

# NAMASTE: Reserve-Level Analysis Methods and Results



**NAMASTE**  
National Marsh Synthesis Team

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For more details see our website:

[www.nerra.org/impact/science/marsh-response-to-sea-level-rise/](http://www.nerra.org/impact/science/marsh-response-to-sea-level-rise/)

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# Introduction

The goal of this document is to provide a detailed data analysis of National Estuarine Research Reserve (NERR) data, including methods and results, to evaluate climate change impacts (primarily sea-level-rise) on tidal marsh plant communities at the **local scale** (e.g., Reserve or site). Following thorough data QA/QC (quality assurance and quality control,) vegetation changes were documented using data summaries, visualizations, and statistical analyses.

The tools and training produced for this Reserve-level analysis were designed to analyze data collected from the NERRs national tidal marsh vegetation monitoring protocol (Moore 2013; NERR 2025), but can also be used for similar monitoring data. For Reserve staff, these tools can be used, customized and re-used to analyze future data, different metrics, and/or different sites. For non-NERR users, these tools can be utilized to analyze similar tidal marsh vegetation monitoring data not collected or associated with the NERR system (i.e., ~1m<sup>2</sup> plot-based monitoring dispersed across all major marsh vegetation sub-communities), following the detailed instructions and resources provided below.

## Research Questions

- Are plant communities shifting over time?
- Are plant community changes accelerated or more prominent where local sea level rise (SLR) is proportionately greater relative to tidal range?
- Are marshes that are failing to keep up with SLR (as ascertained by sediment elevation table (SET) data) showing the largest changes in vegetation?
- Are there predictable, climate change-related geographic shifts in plant abundance and diversity?

Resources: Relevant documents are linked in the [Resources section](#) at the end of this document.

## **Background**

Documenting the data analysis process for this project is important for transparency and replicability. At the start of the project, all Reserves expressed interest in receiving results specific for their Reserve. Therefore, as a first step, we developed analyses and results for each Reserve to lay a foundation of documenting change across the nation that allowed us to 1) better understand marsh ecology and change nationwide, and 2) serve as the basis for our [National-Level Analysis Methods and Results](#).

## Relevant Definitions

- *Reserve* - A National Estuarine Research Reserve (NERR), where one or more sites are monitored
- *Site* - cluster of plots designated by Reserve practitioners as unique sites based on marsh units
- *Plot*- specific area of marsh where a quadrat is repeatedly used to measure the plant community, typically 1m<sup>2</sup>

- *Zone* - vegetative sub-communities within a marsh, described by vegetation species and elevation (e.g., low marsh, high marsh) present at the time of plot establishment
- *Ecotone Migration Index (EMI)*- ratio of Reserve-identified indicator covers of SLR (biotic or abiotic) to total cover. Indicator covers are selected by zone or ‘ecotone’ for each Reserve, (i.e. *Spartina alterniflora* as an indicator cover in the high marsh at Great Bay Reserve, New Hampshire)
- *Technical Advisory Group (TAG)*- larger group of 50 external advisors with experience in tidal marsh ecology, data collection, management, and/or analysis from around the country (NERR staff and external partners), tasked with advising on project methods
- *Technical Working Group (TWG)*- smaller group of 10 project team members with extensive experience in tidal marsh ecology and/or statistics, tasked with analyzing the data

### Process

Our analytical team, composed of ecological and/or statistical experts, closely examined datasets from five individual Reserves in each of the major bioregions of the country (Northeast, Mid-Atlantic, Southeast, Gulf Coast, and West Coast) to serve as a representative on which we could test our analytical techniques. The analytical group reviewed the processes and results with the Technical Working Group (TWG) for incorporation into a local-level analysis plan that has utility for all Reserves, made adjustments as necessary, and conducted the analysis plan for all participating Reserves.

Our vegetation data spanned a relatively small time scale (10 years for most sites); therefore we anticipated seeing small scale plant community shifts within sites rather than large scale shifts in species ranges. Consequently, analyses used plot as the experimental unit, with replication within sites across environmental gradients (e.g., vegetation zone). Due to prevalence of and consistency in percent cover data collection compared to wide variability in Reserve-specific density and height protocols, syntheses used percent cover as the main vegetation response metric. Cover was used in a broad sense, including different methods (ocular, point-intercept), species groupings (e.g., halophytes), and species ratios.

Some species were also coded as ‘migrators’ to highlight potential changes in the marsh plant community across zones. These species were identified by Reserve staff for each zone of their Reserve and together, they created the Ecotone Migration Index (EMI). EMI is the proportional cover of species or cover groupings that are expected to increase within a vegetation zone as sea level rises. A common example of a ‘migrator species or cover’ would be *Spartina alterniflora* in the transition or high marsh zones, or bare cover in the low marsh zone.

## Methods

The Reserve-level analysis was conducted on each participating Reserve and resulted in a [results](#) file for each Reserve with the following sections: **Data Exploration and QA/QC, Summary Figures, Univariate Analyses**, and **Multivariate Analyses**. These sections (below) will provide

further detail into the mechanisms behind the analyses as well as their visual and statistical outputs.

Before the data were able to be analyzed, however, data were first collected from the National Estuarine Research Research's (NERR) [Centralized Data Management Office](#) (CDMO) or from individual Reserves directly. All twenty participating Reserves were individually contacted for an interview with the staff involved in tidal marsh vegetation biomonitoring to clarify sampling methodologies, locations, and timelines, guided by a [questionnaire](#) and [response summary template](#). Subsequently, data from all Reserves were compiled into a [standardized NAMASTE template format](#) and QA/QCed using the following procedures.

To detect errors of input data sets, the following were created and reviewed by Reserve data practitioners.

- *Tables* showing count of PlotID by SiteID and Year - practitioners confirmed number of plots per site and the years that data were collected to be correct.
- *Unique species list* per dataset - practitioners checked for variants of the same species/cover class (e.g., capital vs lowercase, abbreviations, misspellings).
- *Percent cover plots* - practitioners checked for anything unusual (e.g., total covers <100%, total covers >100% when using ocular cover in 2D, sudden drops or spikes in species) over time or space.

To clean and organize the input data sets, the following steps were taken.

- All Reserves and sites were included in our overall analysis. Below lists instances where specific tests were not performed at specific sites due to data limitations (e.g., not enough years of data) and instances where specific plots were excluded from specific analyses (e.g., plot data were rejected by Reserve staff).
- The Technical Working Group (TWG) with input from the Technical Advisory Group (TAG), which included all Reserves with data in this project, determined what plots/data should be removed from analyses based on qualities including timing of surveys and if the site was established to test a specific management action (e.g., restoration).
  - Included all Reserves regardless of number of years for QA/QC and summary bar charts, but required at least 3 years for univariate and multivariate analyses.
  - Some reserves already had some QA/QC flags in their files. We excluded any with a flag of -3 (rejected) and kept any flagged 1 (suspect), and followed up with Reserves as needed.

## **Data Exploration and QA/QC**

Simple tables and visualizations of each Reserve's vegetation data were produced to summarize data attributes and help users identify issues around QA/QC (e.g., accurate number of plots per year, zone assignment of plots, data outliers, etc.)

### Questions addressed

- Do you see the correct number of sampling events per year? If not, what is missing or extra?

- Do you see the correct number of plots per site?
- Are species names spelled correctly? Are there any close variants or duplicates?
- General percent cover in plots - is anything unusual?

Outputs

- List of flagged data rows that were removed before analyses.
- Sampling information including the names of Sites within Reserves, years sampled, and vegetation zone designations for all sample plots (Figure 1).
- Spatial map of latitude and longitude of plots for each Site within a Reserve, with plots coded by vegetation zone (Figure 2).
- Species over time:
  - Scatterplot figures depicting the percent cover of top species or group covers over time, separated by vegetation zone or with all zones combined.
- EMI:
  - Scatterplot figure depicting the EMI value over time, separated by vegetation zone and accompanied by a table that outlines which species were identified by the Reserve as a “migrator” or “invader” species for each vegetation zone and site (Figure 3).
  - Histogram of EMI separated by vegetation zone.

Samples per year

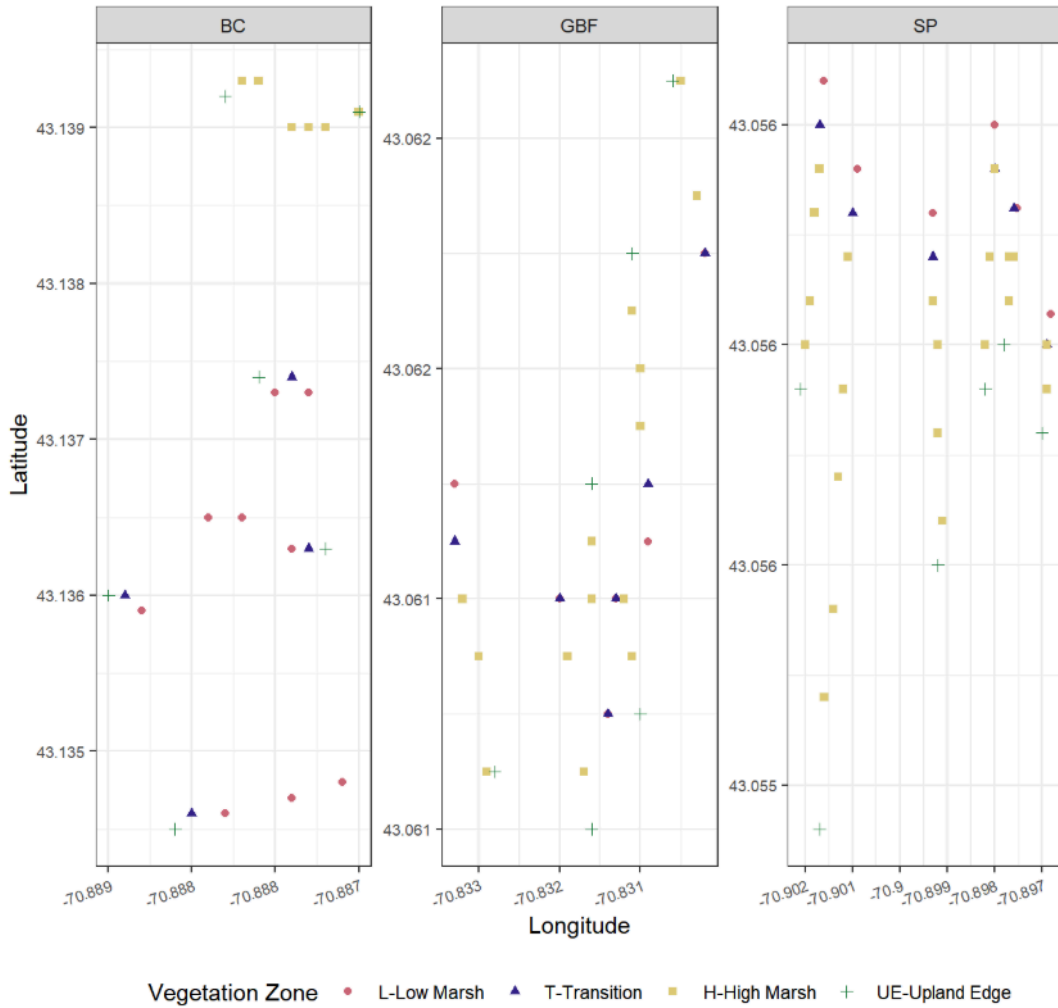
# samples per year, by site											
Site	2010	2011	2013	2014	2016	2017	2018	2019	2020	2021	2022
BC	29	30	30	30	30	30	30	30	30	30	30
GBF	39	39	39	39	39	39	39	39	39	39	39
SP	43	44	44	45	45	45	45	45	45	45	45

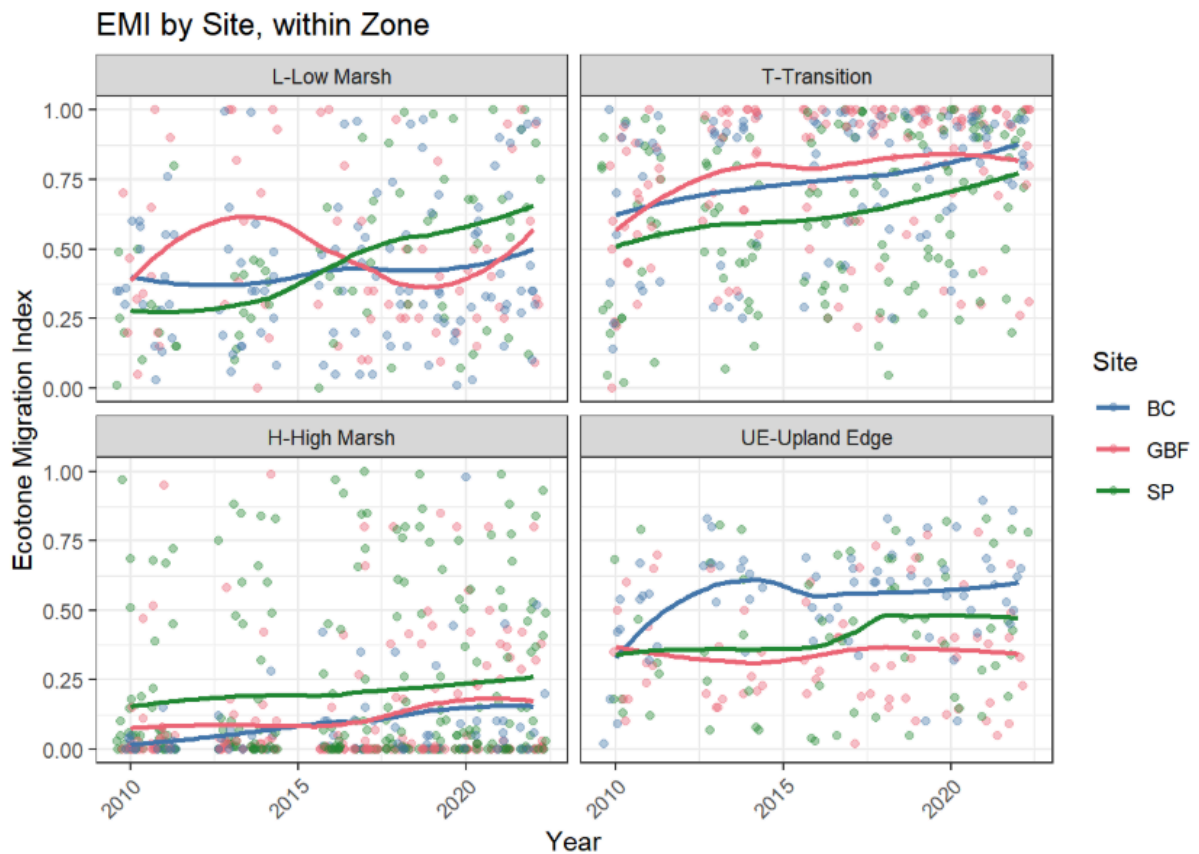
# samples per year, by vegetation zone											
Vegetation_Zone	2010	2011	2013	2014	2016	2017	2018	2019	2020	2021	2022
L-Low Marsh		21	22	22	22	22	22	22	22	22	2
T-Transition		32	32	32	32	32	32	32	32	32	3
H-High Marsh		42	42	42	42	42	42	42	42	42	4
UE-Upland Edge		16	17	17	18	18	18	18	18	18	1

**Figure 1:** Sampling table which provides information on the number of plots samples per site at Great Bay NERR from 2010-2022, and how plots were distributed across vegetation zones.

Plots and their Vegetation Zones, by site



**Figure 2:** Plot locations at each Site within the Great Bay NERR, identified by latitude and longitude and coded by vegetation zone.



**Figure 3:** Scatterplots with loss trendlines visualizing the change in Ecotone Migration Index (EMI) in different zones and sites over time at Great Bay NERR.

## Summary Figures

Summary figures tell a graphical story about current conditions and trends through time. We created two types of figures:

- Averaged stacked bar charts to show the relative distribution of species and cover classes and how these relationships change over time.
- Spatial stacked bar charts to show the relative distribution of species and cover classes as above, but for each plot. These charts are laid out spatially by site.

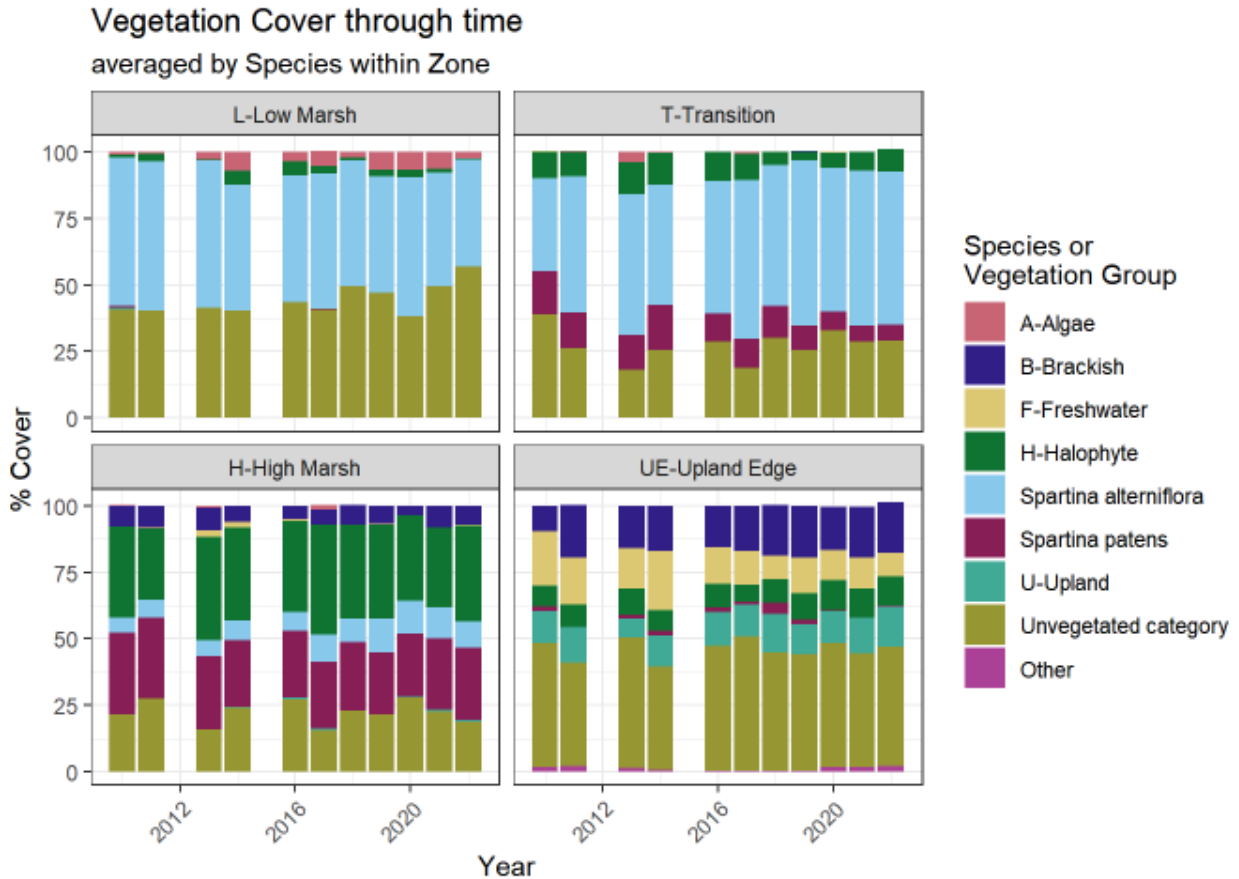
### Questions addressed

- What species characterize each site and marsh zone?
- How do relative abundances of species/groups fluctuate among years and is there a visual trend with time (e.g., potential SLR impacts) or corresponding to severe events (e.g., major storm, staff turnover)?
- For QA/QC purposes, do the data make sense?

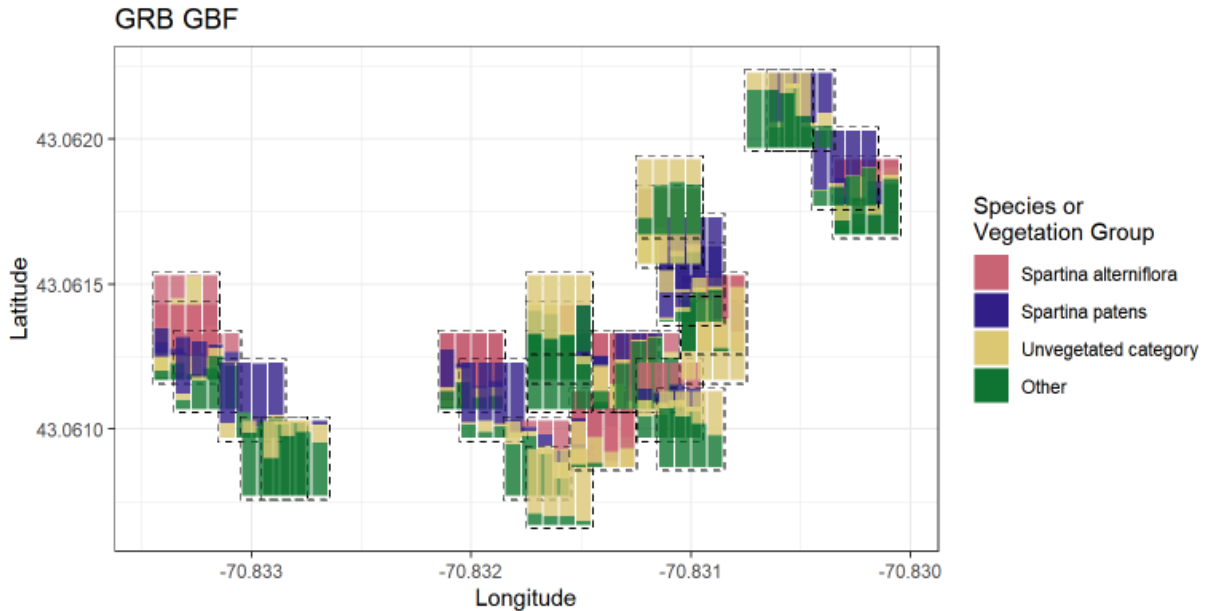
### Output for reports

- Stacked bar charts comparing species composition across every year of data collected for each site and each designated zone, where appropriate (Figure 4).

- Charts have been created at the Site, Zone, and Site x Zone levels.
- Chart categories feature dominant species or species groups as identified by the Reserve in the “veg-specs.xlsx” file, “[Analysis Specs](#)” sheet.
- See graph below as an example where x-axis= year, y-axis= pct cover, color = species or species group, and panel of graph = marsh zone.
- Spatial stacked bar charts are also stacked bar charts but for the plot level and arranged spatially (y-axis = latitude, x-axis = longitude) for each site within a Reserve (Figure 5).
  - Each stacked bar chart represents a single plot through time (x-axis: year; y-axis: pct cover; color = species, abiotic cover or species group).
  - For ease of interpretation, only 4 cover categories are displayed (3 are user defined and 1 is a catchall for all remaining covers listed as “other”).
  - For ease of interpretation, only 4 evenly-spaced time points are used along the x-axis in each bar chart determined as follows: first sample date, last sample date, and 2 in-between dates that were as evenly spaced as possible.



**Figure 4:** Summary stacked bar chart depicting cover type (by color) among plots over time, organized by vegetation zone across all sites at Great Bay NERR.



**Figure 5:** Summary stacked bar charts depicting cover type (by color) among plots over four-evenly dispersed years, displayed along lat/long axes to show their spatial arrangement at the Great Bay Farm site at Great Bay NERR.

## Univariate Analyses

A linear mixed effects model (lme) was used for each of several chosen response variables to estimate change through time and whether this differed by vegetation zone. Response variables included Reserve-selected species, groups (e.g., halophytes), EMI, and diversity metrics (e.g., richness). The lme model used vegetation plot as a random factor to account for repeated measures. Because of limited data availability across the Reserve system, we focused on time as the main explanatory variable. Note, this model was scaled up for regional and national applications.

### Questions addressed

- Are there shifts in key vegetation species/groups over time (beyond annual variation)?
- Do these shifts vary by vegetation zone?
- Where is the plant community changing (which plots) and what characteristics do these areas have in common (e.g., site, zone)?

### Models or tests

The main statistical model used is a linear mixed model, via lme4::lmer(), with the form  **$y \sim \text{Vegetation Zone} + \text{Time} + \text{Zone} * \text{Time} + 1 | \text{Plot}$** , where  $y$  is the response variable given, and each individual plot has a random intercept.

### Variables

- Response variables:
  - Ecotone Migration Index (EMI);

- Species richness and Shannon-Weiner Diversity;
- Up to 4 species, cover types or pre-defined group (e.g., halophytes), identified by Reserve;
- Up to 2 custom metrics such as species ratios (e.g., *Spartina alterniflora* : *Spartina patens*), identified by Reserve.
- Explanatory variables (year, zone, year\*zone); and
- Random effect (plot).

**Outputs**

- Tables of model output and diagnostics (Figure 6):
  - slope/confidence interval (CI) for all responses;
  - slopes (marginal means) for change through time within each zone; and
  - goodness of fit measures (Marginal R<sup>2</sup> and Conditional R<sup>2</sup>).
- Regression model output (Figure 7):
  - all zones (x-axis = time; y-axis = response; line = vegetation zone) separated by vegetation zone (x-axis = time, y-axis = dependent variable; points = individual plots).
- Contrast plots of model outputs (Figure 8):
  - Rate of change for response variable by zone: x-axis = zone, y-axis = change per year; points + bars = slope estimate + 95% confidence interval by zone; and
  - lettering to indicate when significant differences were present between groups.

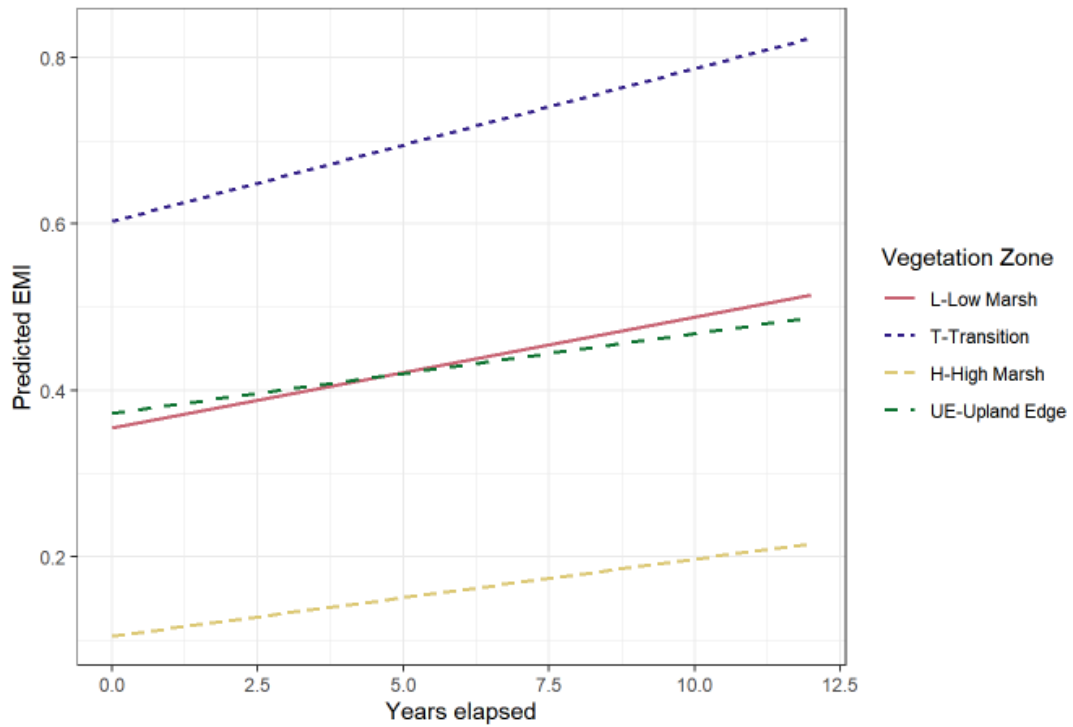
	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
Years_sinceStart	2.5850	2.5850	1	1130.02	88.17	0.0000
Vegetation_Zone	2.7803	0.9268	3	155.09	31.61	0.0000
Years_sinceStart:Vegetation_Zone	0.2823	0.0941	3	1129.83	3.21	0.0224

EMI - Estimated marginal slopes (change per year for each zone)

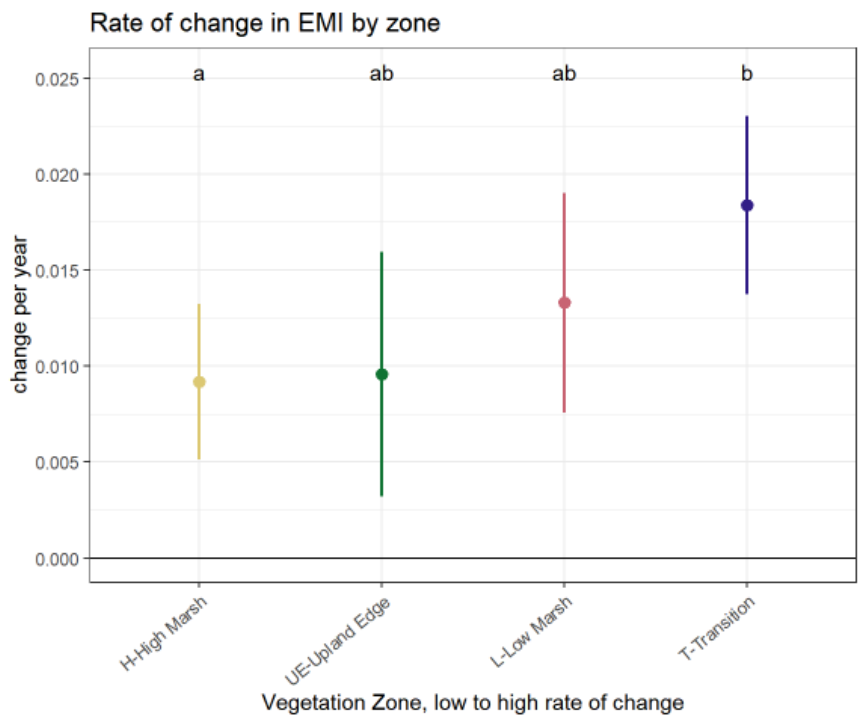
Veg Zone	Trend (per year)	SE	CI lower	CI upper	t	df	p.val
L-Low Marsh	0.0133	0.0029	0.008	0.019	4.6	1129.9	0.0000
T-Transition	0.0184	0.0024	0.014	0.023	7.8	1129.0	0.0000
H-High Marsh	0.0092	0.0021	0.005	0.013	4.4	1129.0	0.0000
UE-Upland Edge	0.0096	0.0032	0.003	0.016	3.0	1131.1	0.0032

R2m	R2c
0.439	0.755

**Figure 6:** Table of univariate model output and diagnostics for Great Bay NERR, investigating the relationship between EMI and zone, time, and zone\*time.



**Figure 7:** Regression model-expected values of EMI by Year and Zone at the Great Bay NERR. Lines represent vegetation zones.



**Figure 8:** Contrast plot depicting the rate of change of EMI by Zone at the Great Bay NERR. Bars represent a 95% confidence interval for rate of change. Zones that do not share a letter have significantly different rates of change in pairwise comparisons.

## Multivariate Analyses

Multivariate analyses were performed to enable understanding of change through time at the community level, rather than at the level of an individual metric. Non-metric multidimensional scaling (NMDS) was used to visualize plant community data. A PERMANOVA tested for differences between the first and last year of monitoring, and between zones when applicable. A similarity analysis (SIMPER) was used when PERMANOVA indicated a difference between zones to determine the species that contributed most to the difference.

### Questions addressed

- Are there shifts in the vegetation community (as defined by the entire percent-cover matrix) over time? Do these shifts vary by zone?
- Which species/groups contribute most to these shifts?
- Where is the plant community changing and what characteristics do those areas have in common (e.g. site, zone, distance from water, elevation)?

### Models or tests

- PERMANOVA, multifactor (year, zone, and their interaction), repeated-measures (via restricted permutations)
  - Overall H0: community change between start and end is consistent across vegetation zones.
  - Zone-wise H0: No community difference between 'start' and 'end' within a vegetation zone.
  - Check for homogeneity of dispersion between zones' start/end years
    - H0: No difference in dispersion between groups
    - PERMANOVA assumes homogeneity of dispersion; if this assumption is violated, caution should be used in interpreting PERMANOVA results.
- SIMPER
  - Generally only one version of the SIMPER was run (across all zones vs. zone-wise; see (ii) below), but when the interaction term of the PERMANOVA was near significant ( $0.05 < p < 0.10$ ), SIMPER was run both ways (across all zones and within zones)
  - Simper was run if...
    - zone-wise the interaction term in the overall PERMANOVA was significant or close to it ( $p \leq 0.10$ ) and the within-zone effect for time in the zone-wise PERMANOVA was significant or close to it ( $p \leq 0.20$ )
    - across all zones the interaction term in the overall PERMANOVA was not significant ( $p > 0.05$ ) and the main effect for time was significant or close to it ( $p \leq 0.20$ )
- NMDS
  - A visualization to inspect potential changes in plant community across time by zone
  - Start/End Year only (not in-between years) were included for ease of interpretation

- Loading factors were used to help understand change. Loadings were species cover, cover groups or environmental factors (e.g. Halophytes, Unvegetated, Distance to water), as identified by each Reserve.

### Variables

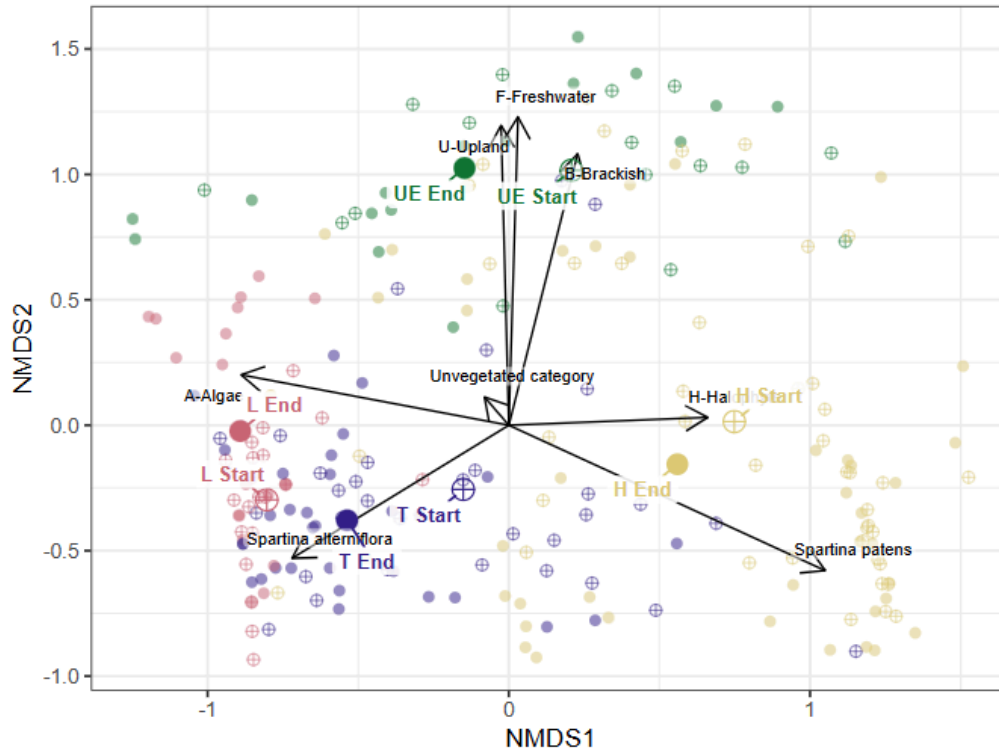
- Response variables: all plot covers
- Explanatory variables (year, zone, year\*zone)

### Outputs

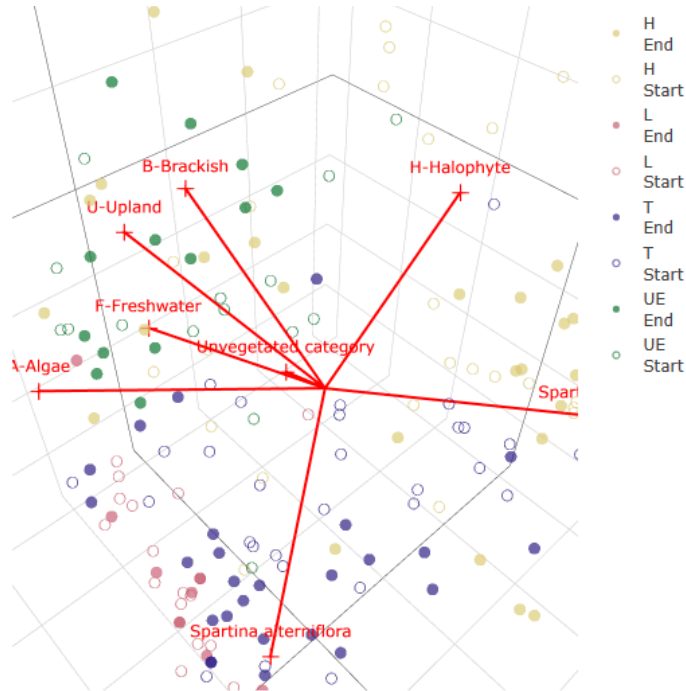
- PERMANOVA
  - Results and summary tables
  - PERMDISP outputs - tables and summaries checking PERMANOVA's assumption of homogeneity of dispersion; for overall test and by zone. If a significant difference in dispersions is present, a boxplot is provided to help visualize the different groups' dispersions.
- SIMPER table
  - Results table by zone for each test run
- NMDS
  - 2D NMDS plot with each point representing a single vegetation plot at a single time point and with color representing vegetation zone and open/filled circles representing start and end year. Includes centroid for each vegetation zone/time period. Black lines and labels represent the loadings, coordinates of species or cover groups specified by the Reserve (Figure 9).
  - Interactive 3D NMDS plot: Each point represents a single vegetation plot at a single time point, colored to represent vegetation zone. Red lines and labels represent the loadings, coordinates of species or species groups identified by the Reserve (Figure 10).
  - Contour plots where loading variables are shown as contours instead of arrows. Contours were fit as spline-based surfaces and labeled with % cover values for the indicated species (Figure 11).

## Ordination results, axes 1 and 2

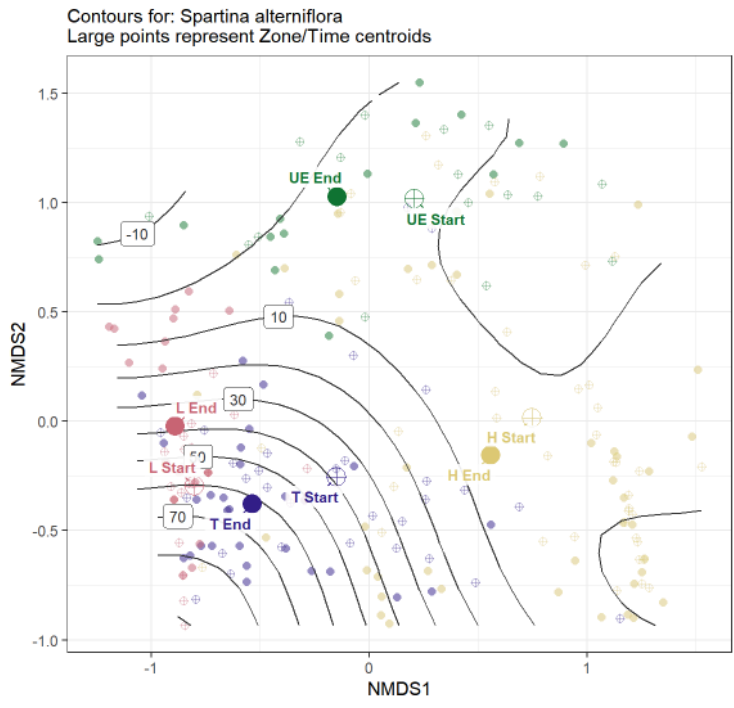
Large points: Zone/Time centroids. Arrows: Species or Groups.



**Figure 9:** NMDS 2D ordination depicting plot cover change over time (first and last year of monitoring) and across vegetation zones with cover species/types and species/type groupings as loading factors (black lines and text) at the Great Bay NERR.



**Figure 10:** NMDS 3D ordination depicting plot cover change over time (first and last year of monitoring) and across vegetation zones with cover species/types and species/type groupings as loading factors (red lines and text) at the Great Bay NERR. Interactive in the html output file.



**Figure 11:** NMDS contour plot depicting plot cover change over time (first and last year of monitoring) and across vegetation zones with contour lines labeled with % *Spartina alterniflora* cover values at the Great Bay NERR.

## Results

The above-listed analyses were run on tidal marsh vegetation data from 29 unique Reserve/site groupings (some Reserves were broken into smaller components). Delaware BCR and Hudson River Piermont sites did not have output results due to lack of sufficient data (<3 years monitoring data). For each of the 27 analyzed Reserves/sites, results were summarized and compiled below. A full report of all Reserves/sites with figures, tables, and statistics can be found in the [Reserve-Level Results folder](#), excluding results from Elkhorn Slough, who preferred to not publish their full results.

A summary of these Reserve results was compiled to highlight high-level findings. Each output was interpreted by NAMASTE team members with a qualitative description and categorization of the degree of community change, degree of SLR impact, and direction of EMI change based on vegetative change over time (Table 1, Figure 12). The degree of community change reflects ordination distances, as well as species diversity and richness changes. The degree of SLR impact reflects specific species and non-vegetated cover gains/losses associated with more frequent and prolonged saltwater inundation. EMI effect reflects the common direction of EMI change across zones at that site: if most zones had a significant upward-trending EMI, it was labeled as ‘increase’; if there were both increasing and decreasing responses, it was labeled as ‘mixed’; if most zones had a significant downward-trending EMI, it was labeled as ‘decrease’; if there were no significant EMI changes, it was labeled as ‘none’. EMI species were chosen by each Reserve’s staff for each zone, leaning on regional expertise. This led some Reserves to have more comprehensive EMI species lists than others.

**Table 1:** Summary results from the Reserve-level analyses for each Reserve/site. Each Reserve was grouped into a geographic region: Northeast (NE), Mid-Atlantic (Mid Atl.), Southeast (SE), Gulf of Mexico (Gulf), or West Coast (West). Community change and SLR effect were categorized as either ‘none’, ‘weak’, ‘moderate’, or ‘strong’. EMI effect was categorized as ‘none’, ‘mixed’, ‘increase’, or ‘decrease’. Shorthands used in the one sentence summaries: *Sp.alt* = *Spartina alterniflora*, *Sp.pat* = *Spartina patens*, SE = Seaward Edge, LM = Low Marsh, TM = Transition Marsh, HM = High Marsh, UE = Upland Edge. Note that Delaware BCR and Hudson River Piermont were removed from the table due to insufficient data. When changes are described as significant,  $p < 0.05$ ; when changes are described as indications,  $p = 0.05-0.20$ .

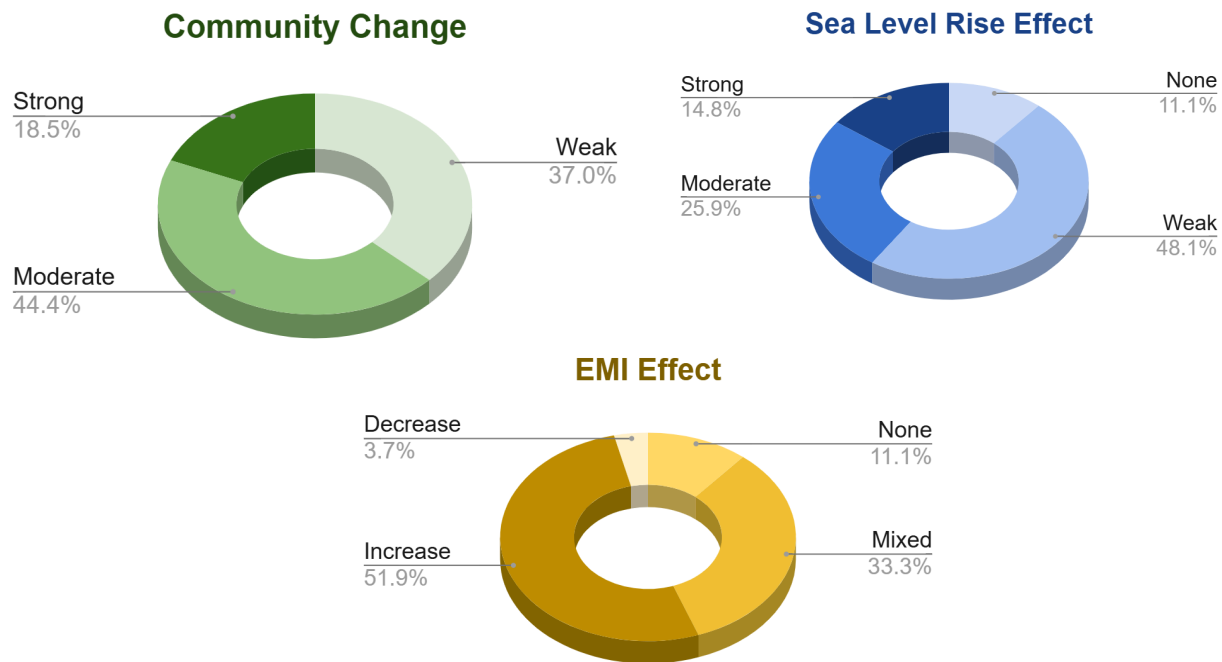
Reserve and Site	Region	Community Change	SLR Effect	EMI Effect	One Sentence Summary
ACE (SC), EIN	SE	Moderate	Weak	Increase	Zones had different changes: HM had less bare/more <i>Sp.alt</i> , LM lost diversity and richness.
ACE (SC), EIS	SE	Weak	Weak	Mixed	Across multiple zones there was a loss of bare cover and an increase of EMI and <i>Sp.alt</i> cover.

Apalachicola (FL), Little St. Marks	Gulf	Strong	Weak	Increase	TIDAL FRESH: Most zones had an increase in EMI and native plants, specifically <i>Biden mitis</i> , and increase of invasive <i>Alternanthera p.</i>
Apalachicola (FL), Pilots' Cove	Gulf	Moderate	Moderate	Increase	All zones are seeing community shifts indicative of SLR.
Chesapeake Bay MD, Jug Bay	Mid Atl.	Moderate	None	Increase	TIDAL FRESH: All zones saw community shift, with decreases in unvegetated cover and an increase of the non-salt tolerant <i>Nuphar advena</i> in the TM (listed as EMI species for TM).
Chesapeake Bay MD, Monie Bay	Mid Atl.	Weak	Weak	Increase	Unvegetated cover is decreasing while non-native cover also decreases. <i>Sp.alt</i> increase is driving the indication of an EMI increase in TM and HM.
Chesapeake Bay MD, Otter Point Creek	Mid Atl.	Weak	Weak	Increase	TIDAL FRESH: EMI increases for mudflat, LM, and HM as unvegetated cover decreases.
Chesapeake Bay (VA)	Mid Atl.	Weak	Moderate	Increase	All zones are experiencing slight community shifts including increases in unvegetated cover and an increase of <i>Phragmites</i> .
Delaware, St. Jones Reserve	Mid Atl.	Moderate	Moderate	Mixed	Indications of EMI increase in LM and HM, plus indications of richness and diversity decrease across all zones.
Elkhorn Slough (CA), Hester	West	Strong	Moderate	Increase	RESTORATION: EMI increases, with community shifts across HM and UE due to loss of bare and increase of <i>Salicornia pacifica</i> (only EMI factor for HM).
Elkhorn Slough (CA)	West	Weak	Weak	Mixed	SLR change only in the UE, which is increasing in <i>Salicornia pacifica</i> cover.
Grand Bay (MS)	Gulf	Strong	Strong	Increase	Significant community change: increase in unvegetated cover across all zones, paired with loss of <i>Juncus r.</i> (TM), loss of <i>Sp.alt</i> (LM), loss of <i>Sp.pat</i> (HM), and loss of <i>Cladium</i> (UE, Freshwater).

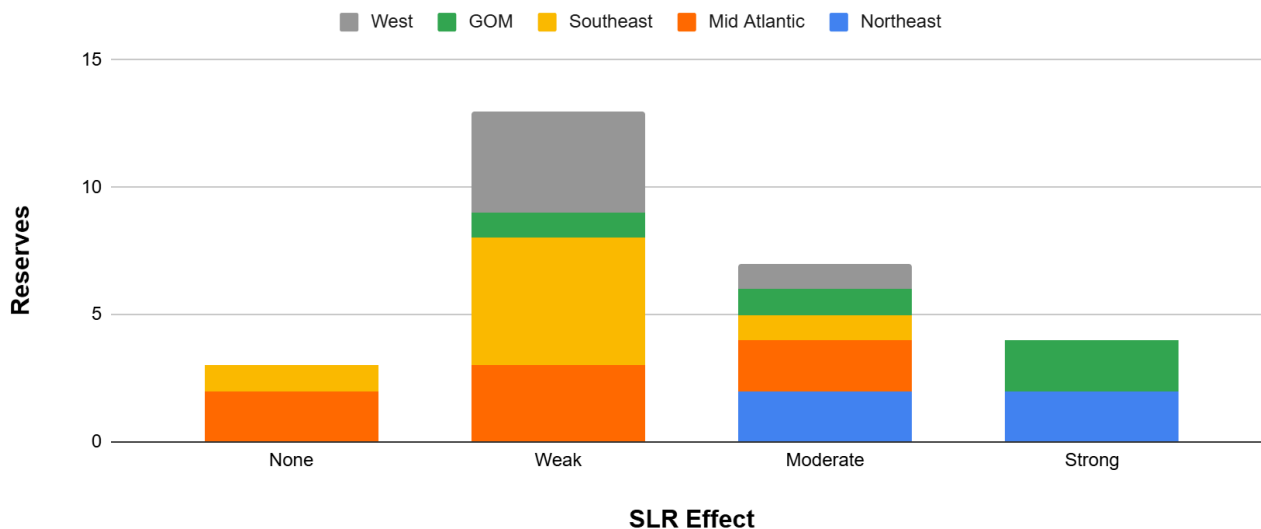
Great Bay (NH)	NE	Moderate	Strong	Increase	EMI is increasing across all zones with community shifts occurring in the low and high marsh which are indicative of SLR.
Guana Tolomato Matanzas (FL)	SE	Weak	Weak	Mixed	Increase in <i>Avicennia</i> and decrease in bare cover contribute to slight community change in LM, with an indication of EMI increase while UE EMI decreases.
Hudson River (NY), Tivoli component	Mid Atl.	Weak	Weak	Mixed	TIDAL FRESH; SE becoming unvegetated while TM and LM often hover around zero change, HM fluctuates species change significantly.
Jacques Cousteau (NJ)	Mid Atl.	Weak	None	Mixed	<i>Sp.alt</i> increases in low marsh and unvegetated cover (only EMI species indicated) decreases.
Kachemak Bay (AK)	West	Strong	Weak	Mixed	Significant community changes highlighted by decreases in bare cover and increases in the plant community (richness, diversity and most plant species).
Mission-Aransas (TX)	Gulf	Moderate	Strong	Increase	Decreasing halophyte cover, increasing EMI (only LM zones observed).
Narragansett Bay (RI)	NE	Strong	Strong	Increase	Bare cover and EMI increased in LM and HM, with LM losing <i>Sp.alt</i> and HM and UE gaining <i>Sp.alt</i> and losing other high marsh graminoid species.
North Inlet Winyah Bay (SC)	SE	Moderate	None	Decrease	Uneven sampling across zones, but depicts general loss of <i>Juncus</i> , increase of <i>Sp.alt</i> , and decrease of EMI in LM (unvegetated cover).
North Carolina - Masonboro Island	SE	Moderate	Weak	Mixed	EMI and unvegetated cover increases in mudflat and decreases in LM, while <i>Sp.alt</i> increases in LM and TM.

North Carolina - Rachel Carson	SE	Weak	Moderate	Mixed	<i>Sp.alt</i> decreases, unvegetated cover and EMI increase in LM while mudflat loses unvegetated cover, has decreased EMI, and gains species diversity.
North Carolina - Zeke's Island	SE	Moderate	Weak	None	<i>Sp.alt</i> increases in LM and TM; <i>Sp.pat</i> increases in HM; <i>Sp.pat</i> and <i>Borrichia</i> decrease in TM; Unvegetated cover decreases in mudflat, LM, and HM.
South Slough (OR)	West	Moderate	Weak	None	Species diversity is increasing in LM, TM, and HM. Live:Unvegetated ratio is increasing in HM and TM zones.
Tijuana River (CA)	West	Weak	Weak	None	Some richness and diversity decrease as well as unvegetated cover decrease over time, but minimal EMI impact. Decrease in 3 main spp ( <i>Salicornia</i> , <i>Sp.alt</i> , <i>Arthrocnemum</i> ), some significant, some indications.
Wells (ME)	NE	Moderate	Moderate	Increase	Increase of <i>Sp.alt</i> and decrease of <i>Sp.pat</i> driving community change, with well informed EMI increasing in HM.
Waquoit Bay (MA)	NE	Moderate	Moderate	Increase	EMI is significantly increasing for LM, HM, and SE, with <i>Sp.alt</i> decreasing in SE and LM but increasing in HM, and <i>Sp.pat</i> decreasing in HM and UE.

All 27 Reserve/sites experienced some degree of community change, described as qualitative categories based on statistical trends: the most common response was 'Moderate' (44%), followed by 'Weak' (37%) and 'Strong' (18.5%; Figure 12). The SLR effect was often described as 'Weak' (48%), followed by 'Moderate' (26%), then 'Strong' (15%) and 'None' (11%; Figure 12). The extent of SLR effect reflects differences in geographic regions where sites in the Northeast and Gulf Coast experience relatively more intense SLR impacts and sites in the Southeast and Mid-Atlantic experience relatively less intense SLR impacts (Figure 13). The Ecotone Migration Index (EMI) increased across the majority of Reserve/sites (52%). Thirty-three percent of Reserve/sites had a mixed EMI response, indicating that in some zones the EMI increased while in others it decreased, and 11% of Reserve/sites experienced no significant EMI changes across any zone. Only one Reserve (3.7%) experienced a decrease in EMI where the Low Marsh and Upland Edge expressed a significant decline of EMI and no other zone experienced any significant change (Figure 12).

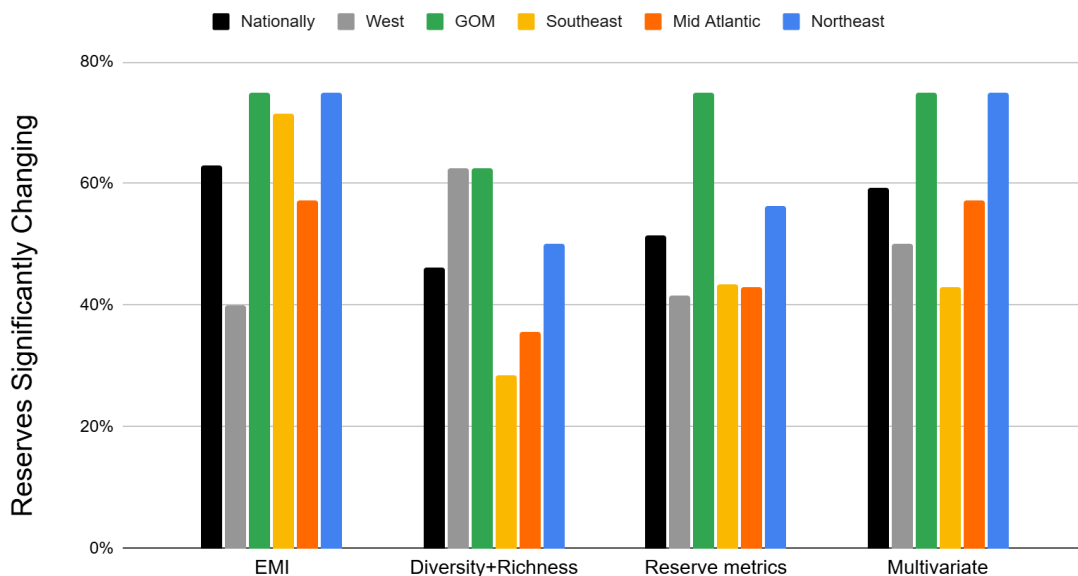


**Figure 12:** The changes in tidal marsh vegetation composition over time across 27 Reserve/sites reflected varying degrees of community change, impacts of sea level rise effects, and EMI effects. These categories (strong, moderate, weak, none, increase, decrease, mixed) were determined by examining the outputs of the Reserve-level analyses for each Reserve/site including the summary figures, univariate analyses, and multivariate analyses.



**Figure 13:** The effect of sea level rise on 27 Reserve/sites varies by geographic region. On average, sites located in the Northeast or the Gulf Coast experienced relatively stronger SLR impacts while sites located in the Southeast and Mid-Atlantic experienced relatively weaker SLR impacts. Sites located on the West Coast commonly experienced weak to moderate SLR impacts.

Approximately half of the changes in EMI, diversity and richness, reserve-specific metrics, and multivariate vegetation community composition over time are significant ( $p < 0.05$ ) at a national and regional scale, regardless of whether these changes reflect an increase, decrease, or mixed response (Figure 14). Nationally, 62% of Reserves experienced a significant change in EMI over time while changes in diversity and richness occurred at less than 50% of Reserves on a national scale. However, patterns of change may vary by region. Northeast ( $n=4$ ) and Gulf of Mexico Reserve/sites ( $n=4$ ) consistently have a higher proportion of sites with a significant change in vegetation composition than other geographic regions. The West Coast Reserves ( $n=5$ ) have the lowest proportion of sites with a significant change in EMI, but tie the Gulf of Mexico for the highest proportion of Reserves experiencing species diversity and richness change. Southeastern ( $n=7$ ) and Mid Atlantic regions ( $n=7$ ) frequently have the lowest proportion of Reserve/sites experiencing significant change measured by the EMI, diversity and richness, Reserve specific species, and multivariate metrics. Reserve metrics represents the average change to several Reserve specific species or abiotic covers of greatest interest, chosen by staff at each Reserve according to their regional expertise for 4 covers. For example, the covers analyzed at Narragansett NERR were *Spartina alterniflora*, Bare, *Spartina patens*, and *Distichlis spicata* while species tracked at South Slough NERR included *Sarcocornia perennis*, *Carex lyngbyei*, *Juncus balticus*, and *Potentilla anserina*. Just under half (49%) of Reserves metrics experienced significant cover change: a greater proportion of Reserves in the Gulf of Mexico saw their Reserve metric species cover change than any other region. Lastly, the multivariate PERMANOVA test provided information on whether the vegetation community changed over time. At the national scale, almost 60% of Reserves had a significant community change, especially in the Northeast Region with 75% of Reserves experiencing a shift in vegetative composition.



**Figure 14:** Percentage of Reserves at both a national and regional scale ( $n=27$  Reserve/sites) experiencing significant ( $p < 0.05$ ) change in tidal marsh vegetation composition as measured by EMI, diversity and Shannon-Weiner richness, Reserve-specific species cover (Reserve metrics), and overall community composition.

## Conclusion

The summary results explored above provide a high-level view of vegetation change over time at 27 Reserve/sites across the country. There were weak-to-moderate community changes demonstrated by shifts in species relative abundance, weak-to-moderate vegetative responses to sea level rise as seen by an increase of bare cover in the low marsh and of *Spartina alterniflora* in the high marsh, and frequent increases in EMI (ecotone migration index) across the Reserves. Identifying these trends can enhance our understanding of the condition of tidal marshes across regions, and as a whole. Further investigations into national trends are detailed in the [NAMASTE National-Level Analysis Methods and Results report](#).

Full results for individual Reserves can be downloaded from the [Reserve-Level Analysis Results folder](#). An exploration into the number of years and plots surveyed, the distribution of these plots across vegetation zones and sites, what species informed EMI, and the changes (or stability) of vegetation cover over time and across zones can provide a well-informed, vivid story of ecological response to sea level rise for each participating Reserve.

As the NERR system continues to collect biomonitoring data, the tools produced for this Reserve-level analysis can be re-used by Reserve staff or collaborators to include new years' data and update their results. Additionally, individuals and groups with marsh vegetation data not collected or associated with the NERR system can run these same analyses for their data with the provided tools. Following the [video guide](#) and utilizing the [data templates](#) and [R scripts](#) provided, any individual can leverage their marsh biomonitoring data to investigate changes over time and between vegetation zones.

## Resources

- Results:
  - [Reserve Level Results](#): access to finalized Reserve-level analyses (html files) by Reserve, denoted by 3 letter Reserve codes (e.g., APA = Apalachicola). To view, files must be downloaded onto a local drive and opened in a web browser.
- Data Analysis:
  - [R-Scripts](#) to edit and run the described analyses and visualizations in this document.
  - [NAMASTE Training Guide](#): Instructions for modifying user options and re-running the analyses.
  - [NAMASTE Training Videos](#): Direct link to our training videos for help with modifying user options and re-running the analyses.
  - [Standardized NAMASTE data template](#): data format for our automated R-tools.
  - [Veg-specs template](#): custom metrics format for our automated R-tools, where users can define test outputs. See above training guide and/or videos for instructions.
  - [Questionnaire](#) interviewer guide and [response summary template](#): Documents used to conduct standardized interviews for all participating Reserves to better

understand biomonitoring methods, sites, and timelines. Includes a template, interviewer guide, and Reserve answers.

- Data Visualization Tools:
  - [ArcGIS dashboard](#): User-friendly GIS application displaying data layers associated with this project (e.g., plot waypoints, site descriptions, project results).
  - [Vegetation Data Exploration App](#): Tools designed to assist Reserves with additional vegetation data QA/QC, exploration, and visualization; See Appendix A
- Related Reports:
  - [National-Level Analysis Methods and Results](#): companion analysis description, focused on the national scale.

## References

- Moore, K.A. 2013. NERRS SWMP Vegetation Monitoring Protocol, Long-term Monitoring of Estuarine Vegetation Communities. National Estuarine Research Reserve System Technical Report, Gloucester Point, VA. 36pp.
- NERRS. 2025. Estuarine Marsh Monitoring Standard Operating Procedure. National Estuarine Research Reserve System Technical Report. 31 pp.

# Appendix A: NAMASTE’s Shiny app for QA/QC and exploring vegetation data

This shiny app was developed by Kim Cressman, Catbird Stats on a subcontract to Waquoit Bay NERR (WQB) as part of the National Salt Marsh Synthesis project (NAMASTE). The primary intention was to assist with data quality assurance/quality control for plot based vegetation monitoring data. Note, the data must be in the NAMASTE format in order to work within this app; please refer to the [vegetation dataset template](#) to get started with NAMASTE formats.

## Vegetation data exploration app:

[https://nerrscdm.o.shinyapps.io/vegData\\_exploration/](https://nerrscdm.o.shinyapps.io/vegData_exploration/)

The vegetation data exploration app will provide tabular summaries of your data which is useful for checking for erroneous or missing values (Figure A1). The sampling summary tab highlights plot-date combinations where there was no vegetation cover recorded. For example, in 2016, the plot at S3-T2-3 (section 2, transect 2, plot 3) was missed and has no cover, density or height measurements.

Year	Site.Transect	PlotIdFull	nSpecies_Cover_m easurements	nSpecies_Density_ measurements	nSpecies_Height_m easurements	Cover_completed	Density_completed	Heights_comple ted
▼ 2016 (10)			749	151	101	true (123), false (26)	true (98), false (27)	true (97), false (27)
	► S1-T1 (10)		58	8	8	true (10)	true (8), false (2)	true (8), false (2)
	► S1-T2 (14)		73	11	12	true (14)	true (9), false (5)	true (11), false (3)
	► S1-T3 (14)		66	12	10	true (14)	true (10), false (4)	true (10), false (4)
	► S2-T1 (17)		112	17	13	true (17)	true (13), false (4)	true (13), false (4)
	► S2-T2 (16)		106	27	15	true (16)	true (13), false (3)	true (14), false (2)
	► S2-T3 (14)		88	21	12	true (14)	true (13), false (1)	true (12), false (2)
	► S3-T1 (11)		65	21	11	true (11)	true (11)	true (11)
	▼ S3-T2 (12)		74	13	9	true (11), false (1)	true (9), false (3)	true (8), false (4)
		S3-T2-1	6	2	1	true	true	true
		S3-T2-2	5	1	1	true	true	true
		S3-T2-3	0	0	0	false	false	false
		S3-T2-4	5	1	1	true	true	true

**Figure A1.** Summary table of vegetation data provided by the vegetation data exploration app highlighting data gaps for QA/QC.

The graphs feature contains options to see how a numeric variable changes over time at a site. The transect profile tab displays plot number along the X-axis and Y-axis is the amount of a numeric variable. You can toggle years to display by using the checkboxes above the figure. Figure A2 shows the amount of bare area in the plots from 2011 to 2020. Because plot numbers

start at the seaward edge and highest plot numbers are at the upland edge, the plot identification roughly follows the elevation profile of the marsh along the transect.



**Figure A2.** The vegetation data exploration app allows users to visualize transect profiles based on different species or group covers. In this transect profile, at Site 2 the Bare cover represented more of the plots in Transect 1 and Transect 2 than Transect 3.

The correlation scatterplots tab shows Pearson and Spearman correlation coefficients and allows the option of adding a line to scatterplots showing the relationship between any two numeric variables.

## Vegetation Exploration Data App Instructions:

How to use this app:

1. Upload your vegetation data file as an Excel file in the [NAMASTE format](#) using the sidebar. This information will not be retained by the app once you close the session.
2. See tabular summaries of your data by selecting 'Tables' from the navigation bar at the top of the app.
  - a. *Data preview:* View, sort, filter, and search the raw data in the 'Cover' worksheet of your file. This table is laid out exactly the same as your original spreadsheet.
  - b. *Column summary:* This table shows you how R 'sees' your data. This table is good to look through to make sure values in your columns align with your expectations (e.g. you do not have any vegetation cover values of 500).
  - c. *Sampling summary:* This table provides a summary of sampling events and flags any vegetation plot-date combinations where there is no vegetation cover recorded.

3. Explore graphs of your data by selecting 'Graphs' from the navigation bar at the top of the app
  - a. *Time series*: See how a variable changes over time at a site. In the sidebar, choose your site and any numeric variable from your file.
  - b. *Transect Profiles*: See how a variable changes along a cross-section of your transect. In the sidebar, choose your site and any numeric variable from your file.
  - c. *Correlation Scatterplots*: Explore relationships between variables, across all sites. This graph only updates when you click the 'Use these choices' button. This is the only graph that is not interactive.

### **Pages in top navigation bar**

1. See tabular summaries of your data by selecting 'Tables' from the navigation bar at the top of the app.
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