1.05	2.20	91.15

SIMPER results from New England low marsh, showing the highest covers contributing most to dissimilarity (up to 90%) between 2010-2017. Blue indicates an increase in cover, orange indicates a decrease.



Drone-captured imagery of Sage Lot Pond in Waquoit Bay.

Our statistical approach was designed to test our main hypothesis: Are New England salt marshes changing over time? As such, time was our primary factor of concern. To address this main hypothesis as well as handle the large volume of data and potential tests, we utilized a two-tiered approach:



**TIER I:** A series of one-way ANOSIMs were conducted to test for significance in plant community composition from the first year to last year of available data across multiple scales (marsh, Reserve, sub-regions and New England) and factor (marsh zone). A total of 60 comparisons were run, in contrast to >1600 comparisons with the same approach but with the addition of all potential year combinations.

**TIER II:** When changes in plant community composition over time were significant ( $p < 0.05$ ) or associated with a general trend ( $p < 0.20$ ), this triggered further investigation using MDS ordination plots to visualize community differences between plots and SIMPER to determine the species contributing most to differences detected between groups. Example of MDS on previous page and SIMPER to the left.

## INUNDATION MODEL

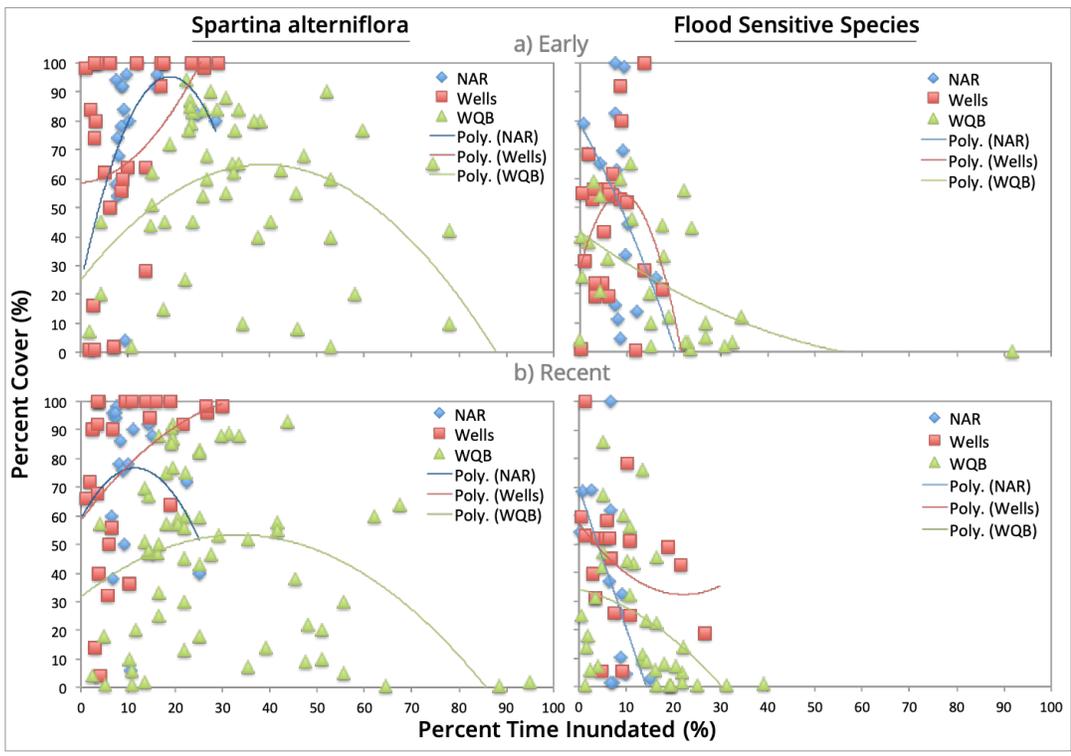
An inundation analysis was conducted to determine changes in plant community composition associated with flooding over time. These analyses compared percent flooding along an elevation gradient from an early time period (2010-2013) to a recent time period (2016-2018), depending on data availability for each Reserve. Data required to run the analysis included water level, elevation, and vegetation measurements (percent cover) for each marsh site. Elevations were collected by GPS RTK or a digital level and

Datalogger data Here!				Flooding (formula)	
Gray cells require data entry or verification that the formula encompasses all data. Don't forget to edit macro where necessary.				This formula will only summarize the flooding	
Elevation of marsh surface and info on the elevation of the water level gauge				Marsh Elevation m, NAVD88	
Avg marsh Surface 0.73381 m NAVD88					
Sensor Depth cm (Distance from Connection Point to the Sensor)					
Sensor Connect Elevation m NAVD88					
Sensor Elevation m, NAVD88				Flooding = 364.20 hour	
Sensor to marsh Surface 0.73381 meters				Total time = 8760 hour	
				% time flooded 4.16	
Raw data from LOGGER or other data source					
Water above sensor				Flooding Macro	Flooding formula
Corrected water level data from the logger				WL data converted to values relative to the marsh surface	WL data converted to NAVD88 elevations
Sensor Depth, meters				Depth on Marsh	Sensor (NAVD88)
Logger Data	Logger data	Logger Data	Logger Data		
Date Time, GMT-05:00	Abs Pres, kPa	Temp, °C (LGR)	Abs Pres Baro		
01/01/2010 00:00:00			0.664	-0.06981	0.664
01/01/2010 00:06:00			0.638	-0.09581	0.638
01/01/2010 00:12:00			0.667	-0.06681	0.667
01/01/2010 00:18:00			0.682	-0.05181	0.682

Screenshot of the macro developed by Jim Lynch, NPS, which calculates percent flooding for each plot.

water levels by an instrument placed directly in the marsh or from the nearest NOAA CO-OPS tide gauge. For each time period (early and recent), percent flooding for each Reserve marsh site was calculated using a macro developed by Jim Lynch (National Park Service). Water levels, measured every 6 minutes over one-year, and each plot surface elevation were inserted into a spreadsheet (pictured above). For each plot, the macro determined how many times over the year a specific elevation was inundated, calculating a percent time

flooded, which was manually repeated for every permanent monitoring plot. After percent flooding was calculated for each plot in each marsh with all required data, it was compiled into a database and compared to the percent cover of vegetation. To determine plant response to flooding, an analysis of percent flooding was compared to multiple individual or grouped cover categories (e.g., *S. alterniflora*, *S. patens*, *D. spicata*, *J. gerardii*, non-vascular cover) across early and recent time periods.



Example of inundation analysis output. These graphs show the relationship between amount of time a plot is flooded and the vegetation cover of *S. alterniflora* (left) or flood sensitive species (right). Data shown is from three Reserves (NAR, WEL, WQB) for a) early (2010-2013) and b) recent (2016-2018) time periods. All regression lines are polynomial best fit for the Reserve with the corresponding color. Flood sensitive species include *D. spicata*, *J. gerardii* and *S. patens*.

# SUMMARY

Identifying significant patterns and trends in long-term monitoring data can reveal ecological responses and inform best management practices useful to scientists, conservation and restoration practitioners and resource managers. Also important is documenting and describing the process involved for local and regional data syntheses to help refine future monitoring efforts and catalyze the examination of other datasets in a similar fashion. Our overall project not only provides this guide to facilitate further data analysis and visualization, but also provides data templates and immediate insights into sea-level-rise effects on marshes throughout New England (see final report Burdick et al. 2020). One of the biggest roadblocks to synthesizing large datasets is *“How”*. We hope we have helped to ameliorate this roadblock by laying out a detailed guide to address issues associated with large datasets covering a breadth of time, geography and methodologies.

The greatest amount of time spent on data synthesis was the standardization process, outlined on pages 3 and 4. We ‘manually’ standardized data from 4 Reserves, 8 marshes, 269 monitoring plots, ~30,000 data points, that included up to 8 years of data. Just for vegetation data alone, dataset formats prior to this project were created and housed by each Reserve individually, leading to 6 different data formats. One Reserve with high rates of staff turnover vegetation used 3 different formats for their vegetation data. Smaller datasets, especially those that have consistent methods and that are constrained to local analyses are less time-demanding. In contrast, datasets covering larger spatial and temporal scales such as national in scope, are likely to be even more time-consuming. For these larger dataset compilations, we recommend utilizing software for automation or, interns (along with additional QA/QC) to reduce staff time spent on standardization. We acknowledge the difficulties in addressing the tradeoff between large datasets spanning multiple geographies and smaller datasets that are locally focused. Larger datasets add power to your conclusions and due to their larger geographic scope, have a greater relevance to a wider audience, but are also more challenging when they encompass different plant communities, methods, and local and regional forcing factors, etc. A more general analysis with relative metrics (such as ratios of flooding tolerant to flooding sensitive species) may be needed in these instances.

# ACKNOWLEDGEMENTS

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# APPENDIX

## REGIONAL DATABASE NOTES

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### Great Bay

Elevations for Sandy Point in 2011 were obtained from NGS 2011 LiDAR. All other reserves elevation measured by RTK or digital levels.

### Narragansett Bay

Point intercept recordings for a 50-point quadrat were doubled, corrected by applying OC vs. PI cover regressions for each of seven morphology types and normalized to 100 (see 4. below for method). Presence of species in plot with no hits (P) was changed to 1. From 2016-2018 Nag marsh cover were not be analyzed because of a high degree of variability among observers, but this data is still included in database. Corrections for inter-observer variability were explored to this time period of data, but were unsatisfactory. Separate observers collected data in various years, cover results using the PI method between observers were highly variable and without a distinct pattern. Regressions provided a weak correlation when conducted for specific cover classes that. This summer (2019) an in-field analysis will be done between observers to try and find a correction factor. Height data is satisfactory through the years.

### Waquoit Bay

Percent cover dead red cedar stump and dead shrub added to dead cover category. Percent cover snails, live mussels, shells, and an unfortunately placed core sample in one plot were added to bare cover. Percent cover trash, overstory wrack, and overstory trash were added to wrack cover. Percent cover standing water and overstory water added to water cover. Foot trampling % cover moved to notes. Algae broken into red, brown and green cover types in 2017 and 2018 data; these were combined into an alga cover category. 0.1% cover was standardized to 0.5% cover and indicates plant presence in a plot. Marsh edge distances based on 2012 LiDAR and 2013 RTK data.

### Wells

Point intercept recordings for a 50-point quadrat were doubled, corrected by applying OC vs. PI cover regressions for each of seven morphology types and normalized to 100 (see 4. below for method). Presence of spp in plot with no hits (P) was changed to 1. Ecads and seaweed were write-ins on datasheets sporadically throughout all years, these were added to algae cover since Wells does not classify wrack cover and write-ins did not distinguish whether wrack or not. In 2014, plots 2I5, 3R5, and 4R5 had the write-in of NY Aster: since this plant has never been recorded on Wells sentinel site monitoring and presence of *Solidago sempervirens* was found throughout the years in these plots, these NY Aster points were changed to

*S. sempervirens*. In 2011 at plot 3I5, *Festuca rubra* was recorded with 50/50 hits; this species was never documented again, but high counts of *Carex palacea* (a similar morphotype plant) were documented in subsequent years; for consistency, *F. rubra* hits at this plot were changed to *C. palacea* for 2011. For restoration efforts, *Phragmites australis* was cut in 2016 and therefore not recorded in plots for this year since Wells does not record dead vegetation.

### All Reserves

Due to discrepancies in nomenclature of various *Salicornia* spp., all were lumped into *Salicornia* spp. category for regional analyses. Due to discrepancies within and between Reserves in classifying short or long form *S. alterniflora*, all were lumped into *S. alterniflora* for regional analyses.

## LOW MARSH CALCULATION EXCEPTIONS

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### Great Bay

Both GBF plots 4-1 and GBF 6-1 are creek bank marsh plots that were classified by equation as High marsh zone; these were kept as their original Low marsh, ground-truthed, classification.

### Narragansett Bay

No exceptions.

### Waquoit Bay

No exceptions for Sections 1 and 2 marshes. Section 3 had no marsh zone designation assigned since it is a restored marsh with lower salinities and had different results in multivariate analyses than other marshes with calculated zones. Section 3 was also excluded from regional analysis for the same reasons.

### Wells

Both plots 1R1 and 2I1 were verified by 2016 plot photos and location to be creek bank marsh plots that were misclassified by the equation as High; these were kept as their original Low marsh classifications. Plot 2R4 was verified with 2016 imagery and location to be a High marsh plot misclassified by equation as a Low marsh plot.

## SET SAMPLING DENSITY ISSUE

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Wells Reserve is the only reserve to measure 8 arm directions instead of 4 arm directions. All reserves needed data to be synthesized to 4 arms to be analyzed together. Potential differences between 8 and 4 arm data were analyzed through ANOVA, and no significant differences were found. Wells 8 arm data were reduced to 4 arm measurements for comparison with other Reserves: only cardinal direction measurements at 0, 90, 180, and 270 degrees were kept and used in this database for regional analysis.