Synthesizing NERR Sentinel Site data to improve coastal wetland management across New England

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Name of Reserves involved in the project:
Wells, Great Bay, Waquoit Bay, Narragansett Bay

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Abstract

Saltmarsh monitoring data collected from the four New England National Estuarine Research Reserves (NERRs) from 2010 to 2017 were combined to form one homogeneous database. These data were collected as part of the NERRs System Wide Monitoring Program (SWMP) to help manage local and regional salt marshes. The goal for this particular project was to synthesize the SWMP data from salt marshes and identify significant changes over time in plant species abundance and marsh surface elevation as distinct from natural annual variation and provide products to help guide syntheses in different regions. As primary stakeholders, Reserve staff wanted to know if there were changes in their salt marshes and if such changes were reflected in the larger geography of New England. Staff from other state and federal agencies as well as non-governmental organizations were also interested in local and regional changes as well as learning what were the best assessment tools, relatively unaffected by interannual variability, that they could include in their monitoring programs.

Despite the use of a common protocol, many monitoring differences were identified among the Reserves. For example, relative abundance of plants by species was assessed using one of two common techniques: point intercept and ocular cover, each used by two of the four Reserves, so a correction factor was devised to make abundance values across Reserves comparable. Those differences that could not be rectified (e.g., plant height) were dropped from the regional analysis, but kept in the regional dataset and individual Reserve datasets. In this way, each Reserve can confidently analyze their common and Reserve-specific data to generate and share information with local collaborators to support improved marsh management with changing climate.

Three tiers of increasing complexity were used to analyze changes in vegetation: graphical, univariate statistics, and multivariate statistics were used to examine vegetation changes in eight marshes spread across four Reserves from Rhode Island to Maine. In all cases, significant trends were found that showed marshes were becoming wetter, with low marsh losing plant cover and high marsh looking more like low marsh over time. Marshes in Rhode Island and the southern shore of Cape Cod have the most dramatic vegetation changes, co-occurring with relatively small tidal ranges. The marshes examined in Maine and New Hampshire have larger tides and showed less change. Both these results reflect the vulnerability of salt marshes to sea level rise in microtidal (more vulnerable) and mesotidal (less vulnerable) estuaries in a general sense.

Over 30 regional researchers and managers participated and helped direct the research by shaping several of the questions used to test the long-term monitoring data. Results from specific Reserves and across the region can be used to help guide salt marsh management.

Narrative

Project background and approach

Many of the 29 National Estuarine Research Reserves (NERRs) established biomonitoring sites in salt marshes in 2010 and 2011 to identify and track changes in salt marshes at each Reserve and serve as Sentinel Sites that could alert managers to local and regional changes. After 7 or more years of collections that assessed plants, marsh surface elevation, local water levels, salinity and other parameters, only one New England Reserve (Narragansett Bay) made a concerted effort to examine changes over time, but when they investigated the possibility of combining data from other Reserves, they found several barriers to data synthesis. Our project sought to overcome the barriers in order to combine the data collections for the four New England Reserves and synthesize the results. The biomonitoring sites were established to identify changes in long-term trends, such as sea level rise (SLR), and an important aspect of the design and future analysis was to be able to identify and account for year-to-year variability. This project would also be able to look at the effect of tide range (two Reserves with small tide ranges and two with large). Where sufficient data were available (RI, MA and ME Reserves), inundation modeling tied the elevation distribution of salt marsh vegetation to local tidal data to assess flooding duration in relationship to vegetation or bare ground cover.

An important component of the project was to provide each Reserve with their data in a common format following Quality Assurance/Quality Control (QA/QC) that is suitable for data reduction and statistical analyses. This empowers Reserve staff to analyze their data and collaborate with other Reserves to develop and answer questions of the dataset. Following data reformatting and corrections, most of the vegetation and surface elevation data for each Reserve were compatible across the four Reserves, with identical formatting, species names, species abundance metrics, and initial zone (habitat) designations. Some components could not be combined across Reserves due to methodological differences, such as plant height or algae cover, and these were included in each Reserve-specific data set so that the common elements could be analyzed with the unique elements for each Reserve.

Figure 1. Location of the four National Estuarine Research Reserves in New England.

Table 1- List of project participants, who helped in design, implementation and review.

Project End Users (Agency / Type)	**Project Role**	**Influence**	**Potential Benefits**
New England NERR staff	Project Team Member or participant sharing data	Shared data, met monthly, shaped project	Confidence in data set Value of standardization Analysis to inform staff & public
State CZM (ME, NH, MA, RI), Natural Heritage	Workshop participant	Proposed / shaped project questions	Share results to influence policy and management
NERR and USFWS	External Advisors	Guidance for tech + outreach	Identify best tools to show change Importance of strict protocols
NOAA staff	Workshop participant	Proposed / shaped project questions	Share results to influence policy and management
NGO staff (TNC, Trustees)	Workshop participant	Proposed / shaped project questions	Share results to influence policy and management
National NERR staff	Targeted End-users	Refined How to Guides	Apply project methods to other areas of the country

At the outset, a kick-off meeting with our wider stakeholder group help shape some of our research questions (e.g., what is the best assessment tool for identifying change in marsh vegetation caused by sea level rise). Project team members from the four Reserves shared the data that had been collected over the past seven to eight years with our team at Great Bay NERR who worked through a variety of data issues and identified conflicts and dissimilarities with the individual Reserves and larger team. Monthly video conference calls with the project team and advisors allowed continued, incremental progress for these data issues. Details can be found in the 'How To' guides for database development and converting point-intercept (PI) to ocular cover (OC) for plant abundance. In late August 2019 we hosted a second workshop where we invited participants to experience the difficulties in measuring plant abundance using the two methods (PI and OC) in the field before the main indoor session where graphical, univariate and multivariate results were presented of plant abundance, surface elevation change and inundation modeling. Meeting notes and the slide deck were distributed to the participants, so they could use our results and share them with a wider audience.

Once data were formatted, underwent QA/QC, and standardized they were combined for all years and Reserves and data analyses were divided among our team. First, simple pie charts were constructed for visualization of plant abundance and change over time in each habitat of each marsh from each Reserve. Data were summarized into categories for ease of visual interpretation and cover types included in categories were decided upon by each Reserve to best summarize their specific marsh. This showed clear trends across Reserves and provided the Reserves with a template for graphic analysis of their other marshes.

Statistical analyses focused on several important questions for plant abundance and marsh surface elevation: What is the year-to-year variability? Do changes over time represent a significant trend? Are responses in the two southern Reserves (small tide ranges) different than that of the two northern Reserves (large tide ranges)? In addition, plot elevation and tidal records were used with plant abundance to produce inundation models showing species elevation distributions in the marshes. Univariate analyses, where one dependent variable is examined at a time, were conducted using JMP software. A small group of variables, selected based on dominance and presence, included single species (*Spartina alterniflora*, *Spartina patens*), SA:SP ratio, grouped species (all halophytes, forbs, the high marsh perennial grasses *D. spicata* + *J. gerardii* + *S. patens*), grouped non-living cover (bare + dead + wrack) and species richness per plot. The SA:SP ratio is:

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

Analyses were run for the entire dataset, northern vs. southern Reserves as well as individual Reserves (Reserves had 1-3 marshes and these are termed 'sites'). The best explanatory model that accounted for most of the variation (except for abundance of forb species) included marsh site, plot habitat, and year as a covariable, with interactions included where significant. Residuals were examined, and some variables were transformed to ensure even variance with changes in abundance and normal distribution.

Marsh vegetation communities were further analyzed using multivariate tests using PRIMER 7 (Clarke and Gorley, 2001), which included non-metric multi-dimensional scaling (MDS), analysis of similarity (ANOSIM), and contributions to similarity analysis (SIMPER). These tests were chosen for their flexibility to handle non-parametric datasets as well as their ability to 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, when appropriate, then analyzed as a Bray-Curtis similarity matrix. For each comparison, NMDS were run using 100 iterations and ANOSIM were run using 999 permutations. First, a series of one-factor ANOSIMs were conducted to test for significant differences in plant communities from the first year to last year of available data for each marsh (n=8), Reserve (n=4) and sub-regions (n=2) and New England as a whole (n = 1) as well as across distinct marsh zones (low marsh, transition when noted, high marsh, upland edge). A total of 60 comparisons were run; a subset of the potential 1,600 comparisons. Second, when significance ($p<0.05$) or a general trend ($p<0.20$) was identified, further investigation was triggered using MDS to visualize community differences between plots and SIMPER to determine the species contributing most to differences detected between groups of samples. Complete ANOSIM and SIMPER results as well as MDS graphics are associated with this second tier of investigation.

Inundation modeling (developed by Jim Lynch, National Park Service) was performed to examine the flooding duration of salt marsh vegetation in the Sentinel Site monitoring plots of the four New England Reserves which span two biogeographic provinces (Acadian and Virginian) corresponding to mesotidal (ME, NH) and microtidal (MA and RI) tidal regimes. Although vegetation abundance and distribution likely differ among these marshes, the dominant plant species are similar. Where sufficient data were available, plot elevations were combined with local tidal data to assess flooding duration in relationship to vegetation or bare ground cover. The three Reserves that had sufficient data to conduct the inundation analyses (ME, MA, RI) also had two different elevation surveys of their Sentinel Site plots, thus allowing us to conduct a change analysis using early (2010-2013) and recent (2016-2018) periods of flooding duration and cover type.

Key findings

Vegetation Changes:

Pie charts (visualizations without statistical analysis) showed plant community changes over time (Figure 2). Overall, marshes across New England have changed between 2010 and 2017 with low marsh areas displaying a loss of live cover and increase in bare, and high marsh areas showing an increase in *S. alterniflora* and decrease in *S. patens*. Overall upland edge plots also displayed transition towards wetter, more tidally influenced systems. See Table 2 for specifics relating to each Reserve.

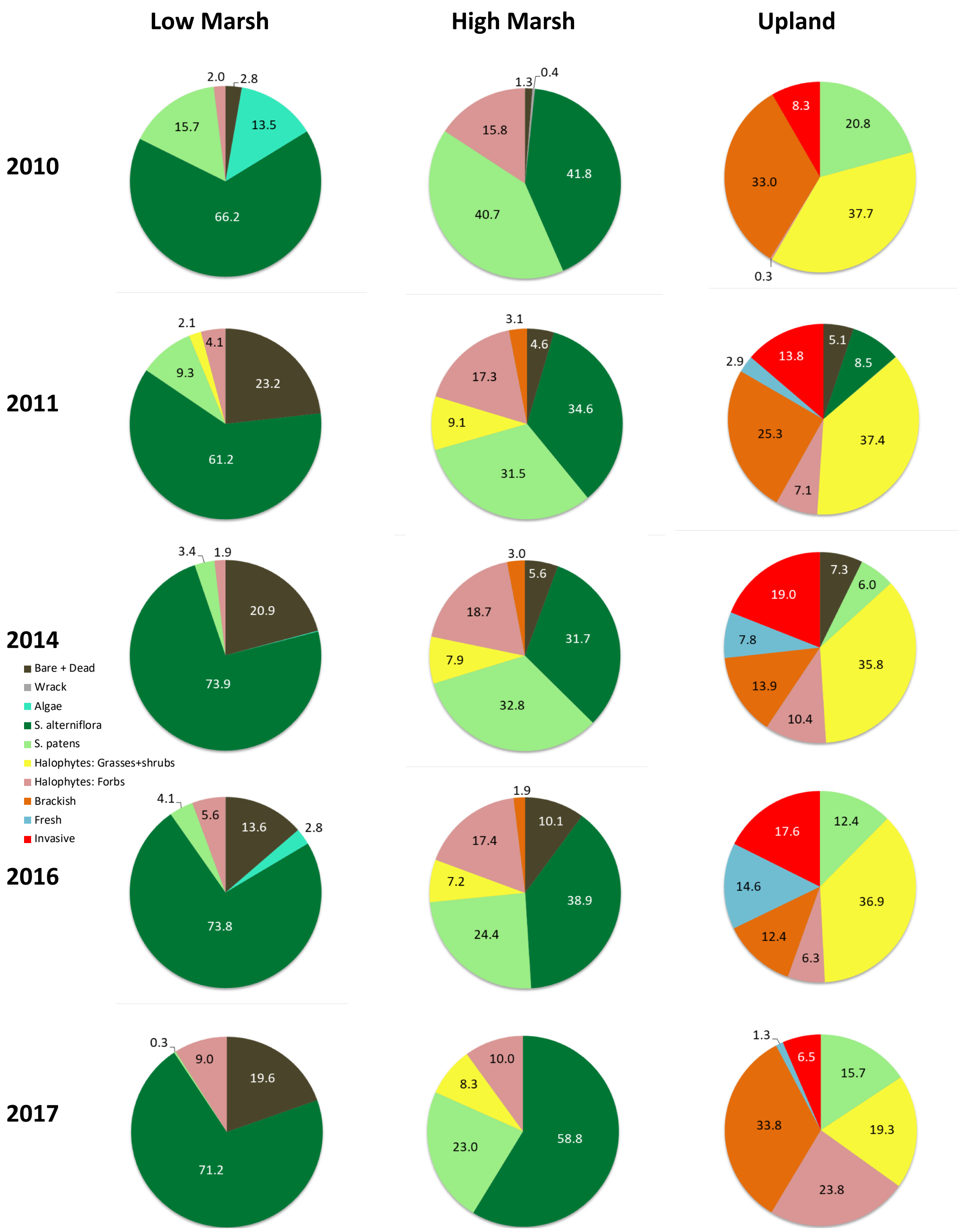

Figure 2. Graphic visualization of plant and cover changes in Webhannet Marsh, Wells, ME.

Table 2: Trends in vegetation abundance for one marsh in each Reserve, examined by habitat type over time across the full monitoring period available. Sandy Point was the only marsh where transition habitat type, located at the boundary of the low and high marsh zones, was included.

Reserve	**Low Marsh**	**Transition**	**High Marsh**	**Upland Edge**
Great Bay Sandy Point	- *S. alterniflora* + Algae + Bare and Dead	+ *S. alterniflora*	+ *S. alterniflora* + Halophytic grasses and shrubs - *S. patens*	+ Brackish species
Narragansett Bay Coggeshall	- *S. alterniflora* + Bare and Dead	n/a	+ Bare and Dead - *S. patens* - Halophytic grasses and shrubs	+ Invasive species
Waquoit Bay Sage Lot Pond Section 2	+ Bare	n/a	+ *S. alterniflora* - *J. gerardii, D. spicata*, and *S. patens*	+ Bare and Dead - *J. gerardii, D. spicata*, and *S. patens*
Wells Webhannet River	+ *S. alterniflora* - *S. patens* + Halophytic forbs	n/a	+ *S. alterniflora* - *S. patens*	+ Halophytic forbs

Statistical analyses of particular species, cover types and various combinations were performed on 1,539 observations across the four Reserves using ANCOVA, with Site and Marsh Zone as main effects and Year as the covariable. Overall, each Reserve and each marsh within Reserves were different, so the marsh site effect was large. Marsh zone (i.e., Habitat type) was a critical main effect because plant abundance in different parts of the marsh vary (i.e., one would expect mostly *S. alterniflora* in the low marsh). In addition, species within Zones behaved differently over time. For example, *S. alterniflora* decreased over time in the low marsh but increased in high marsh plots; this is shown as a significant Marsh Zone by Year interaction (Table 3; Figure 3).

An important result showed that year-to-year variation in the cover of specific or total marsh plants was not large enough to prevent us from identifying long-term trends, likely associated with increases in sea level rise (Figure 3). Trends in plant abundance indicating losses in low marsh vegetation, advance of low marsh into high marsh and declines in high marsh species abundance were shown over all Reserves and for specific Reserves. Comparison of southern, microtidal Reserve marshes with northern, mesotidal Reserve marshes showed geographic and temporal effects (Table 4), with more rapid declines of key species in the south: *S. alterniflora* in the low marsh and *S. patens* in the high marsh (Figure 4). The univariate analyses supported the overall trends shown in the graphic and multivariate analyses, but also provides statistical support and valuable insights for exceptions in specific marshes and details about changes in specific cover types (e.g., SA:SP).

Table 3. Model results for univariate ANCOVA for four Reserves combined showing *p* values for Site, Zone and Year and their interactions as well as the overall *F* statistic and proportion of variance explained, R^2. LN indicates data were log transformed for Forbs. Dispi+Juger+Sppat = *Distichlis spicata*, *Juncus gerardii* and *Spartina patens* combined.

Dependent Variable	SITE	ZONE	YEAR	Site X Zone	Year X Zone	Year X Site	Overall F	R2
Non-Living	0.0001	0.0001	0.0003	0.0001	0.8612	0.0319	26	0.89
Spartina alterniflora	0.0001	0.0001	0.3354	0.0001	0.0025	0.0964	72	0.96
Spartina patens	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	257	0.99
SA : SP Ratio	0.0001	0.0001	0.0001	0.0001	0.0001	0.0056	277	0.99
Dispi + Juger + Sppat	0.0001	0.0001	0.0001	0.0001	0.0308	0.0001	194	0.98
Forbs LN	0.0001	0.0001	0.1973	0.0001	0.2356	0.2608	1.54	0.14
Species richness	0.0001	0.0001	0.4295	0.0001	0.2200	0.1758	40	0.93

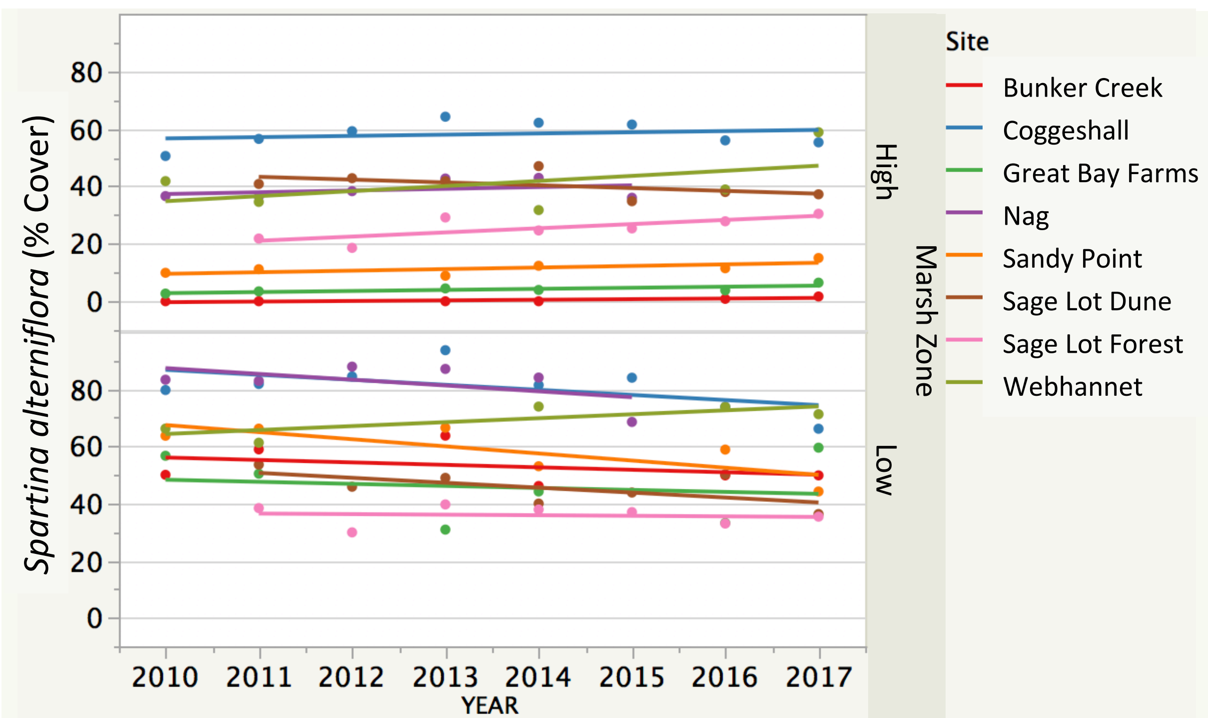

Figure 3. Changes in cover of *Spartina alterniflora* for low (L) and high (H) marsh zones in eight salt marshes of the four New England Reserves. Marshes in Waquoit Bay lie within Sage Lot Pond and include Dune edge marsh (Section 1) and Forested edge marsh (Section 2).

Table 4. Model results for univariate ANCOVA comparing two southern and northern Reserves showing *p* values for Region, Zone and Year and their interactions as well as the overall *F* statistic and proportion of variance explained, R^2. LN indicates data were log transformed. Dispi+Juger+Sppat = *Distichlis spicata*, *Juncus gerardii* and *Spartina patens* combined.

Dependent Variable	REGION	ZONE	YEAR	Year x Zone	Year x Region	Region x Zone	Overall F	R2
Non-Living LN	0.0171	0.0005	0.0013	0.8885	0.0009	0.0295	26	0.89
Spartina alterniflora LN	0.0001	0.0001	0.3285	0.1234	0.1825	0.0001	72	0.96
Spartina patens LN	0.6962	0.0001	0.0077	0.0968	0.1367	0.0002	257	0.99
SA : SP Ratio	0.0001	0.0001	0.5158	0.0008	0.4069	0.0001	277	0.99
Dispi + Juger + Sppat	0.0001	0.0001	0.0007	0.9454	0.0084	0.0001	194	0.98
Species richness	0.3510	0.0001	0.6484	0.8699	0.0918	0.8949	40	0.93

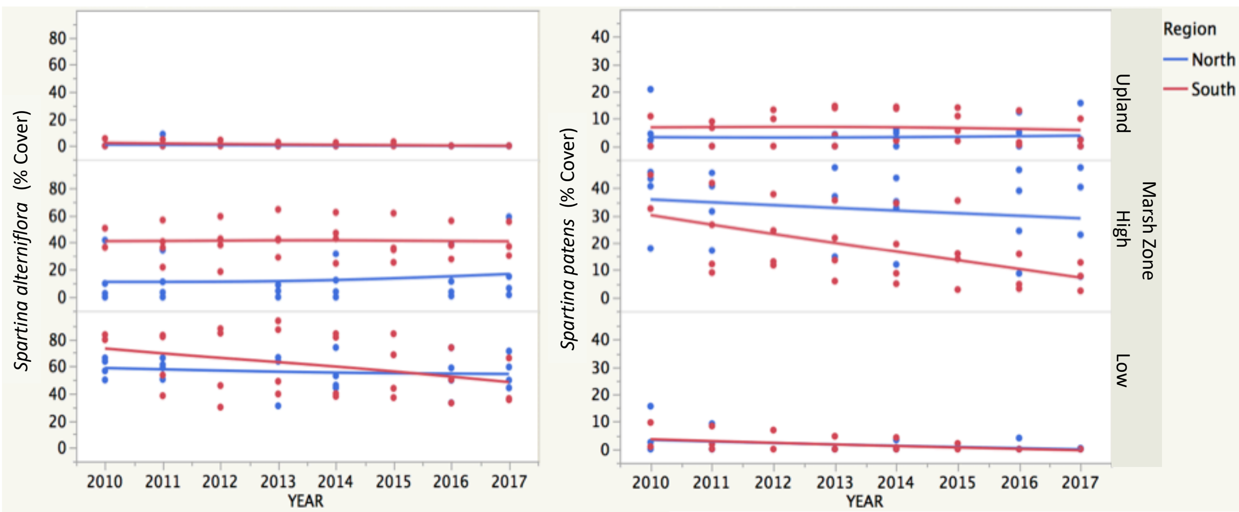

Figure 4. Changes in cover of *Spartina alterniflora* (left) and *S. patens* (right) for Low (L), High (H) and Upland edge (U) marsh Zones (habitats) in southern compared to northern New England Reserves.

Multivariate analyses indicate plant communities are shifting throughout New England towards communities more indicative of wetter environments. This shift becomes even clearer when analyzing by marsh zone. High marsh communities are becoming more similar to low marshes, with losses of dominant perennial grass cover, and gains in *S. alterniflora* and bare cover, whereas low marsh communities appear to be transitioning towards less vegetation, with large increases in bare, dead, and standing water (Table 5).

When examining by sub-region (northern mesotidal marshes vs southern microtidal marshes), we found more significant shifts in southern marshes (Table 6; Figure 5). Plant communities in these smaller tidal range systems show the largest impact from increased inundation, shifting towards bare unvegetated cover throughout the marsh, especially in the low marsh. Finally, the Reserve showing the largest change in the plant community is Narragansett Bay, RI (Table 7). In contrast, we did not find any significant differences in the low or high marsh zones in

Great Bay in NH but did detect significant changes at transitional plots placed at the boundary of low and high marsh zone: S. *alterniflora* was replacing *S. patens* in these transition plots (Table 8).

Table 5. Summary of multivariate PRIMER results for New England. All tests were performed across 1st and last years of data for each marsh: Great Bay and Narragansett Bay Coggeshall = 2010 to 2017. Narragansett Bay Nag = 2010 to 2015. Waquoit Bay = 2011 to 2017 and Wells = 2011 to 2016. Dark Blue shading indicates significance ($p<0.05$), whereas light blue shading indicates a general trend ($p<0.20$). Sp alt = *Spartina alterniflora*, Sp pat = *Spartina patens*, Di spi = *Distichlis spicata*.

	NEW ENGLAND			
	ANOSIM	NMDS	**+** SIMPER	**-**
Overall	0.007	X	Sp alt, Bare	Sp pat, Di spi
Low marsh	0.103	X	Water, Bare, Dead	Sp alt
High marsh	0.023	X	Sp alt, Bare	Sp pat, Di spi
Upland edge	0.542			

Table 6. Summary of multivariate PRIMER results for northern and southern New England. All tests were performed across 1st and last years of data for each marsh (as in Table 5).

	NORTHERN NEW ENGLAND				**SOUTHERN NEW ENGLAND**			
	ANOSIM	NMDS	**+** SIMPER	**-**	ANOSIM	NMDS	**+** SIMPER	**-**
Overall	0.029	X	Sp alt, Bare	Sp pat, Dead	0.004	X	Bare, Water	Sp alt, Sp pat
Low marsh	0.492				0.047	X	Water, Bare, Dead	Sp alt
High marsh	0.282				0.003	X	Sp alt, Bare	Sp pat, Di spi
Upland edge	0.802				0.674			

Table 7. Summary of multivariate PRIMER results for Narragansett Bay. All tests were performed across 1st and last years of data for each marsh (as in Table 5).

	Narragansett Bay			
2010 vs 2017*	ANOSIM	NMDS	**+** SIMPER	**-**
All Plots	0.001	X	Bare	Sp alt, Sp pat, Di spi
Low Marsh	0.016	X	Bare	Sp alt, Sp pat, Di spi
High Marsh	0.002	X	Bare, Sp alt	Sp pat, Di spi
Upland Edge	0.597			

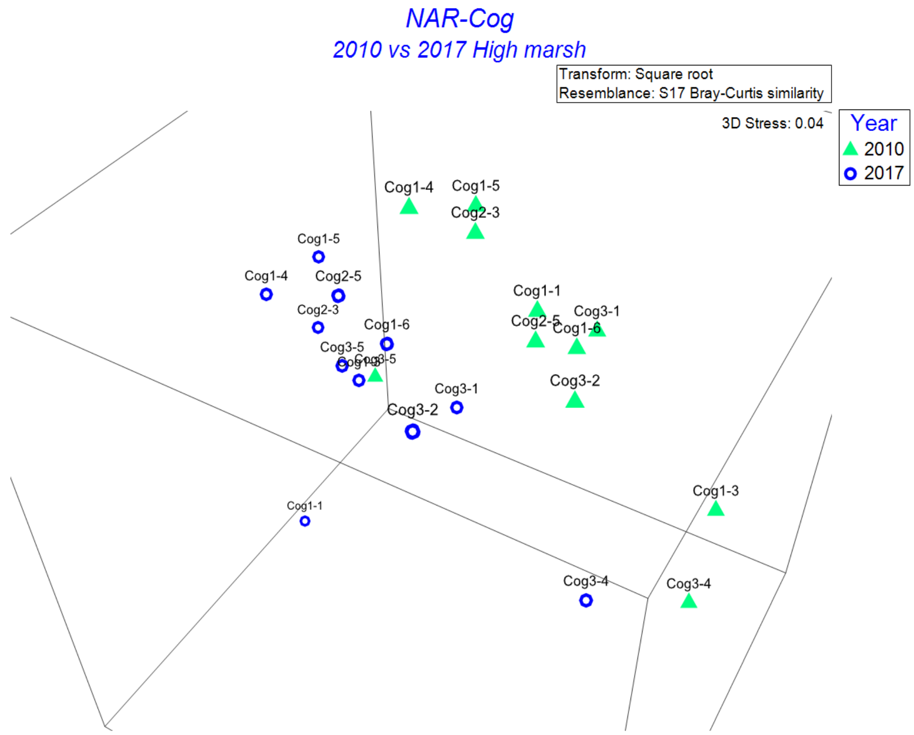

Figure 6. Non-metric multi-dimensional scaling plot of the low marsh plant community at Narragansett Bay - Coggeshall Marsh comparing 2010 with 2017 data. Symbols are labeled with plot IDs.

Table 8. SIMPER results table from Great Bay, NH transition plots located at the boundary of low and high marsh zones, showing the cover classes most contributing to dissimilarity (up to 90%) between 2010 and 2017. Blue shading indicates increased cover, orange indicates a decrease.

	Average Cover		Dissimilarity		
Cover Categories	2010	2017	Avg	%	Cum %
Spartina patens	16.27	10.97	8.59	16.76	16.76
Spartina alterniflora	34.66	59.38	8.1	15.8	32.56
Bare Ground	16.61	16.42	6.93	13.52	46.08
Dead	12.72	1.06	6.31	12.31	58.39
Wrack	9.59	1.38	5.22	10.19	68.58
Distichlis spicata	4.22	6.5	4.83	9.43	78.01
Water	9.06	1.72	3.42	6.67	84.68
Atriplex patula	4.41	0.06	2.29	4.47	89.15
Limonium nashii	0.41	0.73	1.41	2.75	91.9

Marsh Surface Elevation:

Surface elevation tables were used at all Reserves; data from the three Reserves that had multiple stations are reported here, and one Reserve also measured sediment accretion above marker horizons to yield an estimate of belowground subsidence (Table 9). In order to clearly see the change in marsh surface elevation over time, Figure 7 shows each SET location data offset along the Y-axis, which is then labeled relative elevation. Generally, elevation increase varied by marsh. For example, both marshes in Narraganset Bay (Figure 7) lost elevation relative to regional sea level rise (3.23 mm/yr), whereas, both Great Bay and Waquoit had one marsh with a rate of elevation gain similar to SLR and one less than SLR (Table 9). While we recognize that the SLR calculated for 2010 to 2017 at Wells, ME may not reflect local SLR rates at the other Reserves, it provides a reasonable average, matching the recent rates calculated by others (e.g., 3.26 mm/yr from 1993 to 2010 by Nichols and Cazenave 2010), but lower than the rate calculated for Narragansett Bay by Raposa et al. 2016 (5.26mm/yr for 1999-2015). Overall, marshes were building, but many were not building fast enough to maintain their position in the tidal frame in pace with SLR.

Table 9. Results from Surface Elevation Tables (SETs) and Marker Horizons at biomonitoring sites showing elevation increase and comparing it to SLR for the same time period (2010-2017) from tidal data at Wells ME (https://tidesandcurrents.noaa.gov/waterlevels.html?id=8419317).

			Rate of Change in mm/year					
Reserve	**Marsh**	**n**	**Surface Elevation Increase**	**Error**	**Marker Horizon Accretion**	**Subsidence (by difference)**	**Difference from SLR @ Wells 3.23**	**Result**
Wells	**Webhannet**	1	6.9	na			**3.7**	**GAINING**
Great Bay	**Sandy Point**	5	3.2	0.5	3.4	0.2	**0.0**	**EQUAL**
	Great Bay Farms	3	1.9	0.2	3	1.1	**-1.3**	**LOSING**
Waquoit	**SLP Dune Edge (Section 1)**	4	2.5	0.7			**-0.8**	**LOSING**
	SLP Forest Edge (Section 2)	4	3.0	0.7			**-0.2**	**EQUAL**
Narragansett	**Coggeshall**	6	1.1	0.3			**-2.1**	**LOSING**
	Nag	6	2.1	0.7			**-1.1**	**LOSING**

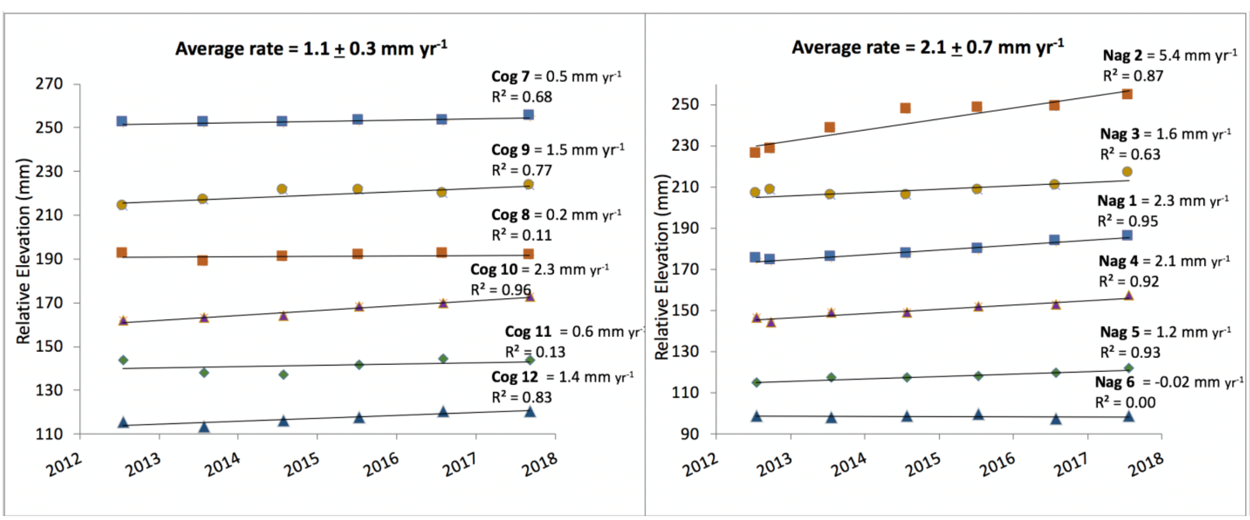

Figure 7. Elevation change determined using Sediment Elevation Tables (SETs) for two marshes in Narragansett Bay: Coggeshall marsh (left) and Nag Marsh (right). Data from the 12 numbered replicates are regressed over time and are offset along the Y-axis to improve readability.

Inundation Modeling:
Across the three Reserves included in the analysis (RI, MA, ME), some general, marsh-wide results are apparent. The percent cover of *S. alterniflora* has decreased in the recent surveys and is shifting to less frequently flooded plots (Figure 8). At the same time, *S. patens* and other flood sensitive high marsh species have also decreased in cover and the elevation distribution has become more restricted (Figure 8). Taken together, the results of the inundation modeling support our vegetation analyses and earlier work (Donnelly and Bertness 2001, Raposa et al. 2017, Watson et al. 2017), showing that *S. patens* and other flood sensitive species are being replaced by *S. alterniflora* as it migrates into marsh that is flooded less and suggesting that inundation due to sea level rise is a key driver in vegetation shifts and loss at lower elevations (Watson et al. 2017). Further, the bare ground cover type has increased at all Reserves, suggesting vegetation dieback or an increase in interior ponding, which may be especially detrimental in the microtidal marshes of Narragansett Bay and Waquoit Bay.

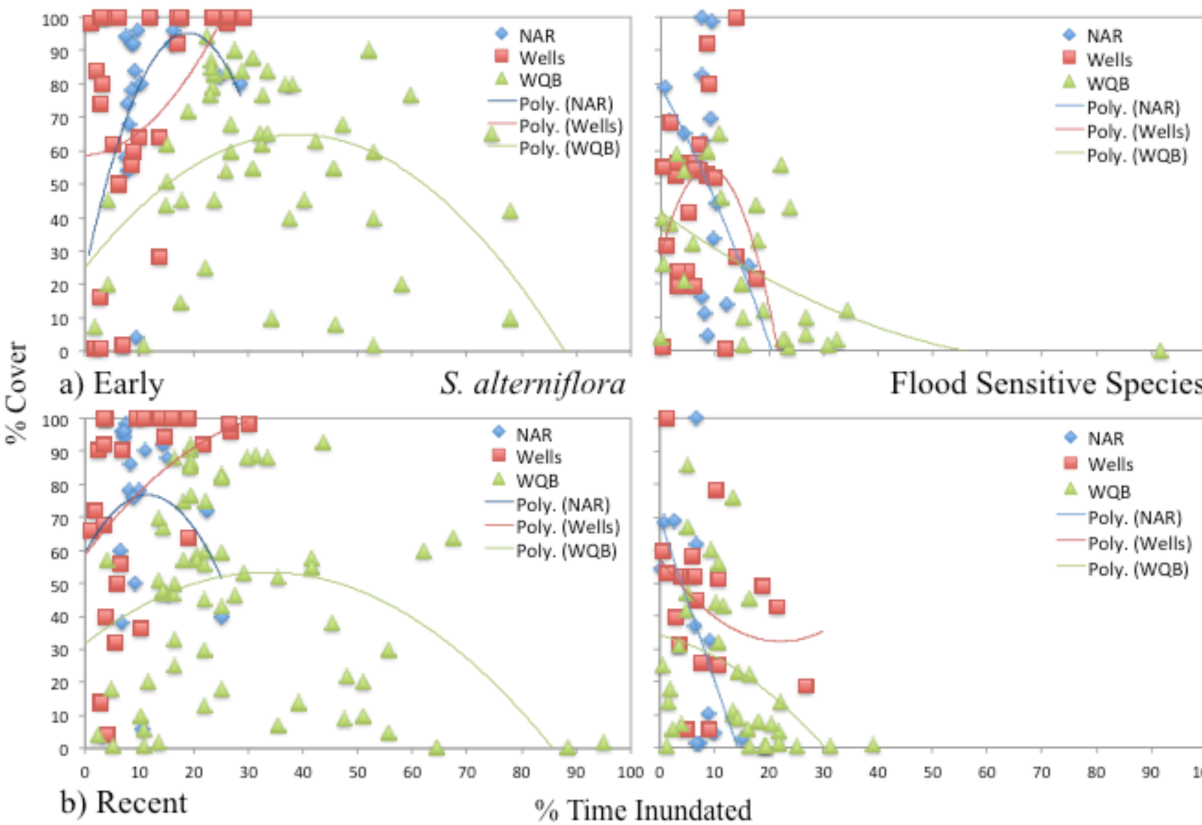

Figure 8. Distribution of *Spartina alterniflora* and flood sensitive species along a tidal inundation gradient between three Reserves for (a) early (2010-2013); and (b) recent (2016-2018) periods. The percent cover of flood sensitive species for Narragansett Bay and Wells were normalized to 100 percent. Lines represent polynomial best fit line generated by Microsoft Excel for the Reserve with corresponding color.

Monitoring recommendations:
Based on our analysis, we recommend that moving forward the following data collection and recording practices outlined in Table 10 be adopted. These suggestions will allow data to be more easily combined New England and other Reserves in the future. All New England Reserves used a 1 m^2 quadrat, so this was not an issue. Other regions should be consistent, but 0.5m^2 quadrats may be used if more samples are collected. We recommend annual monitoring at the height of the biomass, August to mid-September, for New England. Less frequent monitoring will fail to expose interannual variation that might interfere with analyses of long-term change. Marshes with more stable communities and low interannual variation could be sampled with lower frequency. Ecotones, the borders between habitat types, may change more rapidly than the marsh as a whole and specific monitoring protocols could be valuable for Reserves, regions and across the NERR system. The two most used measures of plant abundance, Point Intercept and Ocular Cover, both can be used to show vegetation change, but it is easier to combine data within a region is the same method is used. Within the cover categories, several suggestions are included in Table 10, from assessing algae, bare and dead as distinct cover classes, to including water, wrack and overstory as potentially important subsidiary measures but not to include in the 100 percent of cover totals. Plant height was measured using a variety of techniques; we do not have a recommendation at this point in time. Perhaps in the future, collections using multiple methods might help develop the best metric and protocol. Shoot density of the dominant plants did not show clear changes over time in our analyses; longer time periods and other regions might produce valuable results.

Beyond vegetation and cover types, water levels, plot elevations and Surface Elevation Tables with Marker Horizons were used to characterize marsh condition and change. Water level records are typically obtained using pressure transducers that should be placed in lowest elevation to capture low tide, where possible. Water level measurements should be periodically collected during the growing season, but at least a complete lunar cycle (29 days) and be coordinated with plot elevations (every 3 to 5 years) to allow inundation analysis. Surface Elevation Tables (SETs) and marker horizons have a clear, national protocol that should be followed (https://www.usgs.gov/science/regions/northeast/maryland/science/surface-elevation-table?qt-science_center_objects=0#qt-science_center_objects). If collected together annually, SET+MH show marsh elevation change is the net result of sediment accretion at the surface and peat subsidence.

Table 10. Plant community method variations for New England NERRs. For transects, "U----W" denotes a transect spanning the marsh from upland edge to water edge for the main tidal water body, "U---c" denotes a transect spanning the upland edge to a tidal creek within the marsh interior. For plant cover estimates, PI denotes point-intercept and OC denotes ocular cover. For ecotone monitoring, PL (Plots) = additional plot monitoring within habitat borders, BO (Boundaries) = detect horizontal shifts in zones/plants along transects. For plant heights, "4/5" denotes measuring the 4/5ths canopy height of each marsh dominant species (e.g., *S. alterniflora, S. patens,* etc), i.e., the height at which 1/5 of the shoots will be taller, "12" denotes measuring 12 haphazardly selected plant shoots for each dominant species, 3 at each corner of the quadrat, "3T" denotes measuring the 3 tallest shoots for each dominant at a designated quadrat corner. SET refers to surface elevation table.

New England National Estuarine Research Reserves					
	GRB	**NAR**	**WQB**	**WEL**	**Recommendations**
Transects	U------W	U------W	U------W	U-----c	Establish transects spanning entire marsh
Plots	1m^2	1m^2	1m^2	1m^2	0.5 to 1m^2. If different, target similar total area monitored. e.g., 20, 1m^2 plots = 40, 0.5m^2 plots
Frequency	Annually	Annually	Annually	Biennially	Annual or biennial; longer with stable plant communities
Ecotones	PL	BO	PL		No recommendation. Regional consistency preferred. Trade off between time (BO) and information (PL).
Plant Cover	OC	PI	OC	PI	No recommendation. Regional consistency preferred. Trade off between time (OC) and information (PI)
Algae	X		X		Record live algae. Drift algae 'unrooted' should be classified as wrack
Bare	X	X	X	X	Record. Note difficulty making comparisons across plant cover method (PI, OC)
Dead	X		X		Record as a distinct cover class, separately from bare
Water	X		X		Record 'standing' water near low tide only. Analyze separately (does not contribute to total cover)
Wrack	X	X	X		Record. Then remove and assess vegetation before replacing
Overstory	X		X		Record total overstory as a percentage. Analyze separately (does not contribute to total cover)
Plant Height	4/5	12	12	3T	No recommendation. Regional consistency preferred. Statistical analysis of variability conducted on plots utilizing multiple methods is needed.
Plant Density	X		X	X	No recommendation. Regional consistency preferred. Dominant marsh species and potential value may differ regionally and nationally
Water levels	X		X	X	Monitor during growing season; 6 minute intervals, every 3-5 years with plot elevations
Plot elevations	X*	X	X	X	3-5 years monitoring frequency
SETs	X	X	X	X	Annual frequency
Marker horizon	X	X			Annual frequency to parse out surface/sub-surface elevation changes

Outputs

The project team developed an overall 'How to' Guide describing the process of checking, correcting, formatting, combining all the data into spreadsheets, and summarizing and analyzing the data. Using the report in combination with the datasets, a researcher can completely understand the process and apply it to newly acquired data or data from other Reserves. In addition, our project team created another guide, outlining our steps in transforming data obtained by the point intercept method into proportions of cover, more similar to those collected by ocular cover estimates, constrained to 100%, titled "A Guide to Integrate Plant Cover Data from Two Different Methods: Point Intercept and Ocular Cover."

In addition to our project report, a complete project Data Report was created to show a broader range of results and be able to provide greater depth to show details within particular Reserves with the intent to help salt marsh conservationists, restoration practitioners and managers a clear understanding of the changes occurring in our marshes over the past several years to guide management. These analyses and images can also serve as a springboard for further examination of the long-term marsh monitoring data. Each Reserve has a rich dataset with important trends that can be interpreted and shared with many Reserve sectors (education, stewardship, etc.). The report also includes an analysis of inconsistencies in data collection for a variety of methods to encourage greater consistency in collection and recording in the future.

Our science collaborative catalyst project sponsored three workshops. The first was to help develop the ideas for the proposal, second was a kick-off workshop to share our research plan and solicit new ideas and ways to examine the data, and the final workshop shared our results. The final workshop gave participants an overview of our process and findings as well as first-hand knowledge of the difficulty in collecting plant abundance data using both methods and reconciling them during a field component of the workshop. We included the workshop notes and slide-deck as a product to allow our broader stakeholder group to share the results of the project they helped to guide. We have fielded at least two requests for more information that will be used for planning in the region. A complete list of workshops and presentations are listed in Table 11.

Table 11. Summary of project collaborations, including workshops and presentations.

2018 Jan	Two Proposal Design Workshop (NERRs, USFWS)	Wells, ME	Workshops
2018 Oct	Kickoff Workshop	Wells, ME	Workshop
2018 Nov	National Estuarine Research Reserve Association	Duluth, MN	Poster
2018 Dec	National Science Collaborative	Long Beach, CA	Discussion
2019 Apr	New England Estuarine Research Society	York, ME	Poster
2019 Aug	Regional Project Results Workshop	Wells, ME	Workshop
2019 Nov	Coastal Estuarine Research Federation	Mobile, AL	Presentation
2019 Nov	National Estuarine Research Reserve Association	Charleston, SC	Multiple presentations
2019 Dec	National Science Collaborative www.youtube.com/watch?v=EKbd64FaDyg&feature=youtu.be	NA	Webinar

1) <u>Sharing with the NERRS</u>
   Listed above
2) <u>Students</u>

Degree level (undergraduate, master's, PhD)	Project role	Any associated theses or dissertations (expected or completed)
Post-Doctoral	Inundation Modeling	no

3) Number of individuals engaged

Project Team	Users engaged (e.g., advisory group members not on team)	Attendees of project workshops or other presentations	Volunteers	K-12 Students	Teachers
David Burdick	External Advisors:	Adrianne Harrison			
Chris Feurt	Kerstin Wasson	Cristina Kennedy			
Chris Peter	Susan Adamowicz	Chris Kinkade			
Kenny Raposa		Georgeann Kerr			
Jason Goldstein		Jacob Aman			
Megan Tyrrell		Jamie Carter			
Jenny Allen	Collaborative aides:	Kevin Lucey			
Jordan Mora	Annie Cox	Kristen Puryear			
Briana Fischella	Emily Greene	Marc Carullo			
Laura Crane		Nancy Pau			
Annie Cox		Rachel Stearns			
		Joanne Glode			
		Slade Moore			
		Rachel Stevens			
		Sarah Dodgin			
		Sean Duffey			
		Trevor Mattera			
		Cory Riley			
		Jeffrey Denoncour			
		Paul Dest			
		Claire Enterline			
		Russ Hopping			
		Ruth Indrick			
		Kate O'Brien			
		Karl Stromayer			
		Dwight Trueblood			
		Kirsten Underwood			

4) Leveraging

Many of the team worked on this project as part of their normal research and stewardship activities. All four Reserves added another plant cover method to their 2018 and/or 2019 marsh vegetation monitoring to help build a novel process for integrating both commonly used methods throughout NERRs (PI and OC).

5) <u>Outcomes</u>

Production of new information regarding responses in vegetation and surface elevation was generated for each Reserve. The new information will be used by a variety of sectors for planning, management and education. Our Reserve team members are very positive about the new information, leading to this evaluation: *". . . the set of visual outputs that were generated from this Catalyst project (e.g., graphs, pie charts, etc.) . . . have allowed us to ascertain changes in marsh communities with respect to vegetation." ". . . this project has widened our scope to how we continue our monitoring in years to come. We hope to continue to build out a portfolio of analyses and related outputs that will help to inform management decisions into the future."* In addition, we have received (and responded to) requests to use information in planning activities for the region (Puryear, Duffy). Numerous opportunities for communication among Reserves has led to field comparisons of methodologies and addition of new data being collected. For example, several Reserves conducted point intercept and ocular cover comparisons for a series of vegetation plots, Great Bay began taking monitoring plot photos, marsh surface elevations via RTK and UAS equipped with Lidar, local water levels, as well as monitoring for crabs using pitfall traps, Waquoit Bay added crab burrow counts to vegetation plots, and Wells is adding extra transects to their Sentinel Site monitoring design that run further into the marsh interior as well as considering adding an extra Sentinel Site.

Adoption of protocols, dataset templates and analyses have not yet been adopted outside of the four New England NERRs to our knowledge, but they have made immediate impacts within the Reserves (e.g., Wells). As one research coordinator states: *"As a member of the project team and end-user of this work, I would like to comment on the value and importance of some of the project outputs relevant to the long-term salt marsh monitoring needs at Wells. Probably the most useful output from this Catalyst project was the adoption of a database that has allowed our team to more effectively input, store, QA, and query our data. Prior to this project, we managed all our marsh vegetation data through a series of inefficient spreadsheets and management tools. Streamlining this process into a single, well-designed format complete with metadata will further afford us the opportunity to not only examine our data in more depth, but to also compare our data more consistently in a regional way across the other New England NERR sites. … this project's activities have been pivotal for staff at the Wells NERR to reassess and re-evaluate current methodologies for marsh transect and plot design including discussions with other project team members on how best to resolve and transform plot data. The collective outputs and products from this Catalyst project have allowed staff at Wells to improve our overall approach to how we view, assess, and manage salt marsh monitoring in our sentinel marshes, as well as how best to evaluate and compare these data both within our marsh and between other sites."* In addition, we see great interest in the use of our methods and results at our workshops and presentations elsewhere.

Our four regional templates and data sets will be housed and available to the public on our project webpage (http://www.nerrssciencecollaborative.org/project/Burdick18) of the National Science Collaborative. There are several parallel efforts with regards to marsh monitoring data including this project, another catalyst project focusing on SET data, the

Office of Coastal Management's development of Sentinel Site Application Module 1 (SAM1) and CDMO development of vegetation templates. Our templates may guide CDMO's future development of archiving and disseminating marsh data.

6) Next steps
One outcome is the joining together of our project with the SET visualization catalyst project by Kim Cressman and colleagues to develop a new proposal by Chris Peter and colleagues. This next step will further enable analysis of biomonitoring data by Reserve staff through the development of R scripts for analysis and visualization. Sharing results of our individual projects at the annual meeting and having time set aside to meet with other potential team members encouraged our team and promoted project development into an NSC pre-proposal, including 21 Reserves with enthusiastic support from **managers**: "*This looks like an incredibly valuable project and I fully support our reserve's involvement. And, yes, the project fits well within our management needs. Thanks for taking the lead on it and for rallying such an impressive number of reserves to participate.*" "*I very much support this proposal, want NIW to be a part of it, and would love to see it funded. The proposed absolutely fits with our research and management interests*." And **research and stewardship staff**: "*Love the project – it's what I wanted to initially tackle years ago before we switched lanes and went with MARS*." "*I have so much data, and it seems like the forever task is just organizing it all, and the ball keeps rolling back down the hill*." Additionally, a journal publication detailing the vegetation changes from abundance data and inundation modeling are the logical next steps stemming directly from the project report.

Building off this project, data from the four New England Reserves can be used to further analyze change over time with respect to plant densities and heights. The point intercept and ocular cover comparison should be revisited to include 2019 data that will strengthen regressions and better integrate the two methods. Outside of New England, the project products will be useful to spark vegetation analyses of Sentinel Site data.

7) Other accomplishments & information

Acknowledgements
Many people helped make this project successful. We thank our external advisors, Susan C. Adamowicz of the Rachel Carson Refuge, U.S. Fish and Wildlife Service and Kerstin Wasson of the Elkhorn Slough NERR, who helped us establish project scope from the outset and guided us throughout the project. Our collaborative process was supported by Annie Cox and Emily Greene of the Wells NERR who were critical in workshop organization and implementation. We thank Michele Furbeck and Jacob Aman, both of the Wells NERR, who assisted with data processing. Our workshop participants were outspoken and helped shape our investigation to provide information useful for management. Finally, we thank Maeghan Brass (NSC) and Dwayne Porter (CDMO) who gave us latitude and helpful advice.

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2b) Final Product Inventory

Project title: Synthesizing NERR Sentinel Site data to improve coastal wetland management across New England
Project lead: David Burdick
Reserve(s): Great Bay, Narragansett Bay, Waquoit Bay, Wells
Date of report: 1/31/2020

Directions: The purpose of this inventory is to inform Science Collaborative efforts to catalog and promote access and use of project products. Please use the table below to list all completed or pending products associated with your project, excluding datasets. (Datasets are covered under final data sharing and archiving requirements.) Each row should provide an overview of a product, including its type, status, current or future location, and citation information. Details about audience(s) should be provided in the report narrative. Please add additional rows as necessary.

Product name	Type	Status	Location for access	Appropriate citation
Fact Sheet	Report	Complete	http://nerrssciencecollaborative.org/project/Burdick18	
Final Report	Report	Complete	http://nerrssciencecollaborative.org/project/Burdick18	Burdick et al. 2020. Synthesizing NERR Sentinel Site data to improve coastal wetland management across New England. Final Report to National Science Collaborative.
'How To' Guide	Report	Complete	http://nerrssciencecollaborative.org/project/Burdick18	Burdick et al. 2020. 'How to' Guide for Synthesizing NERR Sentinel Site data. Report to the National Science Collaborative.
Plant Cover Integration Guide	Report	Complete	http://nerrssciencecollaborative.org/project/Burdick18	Peter et al. 2020. A Guide to Integrate Plant Cover Date from Two Different Methods: Point Intercept and Ocular Cover. Report to the National Science Collaborative.
Data Report	Report	Available Feb 2020	http://nerrssciencecollaborative.org/project/Burdick18	Burdick et al. 2020. Synthesis of New England NERR Sentinel Site Data 2010-2017. Data Report to the National Science Collaborative.
Aug 2019 Workshop Slide Deck & Meeting Notes	Multimedia, pdf	Complete	http://nerrssciencecollaborative.org/project/Burdick18	Burdick et al. 2019. Synthesizing NERR Sentinel Site data to improve coastal wetland management across New England. Workshop Proceedings. Wells, ME in August 22, 2019

3) Final Data Sharing & Archiving Requirements

This document explains the process for completing your project's data management activities and ensuring compliance with federal data sharing and archiving standards. *Note: this section (3a and 3b) only applies to projects that collected new data and included a data sharing plan in their original proposal.*

As described below, please complete a final dataset inventory and provide a data sharing plan (DSP) summary. The inventory and DSP summary should be returned to your NERRS Science Collaborative project manager along with your metadata records within 60 days of your project end date.

Data Management Checklist
Within 60 days of project end date, please provide the following to the NERRS Science Collaborative:

- A **final inventory of datasets** using table below;
- A **data management plan summary** using the template below; and
- **Metadata records** for all project datasets.

Next steps after reporting is complete:

- The Science Collaborative will create a summary of the data generated by the project for the program's resource library, and update the project's description in national data catalogs (i.e., InPort);
- The Science Collaborative will confirm that datasets and metadata records have been successfully archived and made accessible following the process and timeline laid out in the DSP summary below; and
- PI will conduct a final review for completeness of all project entries into the Science Collaborative resource library and data archival sites.

For teams using CDMO to archive data, metadata, and/or data products:
The project PI should work directly with Dwayne Porter and Jeremy Cothran from the Centralized Data Management Office (CDMO) to develop a process and timeline for making data accessible, and then sharing datasets and metadata records for long-term archival and accessibility. Once a process has been confirmed, the inventory and DSP summary should be used to document the final arrangements with CDMO.

CDMO Contacts:
Dwayne Porter, porter@sc.edu, 803-777-4615
Jeremy Cothran, jeremy.cothran@gmail.com, 803-665-6454

3a) Final Project Dataset Inventory

Project title: Synthesizing NERR Sentinel Site data to improve coastal wetland management across New England
Project lead: David Burdick
Reserve(s): Great Bay, Narragansett Bay, Waquoit Bay, Wells
Date of report: 1/31/2020

Dataset name	Metadata file name	Location	Uploaded for access	Location for archival, including URL	Uploaded for archival
Regional Vegetation template and dataset	(included as tab in database)	NSC	uploaded	http://nerrssciencecollaborative.org/project/Burdick18	uploaded
Regional SET template and dataset	(included as tab in database)	NSC	uploaded	http://nerrssciencecollaborative.org/project/Burdick18	uploaded
Regional Elevation template and dataset	(included as tab in database)	NSC	uploaded	http://nerrssciencecollaborative.org/project/Burdick18	uploaded
Regional Water level template and dataset	(included as tab in database)	NSC	uploaded	http://nerrssciencecollaborative.org/project/Burdick18	uploaded
Great Bay Data Packet	(included as tab in database)	Sent to Reserves			
Narragansett Bay Data Packet	(included as tab in database)	Sent to Reserves			
Waquoit Bay Data Packet	(included as tab in database)	Sent to Reserves			
Wells Data Packet	(included as tab in database)	Sent to Reserves			

3b) Data Sharing Plan Summary

1. General Description of Project Data

- **Regional Vegetation Template and Dataset**- Database of all New England Reserves (GRB, NAR, WEL, WQB) vegetation data including cover, density and height from years 2010-2018. Includes normalized and regression transformations of point intercept data to ocular cover. Also includes a tab with data in a PRIMER compatible format.
- **Regional SET Template and Dataset** - Database of all New England Reserves (GRB, NAR, WEL, WQB) SET data.
- **Regional Elevation Template and Dataset** - Database of all New England Reserves (GRB, NAR, WEL, WQB) Elevation data. Also includes percent flooding calculation from the inundation macro for each plot that contains required data.
- **Regional Water level Template and Dataset** - Database of all New England Reserves (GRB, NAR, WEL, WQB) water level data.
- **Great Bay Data Packet**- Dataset including all of the Reserve's data (vegetation, SET, elevation, water level) data including additional parameters and calculated metrics unique to the Reserve.
- **Narragansett Bay Data Packet** - Dataset including all of the Reserve's data (vegetation, SET, elevation, water level) data including additional parameters and calculated metrics unique to the Reserve.
- **Waquoit Bay Data Packet** - Dataset including all of the Reserve's data (vegetation, SET, elevation, water level) data including additional parameters and calculated metrics unique to the Reserve.
- **Wells Data Packet** - Dataset including all of the Reserve's data (vegetation, SET, elevation, water level) data including additional parameters and calculated metrics unique to the Reserve.

2. Data Quality Control / Quality Assurance Procedures

We employed multiple levels of additional QA/QC beyond the measures taken at each Reserve.

1. *Data Transfer* - During transfer from individual Reserve datasets to regional templates, each row of data was reviewed.
2. *Identify Suspect Data* - These were identified through graphing and for 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 ocular cover, 100 points for point-intercept per cover [totals multiply by number of covers]), species occurring outside their habitat preference, significant annual plot changes.
3. *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.

3. Data Documentation / Metadata

Metadata was customized for data and is recorded in a “Metadata” tab at the beginning of each excel document dataset or for the Inundation Model dataset it is included in the Inundation Analysis Report. Each dataset has its own individual metadata record.

4. Data Access and Sharing

No new data were collected for this project. Re-formatted data, including created data templates as well as all listed outputs (reports, guides, etc.) are available on our project page, hosted by The National Science Collaborative website, http://www.nerrssciencecollaborative.org/project/Burdick18. Individual Reserve data packets, when finalized will be distributed directly to each Reserve.

5. Data Archival

All data will be archived on The National Science Collaborative website, specifically on our project webpage: http://www.nerrssciencecollaborative.org/project/Burdick18